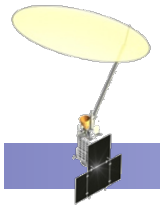


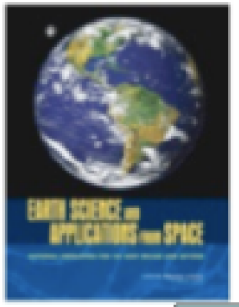
Active/Passive Spaceborne Observation of Land Surface Soil Moisture at L-band with the SMAP Mission

Seungbum Kim, Scott Dunbar, Steven Chan, Narendra Das, Andreas Colliander, Eni Njoku, and SMAP Science Definition Team

NASA/JPL

9/17/09

SMAP mission context



"Earth Science and Applications from Space: National Imperatives for the next Decade and Beyond"

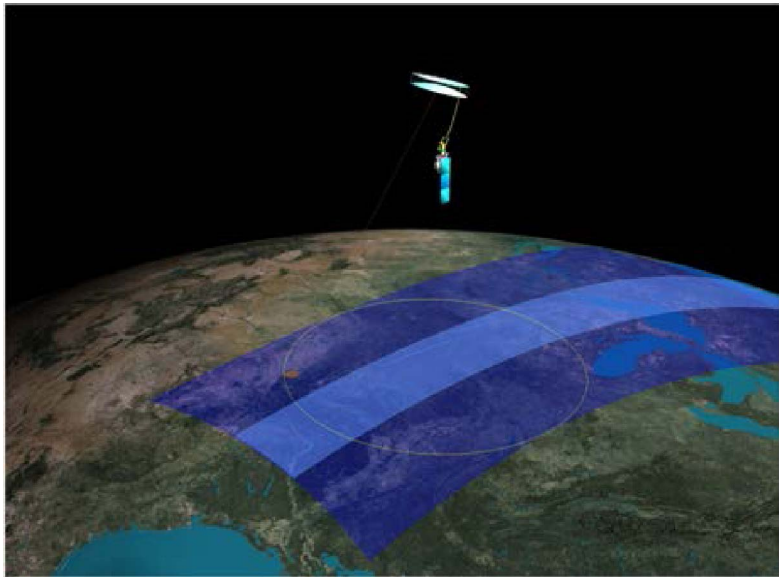
SMAP is one of four missions recommended by the NRC Earth Science Decadal Survey for launch in the 2010–2013 time frame

- On Feb 2, 2008, NASA announced that SMAP would be one of two new start missions initiated in FY08

Tier 1: 2010–2013 Launch
Soil Moisture Active Passive (SMAP)
ICESAT II
DESDynI
CLARREO
Tier 2: 2013–2016 Launch
SWOT
HYSPIRI
ASCENDS
GEO-CAFE
ACE
Tier 3: 2016–2020 Launch
LIST
PATH
GRACE-II
SCLP
GACM
3D-WINDS

SMAP measurement overview

- 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 antenna
    - Conical scan at 14.6 rpm
    - Constant incidence angle: 40 degrees
      - 1000 km-wide swath
      - Swath and orbit enable 2−3 day revisit



- Orbit:
  - Sun-synchronous, 6 am/pm orbit
  - 670 km altitude
- Mission Operations:
  - 3-year baseline mission

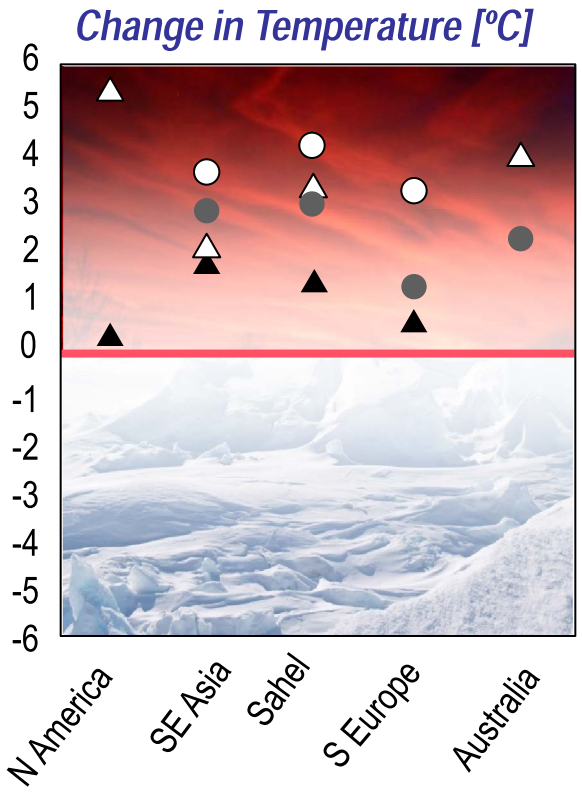
Product overview

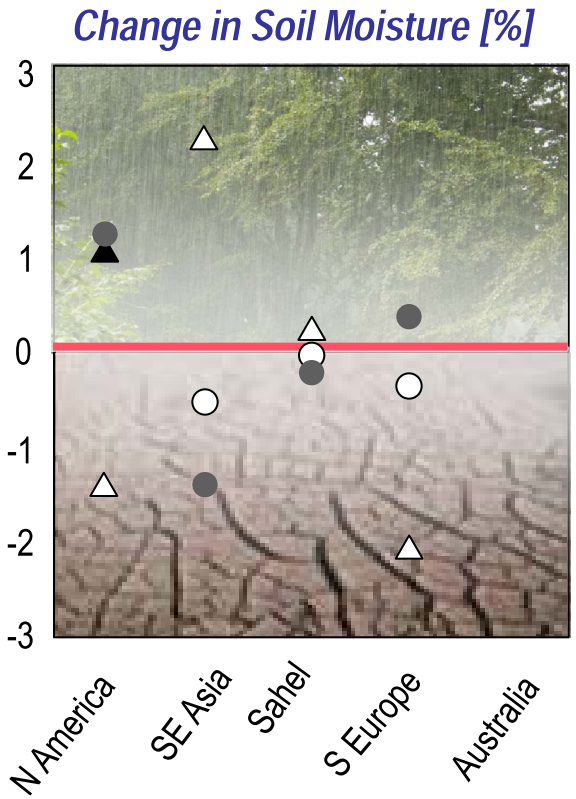
Data Product	Description	Spatial Resolution	Latency*
L1B_S0_LoRes	Low Resolution Radar σ^o in Time Order	30 km	12 hours
L1C_S0_HiRes	High Resolution Radar σ^o on Earth Grid	1 – 3 km	12 hours
L1B_TB	Radiometer T_B in Time Order	40 km	12 hours
L1C_TB	Radiometer T_B on Earth Grid	40 km	12 hours
L3_F/T_HiRes	Freeze/Thaw State on Earth Grid	3 km	24 hours
L3_SM_HiRes	Radar Soil Moisture on Earth grid	3 km	24 hours
L3_SM_40km	Radiometer Soil Moisture on Earth Grid	40 km	24 hours
L3_SM_A/P	Radar-Radiometer Soil Moisture on Earth Grid	10 km	24 hours
L4_SM	Surface & Root Zone Soil Moisture on Earth Grid	10 km	7 days
L4_C	Carbon Net Ecosystem Exchange on Earth Grid	10 km	14 days

Scientific need of SMAP observation-soil moisture

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

Models *agree* on basic temperature response

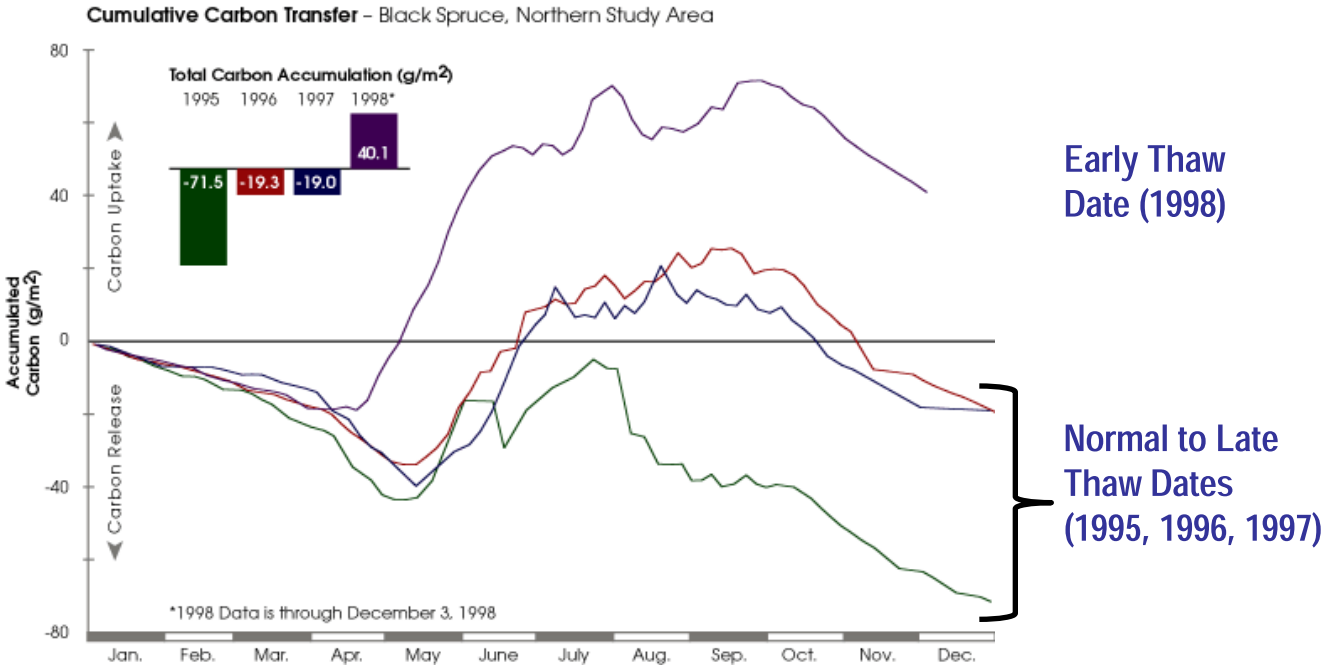




Models *disagree* on whether there would be MORE or LESS water compared to today

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

Scientific need of SMAP observation-Freeze/Thaw



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

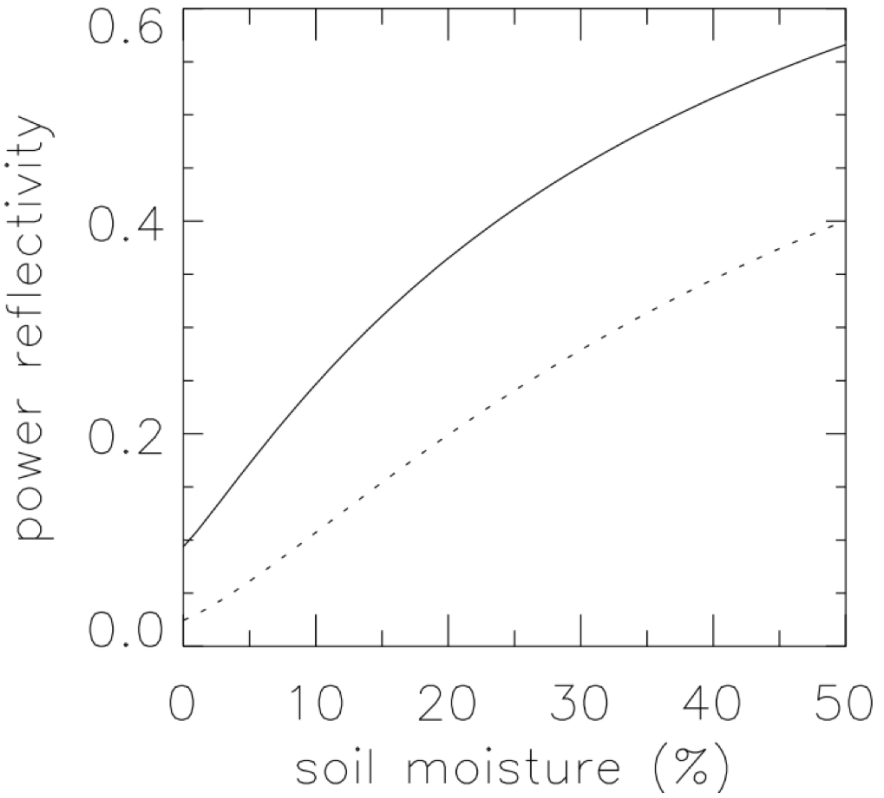
SMAP freeze/thaw measurements would reduce errors in the closing of carbon budget.

Goulden et al., 1998: Sensitivity of Boreal Forest Carbon Balance to Soil Thaw, *Science*, 279.

Herring, D. and R. Kannenberg: The mystery of the missing carbon, *NASA Earth Observatory*.

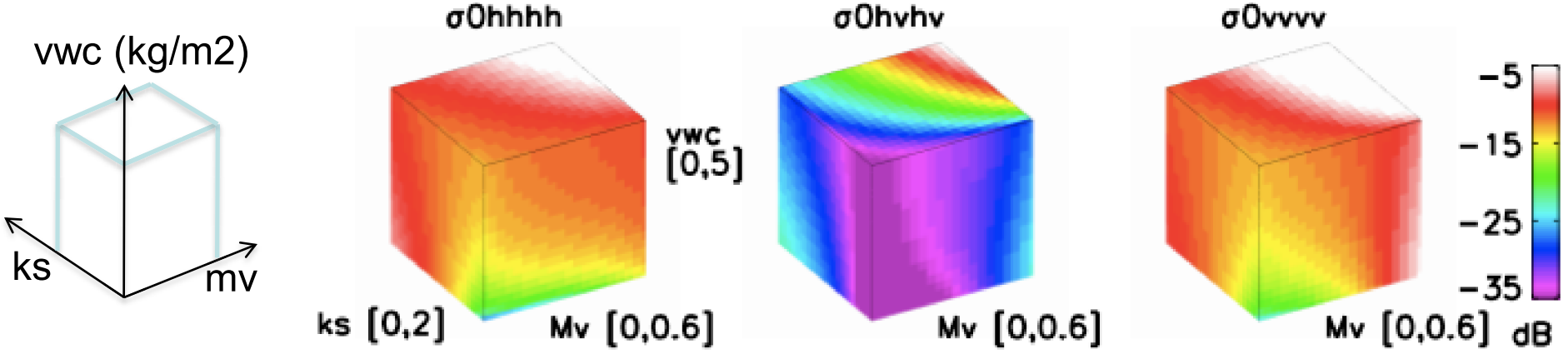
Principle of measurements (passive)

- Brightness T = emissivity * surface T
- Emissivity = 1 – reflectivity
- Reflectivity of the bare specular soil surface for v-pol (dot) and h-pol (solid) at 38° incidence angle.



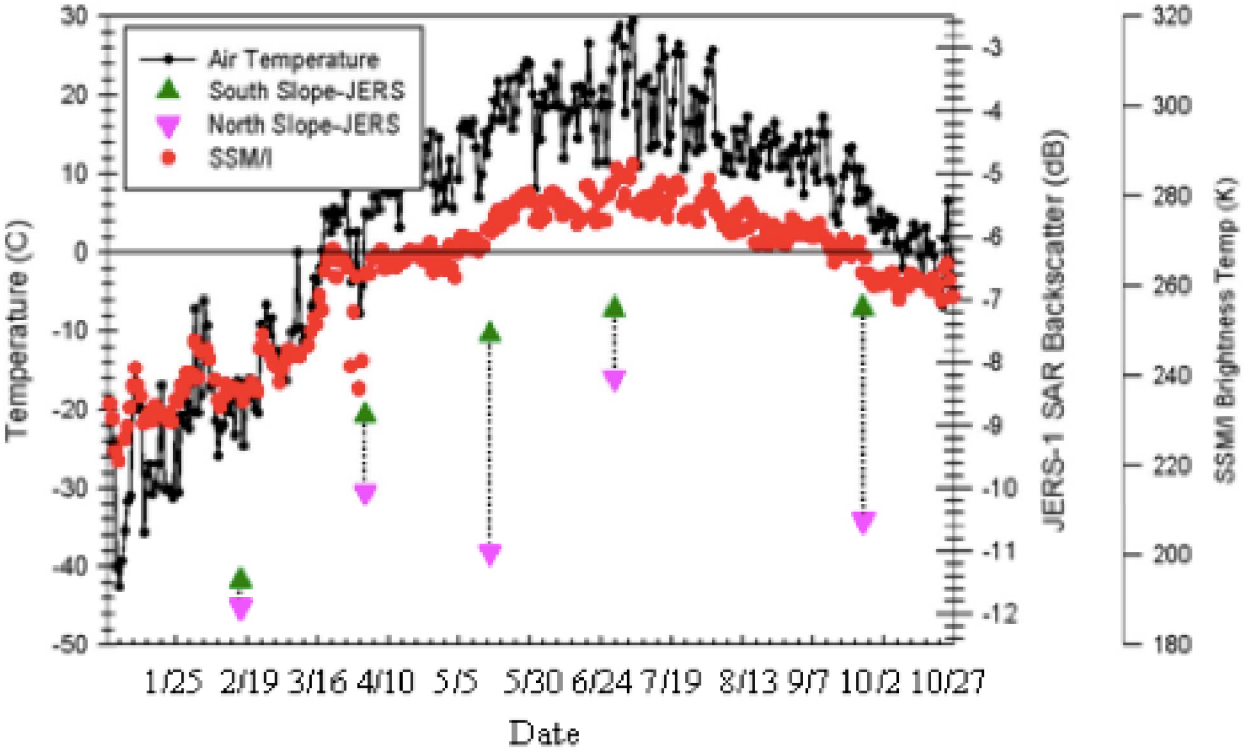
Principle of measurements (radar)

- The reflectivity of the bare surface has positive relationship with soil moisture.
- Effects of soil surface roughness and the vegetation have to be removed during the retrieval.



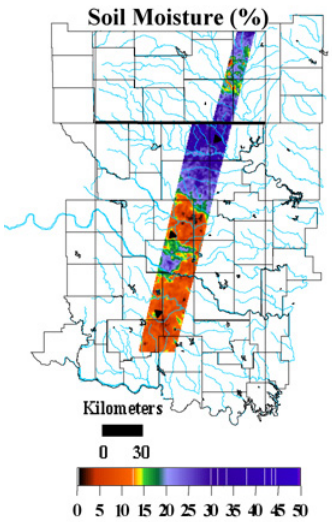
Principle of measurements (freeze/thaw)

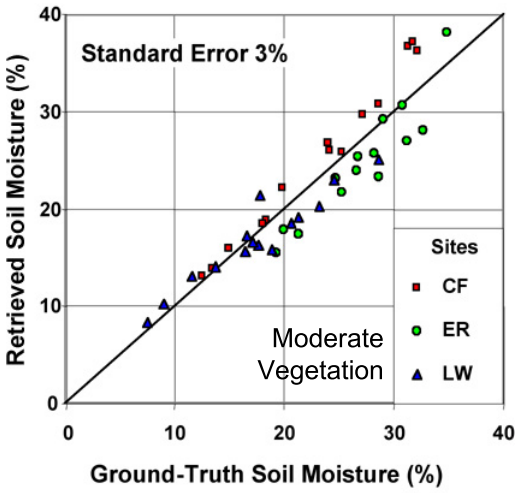
- Dielectric constant (and radar backscatter) is small for frozen surfaces and large for thawed surfaces.

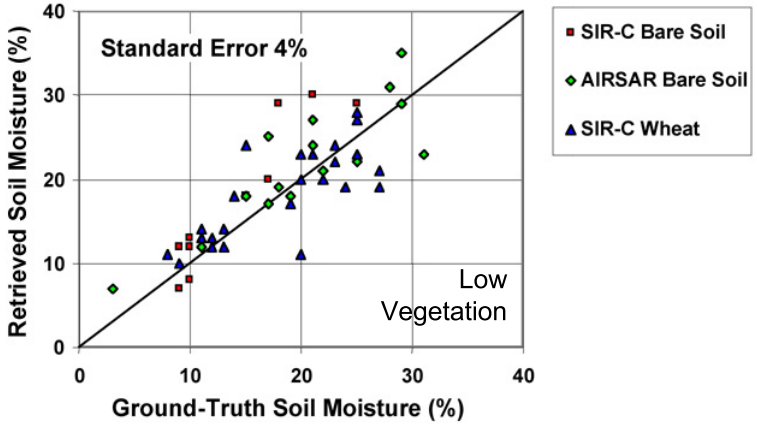


L-band Active/Passive Assessment

- 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

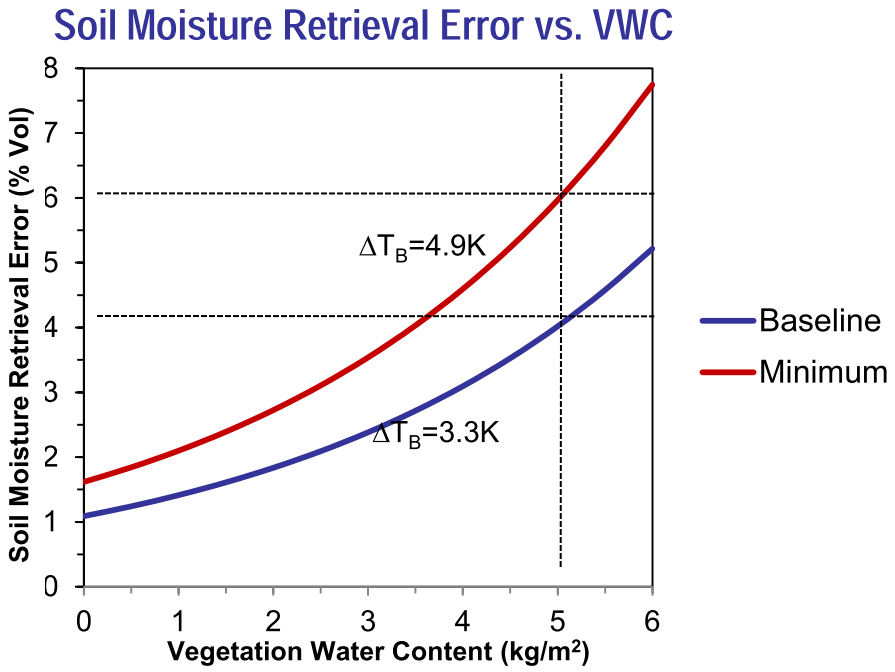






Measurement error budget (passive)

Error Sources (Residuals after Correction/Ancillary Data)	T_B Error (K) (1-sigma)
Atmospheric Gases & Clouds	0.15
Surface Temperature	1.4
Vegetation Water Content	1.2
Model Parameterization	1.1
Landscape Heterogeneity	0.8
RSS of Geophysical Errors	**2.3**
Sensor Relative Error Allocation (1-sigma)	1.3
Total RSS Error (ΔT_B)	**2.7**
Baseline Mission Requirement (ΔT_B)	**3.3**
Minimum Mission Requirement (ΔT_B)	**4.9**

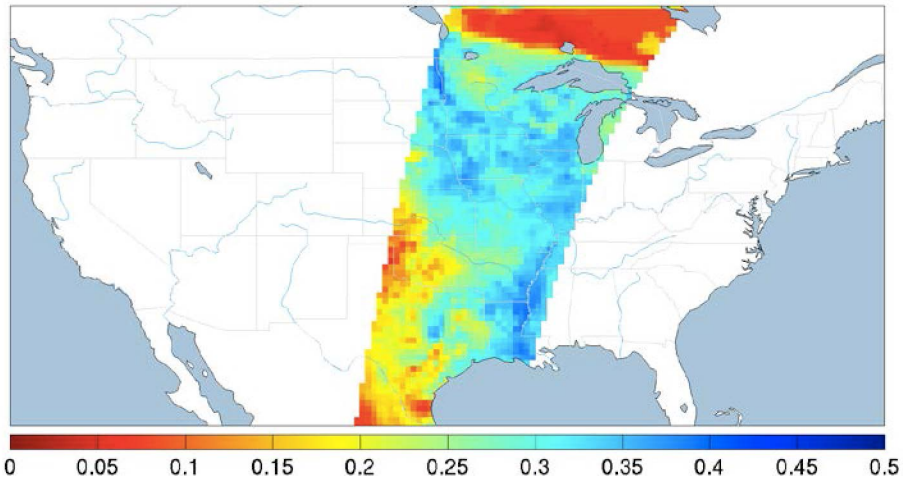


- Assumptions (Baseline):
  - Rain and RFI included in “data loss” allocation
  - Dual radiometer channels (H, V) and radar HV channel used to improve vegetation correction
  - Radar Hi-Res data used to characterize and reduce heterogeneity effects within radiometer footprint
  - Ancillary surface temperature data are available from operational forecast models

Examples of SMAP products

Level 3 Radiometer
40 km Soil Moisture Product

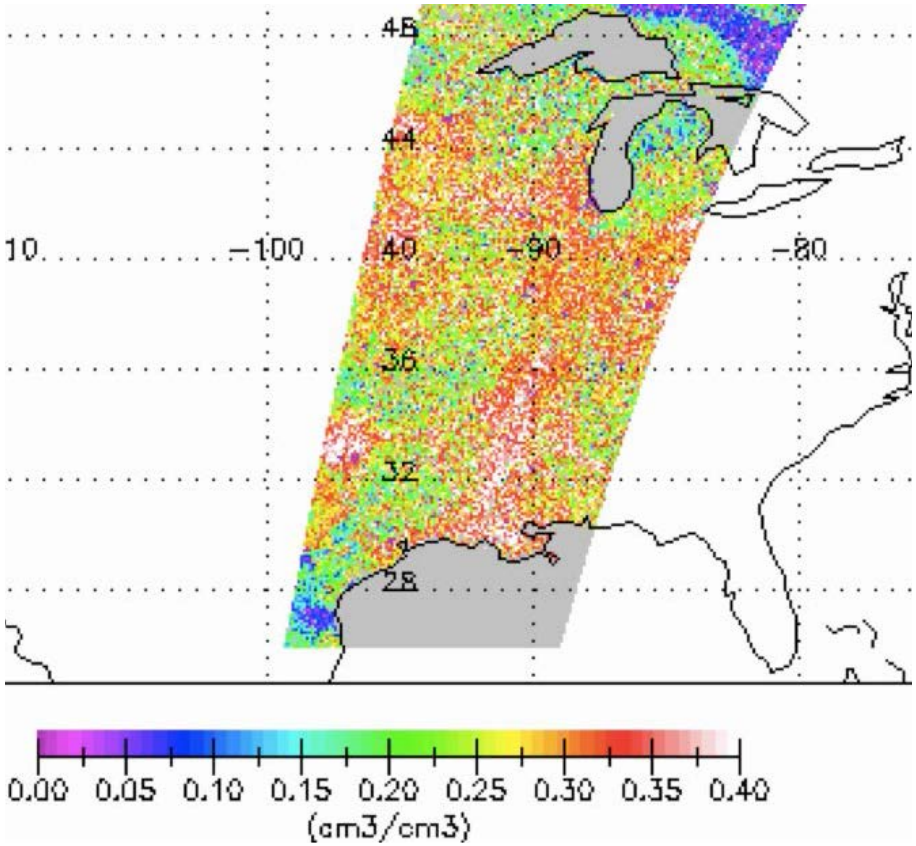
L3 40km Soil Moisture (cm3/cm3)



- Soil moisture estimate over land with 4% accuracy over low-to-moderately vegetated areas (VWC <= 5 kg/m2).
- Global coverage in 2-3 days.
- Estimate is made using only AM observations (current baseline)
- Certain QC masks (e.g. urban areas, mountainous terrain, frozen ground, snow, ice) apply.

Examples of SMAP products

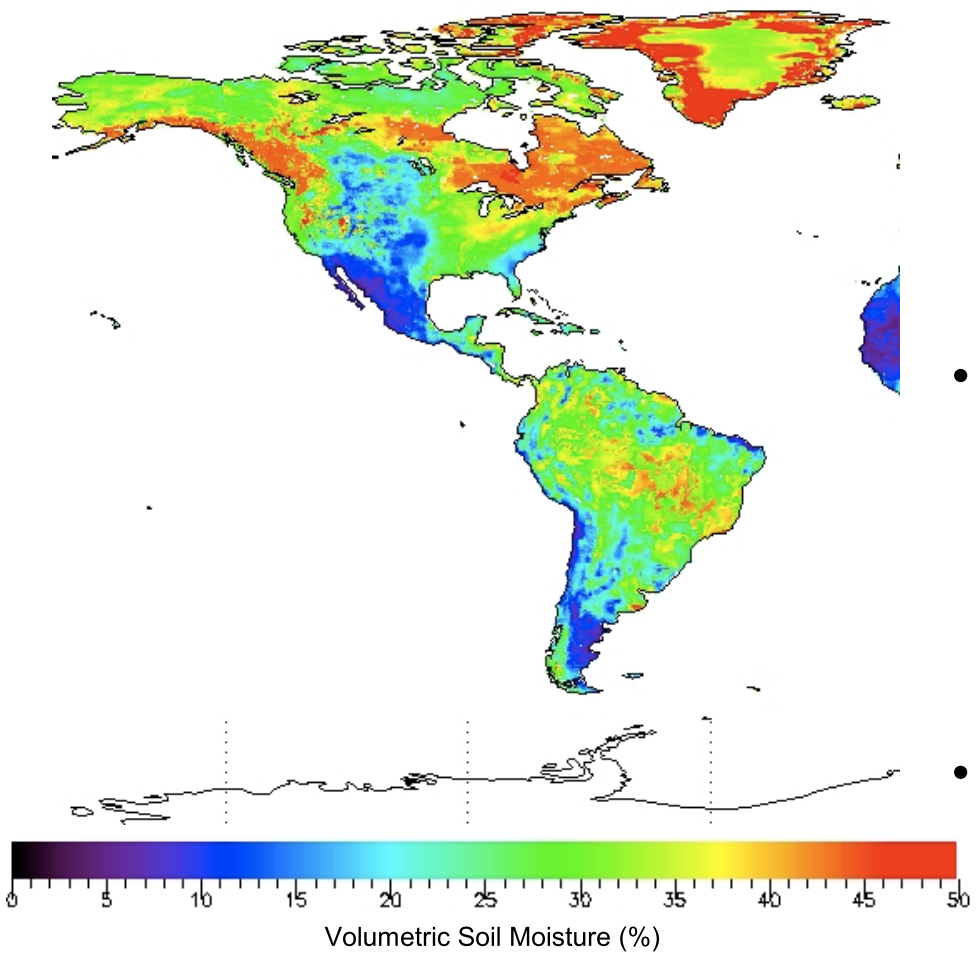
Level 3 Hi-Res Radar
3km Soil Moisture Product



Volumetric Soil Moisture

- Contains retrieved soil moisture over land using snapshot and/or time-series algorithms.
- The 1km HiRes radar L1C data is averaged to perform retrievals at 3km grid postings, to reduce radar Kp noise.
- Depending on the terrain classification, multiple optional models/algorithms may be employed for retrieval.
- Provides scene heterogeneity information for the L3 A/P algorithm processing.

Level 4 Soil Moisture Product

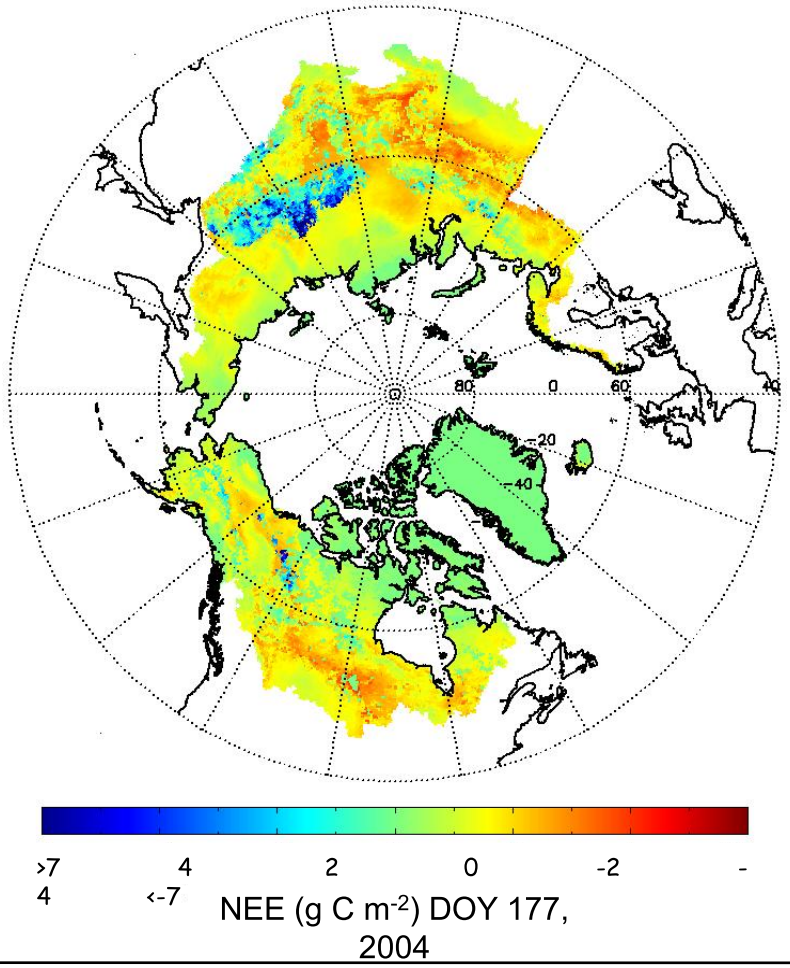


- Assimilate SMAP data into a state-of-the-art land surface model to improve the global surface soil moisture field and estimates of root-zone moisture.
- Uses L3 SM A/P and L3 F/T data with constraints imposed by surface meteorology. (Optionally may use the L1C radiometer and radar data as inputs.)
- Global output at 10km resolution with 5-day latency. Options for daily or 3-hourly average snapshots.

Examples of SMAP products

Level 4 Carbon Product

Mean Daily net CO_2 Exchange



- Quantify net carbon flux in boreal landscapes; reduce uncertainty regarding missing carbon sink on land.
- Apply a soil decomposition algorithm driven by SMAP L4_SM and GPP inputs to compute land-atmosphere CO_2 exchange (NEE).
- Produce daily global maps of NEE at 10 km resolution with a 14-day latency. Maps at 1km resolution are under consideration.
- Accuracy commensurate with tower based CO_2 Obs. (RMSE ≤ 30 g C m^{-2} yr^{-1}).

SMAP Science Cal/Val

- In situ sampling of soil moisture:
  - Sparse networks: one sample point within footprint area
  - Dense networks: several sample points within footprint area

- Requirements for sampling networks along the following lines:
  - Provide the equivalent of volumetric soil moisture obtained using the thermo-gravimetric method
  - Establish that it provides a measure of the 0-5 cm layer
    - Also consider providing the 0-100 cm layer
  - Represent the 10 km product area
    - Also consider providing 40 km and 3 km scales
  - Provide observations concurrent with the satellite measurement
  - Additional constraints
    - Data must be available in a timely manner in order to allow continuous assessments during the validation phase of the mission (2-14 months post launch).
    - All data must be available to other investigators and ideally within the public domain.

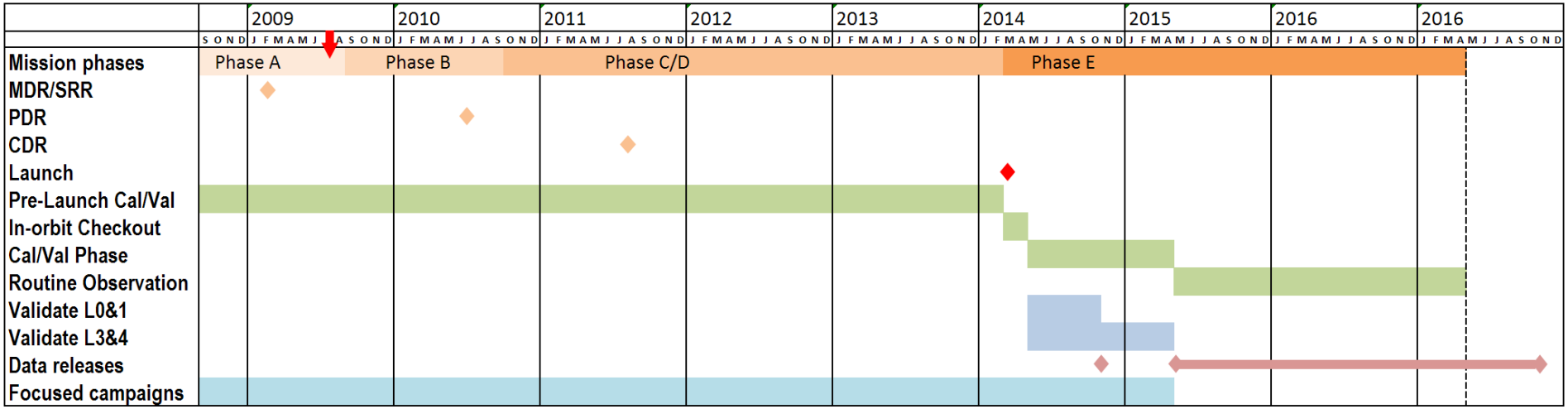
- Consistency among different sampling teams critical

Compatibility of SM Networks with Cal/Val Needs (example)

Requirement	Network						
	SCAN	CRN	OK Mesonet	USDA ARS	COSMOS	GPSR	
Calibrated using thermo-gravimetric	Y/N	Y	Y/N	Y	Y	N	
0-5 cm estimate	Y	Y	Y	Y	N	Y	
0-100 cm	Y	Y	60 cm	Y	Y/N	N	
9 km scale	N	N	N	Y	N	N	
36 km scale	Y/N	N	Y	Y	N	N	
3 km scale	N	N	N	N	N	N	
Concurrent	Y	Y	Y	Y	Y	Y	
No Latency issues	Y	Y	Y	Y	Y	Y	
No restrictions on availability of data	Y	Y	Y/N	Y	Y	Y	
Geographic and climate diversity	Y	Y	Y	Y	Y	Y	
Soil characterization available	Y	Y	Y	Y/N	Y	Y	
Met data available	Y	Y	Y	Y	N	Y	

SMAP Cal/Val Timeline

- Important milestones for Cal/Val planning (and algorithm development) before launch are the Preliminary Design Review (PDR) and Critical Design Review (CDR)
  - Updated draft Cal/Val Plan after the SMAP Algorithms and Cal/Val Workshop
  - Preliminary Cal/Val Plan in place by June 2010 (prior to PDR) , Final by Dec 2010 (prior to CDR)
- L1 data products are to be validated and released within 6 months from end of In-Orbit Checkout (IOC), and L3 and L4 products within 12 months of IOC
- Final consistently processed data will be released within 6 months after the end of the prime science mission
- Early release of data prior to completion of product validation will be considered for approved mission science collaborations, with appropriate data quality caveats applied
- Detailed Cal/Val milestones need to be developed at this meeting



Summary

- SMAP (Soil Moisture Active/Passive) is the first radar/radiometer spaceborne mission dedicated for soil moisture retrieval, and is due for launch in 2014
- SMAP will
  - Retrieve 40km-, 10km-, and 3km- resolution soil moisture
  - Produce 3km-resolution freeze/thaw state
  - Assimilate into land surface and carbon models
  - Designed to satisfy Level 1 Science Requirements:
    - 4% vol., 3 days, at 10 km (soil moisture)
    - 80% classification accuracy, 2 days, at 3 km (freeze/thaw)