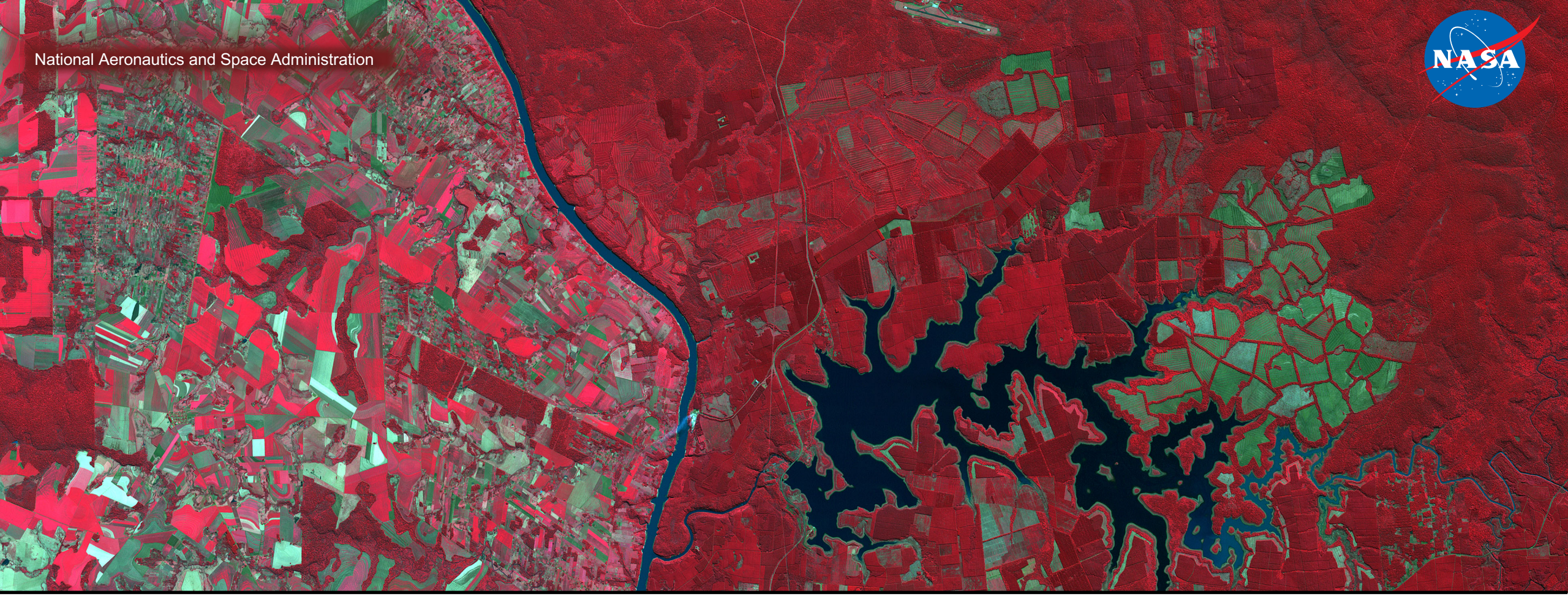
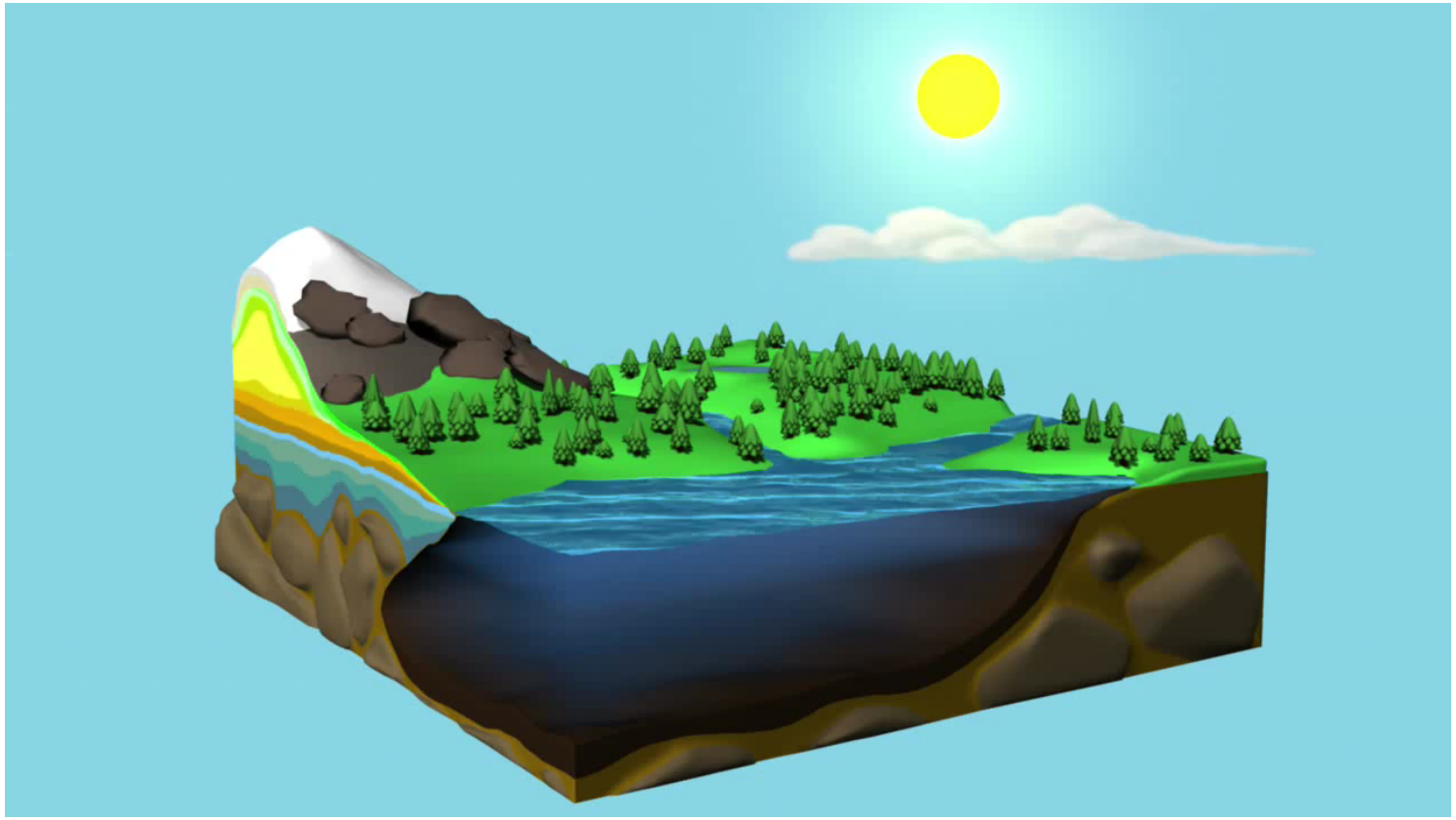


Introduction to the Soil Moisture Active Passive Mission (SMAP)

Erika Podest

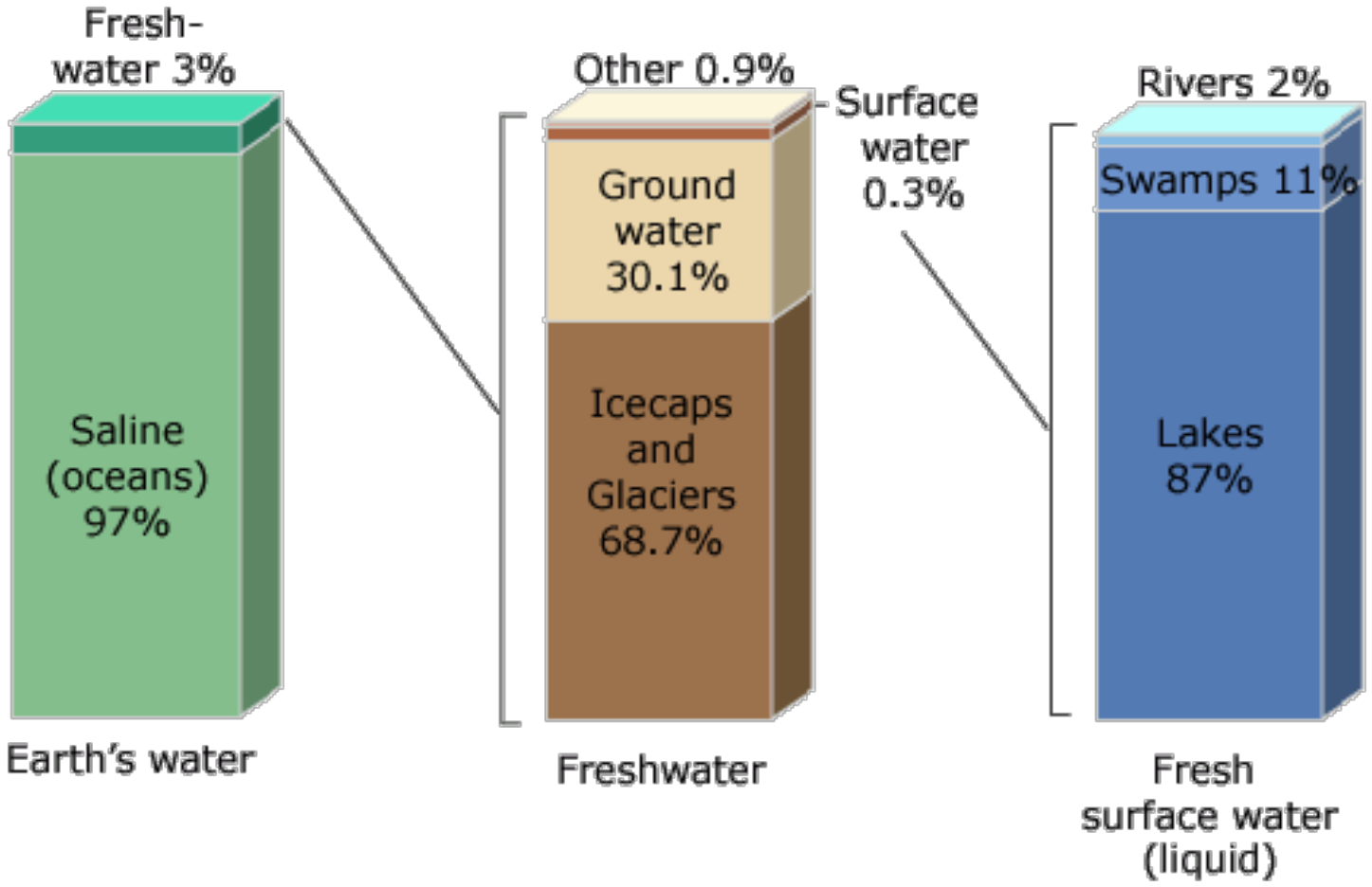
2 December 2017

The Water Cycle



- The total quantity of water on Earth remains essentially constant
- Water moves about, changing form (vapor, liquid, solid) and location as part of the hydrologic cycle

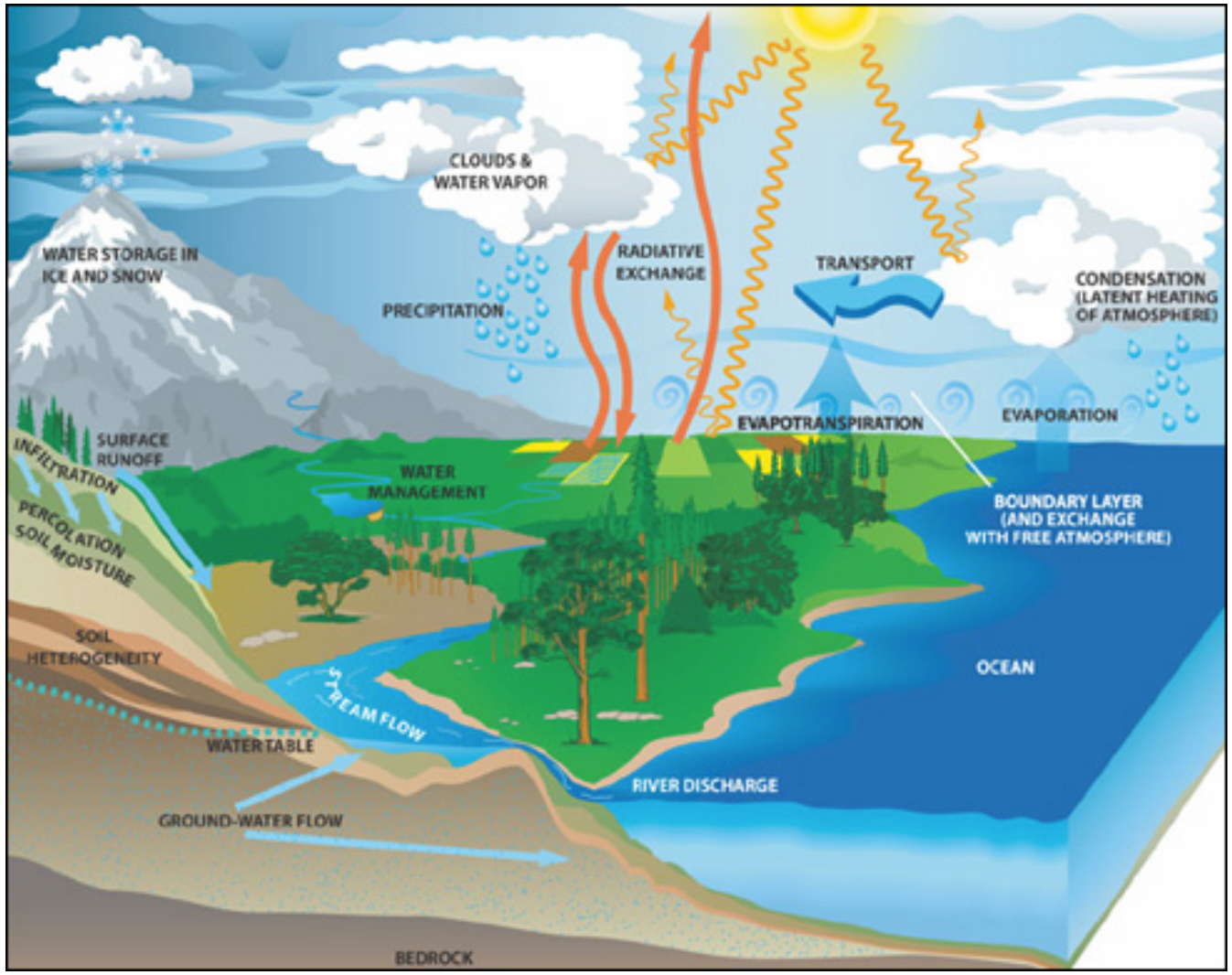
Water Distribution on Earth



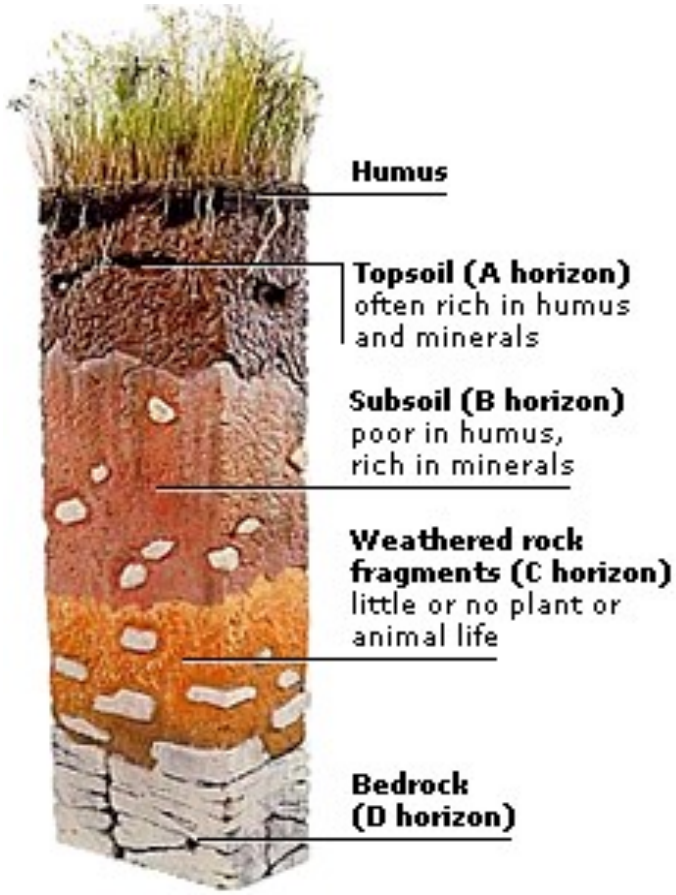
Source credit: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor 1993, Water in Crisis: A Guide to the World's Fresh Water Resources. Note: Numbers are rounded, so percent summations may not add to 100.

Importance of Soil Moisture

- For each kilogram of water on Earth, only 1 milligram is stored as soil moisture
- Soil moisture exerts significant control over:
  - Hydrological Processes
  - Ecological Processes
  - Meteorological Processes



Soil Profile



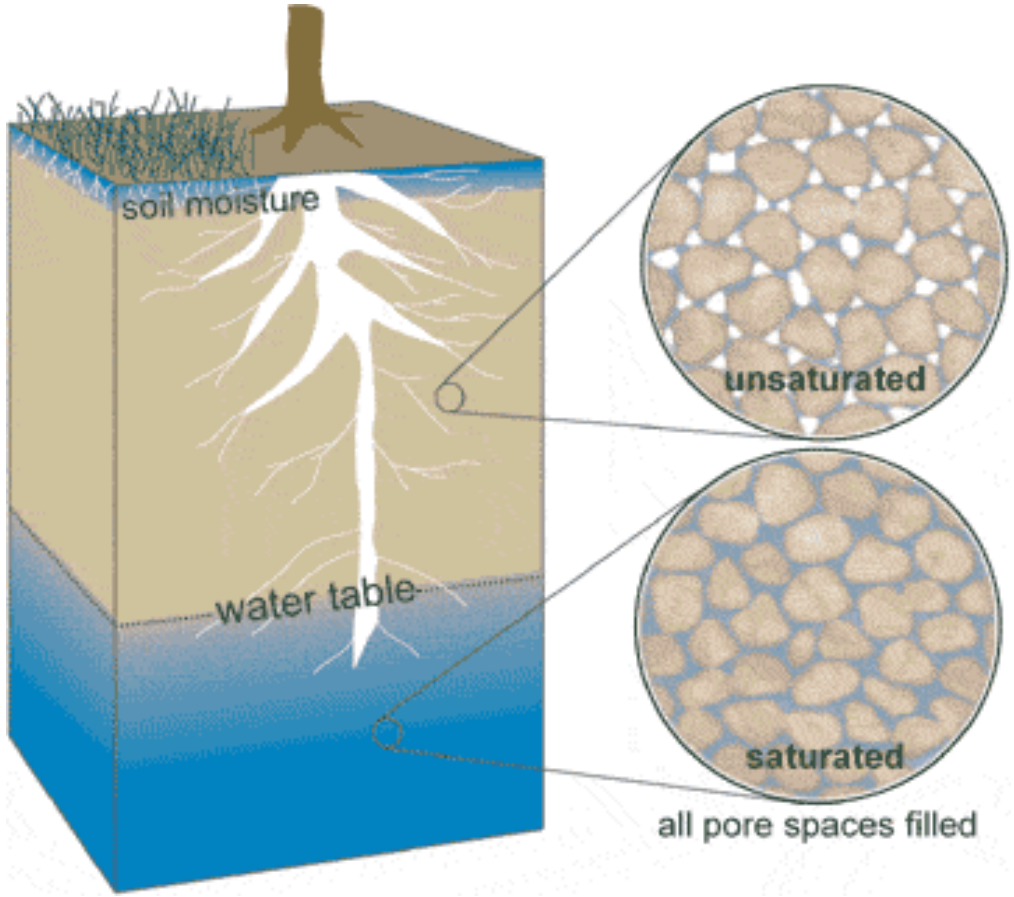


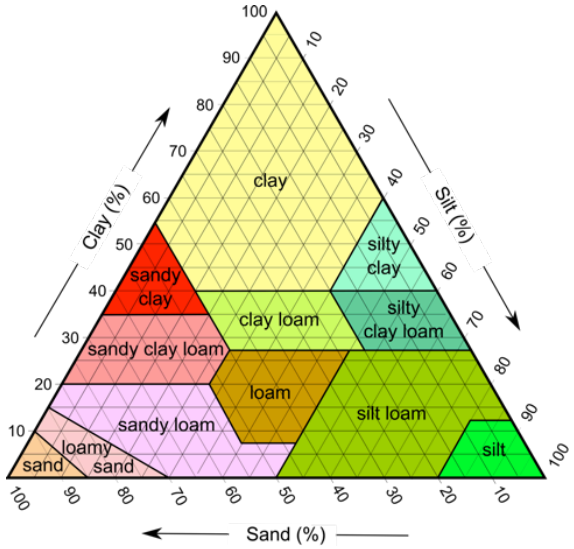
Image Credits Left to Right: x, Radosław Drożdżewski, CC BY-SA 3.0;

Factors Influencing Soil Moisture

- Soil moisture varies with space and time
- Primary factors that influence distribution of soil moisture:

Rainfall

Soil Texture



Vegetation

Topography

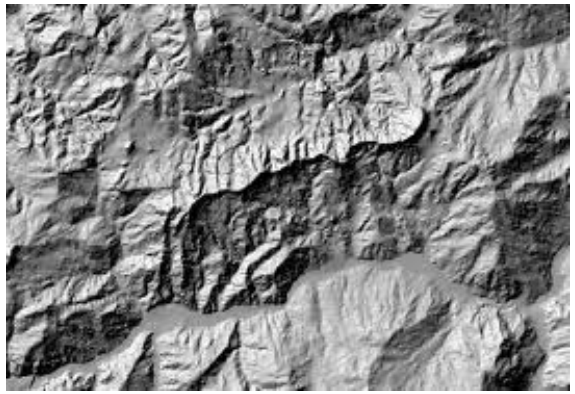
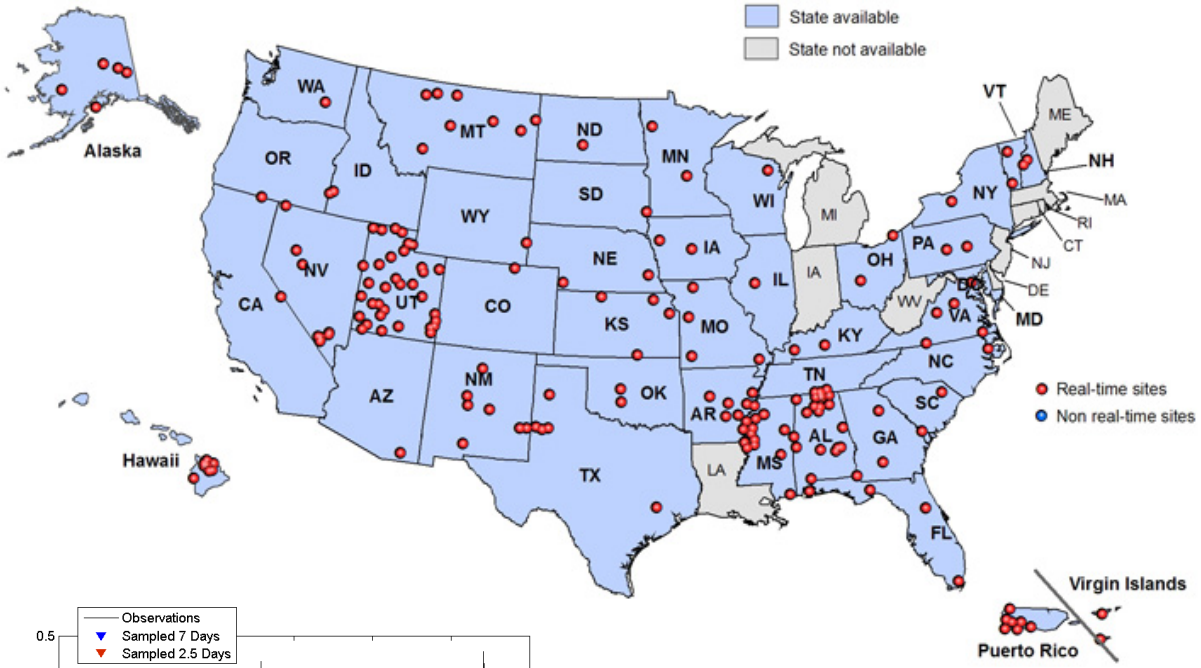
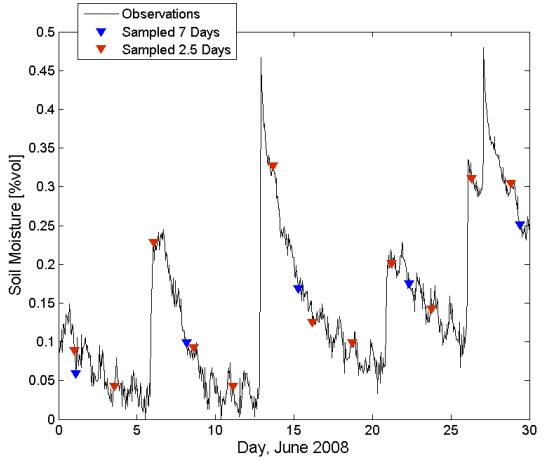


Image Credit, Soil Texture: USDA

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 revisits
- Current ground measurements of soil moisture are sparse and have limited coverage
- Previous space missions have relatively low soil moisture accuracy, resolution, & coverage

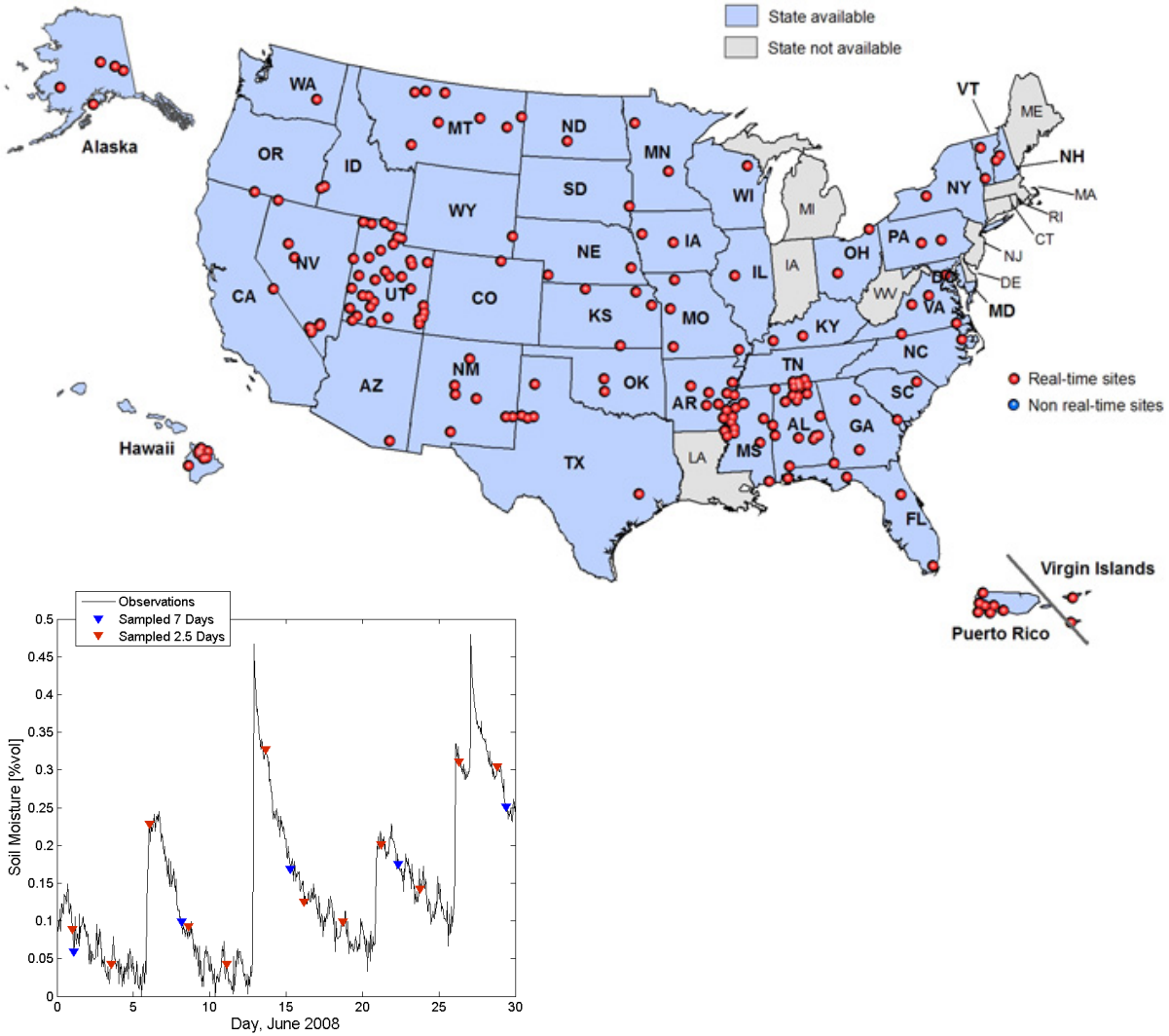




Source: Sun et. al, 2006, How often does it rain? J. Climate, 19

Why Measure from Space?

- SMAP Provides:
  - 10-40 km spatial resolution
  - 3 day global revisit
  - Accuracy of 0.04m^3/m^3
- Inter-Storm Soil Moisture Dry-Down
  - Average inter-storm period implies 3 day sampling or better is required to resolve SM variability



Source: Sun et. al, 2006, How often does it rain? J. Climate, 19

Applications in Soil Moisture

Enhanced weather & climate forecasting

Improved agricultural productivity and crop yield predictions

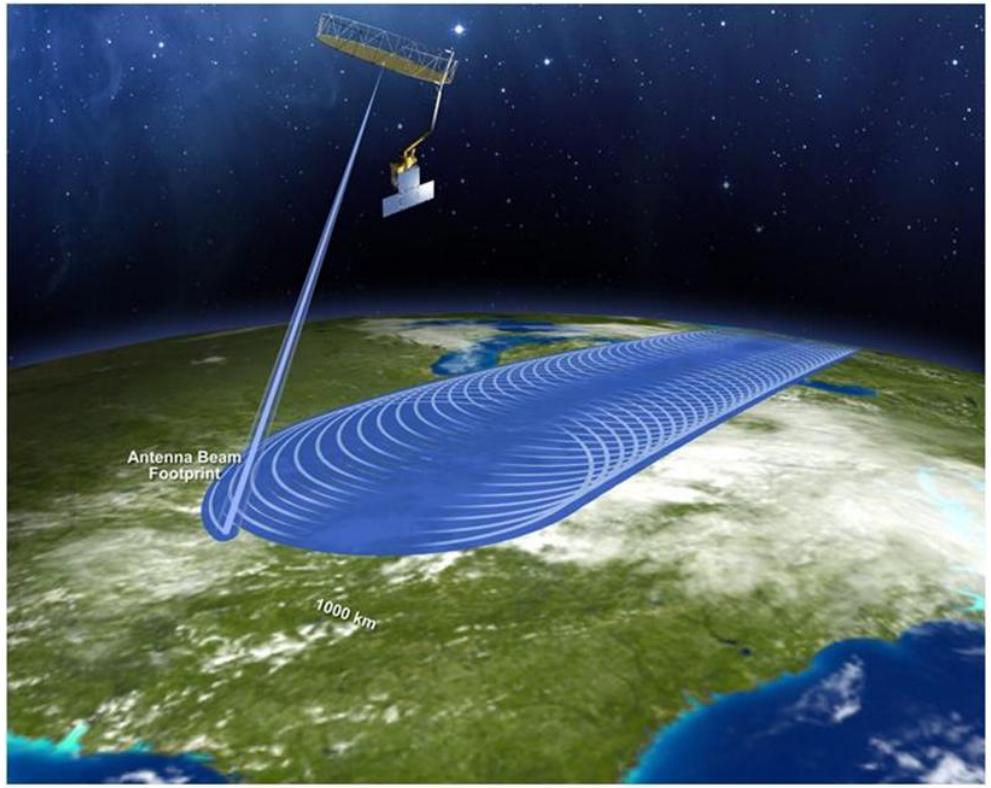
Drought monitoring and early warning

Flood monitoring and prediction

Human health and vector borne diseases

SMAP Overview

Instruments



Launched Jan 31, 2015

Radar (no longer working)

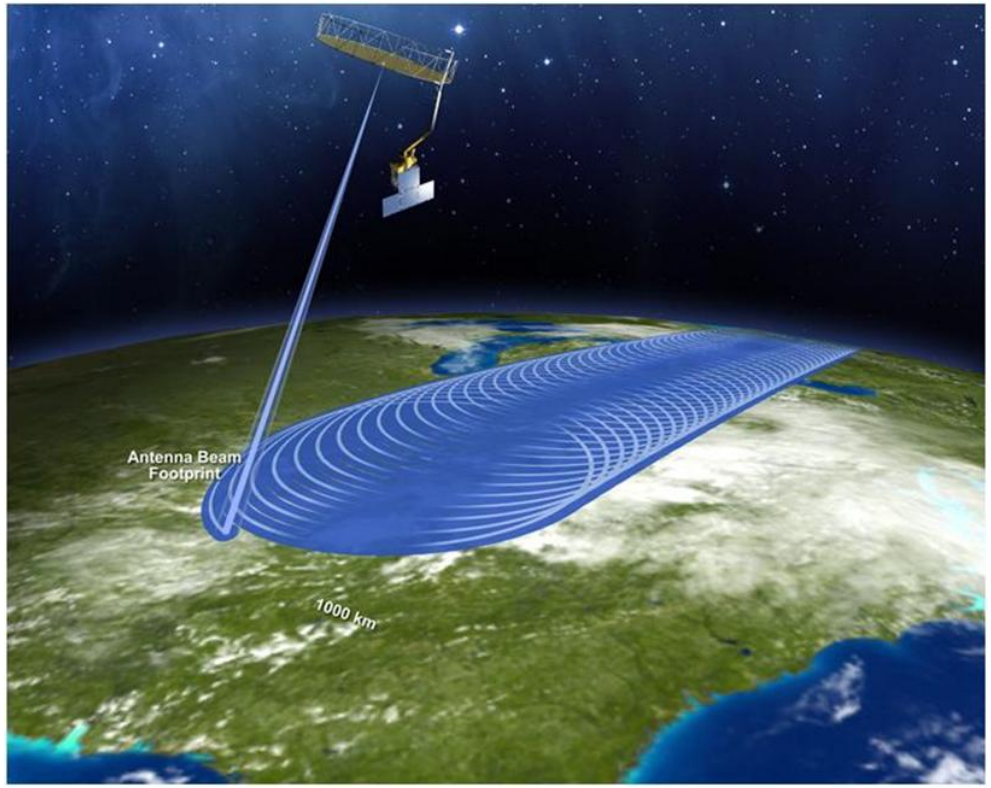
- Frequency: 1.26 GHz
- Polarization: VV, HH, HV
- Resolution: 3 km
- Relative Accuracy: 1.0 dB (HH and VV), 1.5 dB (HV)

Radiometer

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

SMAP Overview

Instruments



Mission Duration: 3 yrs

Shared Antenna

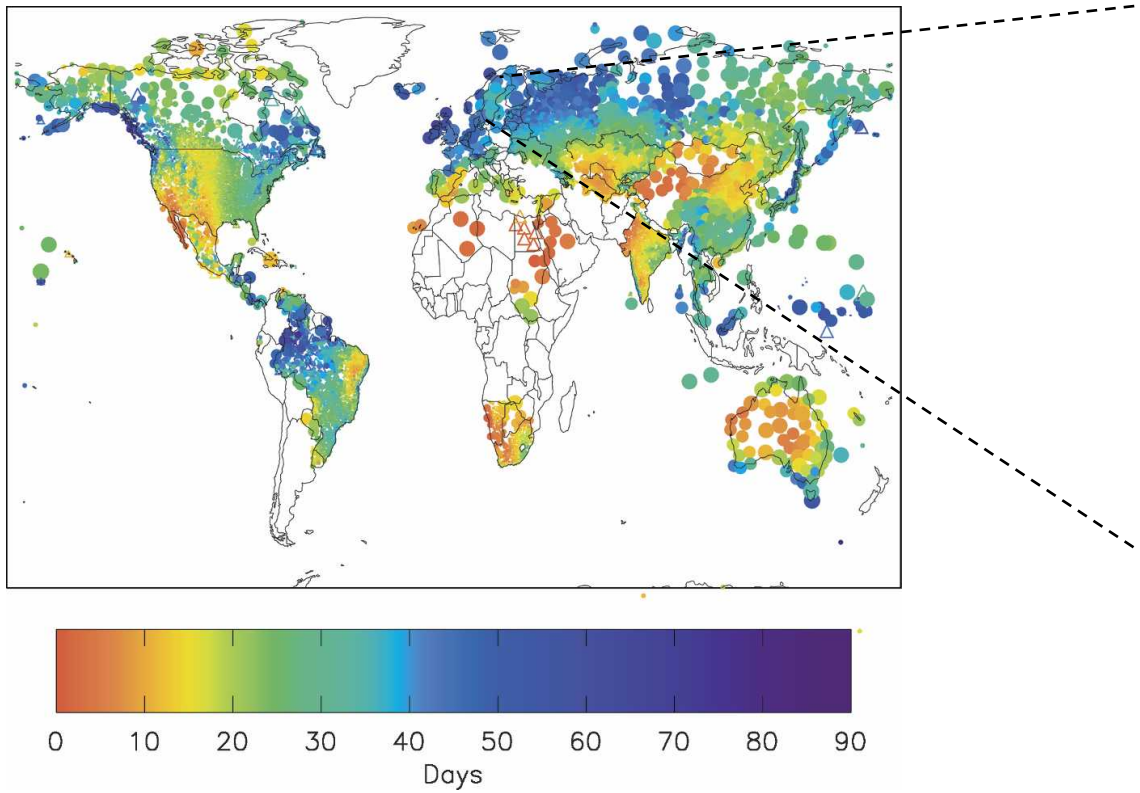
- 6 m diameter
- Conical scanning at 14.6 r.p.m.
- Constant incidence angle: 40 deg
- Swath: 1,000 km wide
- Swath and orbit allow global coverage every 2-3 days

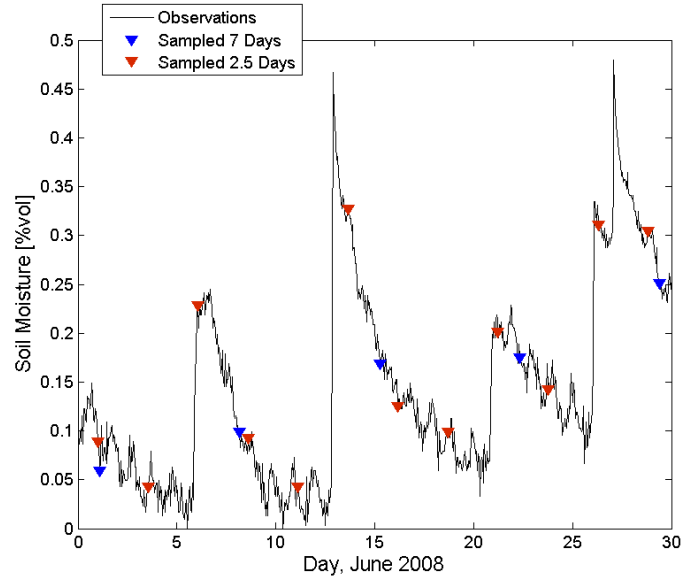
Orbit

- Sun synchronous, 6 am/pm orbit
- 685 km altitude

Justification for 3 Day Temporal Repeat

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





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

SMAP Level 1 Science Requirements

Requirement	Soil Moisture	Freeze/Thaw
Resolution	9 and 36 km	3 km
Refresh Rate	3 days	2 days[1]
Accuracy	0.04 [cm^3/cm^3][2]	80%[3]
Duration	36 months	

[1] North of 45°N Latitude
[2] % Volumetric water content, 1σ
[3] % classification accuracy (binary: freeze or thaw)

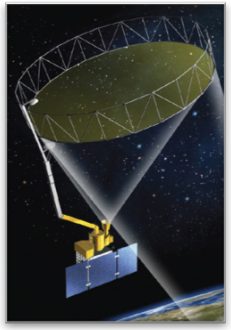
Product Short Name	Description	Data Resolution
L3_FT_HiRes	Daily Global Composite Freeze/Thaw State	1-3 km
L3_SM_P	Daily Global Composite Radiometer Soil Moisture	36 km
L3_SM_AP	**Daily Global Composite Active-Passive Soil Moisture**	**9 km**
L4_SM	Surface & Root Zone Soil Moisture	9 km
L4_C	Carbon Net Ecosystem Exchange	9 km

Uniqueness of SMAP's Radiometer

Operational L-Band Satellite Radiometers

SMOS – ESA satellite

- Launched: Nov. 2009
- L-band radiometer
- Spatial resolution: 40 km
- Temporal Resolution: 3 days
- Sensing depth: ~5 cm



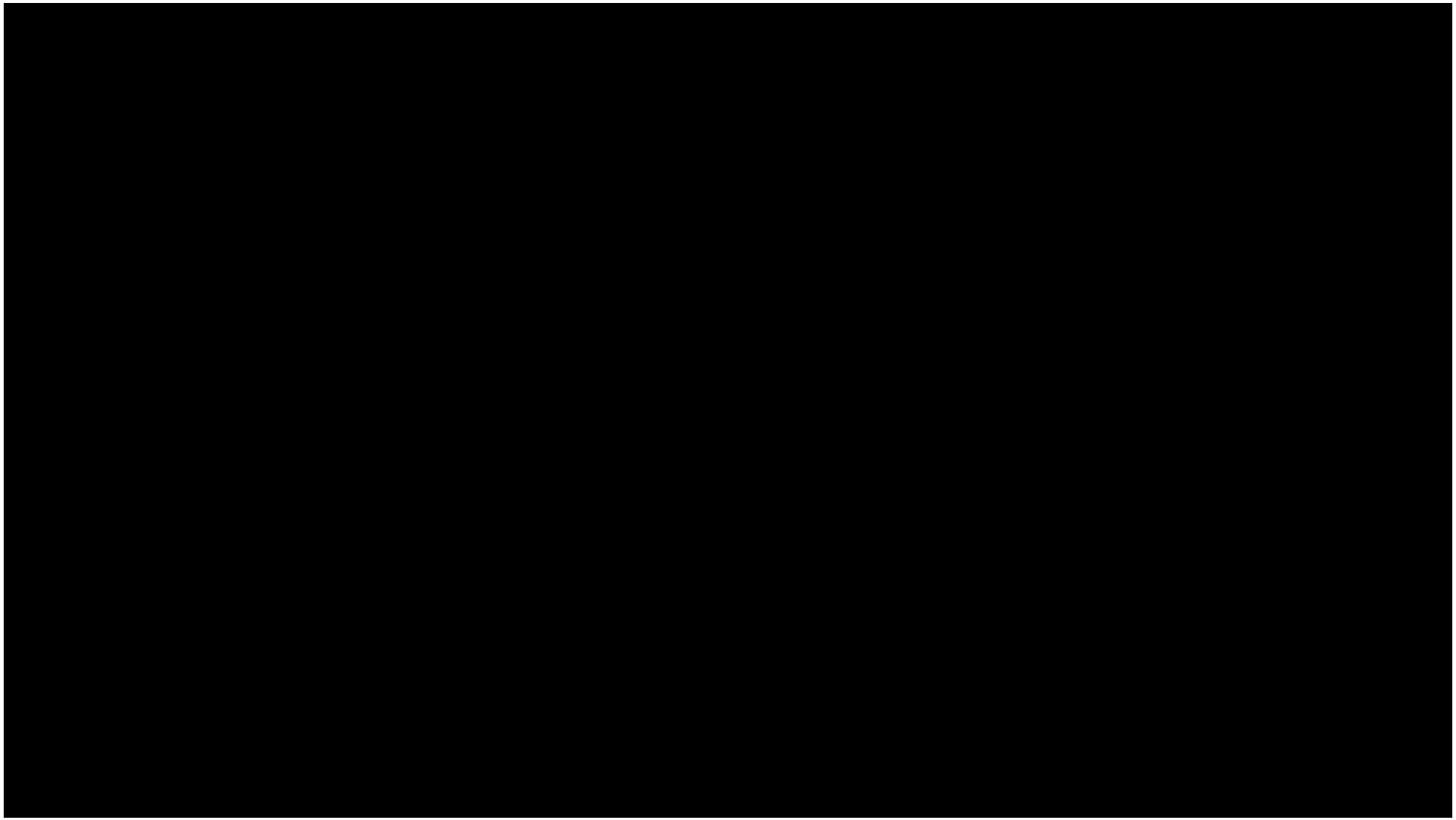
SMAP satellite

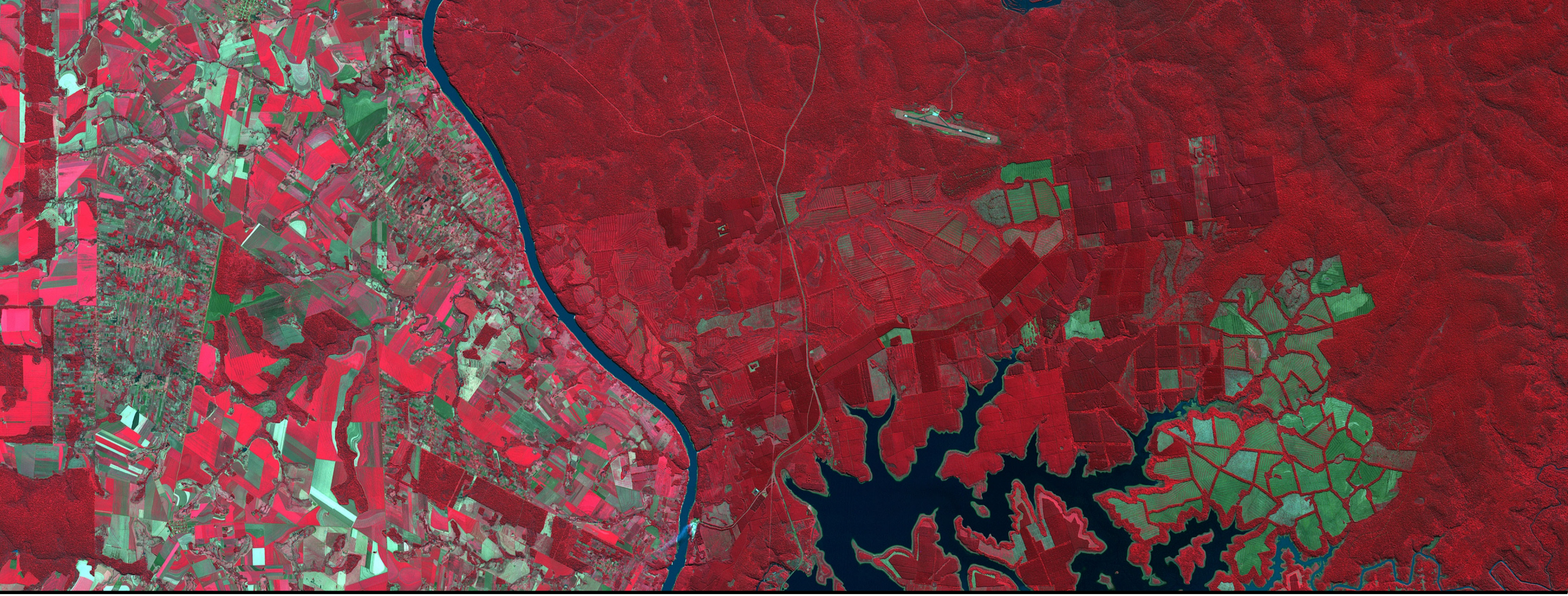
- Launched: Jan. 2015
- L-band radiometer
- Spatial resolution: 40 km
- Temporal Resolution: 3 days
- Sensing depth: ~5 cm

Uniqueness of SMAP:

1. Aggressive approach to radio-frequency interference (RFI) detection and mitigation
2. Constant incidence angle

SMAP Animation

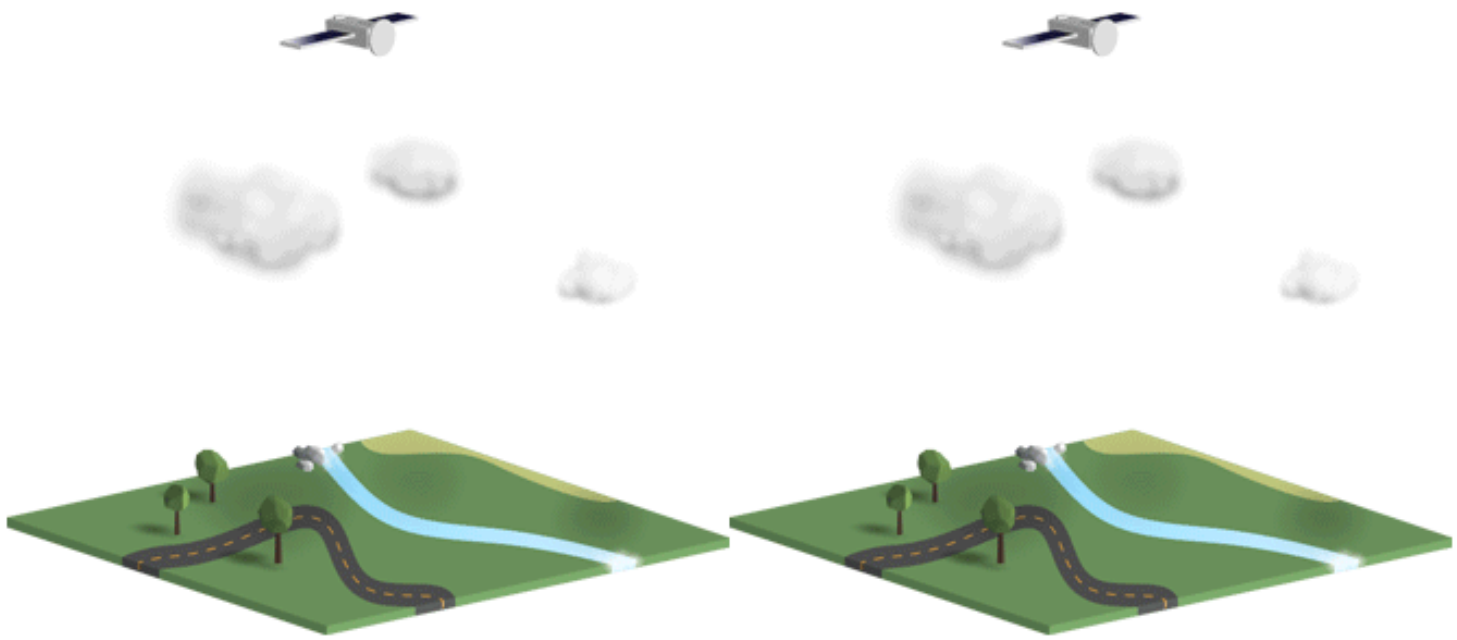




Description of Instruments and Retrieval Algorithms

Passive and Active Remote Sensing

SMAP uses active and passive sensors to measure soil moisture



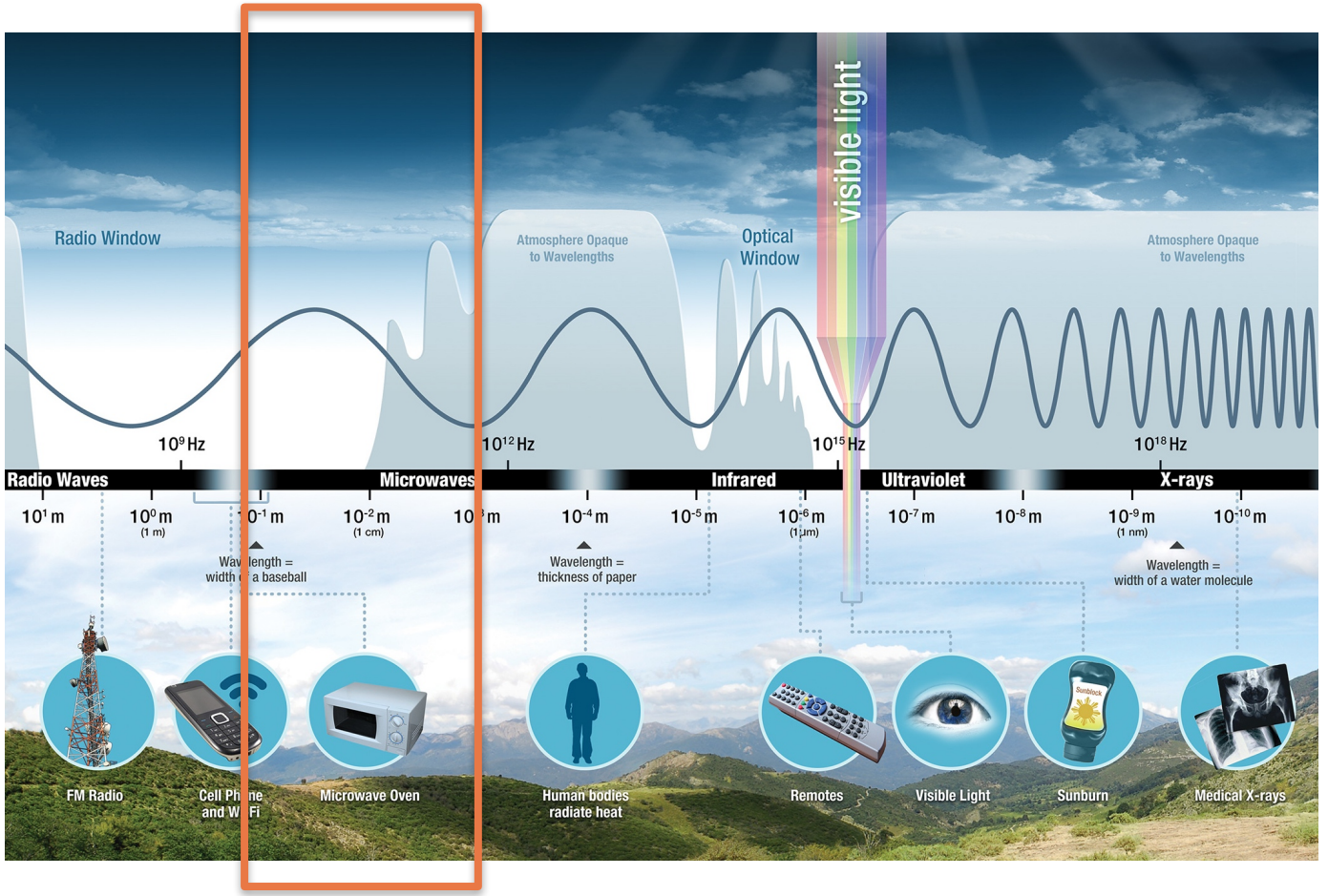
Passive | Sensors detect only what is emitted from the landscape, or reflected from another source (e.g., light reflected from the sun).

Active | Instruments emit their own signal and the sensor measures what is reflected back. Sonar and radar are examples of active sensors.

e.g. RADAR, Synthetic Aperture Radar (SAR), LIDAR

Microwave Remote Sensing

- Soil is masked by clouds and vegetation for visible and infrared sensors
- 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

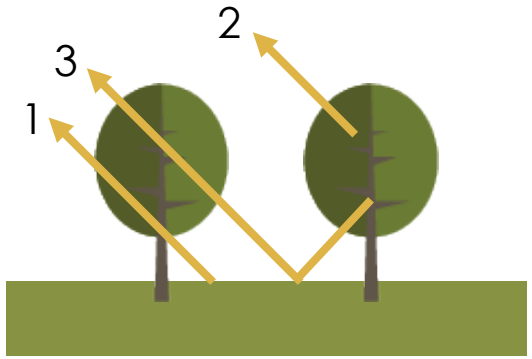


Measurement Approach

- p = H, V (radiometer)
- pq = VV, HH, HV (radar)
- Contributions from: soil, vegetation, and soil-vegetation interaction
- Soil moisture is the dominant contributor to the signal
- Soil moisture measurements are corrected for the effects of vegetation, surface roughness and temperature

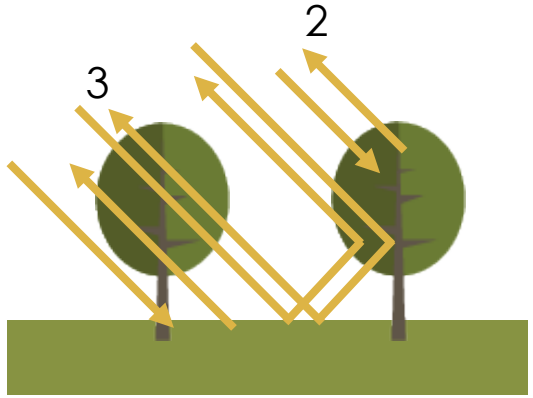
Emission

$$T_{Bp}^{t} = T_{Bp}^{s} L_p + T_{Bp}^{v} + T_{Bp}^{sv}$$



Backscatter

$$\sigma_{pq}^{t} = \sigma_{pq}^{s} L_{pq}^{2} + \sigma_{pq}^{v} + \sigma_{pq}^{sv}$$



Ancillary Data

Requirements

- Single-channel algorithm has good heritage but requires reliable ancillary data
- Ancillary data are used to estimate the key unknown parameters: surface temperature (≈ surface air temp. at 6 am), vegetation opacity, surface roughness and soil texture

Data Sources

Parameter	Description/Sources
Surface Air Meteorology	• Data assimilation (GEOS/DAO) • Forecast models (NCEP & ECMWF)
Vegetation Opacity	• Vis/IR satellite-derived NDVI, LAI, land cover (MODIS, IGBP-DIS) • Historical phenology (AVHRR)
Surface Topography	• Digital elevation models (USGS and SRTM)
Soil Texture	• Soil databases (Global, NGDC; US, STATSGO)
Land/Water Boundaries	• Coastal boundaries and inland water bodies (NGDC)

Ancillary Data

Requirements

- Coefficients for surface roughness, and relations between vegetation indices and vegetation opacity, are derived from field experiments at L-band for a variety of conditions
  - These coefficients are expected to be relatively time-invariant at satellite footprint spatial scales (~40 km)
  - They can be fine-tuned during the post-launch calibration/validation phase

Data Sources

Parameter	Description/Sources
Surface Air Meteorology	• Data assimilation (GEOS/DAO) • Forecast models (NCEP & ECMWF)
Vegetation Opacity	• Vis/IR satellite-derived NDVI, LAI, land cover (MODIS, IGBP-DIS) • Historical phenology (AVHRR)
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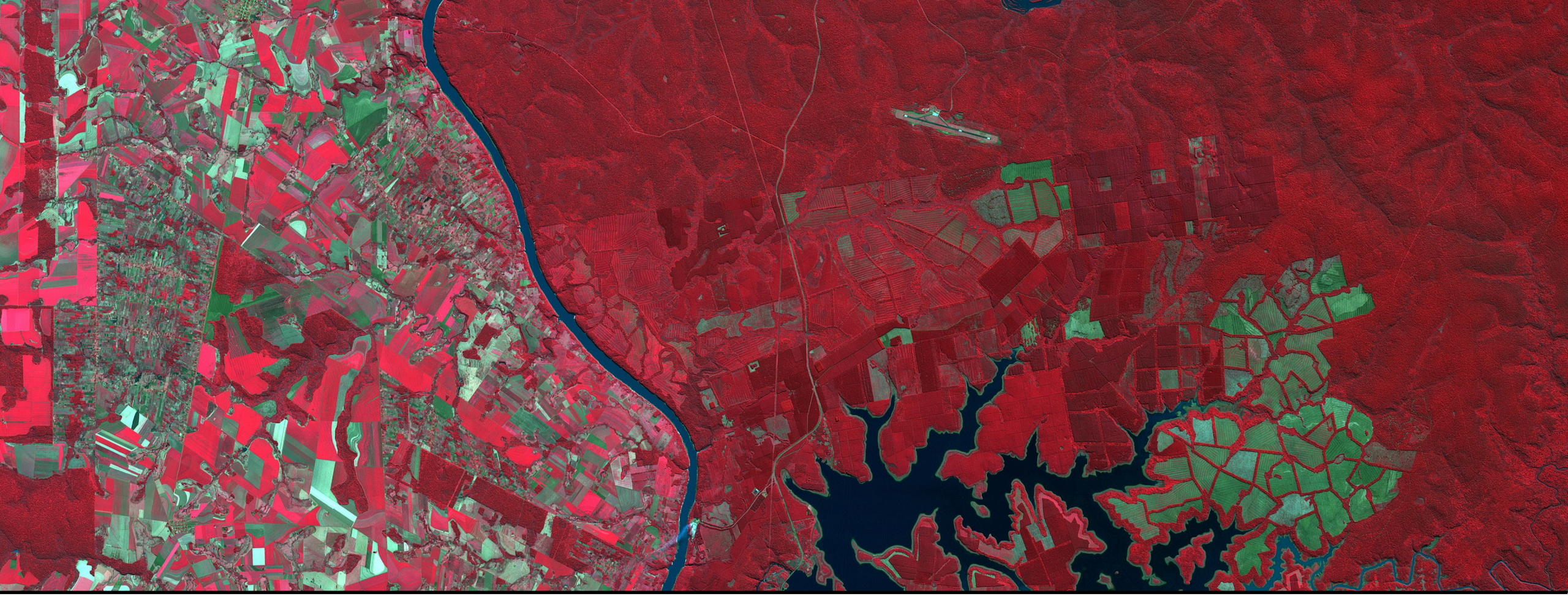


SMAP Products

Status of the SMAP Mission

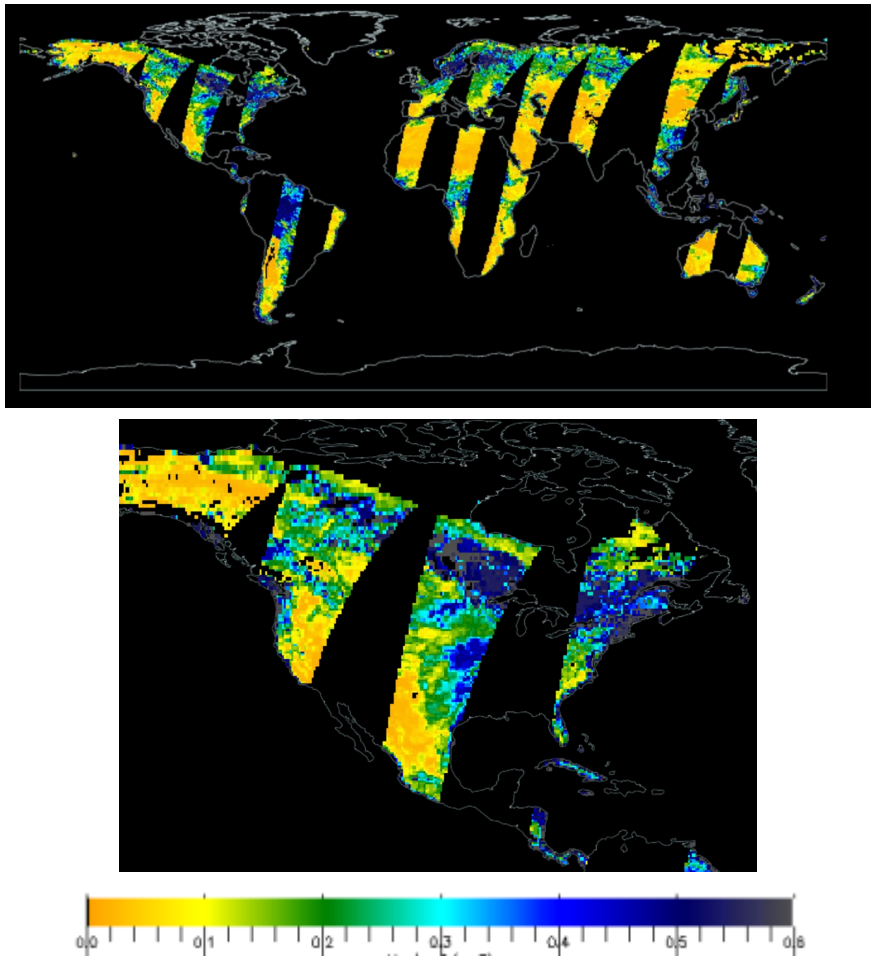
- SMAP launched on Jan 31st, 2015
- Science data acquisition started in April, 2015
- Initially, SMAP Radiometer and Radar worked in tandem with great success
- SMAP Radar malfunctioned on July 7th, 2015
- SMAP Radar is currently inoperable
- SMAP released Beta-Product to public on October 31st, 2015
- SMAP science data acquisition operation finished one year in April 2016
- SMAP released Validated-Product on April 30th, 2016
- SMAP Enhanced Radiometer Products released January 1st, 2017
- SMAP data are now freely available to public through the NASA DAACs at NSIDC and ASF

SMAP Data Product Availability

Data Set ID	Data Set Description	Gridding Resolution	Temporal Coverage	DAAC
SPL1AA	L1A Radar Time-Ordered Parsed Telemetry	—	4/13/15 – 7/7/15	ASF
SPL1BS0	L1B Radar Half-Orbit Time-Ordered Low-Resolution σo Data	5x30 km	4/13/15 – 7/7/15	ASF
SPL1CS0	L1C Radar Half-Orbit High-Resolution Radar σo Data	1 km	4/13/15 – 7/7/15	ASF
SPL1AP	L1A Radiometer Time-Ordered Parsed Telemetry	—	3/31/15 – present	NSIDC
SPL1BTB	L1B Radiometer Half-Orbit Time-Ordered TB	36x47 km	3/31/15 – present	NSIDC
SPL1CTB	L1C Radiometer Half-Orbit EASE-Grid TB	36 km	3/31/15 – present	NSIDC
SPL2SMA	L2 Radar Half-Orbit EASE-Grid Soil Moisture	3 km	4/13/15 – 7/7/15	NSIDC
SPL2SMP	L2 Radiometer Half-Orbit EASE-Grid Soil Moisture	36 km	3/31/15 – present	NSIDC
SPL2SMAP	L2 Radar/Radiometer Half-Orbit EASE-Grid Soil Moisture	9 km	4/13/15 – 7/7/15	NSIDC
SPL3FTA	L3 Radar N. Hemisphere Daily EASE-Grid Freeze/Thaw State	3 km	4/13/15 – 7/7/15	NSIDC
SPL3SMA	L3 Radar Global Daily EASE-Grid Soil Moisture	3 km	4/13/15 – 7/7/15	NSIDC
SPL3SMP	L3 Radiometer Global Daily EASE-Grid Soil	36 km	3/31/15 – present	NSIDC
SPL3SMAP	L3 Radar/Radiometer Global Daily EASE-Grid Soil Moisture	9 km	4/13/15 – 7/7/15	NSIDC
SPL4SMAU	L4 Global Surface & Root Zone Soil Moisture Analysis Update	9 km	3/31/15 – present	NSIDC
SPL4SMGP	L4 Global Surface & Root Zone Soil Moisture Geophysical Data	9 km	3/31/15 – present	NSIDC
SPL4CMDL	L4 Global Daily Carbon Net Ecosystem Exchange (NEE)	9 km	4/13/15 – present	NSIDC

Level 3 Radiometer

36 km Soil Moisture Product

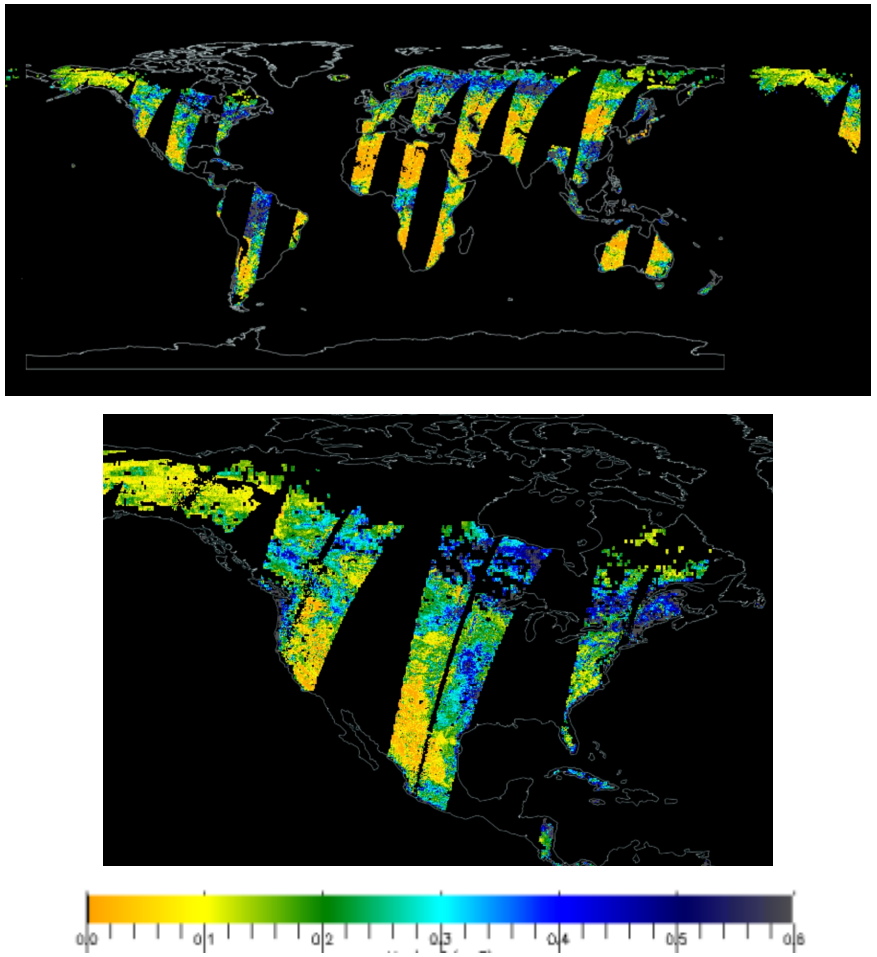


Volumetric Soil Moisture (cm^3/cm^3)

- Composite of all Radiometer Level 2 half orbit products where local acquisition time is the same UTC day
- Posted on a 36 km cylindrical EASE grid using a 2-dimensional array
- Product lists all EASE grid cells, regardless of whether data are available
- Provides retrieved soil moisture over land with 4% accuracy for low-to-moderately vegetated areas
  - Low to moderate vegetation defined as vegetation water content ≤ 5 kg/m^2

Level 3 Active/Passive

9 km Soil Moisture Product

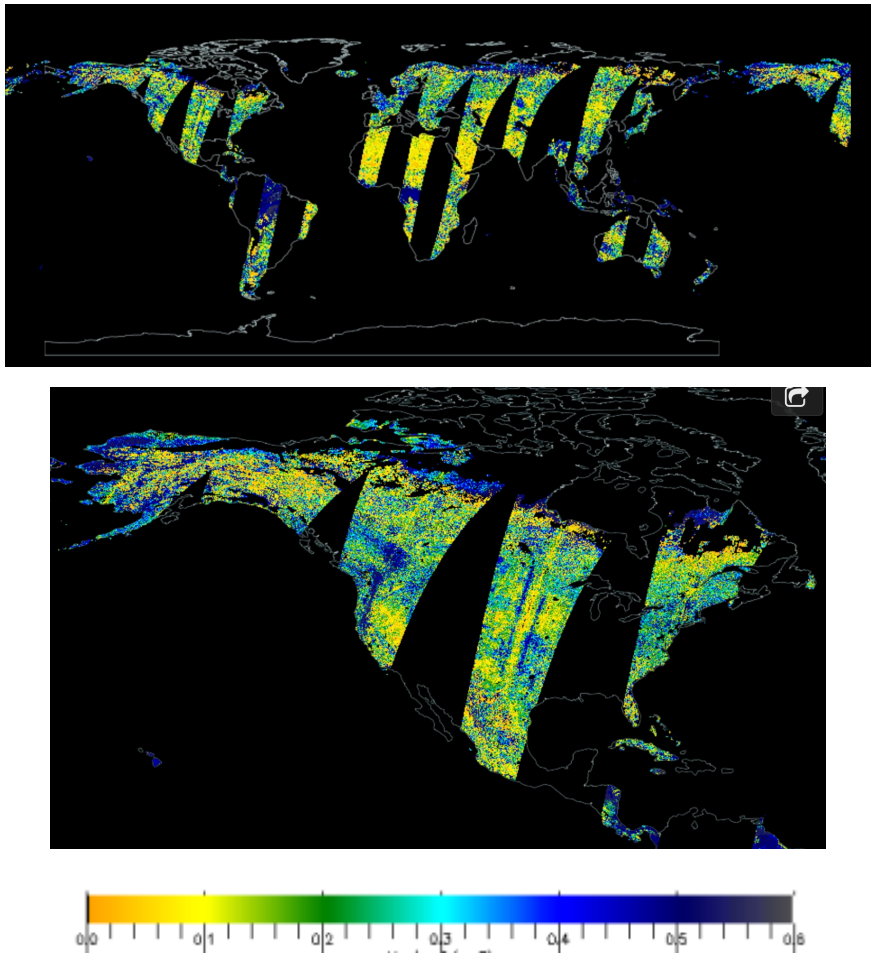


Volumetric Soil Moisture (cm^3/cm^3)

- Composite of all Active/Passive Level 2 half orbit products where local acquisition time is the same UTC day
- Posted on a 9 km cylindrical EASE grid using a two dimensional array
- Product lists all EASE grid cells, regardless of whether data are available
- Provides retrieved soil moisture over land with 4% accuracy for low-to-moderately vegetated areas
  - Low to moderate vegetation defined as vegetation water content ≤ 5 kg/m^2

Level 3 Radar

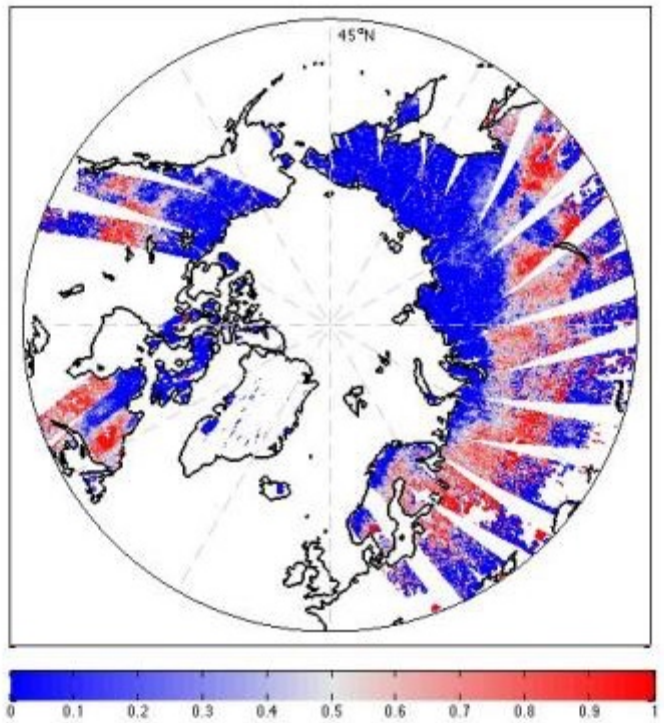
3 km Soil Moisture Product



Volumetric Soil Moisture (cm^3/cm^3)

- Composite of all Radar Level 2 half orbit products where the local acquisition time is the same UTC day
- Posted on a 3 km cylindrical EASE grid using a two dimensional array
- Product lists all EASE grid cells, regardless of whether data are available

Level 3 Freeze/Thaw Product

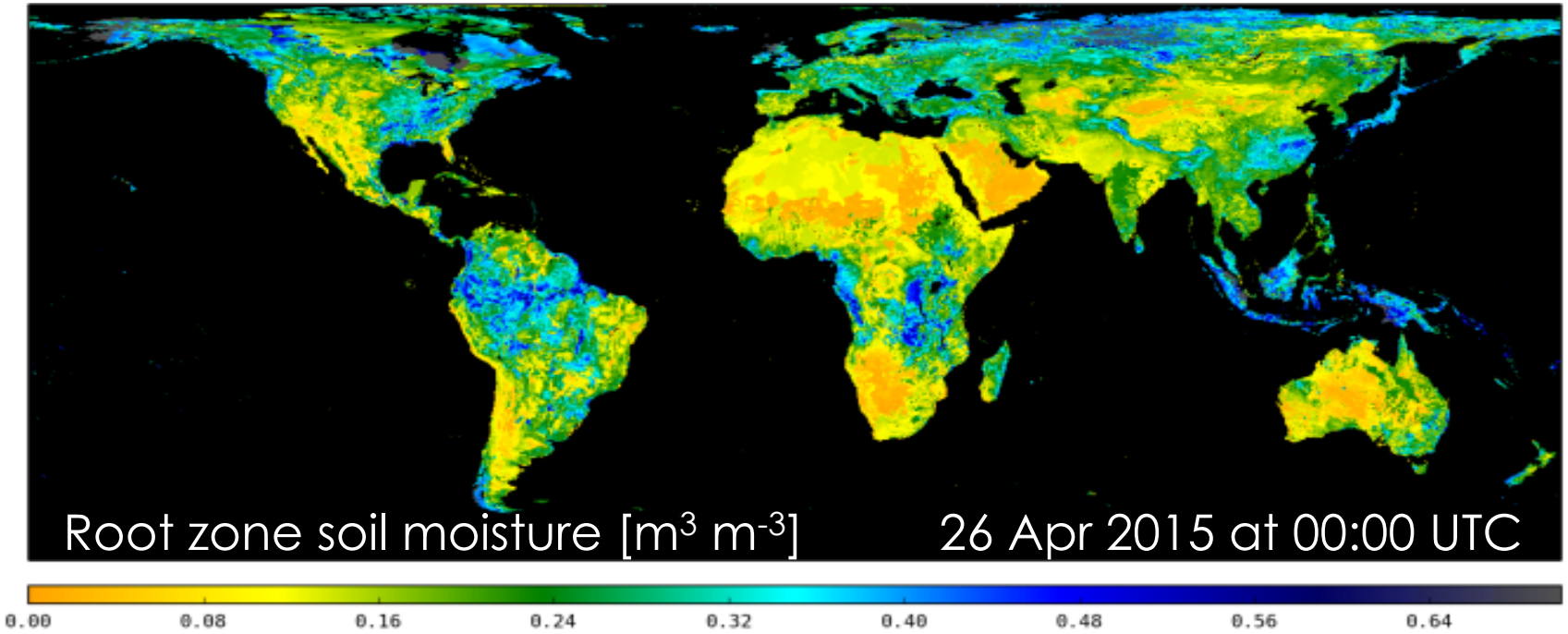


Red: Thawed, Blue: Frozen

Daily Freeze/Thaw State

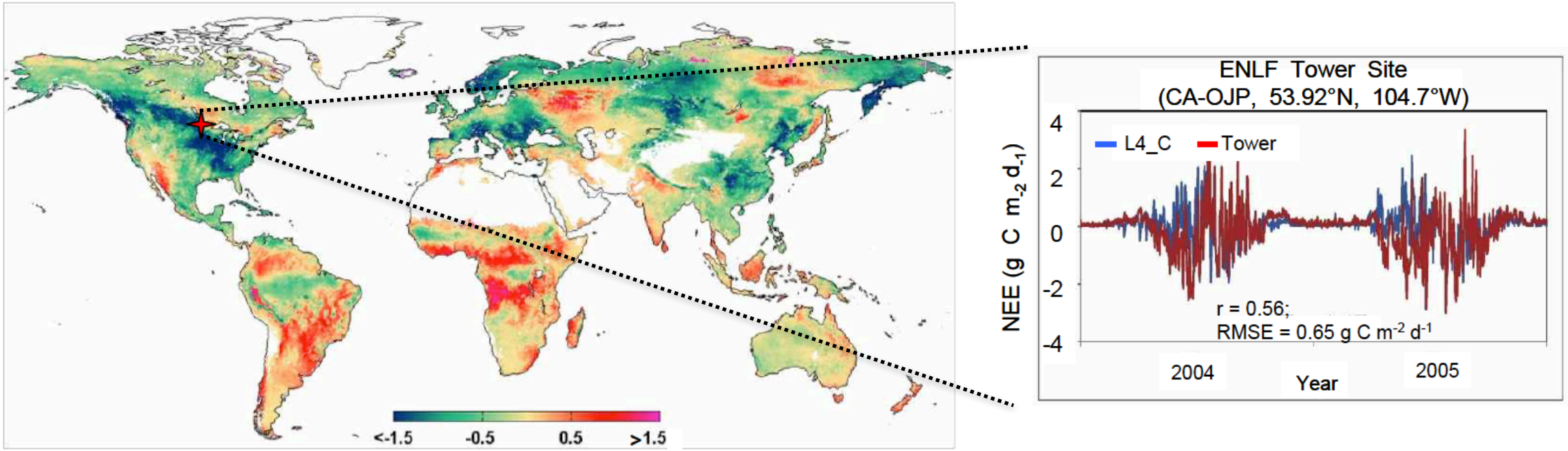
- Employs the 1 km Level 1C high resolution radar data and a time-series change detection algorithm to infer freeze/thaw state
- Quantifies daily freeze/thaw state as a binary condition for land surface
- Includes both AM and PM data, with intra-day state transition flags
- Posted on a 3 km polar EASE grid with 3 km spatial resolution using a two dimensional array
- Each product represents a single calendar day UTC
- Required to achieve 80% freeze/thaw state classification accuracy

Level 4 Surface and Root-Zone Soil Moisture Product



Geophysical Data ("gph" Collection)	Analysis Update Data ("aup" Collection)
3-hour time averages	*3-hour instantaneous (snapshots)*
Surface and **root zone** soil moisture, soil temperature, snow, land surface fluxes, surface meteorological forcing data.	Brightness temperatures (observed and modeled), soil moisture and soil temperature (model forecast and analysis), **uncertainty estimates.**

Net Ecosystem Carbon Exchange – Level 4

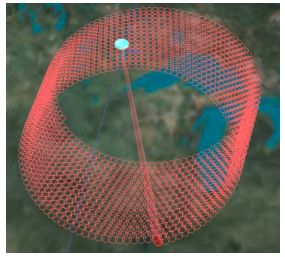


L4_C NEE (DOY 196, g C m^{-2} d^{-1})

Kimball, J., Reichle, R., O'Neill, P., McDonald, K., Njoku, E. (2012) Soil Moisture Active Passive (SMAP) Algorithm Theoretical Basis Document (ATBD) SMAP Level 4 Carbon Data Product (L4_C), JPL.

SMAP Enhanced Products

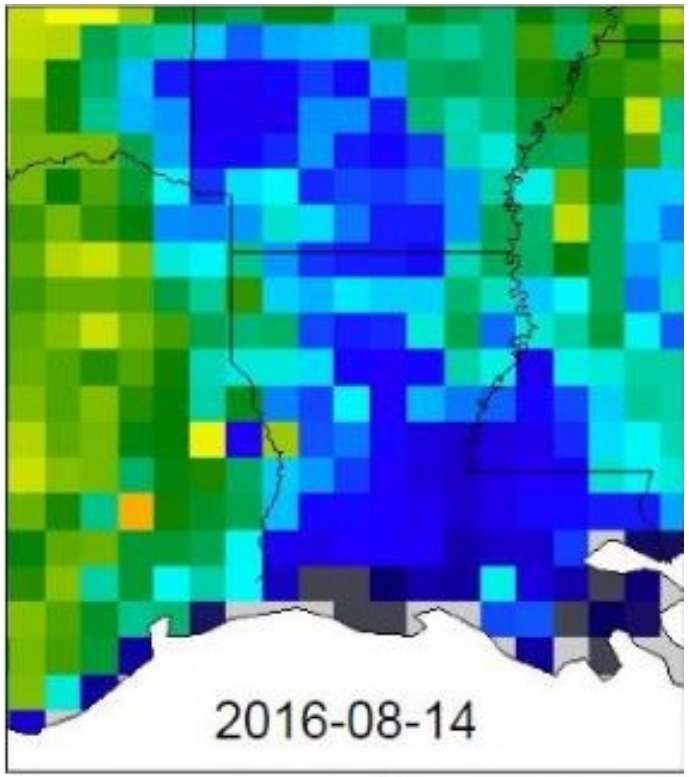
Product Short Name	Description	Data Resolution
SPL3FTA	Daily Global Composite Freeze/Thaw State (Apr-Jul 2015)	3 km
SPL3FTP	Daily Global Radiometer Freeze/Thaw State (Mar 2015 – present)	36 km
SPL3FTP_E	Daily Global Radiometer Enhanced Freeze/Thaw State (Mar 2015 – present)	9 km
SPL3SMAP	Daily Global Composite Radiometer Soil Moisture (Apr-Jul 2015)	9 km
SPL3SMP	Daily Global Radiometer Soil Moisture (Mar 2015 – present)	36 km
SPL3SMP_E	Daily Global Radiometer Enhanced Soil Moisture (Mar 2015 – present)	9 km
L2_SM_SP	3- to 12-day SMAP/Sentinel-1 Soil Moisture (completing validation)	3 km
SPL4SMAU,GP	Surface & Root Zone Soil Moisture (Mar 2015 – present)	9 km
SPL4MDL	Global Daily 9 km Carbon Net Ecosystem Exchange (Apr 2015 – present)	9 km



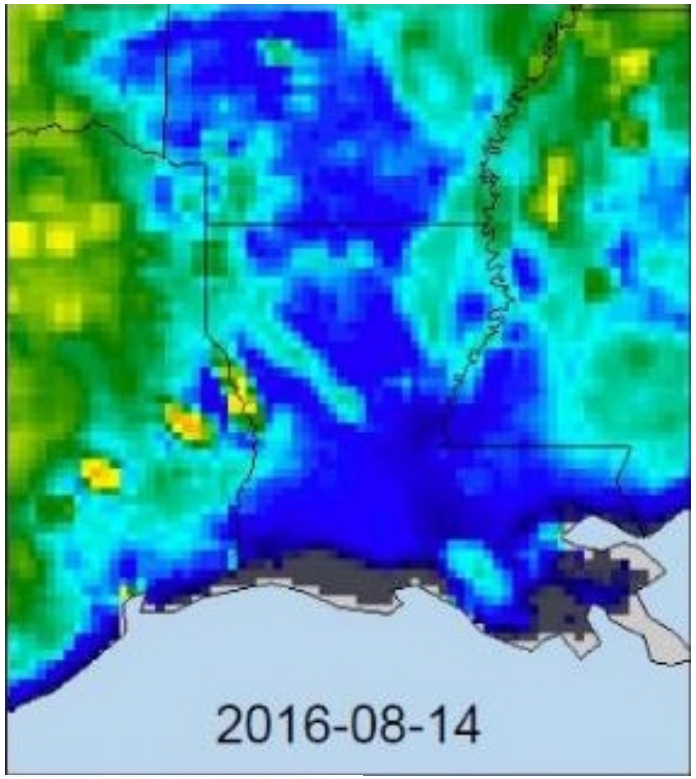
- Radiometer data acquisition
  - continuous collection over the entire orbit and entire 360° antenna scan

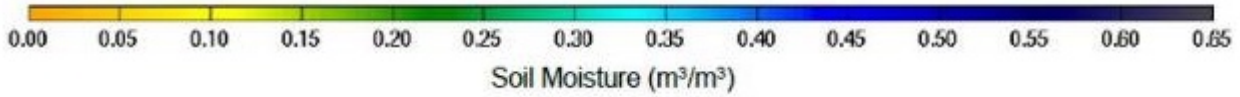
L2SMP and L2SMP_E

L2SMP SMAP Passive Soil Moisture Product (36 km posting)



L2SMP_E SMAP Passive Soil Moisture Product (9 km posting)





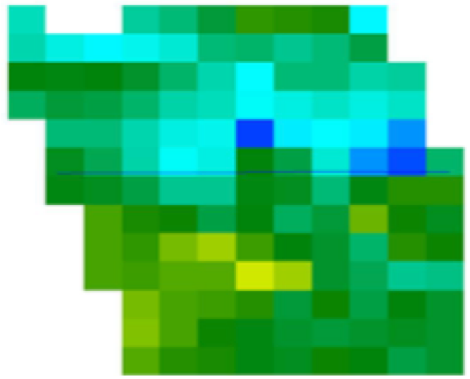
Source: Tom Jackson

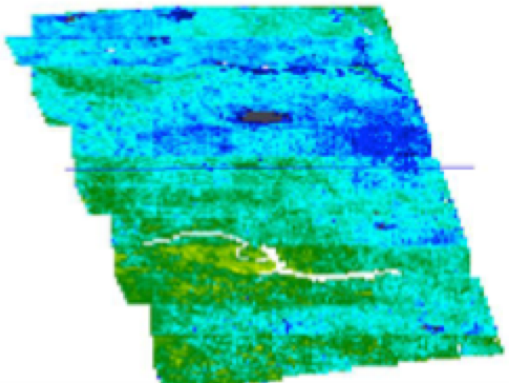
SMAP Enhanced Active-Passive Product Using Sentinel

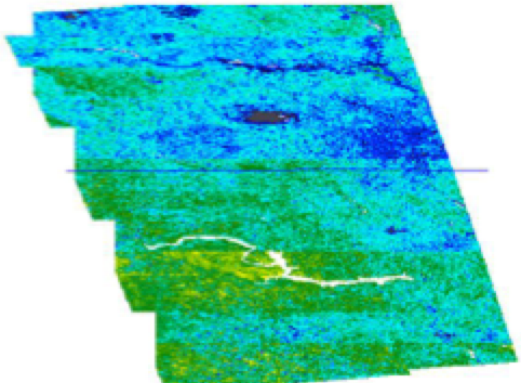
SMAP-only Passive Product, Retrieved Soil Moisture 36 km

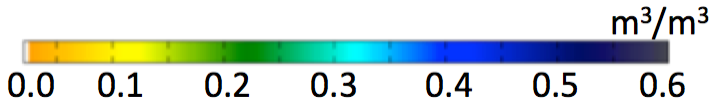
SMAP-Sentinel Active-Passive Product, Retrieved Soil Moisture 3 km

SMAP-Sentinel Active-Passive Product, Retrieved Soil Moisture 1 km







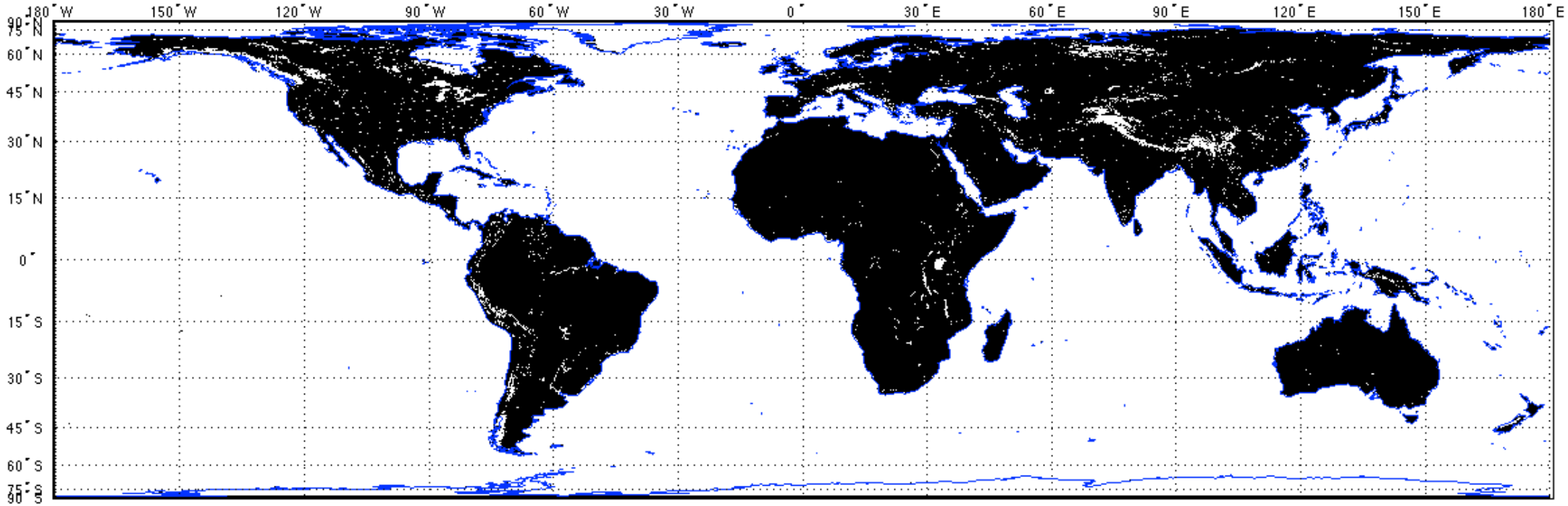


soil moisture at different resolutions, retrieved May 17, 2015, over Manitoba, Canada

Source: Narendra Das

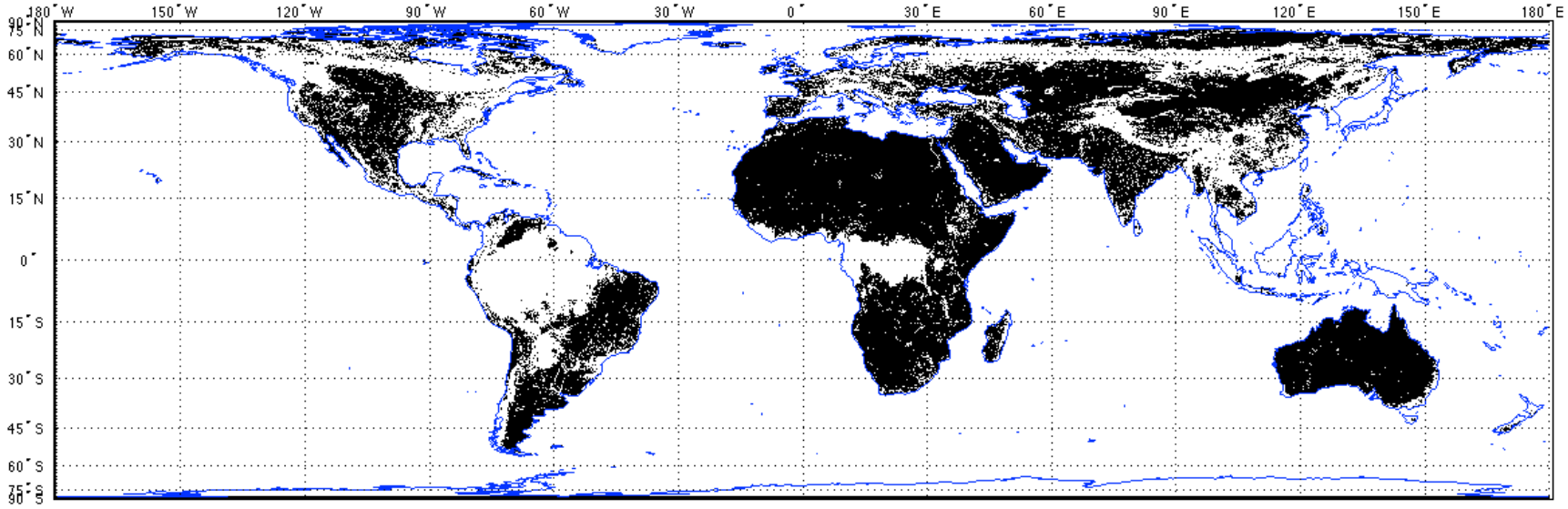
Soil Moisture Retrieval Map

- Retrievable Mask (Black Colored Pixels):
  - Urban Fraction < 1
  - Water Fraction < 0.5
  - DEM Slope Standard Deviation < 5 deg

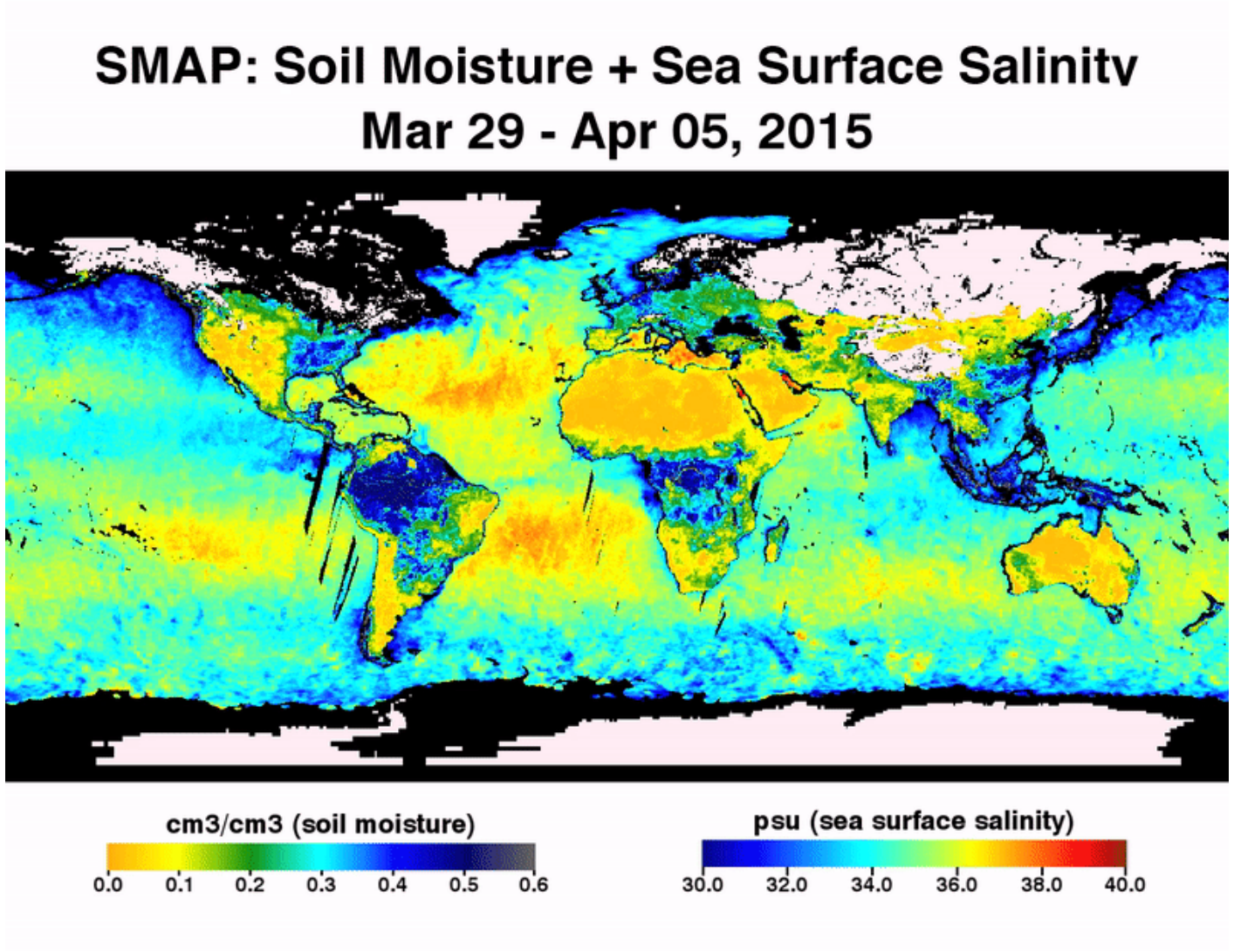


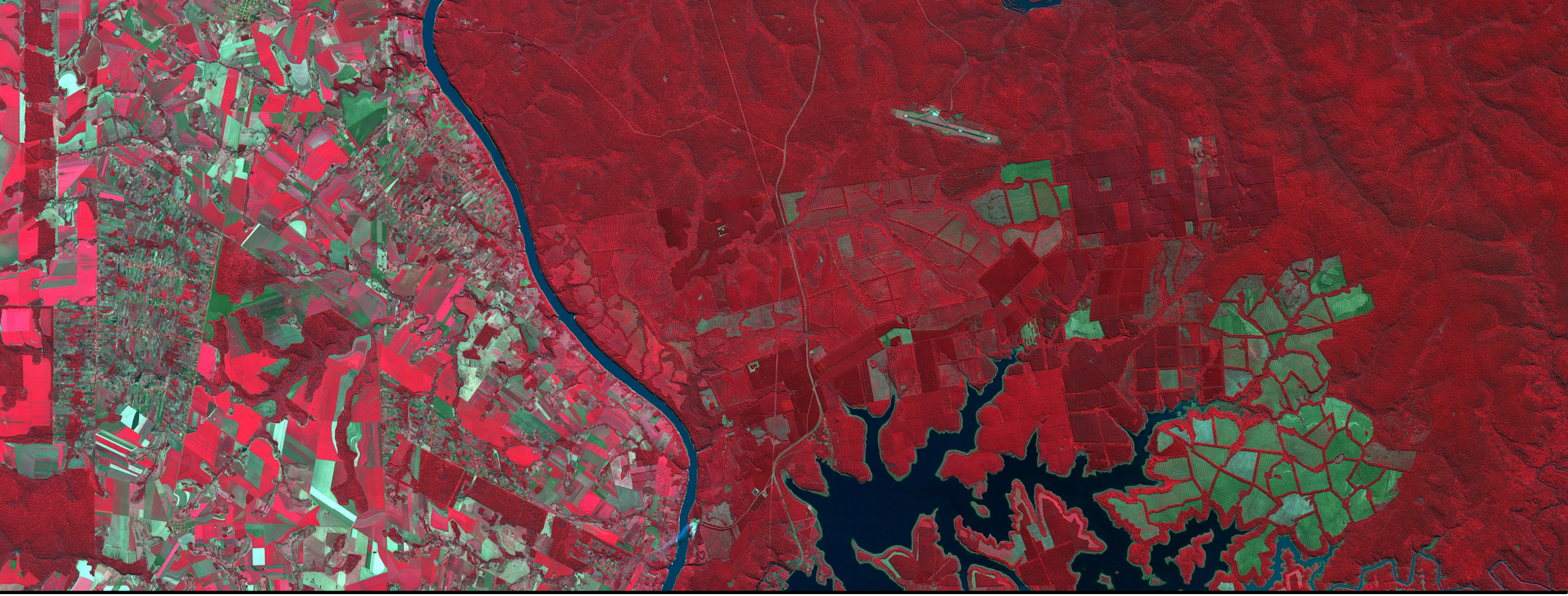
Soil Moisture Expected Accuracy

- Retrieval Expected Quality Mask (black colored pixels indicate good quality)
  - Vegetation Water Content ≤ 5 kg/m^2
  - Urban Fraction ≤ 0.25
  - Water Fraction ≤ 0.1
  - DEM Slope Standard Deviation ≤ 3 deg



Global Soil Moisture Animation





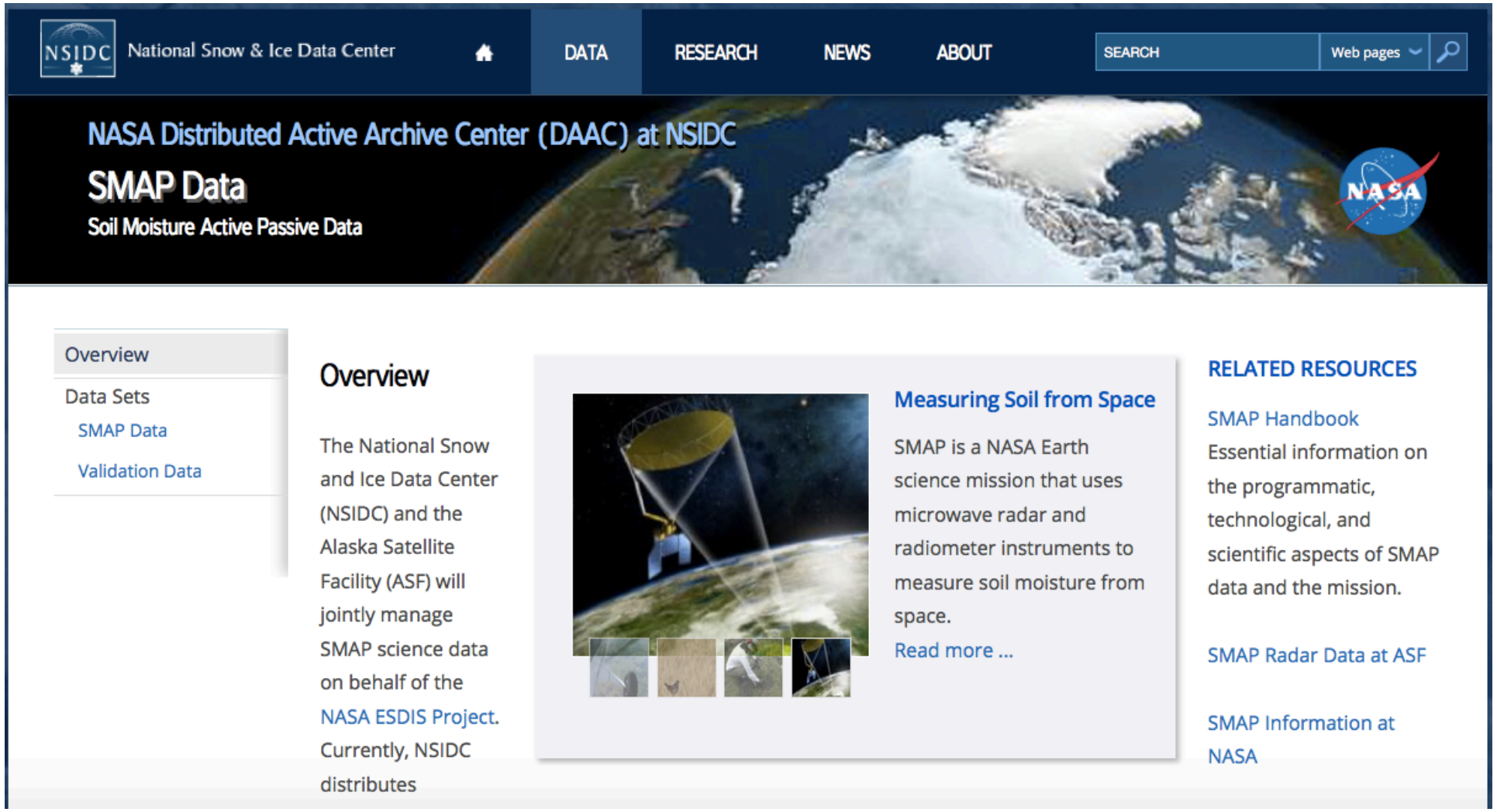
SMAP Data Access

SMAP Data Access

- SMAP data products are **freely** available through the National Snow and Ice Data Center (NSIDC) and Alaska Satellite Facility (ASF)
  - Radar data is provided by the Alaska Satellite Facility
  - NSIDC provides all other data

Access to SMAP Data: NSIDC

http://nsidc.org/data/smap/



Data Product Design

- **All products are in HDF5 format**
  - Each SMAP HDF5 file contains the primary data parameters (e.g., soil moisture, freeze/thaw, sensor data) and all data used in the production of those parameters
  - Files also include metadata, geolocation information, quality flags, etc.
- **Projection: EASE-Grid 2.0**
  - Equal-area projection
  - Level 2, 3, 4, and radiometer L1C are in this projection

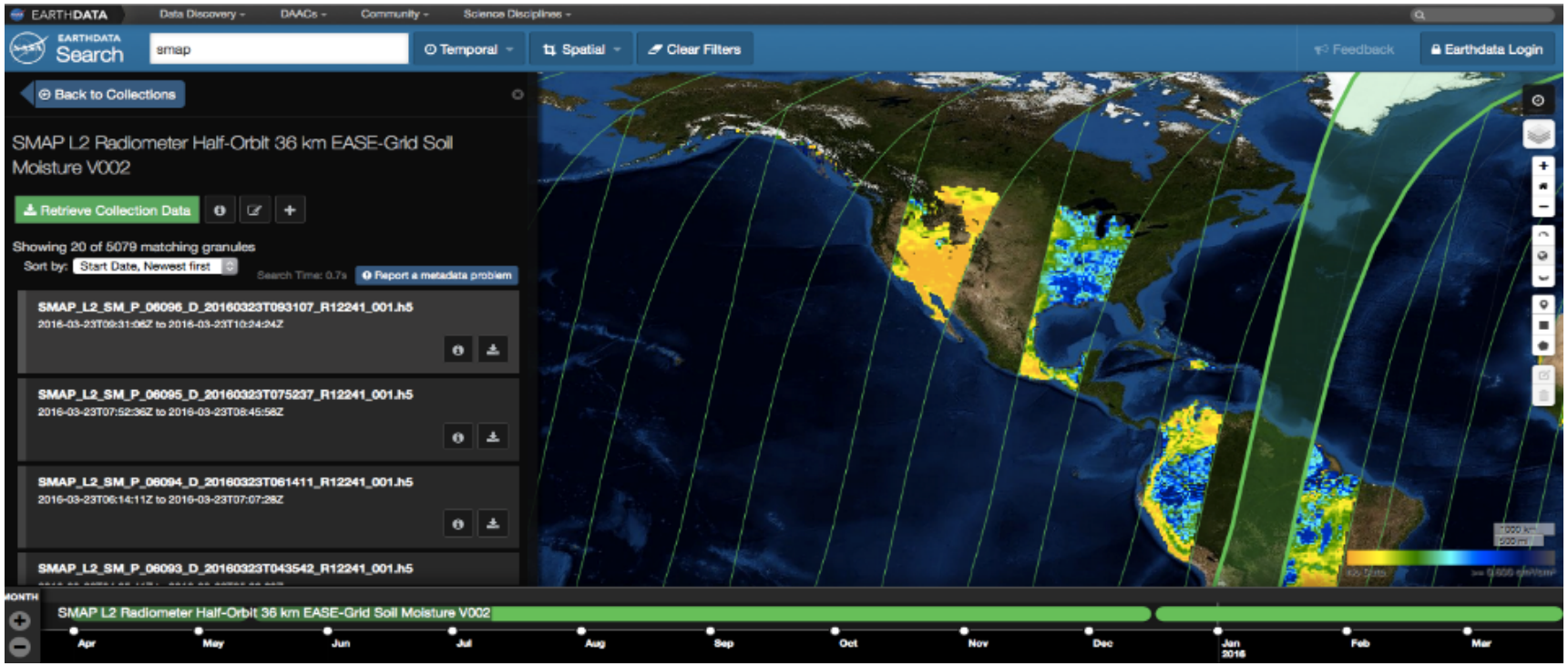
Data Product Design

- **Values**
  - Radiometer data (brightness temperature) is in Kelvin
  - Radar data is in sigma naught
  - Soil moisture is a volumetric measurement expressed as cm3/cm3
  - Freeze/thaw is a binary measurement, either frozen or thawed
  - Net ecosystem exchange is in grams of carbon/square meter per day

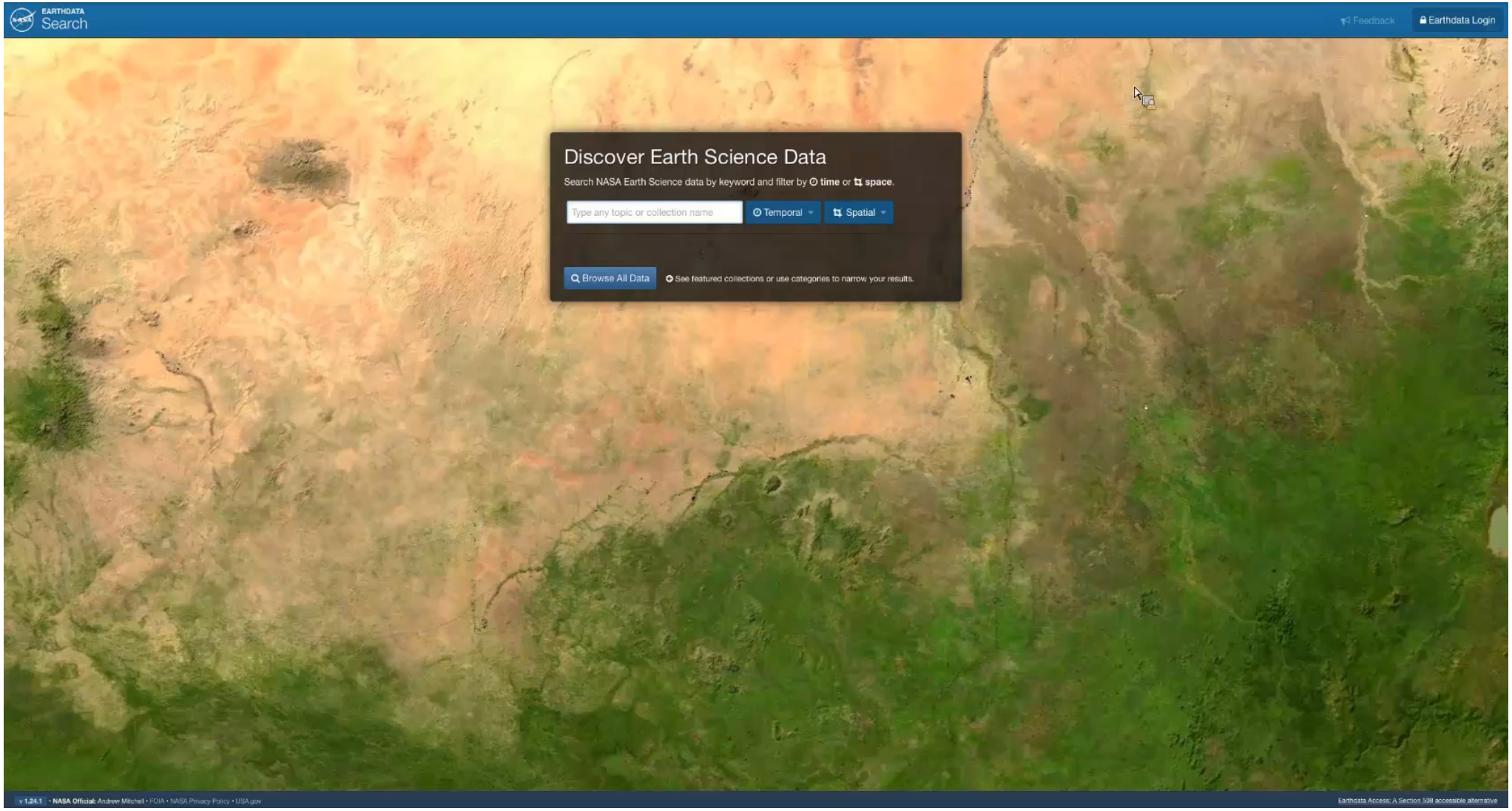
Data Access: Earthdata Search

http://search.earthdata.nasa.gov/

- Search and order all SMAP data
- Keyword, spatial, and/or temporal search
- Reformat, reproject, and subset services for most products



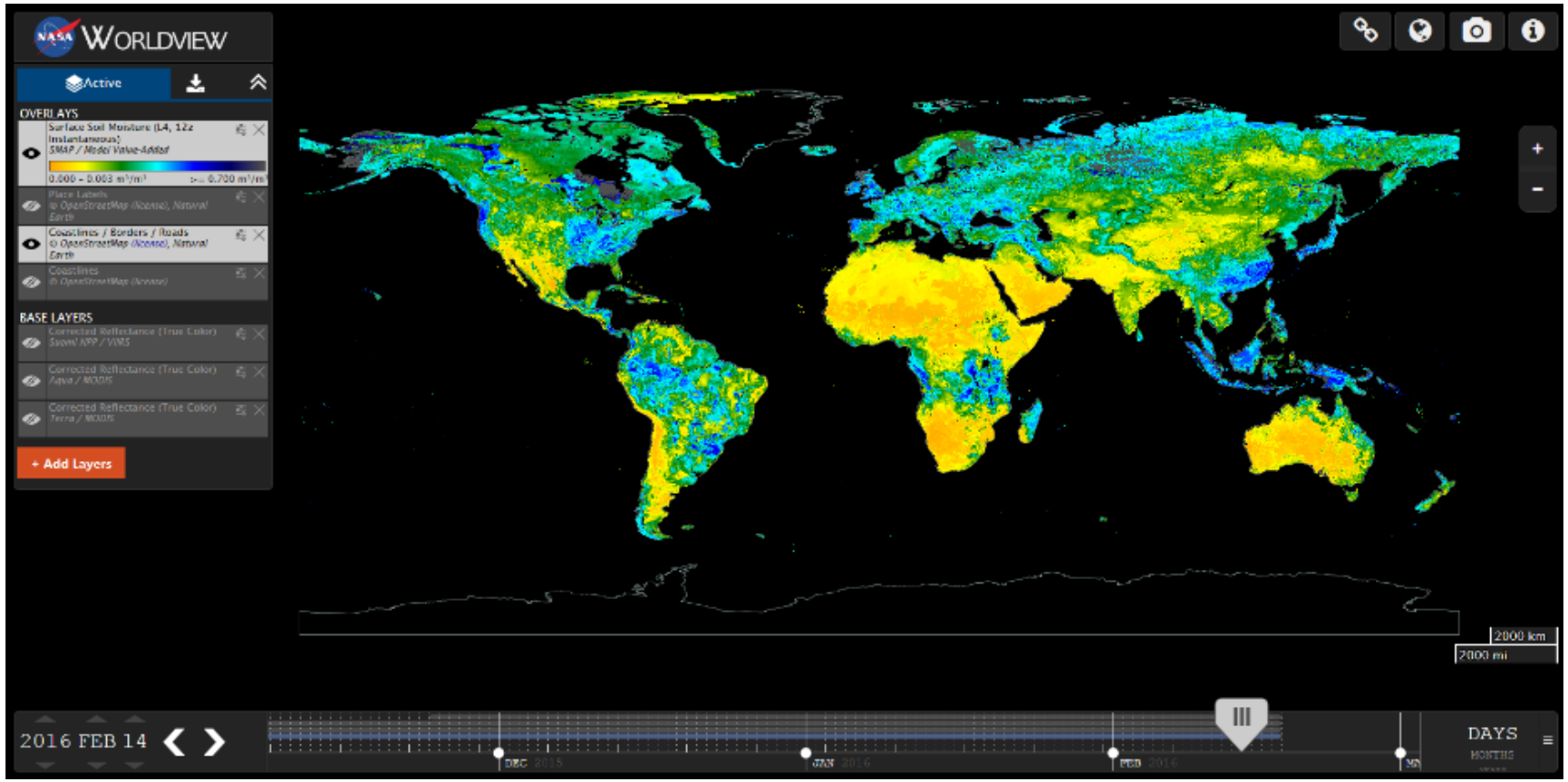
SMAP Product Access at the DAACs



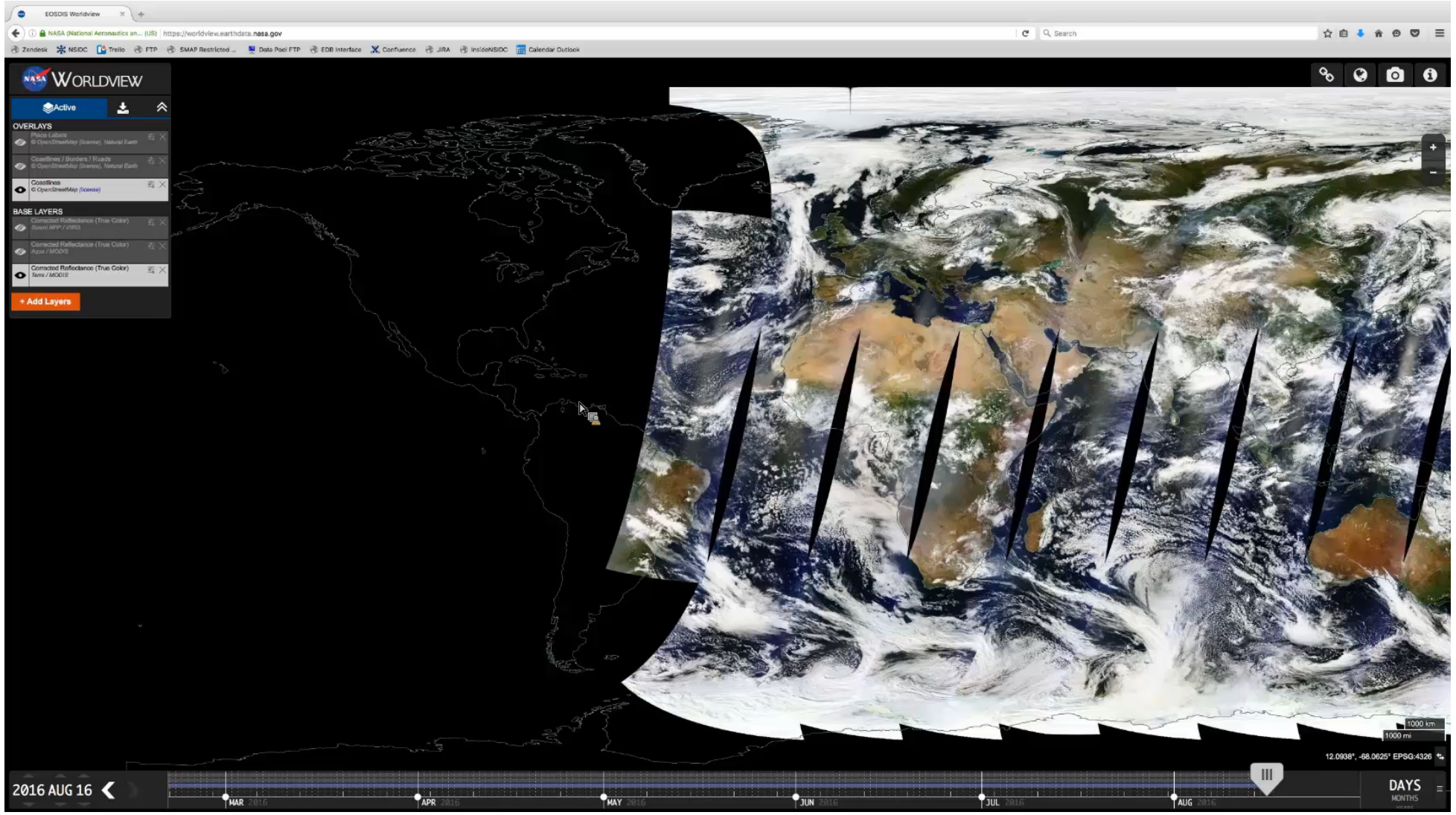
Data Visualization: Worldview

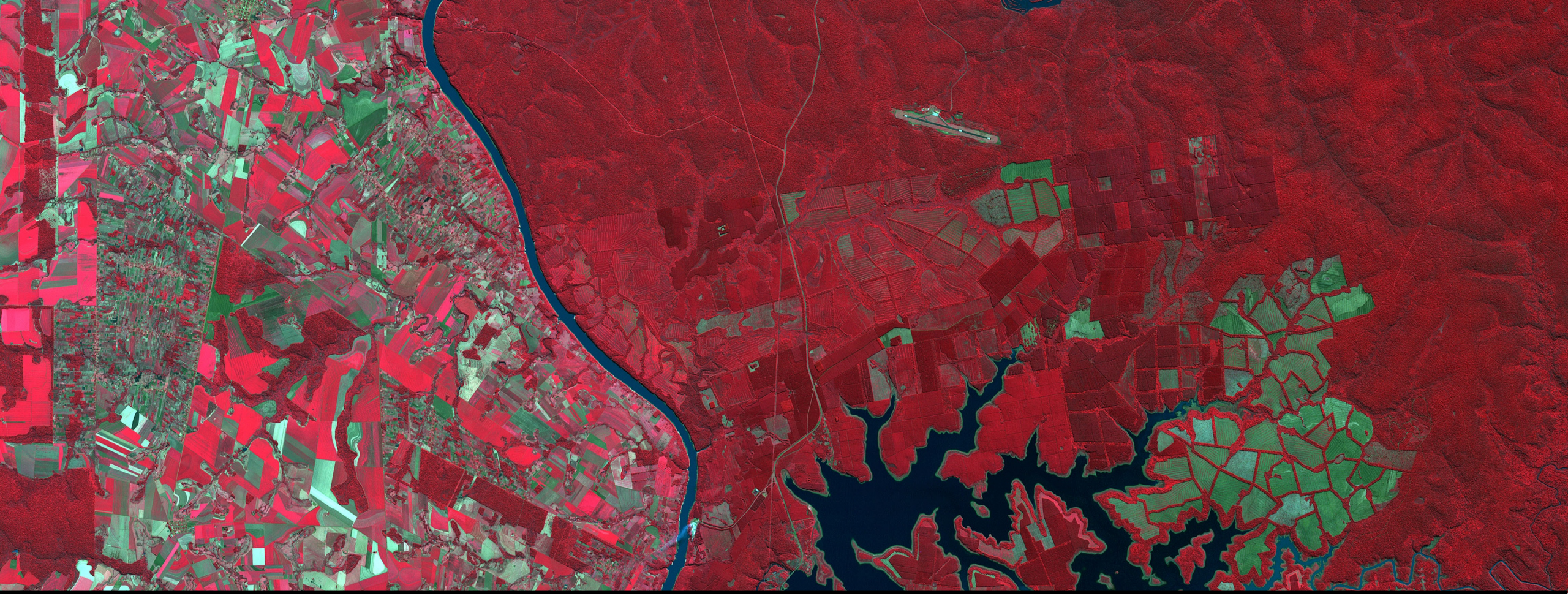
http://worldview.earthdata.nasa.gov/

- Interactively browse and download full resolution imagery, as well as source data files



SMAP Product Visualization at the DAACs



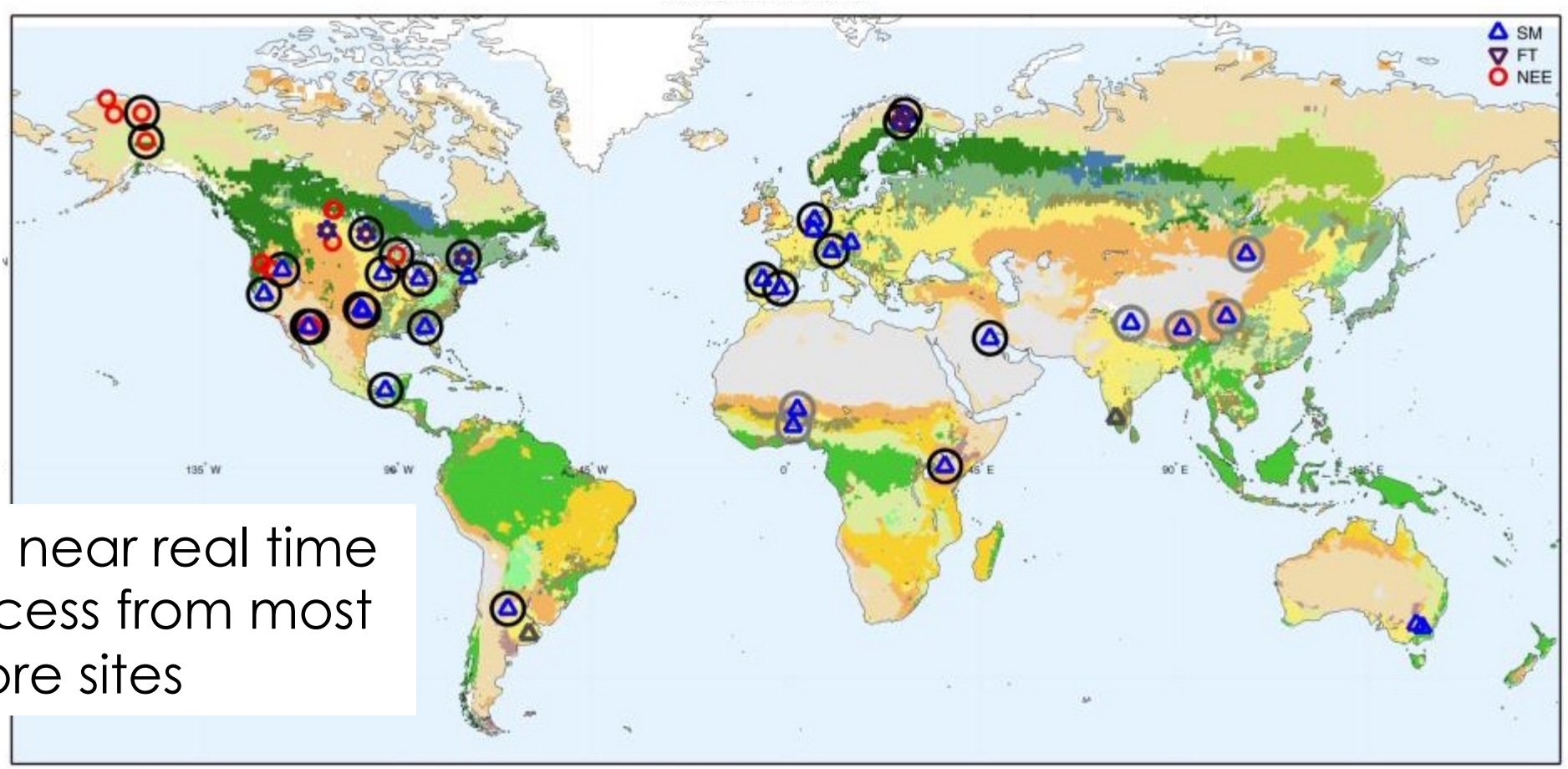


SMAP Calibration and Validation

Calibration and Validation (Cal/Val) Methodologies

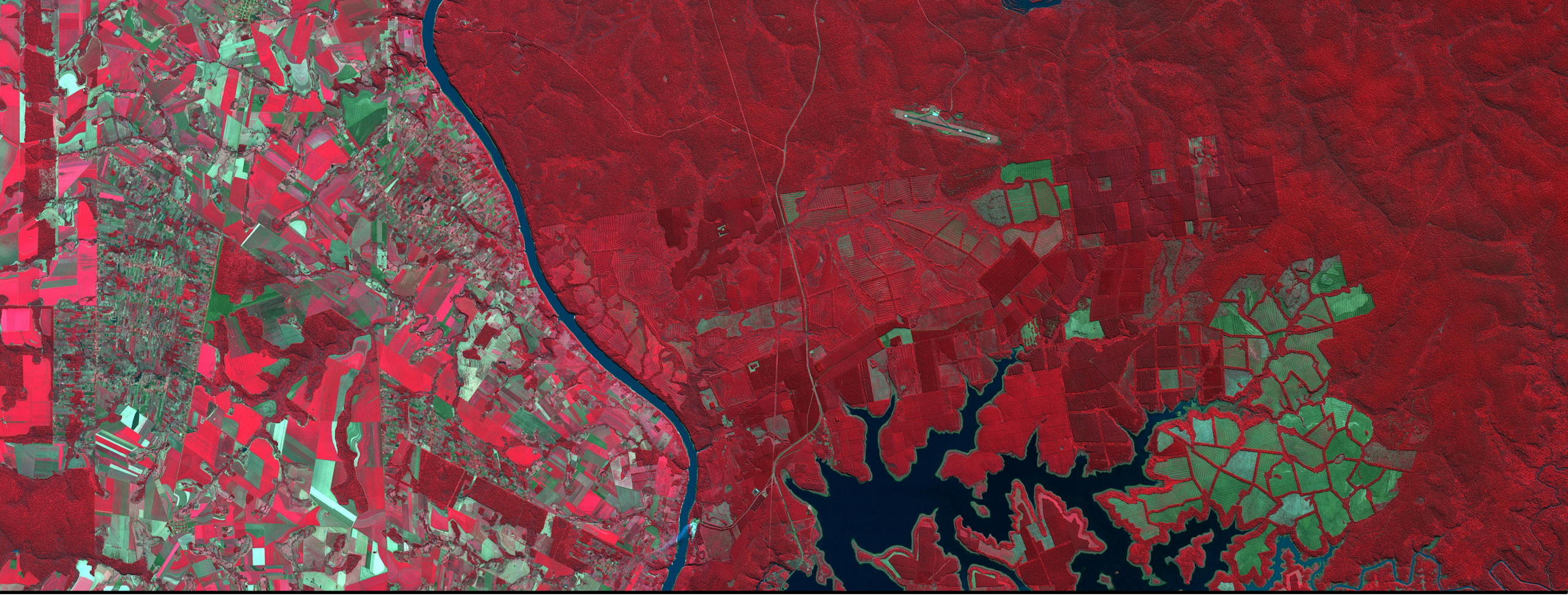
Methodology	Rule	Analysis Tools and Readiness
Core Validation Sites	Accurate estimates of products at matching scales for a set of conditions with spatially distributed in situ sensors	✓ Data transfer from Cal/Val partners set up and/or automated ✓ Scaling methods defined ✓ Offset grid processing
Sparse Networks	One point in the grid cell for a wide range of conditions	✓ Triple collocation method tool completed ✓ Data transfer from Cal/Val partners automated
Satellite Products	Estimates over a very wide range of conditions at matching scales	✓ Cross comparison tool developed for SMOS, GCOM-W and Aquarius ✓ Task group formed
Model Products	Estimates over a very wide range of conditions at matching scales	✓ Developed high-res 3 and 9 km model products ✓ Statistical comparison methods developed
Field Campaigns	Detailed assessment of the scaling issues for a set of high priority conditions	✓ SMAPVEx15 and 16 campaigns defined ✓ Australia campaign planned in 2015

Global Core Validation Sites



Goal is a near real time data access from most of the core sites

Black circles: Near real-time data access established
No circle: Near real-time data access being established (expected to be completed by launch)
Grey circles: No near real-time data access available (data available at the end of Cal/Val Phase)
Grey triangles: installations on-going, but expected to provide useful data at some point during the Cal/Val Phase



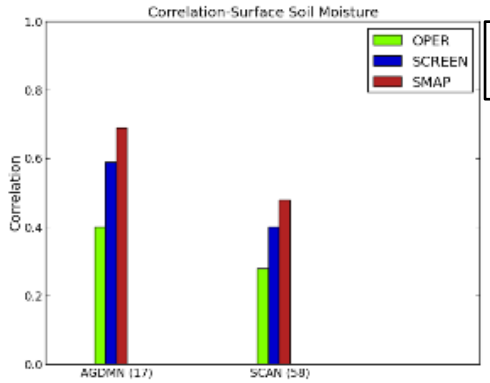
SMAP Applications

Impact of SMAP on Weather Prediction

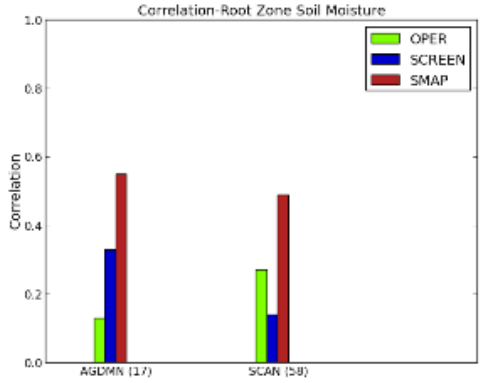
Environment and Climate Change Canada, *Marco Carrera, Stephane Belair*

Environment Canada

Positive Impact of SMAP on Near-Surface and Root-Zone Soil Moisture



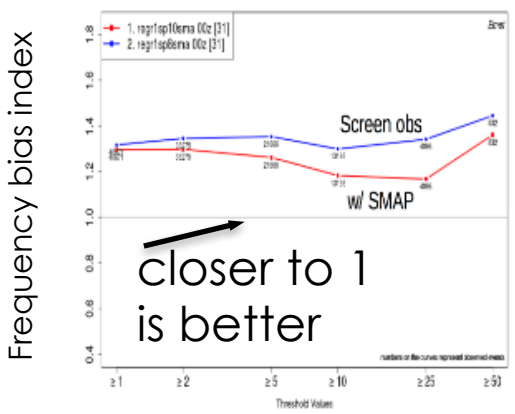
1



2

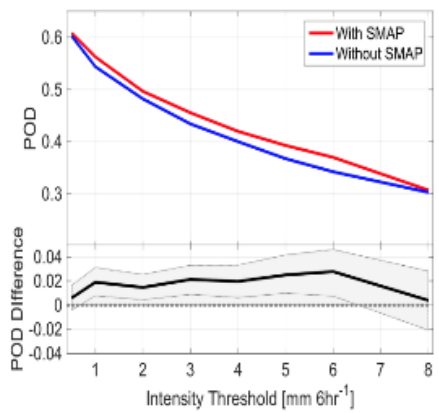
Positive Impact of SMAP on Precipitation Forecasts

Reducing Frequency Bias



3

Better detection of convective



4

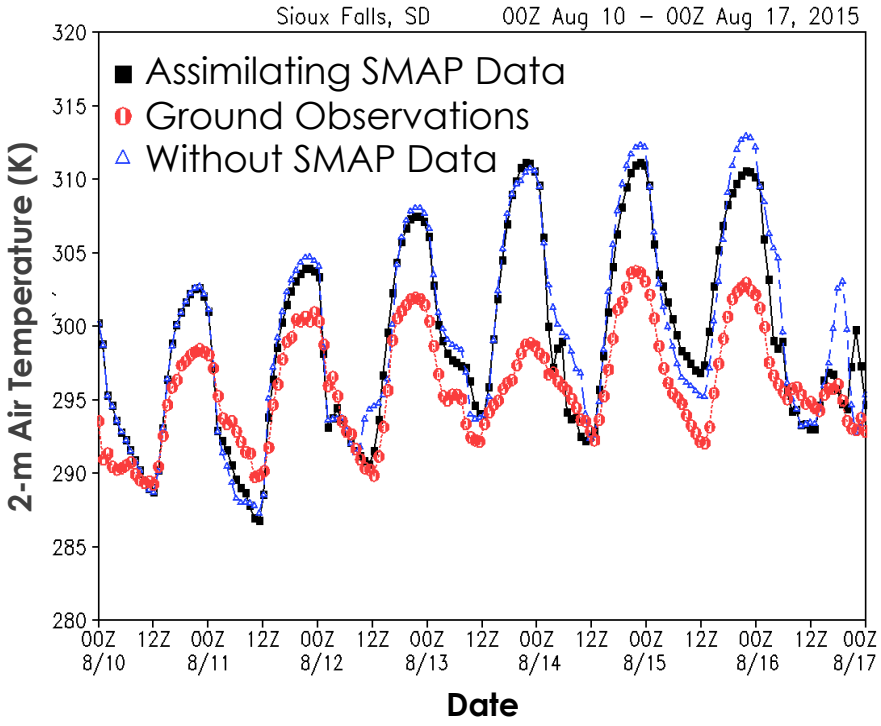
Assimilation of SMAP brightness temperature leads to **significant improvement in surface and root-zone soil moisture estimates**

This improvement further leads to a **positive impact of SMAP on Numerical Weather Prediction** (NWP) as shown in the quantitative precipitation forecasts in ECCC's North America NWP systems

Impact of SMAP on Weather Prediction

NOAA NESDIS-STAR and NWS-NCEP, *Xiwu Zhan, Weizhong Zheng, Mike Ek*

Assimilating SMAP soil moisture from 8/1-10/2015 reduced the warm biases of the global forecast system 7-day forecasts of 2 m air temperature



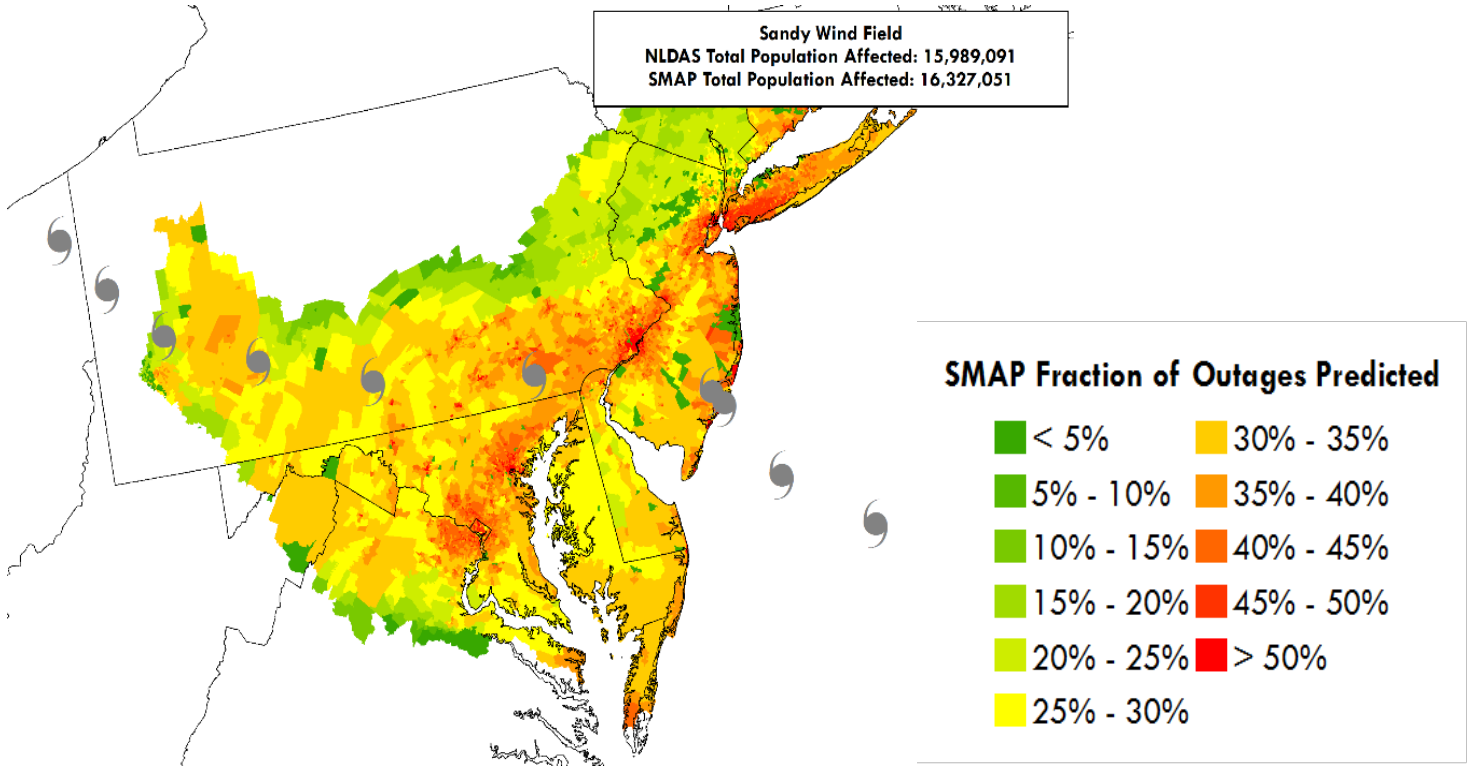
Much progress has been made to shorten the data latency of the SMAP Near Real Time (NRT) Level 1 brightness temperature product to meet the operational needs of NOAA's Numerical Weather Prediction system.

The SMAP EA team at NOAA illustrated a positive impact of SMAP data assimilation on NWP, including a reduction in temperature forecasting bias vs. the current operational system of NOAA.

Hurricane Power Outage Prediction

Texas A&M University, *Brent McRobert, Steven Quiring*

- Prediction of Power Outages for Sandy Wind Field
  - With modeled soil moisture: 15,989,091 people affected
  - With SMAP soil moisture: 16,327,051 people affected



- Outage predictions are sensitive to soil moisture
- Using SMAP data has a significant impact on predictions of people affected by outages

Improve Drought & Flood Early Warning

Texas Water Development Board

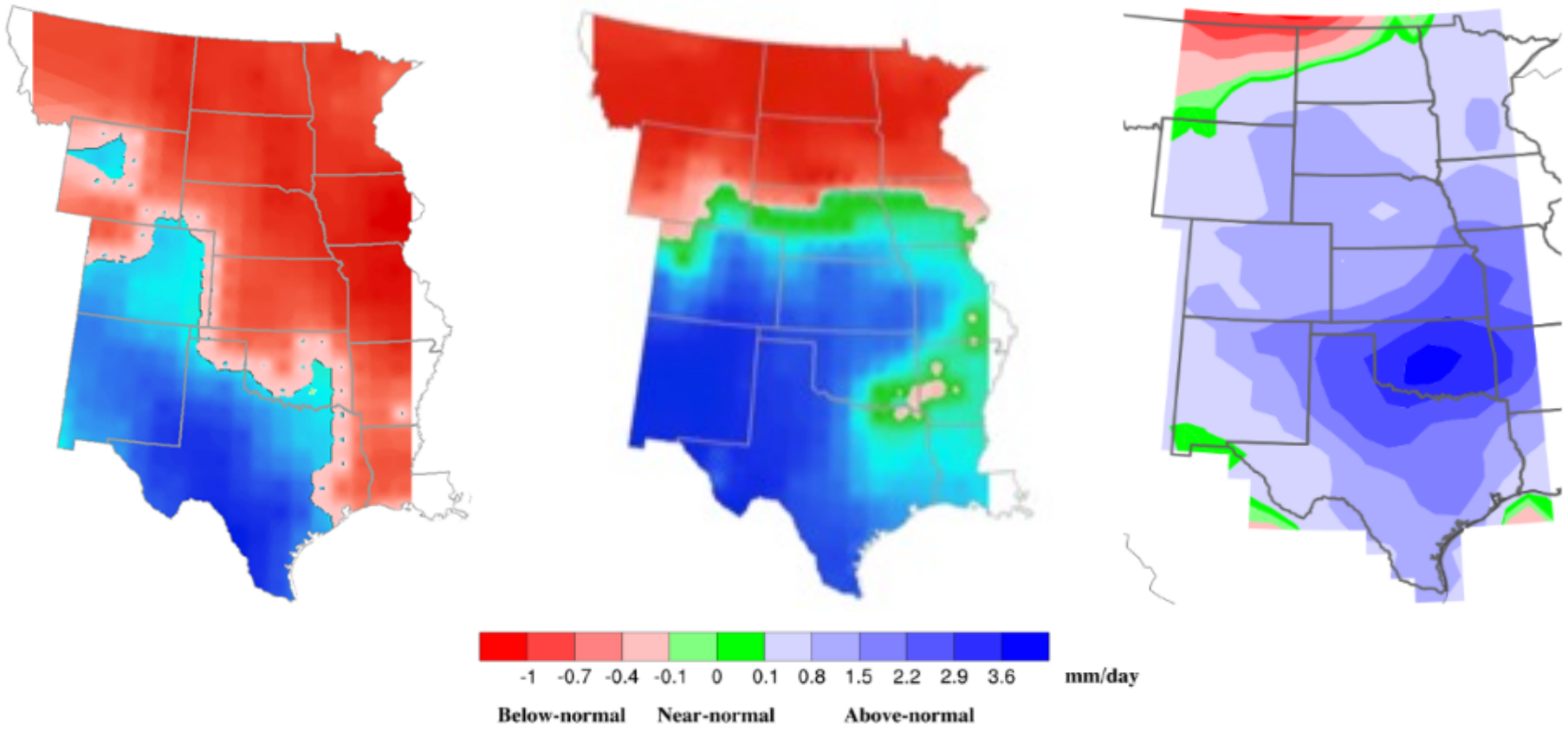
UCLA & TWDB, *Rong Fu, Nelun Fernando*

Prediction of 2015 Summer Rainfall Anomalies

Prediction Using Soil Moisture Estimate

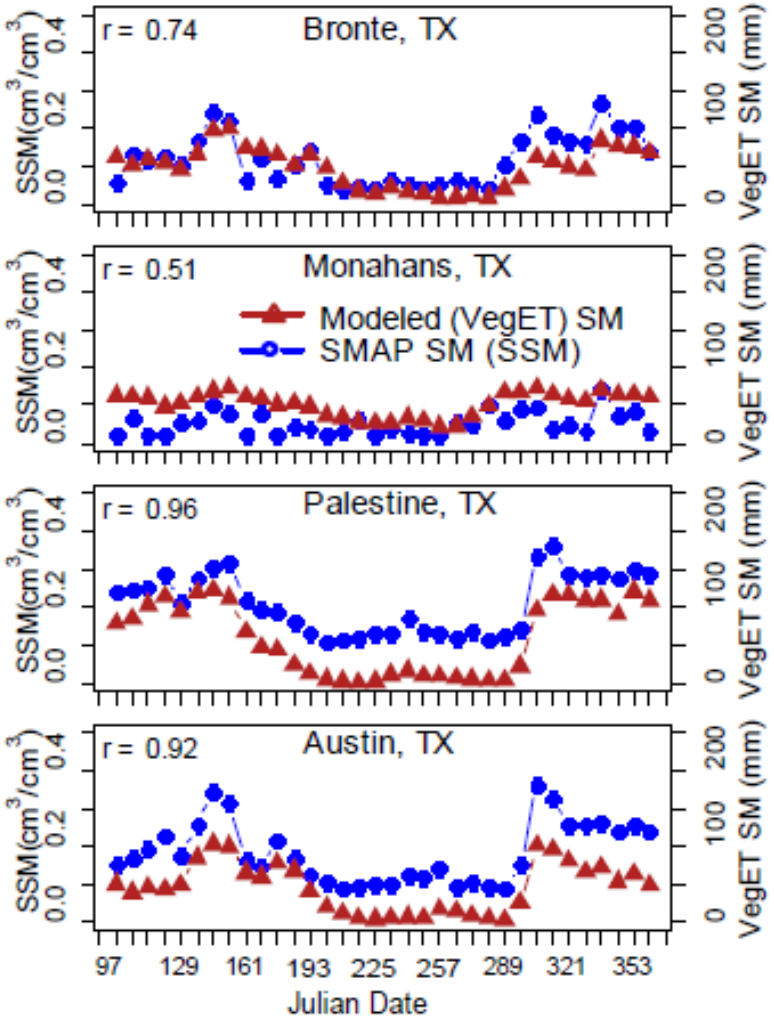
Prediction Using Soil Moisture from SMAP

Observed Rainfall Anomalies



Drought Monitoring

U.S. Geological Survey, *Manohar Velpuri, Jeff Morisette*

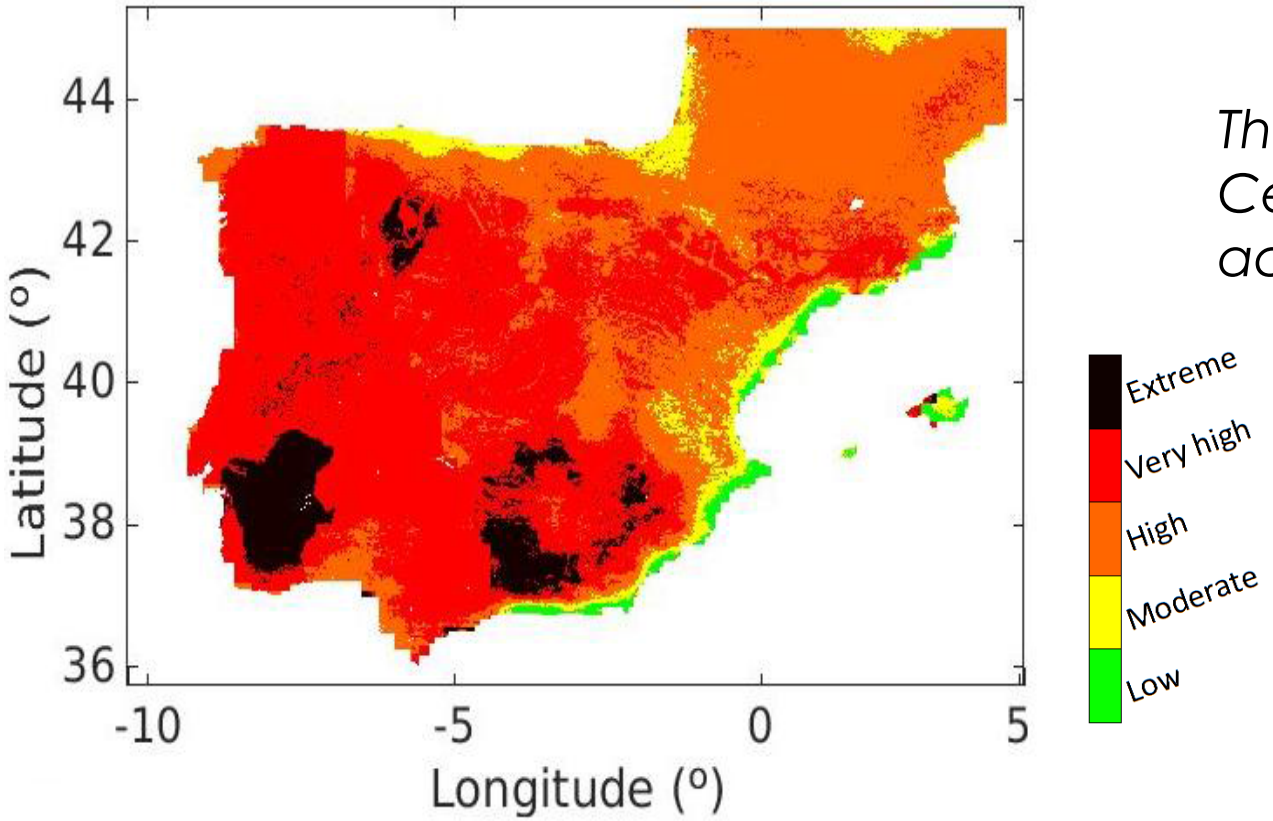


- USGS conducts drought monitoring in areas dominated by grasslands and shrublands
- SMAP showed a reliable and expected response of capturing seasonal soil moisture dynamics in relation to precipitation, land surface temperature, and evapotranspiration

Improving Forest Fire Risk Maps in Spain

Barcelona Expert Center, ICM/CSIC, UPC, *Maria Piles*

Map Showing 5 Fire Risk Categories
Based on Modeling and SMAP Soil Moisture Product



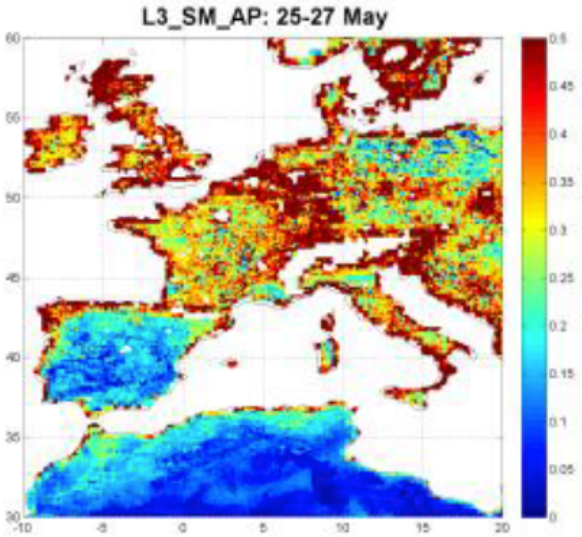
The Barcelona Expert Center provides free access to fire risk maps

Flood Mitigation in Central Italy

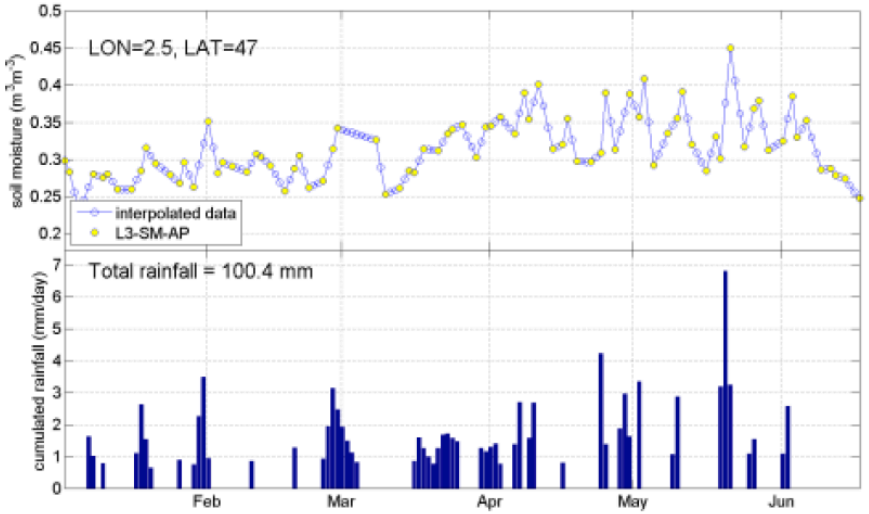
Research Institute for Geo-Hydrological Protection, *Luca Brocca*

- National Scale Flood Warning Program
- Integration of SMAP soil moisture and ground-based precipitation observations for flood (and landslide) alerts issued at the national scale

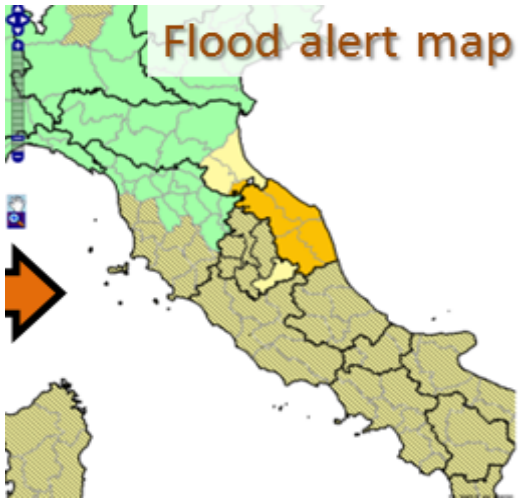
Soil Moisture



Rainfall Estimation



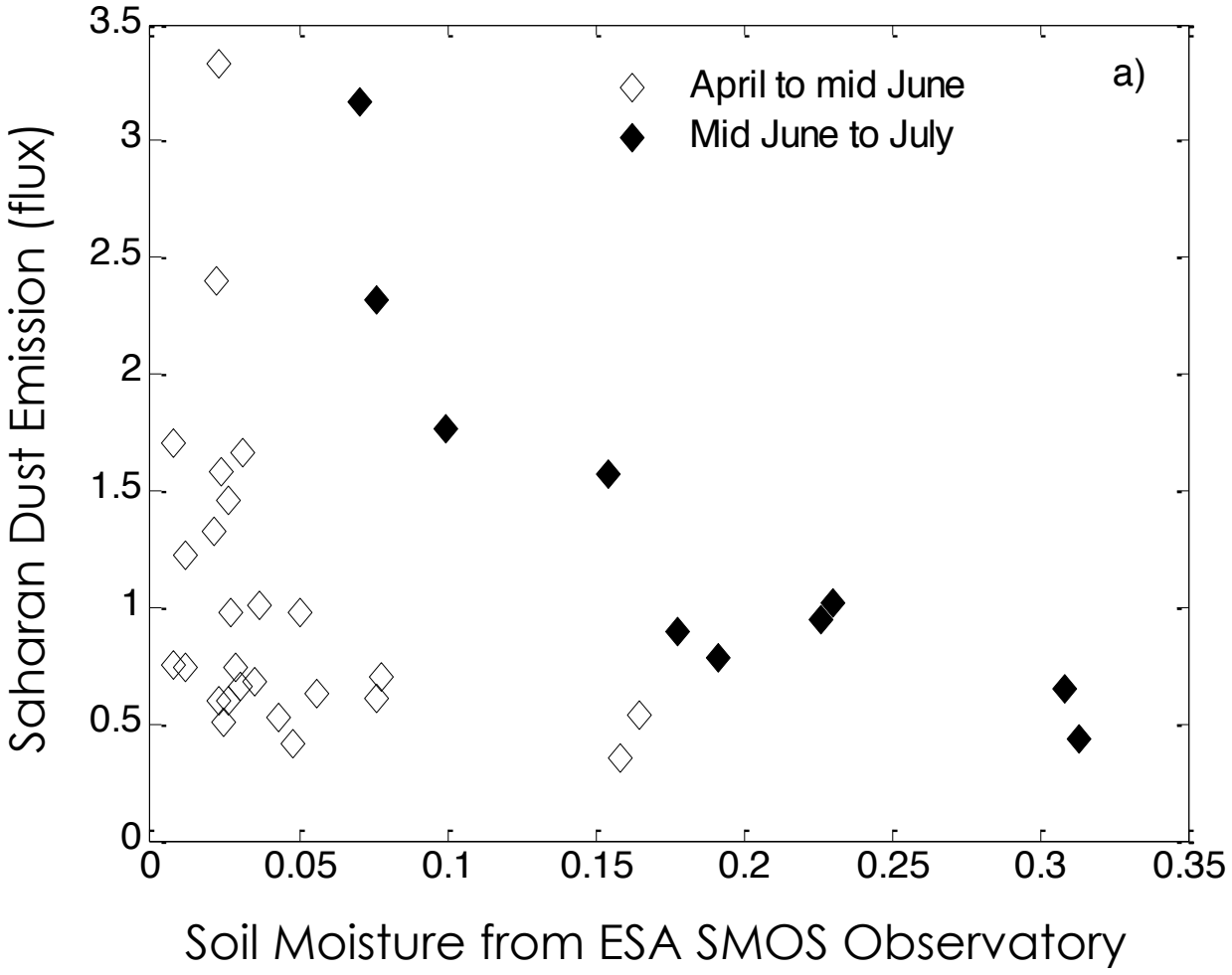
Flood Alert Map



Based on slide from Barry Weiss (JPL)

Mapping the Extent of Saharan Dust Emissions

Masdar Institute, UAE, *Hosni Ghedira and Imen Gherboudj*



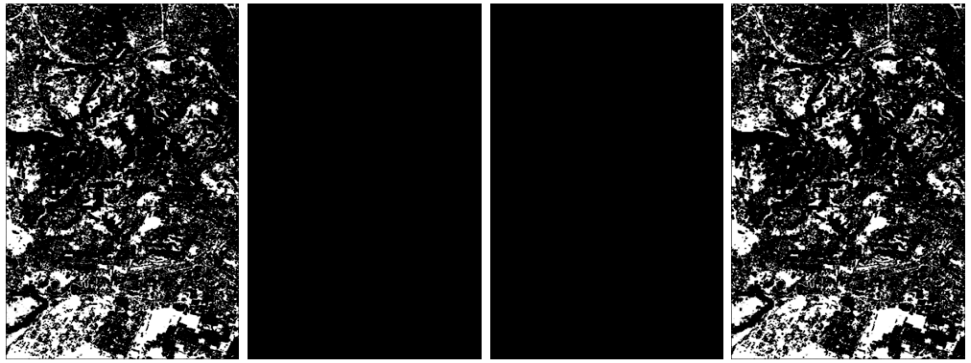
As soil moisture values increase, the dust emission decreases

With satellite estimates of soil moisture, dust predictions improved by up to 50%

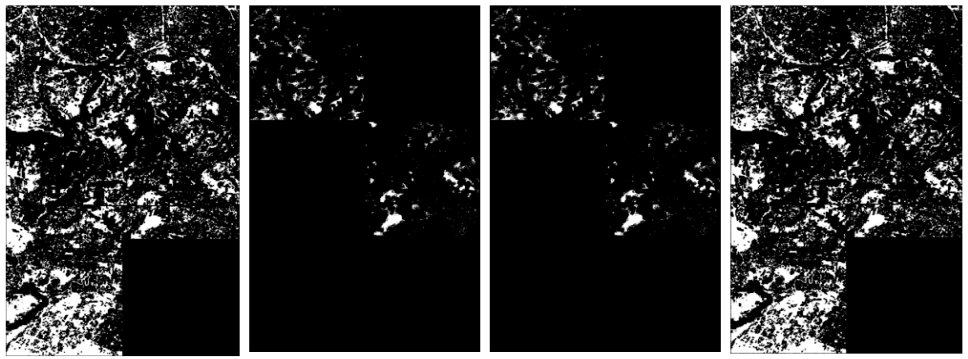
Military Vehicle Mobility

Lockheed Martin, *Derek Ward*

Mobility Map **without using** SMAP data, assuming soil 30% saturation



Mobility Map **using** SMAP data, with a continuum of soil moisture information



HumVee **ATV** **Transport Truck** **Light Truck**

- White denotes areas identified as GO mobility for 4 vehicle types
- With SMAP, we are better able to predict mobility of vehicles in Central Indonesia
- NATO Reference Mobility Model is the basis for the calculations

Google Earth Engine Analysis Platform

Google Technology Company, *Tyler Erickson, Rebecca Moore*

Screenshot of a SMAP L3 Soil Moisture Data Product Within the Earth Engine Platform