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Soil Moisture Observations from the SMAP Mission

Soil Moisture
Active Passive
Mission
SMAP

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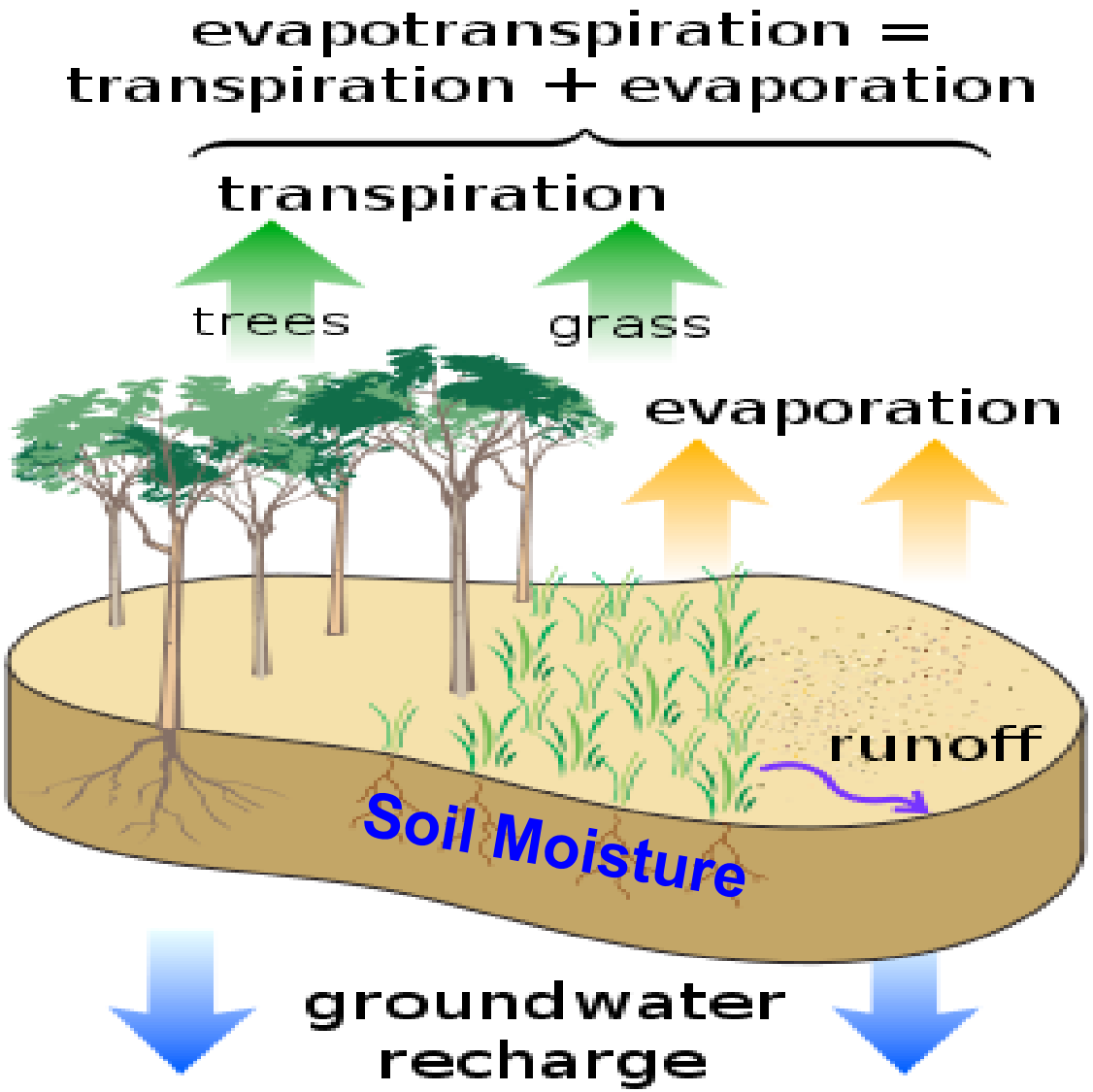
Soil Moisture and Groundwater



Soil Moisture influence partitioning of incoming solar energy into latent heat and sensible fluxes

Soil Moisture Influence partitioning of incoming rain into runoff and infiltration

Soil Moisture is the connecting link between the Water Cycle and Carbon Cycle through its influence on evapotranspiration

Some part of the infiltration is actually the groundwater recharge

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SMAP Background

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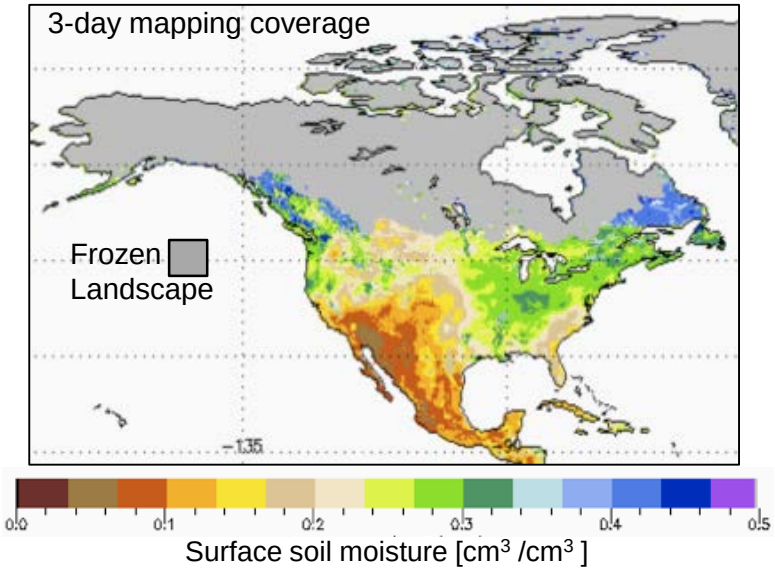
What Is SMAP?

- SMAP is the Soil Moisture Active Passive mission, a NASA Earth science mission
- SMAP's science objective is to provide high-resolution, frequent-revisit, global observations of soil moisture and 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 is defined in terms of volume of water per unit volume of soil

Freeze/thaw state is defined as the phase of the water contained within the landscape including soil and vegetation



SMAP was initiated in 2008 in response to recommendations of the NRC Earth Science Decadal Survey (2007) and was launched in January 31, 2015

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NASA Earth Observing Satellite Fleet

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Why Soil Moisture?

Enhanced weather & climate forecasting

Improved agricultural productivity and crop yield predictions

Drought monitoring and early warning

Flood monitoring and prediction

Human health and vector borne diseases

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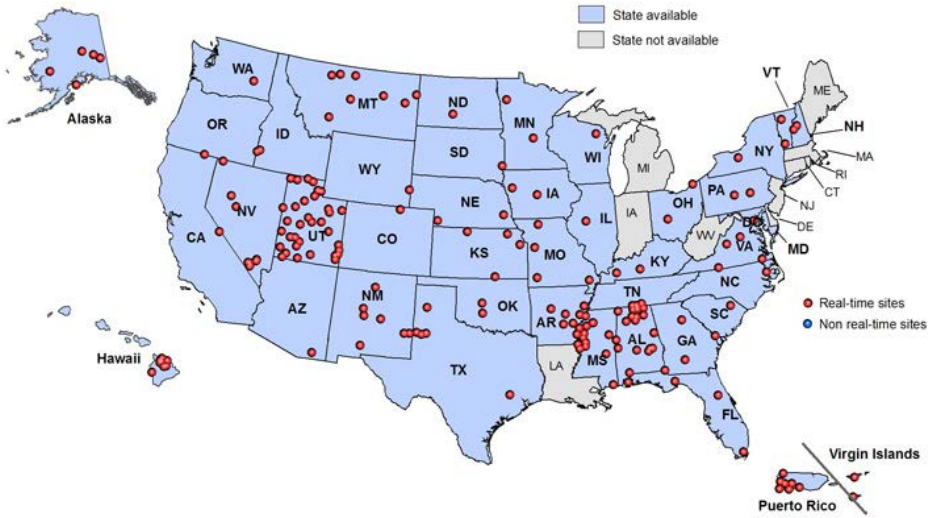
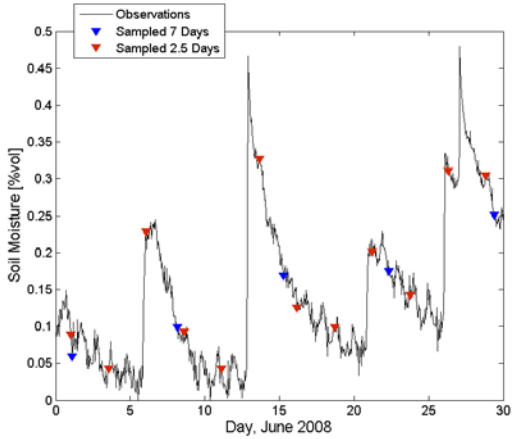
Why Measure from Space?

SMAP provides a capability for global observations of soil moisture and its frozen or thawed state with high spatial resolution and frequent temporal revisit

- Current ground measurements of soil moisture are sparse and have limited global coverage
- Previous space missions have relatively low soil moisture accuracy, resolution, and coverage
- **SMAP provides 10-40 km spatial resolution, 3-day global revisit, accuracy of 0.04 m^3/m^3**



Current network of USDA/SCAN in situ soil moisture sensors



Inter-storm soil moisture dry-down

[Sun et al. (2006): How often does it rain?, *J. Climate, **19***]

- Average inter-storm period implies 3-day sampling or better is required to resolve soil moisture variability

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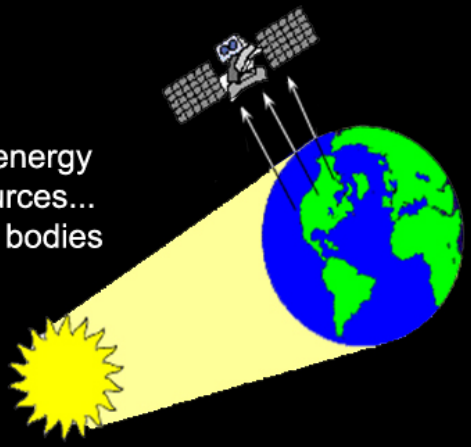
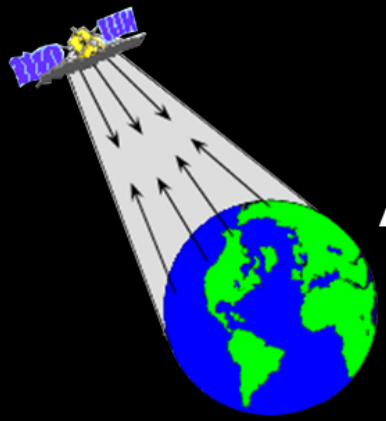
Why Active and Passive?

SMAP uses both "Passive" and "Active"
Remote Sensing to measure Soil Moisture

Passive Sensors:

The source of radiant energy
arises from natural sources...
Sun, Earth, other "hot" bodies





Active Sensors:

Provide their own artificial radiant energy
source for illumination... **RADAR**,
Synthetic Aperture Radar (SAR), **LIDAR**

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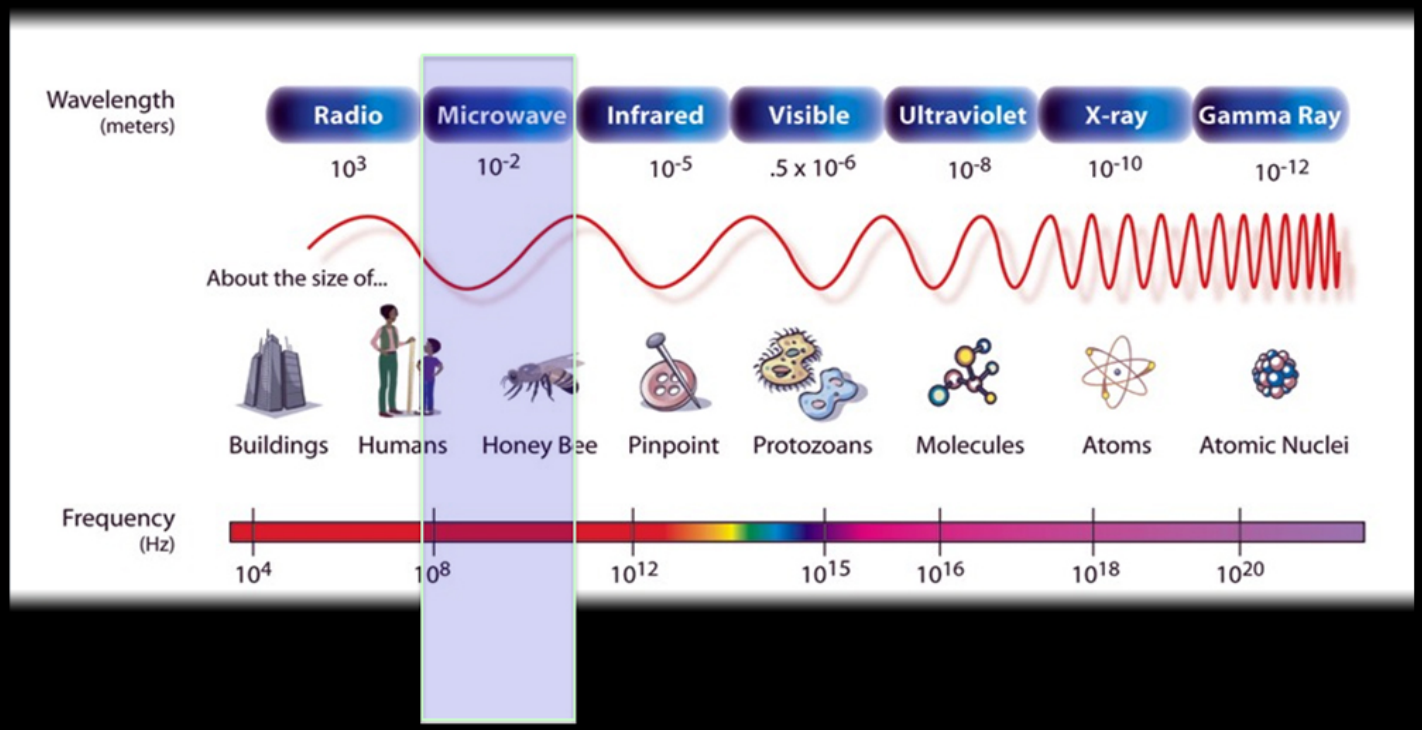
Measurement Frequency

SMAP Views the Earth in the Microwave Region of the Electromagnetic Spectrum



- With optical and infrared wavelength sensors the soil is masked by clouds and vegetation
  Also, optical sensors operate by measuring scattered sunlight and are “daytime only”
- Microwaves can penetrate through clouds and vegetation, operate day and night, and are highly sensitive to the water in the soil due to the change in the soil microwave dielectric properties

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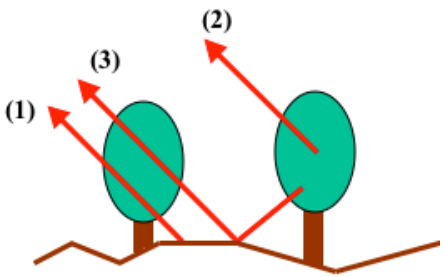
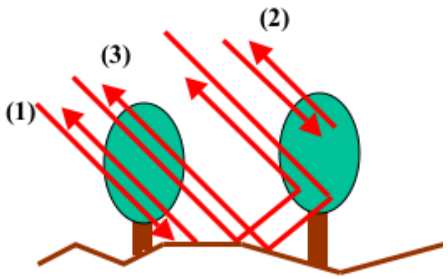
Retrieval of Soil Moisture



Emission (Radiometer)

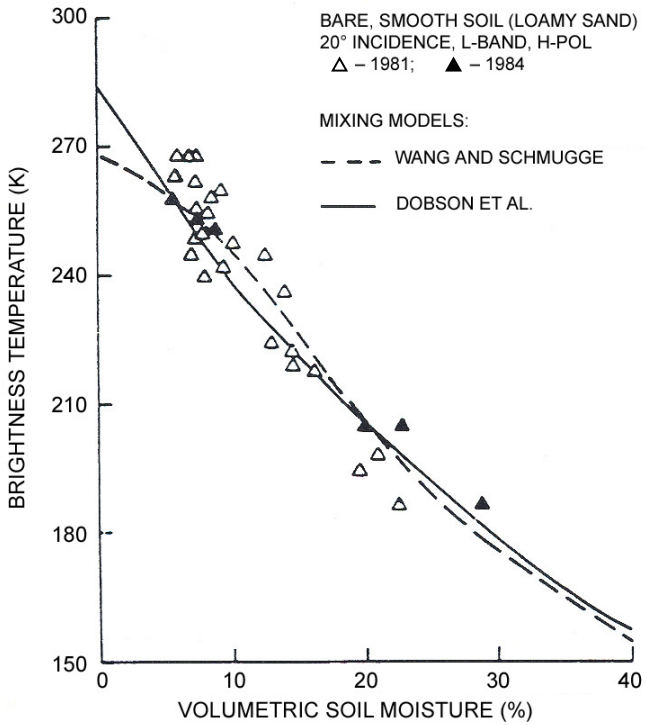


Backscatter (Radar)

$$T_{Bp}^{t} = T_{Bp}^{s} L_p + T_{Bp}^{v} + T_{Bp}^{sv} \qquad \text{(Emission)}$$

$$\sigma_{pq}^{t} = \sigma_{pq}^{s} L_{pq}^{2} + \sigma_{pq}^{v} + \sigma_{pq}^{sv} \qquad \text{(Backscatter)}$$

- Radiometers measure "brightness temperature", T_B (K)
  Radars measure "backscatter cross-section", σ_o (dB)
- Contributions to emission and backscatter include three terms: soil, vegetation, and soil-vegetation interaction
- Soil moisture is the dominant contributor to the signal
- L is the vegetation attenuation factor, $\exp(-\tau_o / \cos\theta)$



Experimental data showing brightness temperature sensitivity to soil moisture for bare, smooth soil

Retrievals invert these equations to obtain soil moisture, with corrections for vegetation, roughness and surface temperature

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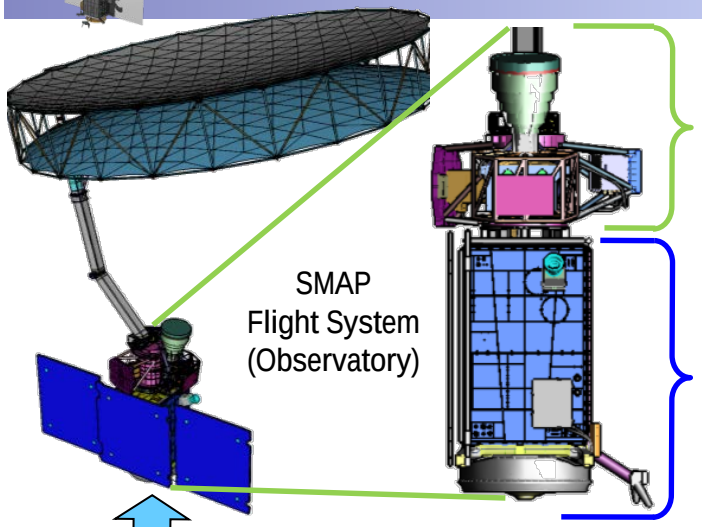
SMAP Mission Design

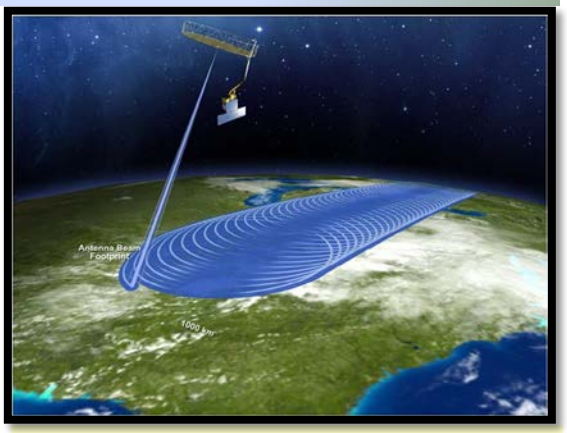


INSTRUMENT

- L-band (1.2-GHz) radar (JPL)
- L-band (1.4-GHz) radiometer (GSFC)
- Shared antenna (6-m diameter)
- Conical scan: 13–14.6 rpm; 40° incidence
- Contiguous 1,000-km swath width

SPACECRAFT (& RADAR ELECTRONICS)

- JPL developed & built
- JPL's MSAP/MSL avionics, power assys with a small number of new mission-unique card designs
- 951-kg wet mass (Observatory-level)
- 1450-W capacity (Observatory-level)
- 80-kg propellant capacity
- Commercial space electronics elsewhere



- 685-km polar orbit (Sun-sync)
- 8-day repeat ground track
- Continuous instrument operation
- 2- to 3-day global coverage
- 3-year mission duration

Delta II 7320-10C

Launch:
January 31, 2015
6:22 AM pacific

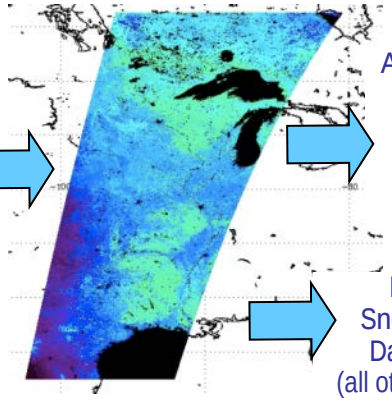
Vandenberg Air
Force Base

Near-Earth Network

Surface Validation

SMAP Mission Operations &
Data Processing
(JPL, GSFC)

SCIENCE DATA PRODUCTS
Soil Moisture & Freeze/Thaw State Data Products



Alaska Satellite
Facility
Data Center
(radar
L1 products)

National
Snow and Ice
Data Center
(all other products)

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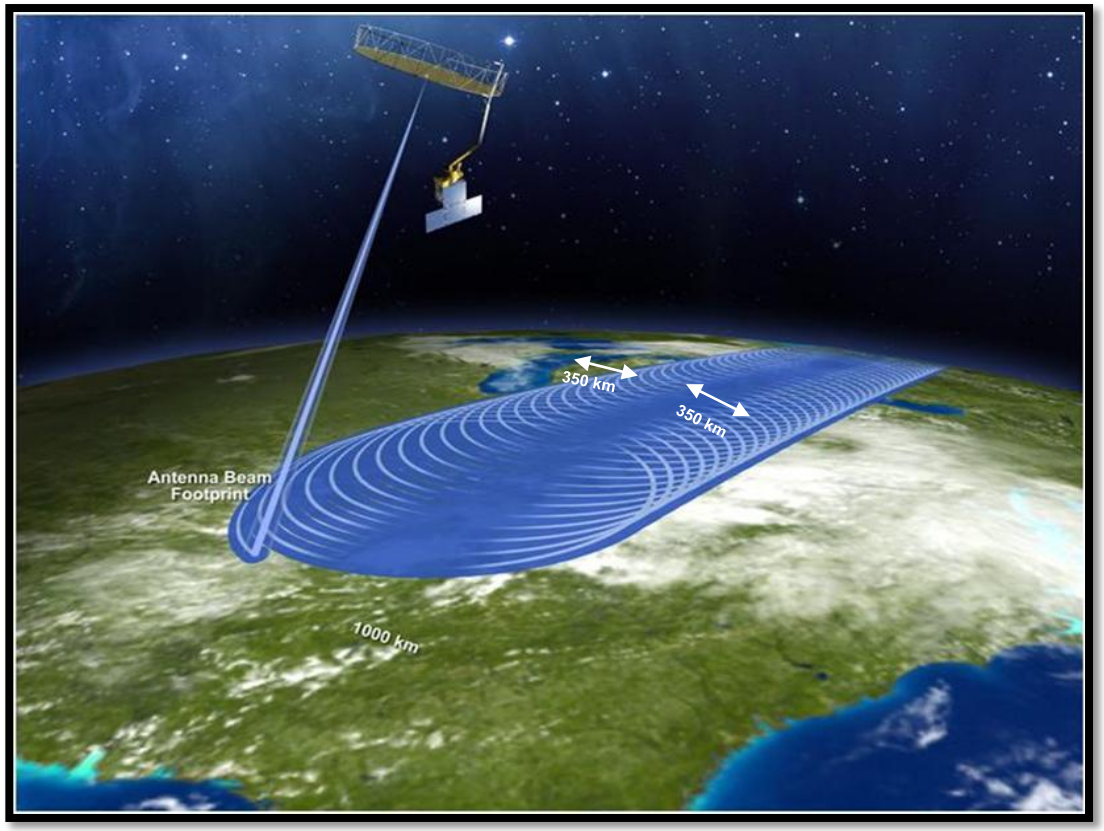
SMAP Instrument and Operating Characteristics

SMAP's objective is to provide high-resolution and frequent-revisit global mapping of soil moisture and landscape freeze/thaw state



Instrument Configuration

Radar
Frequency: 1.26 GHz
Polarizations: VV, HH, HV
Resolution: 1-3 km
Relative Accuracy: 1.0 dB (HH, VV); 1.5 dB (HV)

Radiometer
Frequency: 1.41 GHz
Polarizations: H, V, 3rd & 4th Stokes
Resolution: 40 km
Relative Accuracy: 1.3 K

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, 685 km altitude

Mission Operations
3-year baseline mission

- ***Radar*** - High spatial resolution (1-3 km) but more influenced by surface roughness and vegetation
- ***Radiometer*** - High accuracy (less influenced by roughness and vegetation) but coarser spatial resolution (40 km)
- ***Combined Radar-Radiometer*** **–** Soil moisture product (9 km) provides optimal blend of resolution and accuracy

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SMAP Data Products

Data Product Short Name	Description	Grid (Resolution)	Granule Extent
L1A_Radar	Parsed Radar Instrument Telemetry		Half Orbit
L1A_Radiometer	Parsed Radiometer Instrument Telemetry		Half Orbit
L1B_S0_LoRes	Low Resolution Radar σ_o in Time Order	(5x30 km) (slices)	Half Orbit
L1C_S0_HiRes	High Resolution Radar σ_o on Swath Grid	1 km	Half Orbit
L1B_TB	Radiometer T_B in Time Order	(39x47 km)	Half Orbit
L1C_TB	Radiometer T_B	36 km	Half Orbit
L2_SM_A	Radar Soil Moisture (includes Freeze-Thaw)	3 km	Half Orbit
L2_SM_P	Radiometer Soil Moisture	36 km	Half Orbit
L2_SM_AP	Active-Passive Soil Moisture	9 km	Half Orbit
L3_FT_A	Daily Global Composite Freeze/Thaw State	3 km	North of 45° N
L3_SM_A	Daily Global Composite Radar Soil Moisture	3 km	Global
L3_SM_P	Daily Global Composite Radiometer Soil Moisture	36 km	Global
L3_SM_AP	Daily Global Composite Active-Passive Soil Moisture	9 km	Global
L4_SM	Surface & Root Zone Soil Moisture	9 km	Global
L4_C	Carbon Net Ecosystem Exchange	9 km	Global

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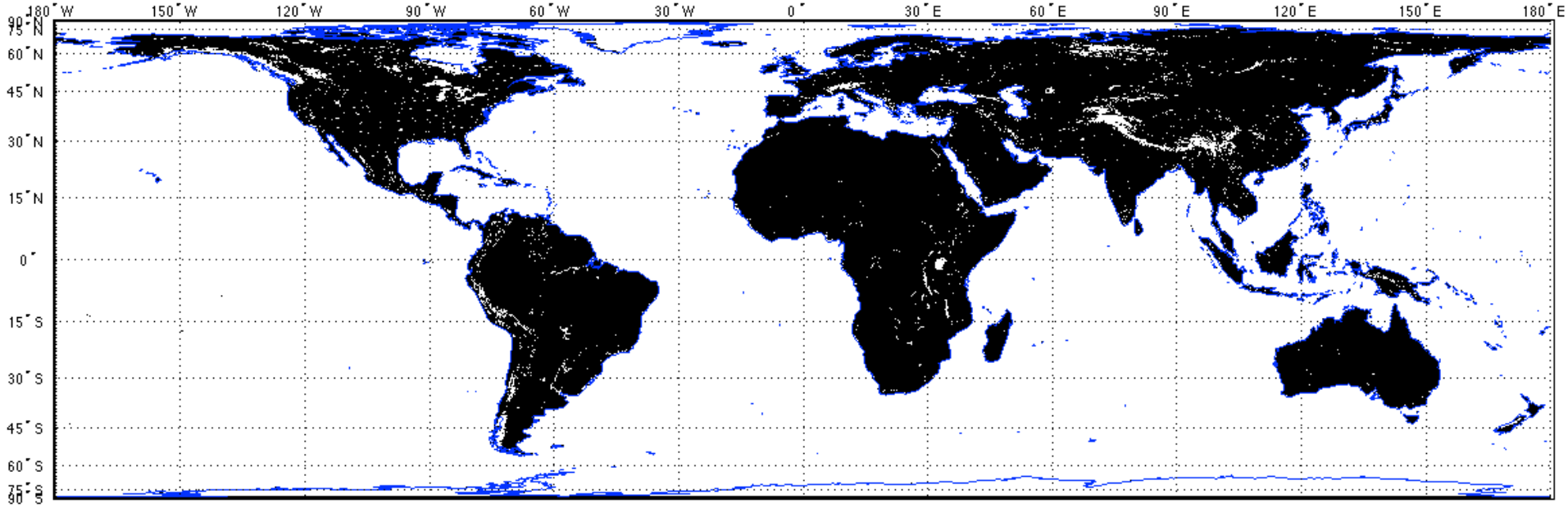
SMAP Retrievable Mask

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

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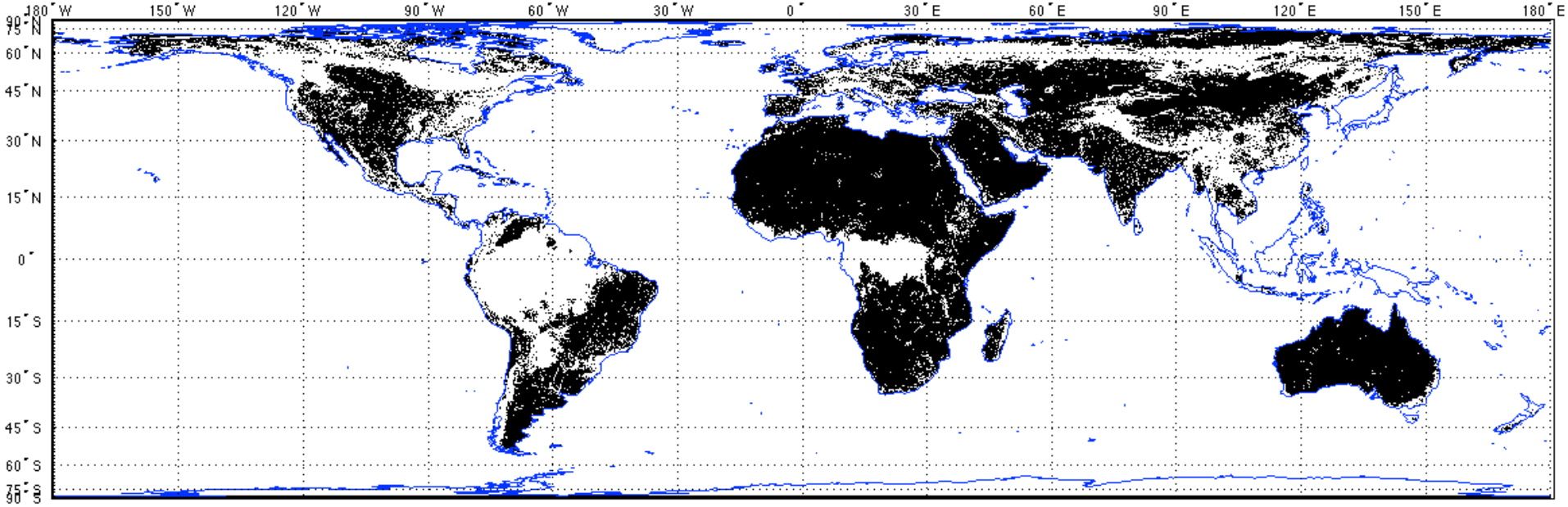
SMAP L1 Mask

Regions Where SMAP Soil Moisture Retrievals Are Expected to Meet L1 Requirements



Retrievable Mask (Black Colored Pixels) Prepared With Following Specifications:

a) VWC ≤ 5 kg/m^2
b) Urban Fraction ≤ 0.25
c) Water Fraction ≤ 0.1
d) DEM Slope Standard Deviation ≤ 3 deg

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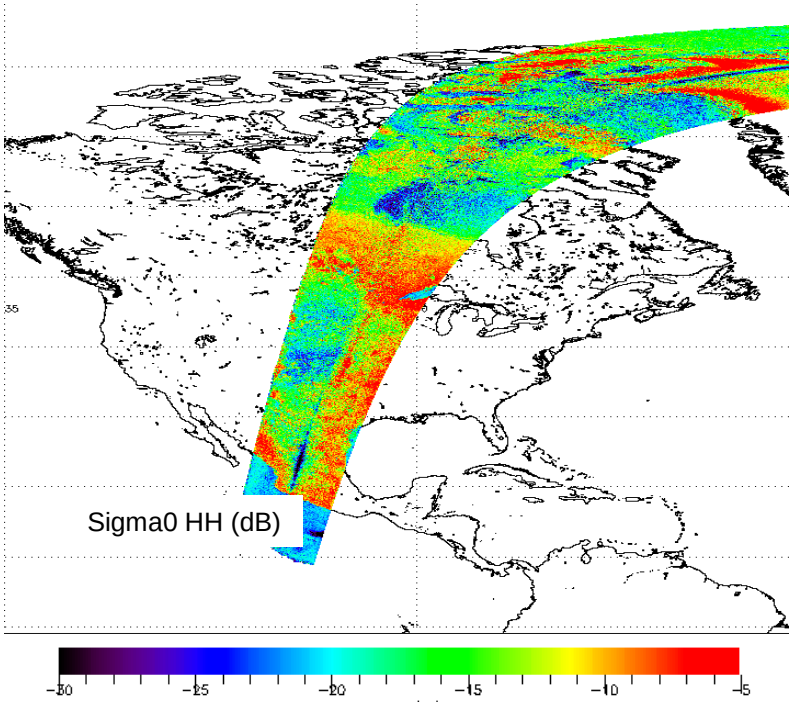
Level 1C Radar Product



- Each granule contains geographically ordered data in 1 km grid cells in an along track/cross track swath grid
- Coverage is restricted to land and coastal water over one spacecraft half orbit
- SAR provides high-resolution single-look measurements. Resolution varies from ~400 m at the swath edge to about 1.2 km at 150 km from the nadir sub-track. Nadir looks are thin slices as wide as the beam footprint
- Contains Earth located and calibrated h-pol, v-pol and cross-pol backscatter measurements, each separately multilooked
- Radar measurements achieve approximately 1 km resolution over the outer 70% of the swath Resolution degrades in the nadir region (middle 30% of swath)
- Forward looking and aft looking measurements are stored separately
- Includes spacecraft orbit and attitude information and instrument pointing geometry
- Includes short term and external calibration data used to generate product output
- Provides reference to global and polar 1-km EASE grid coordinates

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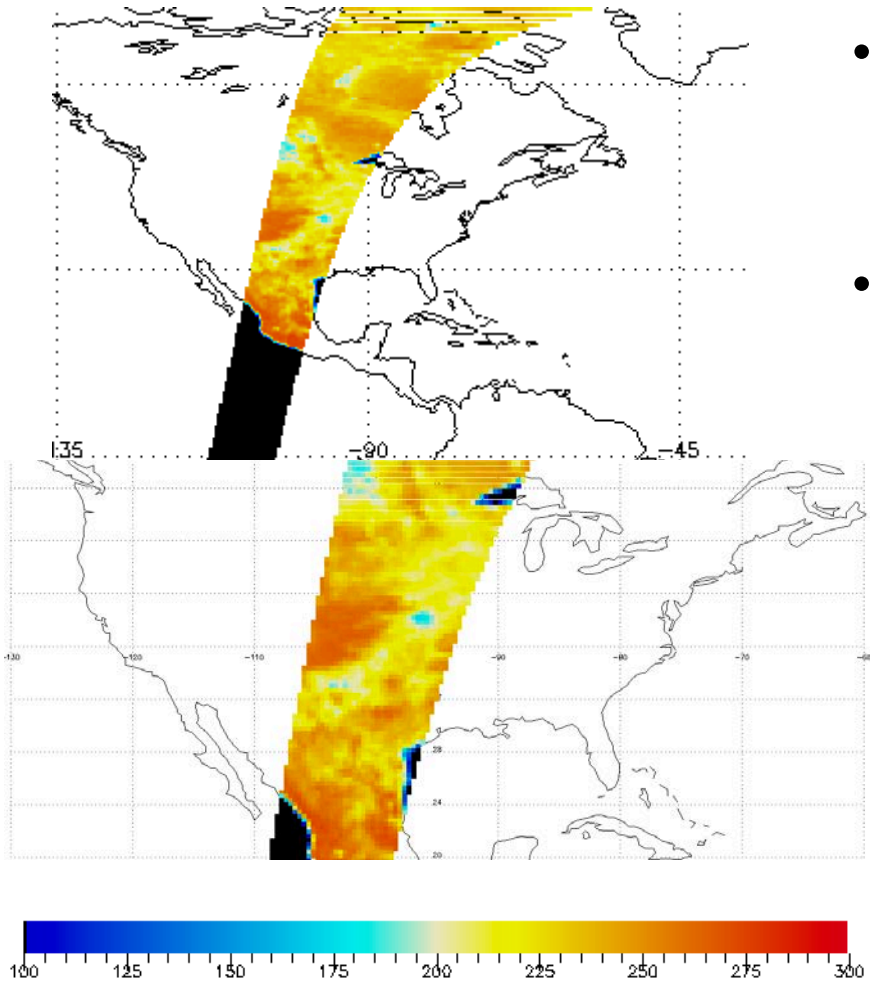
Level 1C Radiometer Product



L1C Earth-fixed H-pol TB (K)

- Consists of level 1B Radiometer data gridded on a 36 km Earth-fixed grid
- Data appear in three projections
  - Global cylindrical grid
  - North polar grid
  - South polar grid

Forward looking and aft looking observations are stored separately

Direct input to level 2 passive soil moisture product (36 km) and level 2 active-passive soil moisture and level 4 soil moisture products (9 km)

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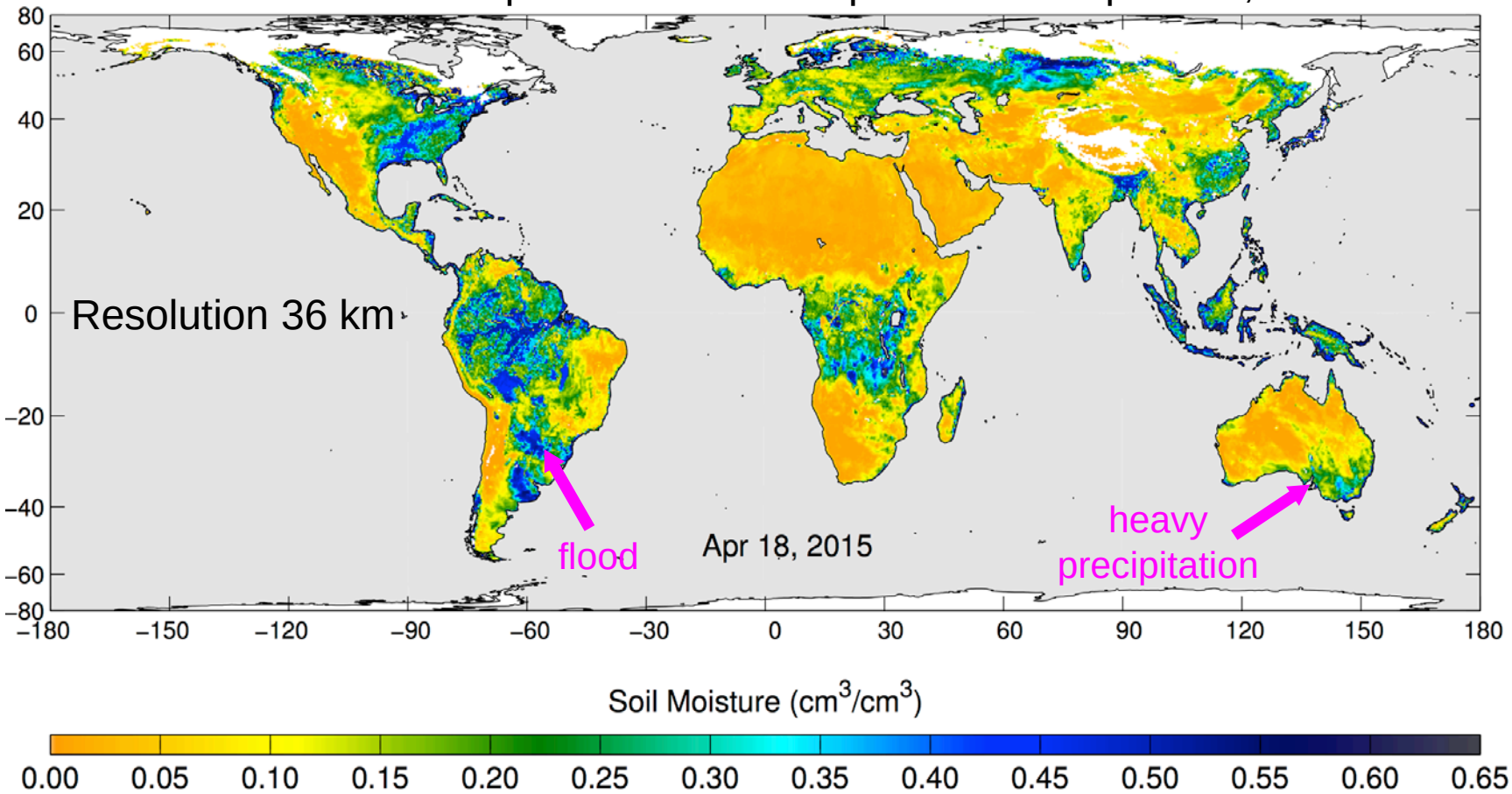
L2SMP – Radiometer only Soil Moisture

Soil moisture composited between April 17th and April 19th, 2015



Regions show good correspondence between increased soil moisture and flood/rainfall

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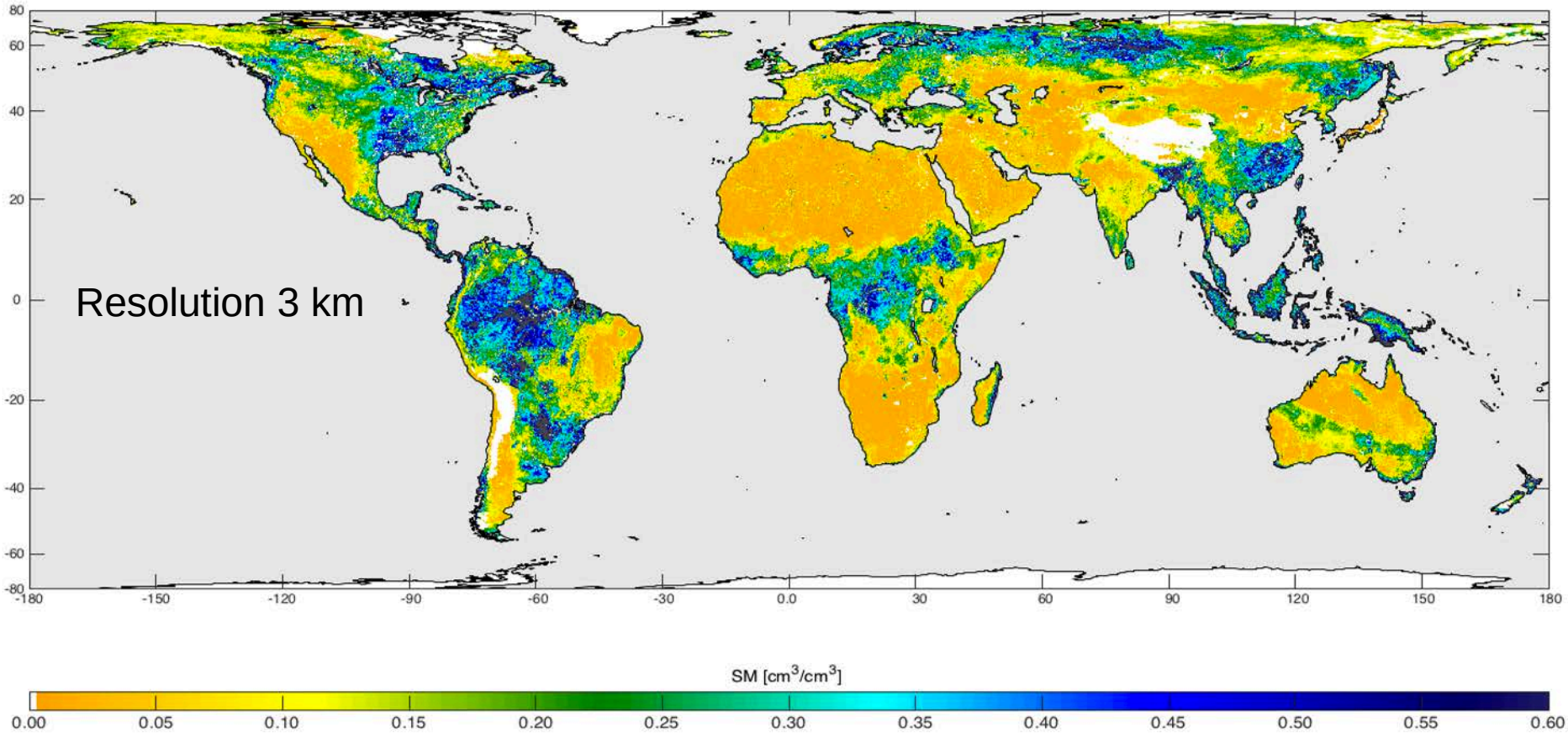
L2SMAP – Radar-Radiometer Combined Soil Moisture

Soil moisture composited between June 12th and June 14th, 2015



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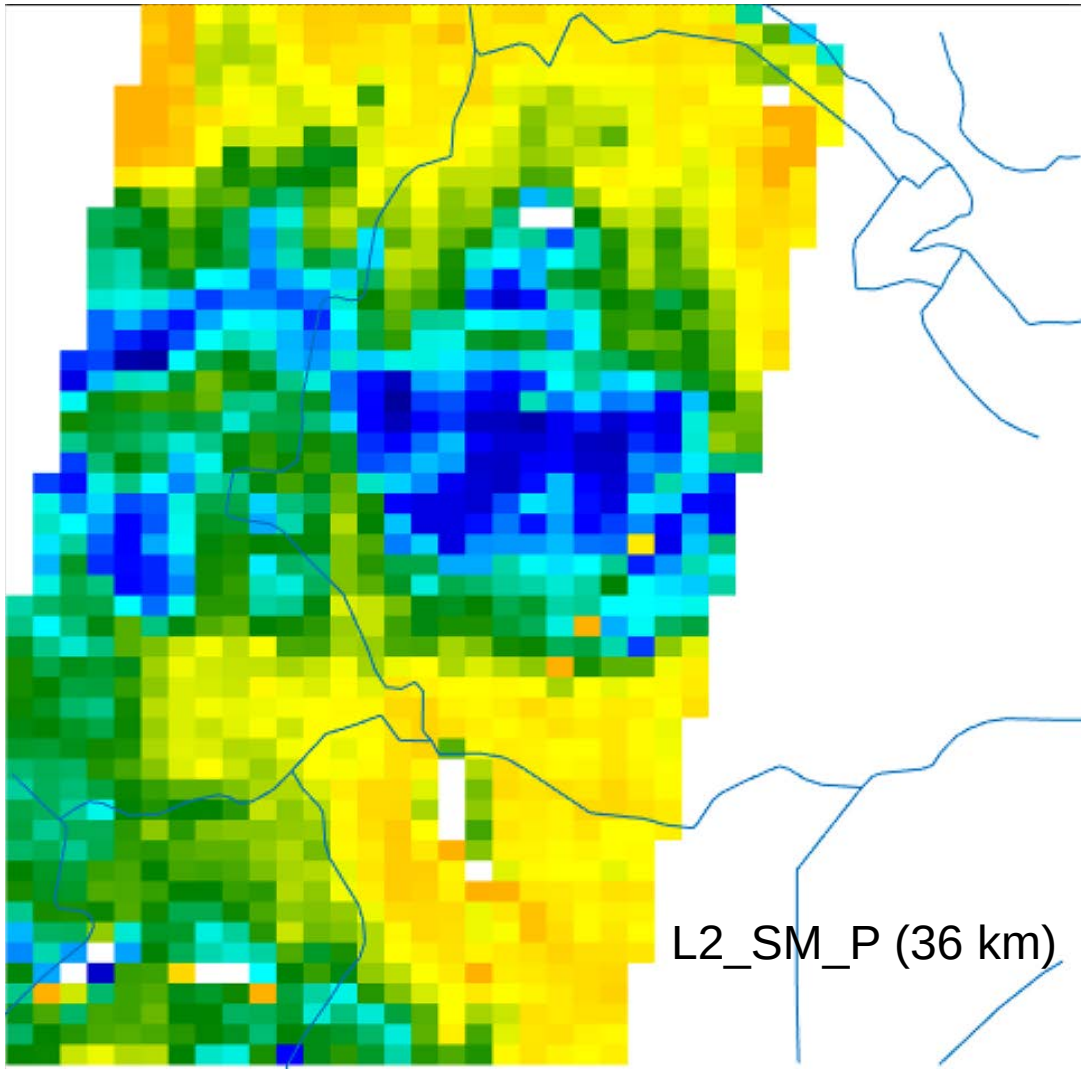
Detail Captured by SMAP



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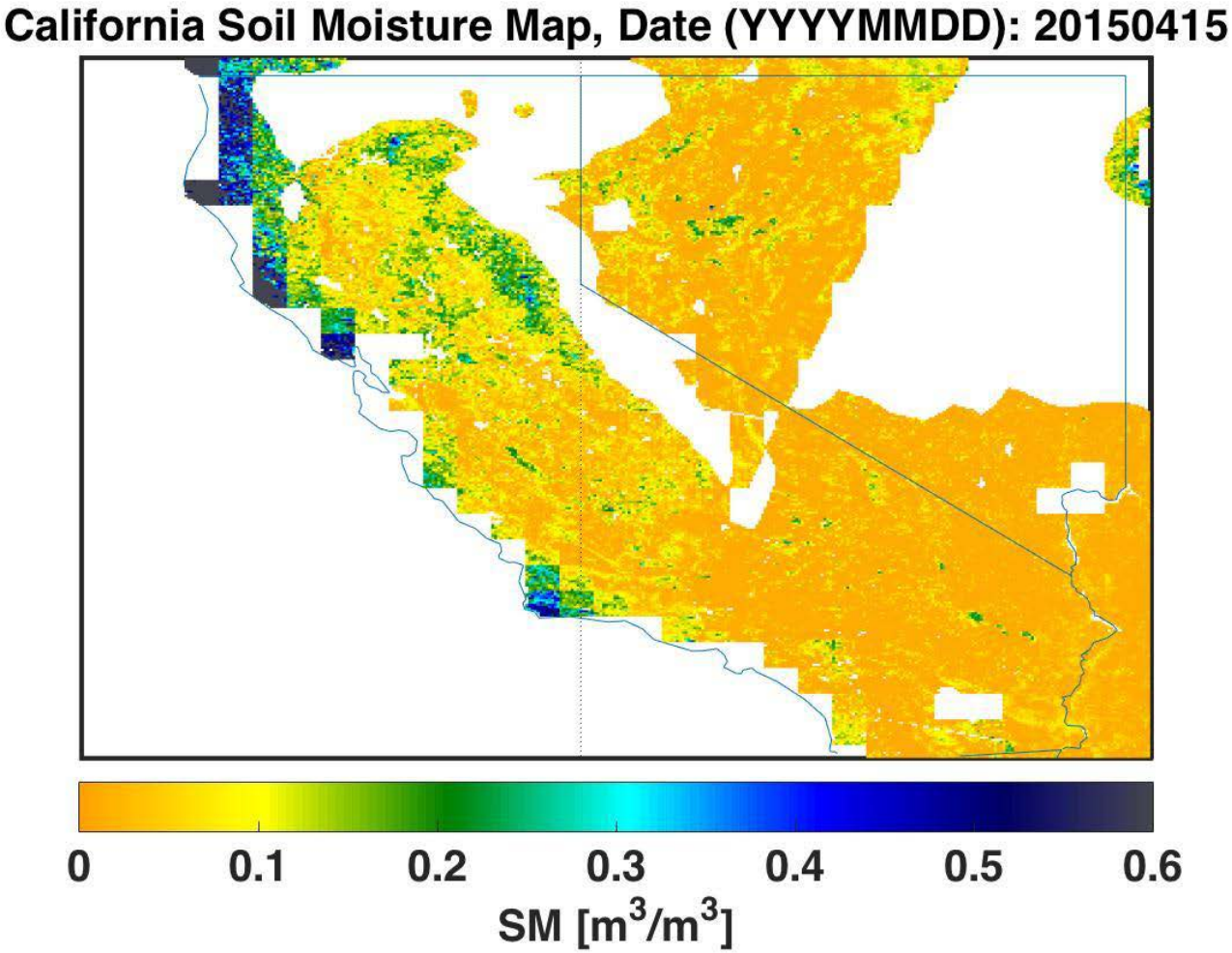
Soil Moisture Evolution over California



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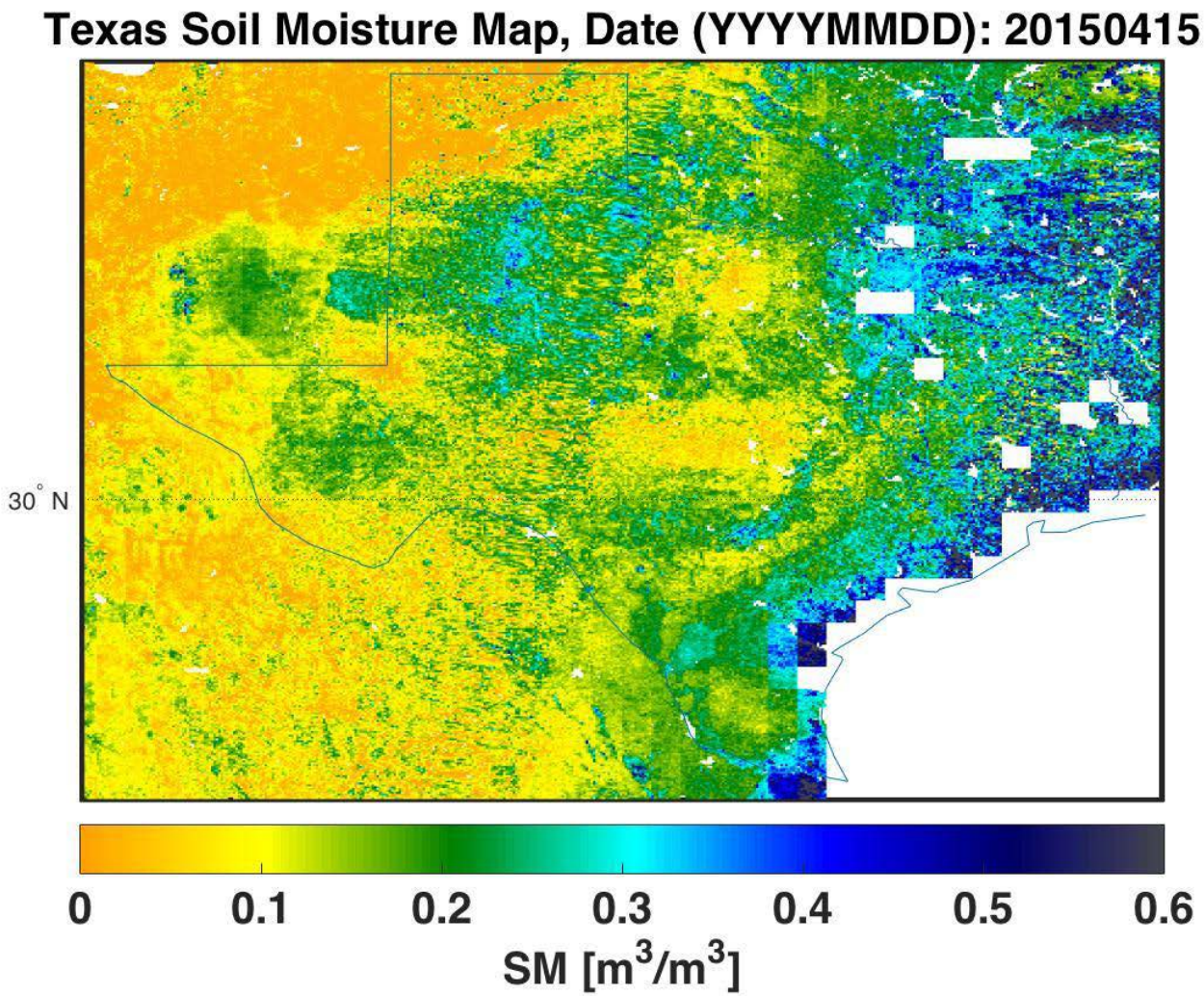
Soil Moisture Evolution over Texas



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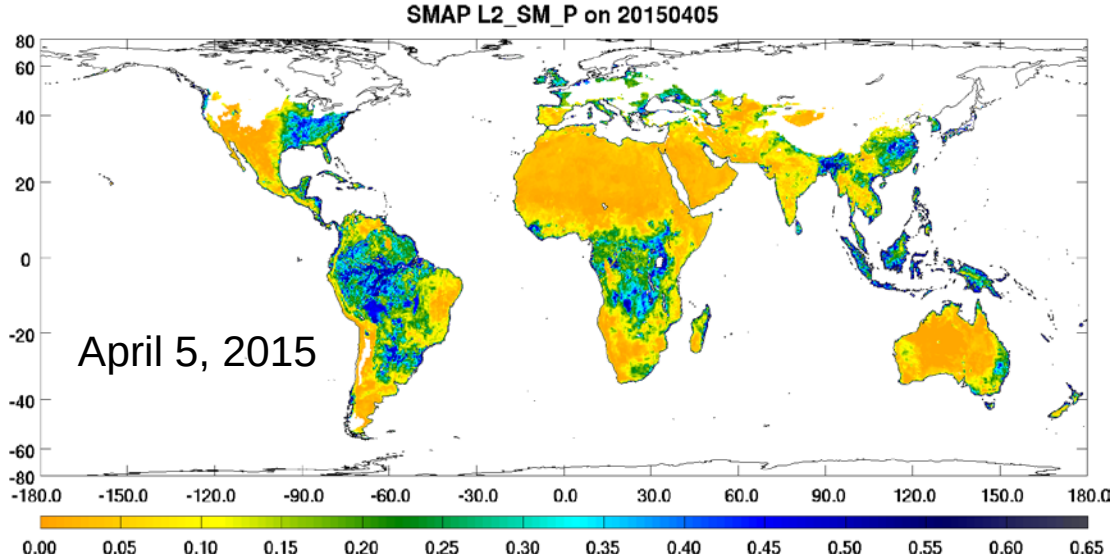
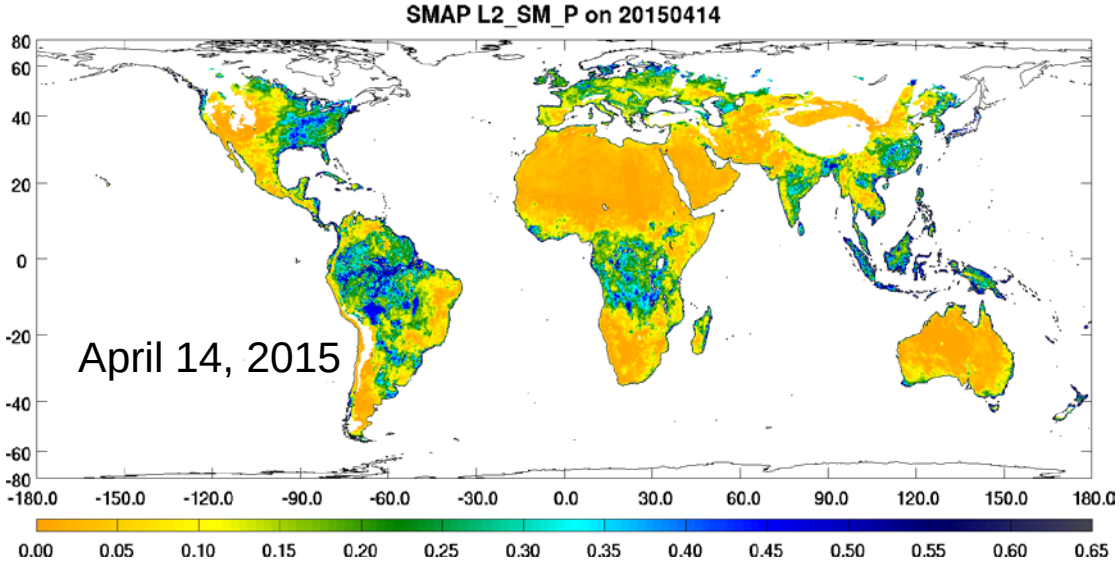
Soil Moisture - Observed Changes

- Passive (36 km) data processed into soil moisture 3-day global images centered on April 5 and 14, 2015
- Soil moisture patterns agree with expected geographical soil moisture





- Soil moisture changes are evident in the time-sequence
- Rainfall in India, Bangladesh, and Vietnam
- Dry-down in eastern Australia and Argentina

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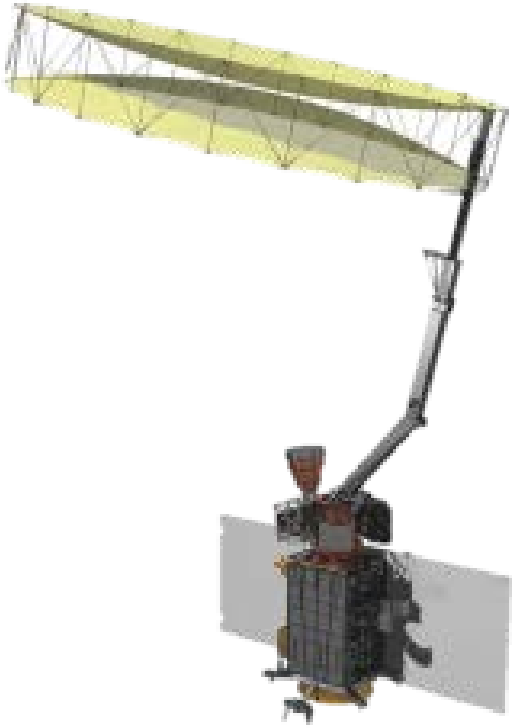
Setback of the SMAP Radar

On July 7th, 2015 the SMAP Radar suffered an anomaly and is inoperable currently



Therefore,

L2SMAP, the radar-radiometer combined product is only available until 7th July, 2015

L2SMA, the radar only soil moisture product is also available until 7th July, 2015

The L2SMP, the radiometer-only soil moisture product is available from April'15 to current

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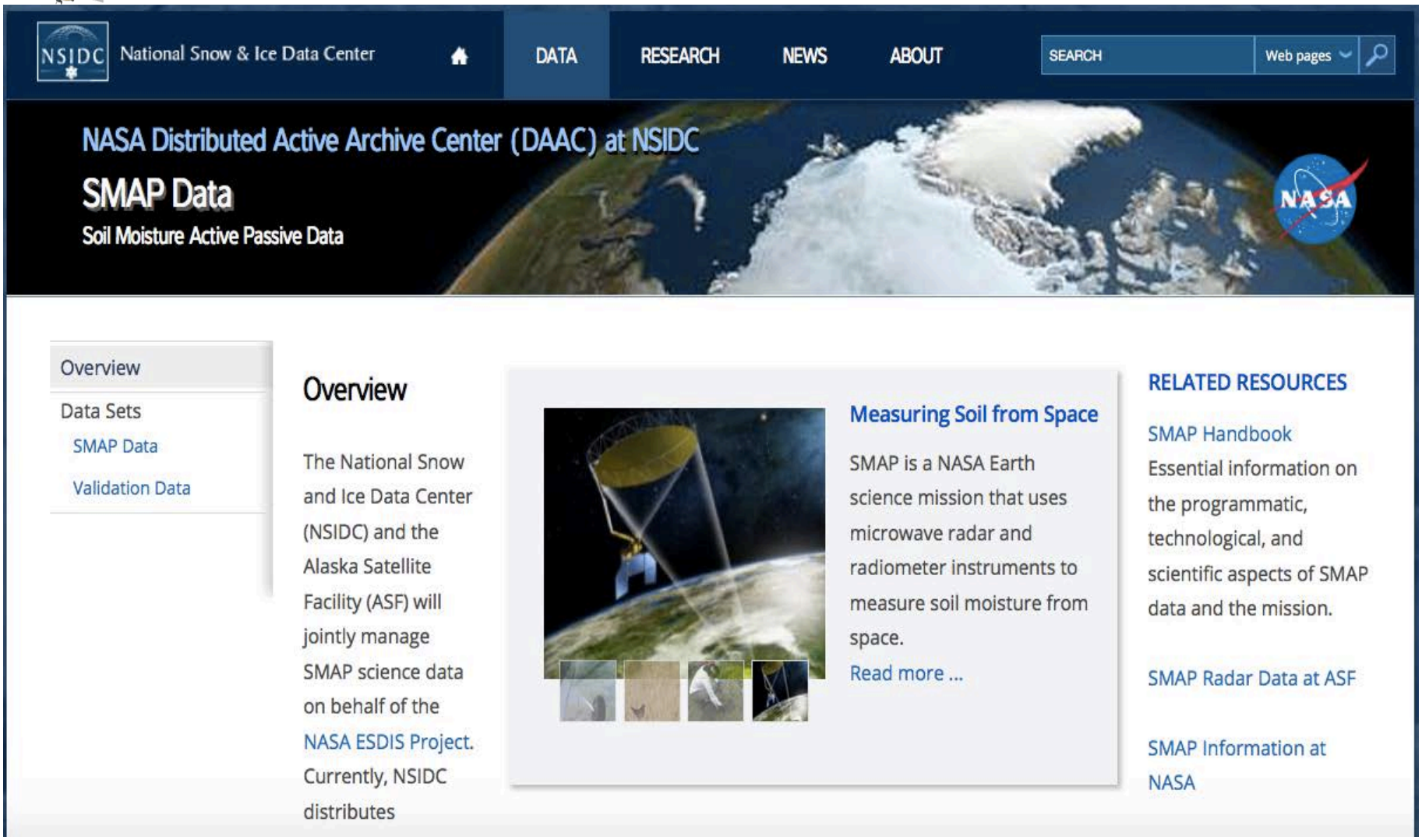
SMAP Portal at the NSIDC DAAC



SMAP Beta Release Soil Moisture Products are available at the portal mentioned above

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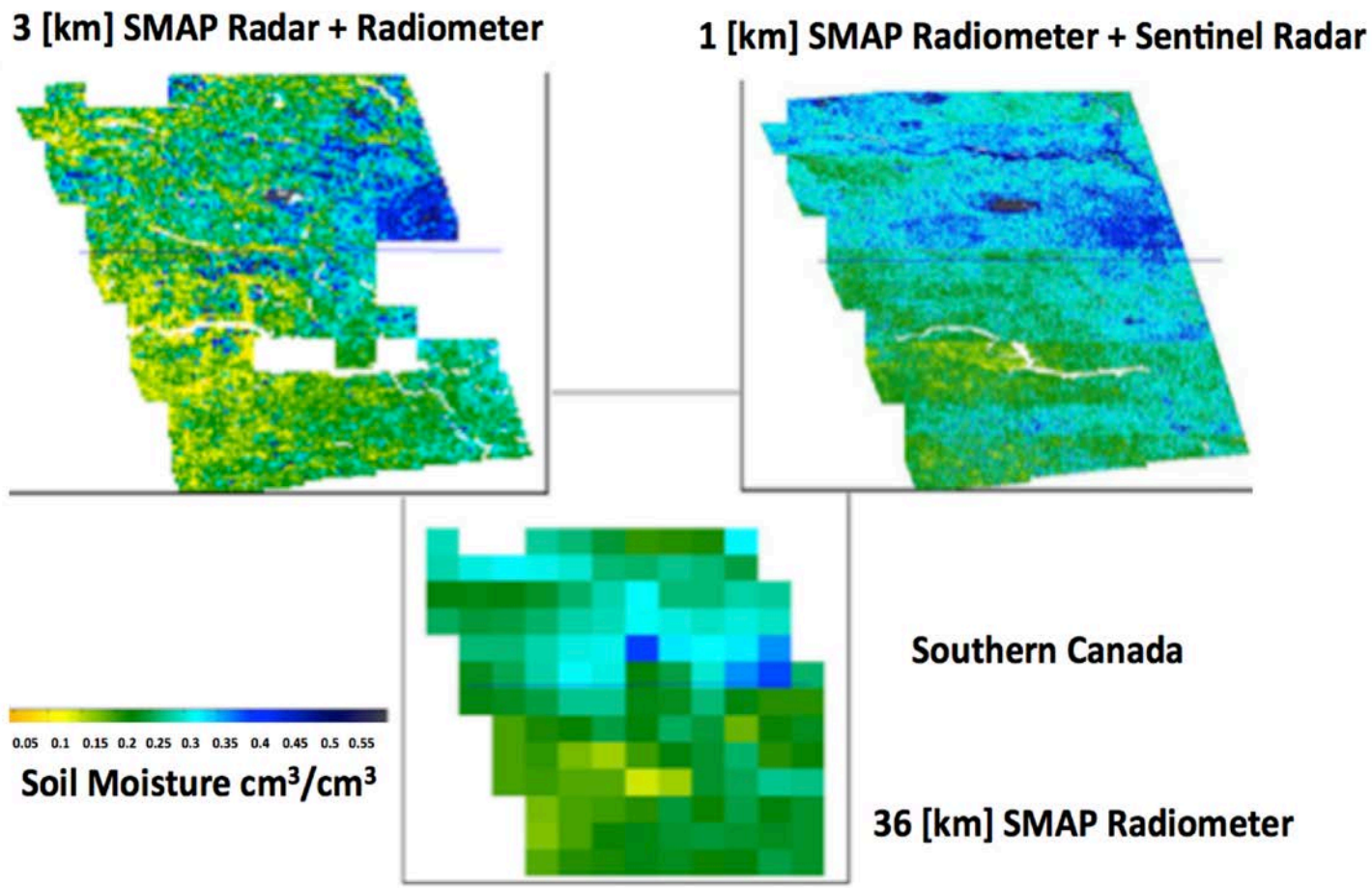
Future Work for SMAP Enhanced Soil Moisture Product

Examples: Replacing SMAP Radar with the Sentinel Radar data



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Summary

- SMAP Radiometer is operating optimally and is producing consistent observations.
- SMAP Radar failed on July 7th, 2015. No radar data is available beyond this date.
- Initial validation of all the SMAP products are conducted and found meeting the requirements
- Beta released Products are available through NASA DAAC (NSIDC)

  (L2SMP: Radiometer only soil moisture – From April'15 to current)

  (L2SMAP: Radar-Radiometer combined soil moisture – From April'15 to July 7th, 2015)

  (L2SMA: Radar soil moisture – From April'15 to July 7th, 2015)

Work is underway to recover lost capabilities of SMAP Observations by exploring SMAP Enhanced soil moisture products

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