WELCOME TO
NASA APPLIED REMOTE SENSING TRAINING (ARSET) WEBINAR SERIES

Water Resources Management Using NASA Earth Science Data

COURSE DATES: EVERY Tuesday, October 13, 20, 27; November 3, 10
TIME: 10 TO 11 AM AND 2 TO 3 PM Eastern US Time
(UTC-4 Hours for October and UTC-5 Hours for November)

Applied Remote Sensing Training

Webinar Outline

Week 1

NASA Remote Sensing Data and Applications for Water Resources Management

Week 2

Precipitation and Soil Moisture Data Access and Applications

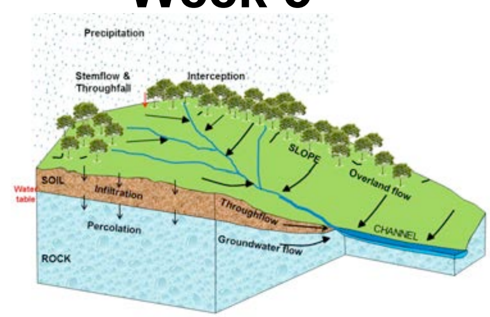
Week 3

Run off, Streamfow and Reservoir Level Data Access and Applications

Week 4

Evapotranspiration and Ground Water Data Access and Applications

Week 5



Land Data Assimilation for Water Budget Estimation and Case Studies with GIS Applications

Training Team

Instructors:

- Amita Mehta (ARSET): amita.v.mehta@nasa.gov
- Cynthia Schmidt (ARSET): cynthia.l.schmidt@nasa.gov (Week-4)
- Brock Blevins (ARSET): bblevins37@gmail.com

Guest Speakers:

- **Eni Njoku(NASA-JPL): eni.g.njoku@jpl.nasa.gov (Week-2)**
- Brian Thomas (NASA-JPL): Brian.F.Thomas@jpl.nasa.gov (Week-4)
- Sujay Kumar (NASA-GSFC): sujay.v.kumar@nasa.gov (Week-5)

Spanish Translation:

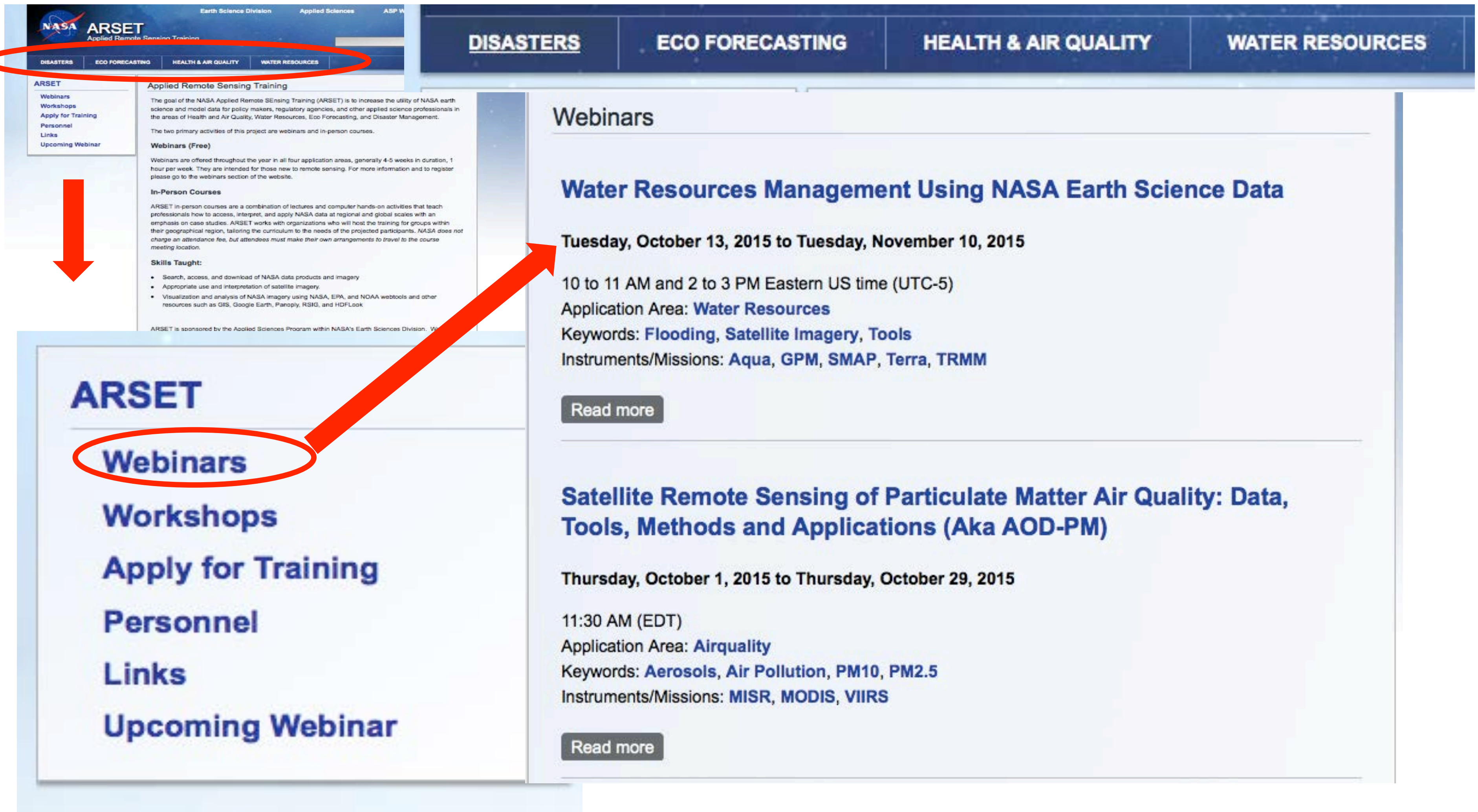
- David Barbato (ARSET): barbato1@umbc.edu

General Inquiries about ARSET:

- Brock Blevins (ARSET) bblevins37@gmail.com
- Ana Prados (ARSET) aprados@umbc.edu

Access to ARSET Trainings

http://arset.gsfc.nasa.gov



Review of Week-1

NASA Satellites and Models for Water Resources Monitoring

Models

GLDAS : Global Land Data Assimilation System

NLDAS : North American Land Data Assimilation System

TRMM: Tropical Rainfall Measuring Mission
GRACE: Gravity Recovery and Climate Experiment
GPM: Global Precipitation Measurements
SMAP: Soil Moisture Active Passive

Landsat (07/1972-present)

TRMM (11/1997-04/2015)

GPM (2/27/2014-present)

Terra (12/1999-present)

Aqua (5/2002-present)

SMAP (1/31/2015-present)

GRACE (3/2002-present)

Jason-1&2 (12/2001-present)

NASA Satellites and Earth Systems Models

Provide global scale water cycle quantities on hourly, daily, seasonal, and multi-year time scales useful for water resources management

- Rain
- Temperature
- Humidity
- Winds
- Soil Moisture
- Snow/Ice
- Clouds
- Terrain
- Ground Water
- Vegetation Index
- Evapotranspiration
- Runoff

Water Resources Management:

Rain Amount, Snowmelt Amount
Runoff
Soil Moisture
Evapotranspiration
Ground Water

Hydrology Modeling Inputs:

Rain Amount, Snowmelt Amount
Surface Temperature, Wind, Humidity
Terrain, Land Cover
Solar and Terrestrial Radiation at the Surface

All other quantities are available from satellite observations as well as from models
Quantities in green are derived from satellite observations
Quantities in red are from atmosphere-land models in which satellite observations are assimilated

Agenda for Week-2

Overview of Precipitation and Soil Moisture Data

- Precipitation Data Products from GPM and TRMM
- Snow Cover Data from Terra and Aqua MODIS
- Overview of Soil Moisture Data from SMAP

Precipitation Data Products from GPM and TRMM

For detailed information about GPM please review the following ARSET webinar

http://arset.gsfc.nasa.gov/disasters/webinars/global-precipitation

NASA Remote Sensing Data for Rain and Snow

Satellite	Sensors	Quantities
GPM 2/2014-Present	Dual Frequency Precipitation Radar (DPR) GPM Microwave Imager (GMI)	Rain Rate, Vertical Rain Rate Profile, Accumulated Rain
TRMM 11/1997-4/2015	Precipitation Radar (PR) TRMM Microwave Imager (TMI) Visible Infrared Scanner (VIRS)	Rain Rate, Vertical Rain Rate Profile, Accumulated Rain
Terra and Aqua 12/1999-Present 5/2002-Present	MODerate Resolution Imaging Spectroradiometer (MODIS)	Snow Cover, Vegetation Index, Leaf Area Index, Land Cover

Rain Rate is measured in mm/hour
Accumulated Rain is measured in mm (over a day or a month)
Snow Cover is the fractional area covered by snow

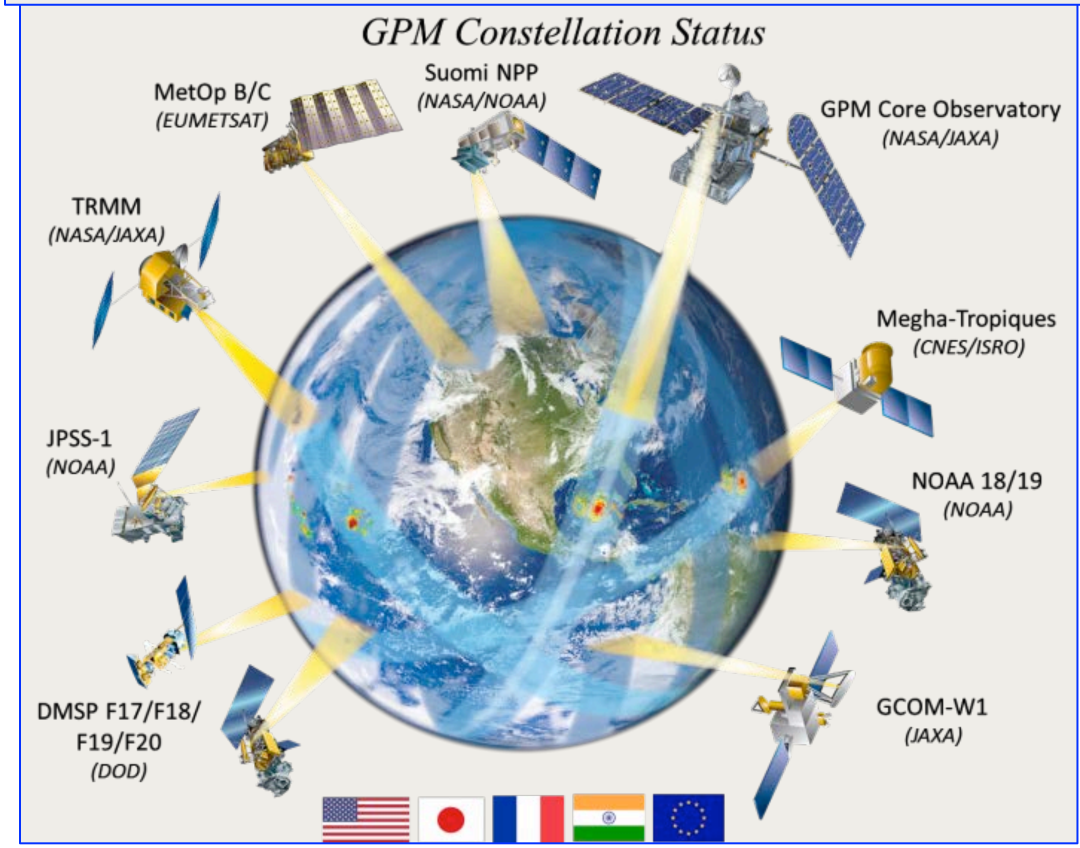
GPM
Global Precipitation Measurement Mission

http://pmm.nasa.gov/GPM

- An international network of satellites with a GPM Core satellite designed to provide global observations of rain and snow

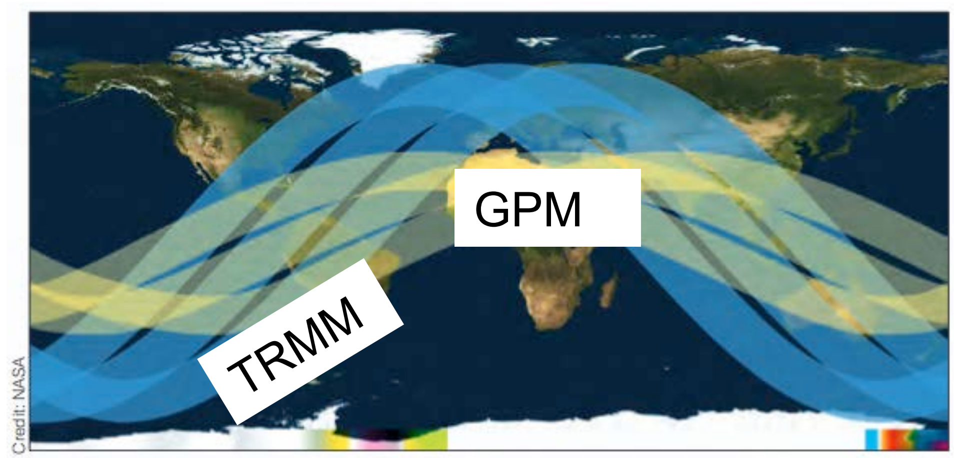
- Initiated by NASA and the JAXA as a successor to TRMM

GPM Core satellite was launched on February 27th, 2014



GPM Orbits and Spatial Coverage

- GPM is in non-polar, low inclination orbit with 16 orbits per day
- GPM observes global regions between 65° S to 65°N latitudes
- TRMM was in non-polar, low inclination orbit with 16 orbits per day **but provides observation** between 35° S to 35°N latitudes



the area covered by three TRMM orbits [yellow] versus orbits of the GPM Core Observatory [blue]

GPM measurements span middle and high latitudes

TRMM and GPM Measurements

http://pmm.nasa.gov/

TRMM Microwave Imager (TMI)
(Passive Sensor)

Frequencies: 10.7, 19.4, 21.3, 37, 85.5 GH
Swath: 760 km (870* km)
Resolution: 5 to 45 km (channel-dependent)

Precipitation Radar (PR)
(Active Sensor)

Frequencies: 13.6 GHz (Ku band)
Swath: 220 km (247* km)
Resolution: 5 km

GPM Microwave Imager (GMI)
(Passive Sensor)

Frequencies: 10.6,18.7,23.8,36.5,89,166 & 183 GHz
Swath width: 885 km
Resolution: ~4 to 32 km ((channel-dependent)

Dual-frequency Precipitation Radar (DPR)
(Active Sensor)

Frequencies: 13.6 GHz (Ku), 35.5 Gz (Ka)
Swath: 245 km, 120 km
Resolution: 5.2 km

TRMM and GPM Measurements

http://pmm.nasa.gov/

Compared to TRMM, GPM has:

- Higher sensitivity to light rain and snow
- Better accuracy of measurements
- Improved light rain and snow detection
- Extended Spatial Coverage

- TRMM measurements provide long-term precipitation that is very useful for monitoring climate variability and trends
- TRMM and GPM data will be inter-calibrated to provide a combined, long-term, record in the near future

TMPA: TRMM Multi-satellite Precipitation Analysis
IMERG: Integrated Multi-satellitE Retrievals for GPM

IMERG and TMPA are produced by combining GMI/DPR and TMI/PR data with global constellation of satellites to yield improved spatial/temporal precipitation estimates:

	IMERG	TMPA
Temporal Resolution :	30-minutes	3 hours
Spatial Resolution:	0.1°x0.1°	0.25°x0.25°
Spatial Coverage:	Global 60°S to 60°N	Global 50°S to 50°N

TMPA, available from 1998-present, is widely used in water resources applications and IMERG with is improved spatial resolution and coverage will replace TMPA in many applications

GPM IMERG Data Products

2. IMERG Data Sets

Multiple runs accommodate different user requirements for latency and accuracy

- "Early" – 4 hours (flash flooding)
- "Late" – 12 hours (crop forecasting)
- "Final" – 3 months (research data)

Time intervals are half-hourly and monthly (Final only)

0.1° global CED grid

- PPS will provide subsetting by parameter and location
- initial release covers 60°N-S

User-oriented services

- interactive analysis (GIOVANNNI)
- alternate formats (KMZ, KML, TIFF WRF files, …)
- area averages

	Half-hourly data file (Early, Late, Final)
1	*[multi-sat.] precipitationCal*
2	[multi-sat.] precipitationUncal
3	*[multi-sat. precip] randomError* ←
4	[PMW] HQprecipitation
5	[PMW] HQprecipSource [identifier]
6	[PMW] HQobservationTime
7	IRprecipitation
8	IRkalmanFilterWeight
9	*probabilityLiquidPrecipitation [phase]*
	Monthly data file (Final)
1	*[sat.-gauge] precipitation*
2	*[sat.-gauge precip] randomError* ←
3	GaugeRelativeWeighting
4	*probabilityLiquidPrecipitation [phase]*

Courtesy: George Huffman (NASA-GSFC)

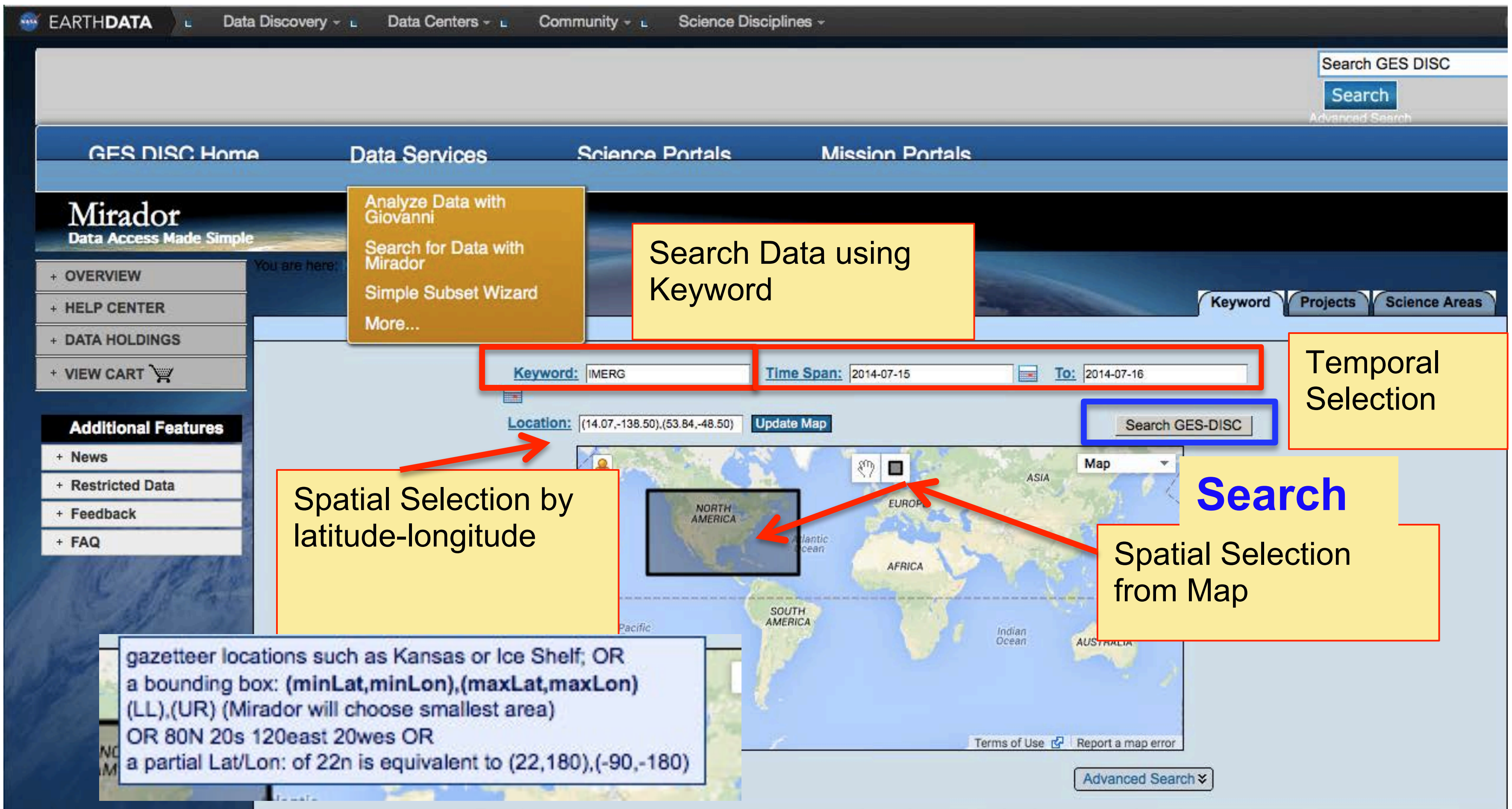
PPS: Precipitation Processing System **CED: Cylindrical Equidistant**

GPM and TRMM Data Access Tools

Tools	**Data Products and Formats**	Analysis and/or Visualization	Data Download
Mirador http://mirador.gsfc.nasa.gov	**L1B, L2, and L3 from TMI and GMI, PR and DPR Data, Combined TMI-PR and GMI-DPR** **TMPA 3-hourly, Monthly** **IMERG Half-hourly, Monthly** Orbital and Gridded Daily, Monthly HDF5, OPenDAP (can be converted to ASCII, Binary, NetCDF)	N/A	Batch Download
Giovanni http://giovanni.gsfc.nasa.gov/giovanni/	**TMPA (3B42) 3-hourly, (3B43) Monthly** **IMERG Half-hourly, Monthly** NetCDF, GeoTIFF, PNG	**Visualization:** Map, Time Series, Scatter Plot Histogram **Analysis:** Time-averaged Maps, Time Series, Scatter Plot, Map Correlations, Vertical Profiles, Time-averaged Differences	Download by Select and Click on Data Files
PPS/STORM https://storm.pps.eosdis.nasa.gov/storm	**L1B and 1C, L2, L3 TMI, PR, GMI, DPR** **TMI-PR and GMI-DPR Combined Data** Orbital and Gridded Daily, Monthly **TMPA 3-hourly, Monthly and IMERG Half-hourly, Monthly** HDF5, PNG	Map Visualization, Interactive Latitude/Longitude Point Data Value Display	FTP

Mirador: Data Search and Access

http://mirador.gsfc.nasa.gov/

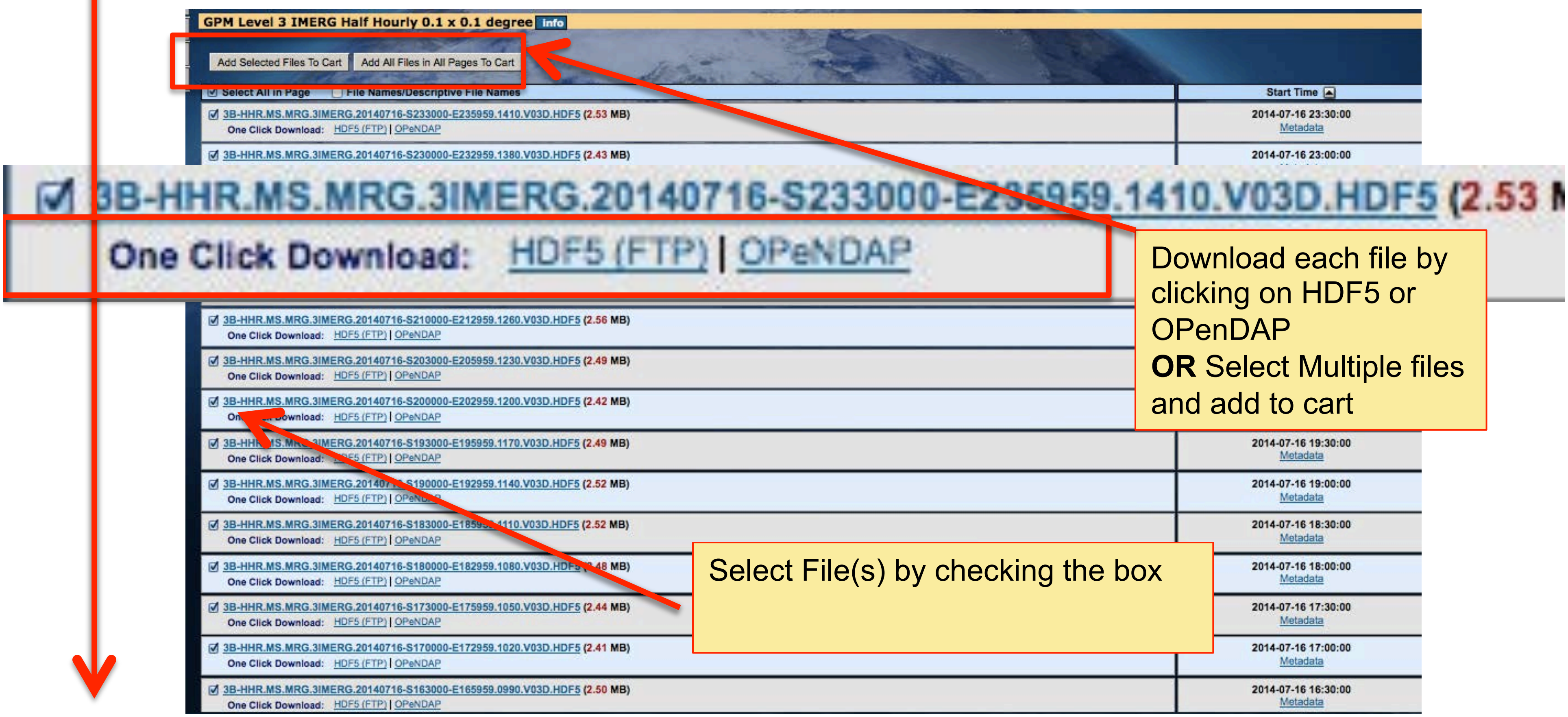


Bulk data download by using scripts

Mirador: Data Search and Access

http://mirador.gsfc.nasa.gov/

IMERG Half-hourly Data Files List



Download each file by clicking on HDF5 or OPenDAP
OR Select Multiple files and add to cart

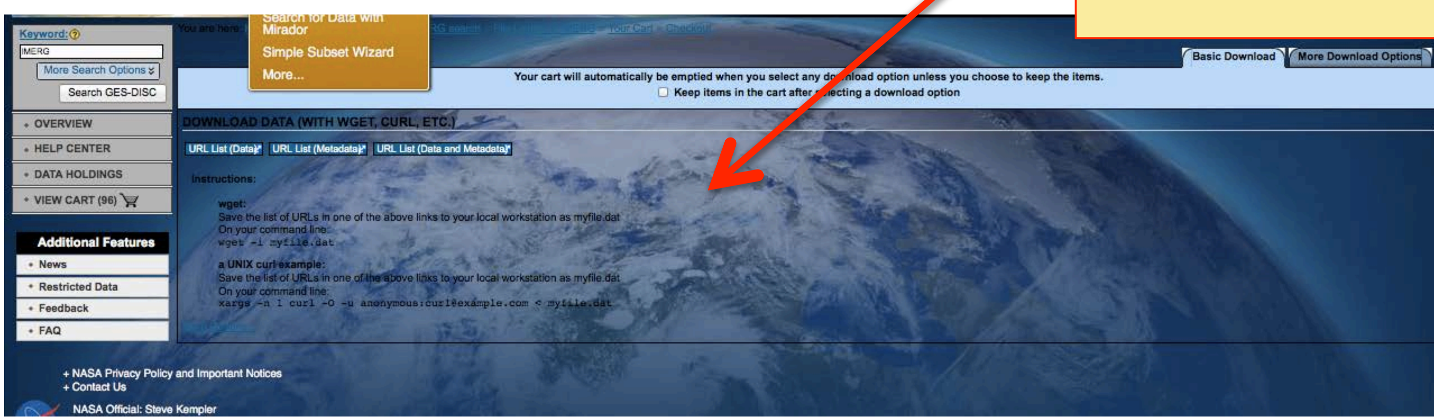
Select File(s) by checking the box

Mirador: Data Search and Access

http://mirador.gsfc.nasa.gov/

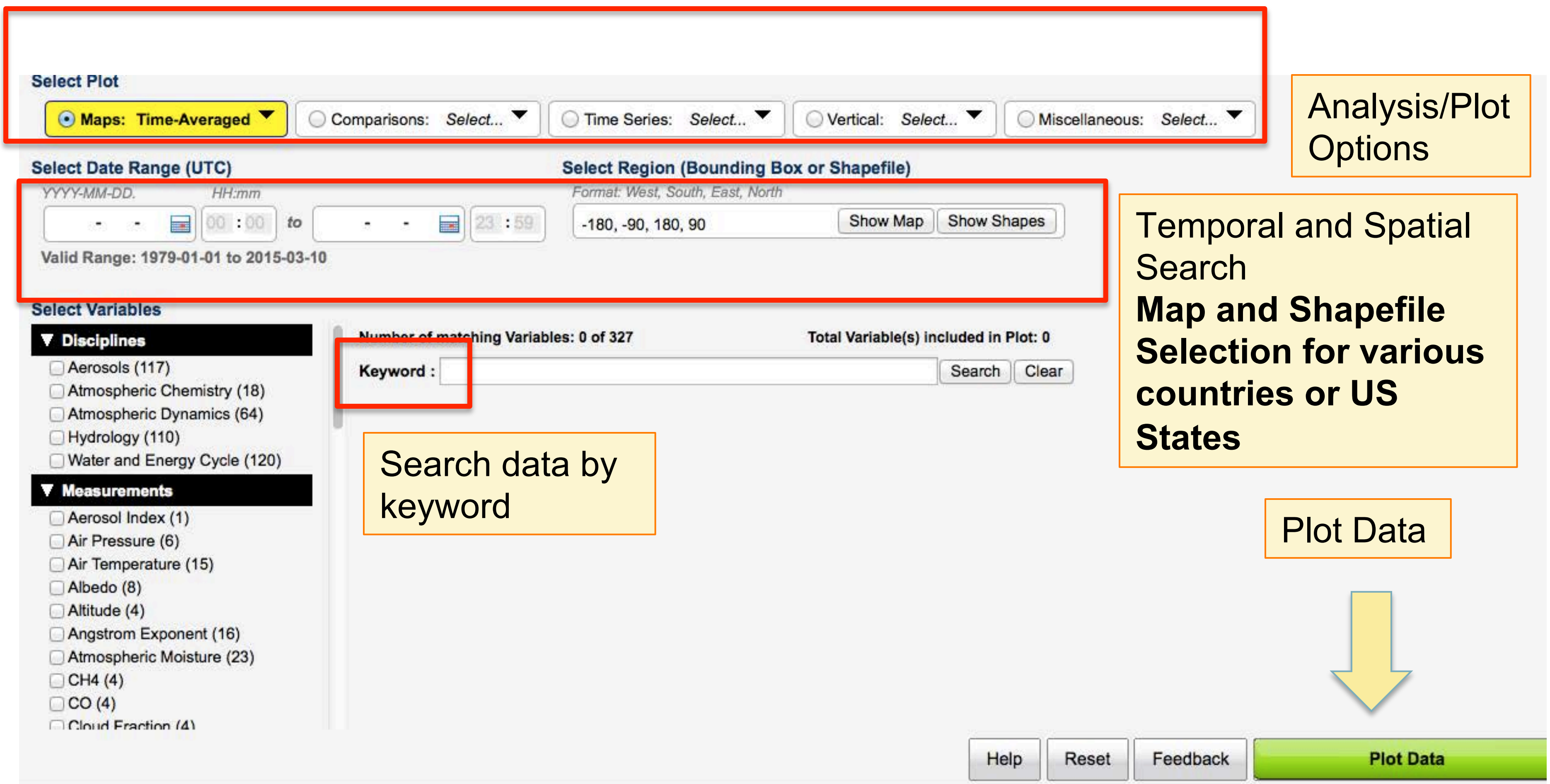
Data Checkout

Download Data by using these scripts



Giovanni Version 4

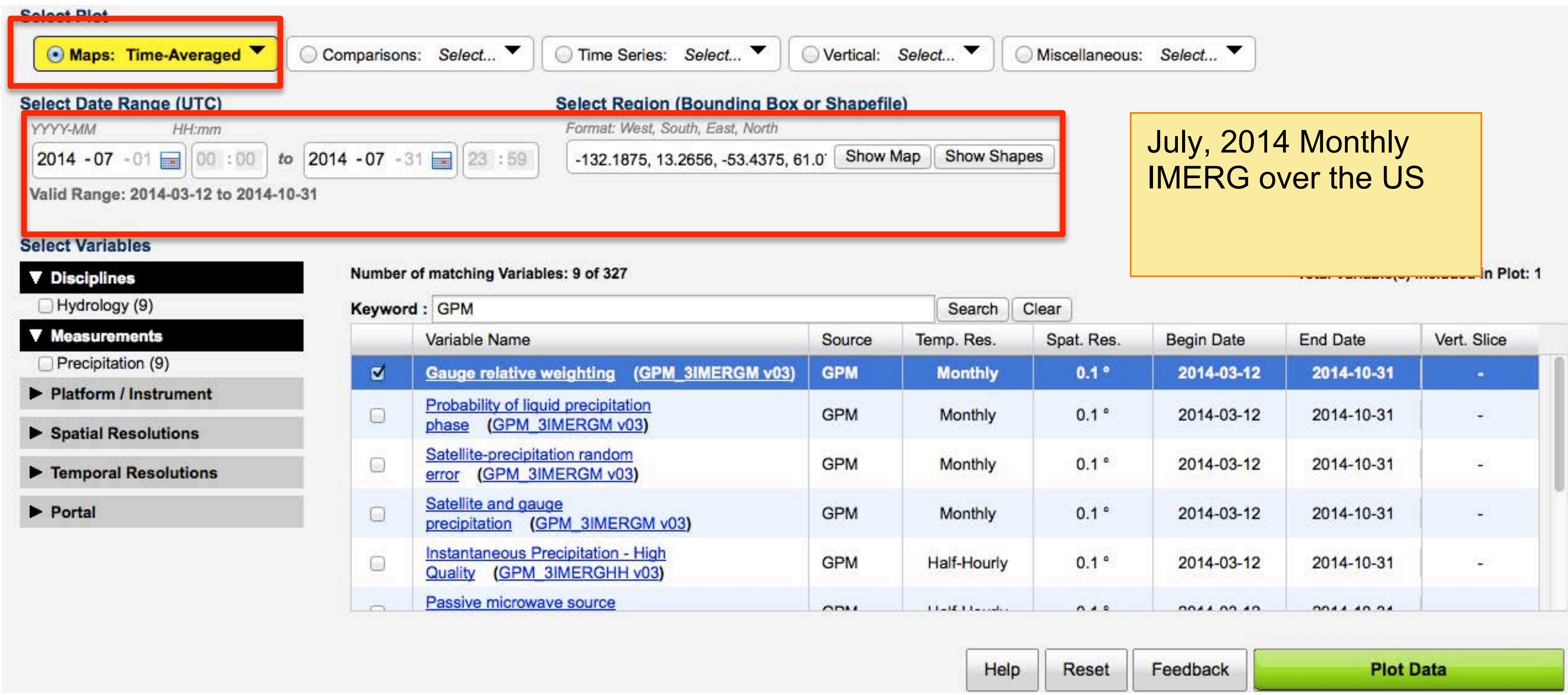
http://giovanni.gsfc.nasa.gov/giovanni/



Giovanni Version 4

http://giovanni.gsfc.nasa.gov/giovanni/

Search GPM data and Select Spatial, Temporal, Plot Options

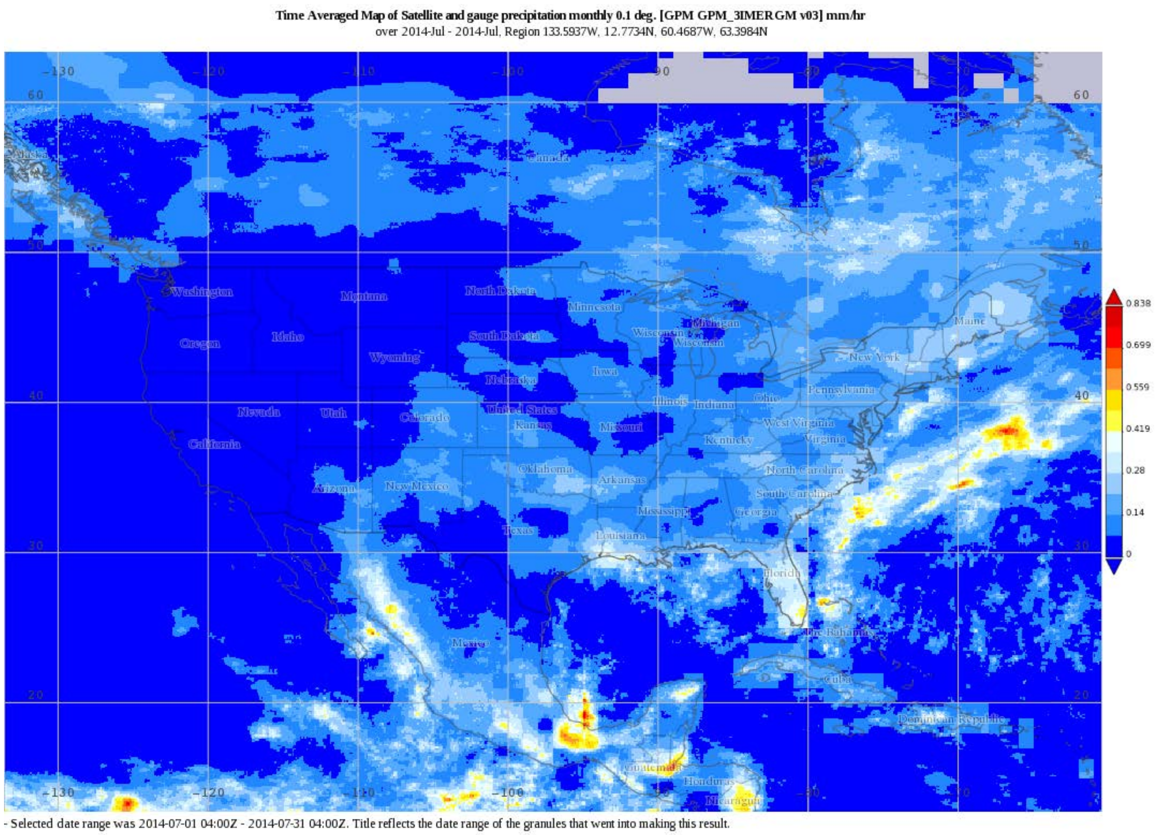


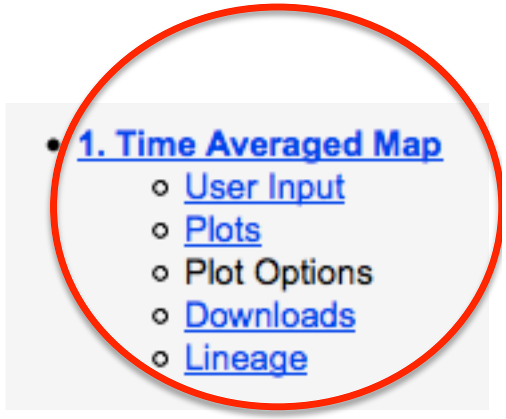
July, 2014 Monthly IMERG over the US

Giovanni Version 4

http://giovanni.gsfc.nasa.gov/giovanni/

Search and Plot Result: IMERG Rain Rate for July 2014 over the US

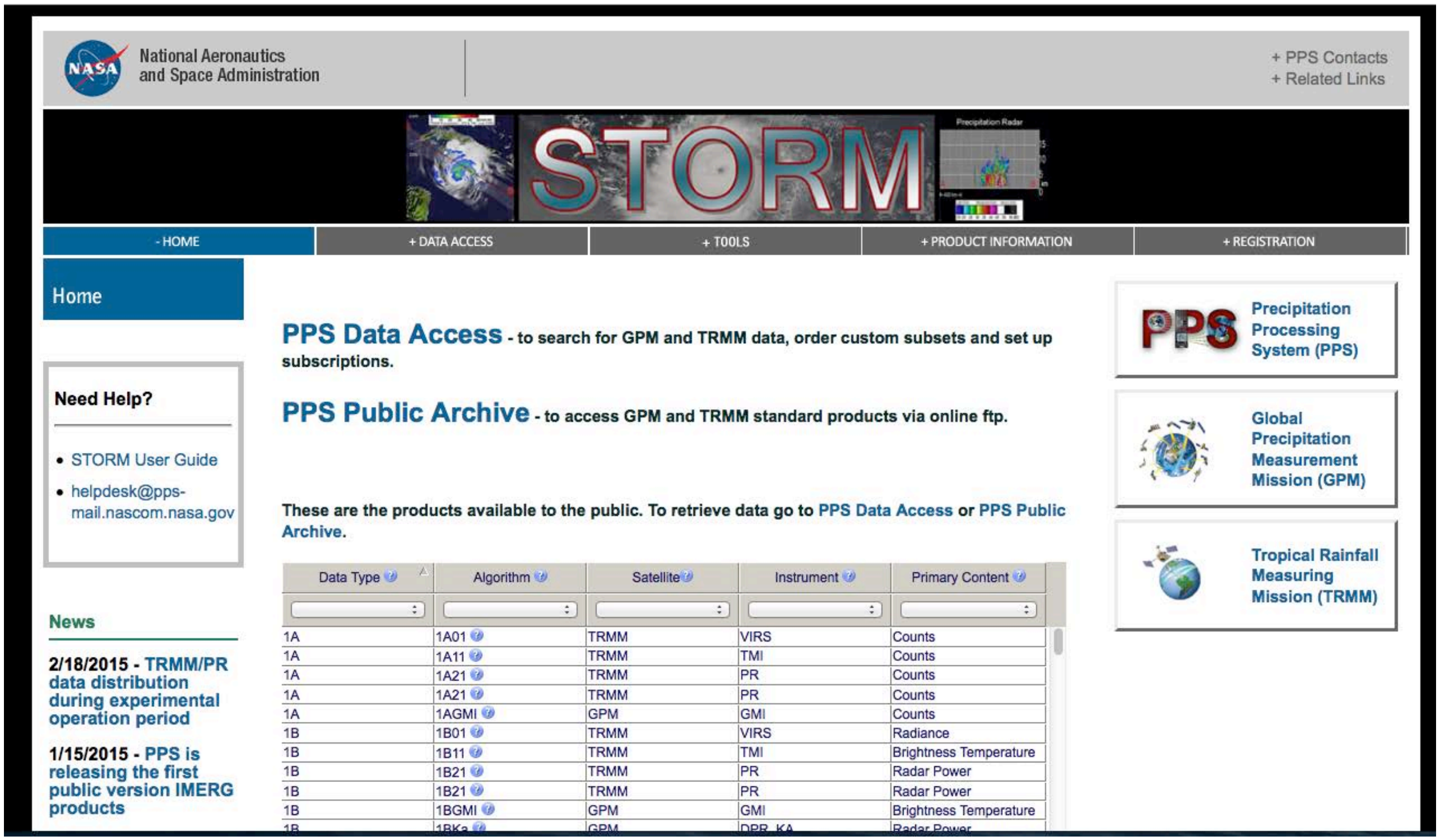




Data and Image Download Options

Precipitation Processing System (PPS)
Science Team On-Line Request Module (STORM)

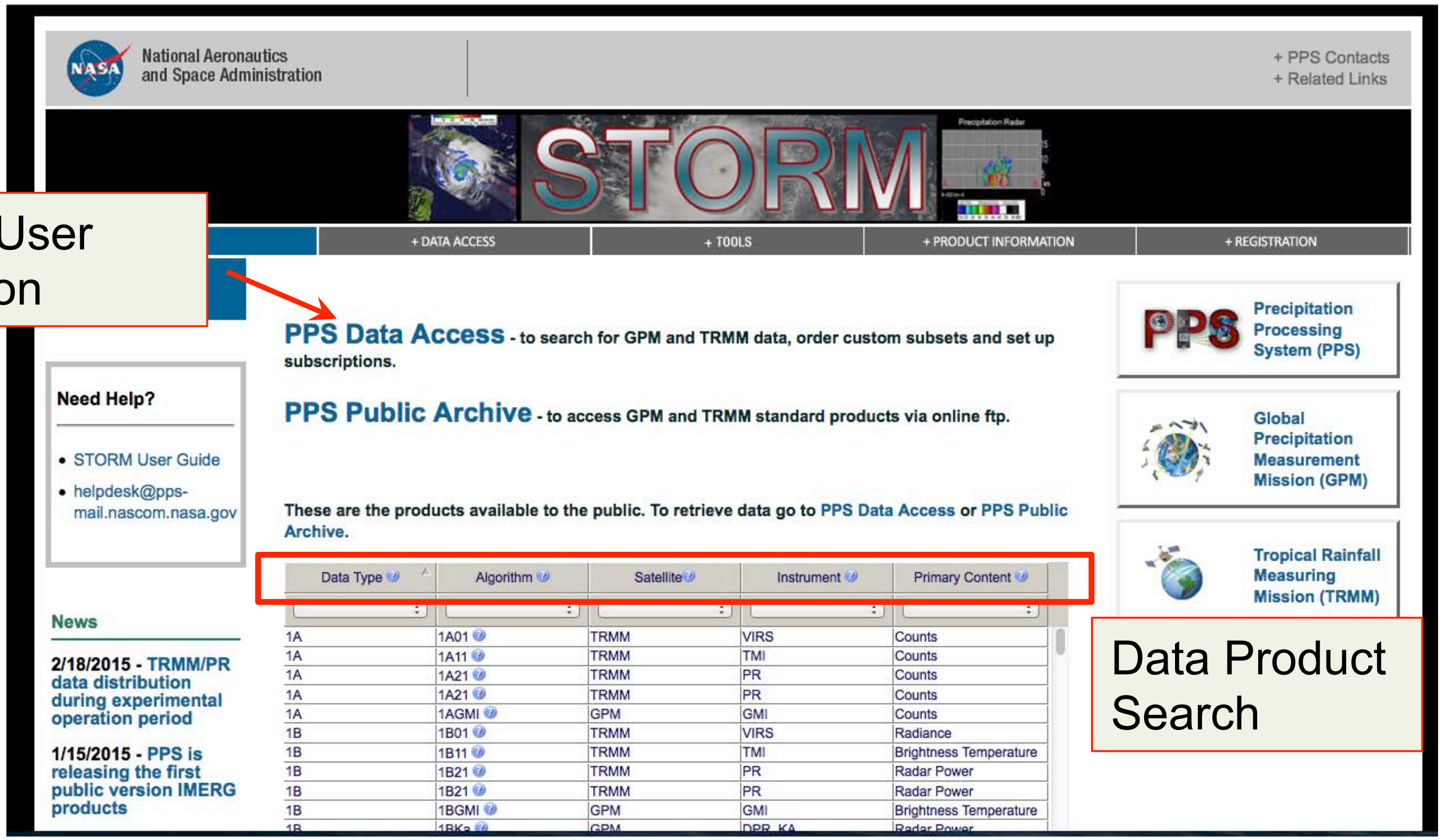
https://storm-pps.gsfc.nasa.gov/storm/



STORM is specifically designed for GPM and TRMM Precipitation data search, selection, download, and visualization

Precipitation Processing System (PPS)
Science Team On-Line Request Module (STORM)

https://storm-pps.gsfc.nasa.gov/storm/



Requires User Registration

Data Product Search

STORM is specifically designed for GPM and TRMM Precipitation data search, selection, download, and visualization

Precipitation Processing System (PPS) Science Team On-Line Request Module (STORM)

https://storm-pps.gsfc.nasa.gov/storm/

Product Type

Required

Product Selection

Left click on the header to sort rows. Right click to show/hide columns

Selec	Data Type	Algorithm	Start Time	Frequency	Satellite or Ground Validation Site	Instrument	Primary Content	Spatial Extent
	3B				GPM			
	3B	3CMB	2014-03-01 00:00:00	MONTH	GPM	DPR, GMI	Precipitation	[70.0,-70.0,180.0,-180.0], [67.0,-67.0,180.0,-180.0]
	3B	3CMB	2014-12-02 00:00:00	DAY	GPM	DPR, GMI	Precipitation	[70.0,-70.0,180.0,-180.0], [67.0,-67.0,180.0,-180.0]
	3B	3IMERGHH	2014-03-12 00:00:00	30_MINUTE	GPM	DPR	Precipitation	[90.0,-90.0,180.0,-180.0]
	3B	3IMERGM	2014-03-12 00:00:00	MONTH	GPM	DPR	Precipitation	[90.0,-90.0,180.0,-180.0]

Total Product Types selected: 0 *Note: Some selected Product Types might not be visible if filters are used*

Temporal Criteria

Date Range *Orbit Numbers*

Valid range is between 20140312 and 20150310

YYYYMMDD [HH:MM]
[ ] = optional fields

Start Date/Time 20150130 00:00

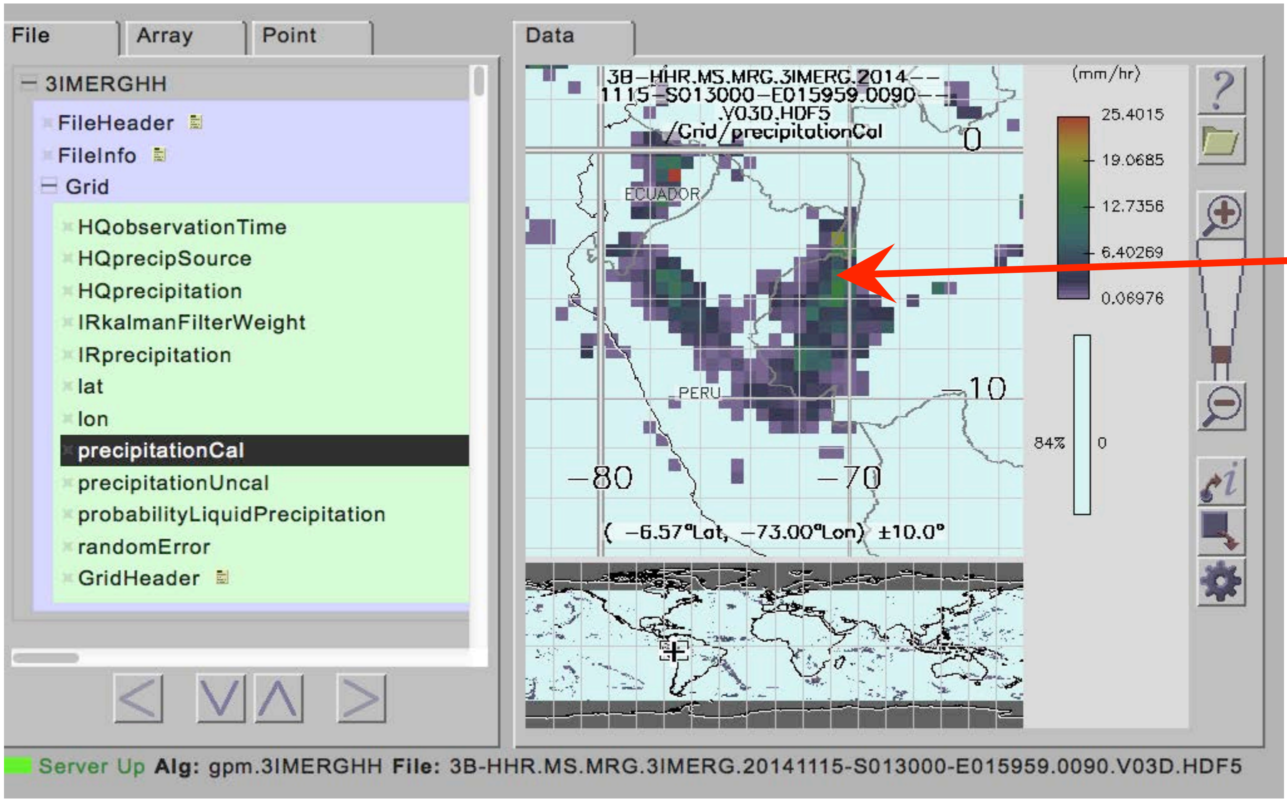
Stop Date/Time 20150130 23:59

Temporal Selection

Precipitation Processing System (PPS) Science Team On-Line Request Module (STORM)

https://storm-pps.gsfc.nasa.gov/storm/

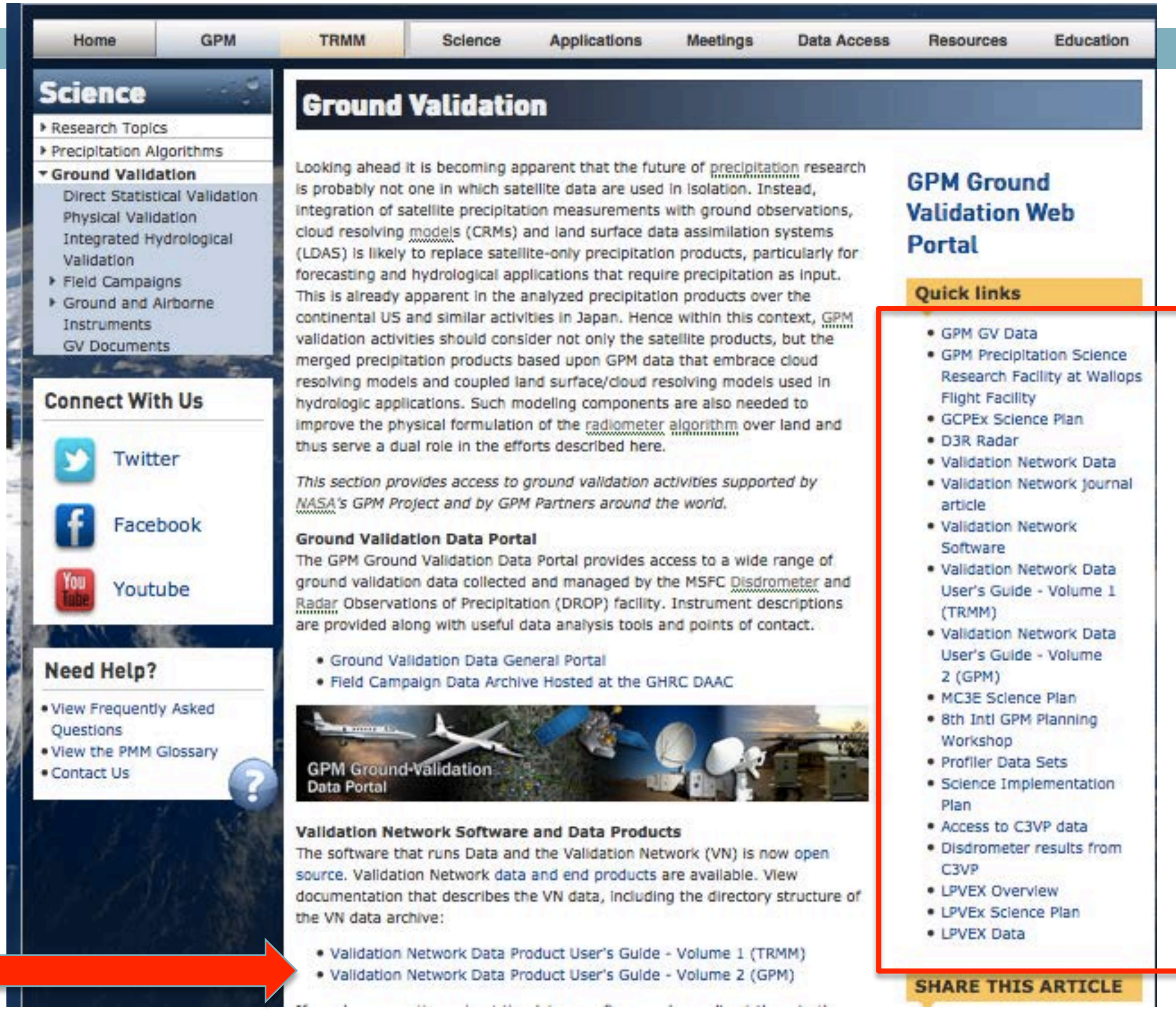
Product Selection, Download, and Visualization by using Tool for High-resolution Observation Review (THOR)



Precipitation on November 15, 2014

Ground Validation and Field Data Information

http://pmm.nasa.gov/science/ground-validation



Home | GPM | TRMM | Science | Applications | Meetings | Data Access | Resources | Education

Science

- Research Topics
- Precipitation Algorithms
- Ground Validation
  - Direct Statistical Validation
  - Physical Validation
  - Integrated Hydrological Validation
  - Field Campaigns
  - Ground and Airborne Instruments
  - GV Documents

Connect With Us

- Twitter
- Facebook
- Youtube

Need Help?

- View Frequently Asked Questions
- View the PMM Glossary
- Contact Us

Ground Validation

Looking ahead it is becoming apparent that the future of precipitation research is probably not one in which satellite data are used in isolation. Instead, integration of satellite precipitation measurements with ground observations, cloud resolving models (CRMs) and land surface data assimilation systems (LDAS) is likely to replace satellite-only precipitation products, particularly for forecasting and hydrological applications that require precipitation as input. This is already apparent in the analyzed precipitation products over the continental US and similar activities in Japan. Hence within this context, GPM validation activities should consider not only the satellite products, but the merged precipitation products based upon GPM data that embrace cloud resolving models and coupled land surface/cloud resolving models used in hydrologic applications. Such modeling components are also needed to improve the physical formulation of the radiometer algorithm over land and thus serve a dual role in the efforts described here.

This section provides access to ground validation activities supported by NASA's GPM Project and by GPM Partners around the world.

Ground Validation Data Portal

The GPM Ground Validation Data Portal provides access to a wide range of ground validation data collected and managed by the MSFC Disdrometer and Radar Observations of Precipitation (DROP) facility. Instrument descriptions are provided along with useful data analysis tools and points of contact.

- Ground Validation Data General Portal
- Field Campaign Data Archive Hosted at the GHRC DAAC

GPM Ground-Validation Data Portal

Validation Network Software and Data Products

The software that runs Data and the Validation Network (VN) is now open source. Validation Network data and end products are available. View documentation that describes the VN data, including the directory structure of the VN data archive:

- Validation Network Data Product User's Guide - Volume 1 (TRMM)
- Validation Network Data Product User's Guide - Volume 2 (GPM)

GPM Ground Validation Web Portal

Quick links

- GPM GV Data
- GPM Precipitation Science Research Facility at Wallops Flight Facility
- GCPEx Science Plan
- D3R Radar
- Validation Network Data
- Validation Network Journal article
- Validation Network Software
- Validation Network Data User's Guide - Volume 1 (TRMM)
- Validation Network Data User's Guide - Volume 2 (GPM)
- MC3E Science Plan
- 8th Intl GPM Planning Workshop
- Profiler Data Sets
- Science Implementation Plan
- Access to C3VP data
- Disdrometer results from C3VP
- LPVEX Overview
- LPVEx Science Plan
- LPVEX Data

SHARE THIS ARTICLE

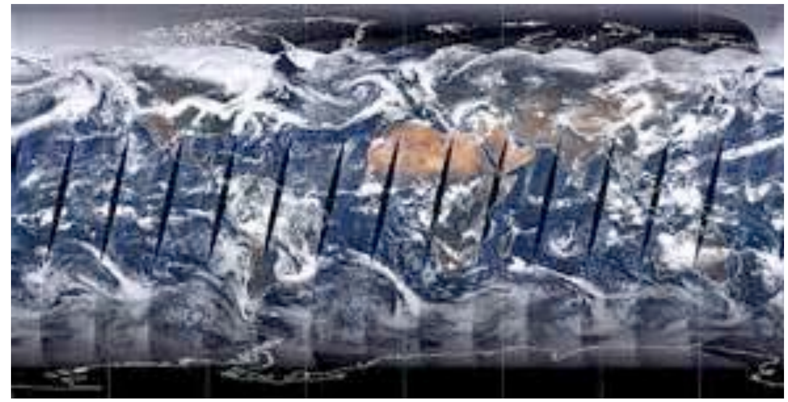
Snow Data Products

Review of Terra and Aqua

http://trmm.gsfc.nasa.gov

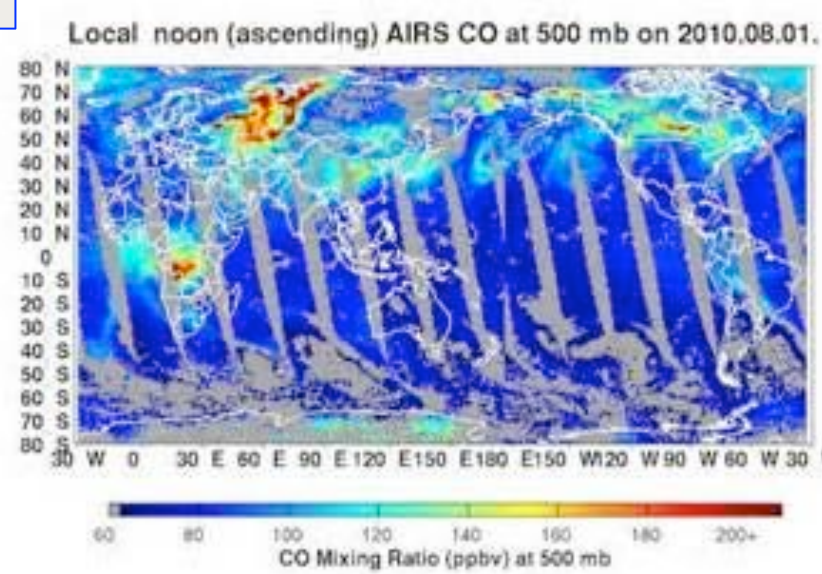
Terra

- Polar, Sun-Synchronous Orbit, Global Coverage
- Twice-daily Observations 10:30 AM/PM Descending Orbits
- From 12/1999 – Present



Aqua

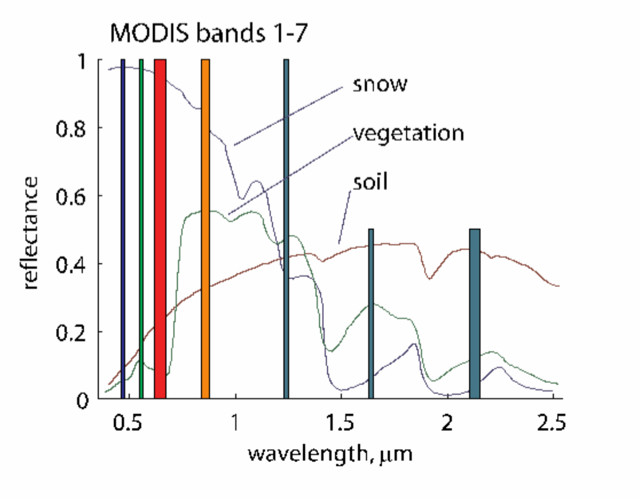
- Polar, Sun-Synchronous Orbit, Global Coverage
- Twice-daily Observations 1:30 AM/PM Descending Orbits
- From 5/2002 – Present



Terra and Aqua
MODerate Resolution ImagingSpectroradiometer (MODIS)

http://modis.gsfc.nasa.gov/

- A key instrument aboard Terra and Aqua providing 4-times per day observations (1:30 and 10:30 AM/PM) from the two satellites
- 36 spectral bands ranging from 0.41 to 14.385 microns
- Many applications, including **snow/ ice,** clouds, vegetation, aerosol
- Available in various resolution (depends on product)

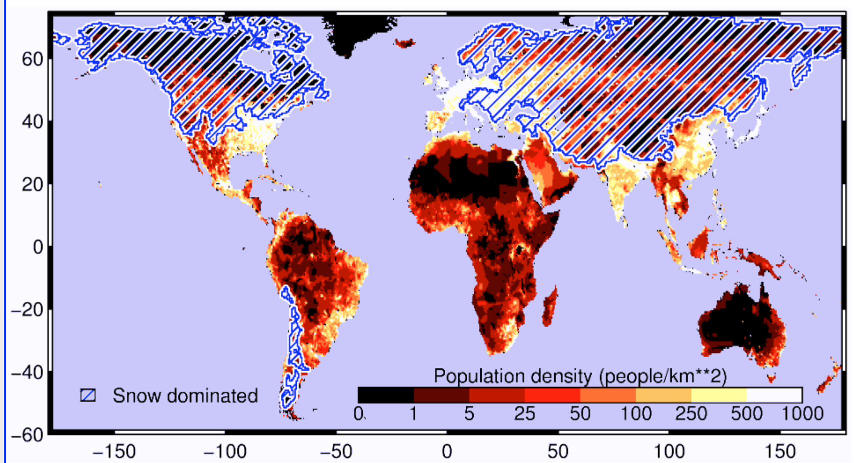


http://modis-snow-ice.gsfc.nasa.gov/

There are Two MODIS-based Snow Data Products

- Standard MODIS Product: Fractional Snow Cover
- MODSCAG (MODIS Snow Covered Area and Grain- size) Product : Fractional Snow Cover, Grain Size, Snow Water Equivalent

Snow-Dominated Regions



MODIS Standard Products: Daily, 8-Day, Monthly Snow Cover available from Terra and Aqua

From Dorothy Hall NASA-GSFC

	Long Name	Earth Science Data Type (ESDT)	Spatial Resolution
Terra	MODIS/Terra Snow Cover 5-Min L2 Swath 500m	MOD10_L2	500-m resolution, swath of MODIS data
Terra	MODIS/Terra Snow Cover Daily L3 Global 500m SIN Grid (includes daily snow albedo)	MOD10A1	500-m resolution, projected, gridded tile data
Terra	MODIS/Terra Snow Cover 8-Day L3 Global 500m SIN Grid	MOD10A2	500-m resolution, projected, gridded tile data
Terra	MODIS/Terra Snow Cover Daily L3 Global 0.05Deg CMG	MOD10C1	0.05° resolution, lat/lon climate modeling grid
Terra	MODIS/Terra Snow Cover 8-Day L3 Global 0.05Deg CMG	MOD10C2	0.05° resolution, lat/lon climate modeling grid
Terra	MODIS/Terra Snow Cover Daily L3 Global 0.25Deg CMG	Not yet a standard product	0.25° resolution, lat/lon climate modeling grid
Terra	MODIS/Terra Snow Cover Monthly L3 Global 0.05Deg CMG	MOD10CM	0.05° resolution, lat/lon climate modeling grid
Aqua	MODIS/Aqua Snow Cover 5-Min L2 Swath 500m	MYD10_L2	500-m resolution, swath of MODIS data
Aqua	MODIS/Aqua Snow Cover Daily L3 Global 500m SIN Grid (includes daily snow albedo)	MYD10A1	500-m resolution, projected, gridded tile data
Aqua	MODIS/Aqua Snow Cover 8-Day L3 Global 500m SIN Grid	MYD10A2	500-m resolution, projected, gridded tile data
Aqua	MODIS/Aqua Snow Cover Daily L3 Global 0.05Deg CMG	MYD10C1	0.05° resolution, lat/lon climate modeling grid
Aqua	MODIS/Aqua Snow Cover 8-Day L3 Global 0.05Deg CMG	MYD10C2	0.05° resolution, lat/lon climate modeling grid
Aqua	MODIS/Aqua Snow Cover Monthly L3 Global 0.05Deg CMG	MYD10CM	0.05° resolution, lat/lon climate modeling grid

MODIS Standard Snow Product
Data Access and Visualization

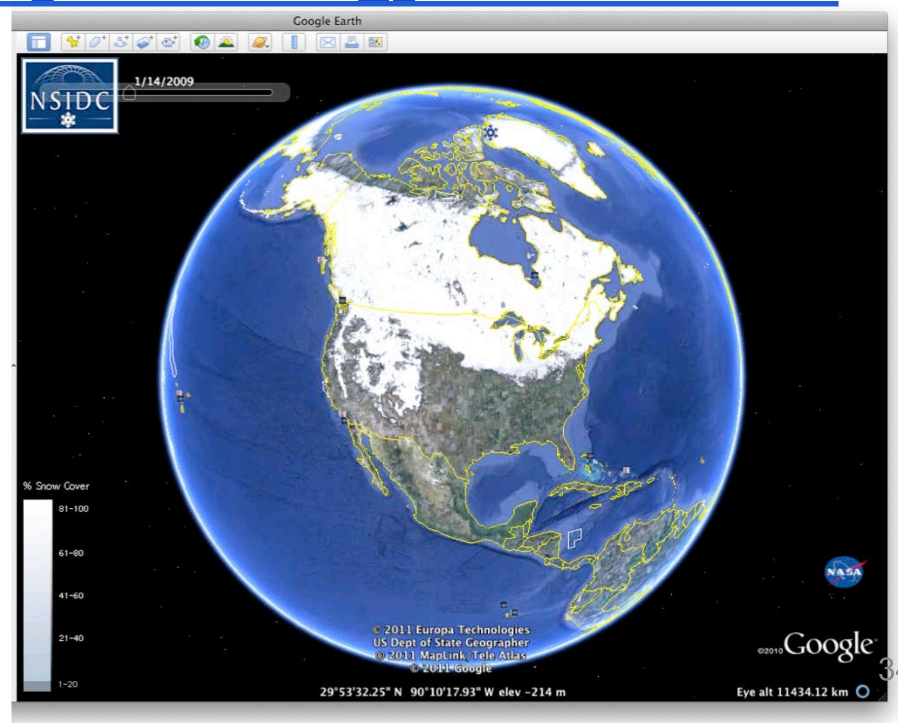
MODIS Snow Products are available from the National Snow and Ice Data Center http://nsidc.org/

MODIS monthly snow cover can be visualized on Google Earth maps from http://nsidc.org/data/virtual_globes/index.html

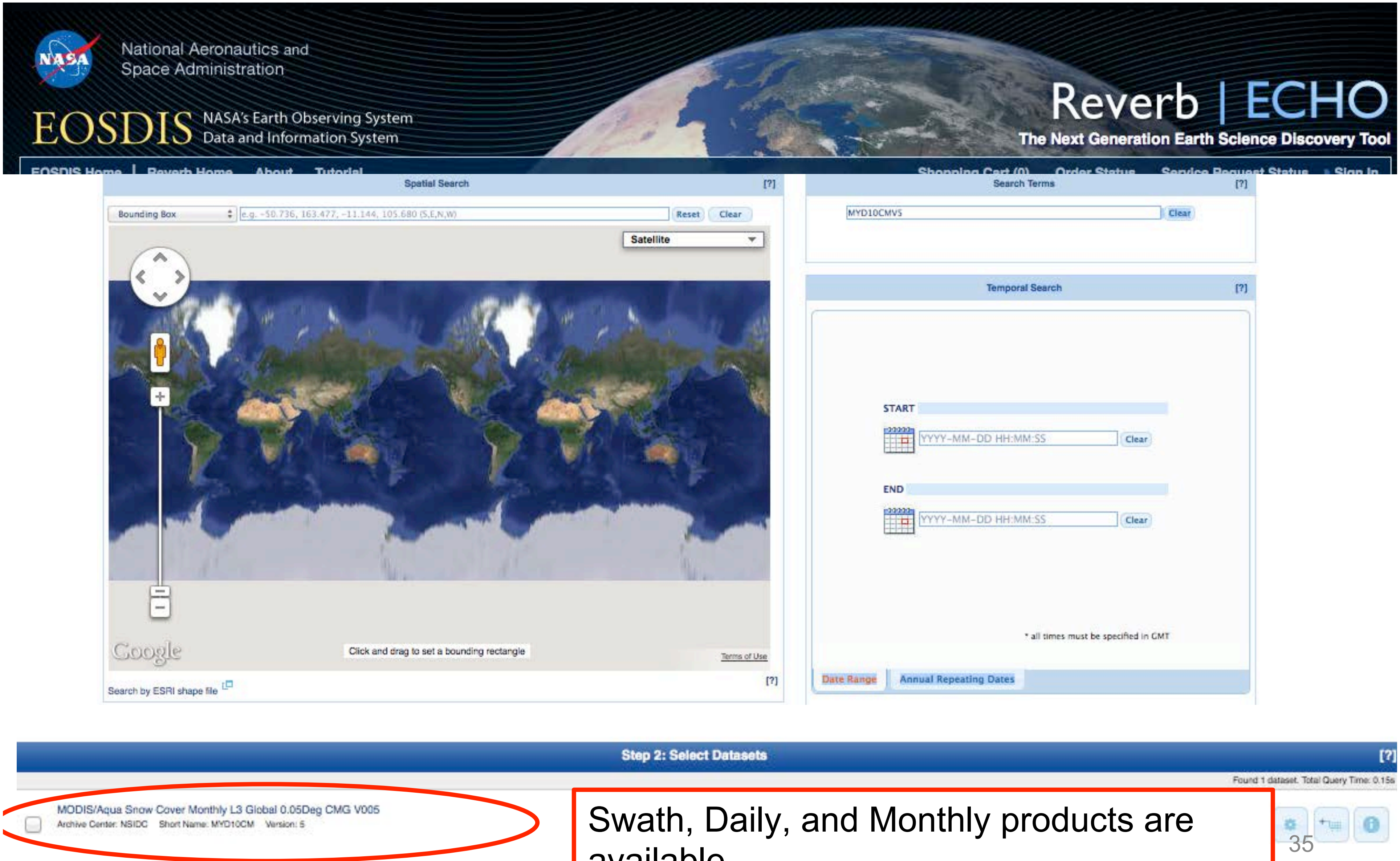
Data Start Date: 2000-02-24
Daily, 8-Day, Monthly

Coverage: Global

Multiple Spatial Resolutions



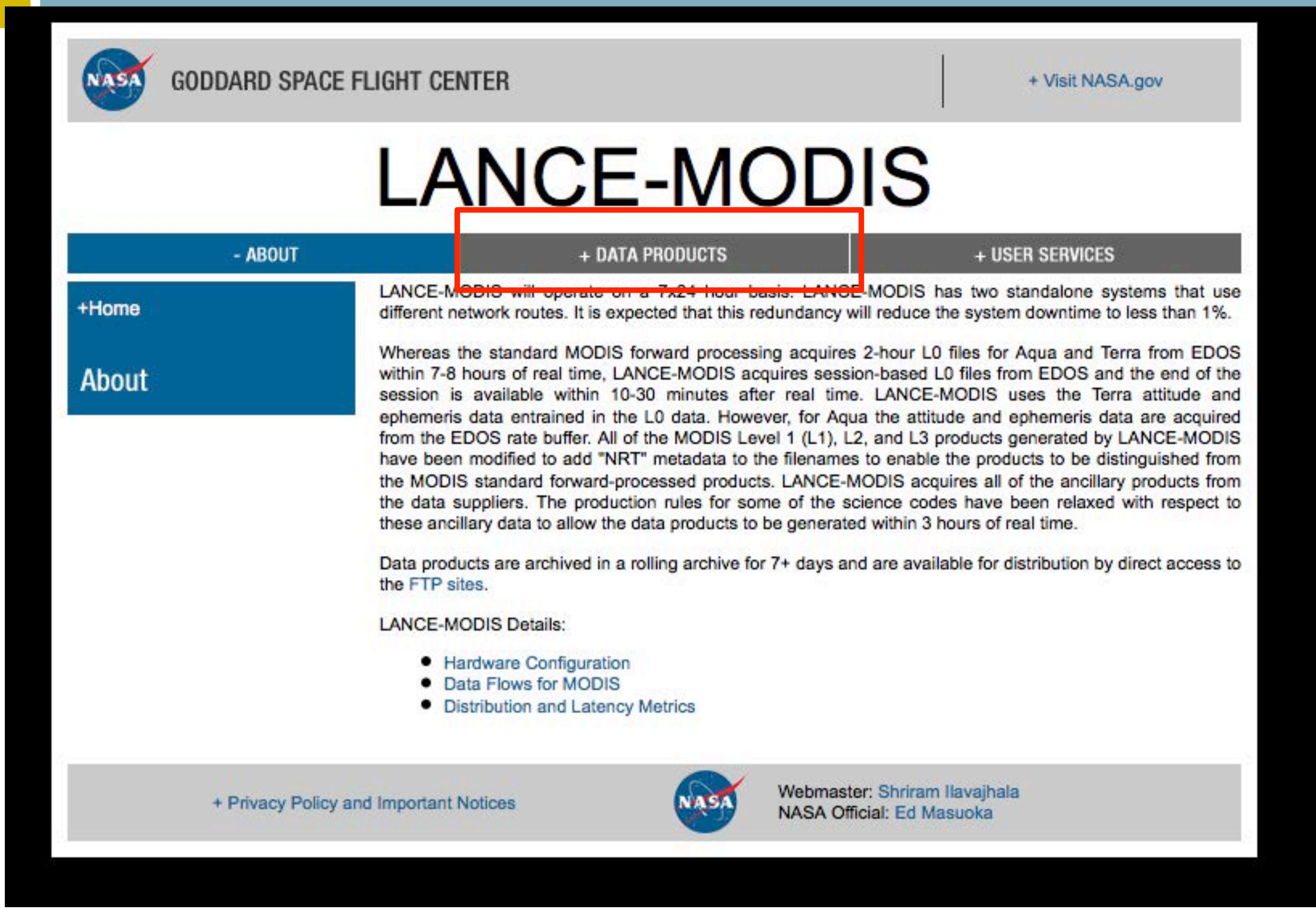
Selected Aqua-MODIS Snow Product from Reverb/ECHO
http://reverb.echo.nasa.gov/reverb



Swath, Daily, and Monthly products are available

Near-real Time Standard MODIS Products

http://lance-modis.eosdis.nasa.gov/



Near-real Time Standard MODIS Products

http://lance-modis.eosdis.nasa.gov/

Level-2 Swath data (500) m and 5 Km resolution Snow Cover available from Terra and Aqua MODIS

Terra

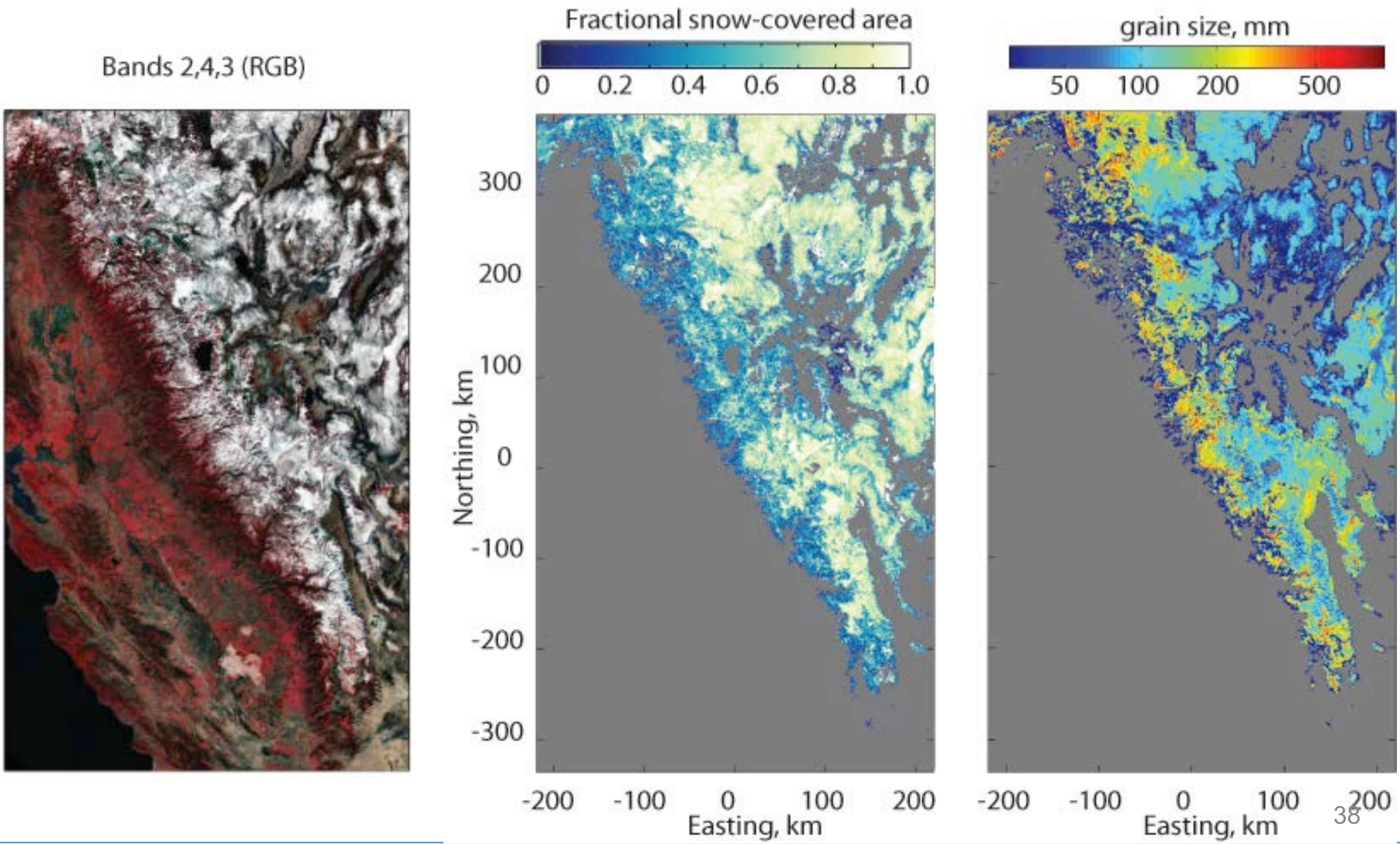
			Fraction Browse					
L2 Snow Cover, 5-Min Swath 500m	MOD10_L2	0.26	L2 Snow Cover Browse	N/A	07	0:46	1:32 (8)	3:14
L2 Coarse Snow Cover, 5-Min Swath 5km	MOD10L2C	0.17				0:46	1:32 (8)	3:14

Aqua

			Browse					
L2 Snow Cover, 5-Min Swath 500m	MYD10_L2	0.26	L2 Snow Cover Browse	N/A	07	1:00	1:47 (25)	3:30
L2 Coarse Snow Cover, 5-Min Swath 5km	MYD10L2C	0.17				1:00	1:47 (25)	3:30

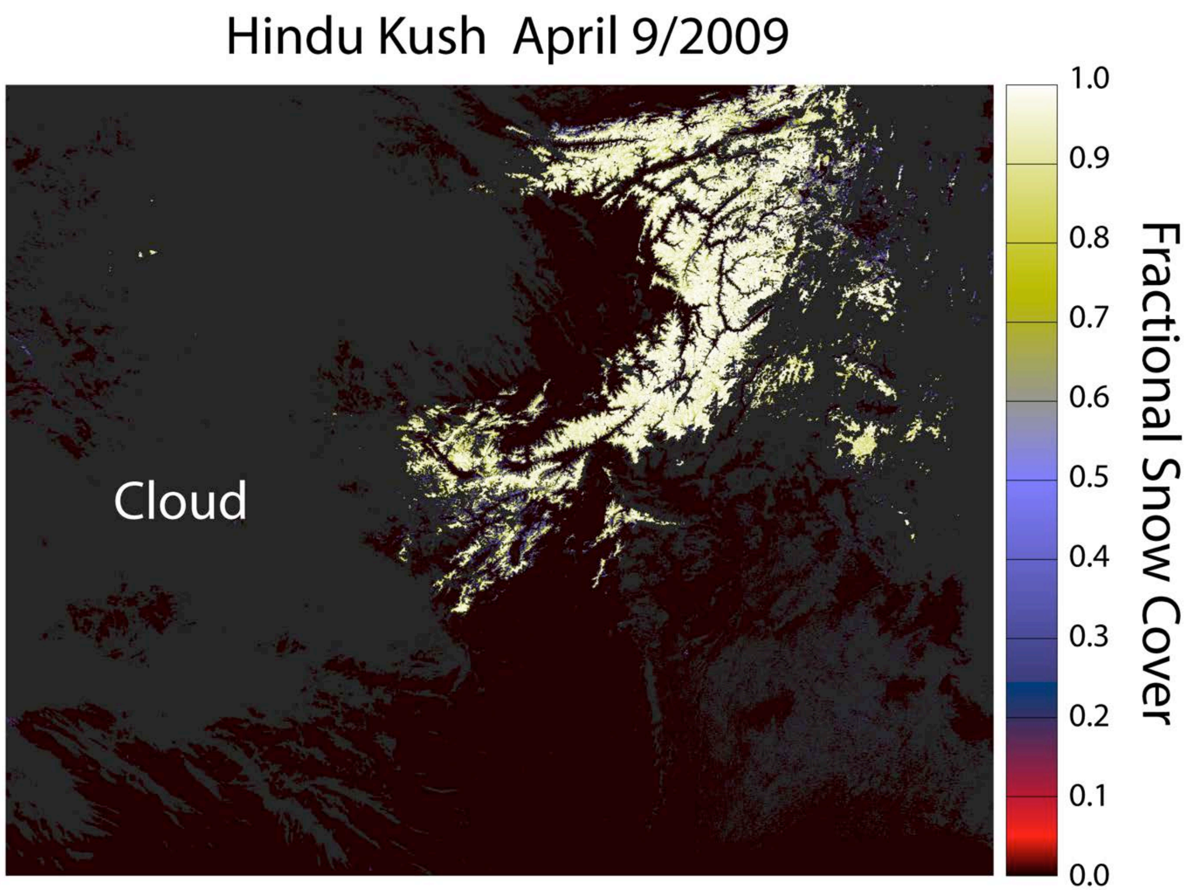
MODSCAG Snow Products

From: Thomas H. Painter and Chris Mattmann (NASA JPL)



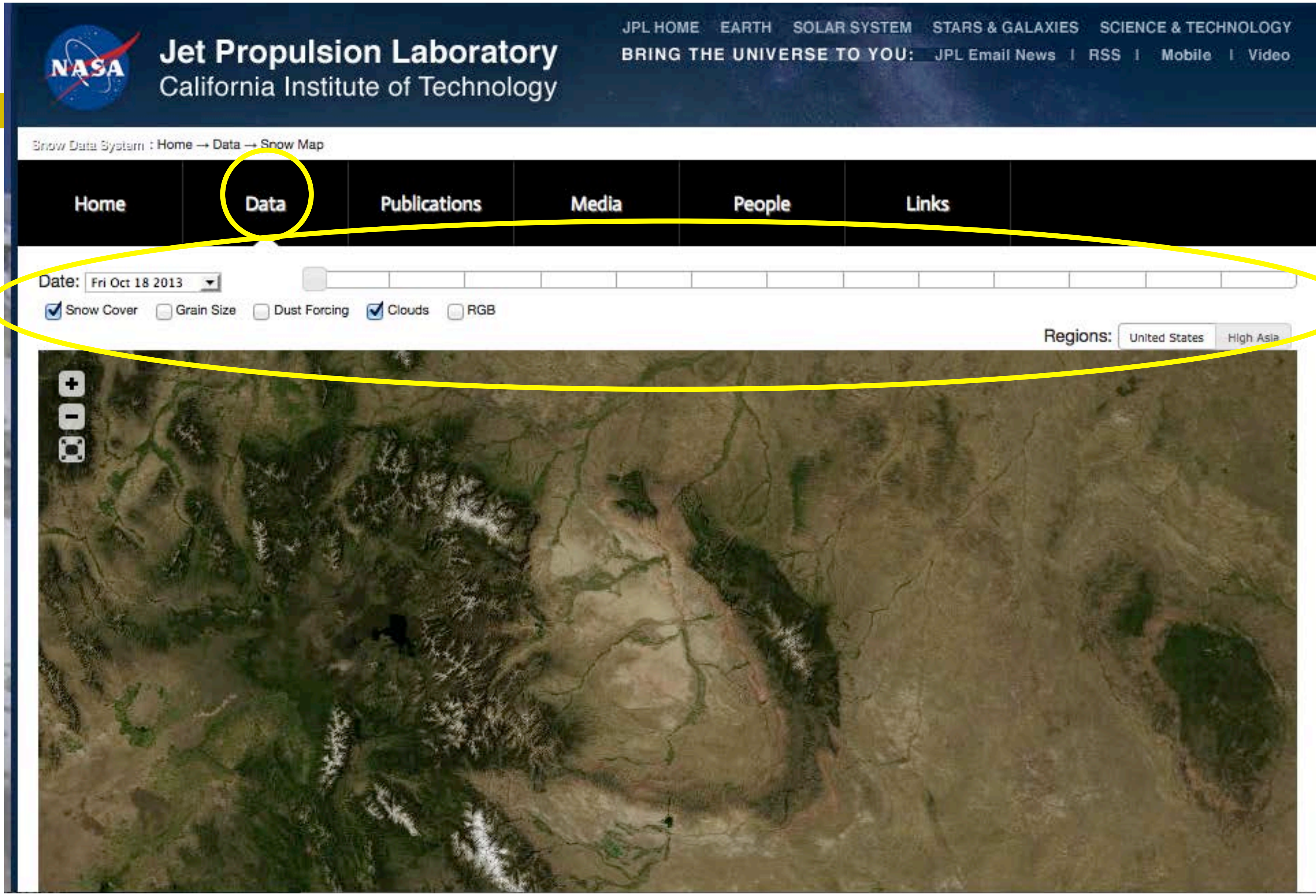
MODSCAG

http://snow.jpl.nasa.gov/portal/browse/dataset/urn:snow:MODSCAG



Limitation of MODIS Data : No Snow Mapping Under Clouds

http://snow.jpl.nasa.gov/portal/browse/dataset/urn:snow:MODSCAG



MODSACG Data Access and Mapping

Water Resources

Integration of Precision NASA Snow Products with the Operations of the Colorado Basin River Forecast Center (CBRFC) to Improve Decision Making Under Drought Conditions

Principle Investigator: Thomas Painter, Jet Propulsion Laboratory

Abstract

The Colorado Basin River Forecast Center (CBRFC) is responsible for the entire Colorado Basin (CRB) and the eastern Great Basin (GB). From a water management perspective, the commitment of water to various users most often occurs in the spring, and is almost entirely based on estimates of the western USA snowpack. Improving seasonal drought predictions requires use of models that provide physically realistic simulations of fundamental hydrologic processes. Among these, for the western USA, representation of snow is perhaps most critical.

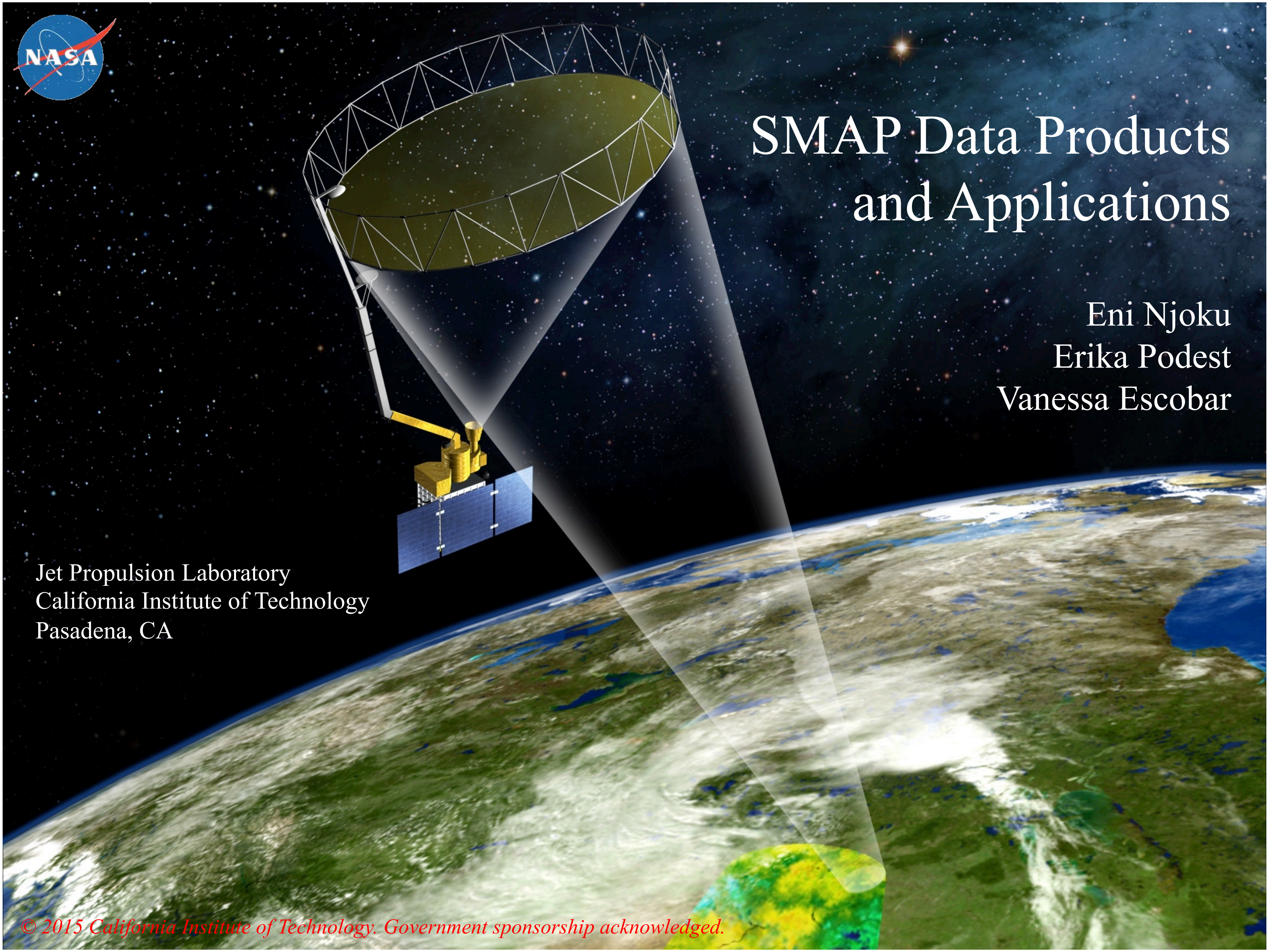
As drought frequency increases in the CRB and GB, it is critical that the CBRFC and the dependent water managers have more comprehensive real-time knowledge of the snow cover and its properties for more precise runoff forecasting and stakeholder decision support. The primary objective of this proposal is to integrate real-time high precision MODIS Snow Covered Area and Grain size (MODSCAG) fractional snow covered area (SCA) into CBRFC modeling and analysis systems and into stakeholder oriented data products, drastically reducing SCA uncertainties that have hampered forecasting operations for decades. A secondary objective is to ingest and study MODIS Dust Radiative Forcing in Snow (MODDRFS) radiative forcing imagery, to better understand its value as a input to modeling and forecasting approaches.

This collaboration directly addresses drought prediction, assessment, adaptation, and mitigation in support of energy security/efficiency; natural resource conservation; and household, municipal, industrial, and in-stream demands for water. It will also improve access and availability of actionable water monitoring, hence drought information. he Snow Cover and Dust Forcing products will be generated and distributed in near real-time by the JPL Snow Server for access by CBRFC. CBRFC will offer a direct connection to stakeholders (End Users) and together with other linked NWS operational centers provides an institutional home to maintain the advances of this effort beyond the project's end.

top

MODSCAG, Snow and Dust Radiative Forcing Information, along with CBRFC Modeling Analysis is used in **Decision Making for River Basin management**

Soil Moisture Data



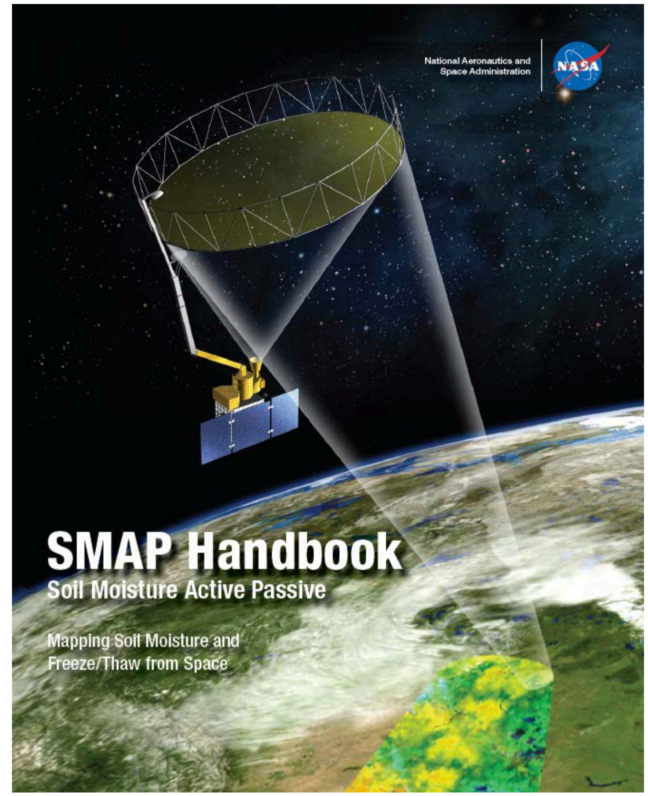
SMAP Data Products and Applications

Eni Njoku
Erika Podest
Vanessa Escobar

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

Outline

1. *Overview and Mission Objectives*
2. *Instruments (radar and radiometer)*
3. *Retrieval Algorithms*
4. *Data Products*
5. *Applications*



Details provided in SMAP Handbook

http://smap.jpl.nasa.gov/mission/description/

Credits: *SMAP Project Team*
SMAP Science Team

Why Soil Moisture?

Enhanced weather & climate forecasting

Improved agricultural productivity and crop yield predictions

Drought monitoring and early warning

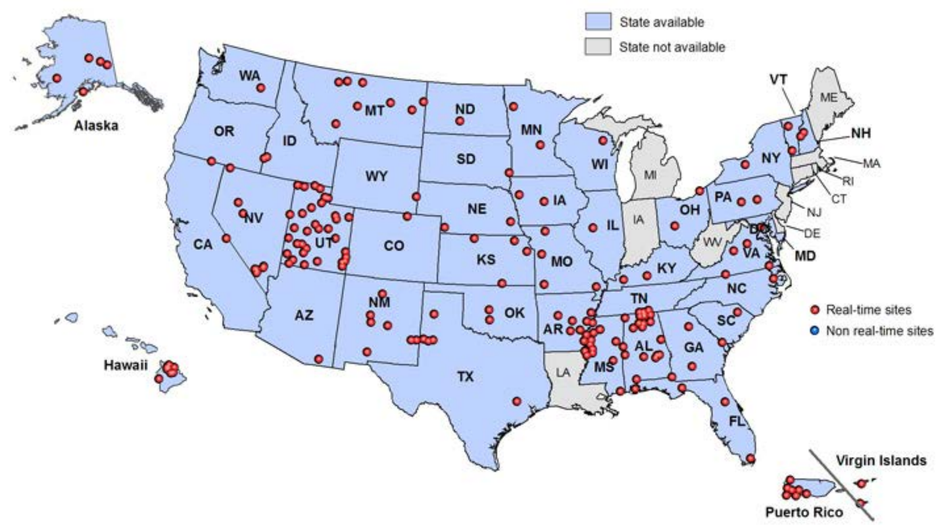
Flood monitoring and prediction

Human health and vector borne diseases

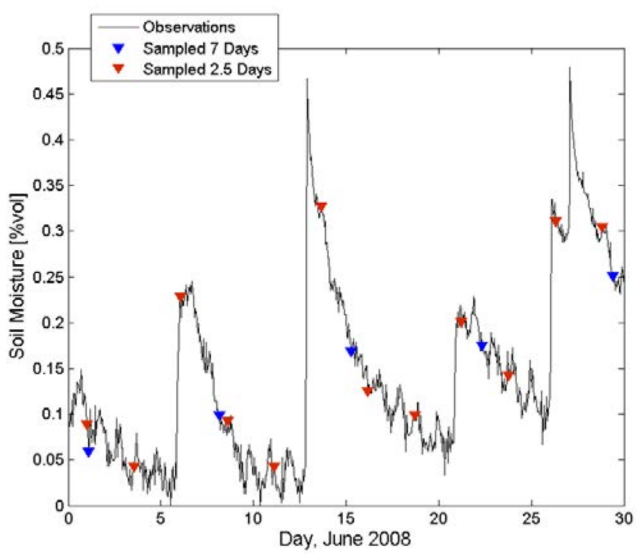
Why Measure from Space?

SMAP provides a capability for global observations of soil moisture and its frozen or thawed state at 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

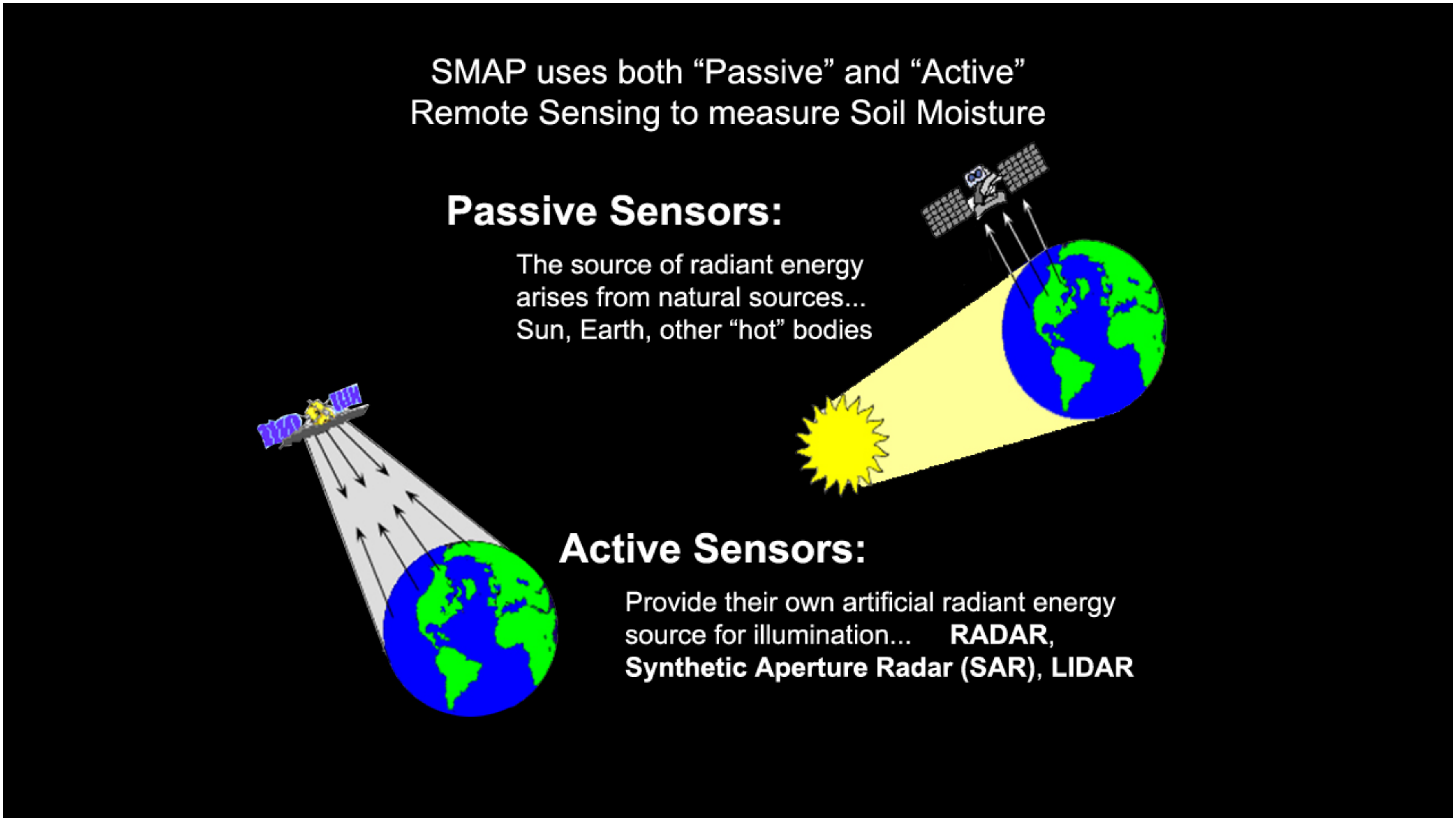


Inter-storm soil moisture dry-down

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

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

Measurement Approach

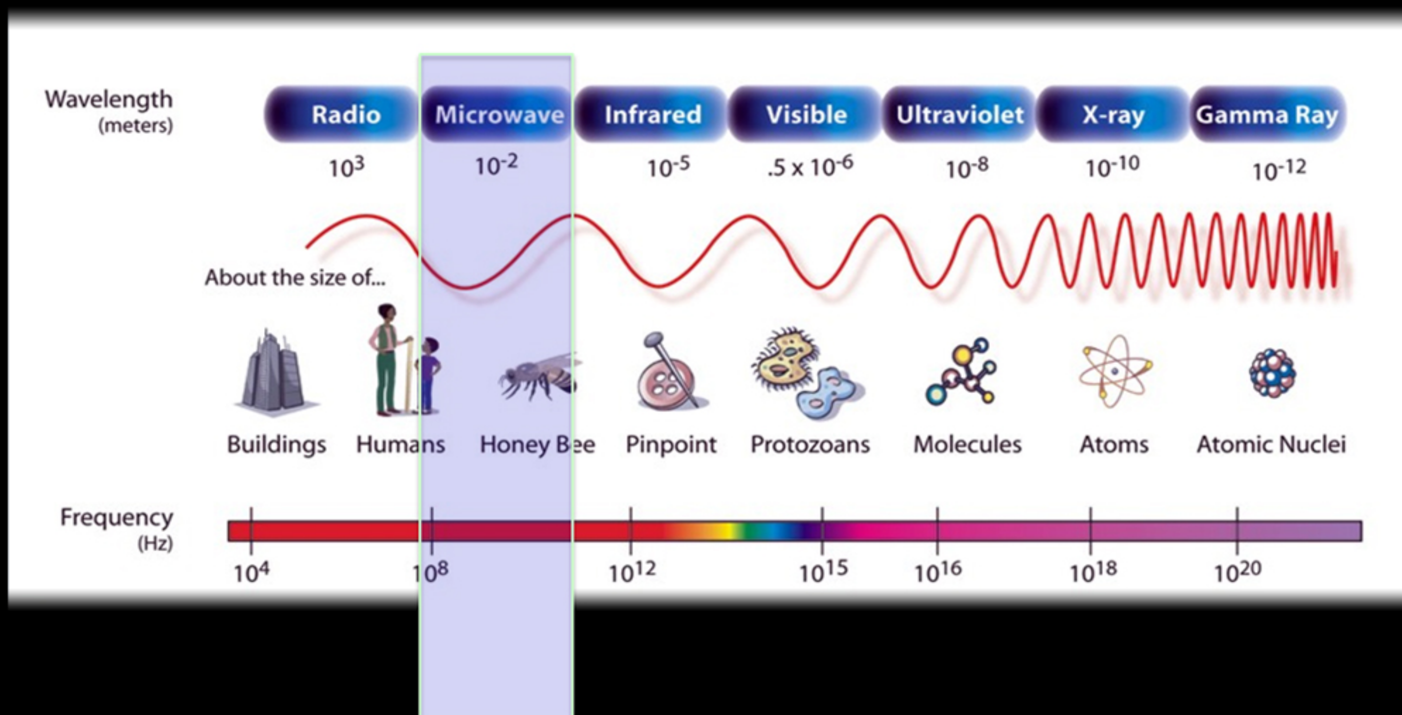


National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

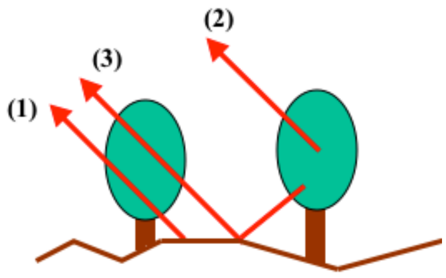
Measurement Approach (2)

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

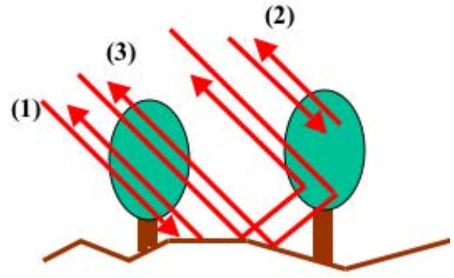


- With optical and infrared wavelength sensors the soil is masked by clouds and vegetation Also, optical sensors operate by measuring scattered sunlight and are “daytime only”
- Microwaves can penetrate through clouds and vegetation, operate day and night, and are highly sensitive to the water in the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

Measurement Approach (3)



Emission (Radiometer)

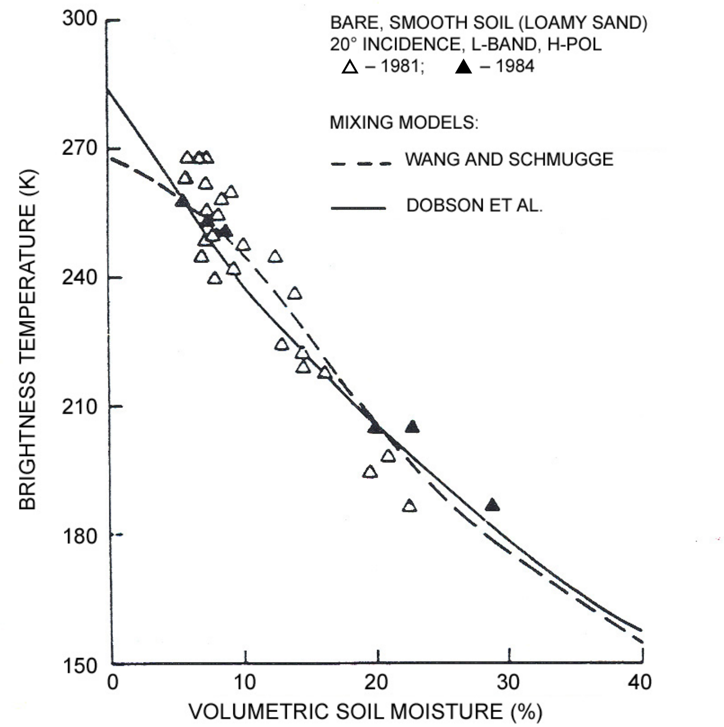


Backscatter (Radar)

$$T^{t}_{Bp} = T^{s}_{Bp} L_{p} + T^{v}_{Bp} + T^{sv}_{Bp} \quad \text{(Emission)}$$

$$\sigma^{t}_{pq} = \sigma^{s}_{pq} L^{2}_{pq} + \sigma^{v}_{pq} + \sigma^{sv}_{pq} \quad \text{(Backscatter)}$$

- 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, $\exp(-\tau_o / \cos\theta)$



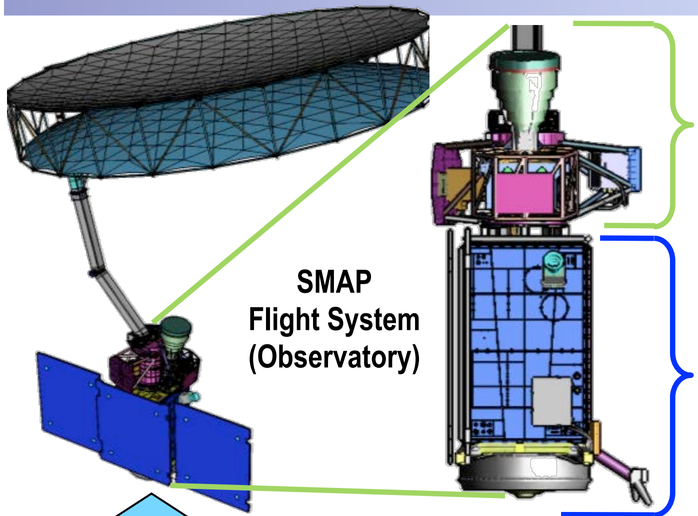
Experimental data showing brightness temperature sensitivity to soil moisture for bare, smooth soil

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

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

SMAP Mission Design

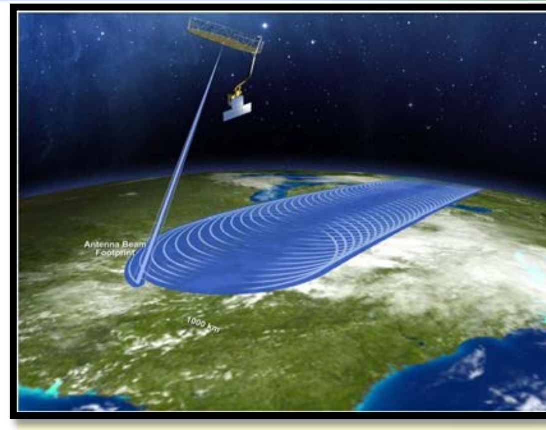


INSTRUMENT

- 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

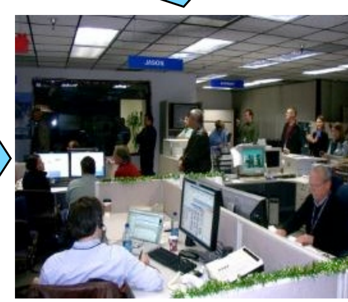
Delta II 7320-10C

Launch:
January 31, 2015
6:22 AM pacific

Vandenberg Air
Force Base

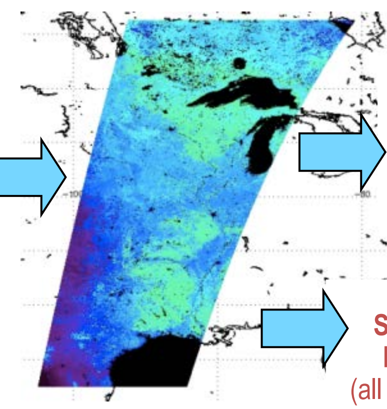
Near-Earth Network

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)

SMAP Data Products

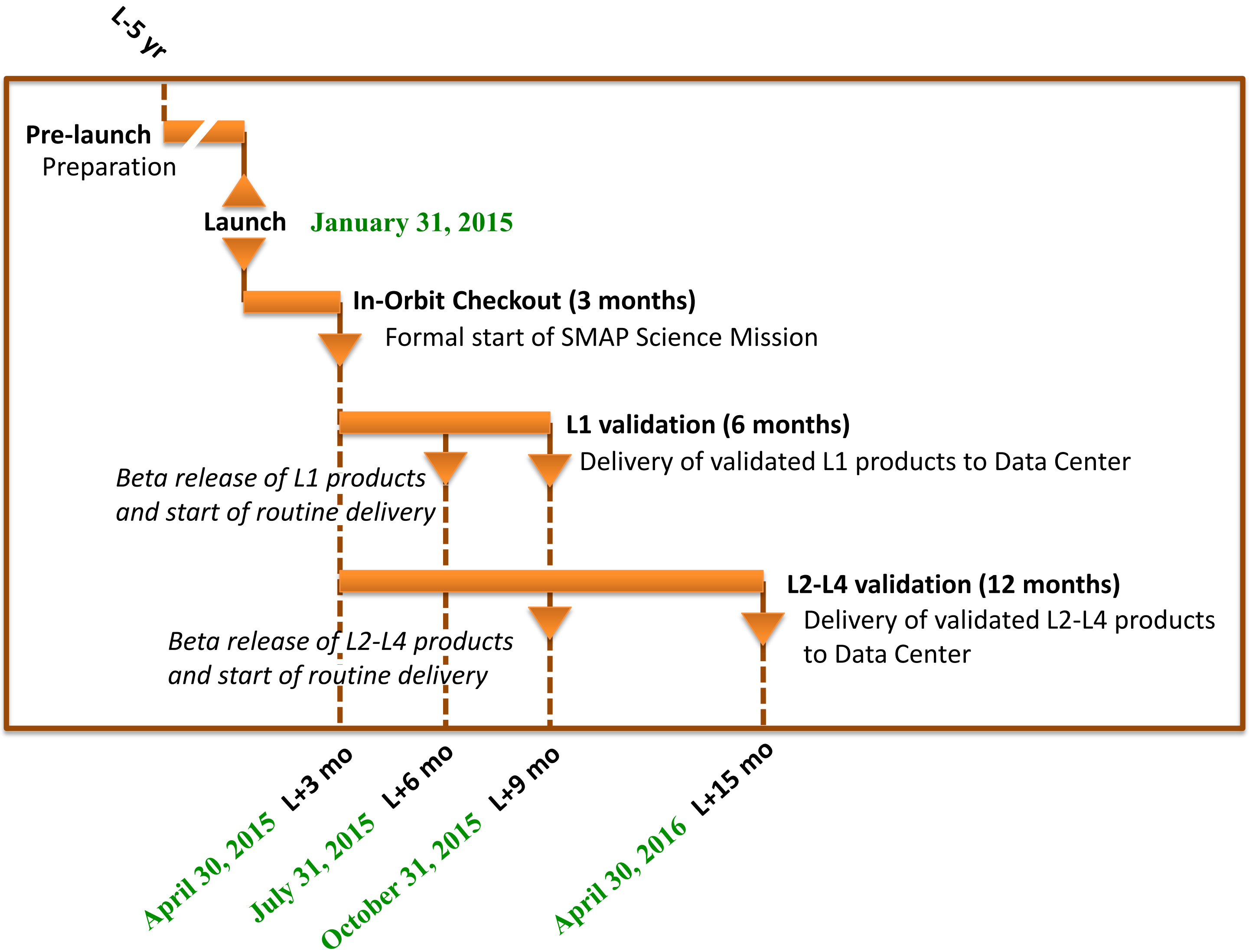
- Datasets in **Green Text** are publicly available in "beta" version via the ASF and NSIDC data centers

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 (10 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

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Planned Data Delivery Schedule



Current Status

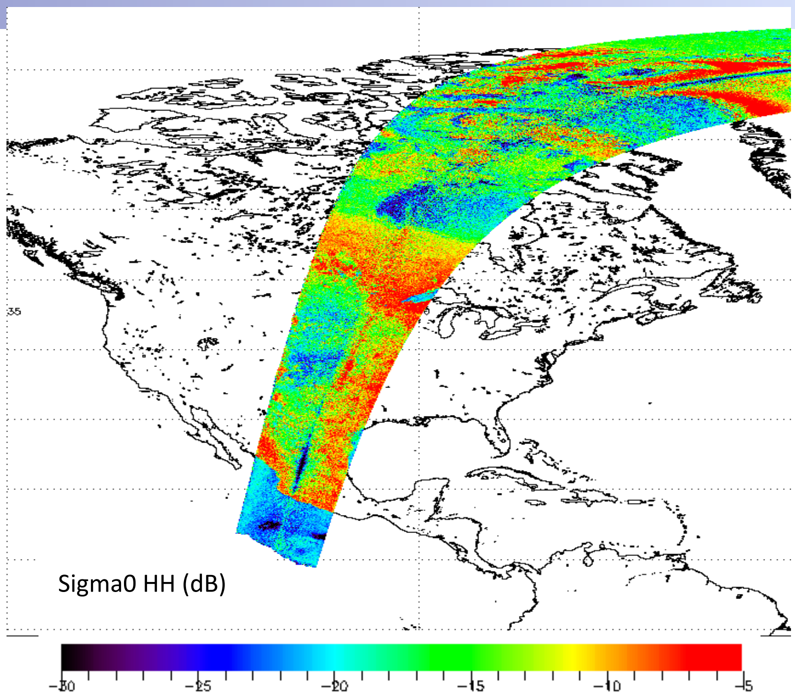
Date	Milestone
January 31, 2015	SMAP launch
February 24	Antenna reflector deployed
March 26	Antenna spin-up to 14.6 RPM
March 31	Radiometer begins routine science operation
April 13	Radar begins routine science operation
July 7	Radar stops transmitting (traced to low-voltage power supply of radar amplifier) Radiometer continues to operate normally
July 31	Beta data for L1 Radiometer and Radar released to DAACs
September 2	NASA official announcement that all efforts to restart the radar are unsuccessful
September 9	Beta data for L2/3 Soil Moisture Passive (radiometer) released to DAAC
Early November	Validated data for L1 Radiometer and Radar will be released
Early November	Beta data for L2/3 Soil Moisture Active/Passive, L4 Soil Moisture and L4 Carbon will be released
Through April 2018 (nominal mission)	Science data available through data centers will be used to demonstrate SMAP applications

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Radar Level 1C Product

[Data available April 13-July 7, 2015]



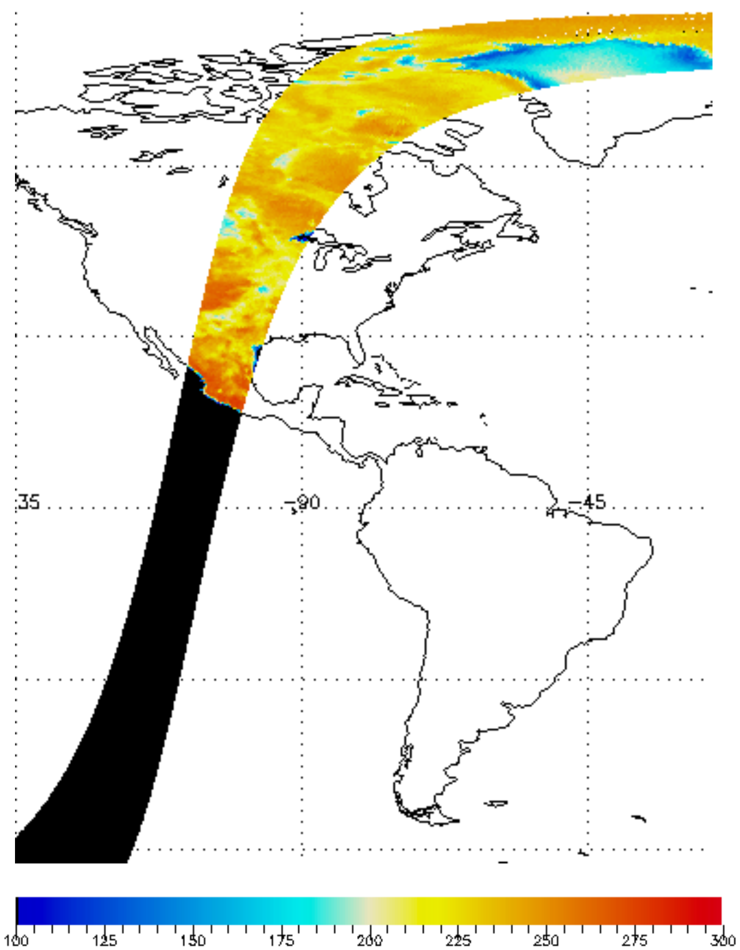
- Each granule contains geographically ordered data in 1 km grid cells in an along track/cross track swath grid.
- Coverage is restricted to land and coastal water over one spacecraft half orbit.
- SAR provides high-resolution single-look measurements. Resolution varies from ~400 m at the swath edge 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 1 km resolution over 70% of the swath. Resolution degrades in the nadir region.
- Forward looking and aft looking measurements 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.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

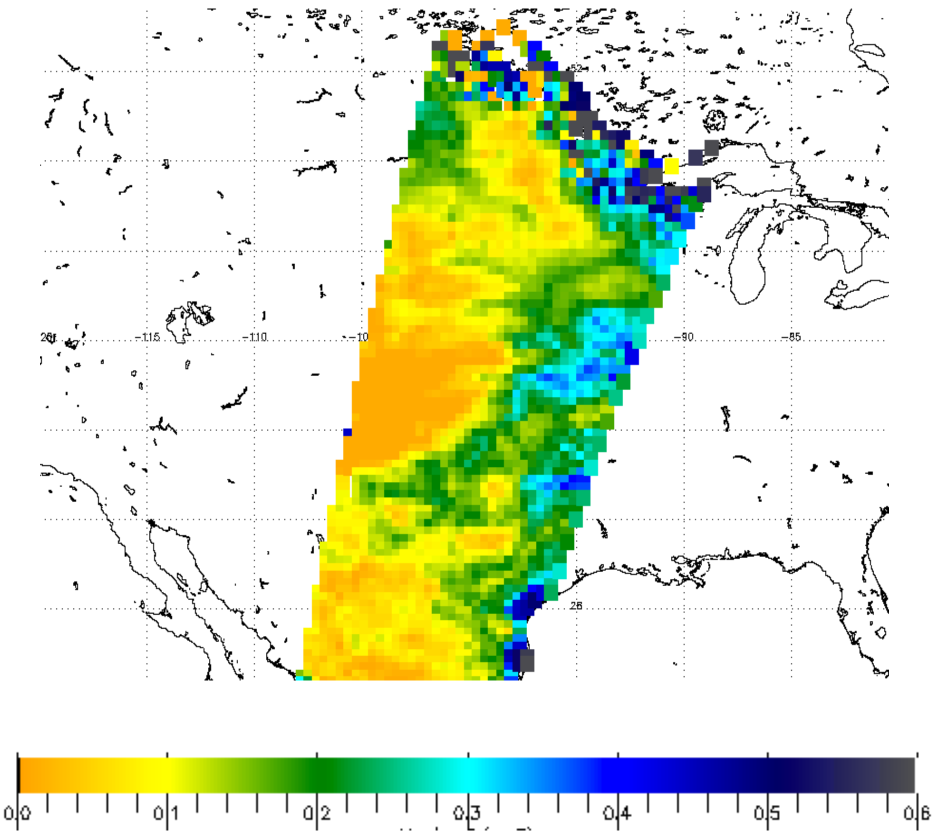
Radiometer Level 1B Product



L1B Time-ordered H-pol TB (K)

- Each granule contains time ordered data that covers one spacecraft half orbit
- Effective field of view footprint is a 39 km by 47 km ellipse
- Earth-located calibrated data for each EFOV
  - Apparent aperture (antenna) temperatures
  - Top-of-ionosphere (TOI) brightness temperature
  - Surface-referenced brightness temperatures
- Coverage continuous over all surface types.
- All four modified Stokes parameters (V, H, 3 & 4)
  - 3rd Stokes used for Faraday rotation correction
  - Brightness temperature third Stokes is always zero
- Time-frequency-polarization diversity used for RFI detection and removal
- Forward looking and aft looking measurements stored separately
- Includes spacecraft orbit and attitude information and instrument pointing geometry

L2 Radiometer 36 km Soil Moisture Product



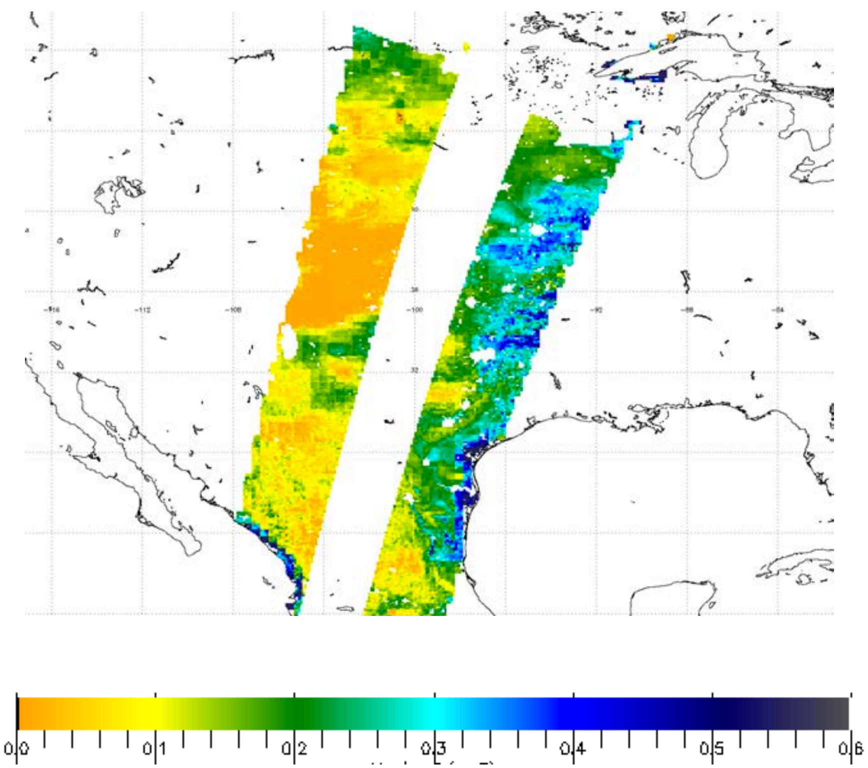
Volumetric Soil Moisture (cm^3/cm^3)

- Each granule contains one half orbit of data posted on 36 km cylindrical EASE grid cells
- Data are represented in a one dimensional array
- Product lists only those EASE grid cells within the half orbit swath
- 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
- Applies water body correction and freeze-thaw state detection that were generated with high resolution radar retrievals
- Estimates soil moisture based on AM observations
- Includes quality masks for urban areas, mountainous terrain, dense vegetation, precipitation, snow and ice

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

L2 Active/Passive 9 km Soil Moisture Product

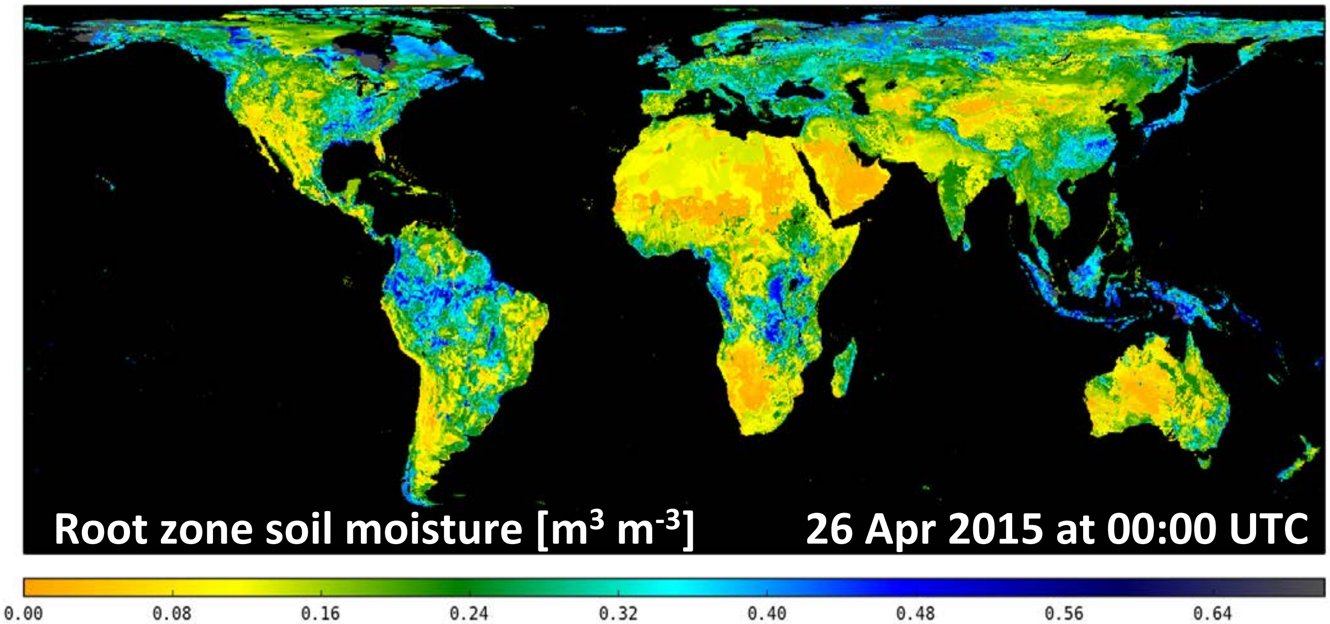


Volumetric Soil Moisture (cm^3/cm^3)

- Each granule contains one half orbit of data posted on 9 km cylindrical EASE grid cells
- Data are represented in a one dimensional array
- Product lists only those EASE grid cells within the half orbit swath.
- Merges radar and radiometer channels using a time series algorithm and spatial heterogeneity of L1C radar product
- Provides dis-aggregated brightness temperatures at 9 km resolution
- 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
- Employs transient water body and freeze-thaw state generated with high resolution radar retrievals
- Include quality masks for urban areas, mountainous terrain, dense vegetation, precipitation, snow and ice

L4 Surface and Root-Zone Soil Moisture Product

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

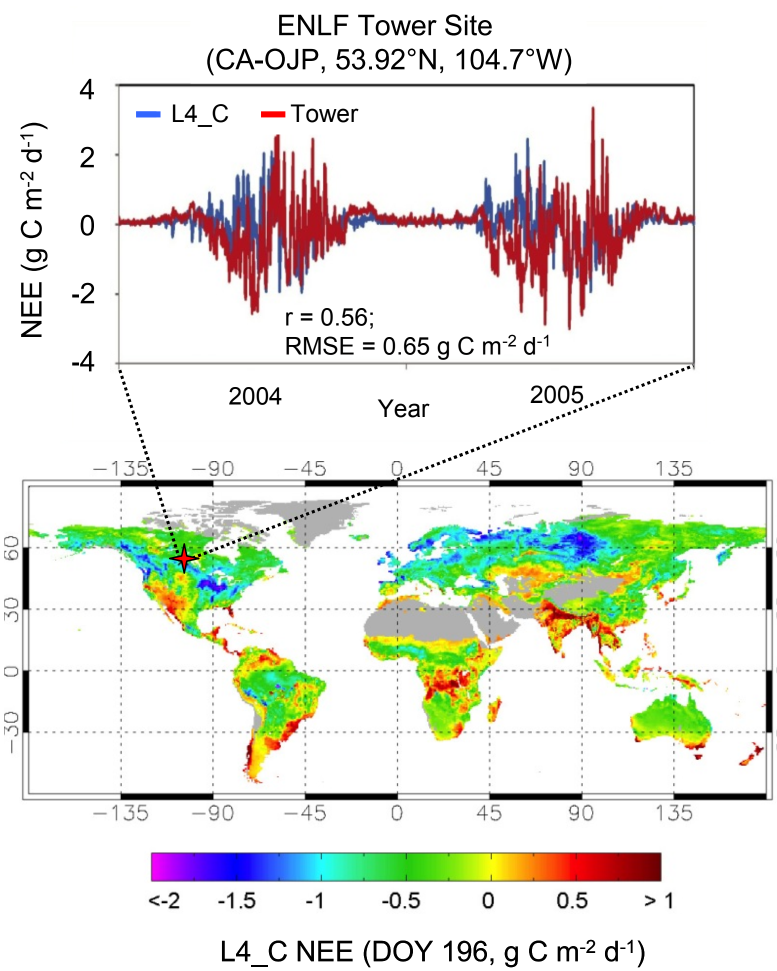


- Global product, presented in two collections
- Based on assimilation of SMAP brightness temperatures from the L1C_TB and L2_SM_AP products into a state-of-the-art land surface model

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**

L4 Carbon Product

Mean Daily net CO_2 Exchange



- Daily global maps of net ecosystem CO_2 exchange (NEE) at 9 km resolution with 14-day latency
- Quantifies the net carbon flux in boreal landscapes
- Reduces uncertainty with regard to existing carbon sinks on land
- Applies a soil decomposition algorithm driven by SMAP L4_SM and Gross Primary Production (GPP) inputs to compute net land-atmosphere CO_2 exchange (NEE)
- Accuracy commensurate with tower based CO_2 observations (RMSE ≤ 30 g C m^{-2} yr^{-1} or 1.6 g C m^{-2} d^{-1})

SMAP Resources at the ASF DAAC

The ASF DAAC archives and supports user services for SMAP Radar Level 1 Products

1. ASF SMAP web interface at https://www.asf.alaska.edu/smap

2. ASF Data Access and Distribution
   a. ASF API at https://portal.asf.alaska.edu/get-data/api
   b. Vertex at https://vertex.daac.asf.alaska.edu

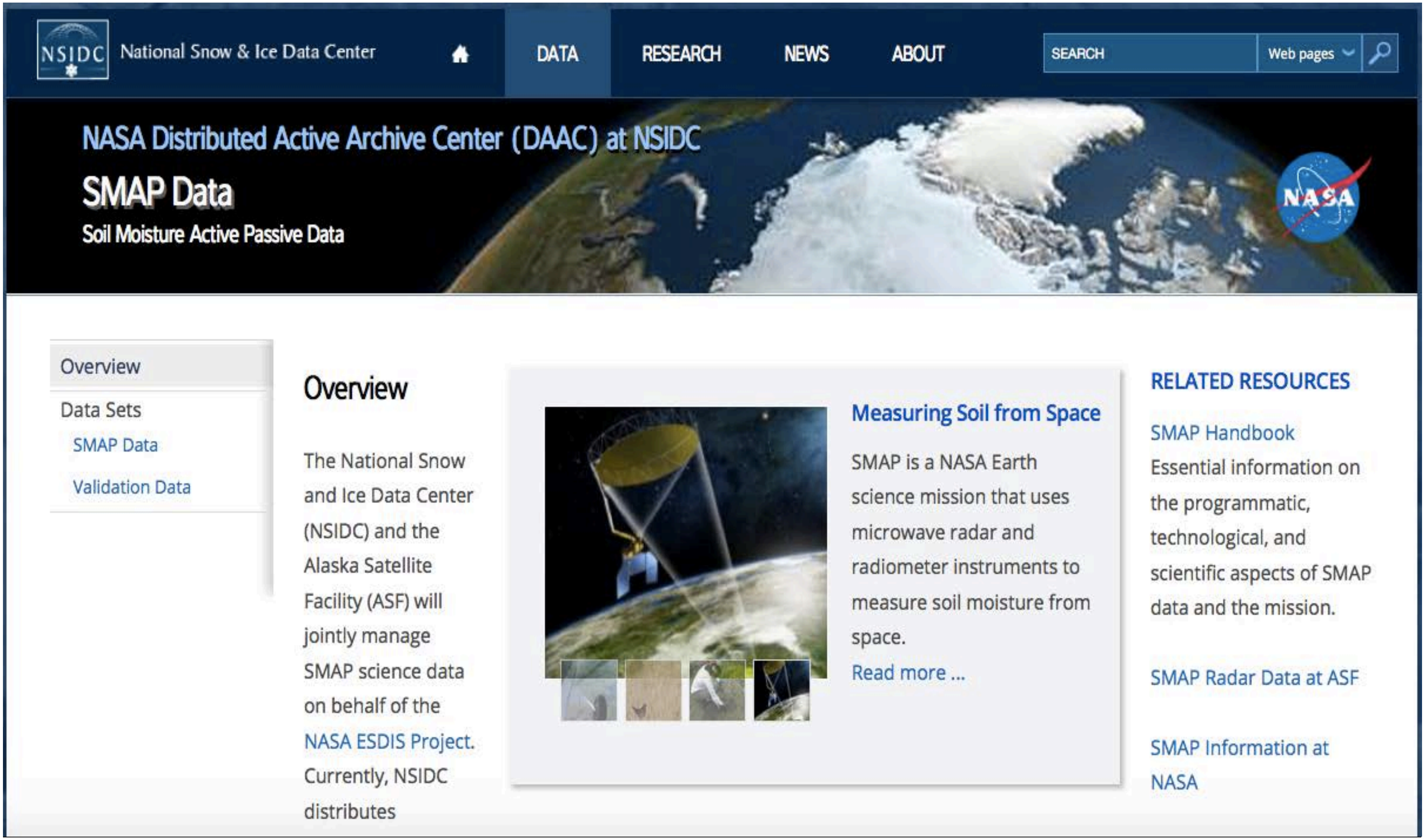
3. ASF User Services and Points of Contacts
   a. User Services Representative (uso@asf.alaska.edu)
   b. Project Manager – Scott Arko (saarko@alaska.edu)
   c. Product Owner – Angela R. Allen (arallen@alaska.edu)

SMAP Resources at the NSIDC DAAC

The NSIDC DAAC archives and provides user support for Level 1 Radiometer Products as well as all SMAP Level 2, Level 3 and Level 4 Products

- SMAP Web site
  - http://nsidc.org/data/smap/
- NSIDC Data Search
  - http://nsidc.org/data/search/
- SMAP Data Tools
  - Will be released with data products
  - Subsetting and reformatting on-demand services
  - HDF utilities. Matlab and IDL readers
- User Support
  - http://nsidc.org/forms/contact.html
  - nsidc@nsidc.org

SMAP Website at NSIDC DAAC



National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Worldview

EOSDIS Data Visualization, Discovery, and Download Tool for GIBS

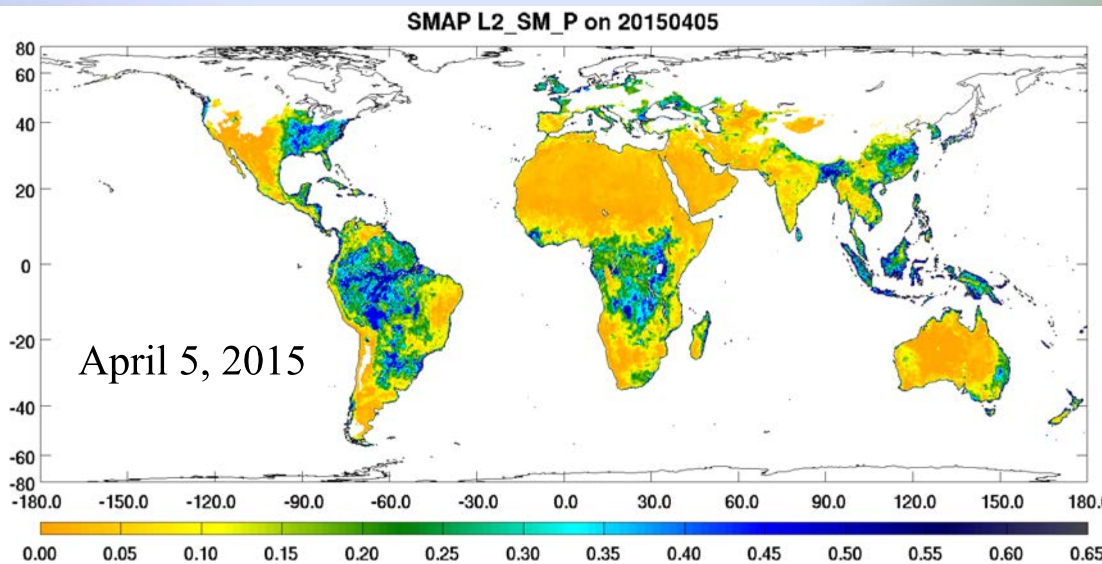
- General-purpose, full-resolution satellite imagery browser built to
  - Explore
  - Compare
  - Download
  - Share
  - Educate
- Web browser-based and open source

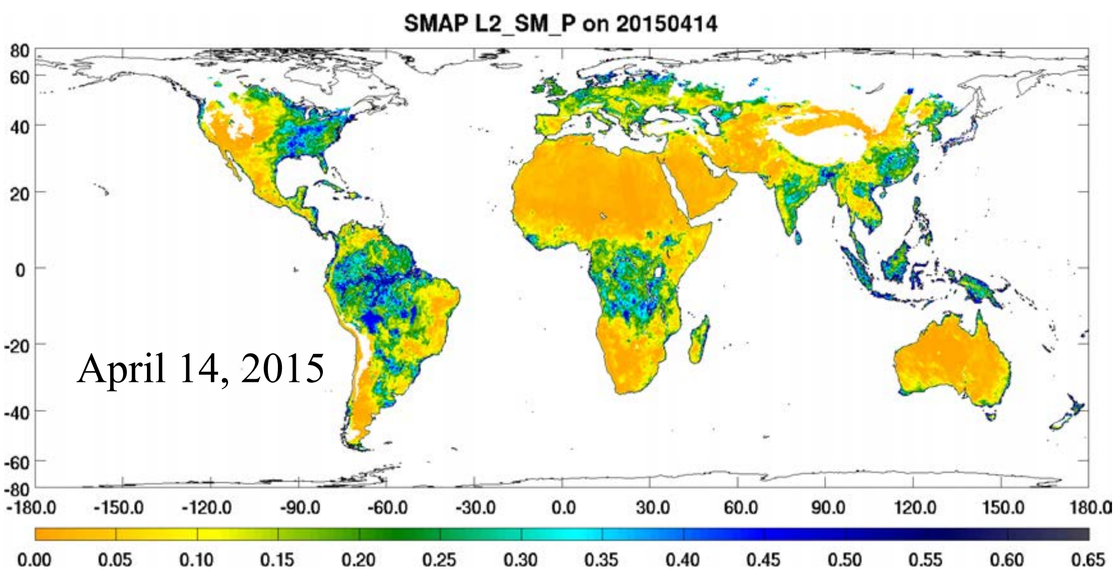
https://earthdata.nasa.gov/worldview

https://github.com/nasa-gibs/worldview

Soil Moisture Product (36 km) Observed Changes

- Passive data successfully processed into soil moisture
- Soil moisture patterns agree with expected geographical soil moisture distribution

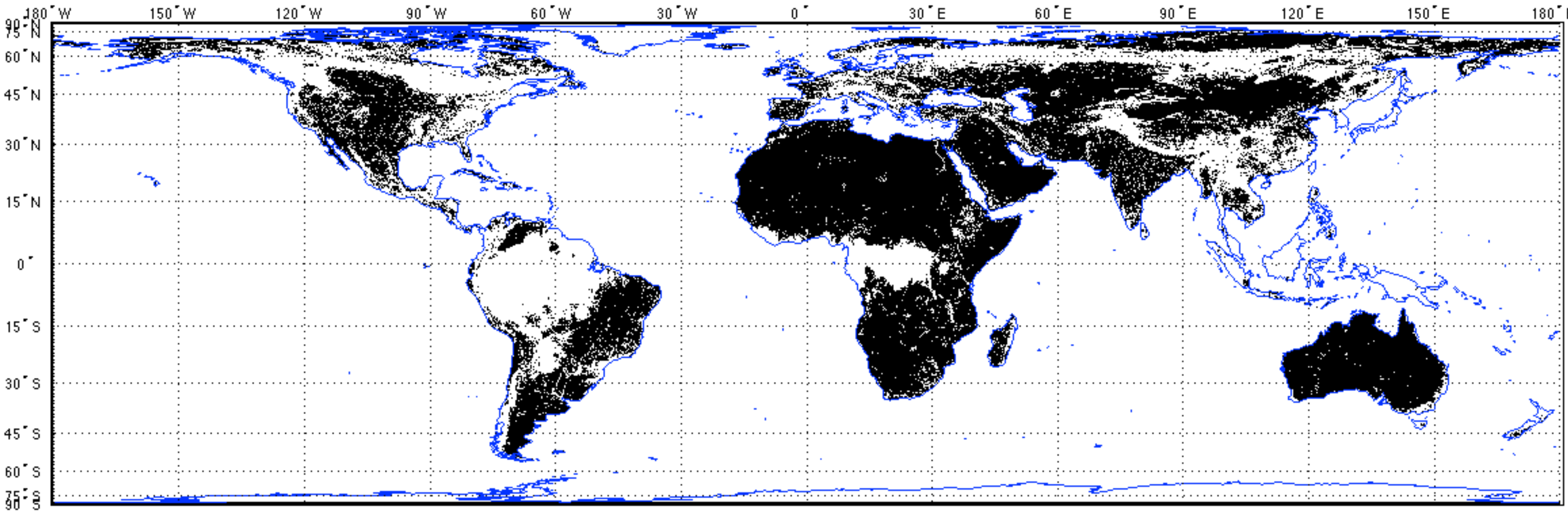




- Soil moisture changes are evident in the time-sequence
- Rainfall in India, Bangladesh, and Vietnam
- Dry-down in eastern Australia and Argentina

Soil Moisture Product Expected Accuracy

Regions where SMAP soil moisture retrievals are expected to meet accuracy requirement of 0.04 m^3/m^3



Retrieval expected quality mask (black colored pixels) prepared with following specifications:

a) Vegetation water content $\leq$ 5 kg/m^2
b) Urban fraction $\leq$ 0.25
c) Water fraction $\leq$ 0.1
d) DEM slope standard deviation $\leq$ 3 deg

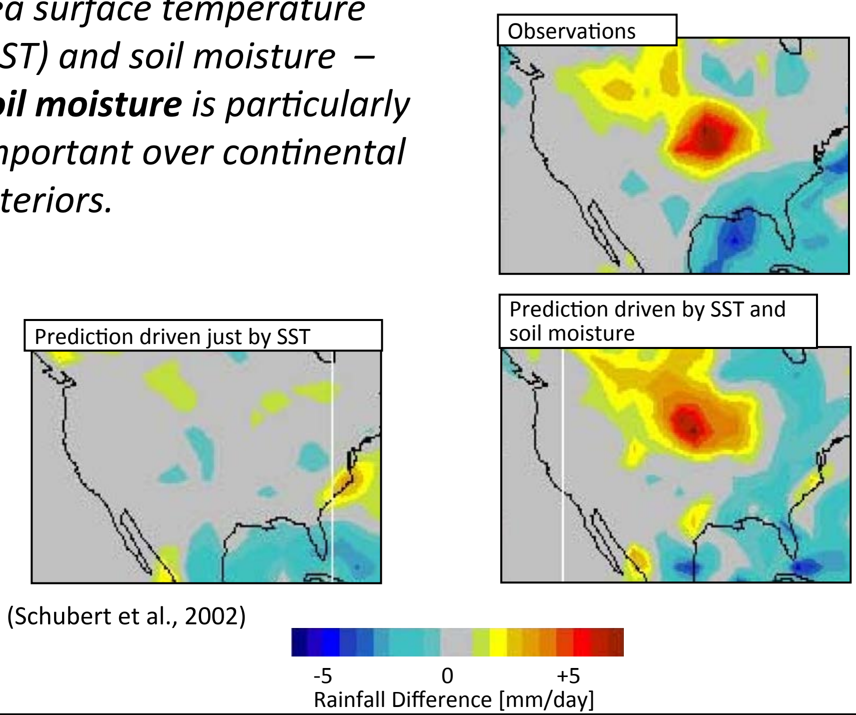
Value of Soil Moisture Data to Weather and Climate

New space-based soil moisture observations and data assimilation modeling can improve forecasts of local storms and seasonal climate anomalies

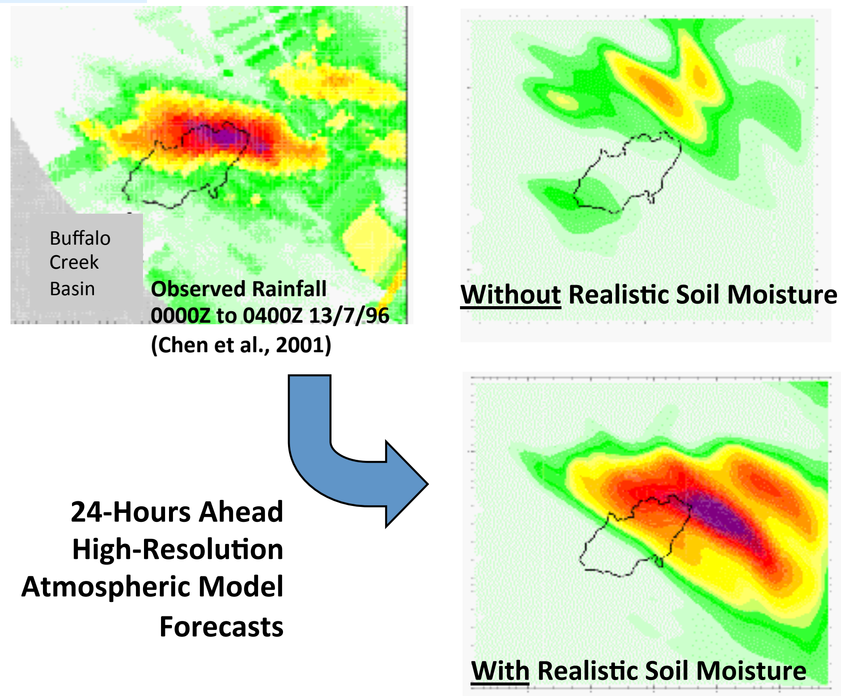
Seasonal Climate Predictability

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

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

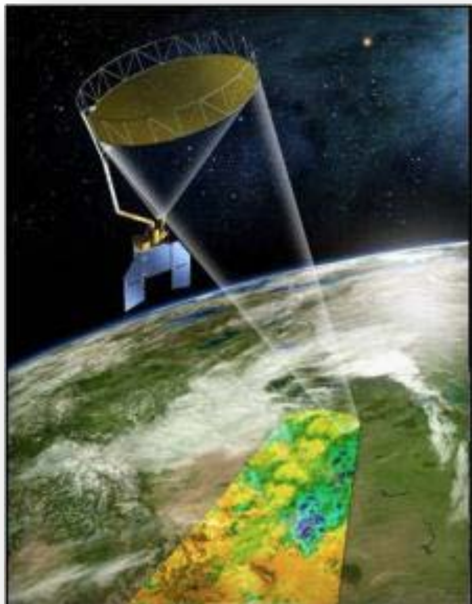


NWP Rainfall Prediction



In weather forecasting, SMAP surface soil moisture, with x10 higher resolution than existing model estimates, will result in enhanced predictions.

A Flood Example



Application of a SMAP-Based Index for Flood Forecasting in Data-Poor Regions

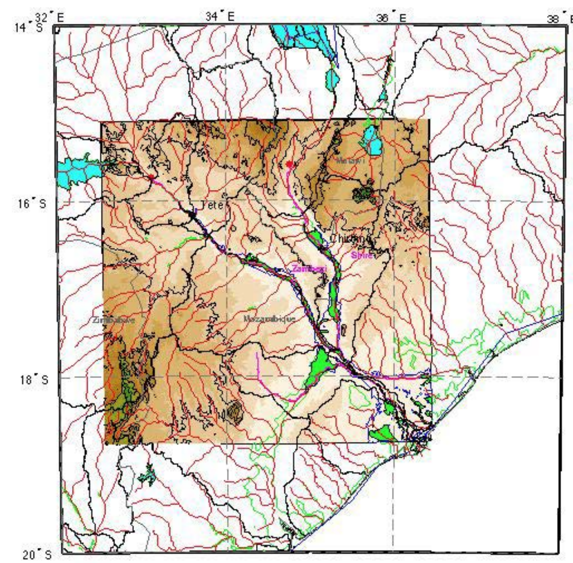
Current Capability: The UN-WFP uses satellite derived flood maps to locate floods and map delivery routes to affected areas.

Enhanced Capability: Use SMAP to expand their current flood database with look-up information that produces flood indices for a given rainfall forecast (ECMWF) and soil moisture condition (SMAP).

Study Area: Zambezi basin and its delta in Mozambique.

Algorithm Structure: VIC output on flow is input into a hydrodynamic model (LISFlOOD-FP), which is complemented with a sub-grid channel formulation to generate flood inundation variables (inundated area, floodplain water volume) for the lower Zambezi basin. ECMWF archived forecast rainfall data is used to compute flows for daily inundation patterns over 10 years.

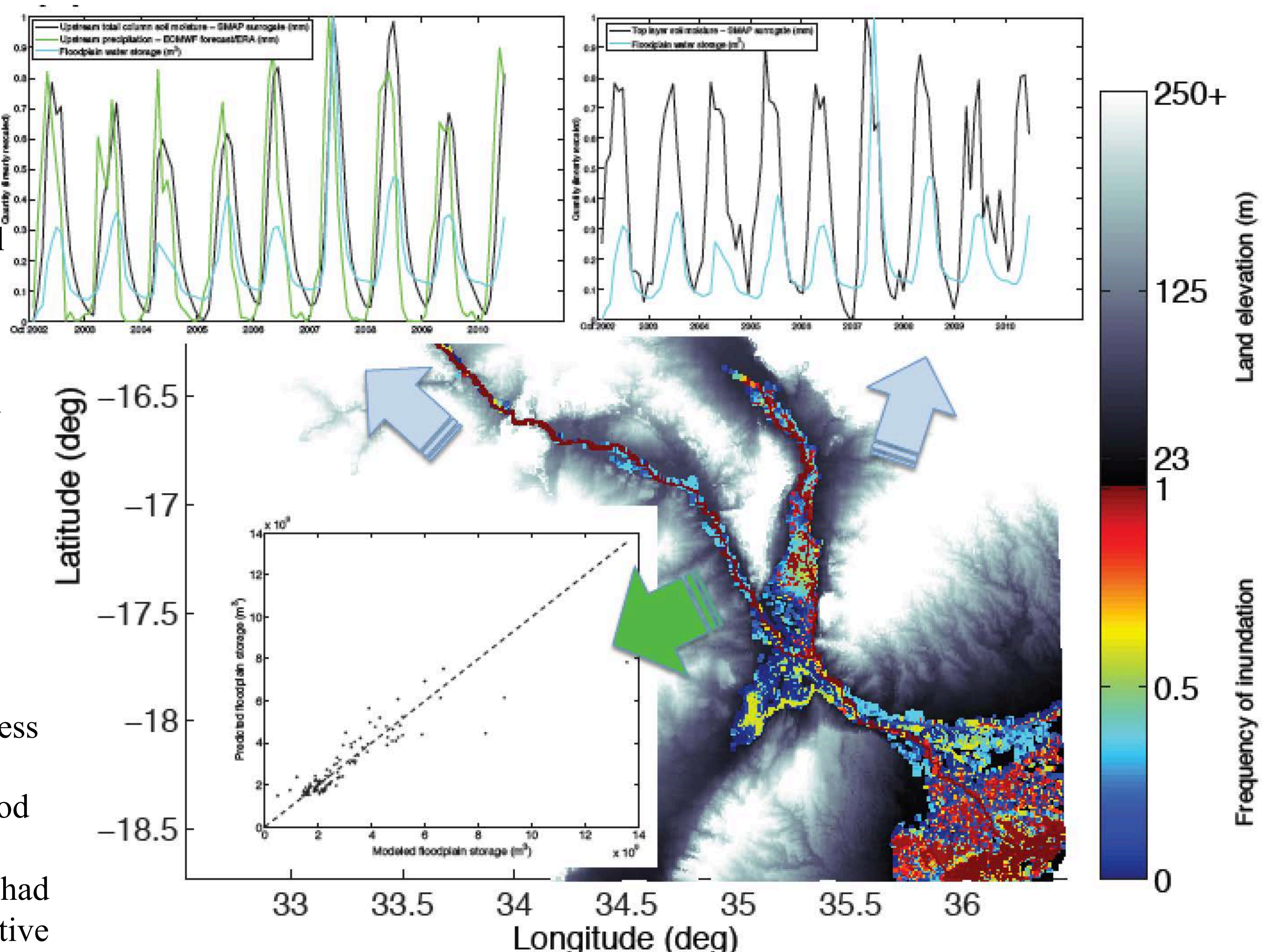
Courtesy of
Guy Schumann
UCLA



A Flood Example: Results

Long-term variations in upstream rainfall and soil moisture column vs. floodplain inundation volume (top left panel) and downstream top layer soil moisture (top right panel). Upstream rainfall plus soil moisture 0.88 and rainfall only 0.49. Downstream top layer soil moisture 0.52. The map depicts long-term variations in floodplain inundation patterns from the LISFLOOD-FP flood model. Regression model results for predicting floodplain inundation volume are shown in the bottom left scatter plot.

These variables were used to regress and predict floodplain inundation volume for the February 2007 flood event, which was taken out when regressing. The regression model had a relative bias of 17%, with a relative error in predicting the 2007 event of 33%.



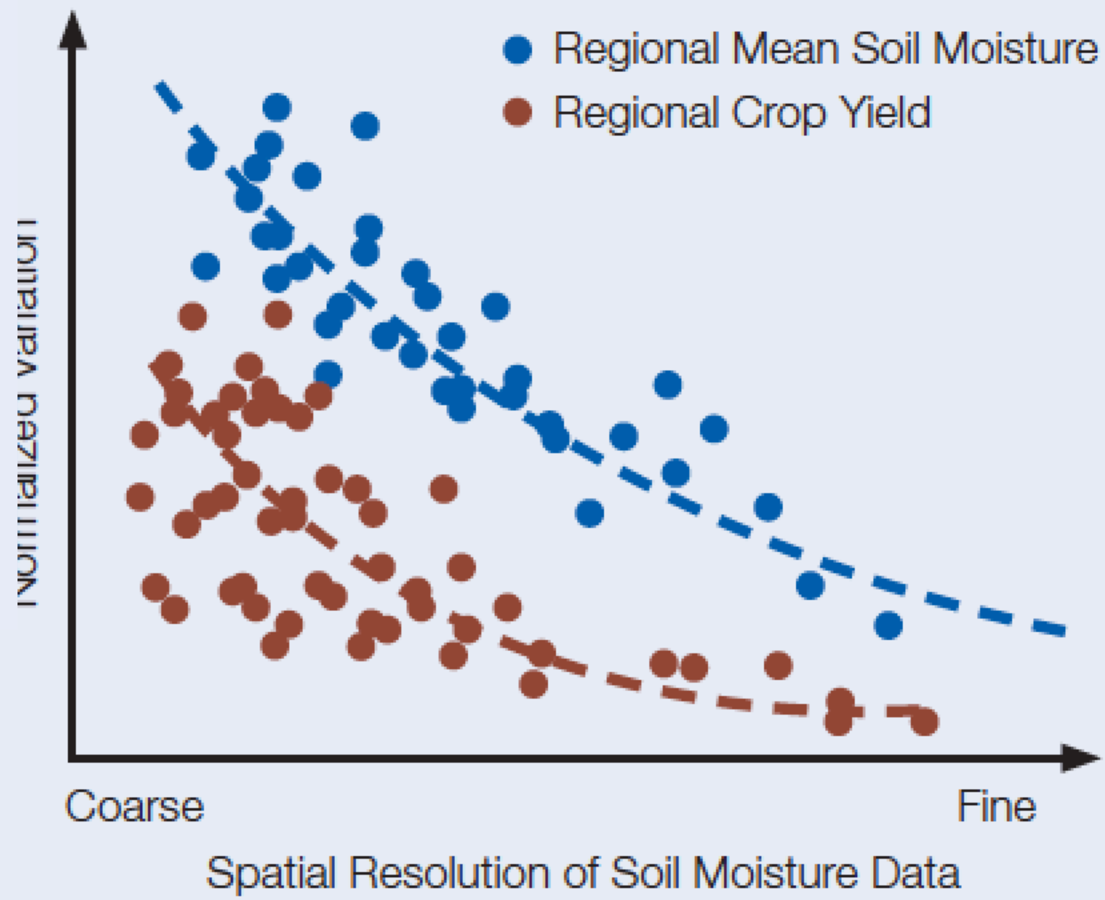
Courtesy of Guy Schumann, UCLA

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Crop Yield Modeling

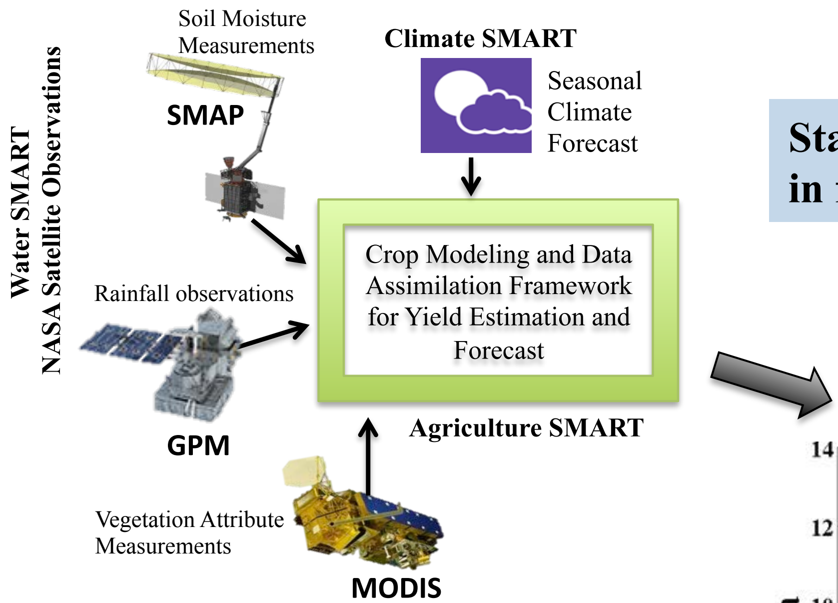
Agricultural models have been developed to predict the yield of various crops at field and regional scales. One key input of the agricultural models is soil moisture. The conceptual diagram relates variation in regional domain-averaged soil moisture to variation in total crop yield. Statistical analysis would lead to the development of probability distributions of crop yield as a transformation of the probability distribution of domain averaged soil moisture at the beginning of the growing season.



National Aeronautics and Space Administration

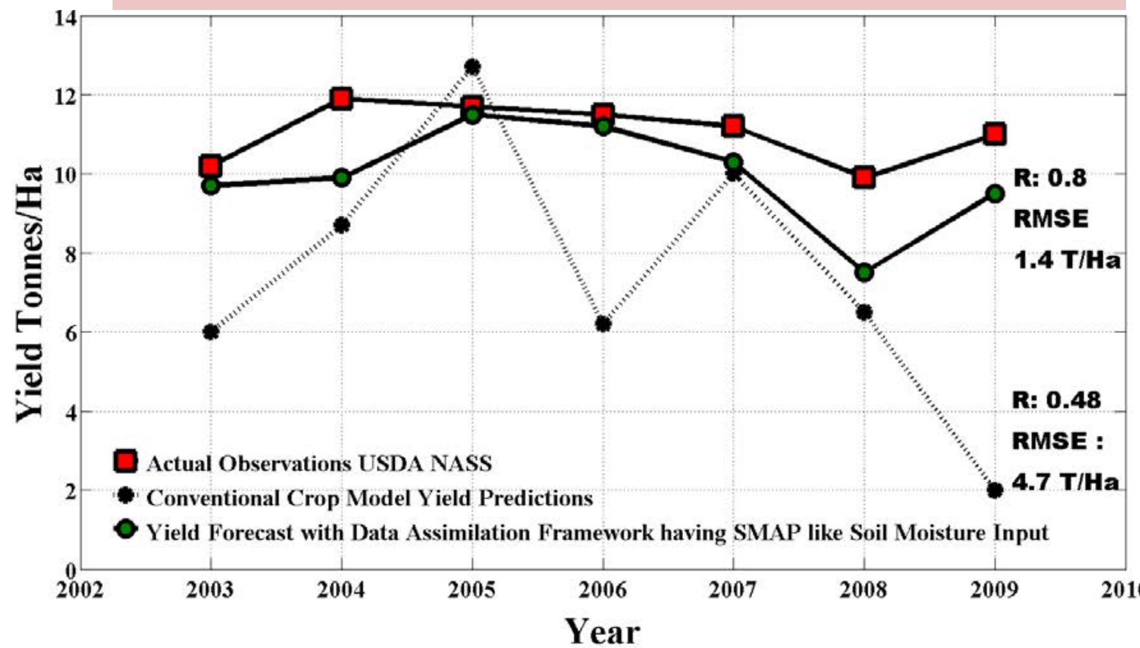
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

SMAP for Agricultural Crop Yield and Food Security Applications



Statement of Problem: The world faces an uphill struggle in feeding a projected nine to ten billion people by 2050.

Corn Yields with Improved Estimation and Optimal Forecast based on use of SMAP-like Soil Moisture Estimates



Crop Simulation Model for Maize Yield Prediction. RSE-D-12-00872R2: Remote Sensing of Environment, *In Press*

<u>Water</u> is the defining link between the climate and agriculture. To improve <u>agricultural drought decision support</u> systems and ensure <u>food security</u>, better quality and better use of <u>Soil Moisture/ Water</u> information is vital.

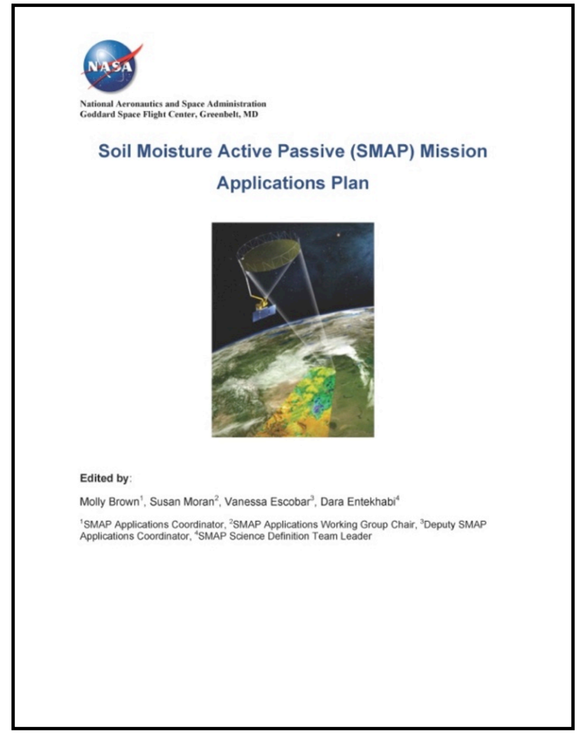
This information will increase the lead time and skill of of crop yield forecasts.

Courtesy of Narendra Das, JPL

SMAP Applications Development Approach

- A primary goal of NASA's SMAP Mission is to engage applications end users and build broad support for SMAP applications through a transparent and inclusive process.

- Toward that goal, the SMAP Mission:
  1. Formed the SMAP Applications Working Group (200+ members)
  2. Supports a SMAP Applications Coordinator
  3. Developed the SMAP Applications Plan (right)
  4. Developed the "Early-Adopter" Program (50+ Members)
  5. Holds SMAP Applications Workshops at user agencies and institutions (e.g., NOAA, USDA, USGS)
  6. Conducts hands-on tutorials and workshops


National Aeronautics and Space Administration
Goddard Space Flight Center, Greenbelt, MD

Soil Moisture Active Passive (SMAP) Mission
Applications Plan

Edited by:

Molly Brown[1], Susan Moran[2], Vanessa Escobar[3], Dara Entekhabi[4]

[1]SMAP Applications Coordinator, [2]SMAP Applications Working Group Chair, [3]Deputy SMAP Applications Coordinator, [4]SMAP Science Definition Team Leader

http://smap.jpl.nasa.gov/science/applications/

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

SMAP Applications Early Adopters

SMAP Early Adopters†, SMAP project contacts, and applied research topics. Many Early Adopters cross multiple applications.	
Early Adopter PI and institution **SMAP Contact**	**Applied Research Topic**
Weather and Climate Forecasting	
* **Stephane Bélair**, Meteorological Research Division, Environment Canada (EC); SMAP Contact: **Stephane Bélair**	Assimilation and impact evaluation of observations from the SMAP mission in Environment Canada's Environmental Prediction Systems
* **Lars Isaksen and Patricia de Rosnay**, European Centre for Medium-Range Weather Forecasts (ECMWF); SMAP Contact: **Eni Njoku**	Monitoring SMAP soil moisture and brightness temperature at ECMWF
* **Xiwu Zhan, Michael Ek, John Simko and Weizhong Zheng**, NOAA National Centers for Environmental Prediction (NCEP), NOAA National Environmental Satellite Data and Information Service (NOAA-NESDIS); SMAP Contact: **Randy Koster**	Transition of NASA SMAP research products to NOAA operational numerical weather and seasonal climate predictions and research hydrological forecasts
* **Michael Ek, Marouane Temimi, Xiwu Zhan and Weizhong Zheng**, NOAA National Centers for Environmental Prediction (NCEP), NOAA National Environmental Satellite Data and Information Service (NOAA-NESDIS), City College of New York (CUNY); SMAP Contact: **Chris Derksen**	Integration of SMAP freeze/thaw product line into the NOAA NCEP weather forecast models
* **John Galantowicz**, Atmospheric and Environmental Research, Inc. (AER); SMAP Contact: **John Kimball**	Use of SMAP-derived inundation and soil moisture estimates in the quantification of biogenic greenhouse gas emissions
◊ **Jonathan Case, Clay Blankenship and Bradley Zavodsky**, NASA Short-term Prediction Research and Transition (SPoRT) Center; SMAP Contact: **Molly Brown**	Data assimilation of SMAP observations, and impact on weather forecasts in a coupled simulation environment
Droughts and Wildfires	
* **Jim Reardon and Gary Curcio**, US Forest Service (USFS); SMAP Contact: **Dara Entekhabi**	The use of SMAP soil moisture data to assess the wildfire potential of organic soils on the North Carolina Coastal Plain
* **Chris Funk, Amy McNally and James Verdin**, USGS & UC Santa Barbara; SMAP Contact: **Molly Brown**	Incorporating soil moisture retrievals into the FEWS Land Data Assimilation System (FLDAS)
◊ **Brian Wardlow and Mark Svoboda**, Center for Advanced Land Management Technologies (CALMIT), National Drought Mitigation Center (NDMC); SMAP Contact: **Narendra Das**	Evaluation of SMAP soil moisture products for operational drought monitoring: potential impact on the U.S. Drought Monitor (USDM)
◊ **Uma Shankar**, The University of North Carolina at Chapel Hill – Institute for the Environment; SMAP Contact: **Narendra Das**	Enhancement of a Bottom-up Fire Emissions Inventory Using Earth Observations to Improve Air Quality, Land Management, and Public Health Decision Support
Floods and Landslides	
* **Fiona Shaw**, Willis, Global Analytics; SMAP Contact: **Robert Gurney**	A risk identification and analysis system for insurance; eQUIP suite of custom catastrophe models, risk rating tools and risk indices for insurance and reinsurance purposes

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

SMAP Applications Early Adopters Video

SMAP Early Adopters video

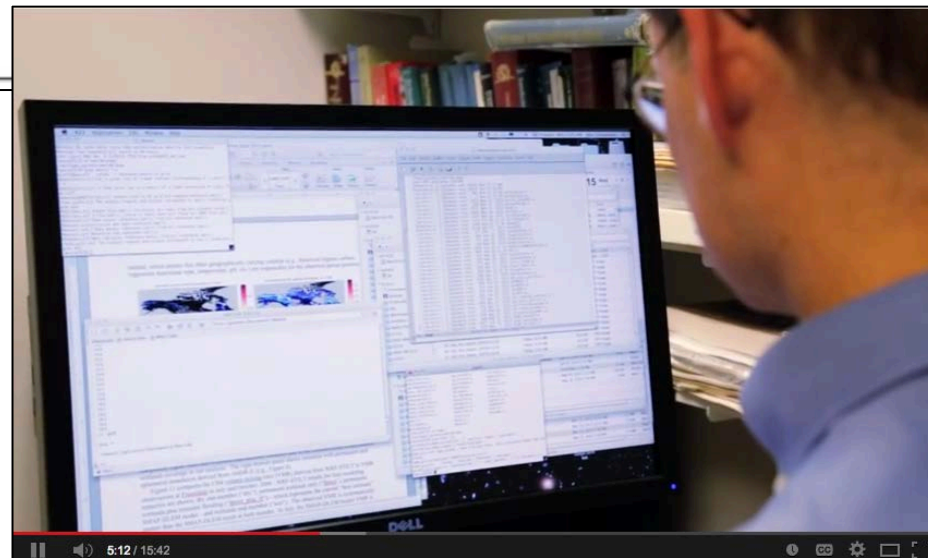
This diverse group represents a cross-section of end-users of SMAP data who collaborate to ensure integration of SMAP data into operations that affect our day-to-day lives. Examples include the U.S. Forest Service, the UN World Food Programme, and the U.S. Department of Agriculture.

VTT files: English (VTT, 18 KB) | Italian (VTT, 18 KB) | Spanish (VTT, 19 KB)

Early Adopters

http://smap.jpl.nasa.gov/early-adopters/

Thank you
for your attention!



SMAP Early Adopters

Thank You!

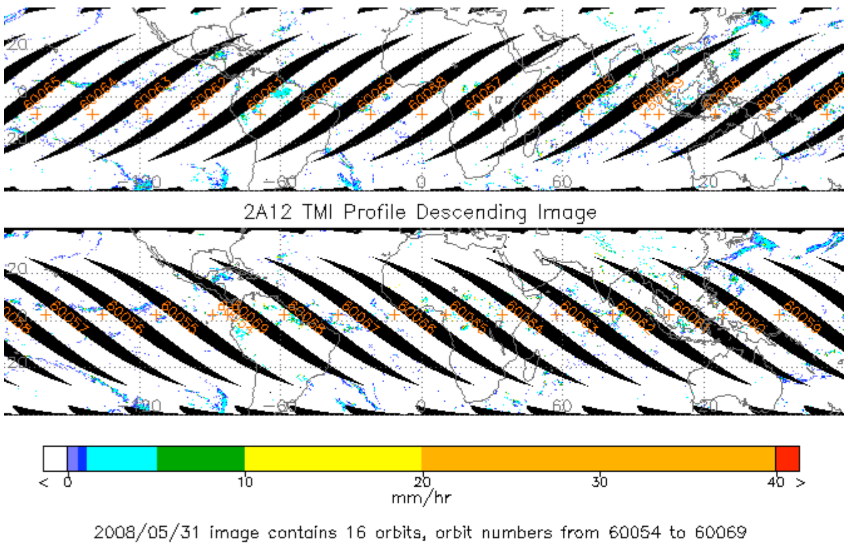
Amita Mehta

email: amita.v.mehta@nasa.gov

Extra Slides

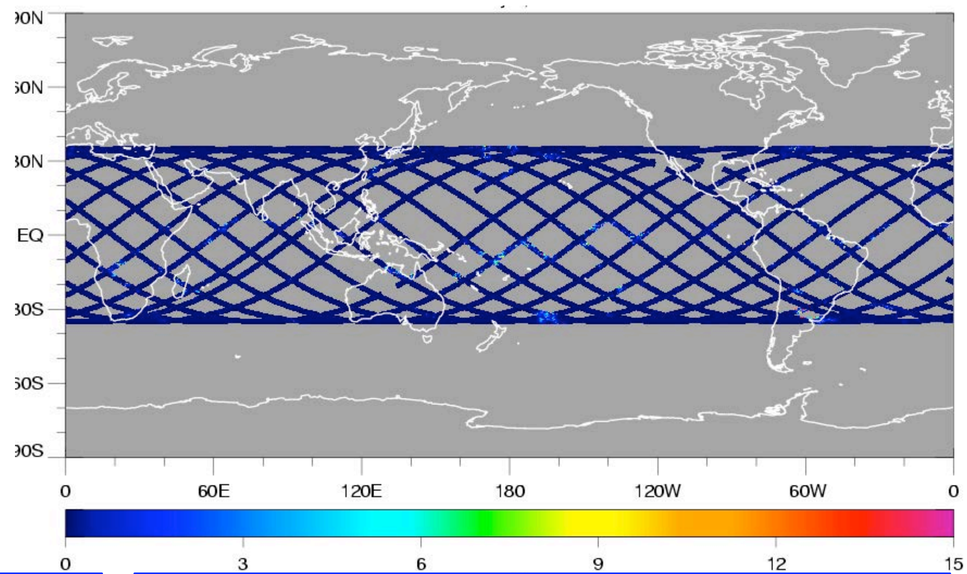
TRMM Measurements

TMI



Frequencies: 10.7, 19.4, 21.3, 37, 85.5 GH
Swath: 760 km (870* km)
Resolution: 5 to 45 km (channel-dependent)

PR+



Frequencies: 13.6 GHz
Swath: 220 km (247* km)
Resolution: 5 km

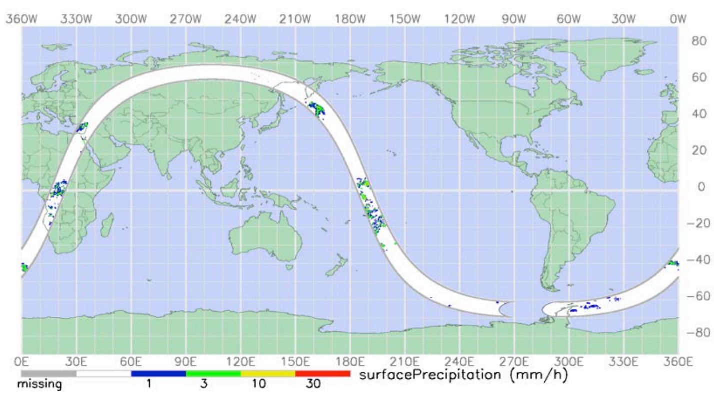
* After the orbit was raised in August 2001 +Stopped after October 7, 2014

Strength: High pixel resolution, Accurate measurements
Limitation: **No global, diurnal coverage on daily basis**

GPM Measurements

http://pmm.nasa.gov/GPM

GMI



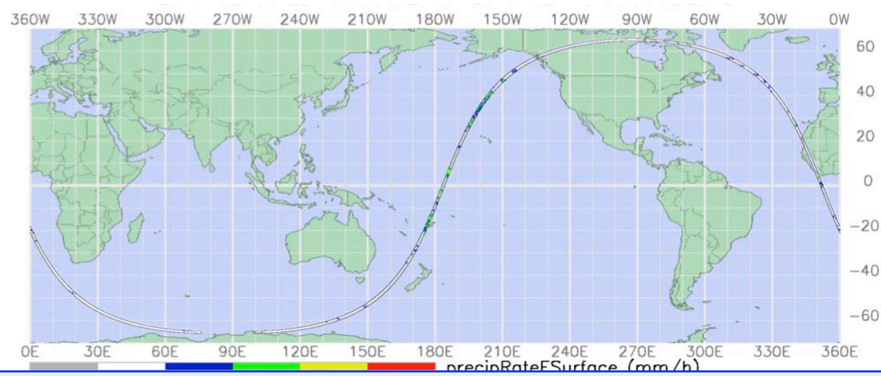
GMI Frequencies:
10.6,18.7,23.8,36.5,89,166 & 183 GHz

Swath width 885 km

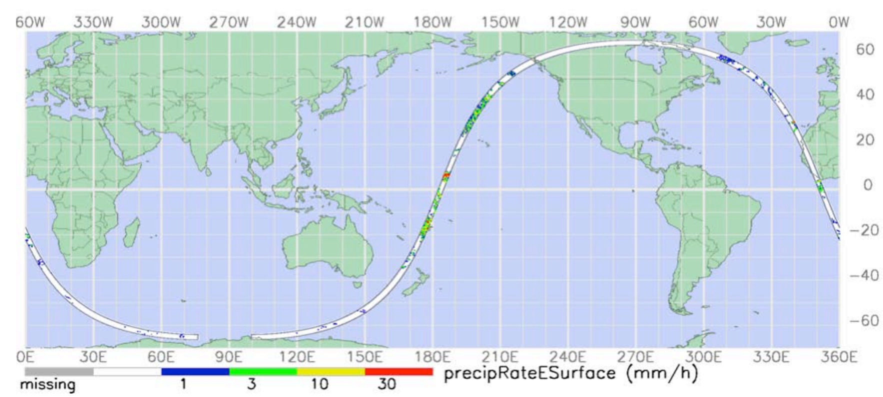
Resolution: 19.4km x 32.2km (10 GHz)
to 4.4km x 7.3km (183 GHz)

Higher spatial resolutions than TMI
High frequencies help measure snow

DPR



Ka 35.5 GHz, Swath Width 120 km, Resolution 5.2 km



Ku 13.6 GHZ, Swath Width 245 km, Resolution 5.2 km

Summary of GPM Level-2 Precipitation Products

*Surface Rainfall Rate in mm/hour

GPM data are available from March 2014 to present

Sensor/Product Name	**Spatial Resolution and Coverage**	Temporal Resolution	Data Format
DPR Ku-only/ 2A-Ku DPR Ka-only/2A-Ka DPR KU & Ka/ 2A-DPR	5.2 km x125 m Single Orbit and 16 orbits per day (70°S-70°N)	20-120 minutes 24 hours	HDF5 and OPenDAP
GMI/2A-GPROF	4 km x 4 km Orbital and 16 orbits per day (70°S-70°N)	2 – 40 hours	
Combined GMI and DPR/2A-CMB	Orbital (70°S-70°N) 5 km x 5 km, Coincident Ku-Ka-GMI footprints	3 – 40 hours	

*In addition to surface rainfall rate in mm//hour, vertical precipitation profiles and latent heating are available in these data products

Summary of GPM Level-3 Precipitation Products

*Surface Rainfall Rate in mm/hour

GPM data are available from March 2014 to present

Sensor/Product Name	**Spatial Resolution and Coverage**	Temporal Resolution	Data Format
IMERG	0.1°x0.1° (90°S-90°N)	30-minutes(Near Real Time) with 4-hour latency, 12-hour latency and 4-months latency	HDF4, NetCDF, OPenDAP, ASCII GIF, PNG Images KML for Google Earth
3-CMB Combined GMI + DPR rainfall Averages	0.1°x0.1° (70°S-70°N)	Monthly	
3-DPR rainfall Averages	0.25°x0.25° 5.0°x5.0° (67°S-67°N) for Daily (70°S-70°N) for Monthly	Daily and Monthly Daily and Monthly	
3-GPROF GMI rainfall Averages	0.25°x0.25° (90°S-90°N)	Daily and Monthly	

*In addition to surface rainfall rate in mm//hour, vertical precipitation profiles and latent heating are available in these data products