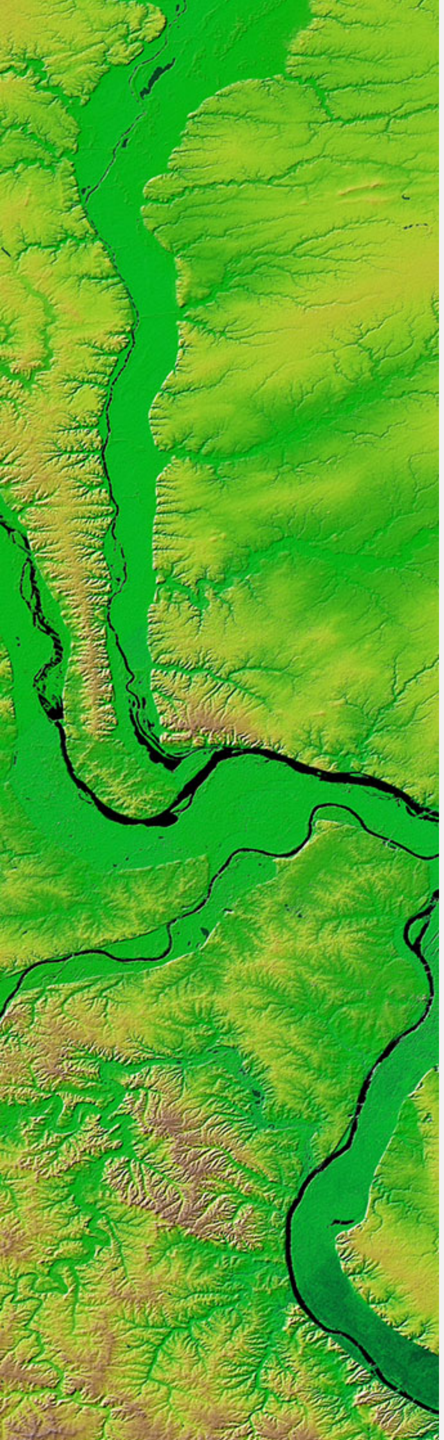


National Aeronautics and
Space Administration

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

Remote Sensing of Precipitation

Overview of Global Precipitation Measurement (GPM) and Tropical Rainfall Measurement Mission(TRMM)

Amita Mehta

Amita.v.mehta@nasa.gov

Learning Objectives for this Session

- Understand the basics of remote sensing of precipitation
- Identify NASA satellites and sensors used for deriving precipitation
  - describe precipitation data available from these sensors
  - describe data used to track heavy or extreme precipitation and flood monitoring

Presentation Outline

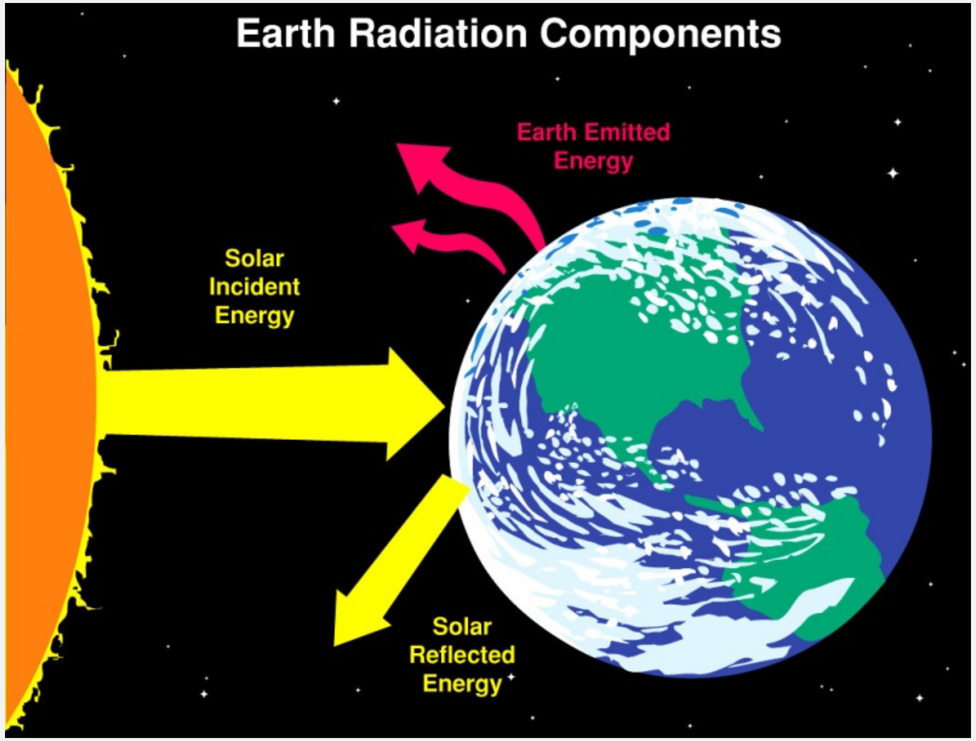
- Precipitation Remote Sensing
  - *Advantages*
- Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurements (GPM) Mission
- TRMM and GPM Data Products
- TRMM/GPM Data Access
  - Demonstration Precipitation Processing System – STORM
  - Demonstration of Giovanni

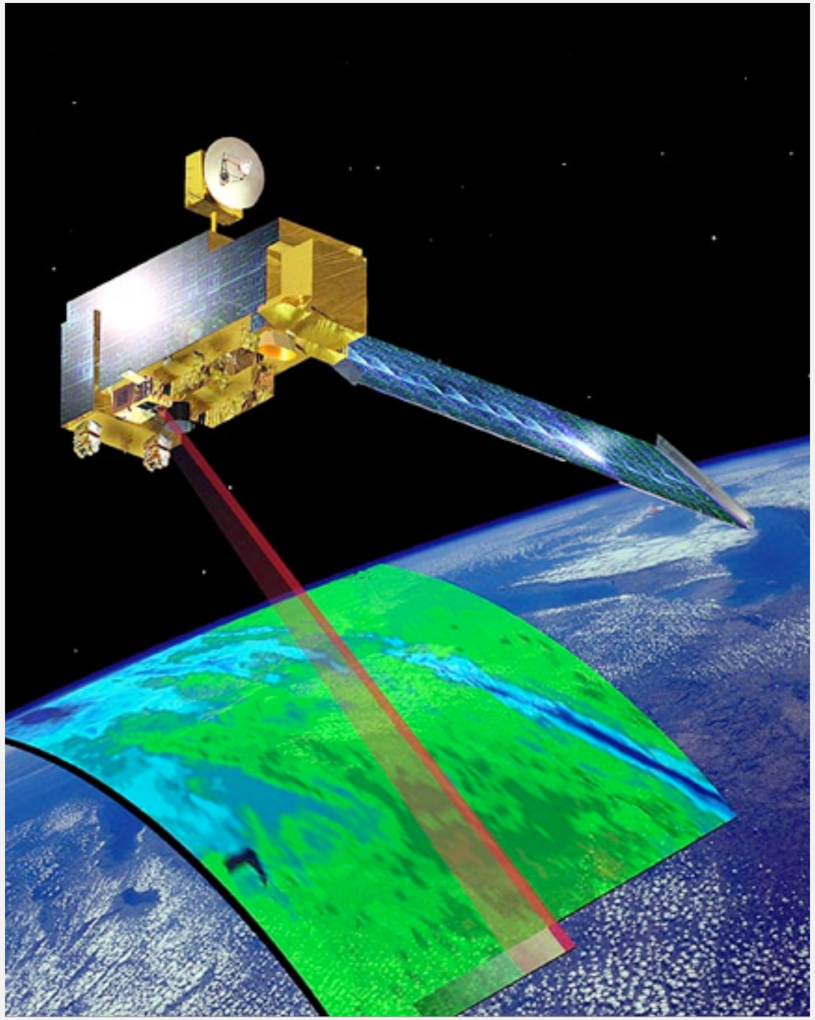
Precipitation Remote Sensing

Satellite Remote Sensing

http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing

Satellites carry instruments or sensors that measure **electromagnetic radiation** coming from the Earth-atmosphere system



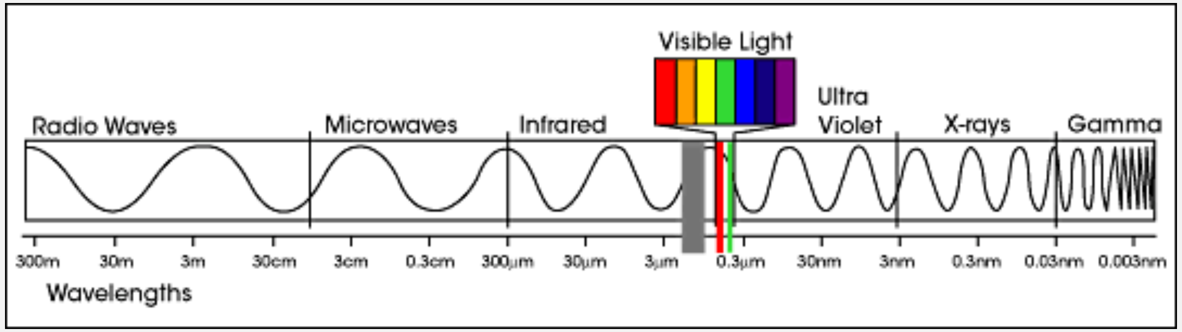


Electromagnetic Spectrum

http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing

Earth-Ocean-Land-Atmosphere System:

- Reflects solar radiation back to space
- Emits infrared and microwave radiation to space

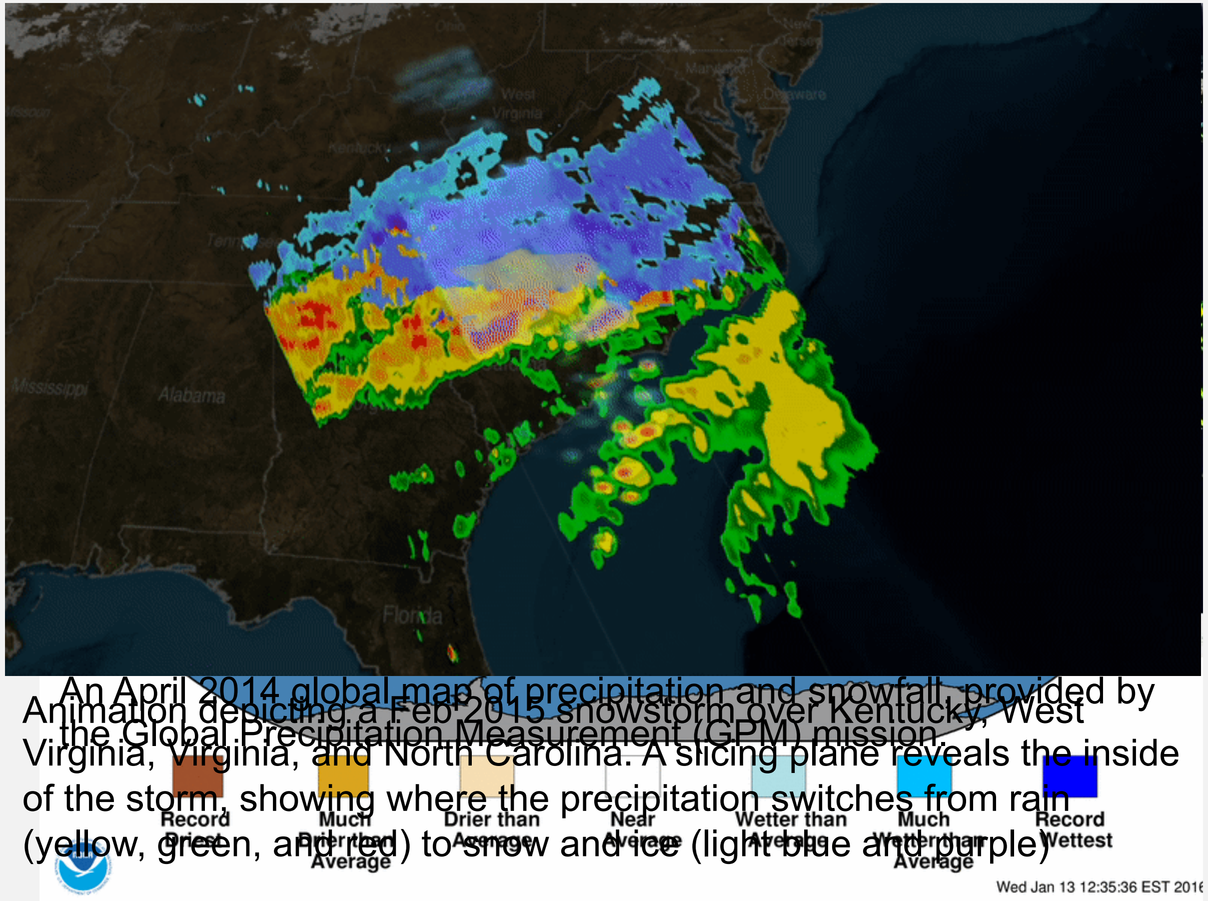


- The intensity of reflected and emitted radiation to space is influenced by surface and atmospheric conditions
- Satellite measurements contain information about both the surface and atmospheric conditions

Image Credit: UCAR COMET, comet.ucar.edu

Advantages of Remote Sensing

- Provides information where surface-based measurements are not available and augments existing measurements
- Provide global and near-global coverage with consistent observations
- Provides large-scale perspective compared to point measurements



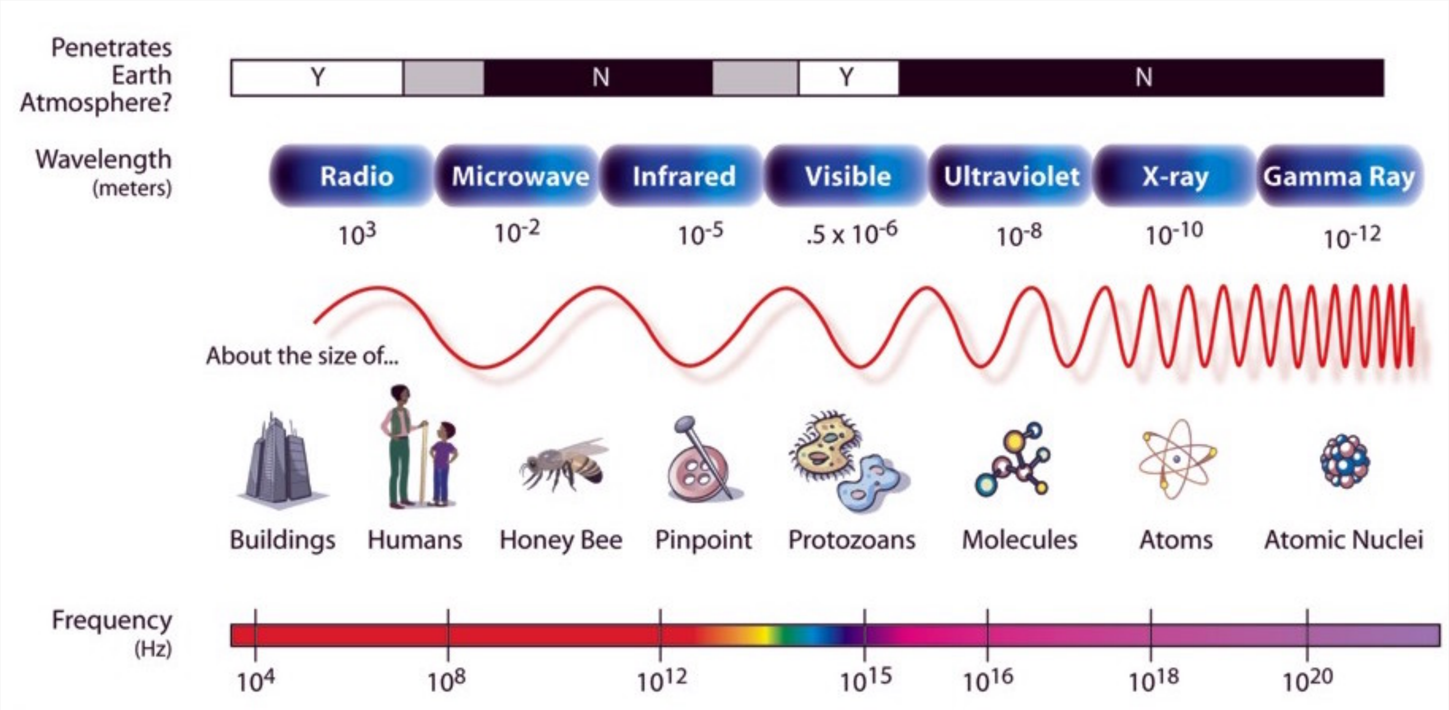
An April 2014 global map of precipitation and snowfall, provided by the Global Precipitation Measurement (GPM) mission.

Animation depicting a Feb 2015 snowstorm over Kentucky, West Virginia, Virginia, and North Carolina. A slicing plane reveals the inside of the storm, showing where the precipitation switches from rain (yellow, green, and red) to snow and ice (light blue and purple)

The dots on the global map above show land-based rain gauges. Image Credit: NOAA

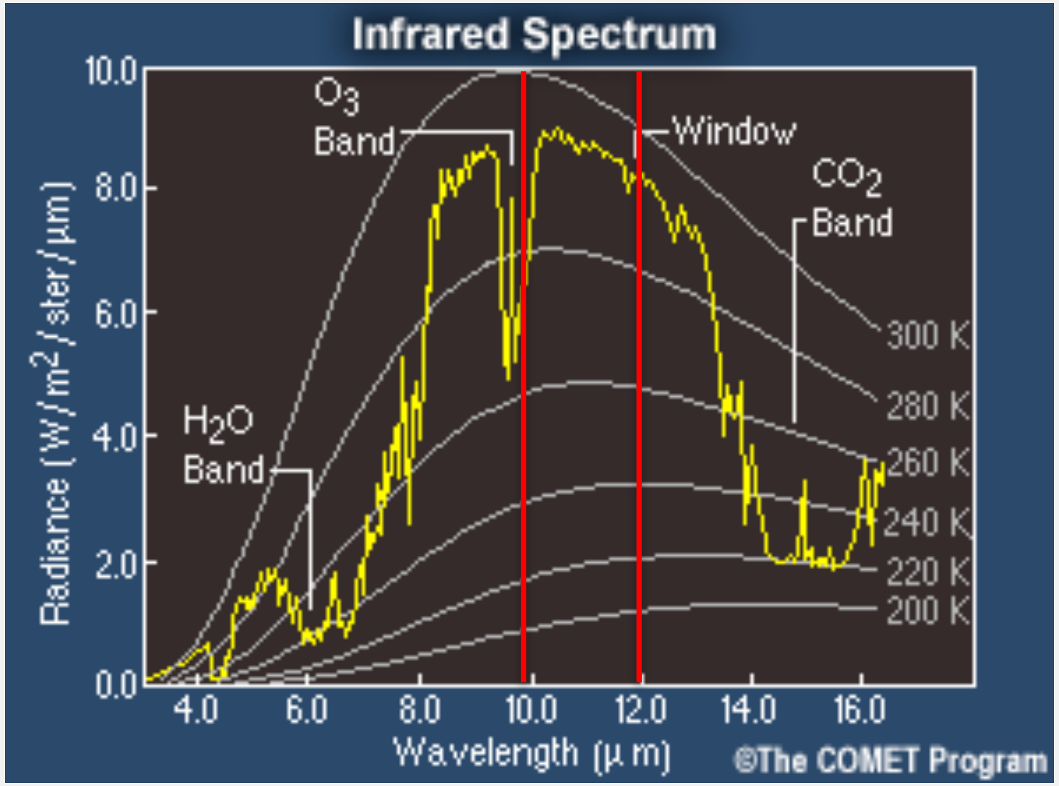
Precipitation Remote Sensing

- Derived from:
  - reflected visible radiation (0.5 to 0.6 micrometer wavelength)
  - emitted infrared radiation (10-12 micrometer wavelength)
  - emitted microwave radiation (10 to 183 Ghz frequency or mm to cm wavelength)



Precipitation Remote Sensing

Passive Remote Sensing: Inferred indirectly from emitted infrared (IR) radiation by clouds



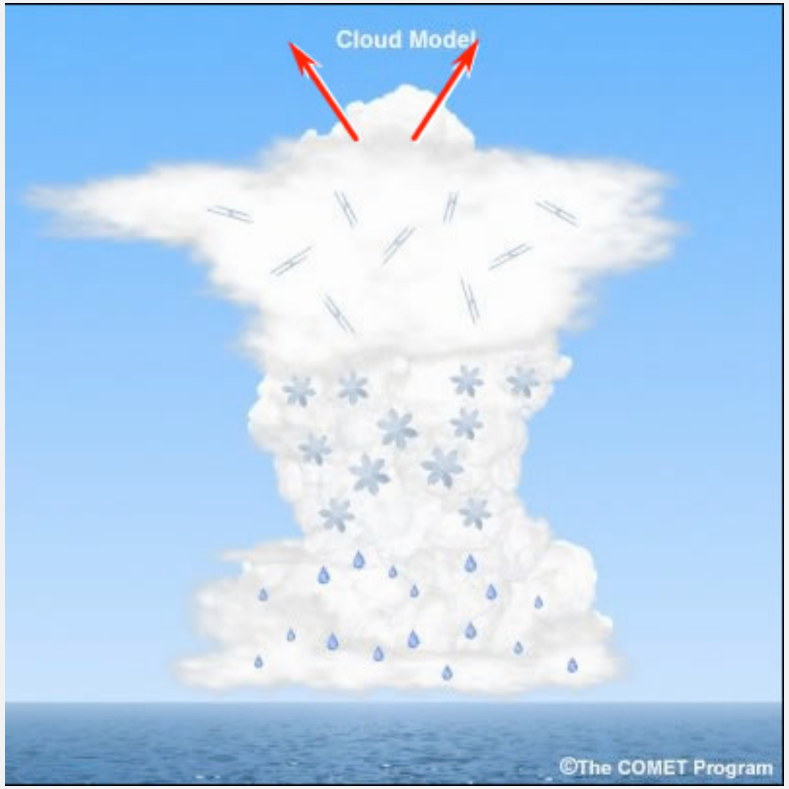
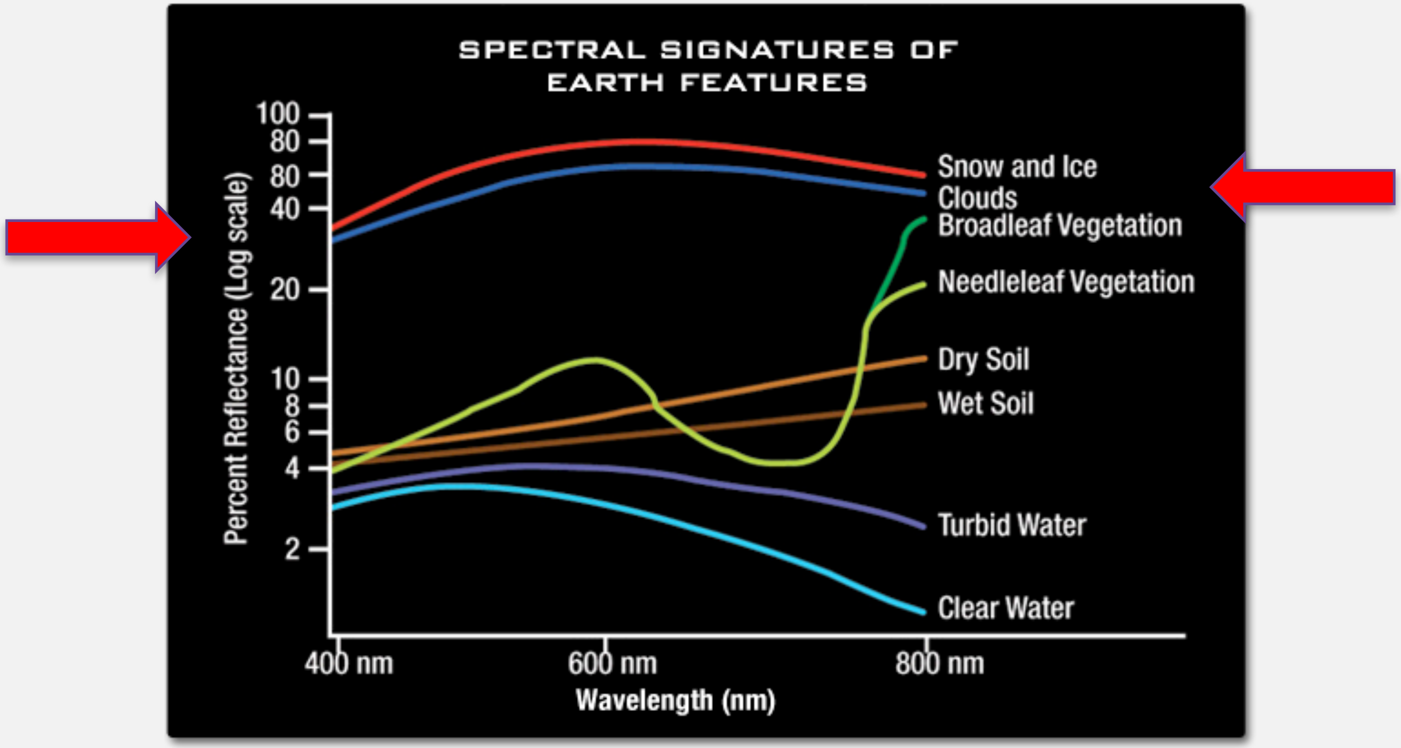


Image Credit (Left): UCAR COMET, comet.ucar.edu

Precipitation Remote Sensing

Passive Remote Sensing: Inferred indirectly from reflected solar visible (VIS) radiation by clouds



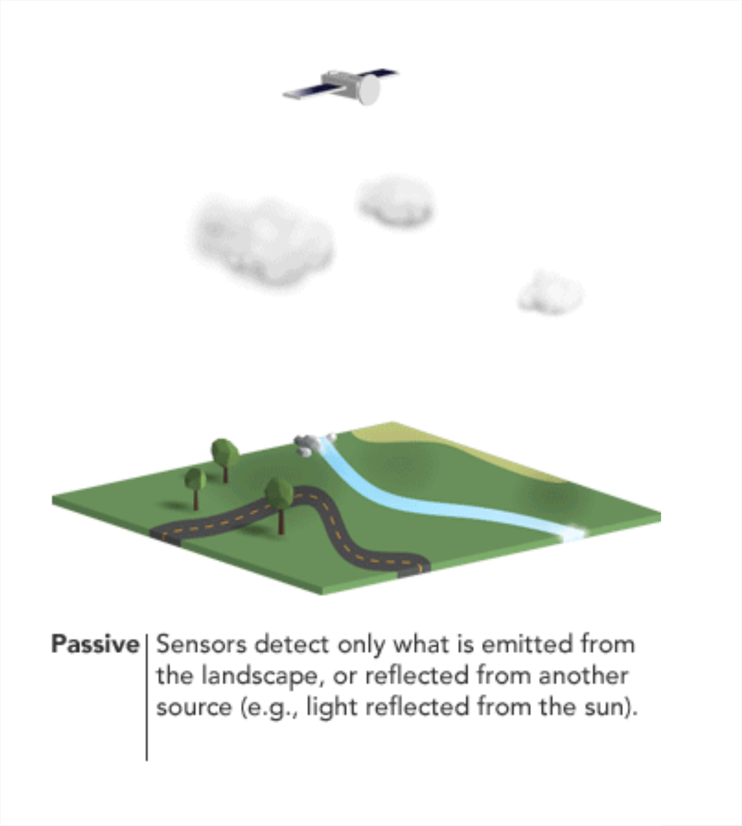
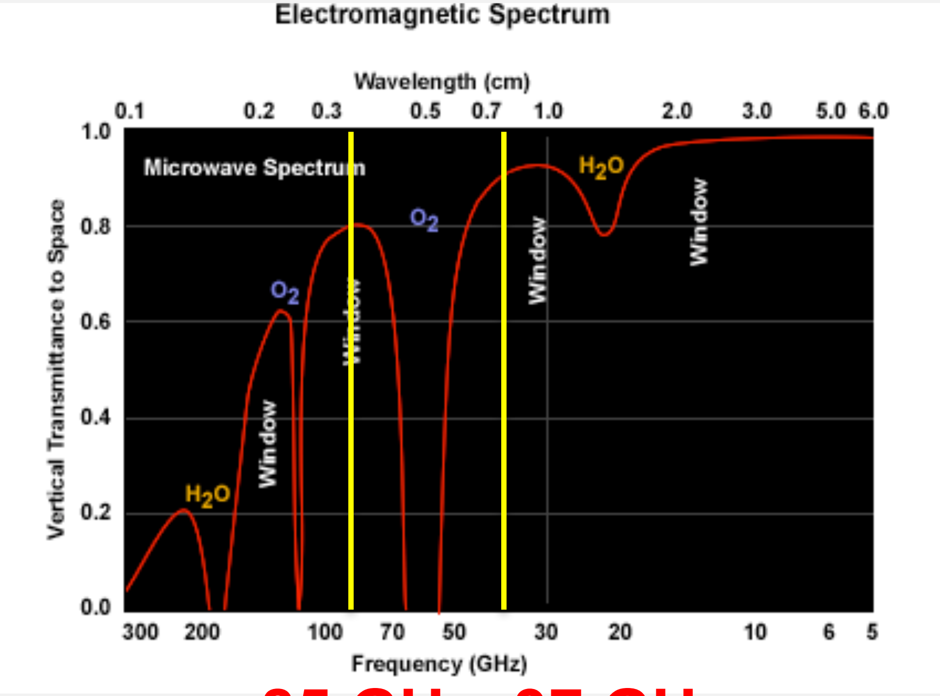


Image Credit (Left): UCAR COMET, comet.ucar.edu

Precipitation Remote Sensing

Passive Remote Sensing: Estimated from microwave radiation emitted or scattered by precipitation particles



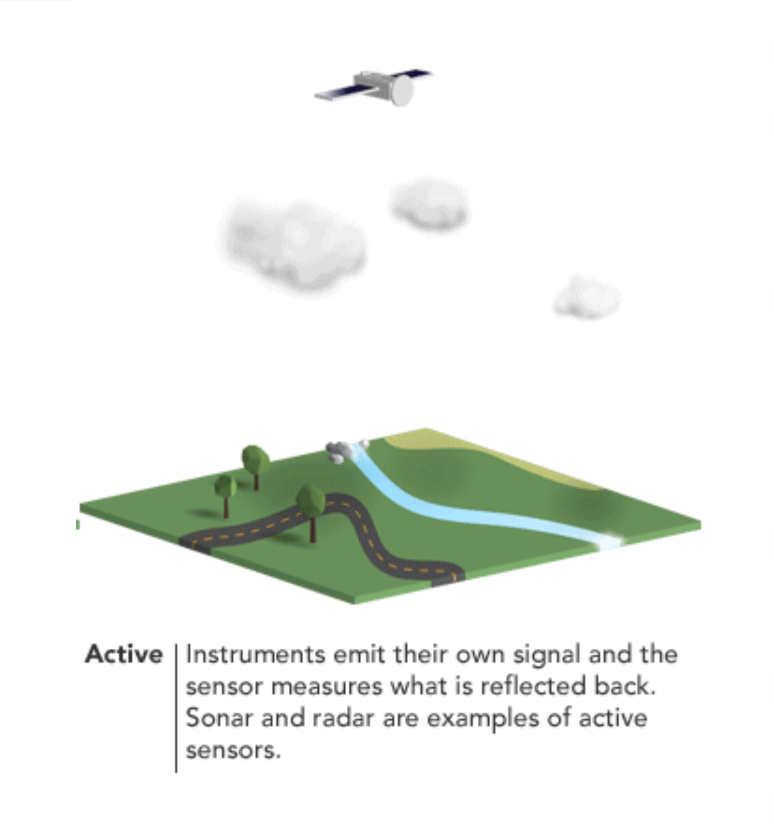
85 GHz 37 GHz

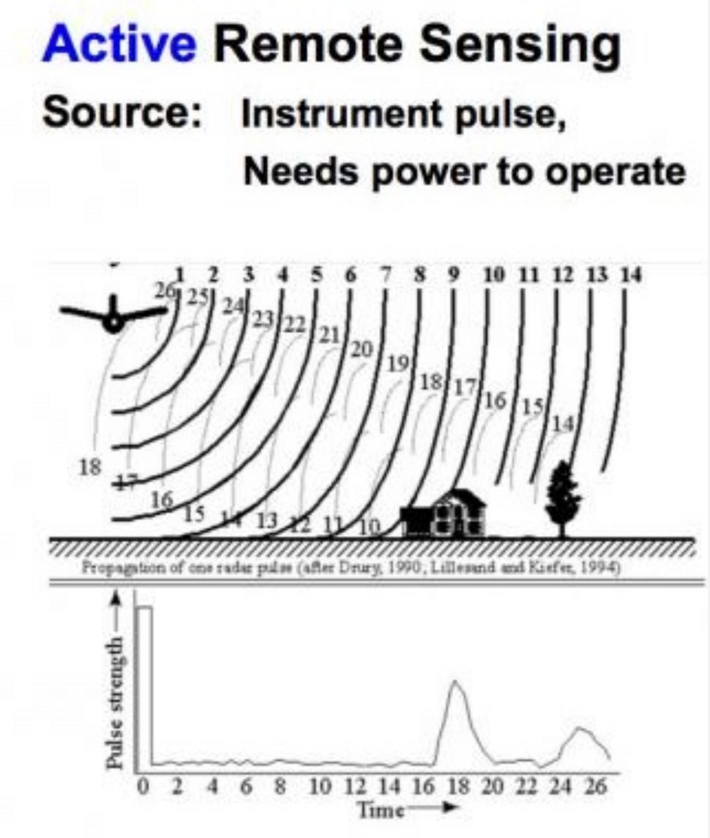
- The lower frequencies, referred to as "emissions channels," measure precipitation mainly from energy emitted by raindrops (37 GHz)
- The higher frequencies, or "scattering channels," gather energy scattered by ice particles above the freezing level (85 GHz)

Image Credit (Left): UCAR COMET, comet.ucar.edu

Precipitation Remote Sensing

Active Remote Sensing: Estimated from back-scattered microwave radiation transmitted by radars





- NASA Satellites TRMM and GPM use K-band radar
- K-band generally has a frequency range within 27-40 GHz and 12-18 GHz

TRMM and GPM Precipitation Data

Tropical Rainfall Measurement Mission (TRMM)

http://trmm.gsfc.nasa.gov

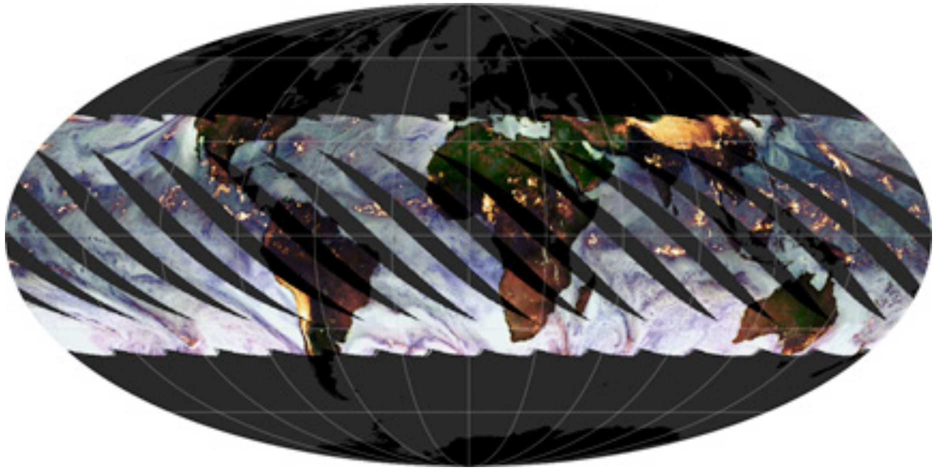
- The first satellite dedicated to measuring tropical and subtropical rainfall
- Launched November 27, 1997, and ended April 15, 2015
- First satellite to carry a microwave precipitation radar
- Predecessor to Global Precipitation Measurement (GPM) Mission
- Joint mission between NASA and JAXA (the Japanese Space Agency)

TRMM Satellite & Sensors

http://trmm.gsfc.nasa.gov

- In a non-polar, low-inclination orbit
- Altitude of approximately 350 km, raised to 403 km after August 23, 2001
- Spatial Coverage
  – 16 TRMM orbits a day covering global tropics between 35°S – 35°N latitude
- Sensors:
  – TRMM Microwave Imager (TMI)
  – Precipitation Radar (PR)
  – Visible and Infrared Scanner (VIRS)
  – Lightening Imaging Sensor (LIS)
  – Clouds and the Earth's Radiant Energy System (CERES)

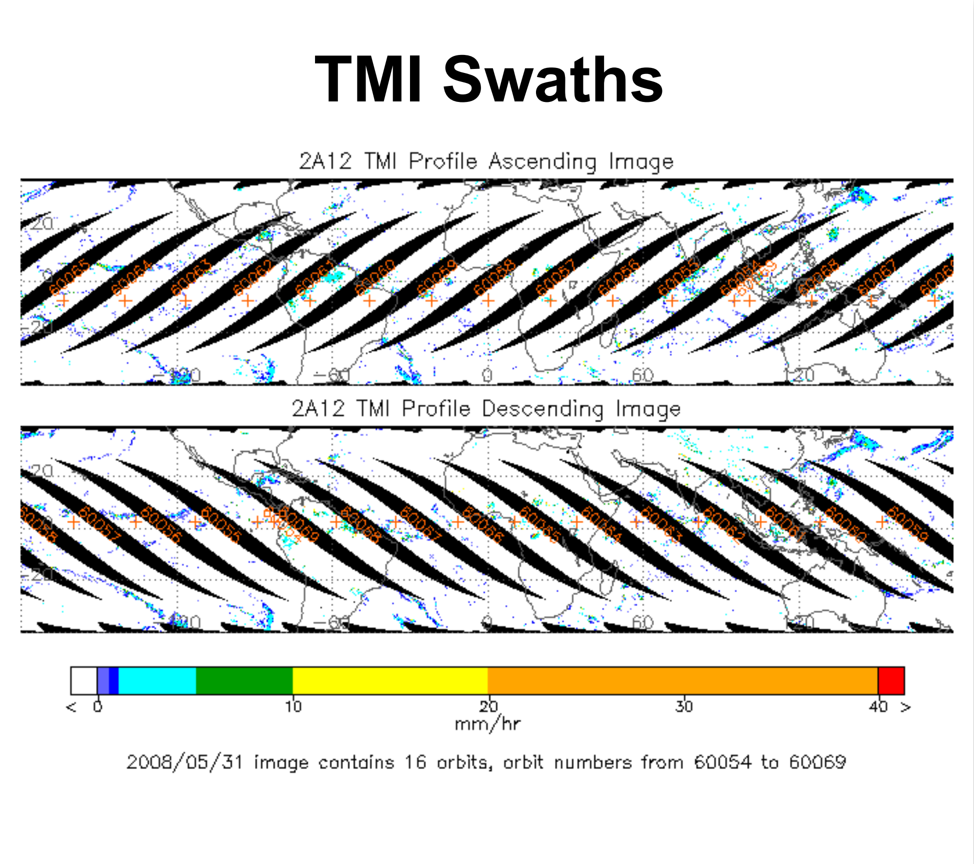
TRMM Orbits



TRMM Microwave Imager (TMI)

http://pmm.nasa.gov/TRMM/TMI

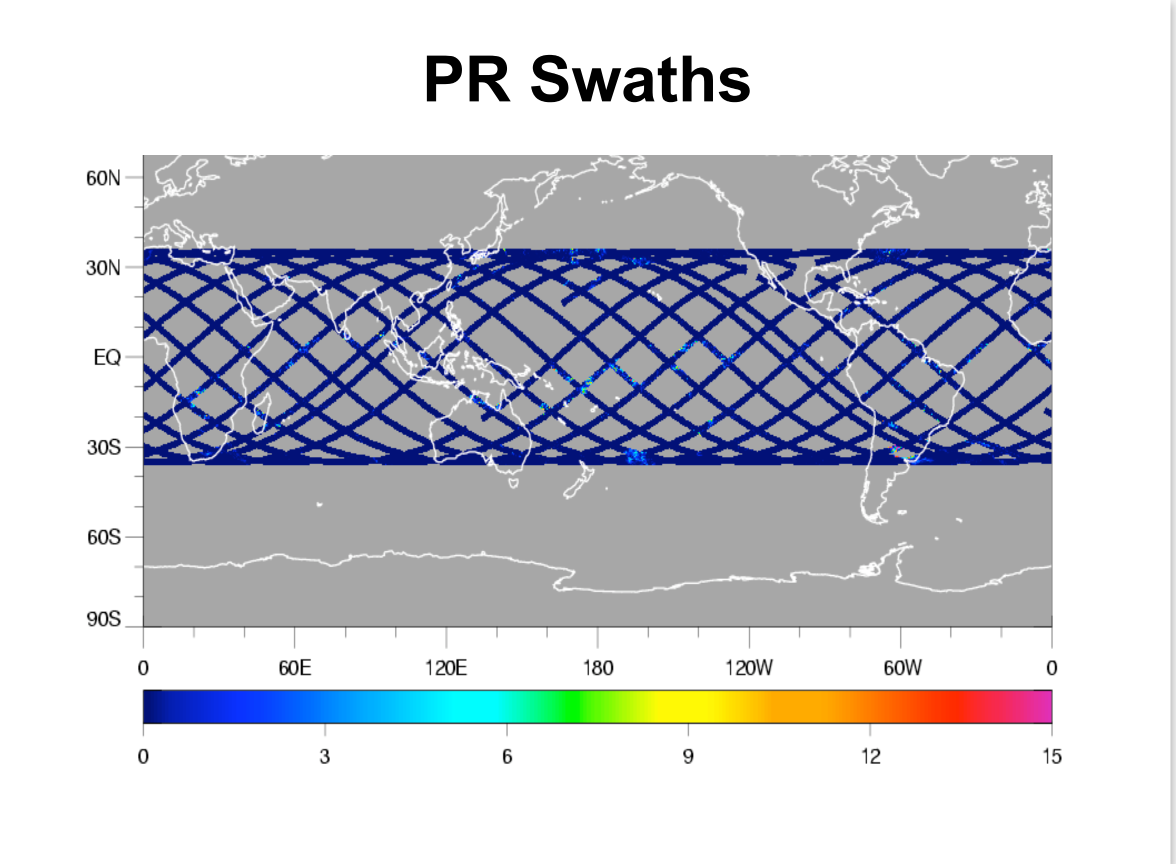
- Spatial Coverage and Resolution:
  - Coverage: -180° – 180°, 35°S – 35°N
  - Swath: 760 km (878 km after 8/2001)
  - Vertical Resolution:
    - 0.5 km from surface – 4 km
    - 1.0 km from 4-6 km
    - 2.0 km from 6-10 km
    - 4.0 km from 10-18 km
- Temporal Coverage and Resolution:
  - November 27, 1998 - April 15, 2014
  - 16 orbits per day
- Chanel Frequencies
  - 10.7, 19.4, 21.3, 37, 85.5 GHz



Precipitation Radar (PR)

http://pmm.nasa.gov/TRMM/PR

- Spatial Coverage and Resolution:
  - Coverage: 35°S – 35°N
  - Swath: 215 km (247 after 8/2001)
  - Spatial Resolution: 4.3 km (5 km)
  - Vertical Resolution: 250 m (from 0-20 km)
- Temporal Coverage and Resolution:
  - November 27, 1998 – October 7, 2014
  - ~16 orbits per day
- Frequency:
  - 13.6 GHz



Kummerow, C., et. al, 1998: The tropical rainfall measuring mission (TRMM) sensor package, J. Atmos. Oceanic Technol., 15, 809-817.

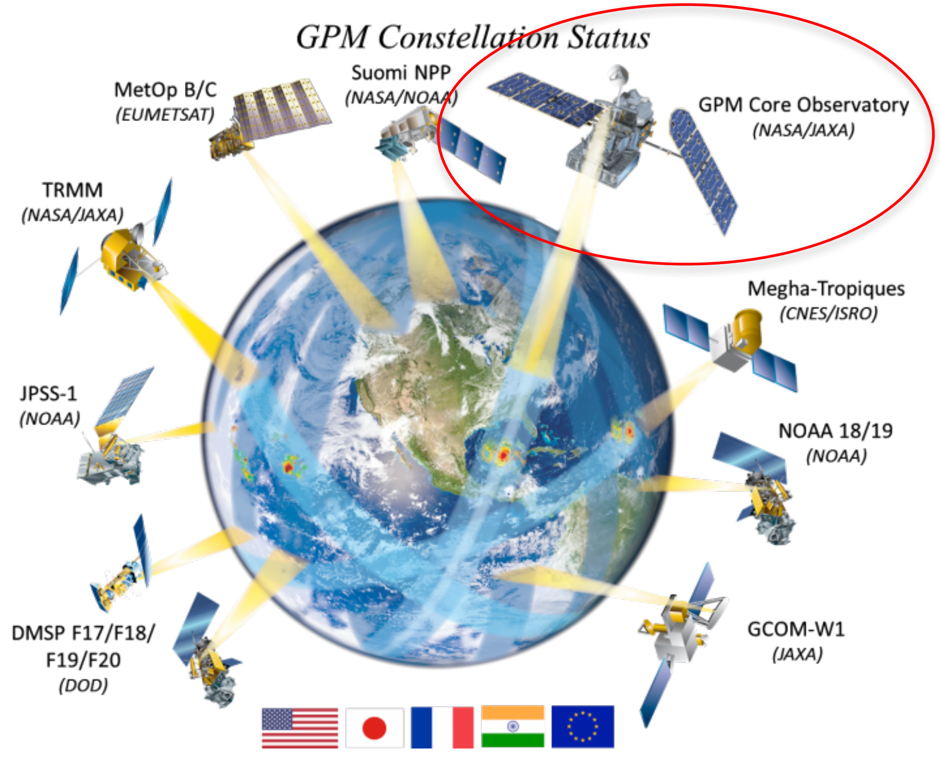
GPM Satellite & Sensors

http://pmm.nasa.gov/GPM

- GPM core satellite is in a non-polar, low inclination orbit
  - Altitude: 407km
- Spatial Coverage:
  - 16 T orbits a day covering global tropics, between 65°S-65°N
- Along with constellation of satellites, GPM has revisit time of 2-4 hrs. over land
- Sensors:
  - GMI (GPM Microwave Imager)
  - DPR (Dual Frequency Precipitation Radar)

GPM Core Satellite

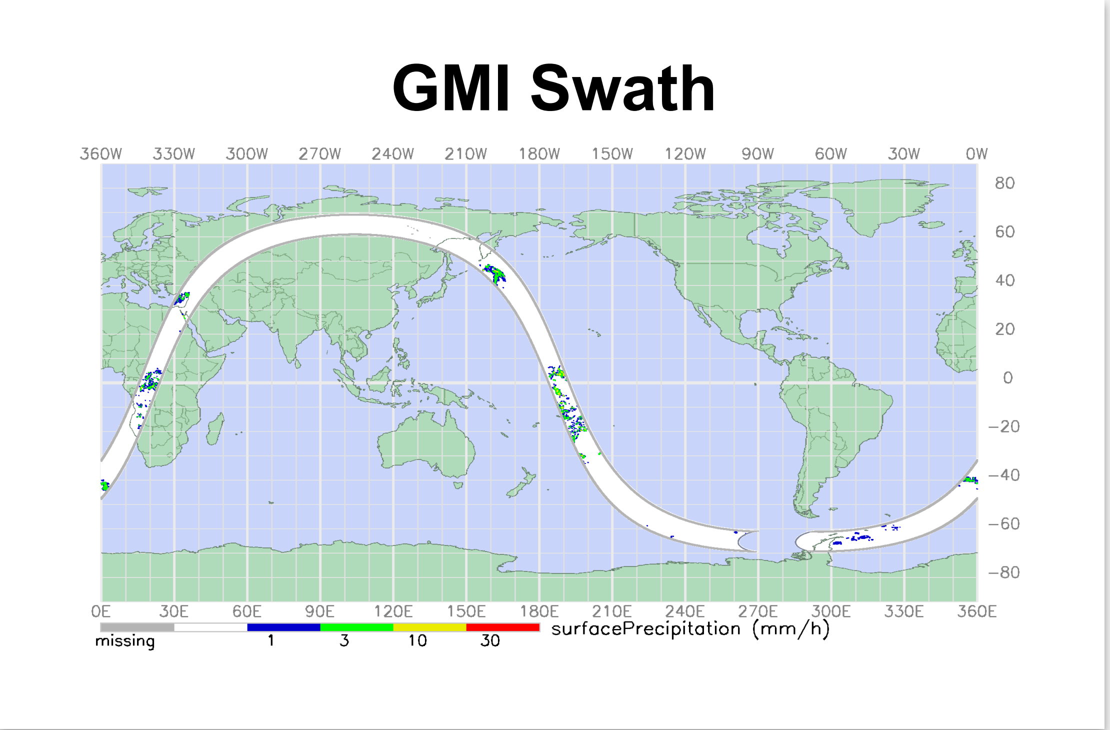
Launched Feb 27, 2014



GPM Microwave Imager (GMI)

http://pmm.nasa.gov/GPM/flight-project/GMI

- Spatial Coverage and Resolution:
  - Coverage: -180°-180°, 65°S - 65°N
  - Swath: 885 km
  - Spatial Resolution: 4.4-32 km
  - Vertical Resolution:
    - 0.5 km from surface – 4 km
    - 1.0 km from 4-6 km
    - 2.0 km from 6-10 km
    - 4.0 km from 10-18 km
  - Temporal Coverage and Resolution
    - Feb 2014 – present
    - ~2-4 hr observations

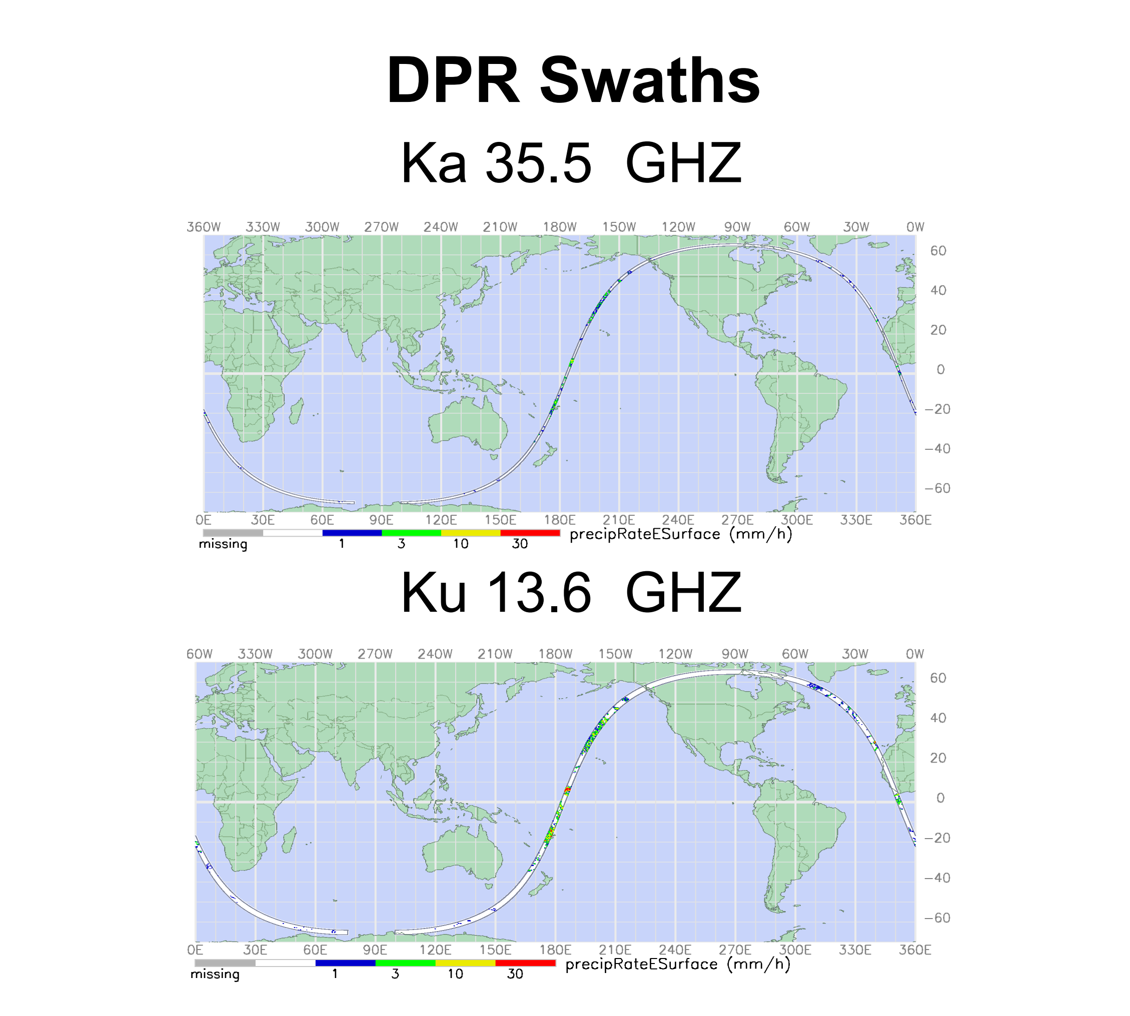


- Channel Frequencies:
  - 10.6, 18.7, 23.8, 36.5, 89, 166, 183 GHz

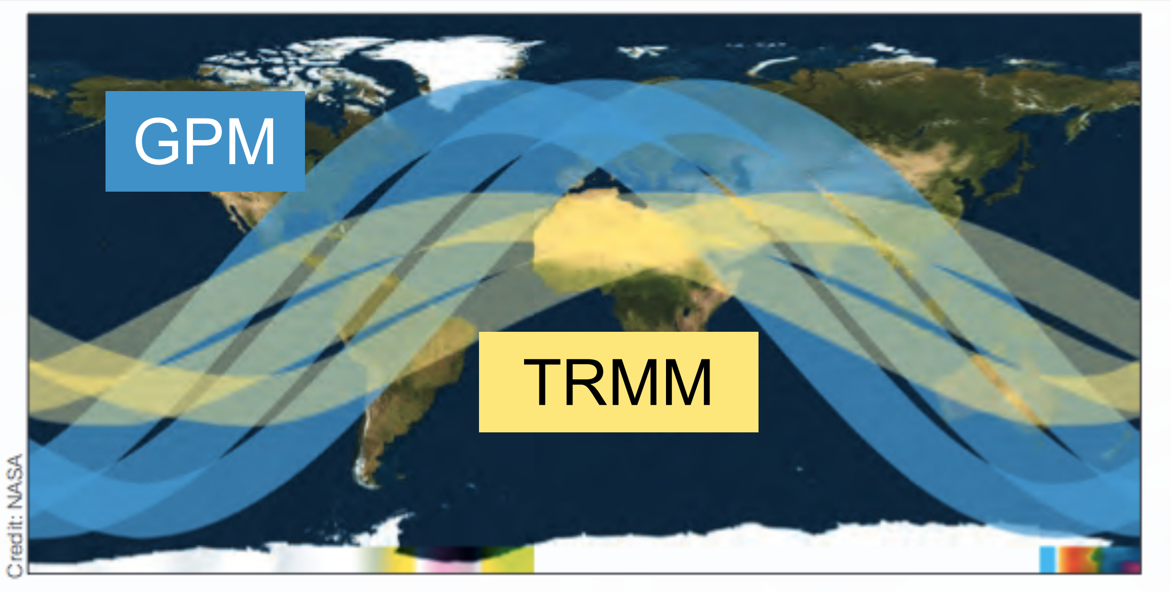
Dual Precipitation Radar (DPR)

http://pmm.nasa.gov/GPM/flight-project/DPR

- Spatial Coverage and Resolution:
  - Coverage: -180°-180°, 65°S-65°N
  - Swath: 120km (Ka) and 245km (Ku)
  - Spatial Resolution: 5.2km
  - Vertical Resolution: 250m (from 0-20km)
- Temporal Coverage and Resolution:
  - Feb 27, 2014 – present
  - ~2-4 hr observations
- Frequency:
  - 13.6 and 35.5 GHz



TRMM and GPM Comparison



- TRMM measurements are limited to the tropics
- GPM measurements span middle and high latitudes

- GMI & DPR
  - provide improved reference standards for inter-calibration of constellation precipitation measurements
  - better accuracy measurements
- GMI has a higher spatial resolution than TMI
- Improved light rain and snow detection in GMP
- DPR has better identification of liquid, ice, mixed-phase precipitation particles

Importance of TRMM Data Products

- TRMM provided high resolution precipitation data for 17 years
  - Useful for detecting and understanding climate variability and change
- Many applications are developed from TRMM data and still have to transition to using GPM data
  - extreme rain, flood, and drought monitoring and mapping
  - agriculture
  - health
- GPM algorithms are conceptually similar
  - **TRMM and GPM data will be inter-calibrated to provide a combined long-term precipitation record**

Precipitation Algorithms for TRMM and GPM

http://pmm.nasa.gov/science/precipitation-algorithms

There are four major algorithms used to obtain precipitation estimates from GPM/TRMM observations:

1. Radar Algorithms
2. Radiometer Algorithms
3. Combined Radar + Radiometer Algorithms
4. Multi-Satellite Algorithms
    - TRMM and GPM Core are used as calibrators for multiple national and international constellation satellites

Summary of TRMM Level-2 Precipitation Products

Sensor/Product Name	Spatial Resolution & Coverage	Temporal Resolution	Data Format
PR only: 2A25	• 5km x 5km • Single orbit • 16 orbits/day (35°S-35°N)	• 7-day latency for Near Real-Time • 3-hour, 2-day, 5-day	HDF4
TMI only: 2A12	• 5km x 5km • Orbital • 16 orbits/day (38°S-38°N)	• 3-hour, 2-day, 15-day	
Combined TMI & PR: 2B31	• 5km x 5km • Orbital • 16 orbits/day (38°S-38°N)	• 7-day latency for Near Real-Time • 3-hour, 2-day, 5-day	

Summary of TRMM Level-3 Precipitation Products

Sensor/Product Name	Spatial Resolution & Coverage	Temporal Resolution	Data Format
TMPA: 3B42RT & Final 3B42	• 0.25° x 0.25° • 50°S x 50°N	• RT is NRT with 8 hr latency • 3-hourly	• RT data in binary and OpenDAP
TMPA: 3B43		• Monthly • 2 month latency	• HDF4 • NetCDF
PR only: 3A12	• 0.5° x 0.5° and 5° x 5° • 37°S x 37°N	• Monthly	• HDF4 • OpenDAP
TMI only: 3A12	• 0.5° x 0.5° • 38°S x 38°N	• Monthly	
TMI-PR Combined: 3B31	• 5° x 5° • 40°S x 40°N	• Monthly	

Summary of GPM Level-2 Precipitation Products

Sensor/Product Name	Spatial Resolution & Coverage	Temporal Resolution	Data Format
DPR Ku-only: 2A-Ku DPR Ka-only: 2A-Ka DPR Ku & Ka: 2A-DPR	• 5.2km x 125m • Single orbit • 16 orbits/day (70°S-70°N)	• 20-120 minutes • 24 hrs	• HDF5 • OpenDAP
GMI/2A-GPROF	• 4km x 4km • Orbital • 16 orbits/day (70°S-70°N)	• 2-40 hrs	
Combined GMI+DPR:2A-CMB	• 5km x 5km • Orbital (70°S-70°N) • Coincident Ku-Ka GMI footprints	• 3-40 hrs	

Summary of GPM Level-3 Precipitation Products

Sensor/Product Name	Spatial Resolution & Coverage	Temporal Resolution	Data Format
IMERG	• 0.1° x 0.1° • 90°S-90°N	• 30 min (NRT) • 6 hr, 16 hr, & 3 month latency	• HDF4 • NetCDF • OpenDAP • ASCII • .gif, .png • KML (Google Earth)
Combined GMI + DPR Rainfall Averages: 3-CMB	• 0.1° x 0.1° • 70°S-70°N	• Monthly	
DPR Rainfall Averages: 3-DPR	• 0.25° x 0.25° • 5.0° x 5.0° • Daily: 67°S-67°N • Monthly: 70°S-70°N	• Daily & Monthly	
GMI Rainfall Averages: 3-GPROF	• 0.25° x 0.25° • 90°S-90°N	• Daily & Monthly	

Multi-Satellite Algorithms for TRMM and GPM

http://pmm.nasa.gov/science/precipitation-algorithms

- TRMM & GPM Core satellites are used to calibrate microwave observations from a constellation of national and international satellites
- Allow improved spatial and temporal coverage of precipitation data
- TRMM Multi-satellite Precipitation Analysis (**TMPA**)
- Widely used for applications
- TMPA will be extended to match Integrated Multi-satellitE Retrievals for GPM (**IMERG**)

TRMM Multi-satellite Precipitation Analysis (TMPA)

http://precip.gsfc.nasa.gov/trmm_comb.html

- TMPA combines PR & TMI rain rates
- Inter-calibrates passive rain rates from other satellite sensors
  – TMI, SSM/I, AMSR, AMSU-B, MHS, IR radiometers*
- Inter-calibrates with national and international geostationary and NOAA low-earth orbiting satellites infrared measurements by using VIRS
- Final rain product is calibrated with rain gauge analyses on a monthly time scale

*AMSR: Advanced Microwave Scanning Radiometer - onboard NASA Aqua Satellite

AMSU: Advanced Microwave Sounding Unit – onboard NOAA operational satellite

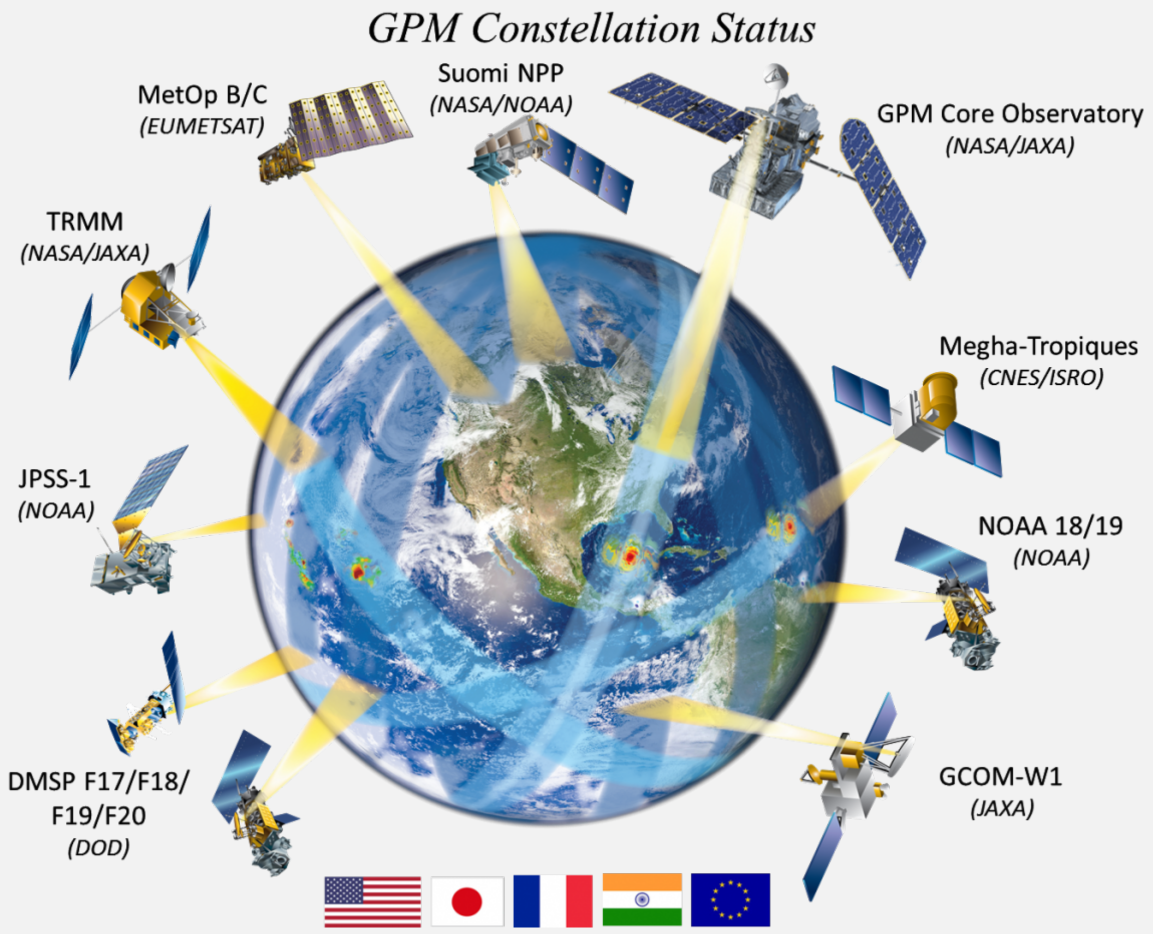
SSM/I: Special Sensor Microwave Imager

MHS: Microwave Humidity Sounder

Integrated Multi-satellitE Retrievals for GPM (IMERG)

http://pmm.nasa.gov/sites/default/files/document_files/IMERG_ATBD_V4.5.pdf

- Conceptually similar to TMPA
- GPM constellation satellites include:
  - GCOM-W
  - DMSP
  - Megha-Tropiques
  - MetOp-B
  - NOAA-N’
  - NPP
  - NPOESS
- Final rain product is calibrated with rain gauge analyses on monthly time scale



Integrated Multi-satellitE Retrievals for GPM (IMERG)

http://pmm.nasa.gov/sites/default/files/document_files/IMERG_ATBD_V4.5.pdf

- **Multiple runs accommodate different user requirements for latency and accuracy**
  – "Early" – now 5 hours (flash flooding) – will be 4 hours
  – "Late" – now 15 hours (crop forecasting) – will be 12 hours
  – "Final" – 3 months (research data)
- **Native time intervals are half-hourly and monthly (final only)**
  – Value-added products at 3 hrs, 1, 3, and 7 days - .tiff will be available
  – Initial release covers 60°N-60°S – will be 90°N-90°S

TMPA and IMERG

	TMPA	IMERG
Spatial Resolution	0.25° x 0.25°	0.1° x 0.1°
Spatial Coverage	Global, 50° S-50°N	Global, 60°S-60°N (will be extended from pole to pole)
Temporal Resolution	3 hours	30 minutes
Temporal Coverage	12/1997 – Present*	2/27/2014 – Present⁺

* After April 8, 2015, TRMM climatological calibration is being used to generate TMPA

⁺TMPA and IMERG combined data will be available in early 2018 at IMERG data resolution

TRMM and GPM Data Type Convention

http://pps.gsfc.nasa.gov/Documents/FileNamingConventionForPrecipitationProductsForGPMMissionV1.4.pdf

Type	Description
1A	Instrument count, geolocated, at instantaneous field of view (IFOV).
1B	Geolocated, calibrated T_b or radar power at IFOV.
1C	Intercalibrated brightness temperatures T_c at IFOV.
2A	Geolocated geophysical parameters at IFOV from a single instrument.
2B	Geolocated geophysical parameters at IFOV from multiple instruments.
3A	Space/time averaged geophysical parameters from a single instrument.
3B	Space/time averaged geophysical parameters from multiple instruments.
4	Combined satellite, ground and/or model data.

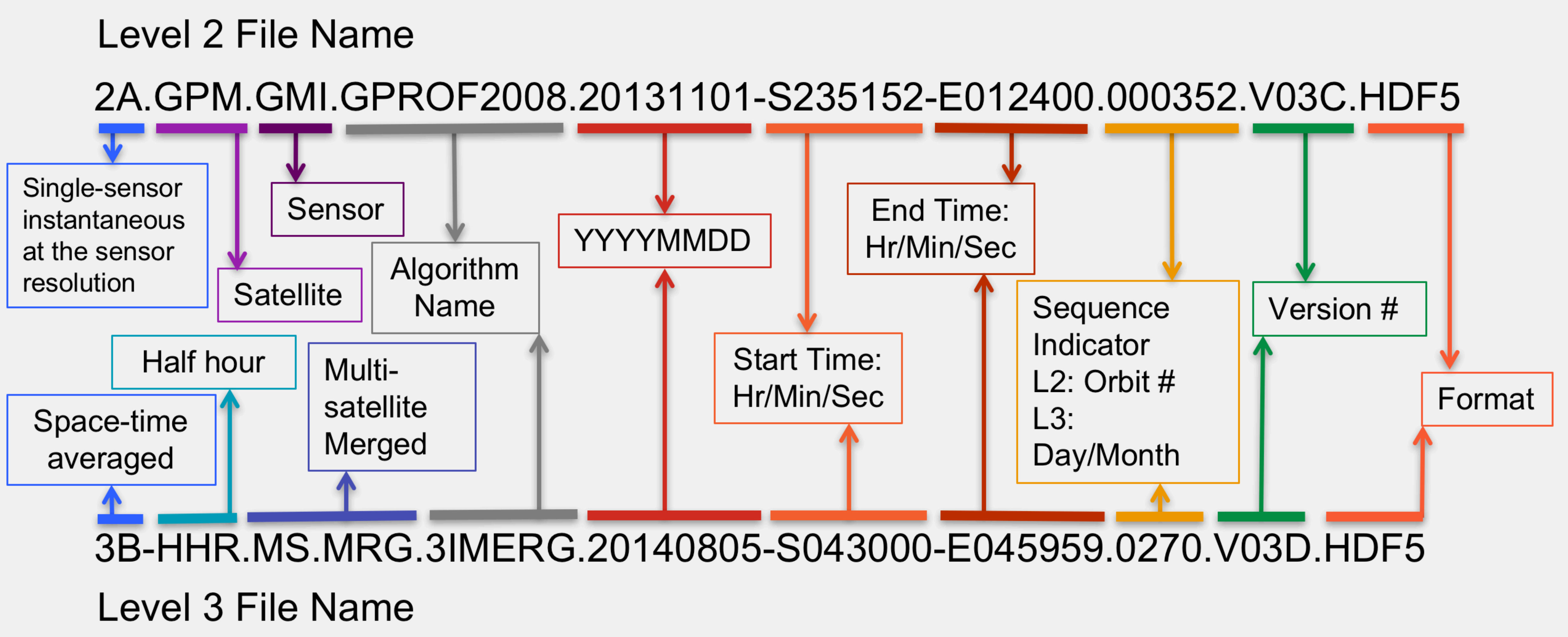
Trade-Offs Between Level 2 and Level 3 Precipitation Data Products

- IMERG and TMPA have lower spatial resolutions than Level 2 data
  - e.g. 2A12, 2A25, 2B31, 2A-GPROF, 2A-2DPR, 2BCMB
- IMERG and TMPA have better spatial coverage with no orbit gaps compared to Level 2 and Level 3 radar, imager, and radar/imager combined data
- IMERG and TMPA:
  - are uniformly gridded
  - have uniform temporal resolution to cover diurnal variations
  - are available in multiple formats

Used by Flood Monitoring Tools

GPM File Name Convention

http://pps.gsfc.nasa.gov/Documents/FileNamingConventionForPrecipitationProductsForGPMMissionV1.4.pdf



TRMM and GPM Data Access

Precipitation Data Access Tools

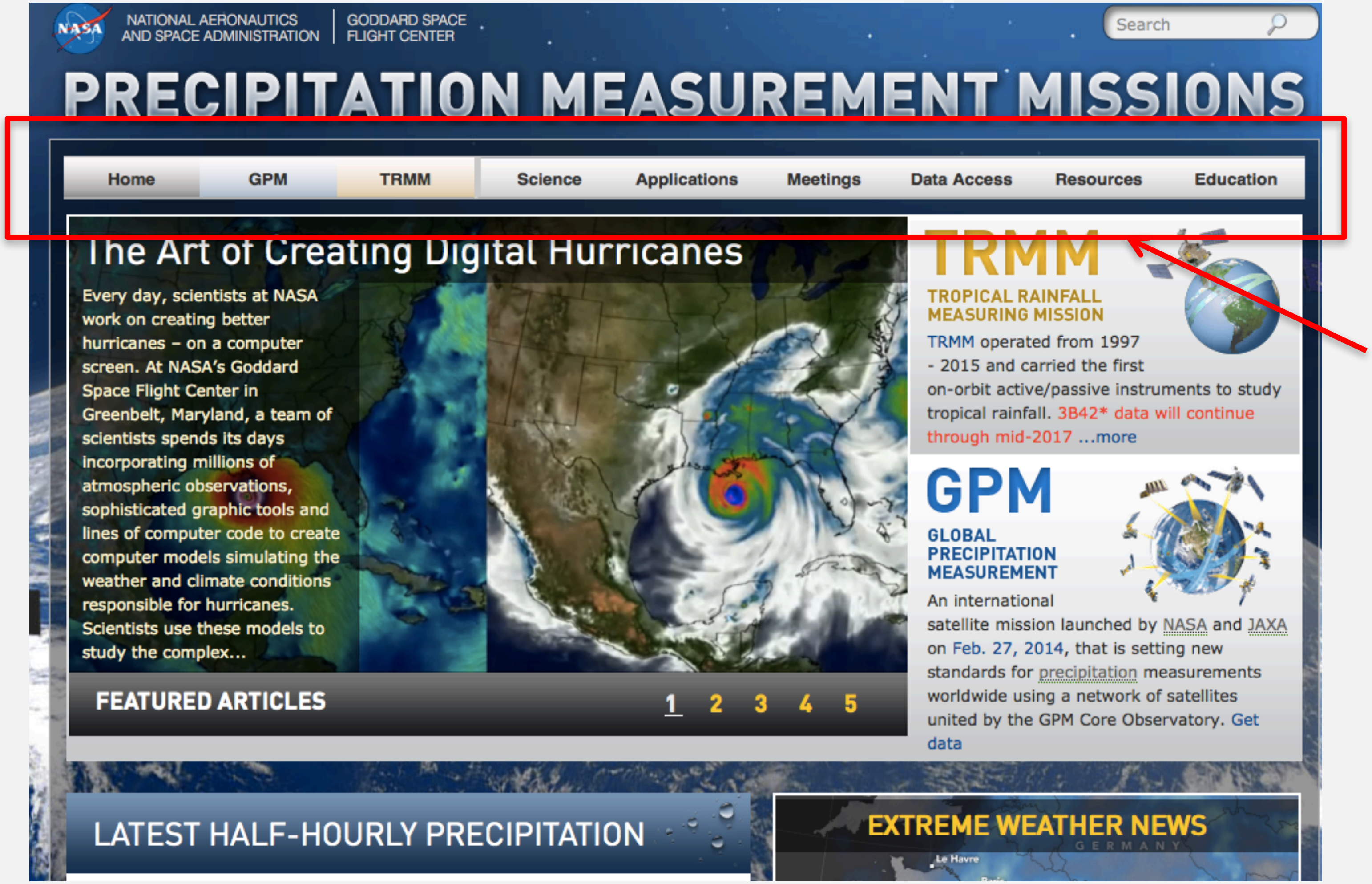
Tools	Data & Format	Features
PPS/STORM http://storm.pps.eosdis.nasa.gov/storm/	• Rain Rate (TRMM, GPM) • HDF, PNG	• Orbital and Gridded Data Search • Spatial/Temporal Subsetting • Individual Data and FTP Batch Download • Images and Interactive Data Viewer

Giovanni
http://giovanni.gsfc.nasa.gov
	• Rain Rate (TRMM, GPM)
	• NetCDF, GeoTIFF, PNG, KMZ, CSV (time series only)
		• Spatial/Temporal Subsetting
		• Analysis:
		  • Time-averaged maps, animation, time series, scatter plots, map correlations, vertical profiles, time-averaged differences
		• Visualization:
		  • Maps, time series, scatter plots, histograms
		• Near Real-Time Rain Rate Access

Mirador http://mirador.gsfc.nasa.gov	• Rain Rate (TRMM, GPM) • HDF, OPenDAP (select data can be converted into ASCII, binary, NetCDF)	• Spatial/Temporal Subsetting • Individual Data File Download • Batch Download

Precipitation Measurement Missions

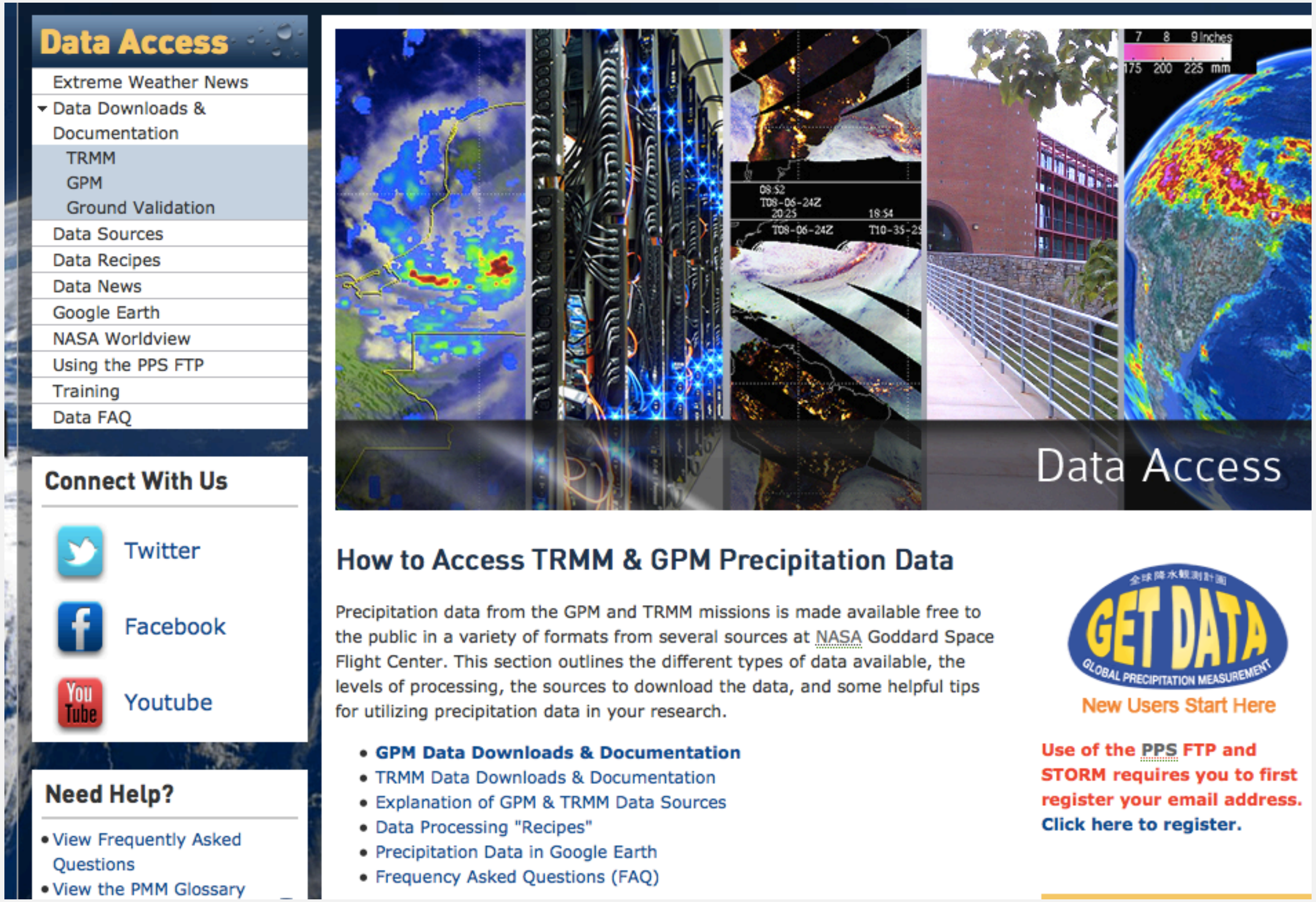
https://pmm.nasa.gov/



- Home of all information related to TRMM and GPM
- Links to data documentation and access

Precipitation Measurement Missions: Data Access

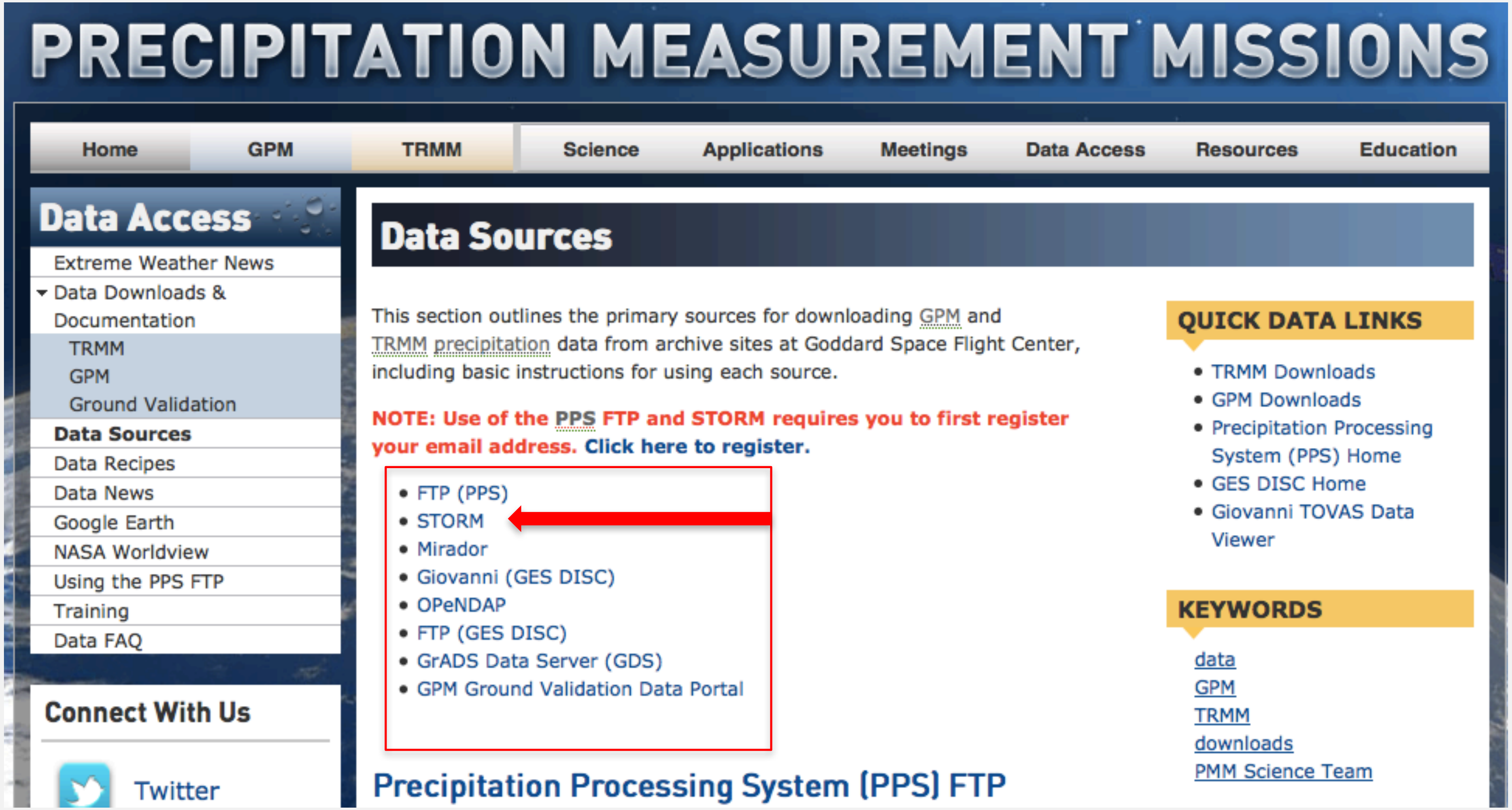
https://pmm.nasa.gov/data-access



- All about TRMM and GPM data
  - Including updates, news, and FAQ
- Quick data access links and user registration

Precipitation Measurement Missions: Data Sources

https://pmm.nasa.gov/data-access/data-sources



PPS & STORM

http://storm.pps.eosdis.nasa.gov/storm

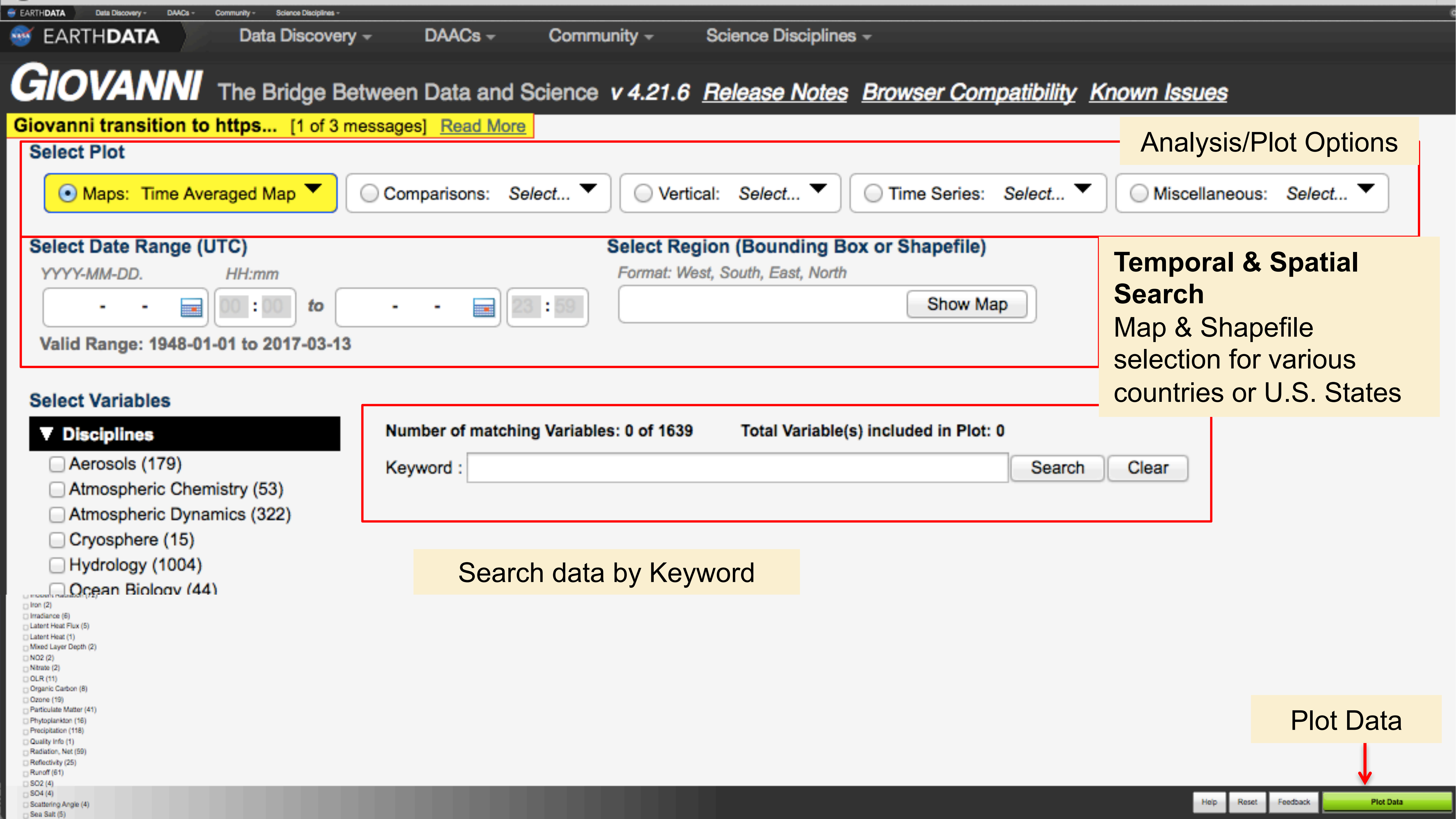
Precipitation Processing System: STORM

https://storm.pps.eosdis.nasa.gov/storm/

- All TRMM and GPM data products can be downloaded from STORM
- Data images and HDF5 data viewer are available in STORM

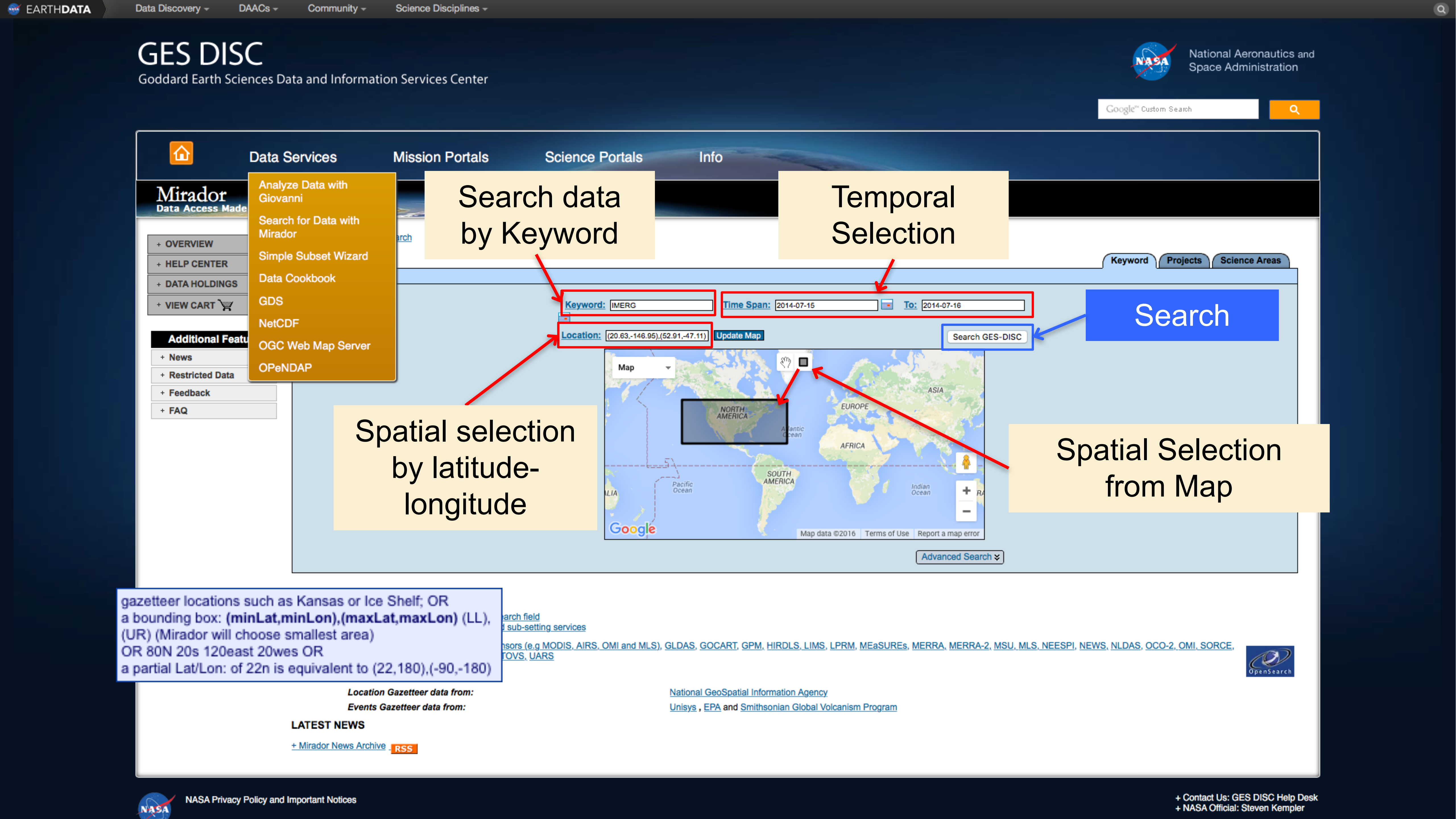
Giovanni

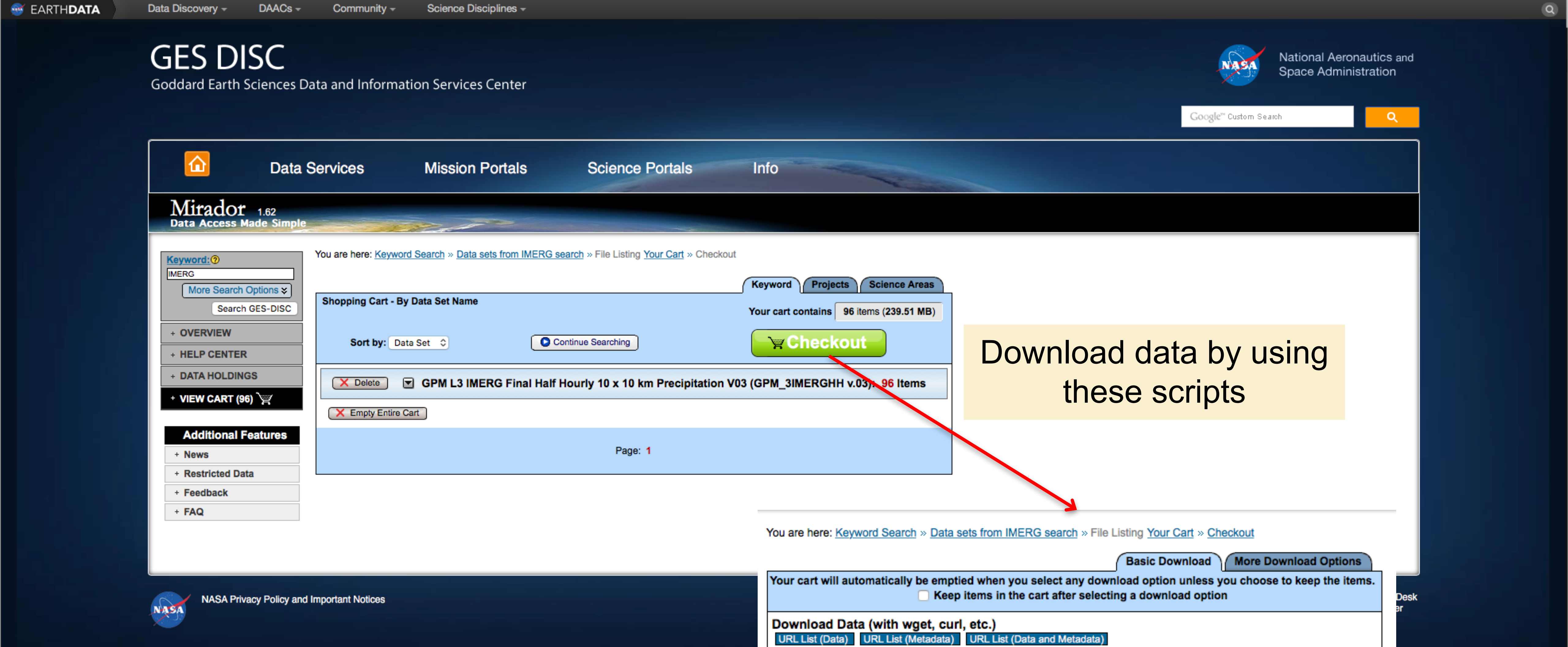
http://giovanni.gsfc.nasa.gov/


EARTHDATA
Data Discovery
DAACs
Community
Science Disciplines
GIOVANNI The Bridge Between Data and Science v 4.21.6 Release Notes Browser Compatibility Known Issues
Giovanni transition to https... [1 of 3 messages] Read More
Analysis/Plot Options
Select Plot
Maps: Time Averaged Map
Comparisons: Select...
Vertical: Select...
Time Series: Select...
Miscellaneous: Select...
Select Date Range (UTC)
YYYY-MM-DD.
HH:mm
to
Valid Range: 1948-01-01 to 2017-03-13
Select Region (Bounding Box or Shapefile)
Format: West, South, East, North
Show Map
Temporal & Spatial Search
Map & Shapefile selection for various countries or U.S. States
Select Variables
Disciplines
Aerosols (179)
Atmospheric Chemistry (53)
Atmospheric Dynamics (322)
Cryosphere (15)
Hydrology (1004)
Ocean Biology (44)
Number of matching Variables: 0 of 1639
Total Variable(s) included in Plot: 0
Keyword :
Search
Clear
Search data by Keyword
Iron (2)
Irradiance (6)
Latent Heat Flux (5)
Latent Heat (1)
Mixed Layer Depth (2)
NO2 (2)
Nitrate (2)
OLR (11)
Organic Carbon (8)
Ozone (19)
Particulate Matter (41)
Phytoplankton (16)
Precipitation (118)
Quality Info (1)
Radiation, Net (59)
Reflectivity (25)
Runoff (61)
SO2 (4)
SO4 (4)
Scattering Angle (4)
Sea Salt (5)
Plot Data
Help
Reset
Feedback
Plot Data

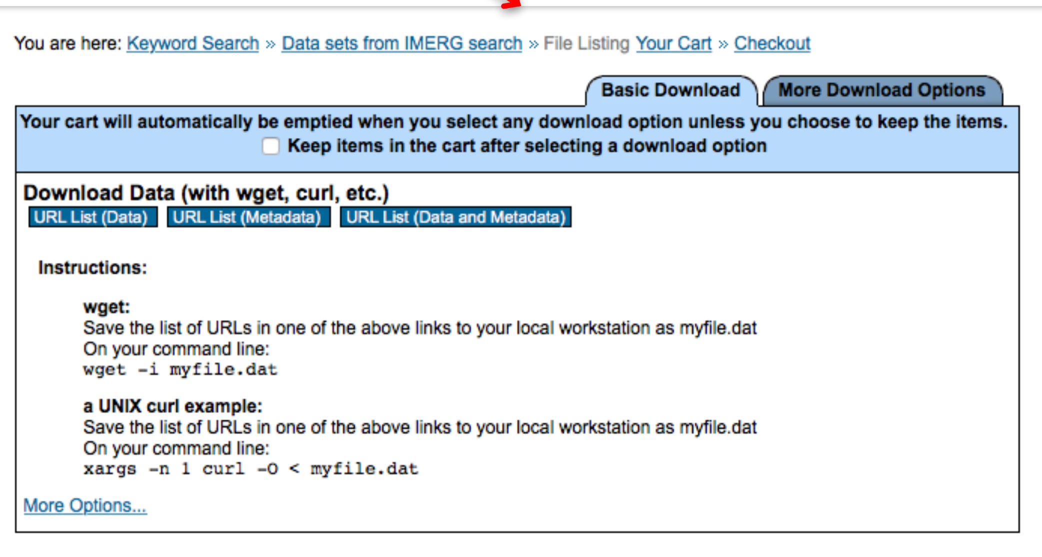
Mirador: Data Search & Access

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


EARTHDATA
Data Discovery
DAACs
Community
Science Disciplines
GES DISC
Goddard Earth Sciences Data and Information Services Center
National Aeronautics and Space Administration
Data Services
Mission Portals
Science Portals
Info
Mirador
Analyze Data with Giovanni
Search for Data with Mirador
Simple Subset Wizard
Data Cookbook
GDS
NetCDF
OGC Web Map Server
OPeNDAP
OVERVIEW
HELP CENTER
DATA HOLDINGS
VIEW CART
News
Restricted Data
Feedback
FAQ
Search data by Keyword
Temporal Selection
Keyword
Projects
Science Areas
Keyword: IMERG
Time Span: 2014-07-15
To: 2014-07-16
Search
Location: (20.63,-146.95),(52.91,-47.11)
Update Map
Search GES-DISC
Map
ASIA
EUROPE
NORTH AMERICA
AFRICA
SOUTH AMERICA
Pacific Ocean
Indian Ocean
Spatial selection by latitude-longitude
Spatial Selection from Map
Map data ©2016
Terms of Use
Report a map error
Advanced Search
gazetteer locations such as Kansas or Ice Shelf; OR
a bounding box: (minLat,minLon),(maxLat,maxLon) (LL),(UR) (Mirador will choose smallest area)
OR 80N 20s 120east 20wes OR
a partial Lat/Lon: of 22n is equivalent to (22,180),(-90,-180)
Location Gazetteer data from:
National GeoSpatial Information Agency
Events Gazetteer data from:
Unisys, EPA and Smithsonian Global Volcanism Program
LATEST NEWS
+ Mirador News Archive
RSS
NASA Privacy Policy and Important Notices
+ Contact Us: GES DISC Help Desk
+ NASA Official: Steven Kempler



Download data by using these scripts



Demonstration of STORM and Giovanni

Next

Hands-on Exercise: Precipitation Data Access & Analysis in QGIS