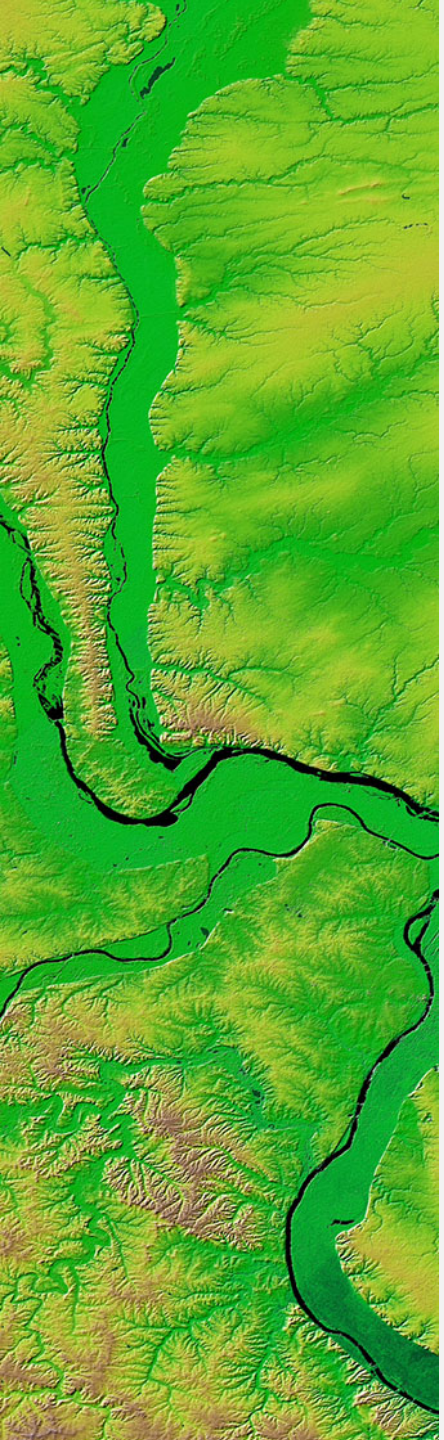


National Aeronautics and
Space Administration

ARSET
Applied Remote Sensing Training
http://arset.gsfc.nasa.gov
@NASAARSET

Overview of the Soil Moisture Active Passive (SMAP) Satellite Mission

Erika Podest and Amita Mehta

Learning Objectives

By the end of this presentation, you will be able to:

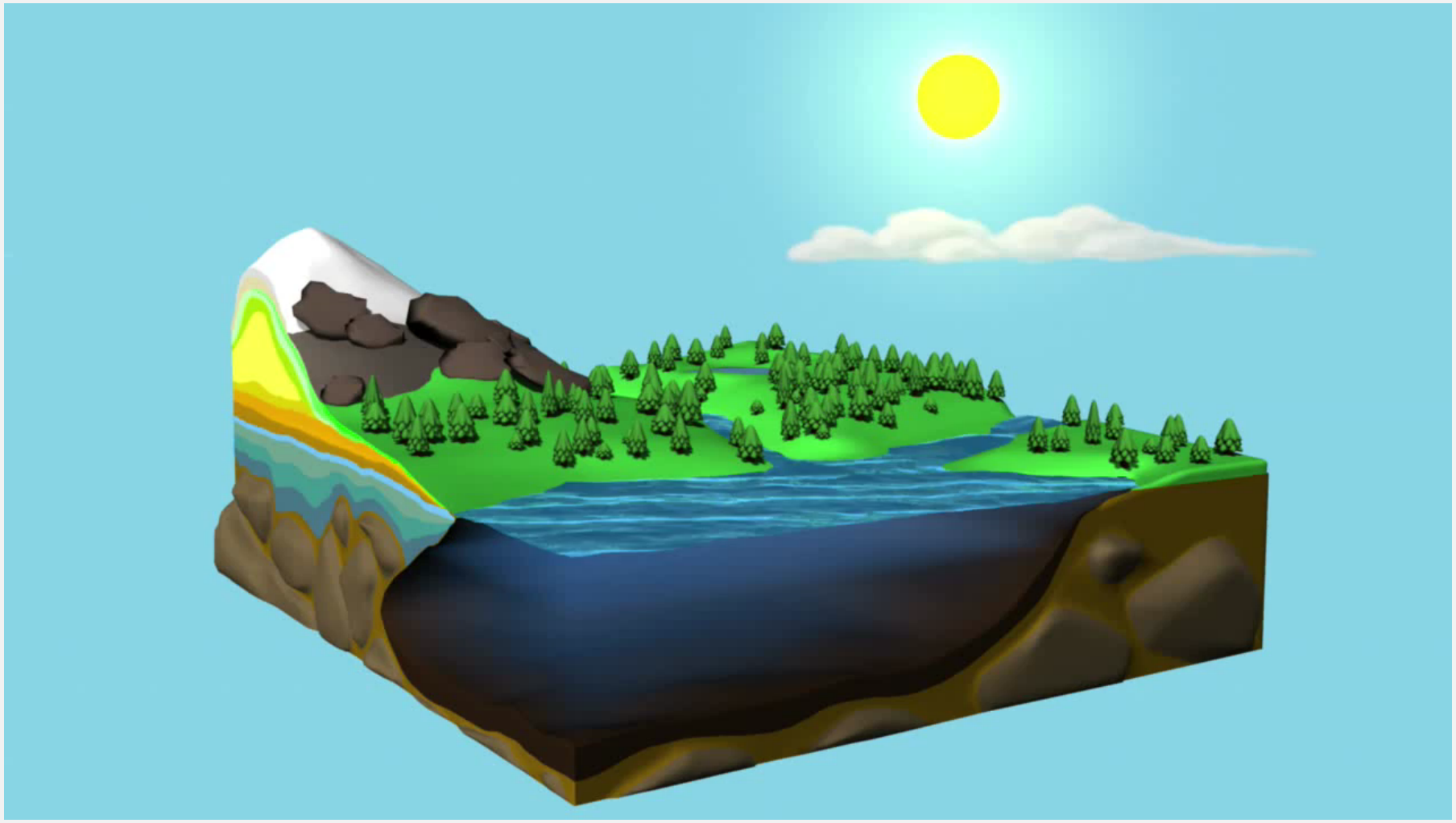
- Describe the Soil Moisture Active Passive (SMAP) Mission
- Identify the instruments on SMAP
- Identify the type of data product being generated from SMAP and their characteristics
- Be familiar with how SMAP data is calibrated and validated

Outline

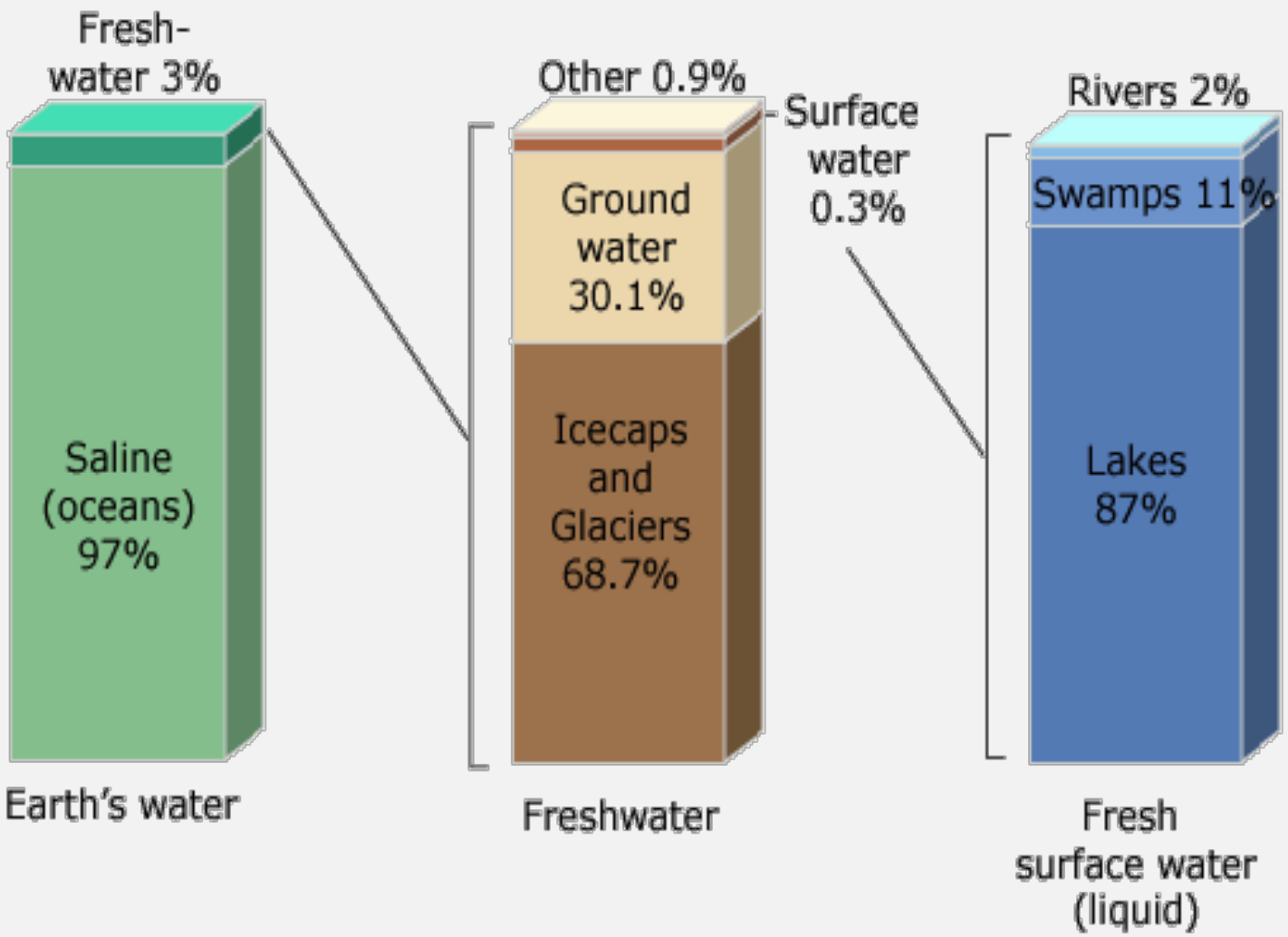
1. Soil Moisture and Surface Freeze/Thaw
2. Mission Objectives
3. Instruments
4. Data and Products
5. Calibration and Validation

Soil Moisture and Surface Freeze/Thaw

The Water Cycle

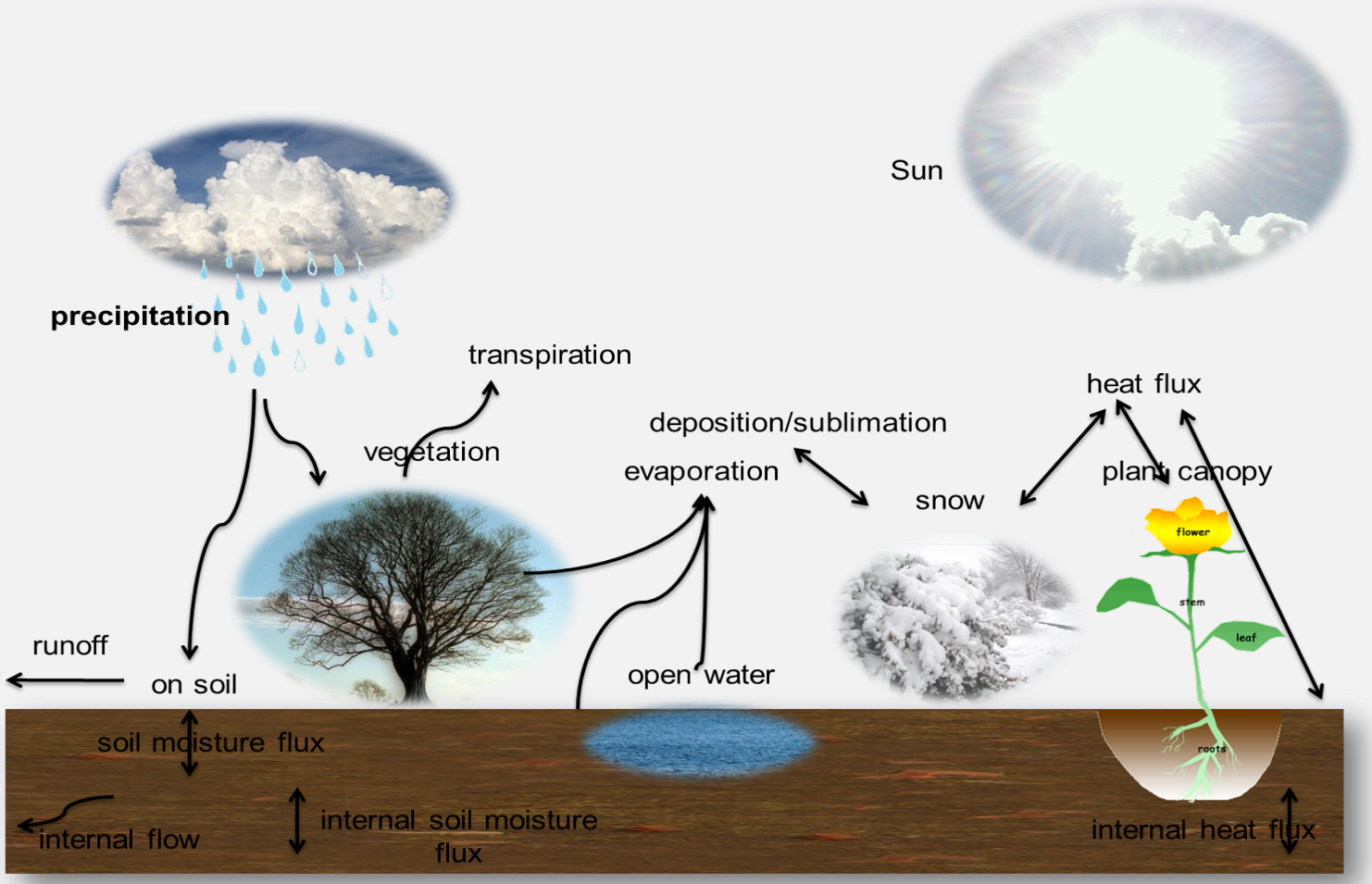


Water Distribution on Earth



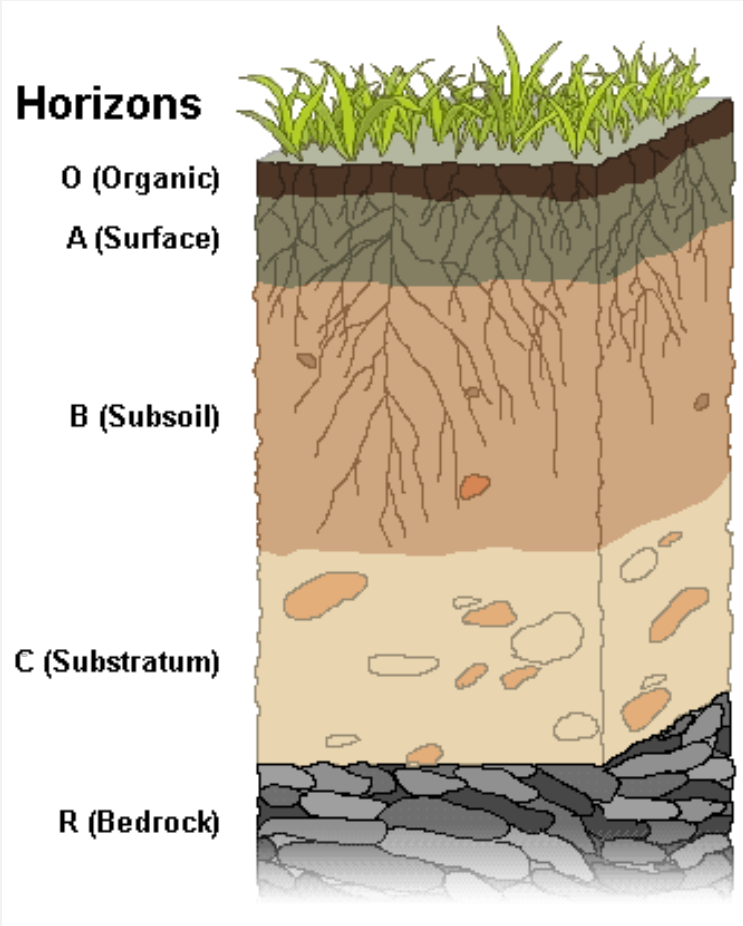
Importance of Soil Moisture

- For every kilogram of water on Earth, 1 milligram is stored as soil moisture
- This miniscule amount of water exerts significant control over various processes:
  - hydrological
  - ecological
  - meteorological



(Chen et. al., 1996, 1997; Chen and Dudhia, 2001; Ek et. al., 2003; Koren et. al., 1999)

Soil Profile



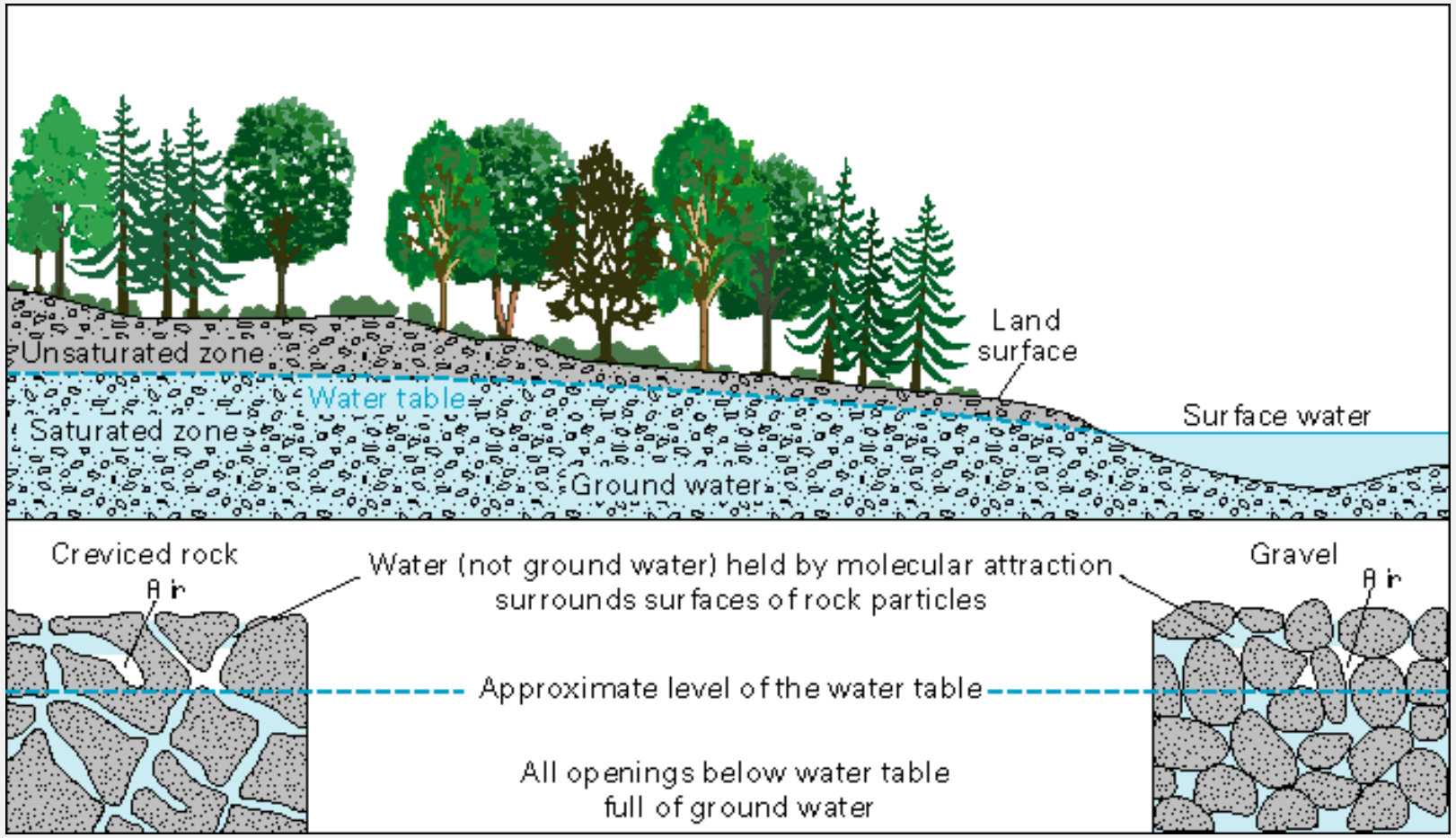


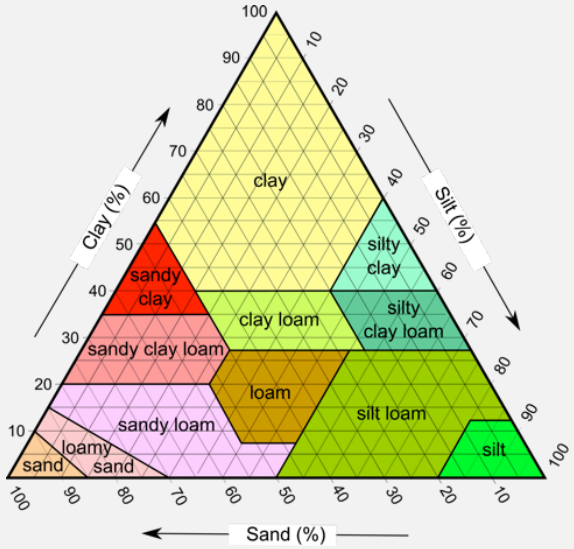
Image Credits: (Left) Wikipedia soil horizon; (Right) USGS

Factors Influencing Soil Moisture

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

Rainfall

Soil Texture



Vegetation

Topography

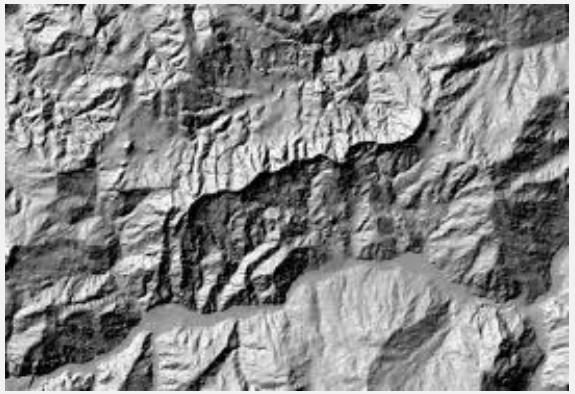


Image Credit: (Soil Texture) Wikipedia, Soil Texture Diagram

Limitations in Measuring Soil Moisture with Ground Sensors

Current ground measurements of soil moisture are sparse and have limited coverage

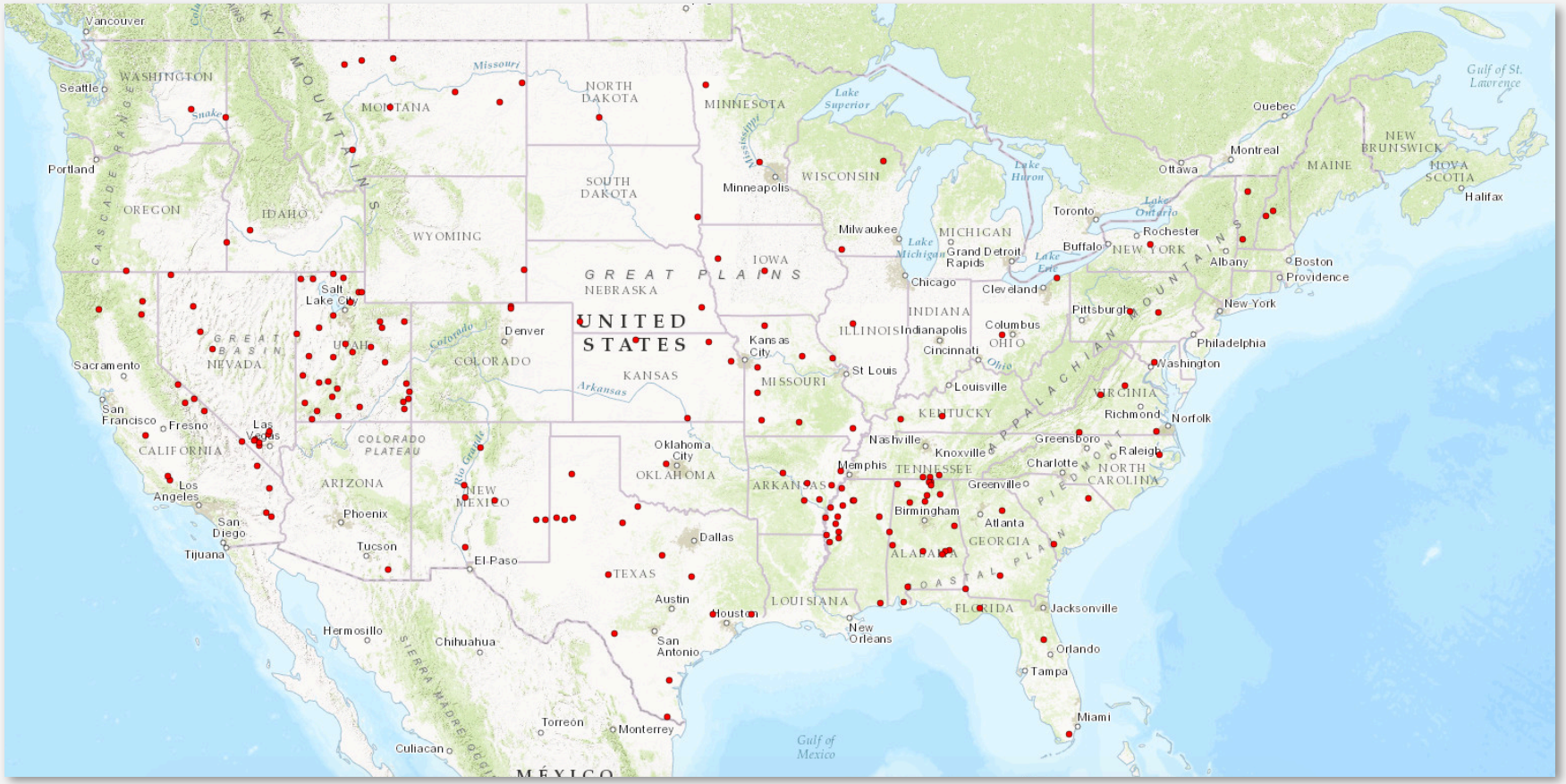
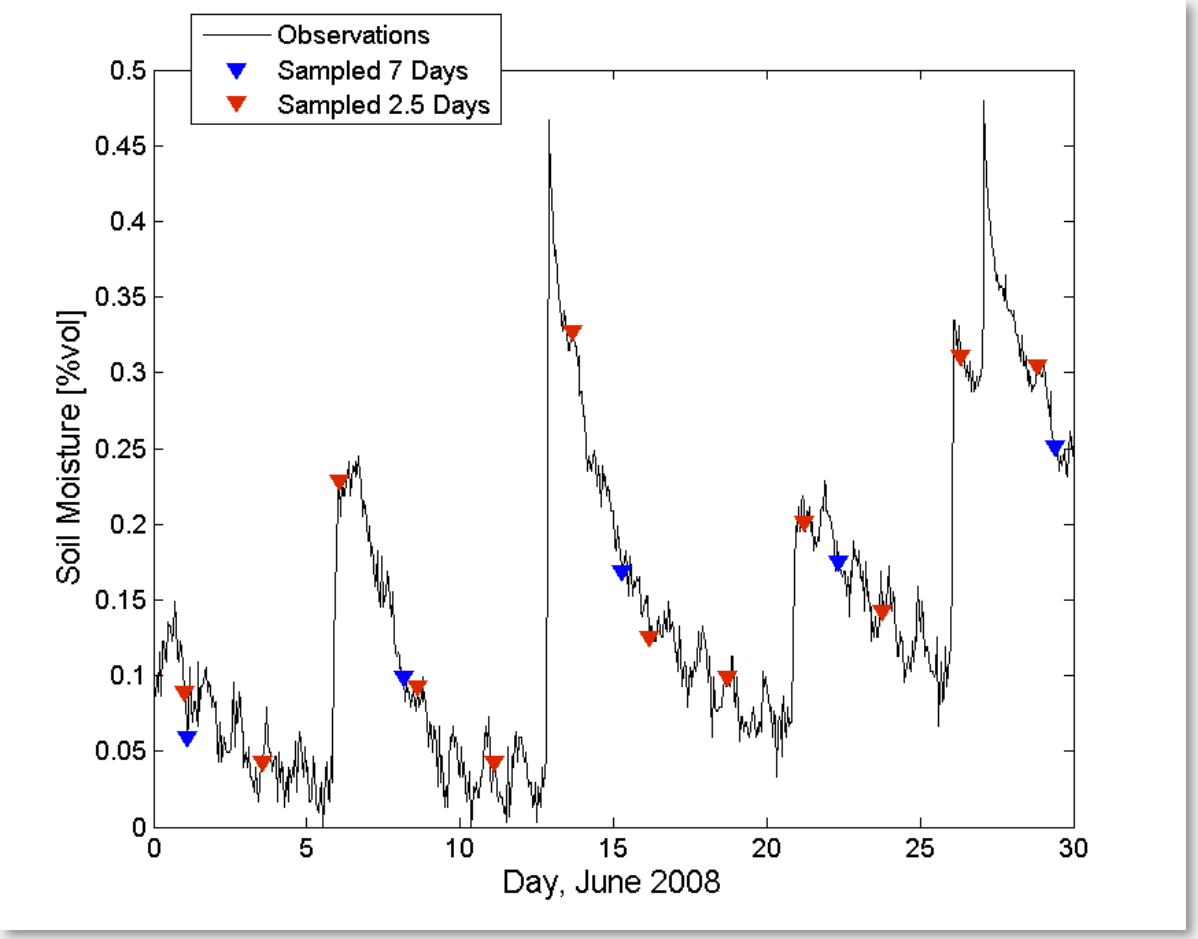


Image Credit: Natural Resources Conservation Service, Soil Climate Analysis Network (SCAN) Data & Products

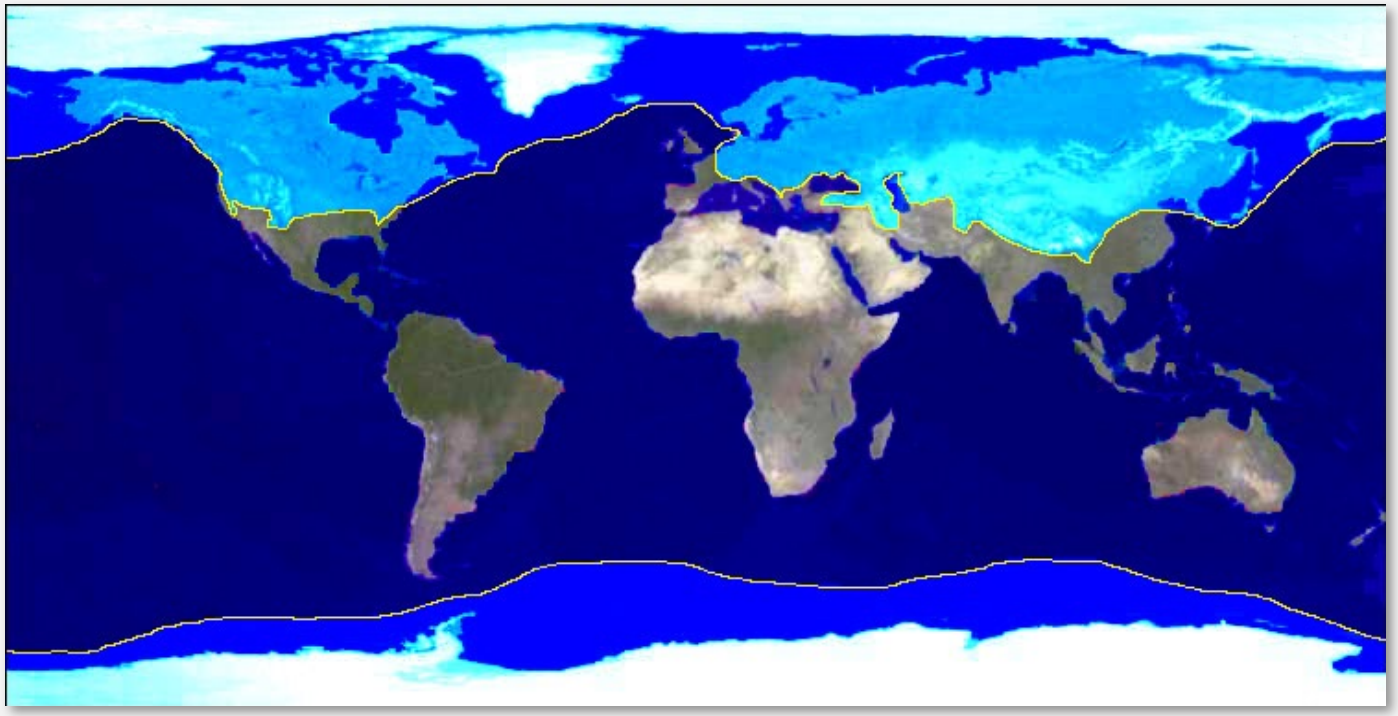
The Dynamic Nature of Soil Moisture

Observations are needed every 3 days or less to best determine the variability in soil moisture

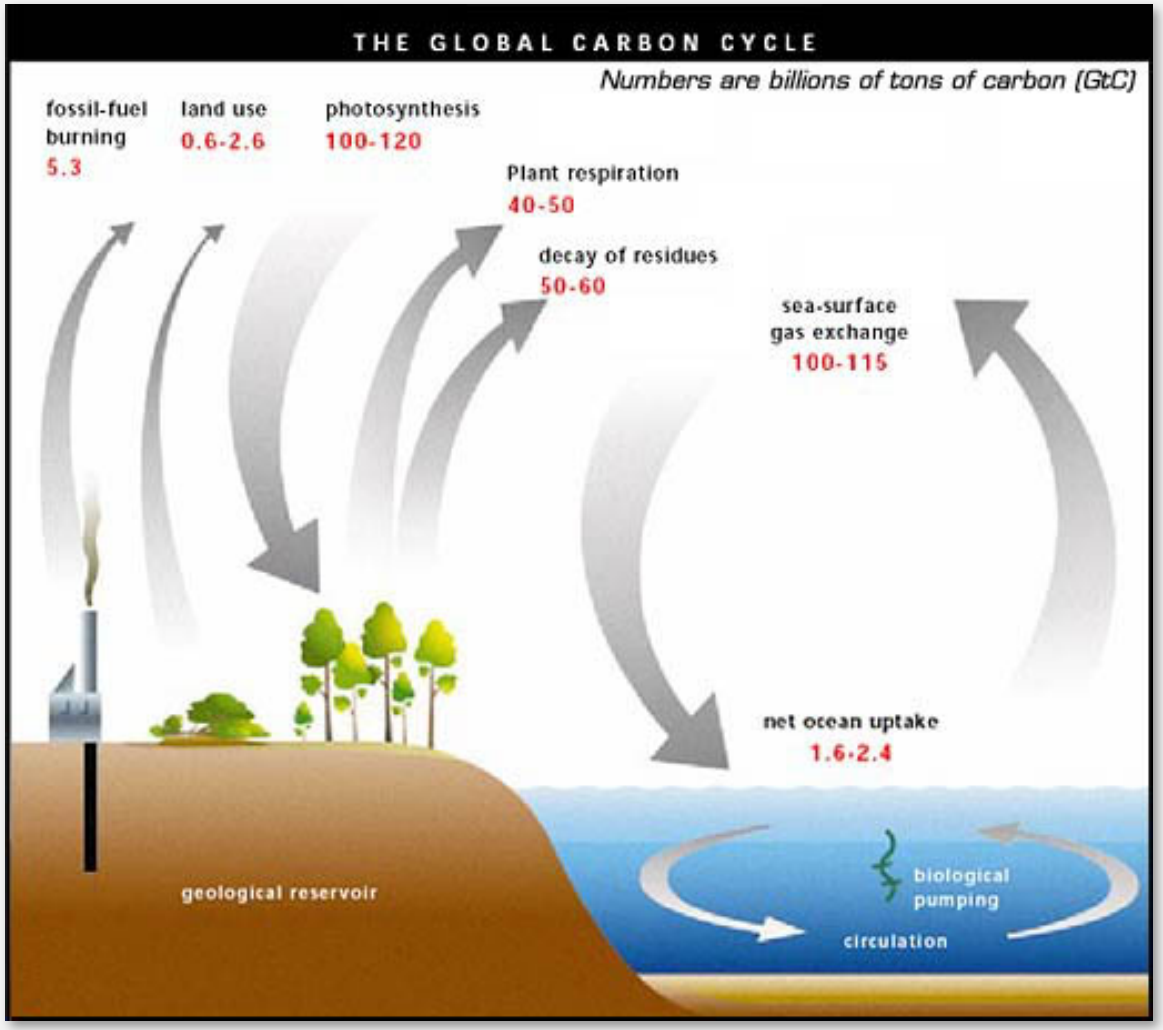


Sun et al. (2006): How often does it rain?, *J. Climate, **19***

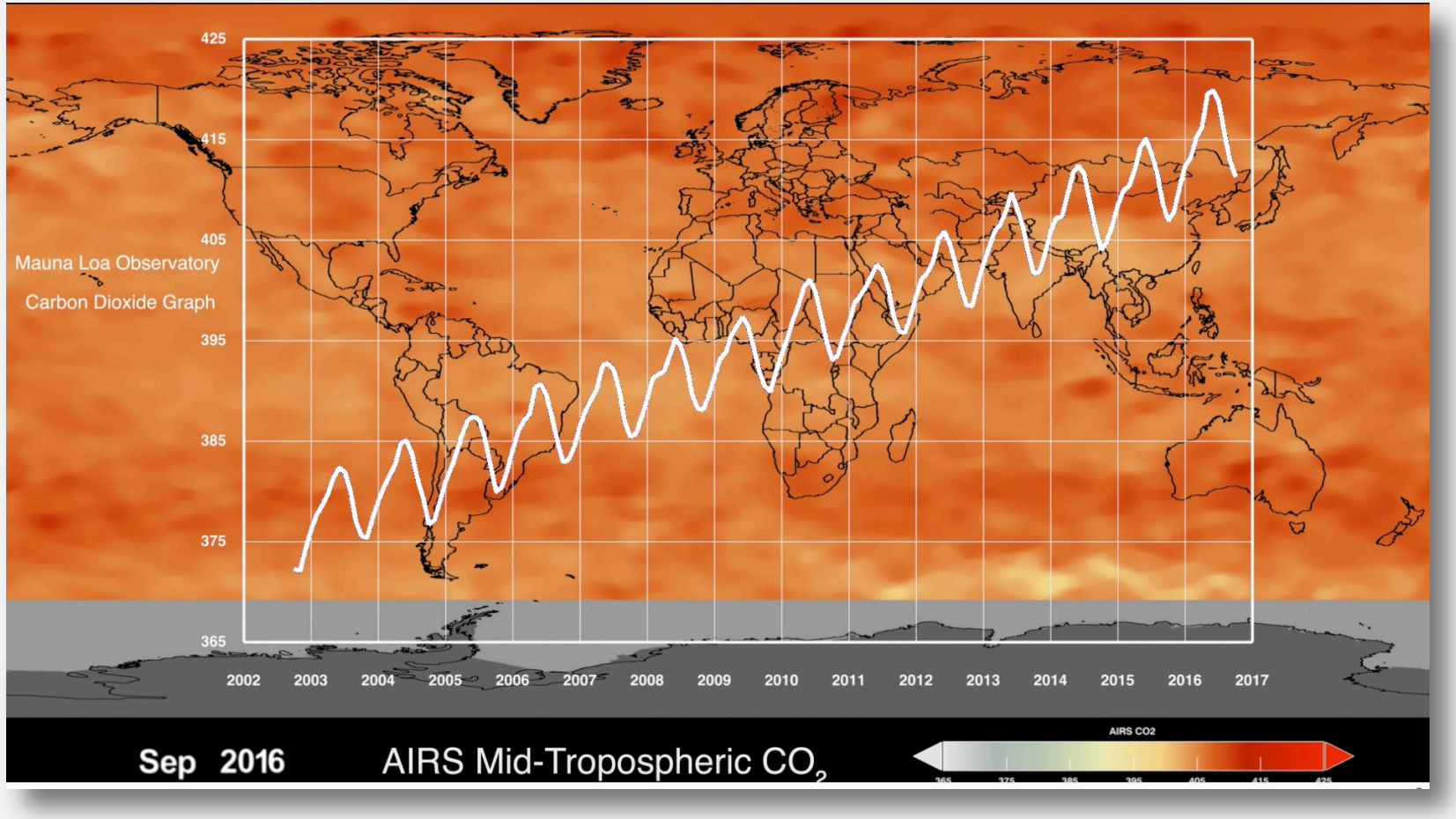
Importance in Knowing Freeze/Thaw State of the Land Surface



The Carbon Cycle



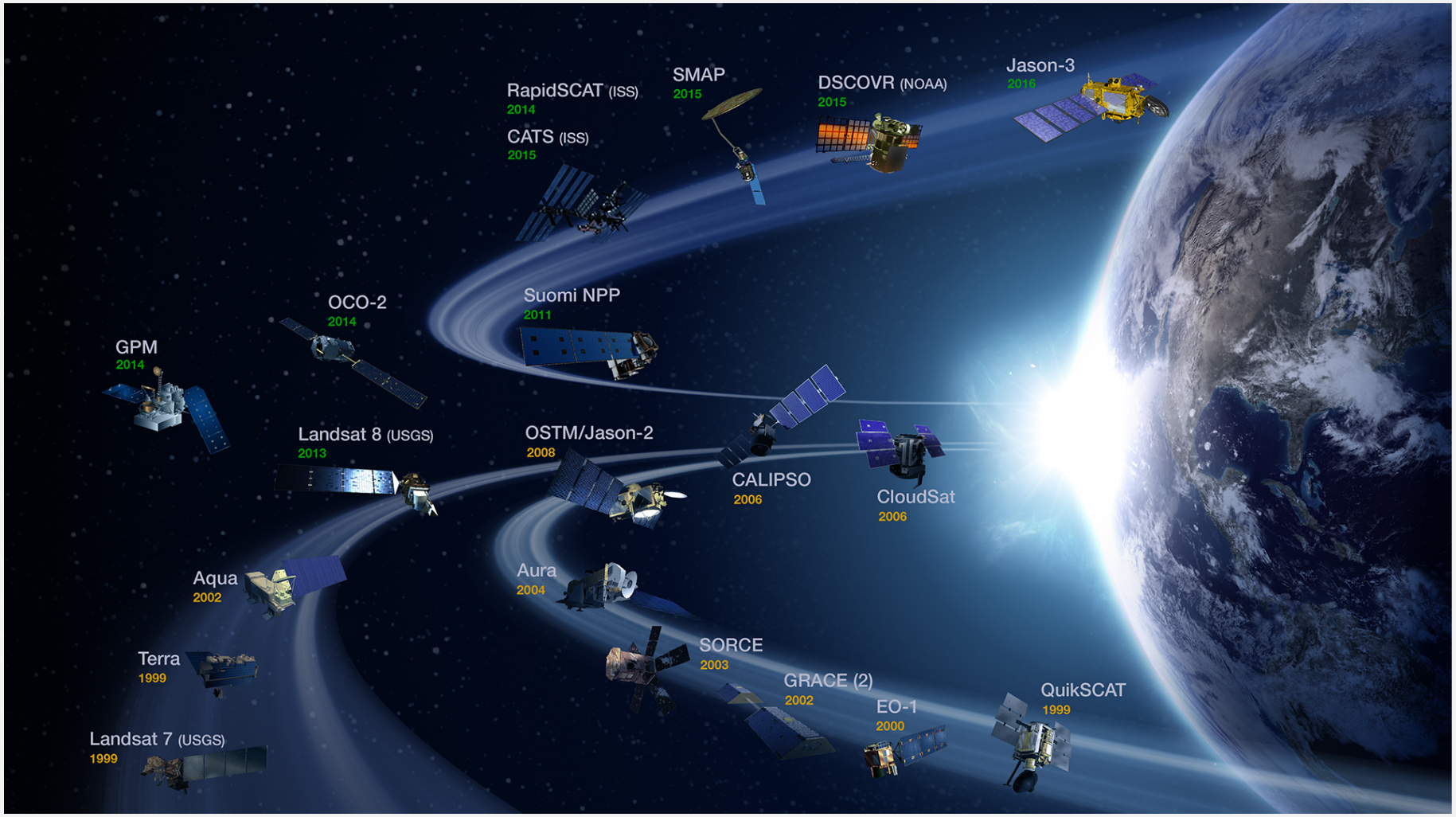
Atmospheric CO2 Concentration



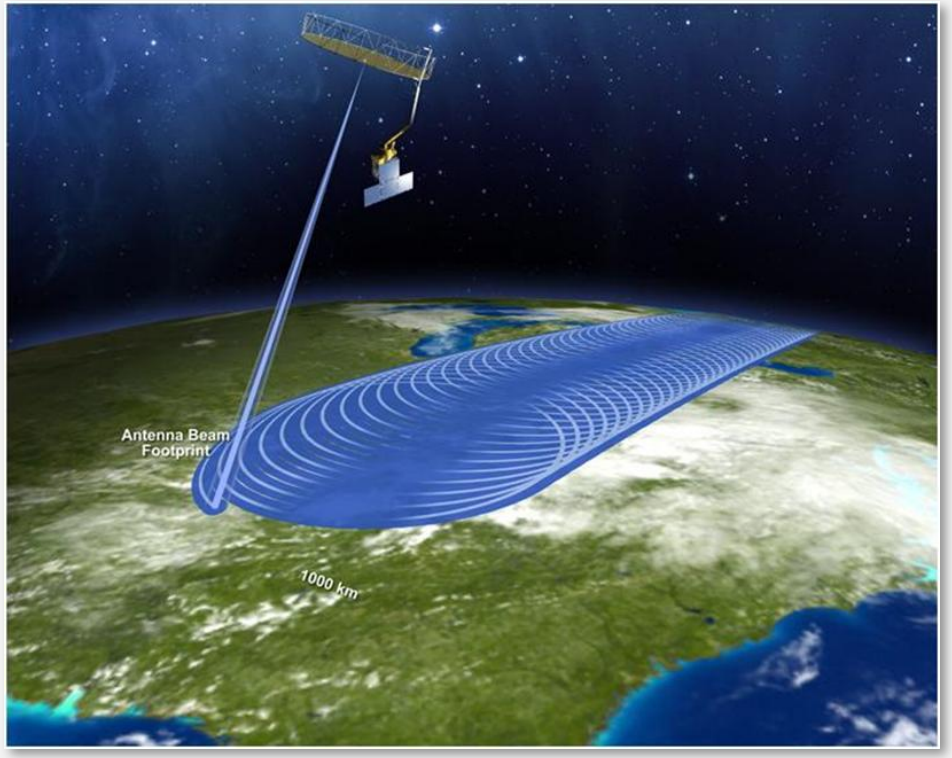
Credit: Goddard Visualization Lab

SMAP Mission Objectives

NASA Earth Observing Fleet



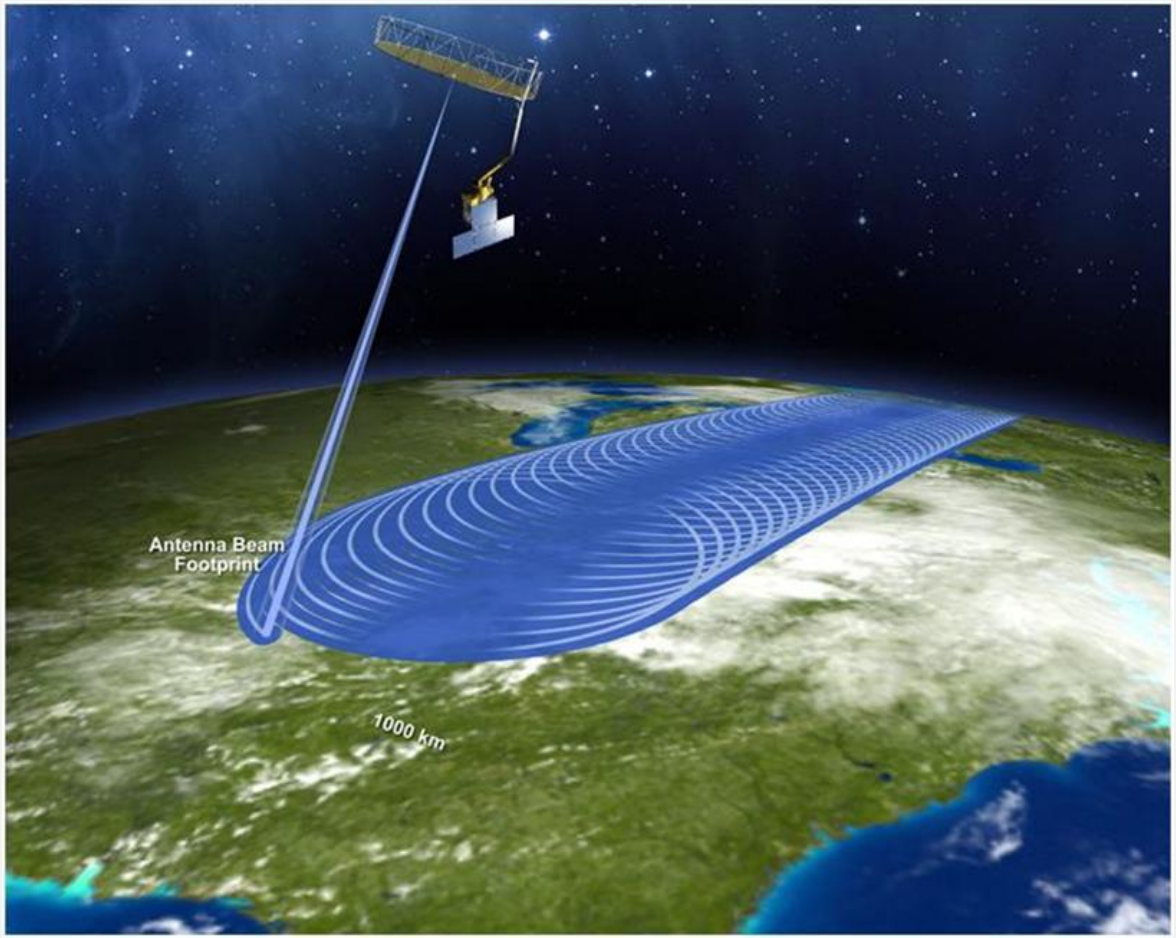
SMAP Overview



Launch: Jan 31, 2015, from Vandenberg Air Force Base in CA onboard a Delta II

- **Radar (no longer working)**
  - Frequency: 1.26 GHz
  - Polarization: VV, HH, HV
  - Resolution: 3km
  - 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

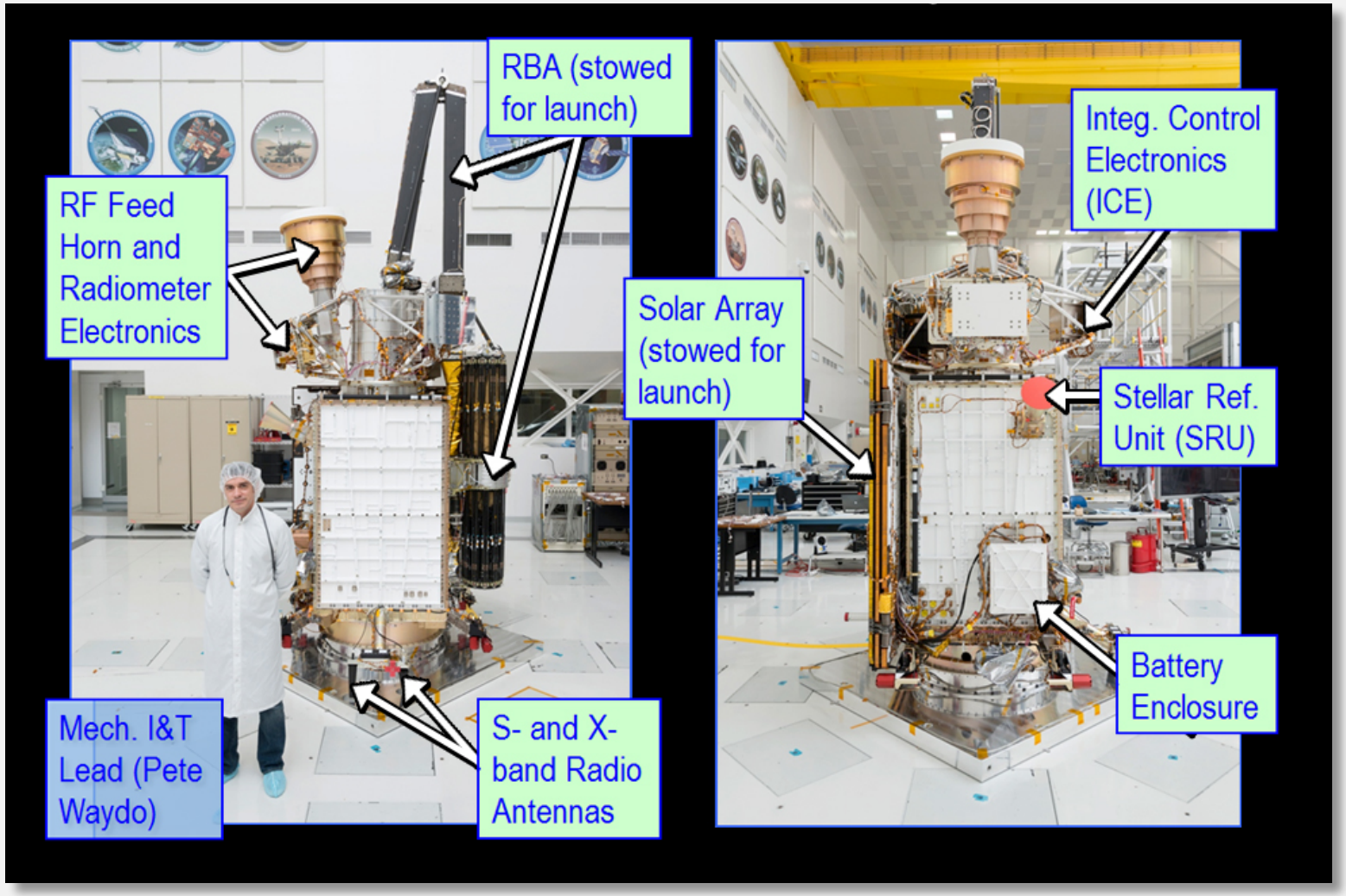
SMAP Overview



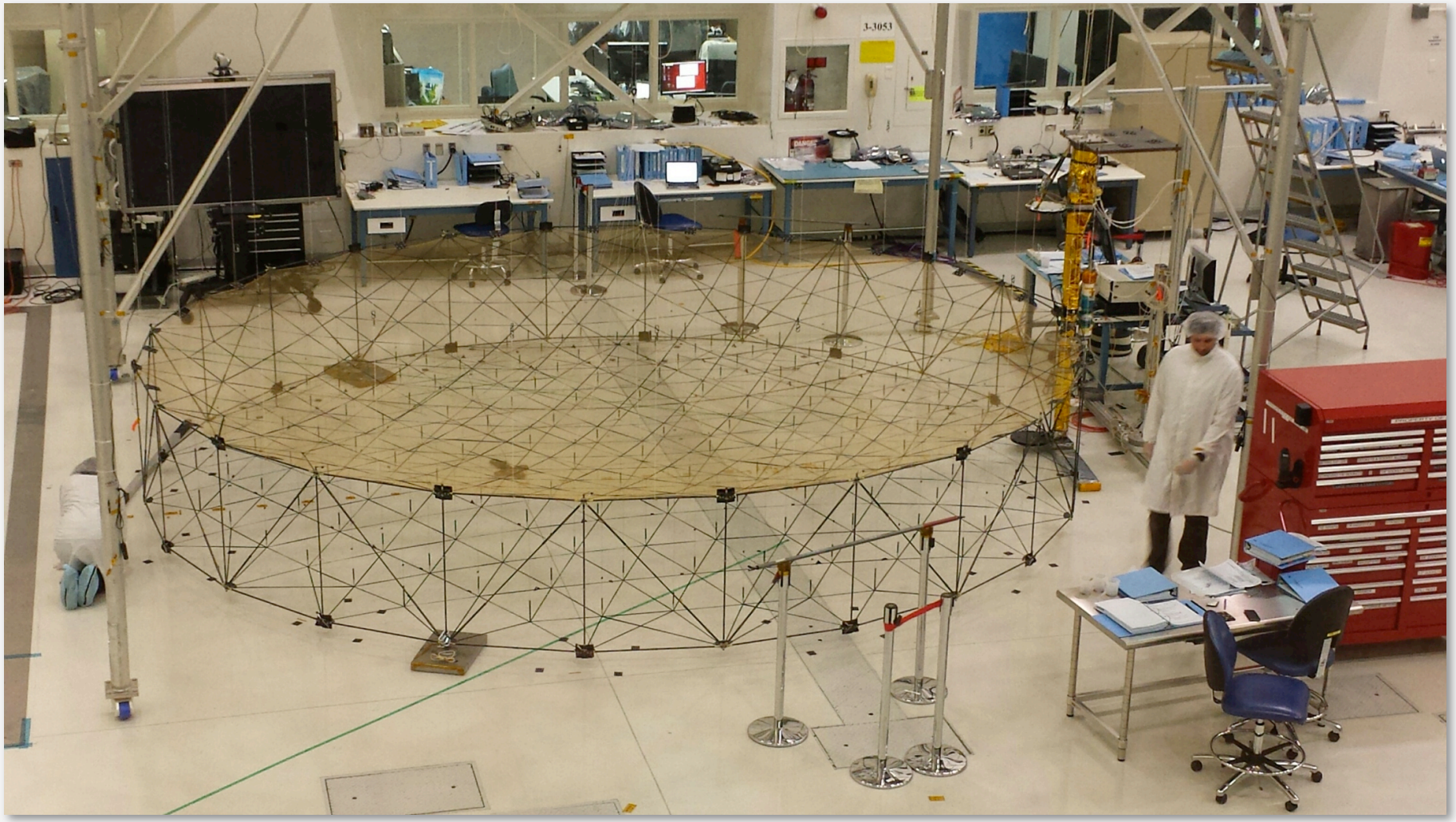
- **Shared Antenna**
  - 6m diameter
  - Conical scanning at 14.6 rpm
  - Constant incidence angle: 40 degrees
  - Swath 1000 km – wide
  - Swath and orbit allow global coverage every 2-3 days
- **Orbit**
  - Sun synchronous, 6 am/pm orbit
  - 685 km altitude
- **Mission Duration**: 3 years

SMAP Animation

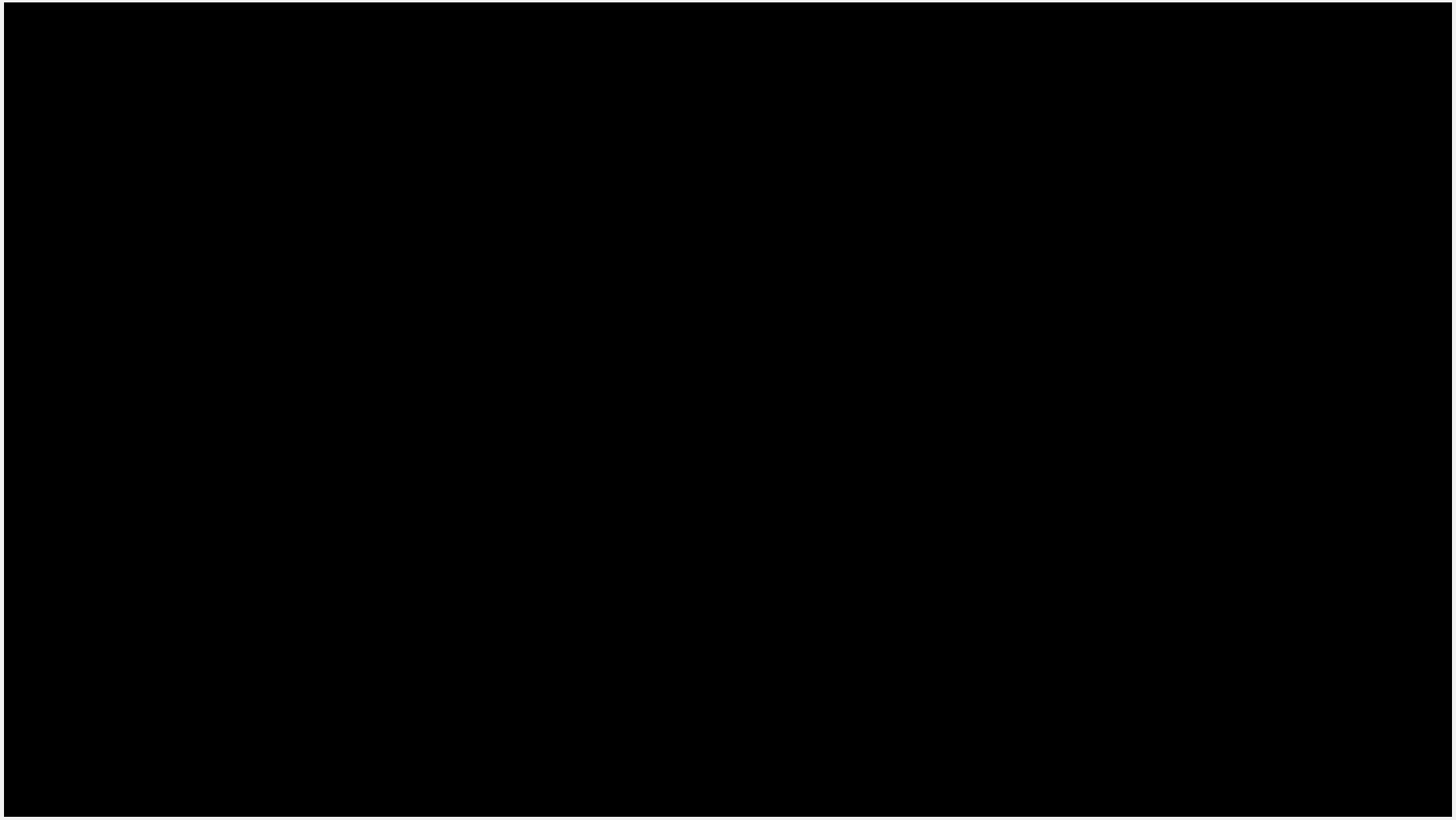
SMAP


RBA (stowed for launch)
RF Feed Horn and Radiometer Electronics
Mech. I&T Lead (Pete Waydo)
S- and X-band Radio Antennas
Solar Array (stowed for launch)
Integ. Control Electronics (ICE)
Stellar Ref. Unit (SRU)
Battery Enclosure

The SMAP Antenna



Testing the Antenna



SMAP Status

Loss of SMAP Radar

- On July 7, 2015, the SMAP radar suddenly stopped operating after collecting data for 2.5 months

Implications for SMAP

- Surface freeze/thaw state product at 3 km will not be produced
- Soil moisture products at 9 km will not be produced

SMAP Status

Current Configuration

- Soil moisture accuracy requirements will be met and global soil moisture maps will be produced every 2-3 days with the radiometer.
  - Resolution: 40 km
- Produced a radiometer resolution enhanced dataset and soil moisture product

Future Plans

- Freeze/thaw product at 40 km resolution using the radiometer
- Soil moisture product using Sentinel 1-A/B radar data
- Other products are being developed such as sea surface salinity and ocean winds

SMAP Status

- **Loss of the SMAP Radar**
- On July 7 2015 the SMAP radar suddenly stopped operating after collecting data for 2.5 months
- **Implications for SMAP**
- Surface freeze/thaw state product at 3 km will not be produced
- Soil moisture products at 9 km will not be produced
- **Current Configuration**
- Soil moisture accuracy requirements will be met and global soil moisture maps will be produced every 2-3 days with the radiometer. The resolution will be at 40 km
- SMAP will produce a freeze/thaw product at 40 km resolution using the radiometer
- A radiometer resolution enhanced dataset and soil moisture product have been produced
- A soil moisture product using Sentinel-1 A/B radar data (in lieu of SMAP radar) is being produced
- Other products are being developed such as sea surface salinity and ocean winds

SMAP Products

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

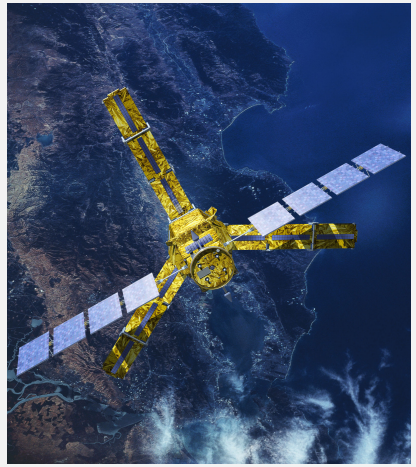
(1) North of 45°N Latitude
(2) % volumetric water content, 1-sigma
(3) % classification accuracy (binary: Freeze or Thaw) Item

Soil Moisture Products from Different Satellites

- SMAP
  - L-Band
  - 40 km
  - Observations every 3 days
  - https://nsidc.org/data/smap/smap-data.html
- SMOS
  - L-Band
  - 40 km
  - Observations every 3 days
  - http://bit.ly/2ocXevG
- ASCAT
  - C-band
  - 50 km
  - Observations every 2 days
  - http://rs.geo.tuwien.ac.at/dv/ascat/

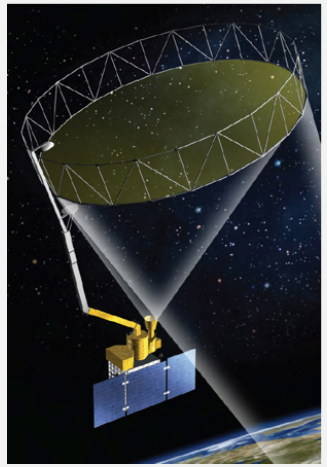
Uniqueness of the SMAP Radiometer

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

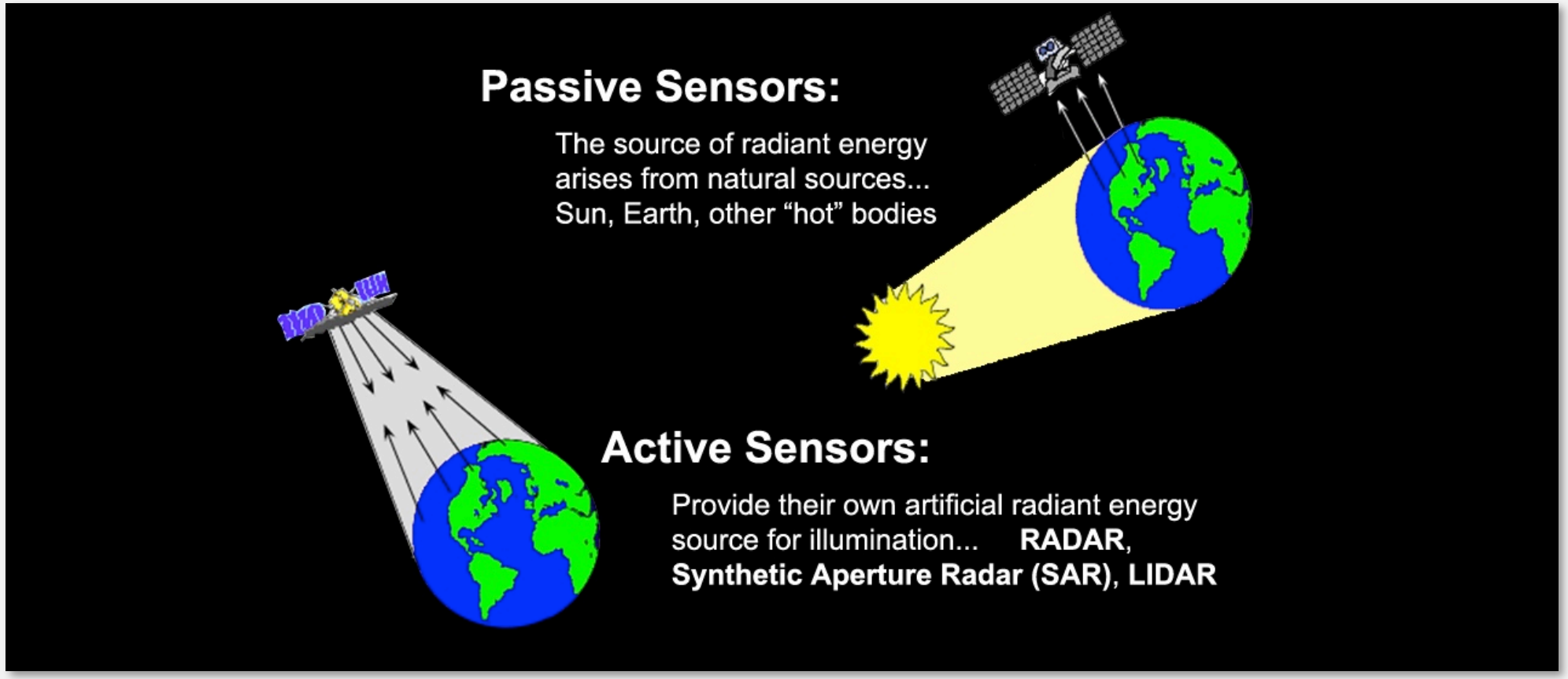
Uniqueness of SMAP

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

SMAP Instruments and Algorithm Approach

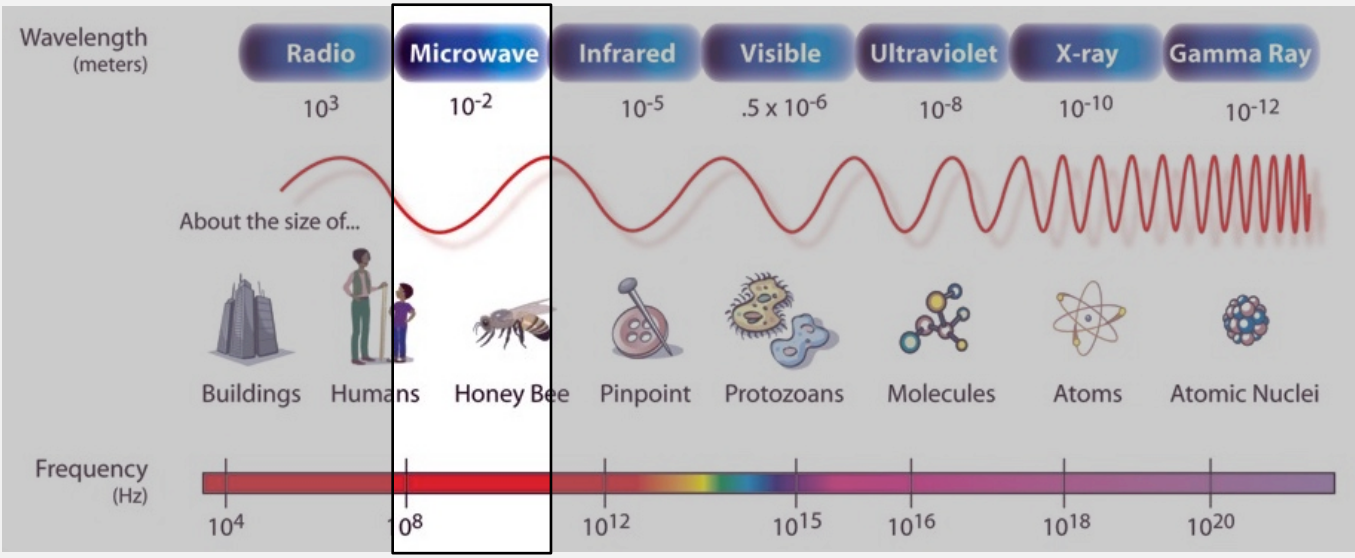
Passive and Active Remote Sensing

SMAP uses active and passive sensors to measure soil moisture



Microwave Remote Sensing

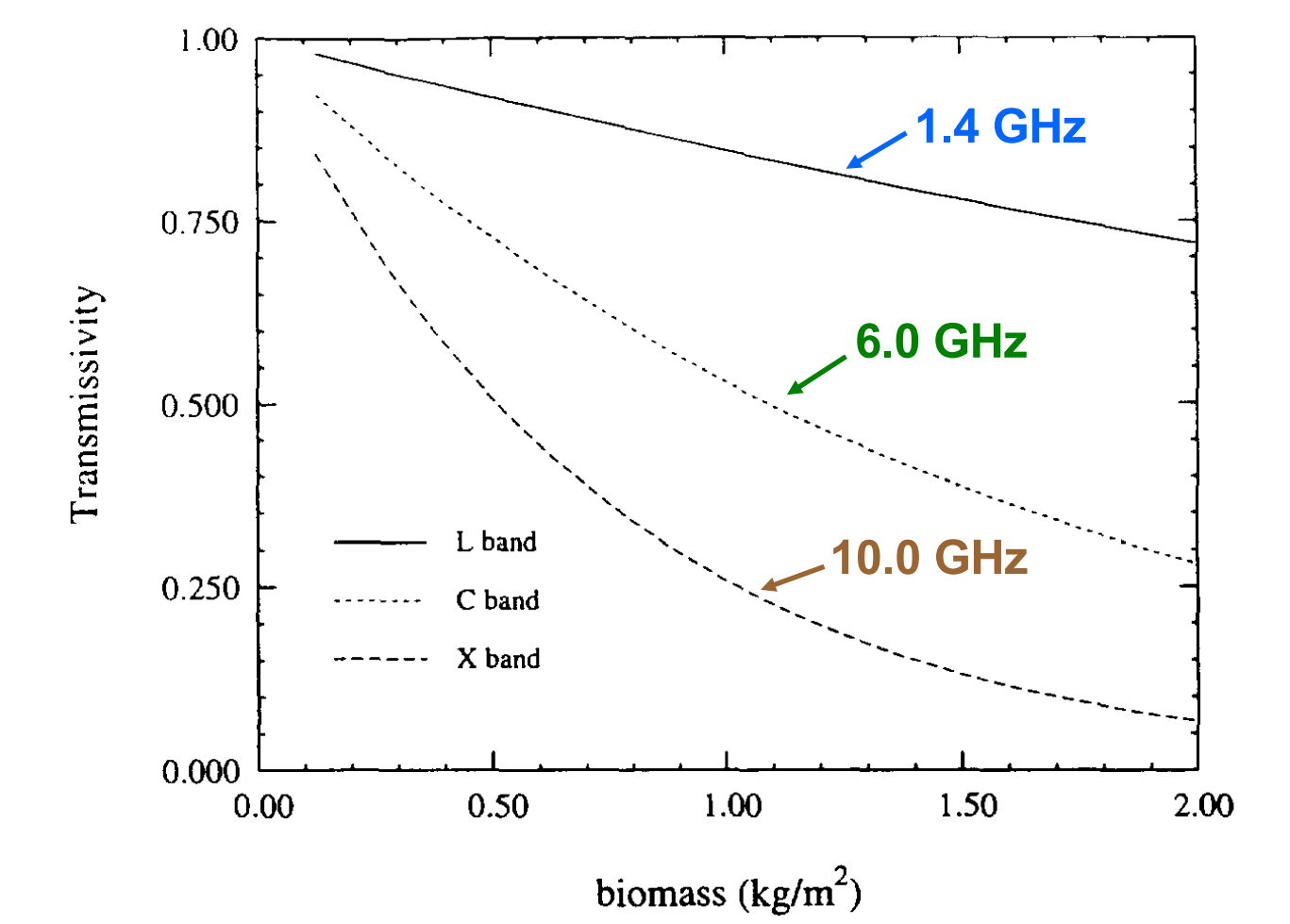
- With visible and infrared sensors, the soil is masked by clouds and vegetation
- Optical sensors operate by measuring scattered sunlight and are “daytime only”



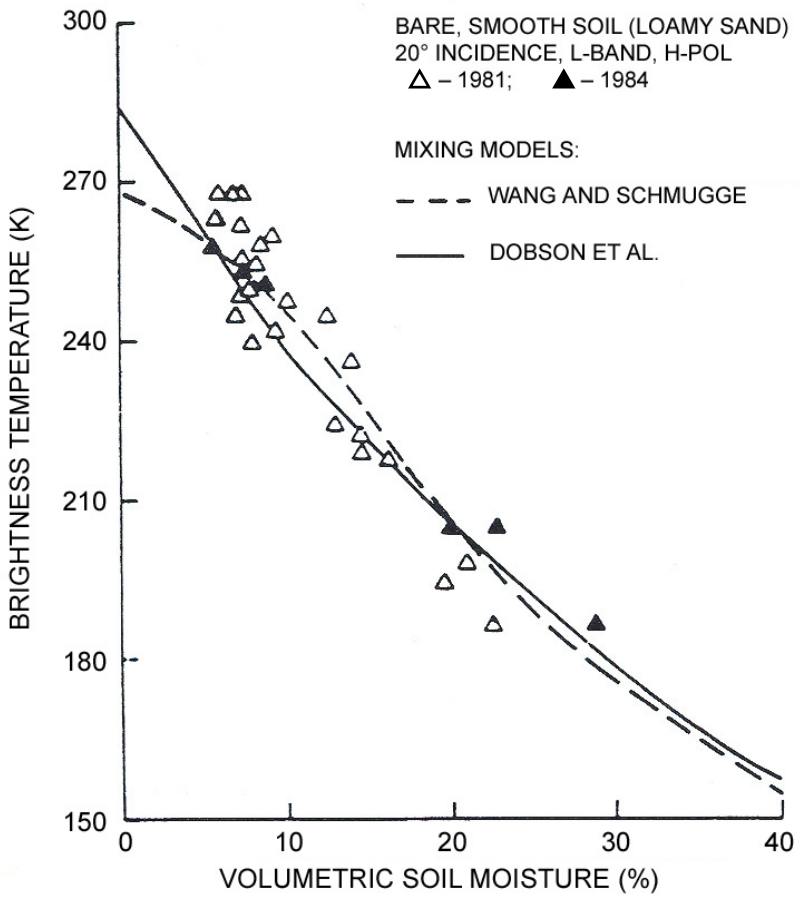
- Microwaves can
  - penetrate through clouds and vegetation
  - operate day and night
  - are highly sensitive to the water in the soil due to the change in the soil microwave dielectric properties

Advantages of L-Band

Vegetation attenuation increases as frequency increases



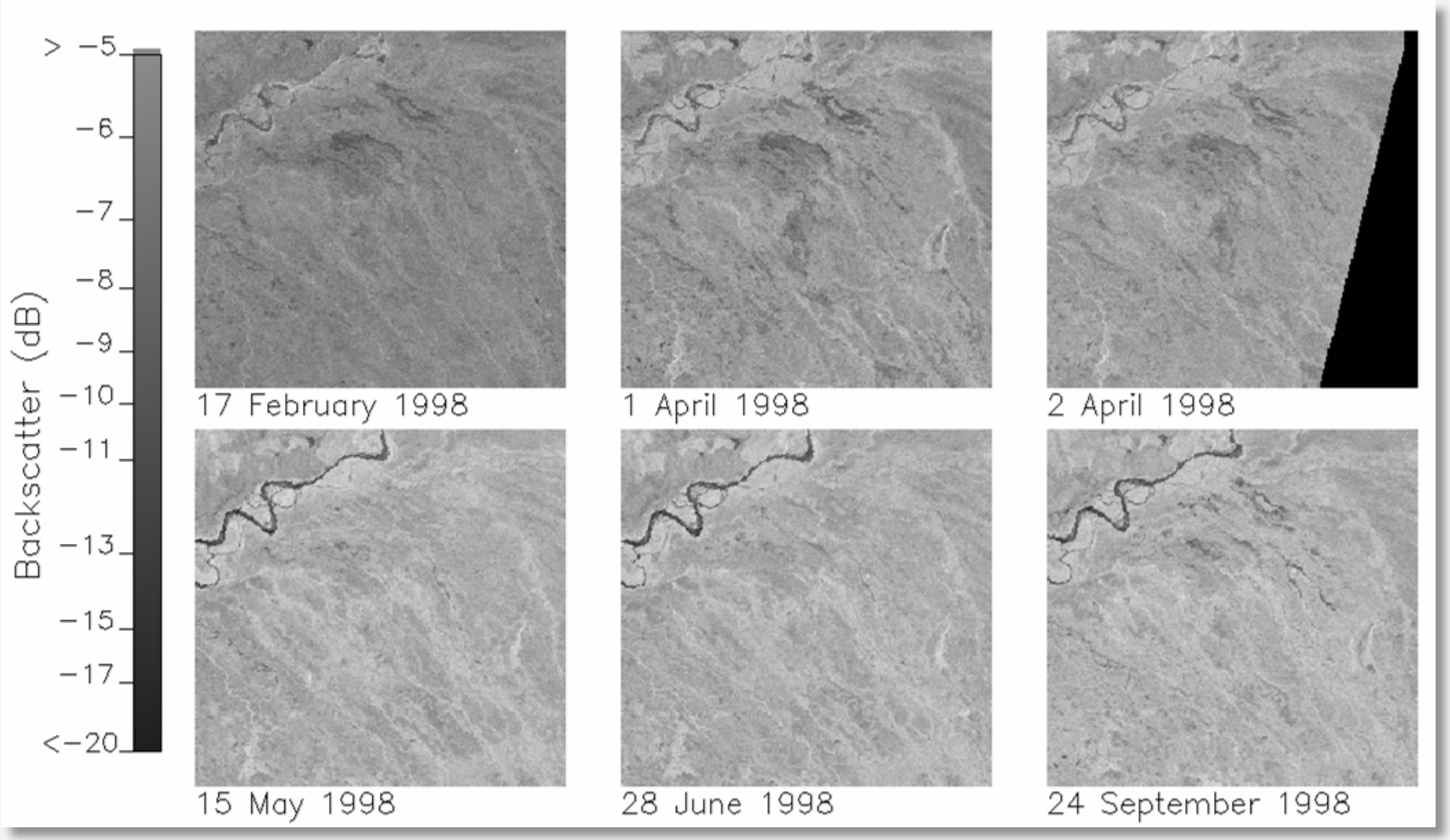
Relation Between Brightness Temperature and Soil Moisture



[Jackson and O'Neill, *IEEE TGARS, GE-25*, 1987.]

Land Surface Dielectric: Surface Freeze/Thaw State

- Land surface transitions from frozen to thawed
- This transition causes a large change in dielectric
- As a result, radar backscatter increases, on the order of 3 dB

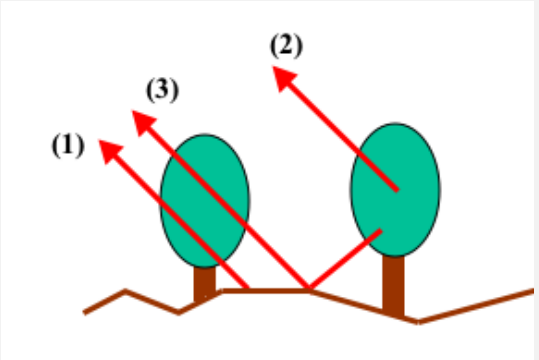


Measurement Approach

- p = H, V (radiometer)
- pq = VV, HH, HV (radar)
- Contributions from the: 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

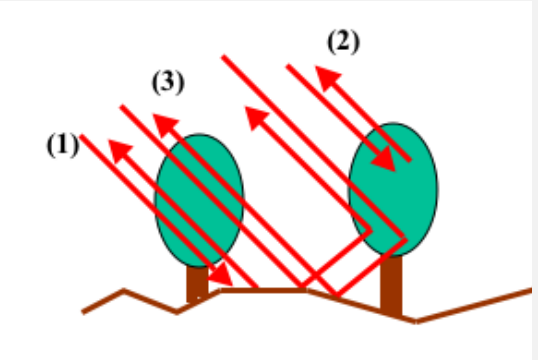
Emission

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



Backscatter

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

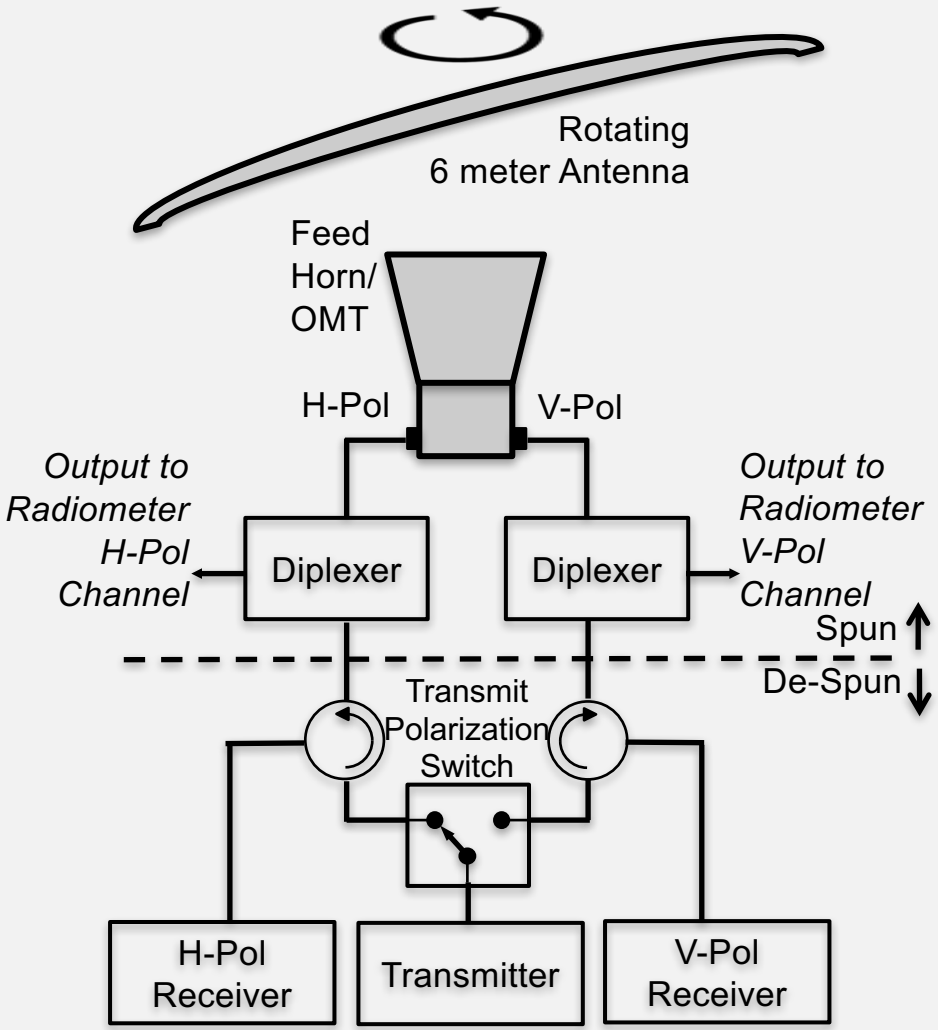


Ancillary Data Sources

- Ancillary data are used to estimate the key unknown parameters: surface temperature (≈ surface air temp. at 6 a.m.), vegetation opacity, surface roughness, and soil texture

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

Radar and Radiometer Operation



SMAP Data and Products

SMAP Data Product Summary

Data Product	Data Product Description	Gridding/ Resolution	Algorithm Source
L1A_Radiometer	Radiometer Data in Time-Order	-	Mission DA
L1B_TB	Radiometer T_B in Time-Order	(36×47 km)	Mission DA
L1C_TB	Radiometer T_B in Half-Orbits	36 km	Mission DA
L1C_TB_E	Radiometer T_B in Half-Orbits, Enhanced	9 km	Mission DA
L2_SM_P	Soil Moisture (Radiometer)	36 km	Mission DA
L2_SM_P_E	Soil Moisture (Radiometer, Enhanced)	9 km	Mission DA
L2_SM_SP	Soil Moisture (Sentinel Radar + Radiometer)	3 km	Mission DA
L3_FT_P	Freeze/Thaw State (Radiometer)	36 km	Mission DA
L3_FT_P_E	Freeze/Thaw State (Radiometer, Enhanced)	9 km	Mission DA
L3_SM_P	Soil Moisture (Radiometer)	36 km	Mission DA
L3_SM_P_E	Soil Moisture (Radiometer, Enhanced)	9 km	Mission DA
L4_SM	Soil Moisture (Surface and Root Zone)	9 km	Mission DA
L4_C	Carbon Net Ecosystem Exchange (NEE)	9 km	Mission DA

SMAP Data Product Delivery

Data Product	Description	Delivery of Additional Products to Data Center	Subsequent Data Delivery to NASA Data Center (nominal)	NASA Earth Science Data Center
Level 1	Standard Resolution Passive data	Complete	24 hours after receipt on the ground	NSIDC
Level 1	Enhanced Resolution Passive data	Dec 2016	24 hours after receipt on the ground	NSIDC
Level 2	Standard Resolution Soil Moisture (swaths)	Complete	48 hours after receipt on the ground	NSIDC
Level 2	Enhanced Resolution Soil Moisture (swaths)	Dec 2016	48 hours after receipt on the ground	NSIDC
Level 3	Standard Resolution Soil Moisture (global)	Complete	72 hours after receipt on the ground	NSIDC
Level 3	Enhanced Resolution Soil Moisture (global)	Dec 2016	72 hours after receipt on the ground	NSIDC
Level 3	Passive Freeze/Thaw (>45°N)	Dec 2016	72 hours after receipt on the ground	NSIDC

Data Product Design

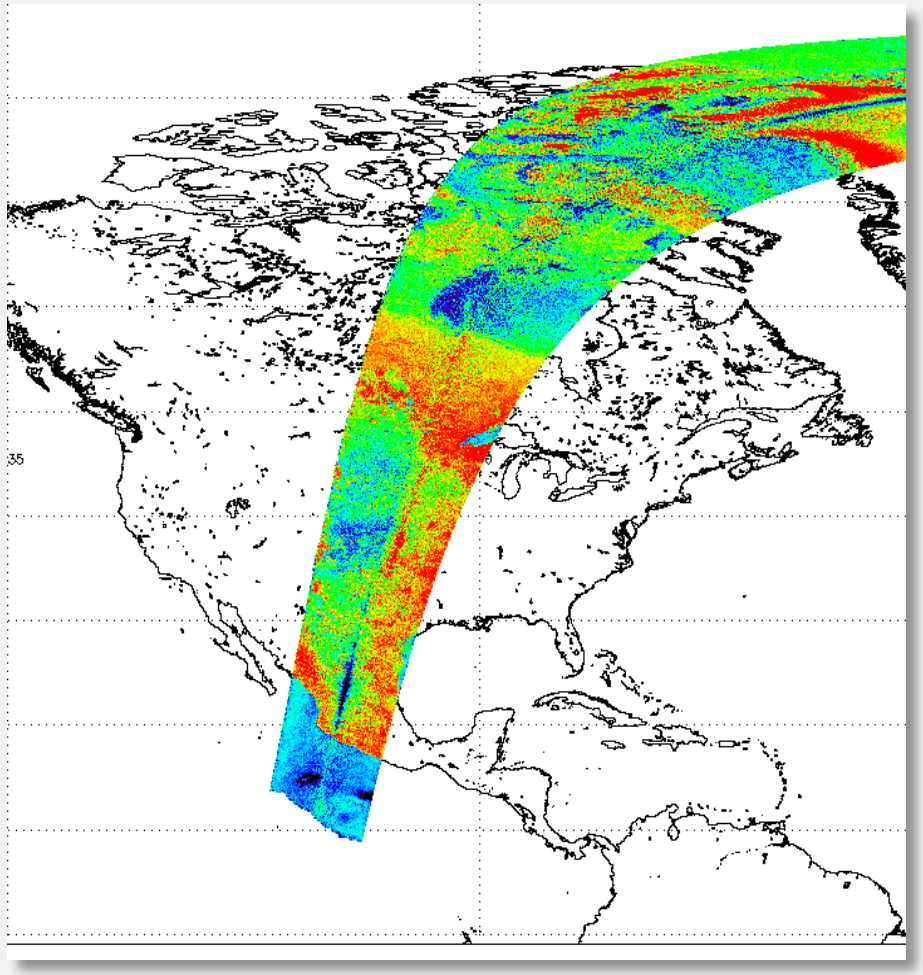
- **All products are in HDF5 format**
  - Each SMAP HDF5 file contains the primary data parameters
    - e.g., soil moisture, freeze/thaw, sensor data
  - All data is used in the production of those primary parameters
  - These files also include metadata, geolocation information, quality flags, etc.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

Data Product Design

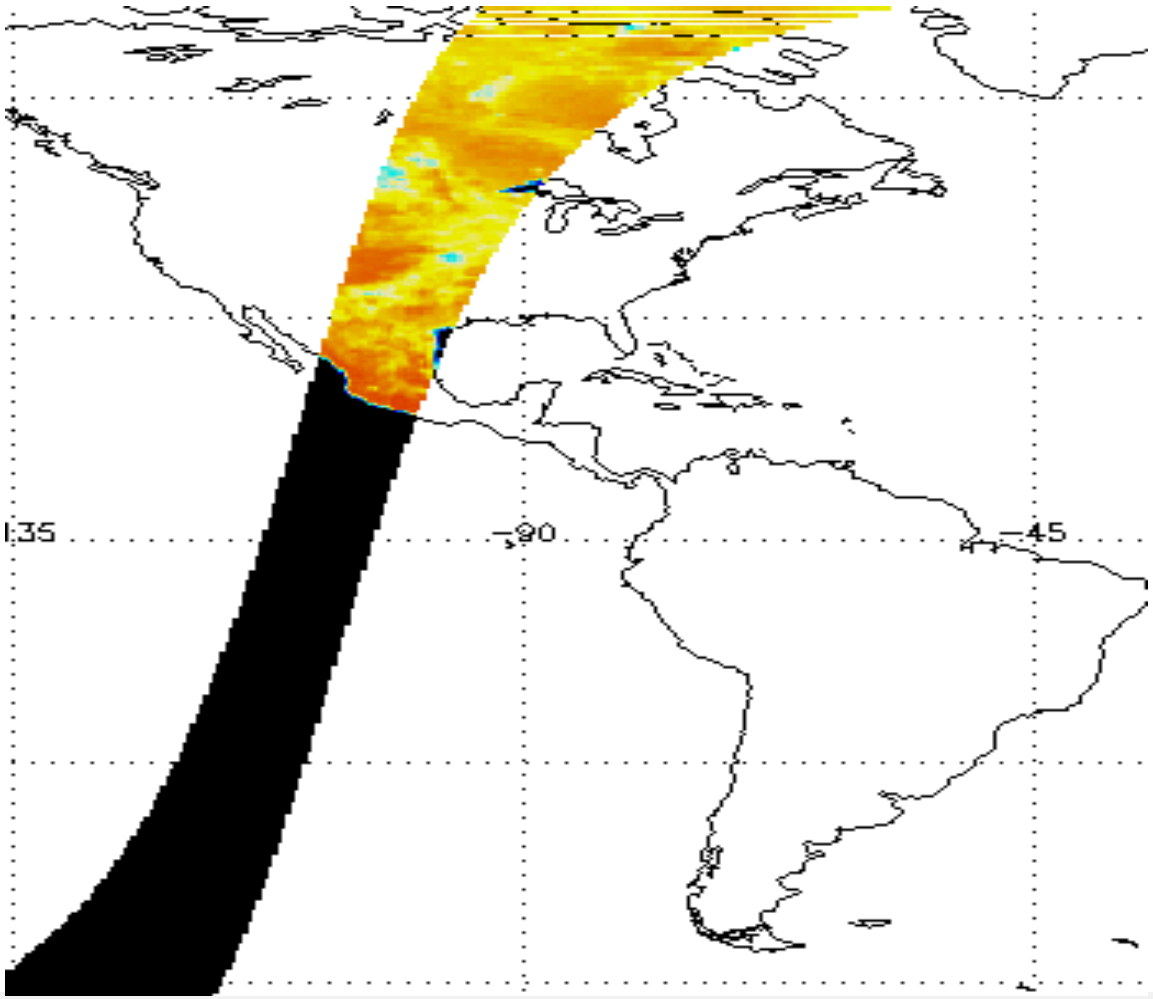
- **Values**
  - Radiometer data (brightness temperature) is in Kelvin
  - Radar data is in σ^0
  - Soil moisture is a volumetric measurement expressed as cm^3/cm^3
  - Freeze/thaw is a binary measurement, either frozen or thawed
  - Net ecosystem exchange is in grams of carbon per square meter per day

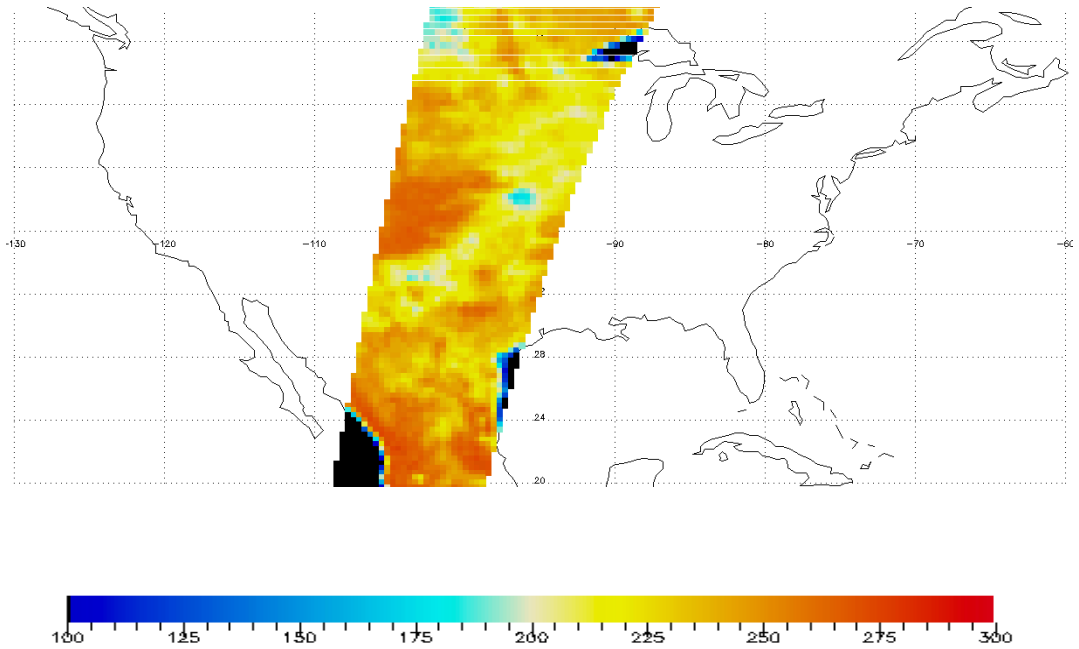
Radar Level 1C Data

- Radar data available from Apr – Jul 7, 2015
- Coverage: restricted to land and coastal water
- Resolution: gridded to 3km spatial resolution
- Earth located and calibrated h-pol, v-pol, and cross-pol backscatter measurements

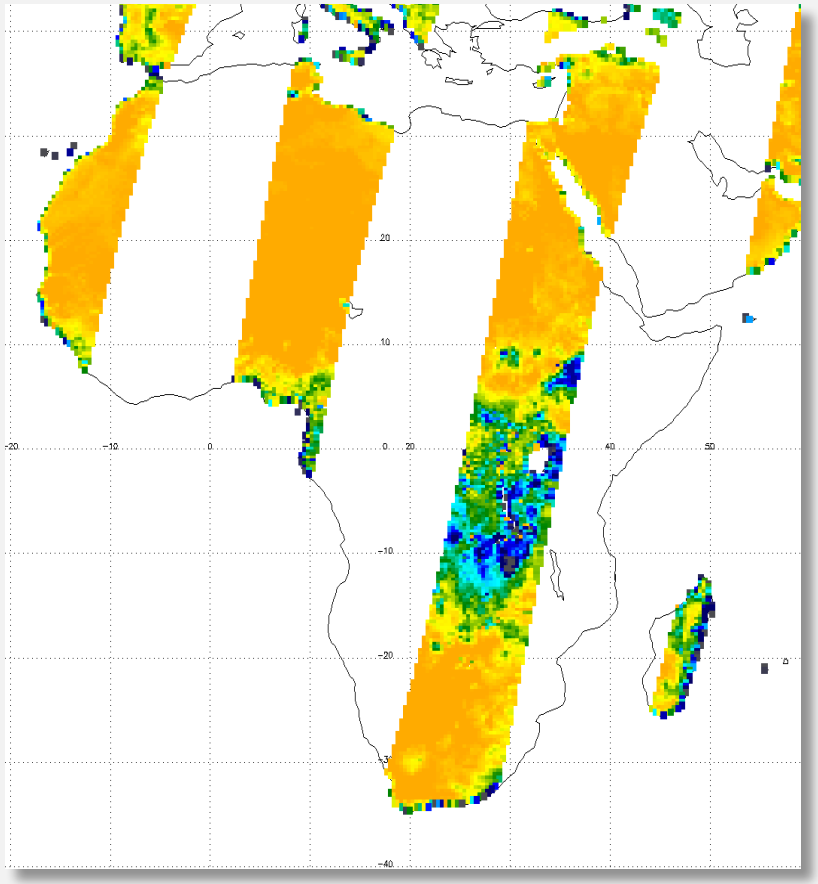


Radiometer Level 1C Data





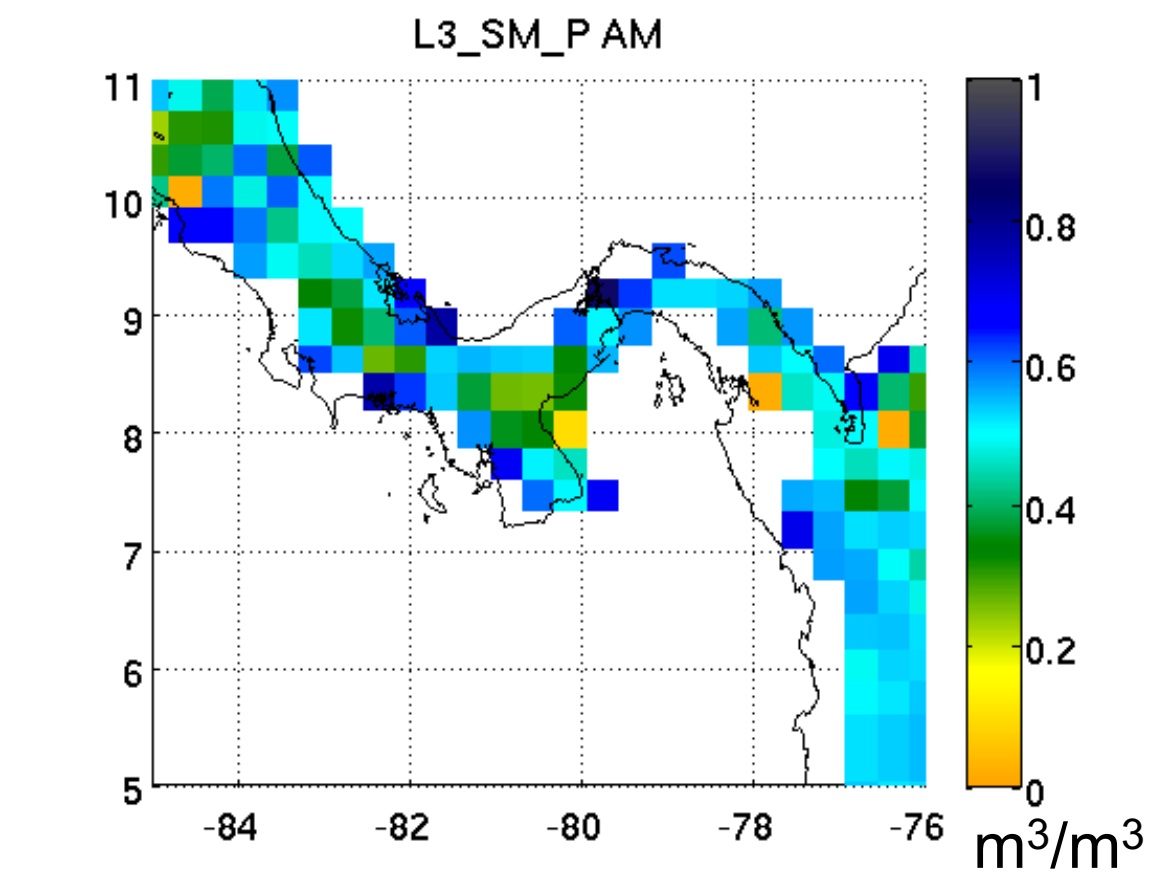
Radiometer Level 3: 36 km Soil Moisture Product

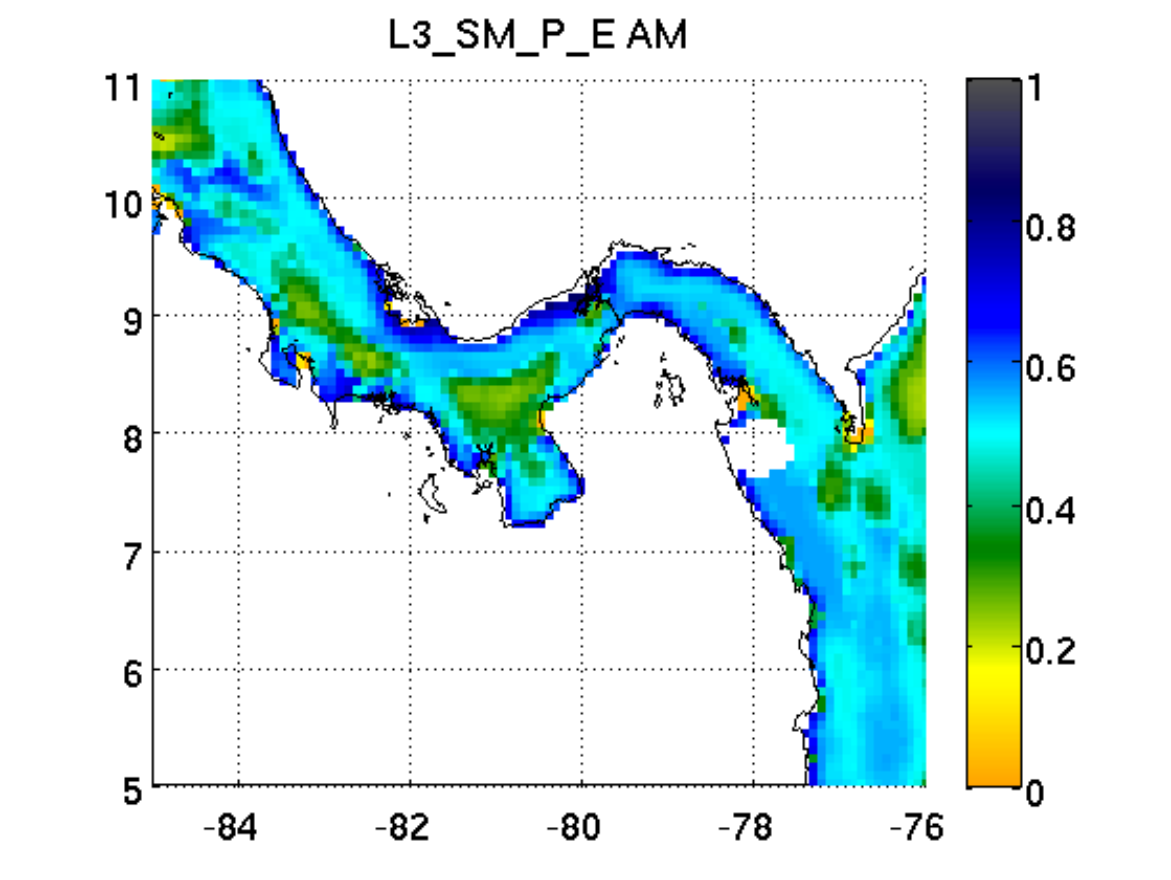


- Composite of all radiometer level 2 half-orbit products
- Algorithm selects measurements acquired closest to 6 a.m. local solar time
- 36 km cylindrical EASE grid using a two-dimensional array
- Soil moisture over land with 4% accuracy for low-to-moderately vegetated areas
- Low to Moderate Vegetation: vegetation water content ≤ 5 km/m^2
- Based exclusively on a.m. data

Radiometer Level 3_SM_P_E

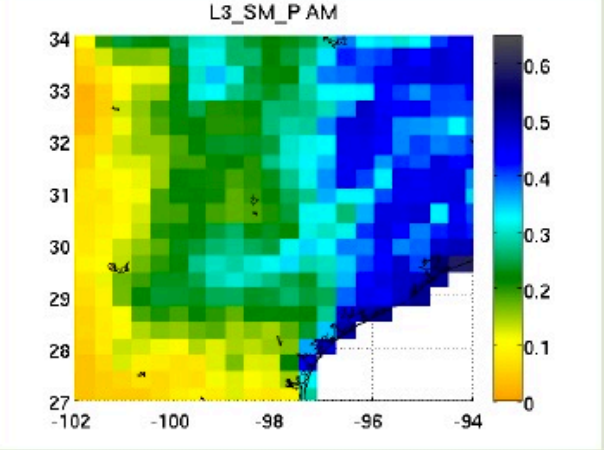
August 25-27, 2015

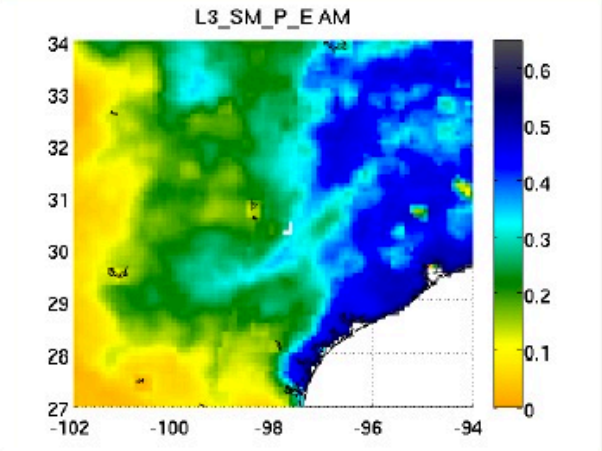




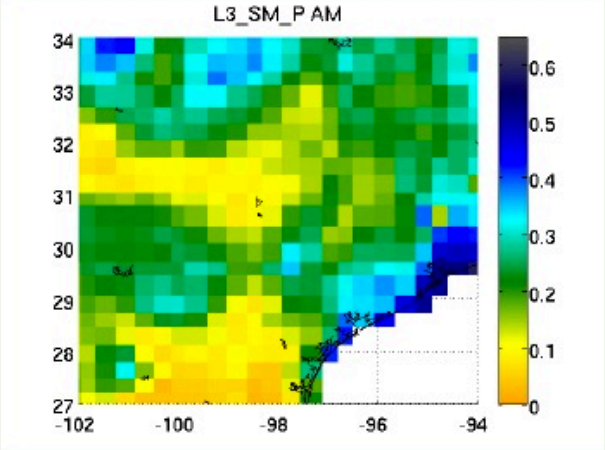
Radiometer Level 3_SM_P_E - Texas

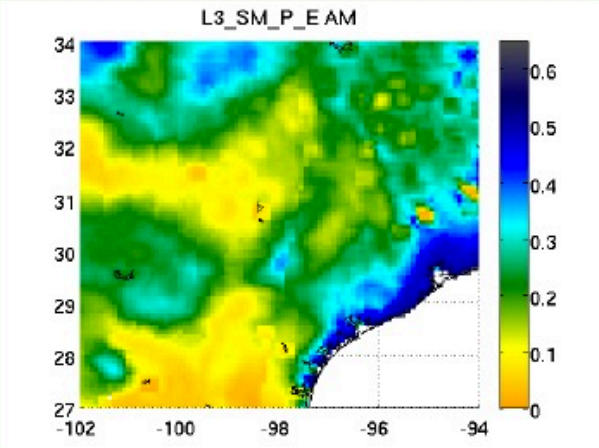
April 25-27, 2015





June 14 & 16, 2015





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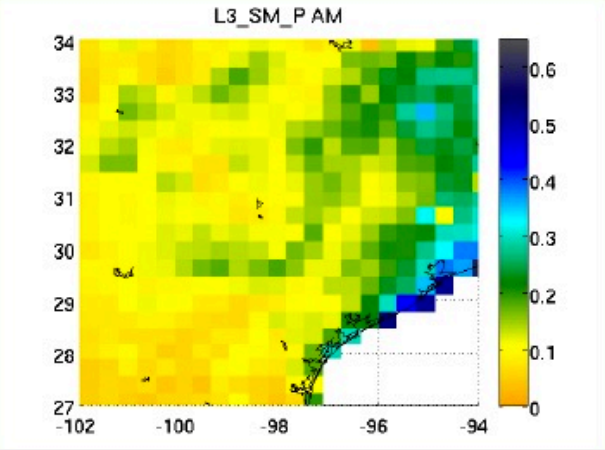
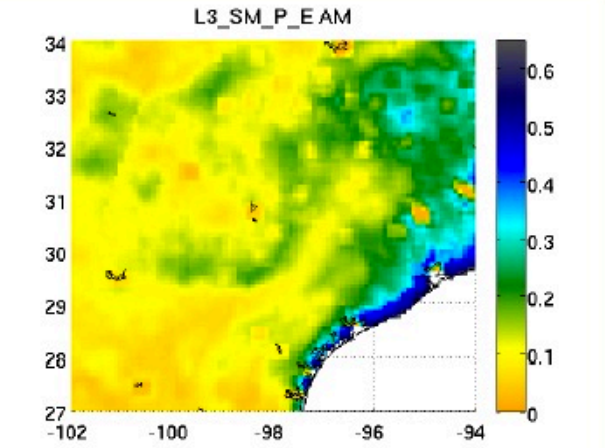
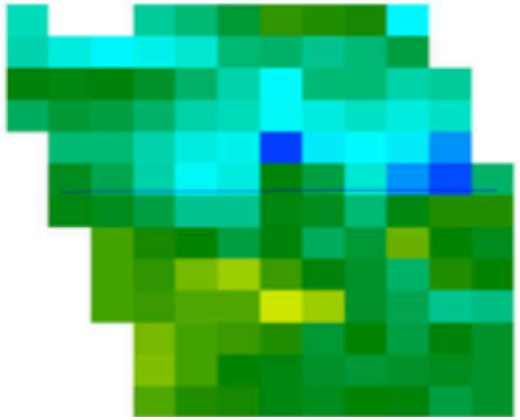




Enhanced Active-Passive Soil Moisture Product Using Sentinel-1

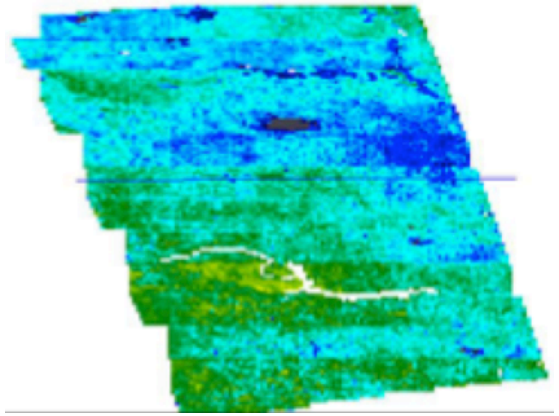
SMAP-Only Passive Product

Retrieved Soil Moisture: 36 km



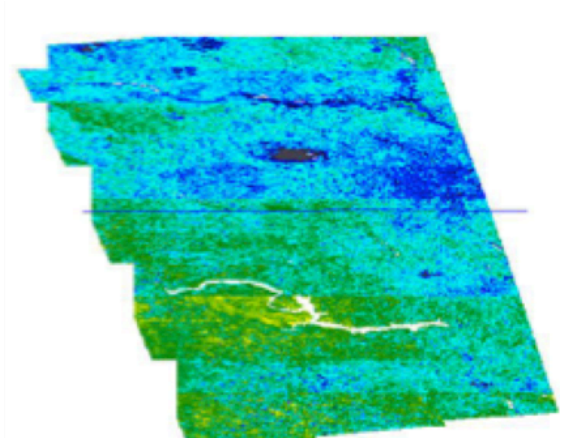
SMAP-Sentinel Active-Passive Product

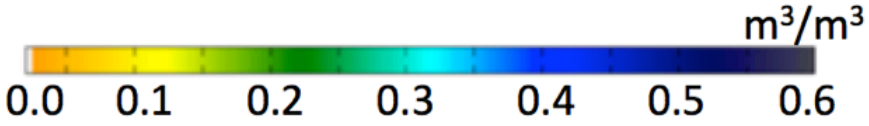
Retrieved Soil Moisture: 3 km



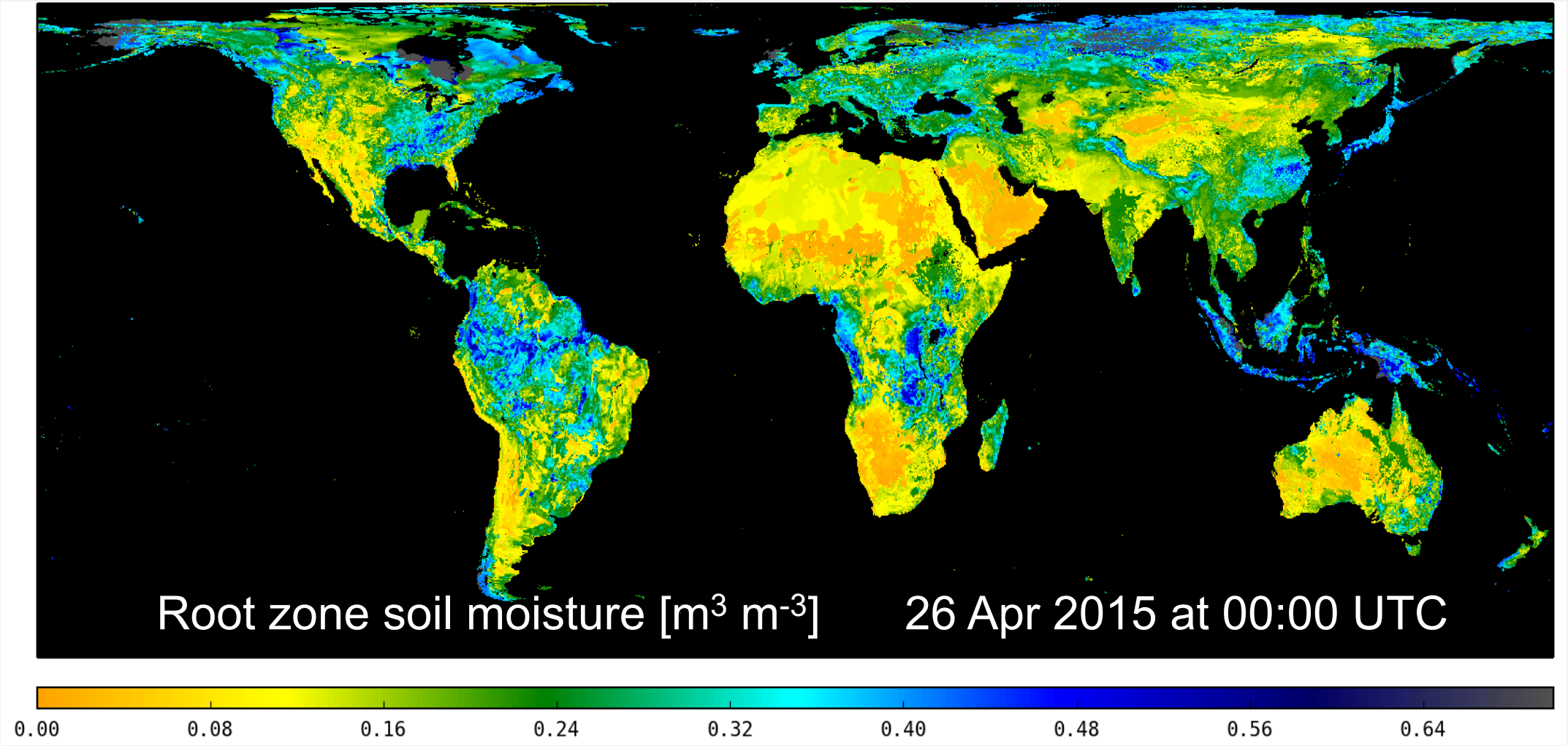
SMAP-Sentinel Active-Passive Product

Retrieved Soil Moisture: 1 km

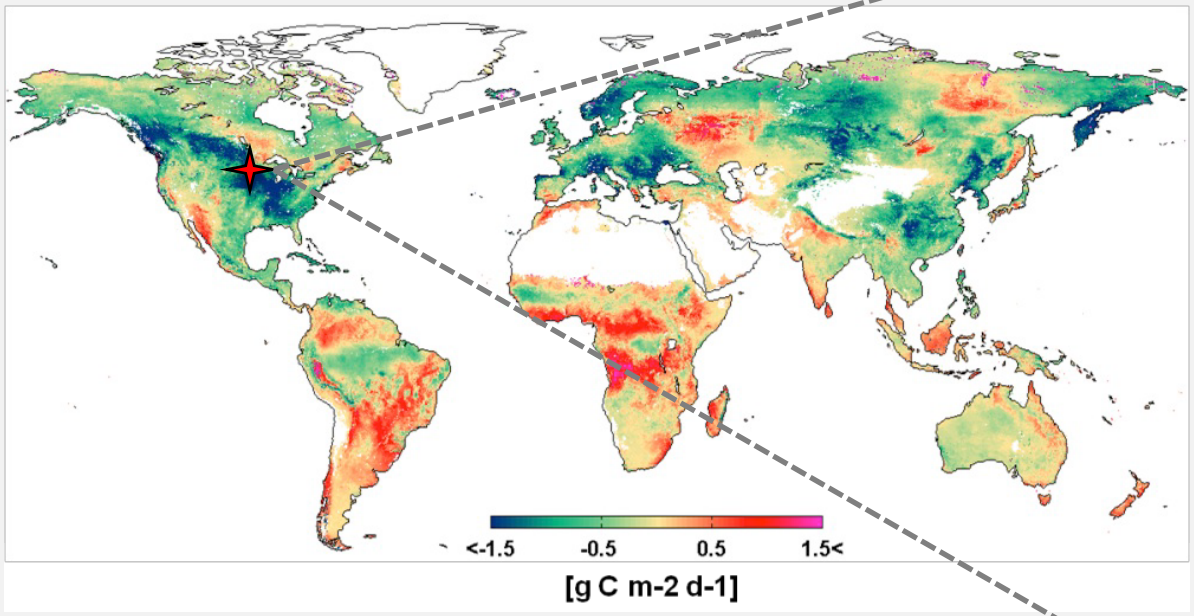


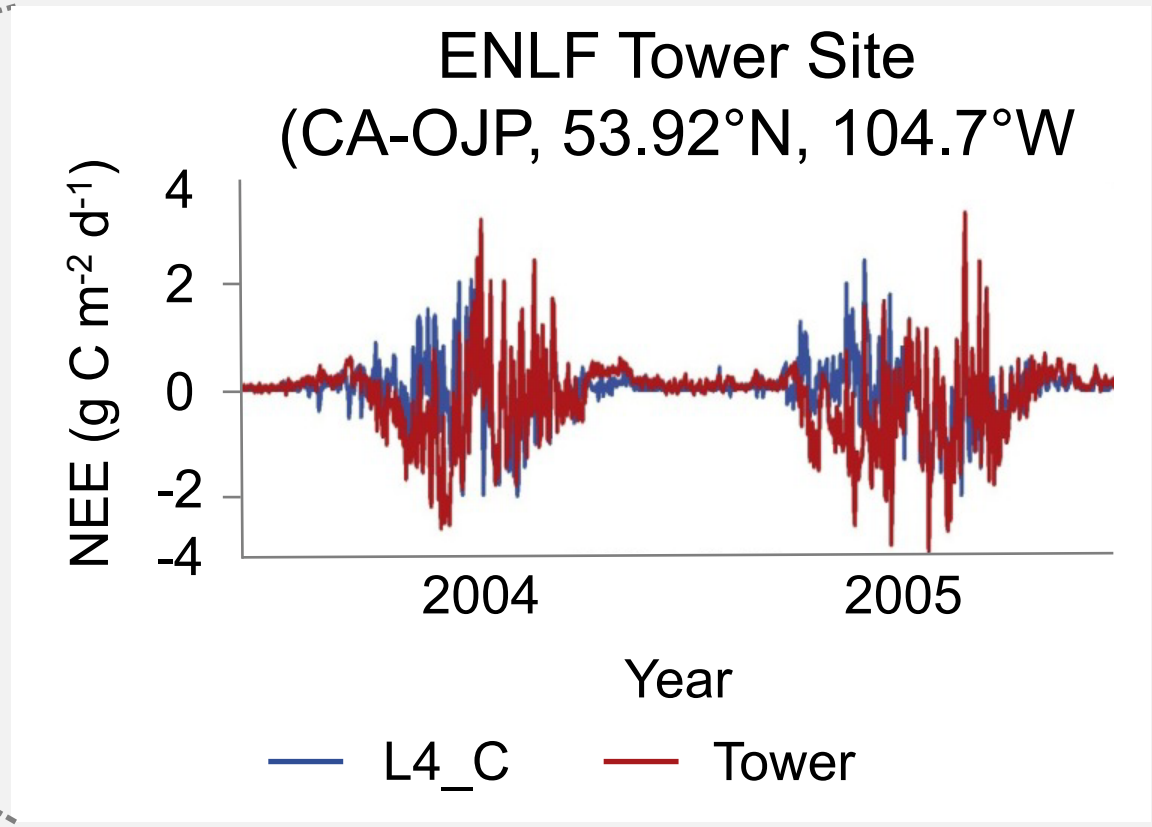


Level 4 Root Zone Soil Moisture Product



Level 4 Net Ecosystem Exchange Product

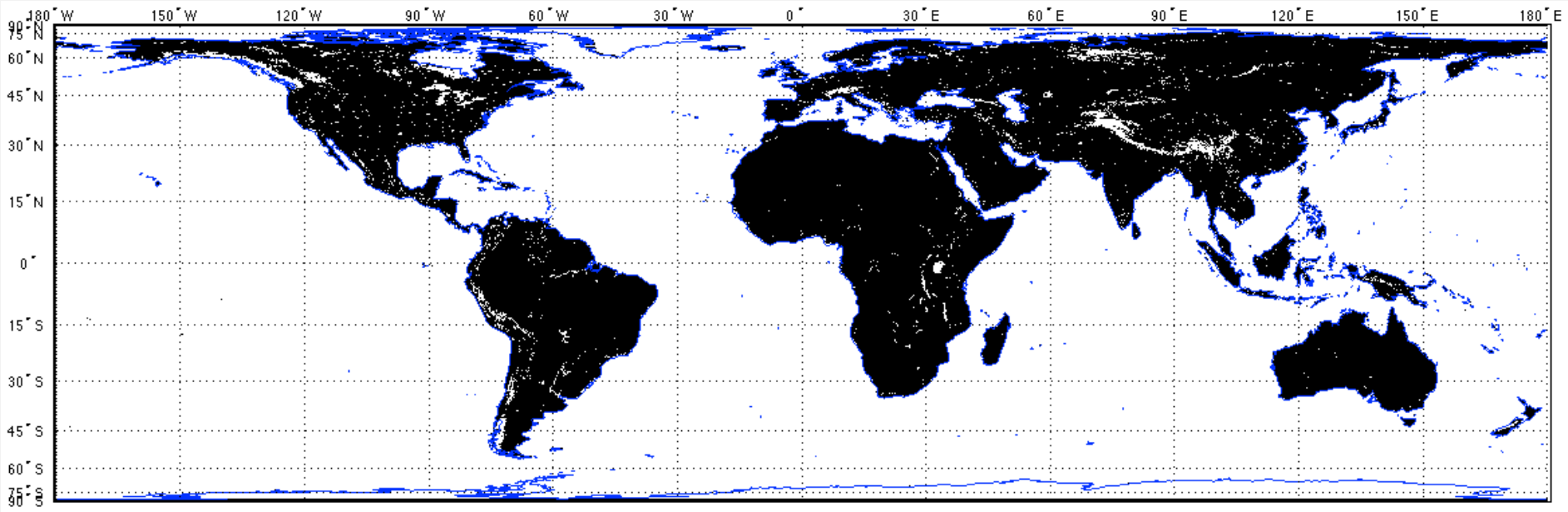




Level 4 Net Ecosystem Exchange Product

- Daily global maps of net ecosystem CO2 exchange (NEE) at 9 km resolution with 14-day latency
- Quantifies net carbon flux in boreal landscapes
- Reduces uncertainty
- Applies a soil decomposition algorithm driven by SMAP L4_SM and Gross Primary Production inputs to compute NEE
- Accuracy commensurate with tower-based CO2 observations.
- RMSE ≤ 30 g C m-2 yr-1 or 1.6 g C m-2 d-1

Soil Moisture Retrieval Map



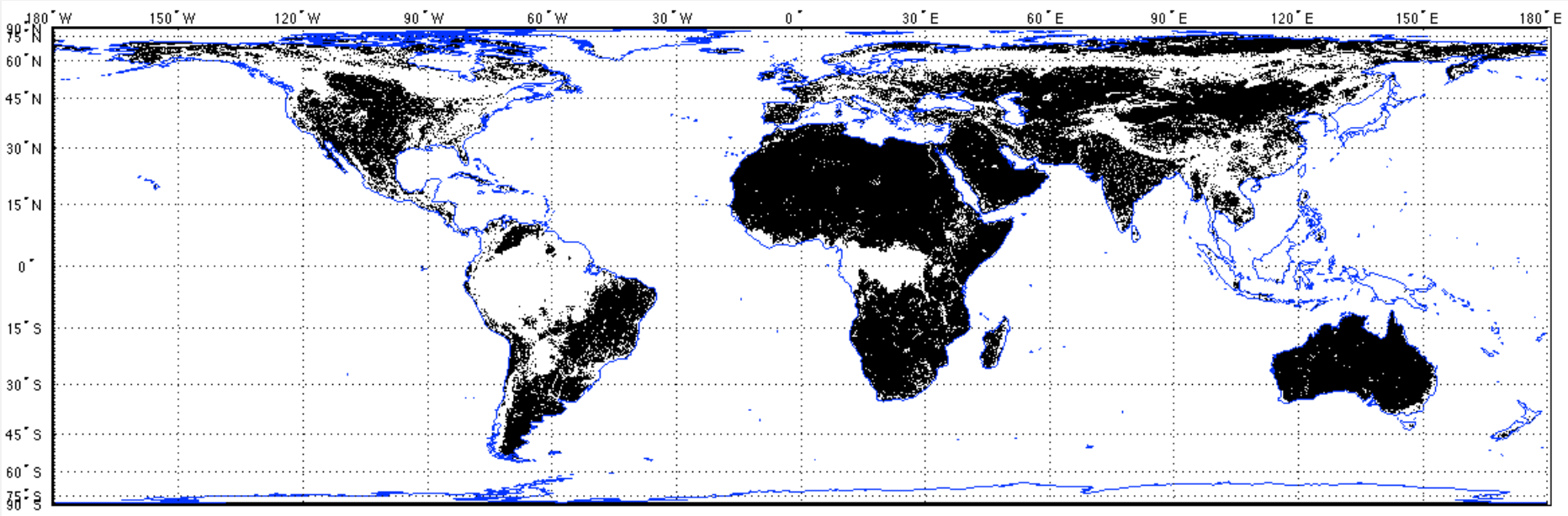
Retrievable Mask (Black Colored Pixels) Prepared with the Following Specifications:

a) Urban Fraction < 1

b) Water Fraction < 0.5

c) M Slope Standard Deviation < 5 deg

Soil Moisture Expected Accuracy



Retrieval expected quality mask with the following specifications:

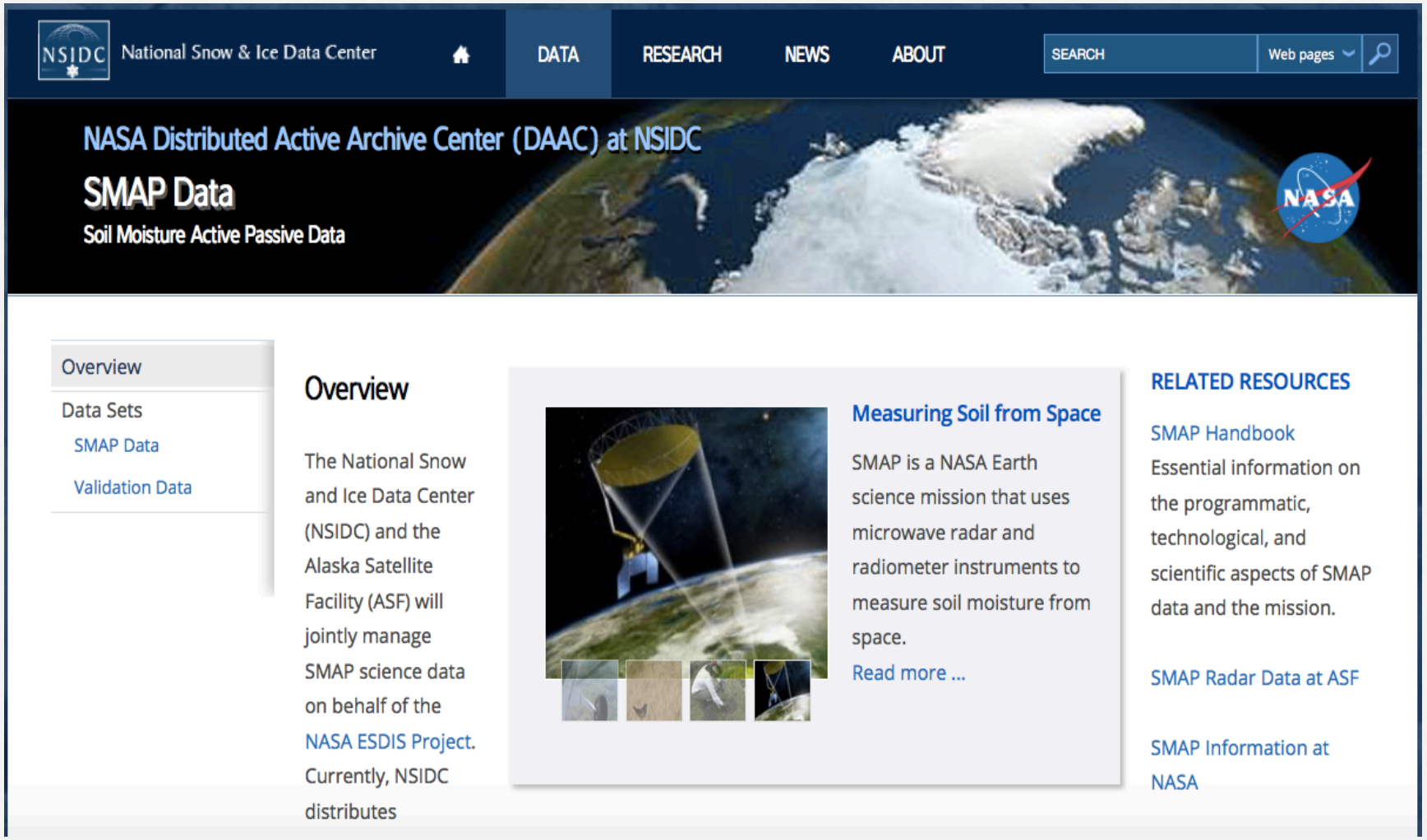
a) Vegetation water content ≤ 5 kg/m^2

b) Urban fraction ≤ 0.25

c) Water fraction ≤ 0.1; d) DEM slope standard deviation ≤ 3 deg

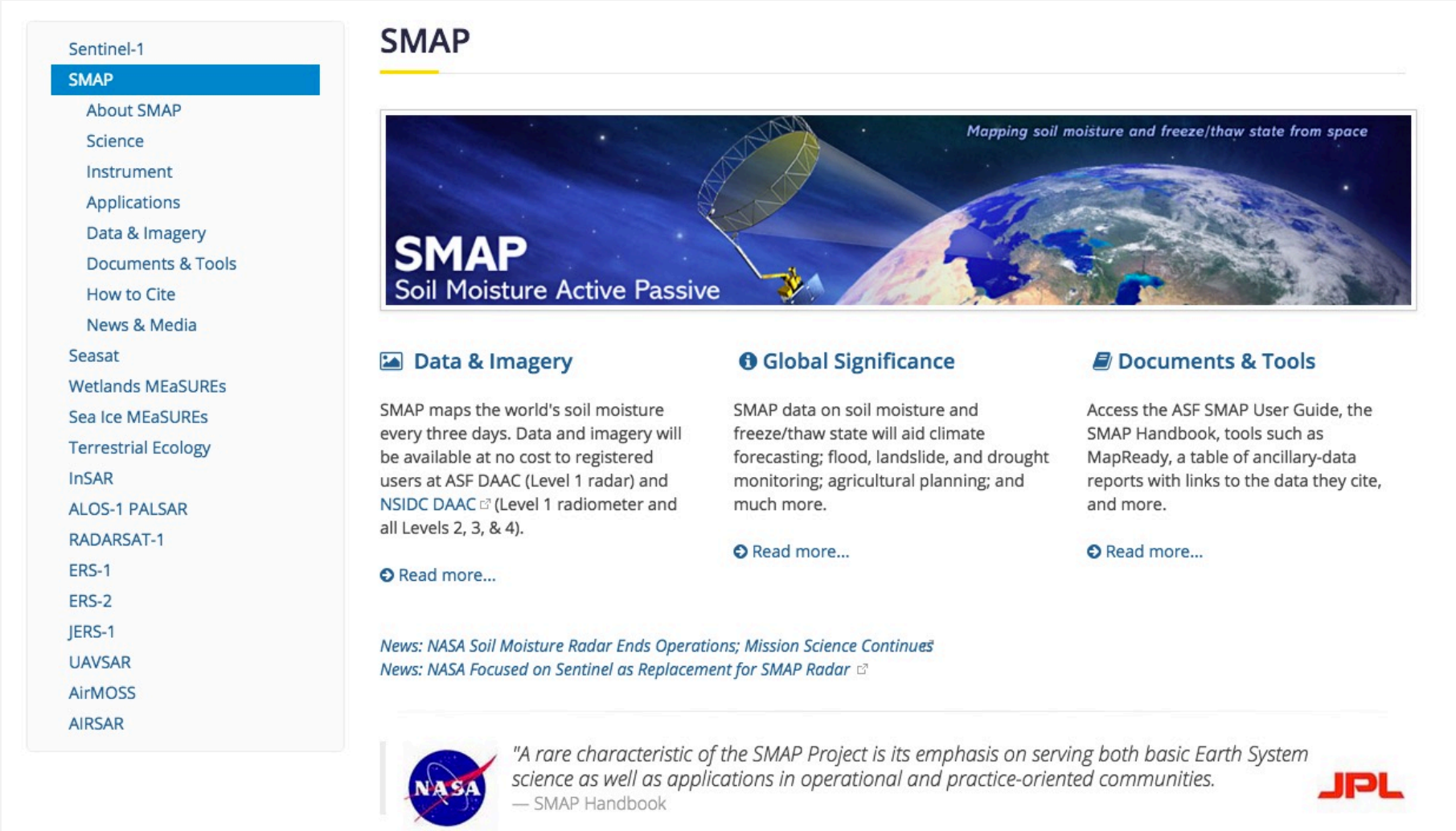
Access to SMAP Radiometer Data and All Products: NSIDC

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

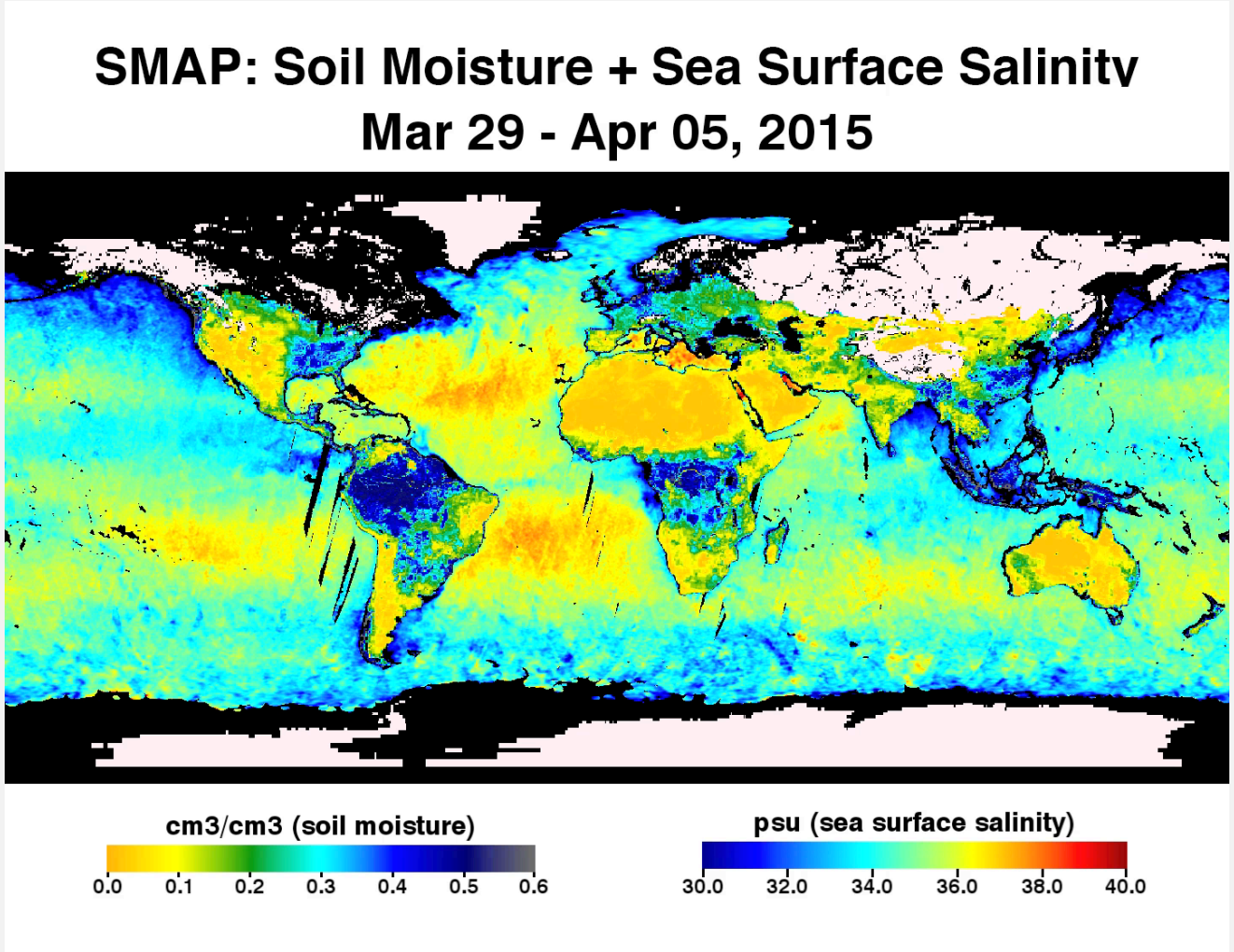


Access to SMAP Radar Data: ASF

https://www.asf.alaska.edu/smap



Global Soil Moisture Animation

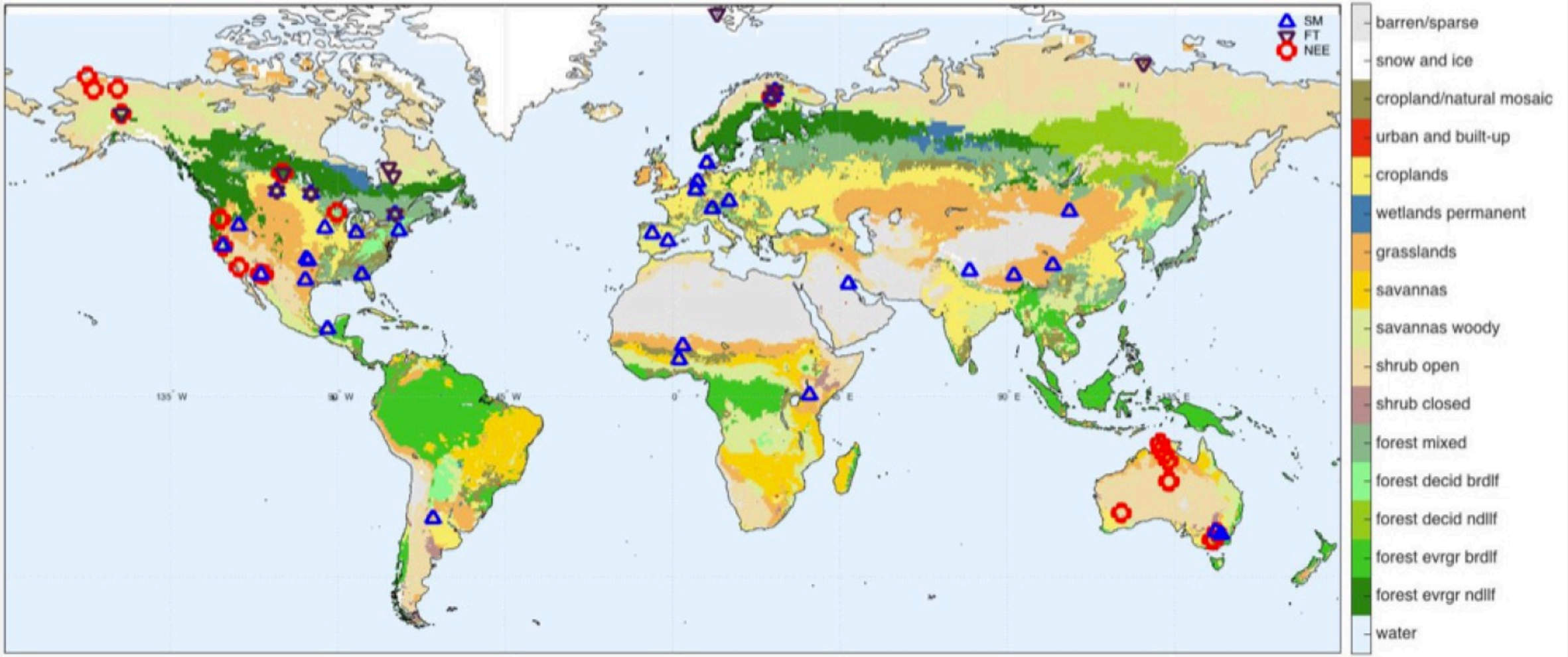


SMAP Calibration and Validation

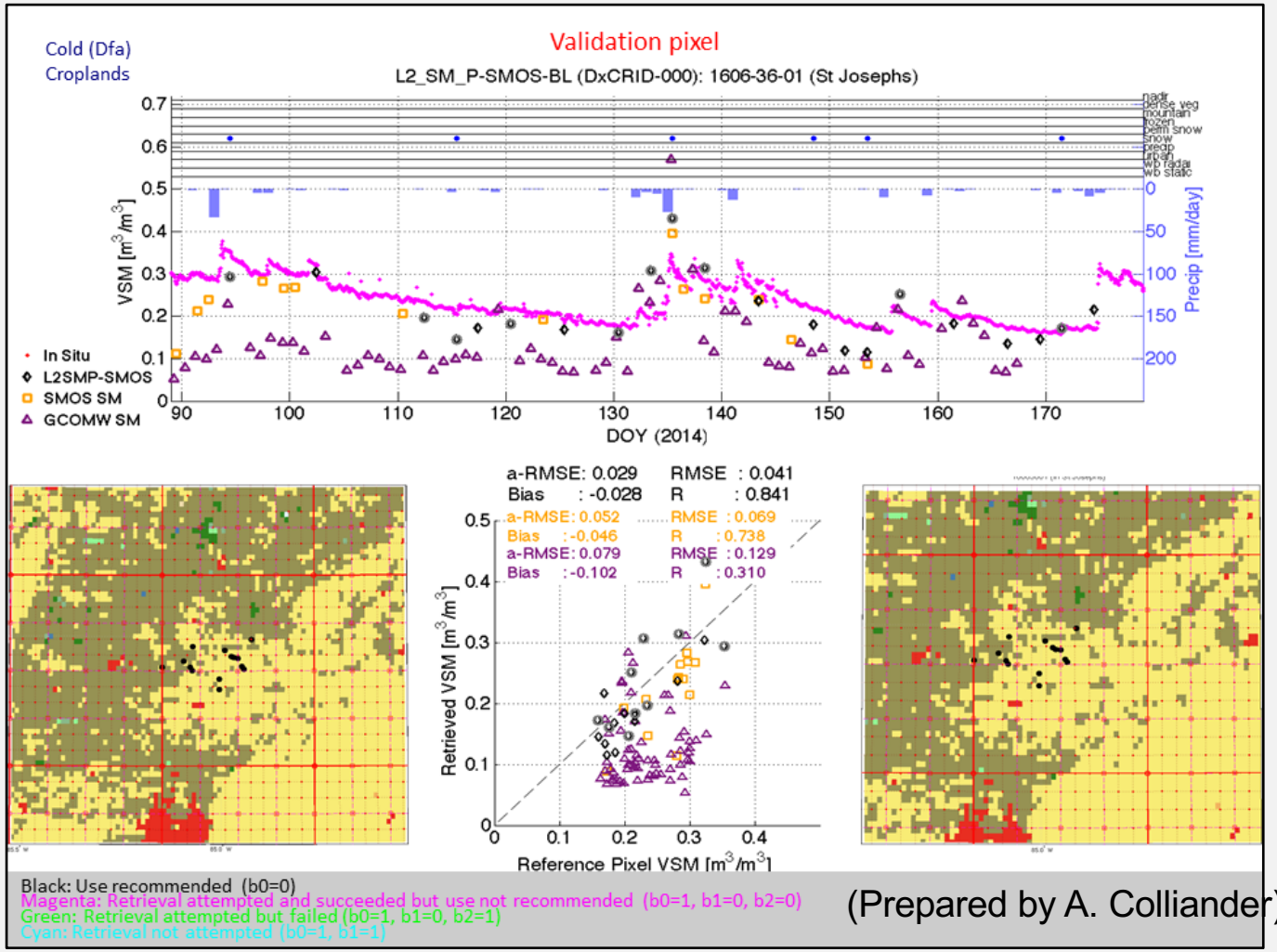
Cal/Val Methodology

Methodology	Role	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 has been 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 tools 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 in 2015

SMAP Calibration and Validation Sites



Comparison Between SMAP and In Situ Soil Moisture



(Prepared by A. Colliander)

Questions?