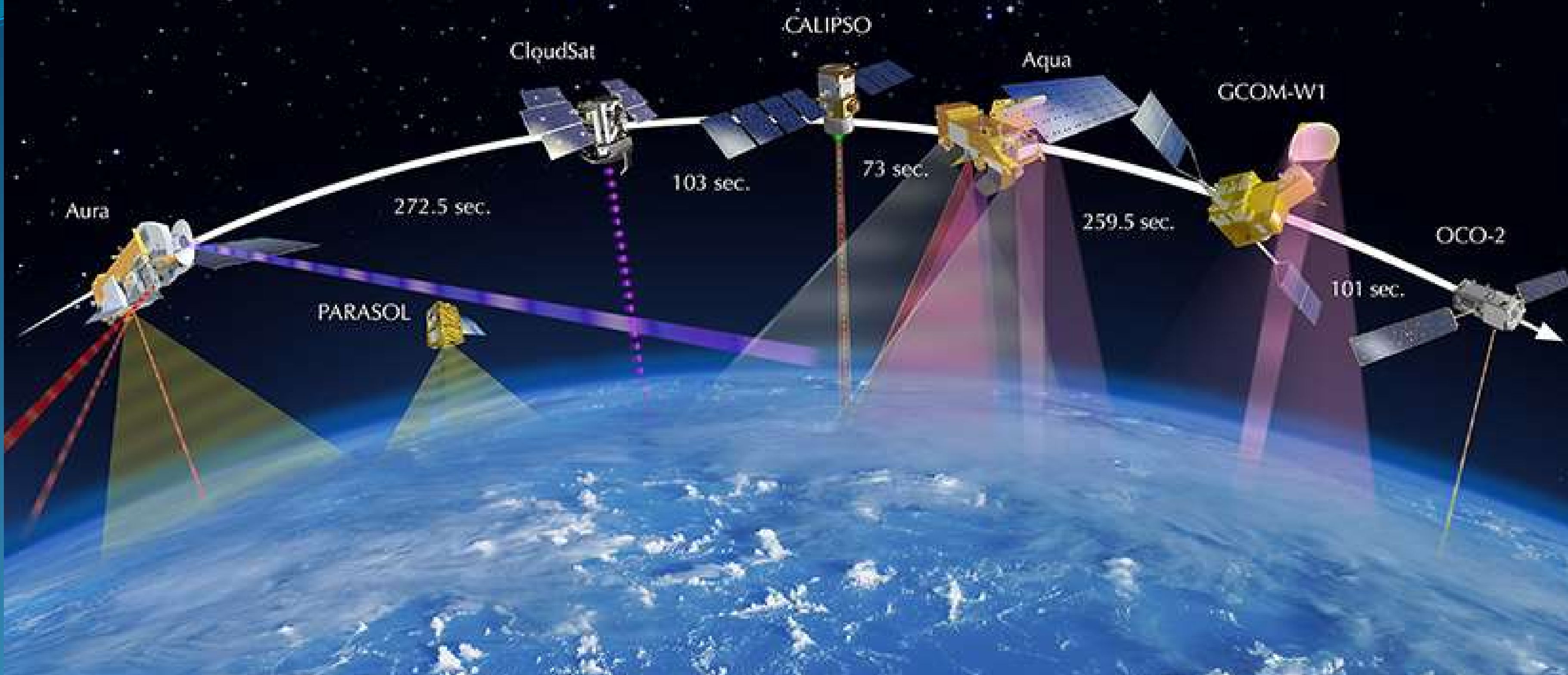
MET 611 – Satellite Data Applications

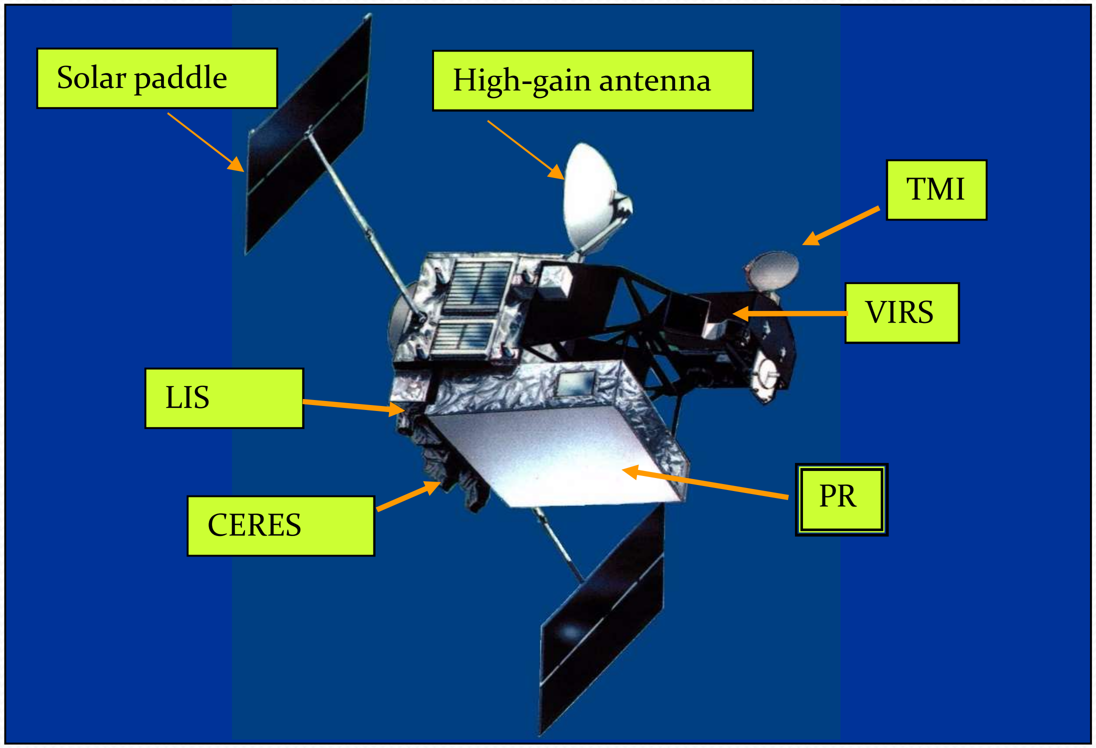


TRMM Precipitation Radar & GPM

Sections of take from Toshio Iguchi (iguchi@nict.go.jp)
Achieving Satellite Instrument Calibration for Climate
Change (6-18 May 2006)

Jennifer D. S. Griswold

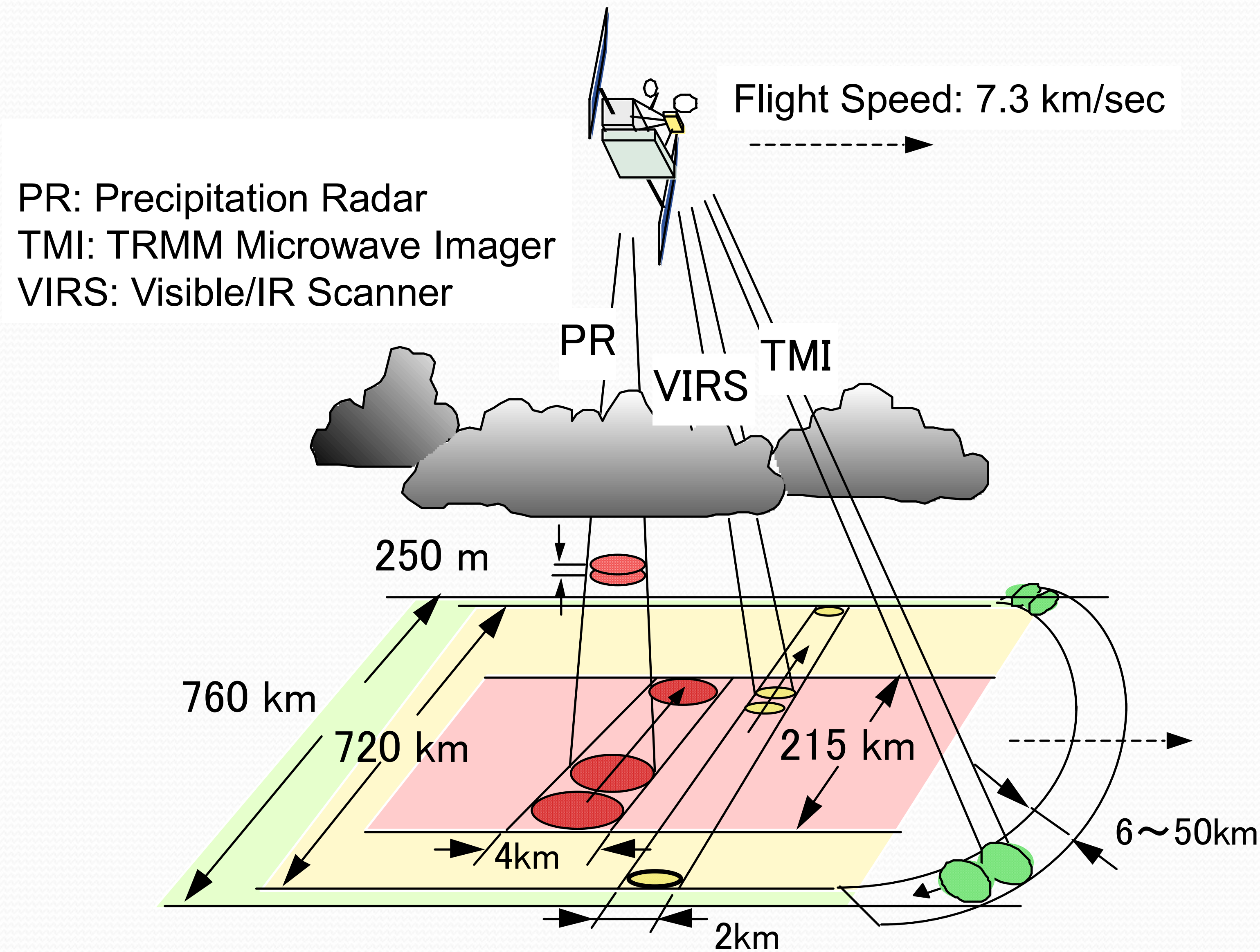
Tropical Rainfall Measuring Mission: TRMM



Orbit Altitude Inclination	Circular （Non-Sun Synchronous） 350km (402.5km since Aug. 2001) (±1.25km) 35 deg.
Sensor	**Precipitation Radar (PR)** TRMM Microwave Imager (TMI) Visible and Infrared Scanner (VIRS) Clouds and the Earth's Radiation Energy System (CERES) Lightning (LIS)

- Observation of tropical rainfall (Driving engine of global atmosphere)
- US-Japan joint mission (Japan: PR, Launch, US: Bus, 4 sensors, operation)
- Launched in Nov., 1997, turned off in April 2015
- First space-borne precipitation radar developed by CRL and NASDA

Concept of TRMM Rain Observation



Mission Requirements of TRMM PR

- Sensitivity : < 0. 7 mm/h
- Dynamic range : > 70dB
- Horizontal resolution : < 5 km
- Range resolution : < 250m
- Number of independent samples : > 64

  （SD of fading noise ＜ 0.7 dB）
- Swath width : > 200km
- Observable range : Surface to 15km

Major Parameters of TRMM PR

Radar type	Pulse radar
Antenna type	128-elem. WG slot array
Beam scanning	Active phased array
Frequency	13.796, 13.802 GHz
Polarization	Horizontal
TX/RX pulse width	1.57 / 1.67 μsec
RX band width	0.6 MHz
Pulse rep. freq.	2776 Hz
Data rate	93.5 kbps
Mass	460 kg
Life time	3 years
TX peak power	> 500 W (708 W)
Antenna gain	> 47.4 dB (47.5 dB)
Beam width	0.71±0.02 deg (0.71 deg)
Min det. lv.	< -110 dBm (-110.3 dBm)
Min detectable RR	< 0.7 mm/h (0.48 mm/h)
Power cons.	< 250 W (215 W)

Lasted 17 Years!!

All numbers are designed values. The numbers in parentheses are the measured values.

Precipitation Radar in more detail!

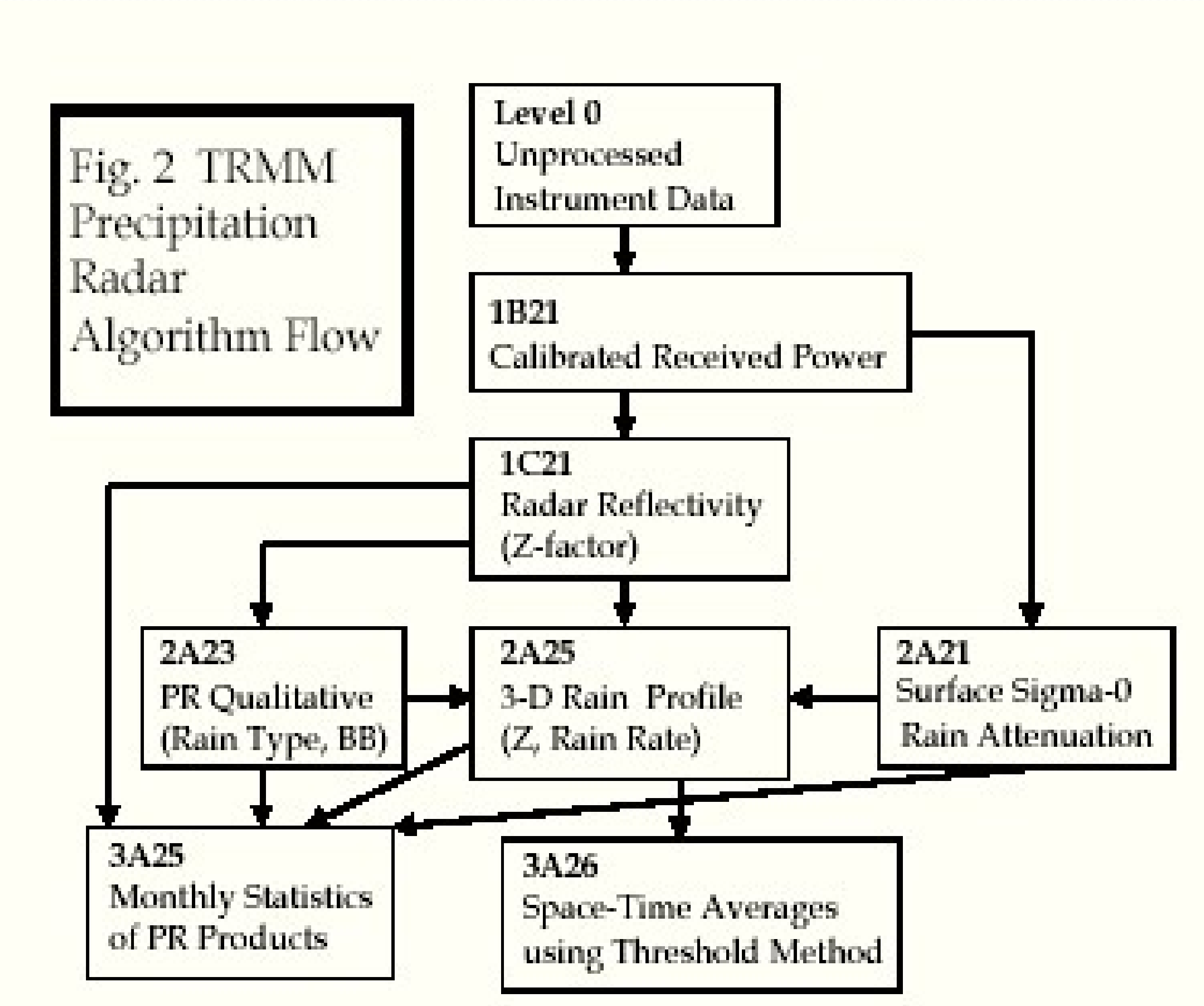
- **Introduction:**
  - The Precipitation Radar is the first active space borne radar designed to provide three-dimensional maps of storm structure

- **PR provides valuable information on:**
  - Rain size, speed, and altitude
  - Intensity and distribution of the rain
  - Rain type
  - Storm depth
  - Melting layer altitude: The height at which snow melts into rain

Precipitation Radar Specifications

- **Specifications:**
  - **Frequency : 13.8 GHz (Ku-band)**
    - More than four times higher than that of a typical ground based radar (NEXTRAD ~ 3 GHz, S-band)
    - **Horizontal Resolution: 4.3 km**
    - **Swath Width: 215 km**
    - **Vertical Profile of Rain and Snow: 19.3 km**
      - Able to detect rainfall rate down to .7 millimeters/hr
      - Able to separate vertical rain echo samples of 250 meters
  - **Power Consumption: 224 W**
    - Solid state power amplifiers (128) are used to conserve power
  - **Target Area:**
    - phased array antenna that steers the beam electronically

TRMM Precipitation Radar Algorithm



- **Level 1**
  - IB21
  - IC21
- **Level 2**
  - 2A21
  - 2A23
  - 2A25
- **Level 3**
  - 3A25
  - 3A26

TRMM Precipitation Radar Algorithm

- **Level 1 (IB21, IC21)**
  - **IB21**
    - Calculates received power by performing extensive internal calibrations
  - **Data in IB21 include:**
    - Location of Earth surface and surface clutter
    - System noise level
    - Land/Ocean Flag
    - And many more…

Location of earth is useful to identify whether the echo is rain or surface

TRMM Precipitation Radar Algorithm

- Some Examples of IB21 Data:
  - **Navigation**
    - X, Y, Z Components of Space Craft Velocity and Position
    - Latitude
    - Longitude
    - Altitude
    - Sensor Orientation
  - **Min. Echo Flag**
    - 0 : No Rain
    - 10: Rain possible but maybe noise
    - 20: Rain Certain
  - **Land / Ocean Flag**
    - 0: Water
    - 1: Land

Table 1-1. 1B21 product file structure

Name	Format
Data Granule (Data object per granule)	
Metadata	
Calibration Coefficients	72 byte
Ray Header	60 byte*49
Swath Data (Data object per scan =0.6 sec.)	
Scan Time	*float64 scantime[nscan]*
Geolocation	*float32 geolocation[2][49][nscan]*
Scan Status	*table 15 byte*[nscan]*
Navigation	*table 88 byte*[nscan]*
Power	*table 6 byte*[nscan]*
System Noise	*int16 systemNoise[49][nscan]*

TRMM Precipitation Radar Algorithm

- **Level 1** (IB21, **IC21**)
  - **Output**: Radar Reflectivity Factor
  - Almost same file format as that of IB21:
    - Power replaced by Radar Reflectivity Factor
    - Noise replaced by Dummy Variable

- **Level 2** (**2A21**, 2A23, 2A25)
  - **Primary Objective:**
    - Compute Path Integrated Attenuation (PIA) using the Surface Reference Techniques (SRT).
  - **Input Data:** IB21
  - **Output used by:** 2A25, 3A25, and 3A26

attenuation: refers to any reduction in the strength of a signal (digital or analog)
The extent of att. is usually expressed in units of dB, but sometimes Voltage

TRMM Precipitation Radar Algorithm

- Level 2 (2A21, **2A23**, 2A25)
  - **Main Objectives:**
    - **Classification of Rain Types**
    - **Output of Rain / No Rain Flag**
    - **Computation of estimated height of freezing level**
    - **Output of the height of storm top**
  - **Input Data:** IC21
  - **Output used by:** 2A25, 2B31, 3A25, 3A26
- Level 2 *(Cont'd)* (2A21, 2A23, **2A25**)
  - **Input Data:** IC21, 2A21, 2A23
  - **Output used by:** 3A25, 3A26
    - Correct for the Rain Attenuation in measured Radar Reflectivity
    - Estimate instantaneous **3-D distribution of rain**

TRMM Precipitation Radar Algorithm

- **Level 3** (**3A25**, 3A26)
  - **Objective:**
    - calculate various statistics over a month from the level 2
  - **Four types of statistics are calculated:**
    1. probabilities of occurrence
    2. means and standard deviations
    3. histograms
    4. correlation coefficients

- **Level 3** (3A25, **3A26**)
  - **Objective:**
    - Compute rain rate statistics
  - **Compared to 3A25**
    - statistics produced from 3A25 are conditioned either on the presence of rain or on the presence of a particular type of rain but statistics from 3A26 are unconditioned.

compute rain rate statistics over 5 degree (latitude) x 5 degree (longitude) x 1 month space-time regions.

Flow of Rain Profile Estimation

Hardware Calibration

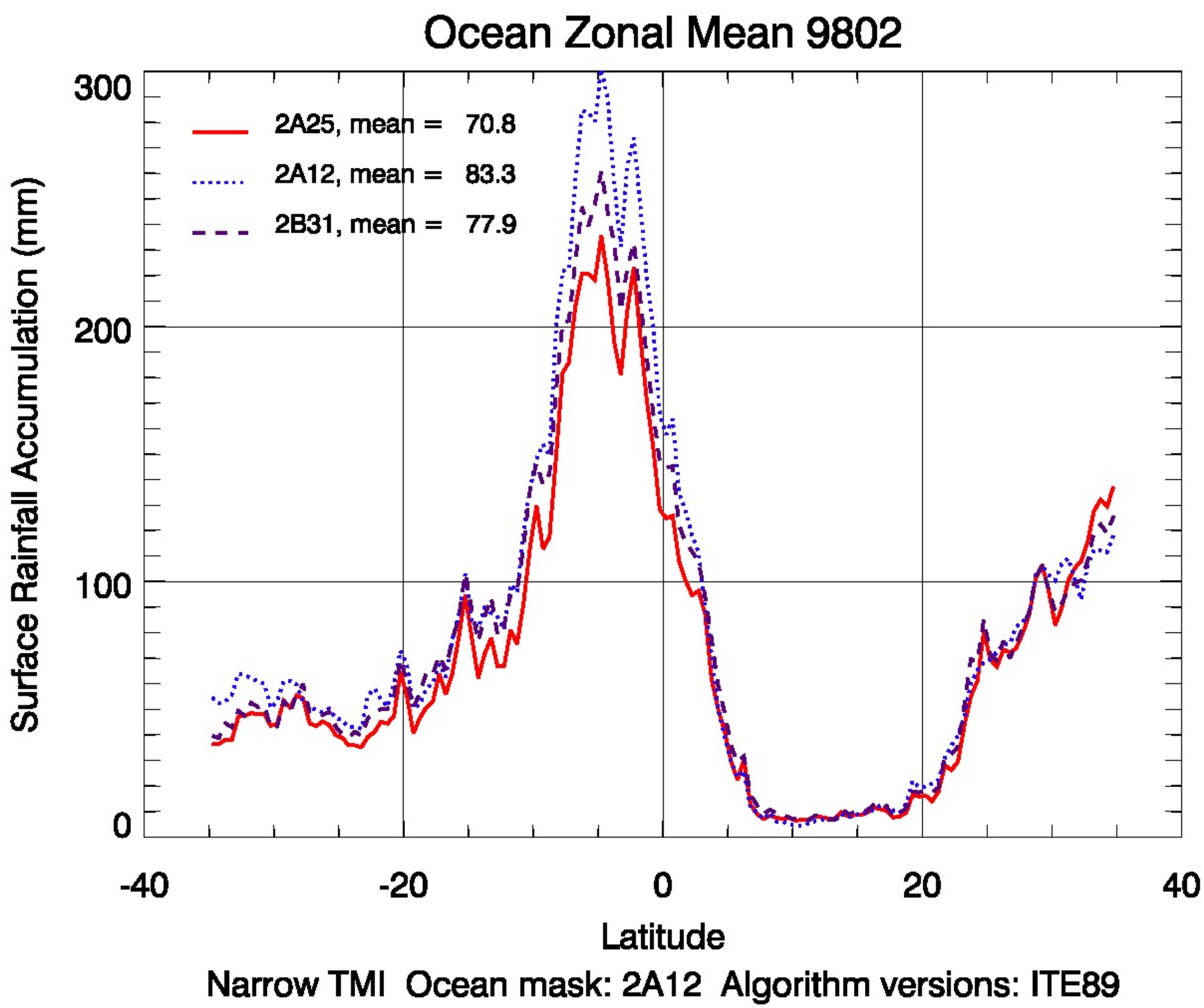
- Received Power (Pr)
- Conversion of Pr to Zm (Apparent measured radar reflectivity factor) using calibration factor of PR
  - Pr →Zm

Retrieval Algorithm

- Correction of attenuation due to CLW, WV, and O2
  - Zm→Zm'
- Correction of attenuation due to precipitating particles (rain att. correction assuming k-Ze relation (DSD))
  - Zm'→Ze
- Conversion of Ze to R (rain rate)
  - Ze→R

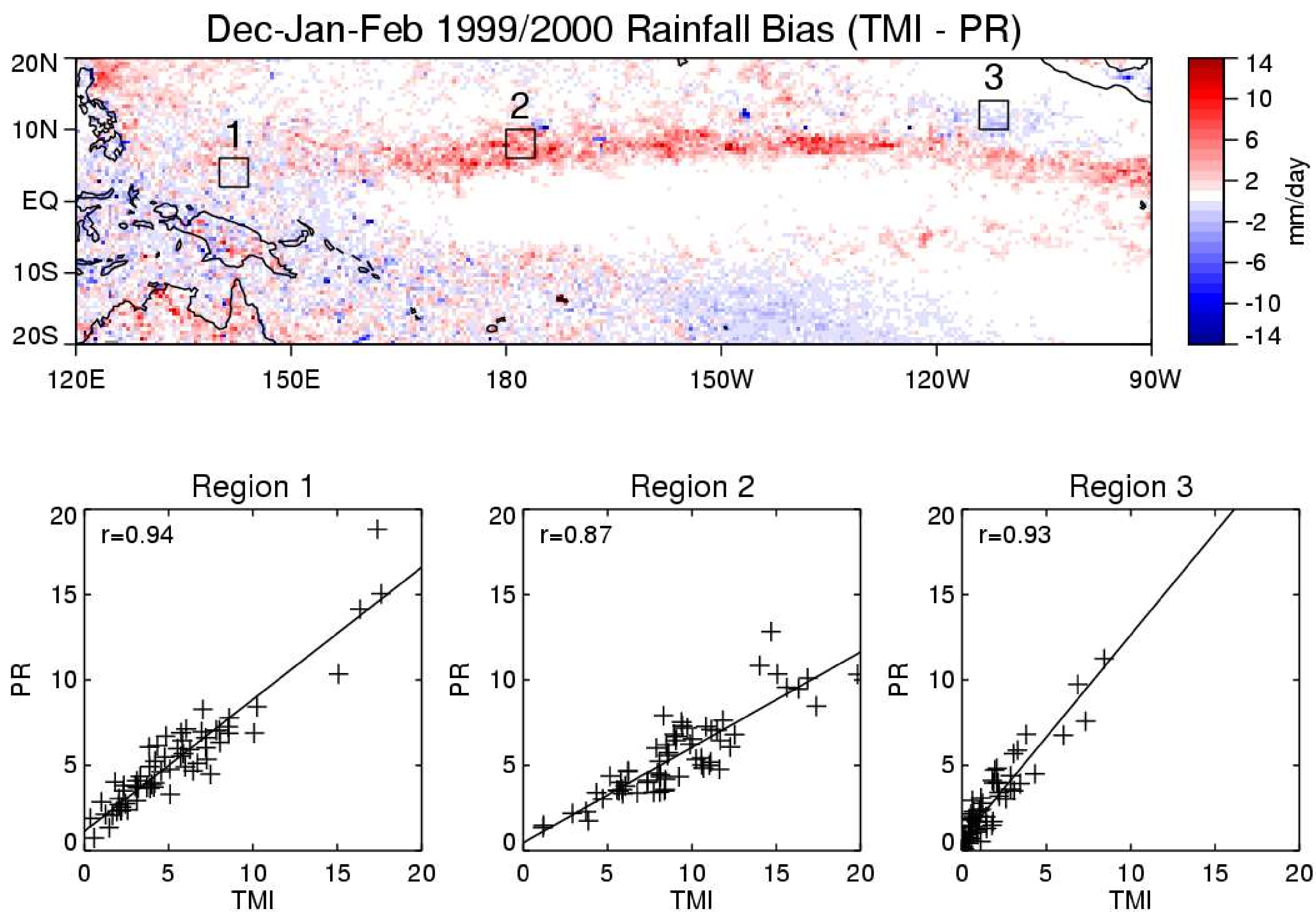
Assumptions: distribution of CLW as a function of R, distribution of WV, type of precipitating particles as a function of height, DSD model, homogeneity of rain distribution within an IFOV, vertical profile of rain in surface cluttered range, stable surface scattering cross sections

Comparison of rain estimates from different algorithms (PR and TMI)



(Essentially the same as V6)

PR and TMI Regional Validation



TMI V6, PR V5

(W. Berg, et al.)

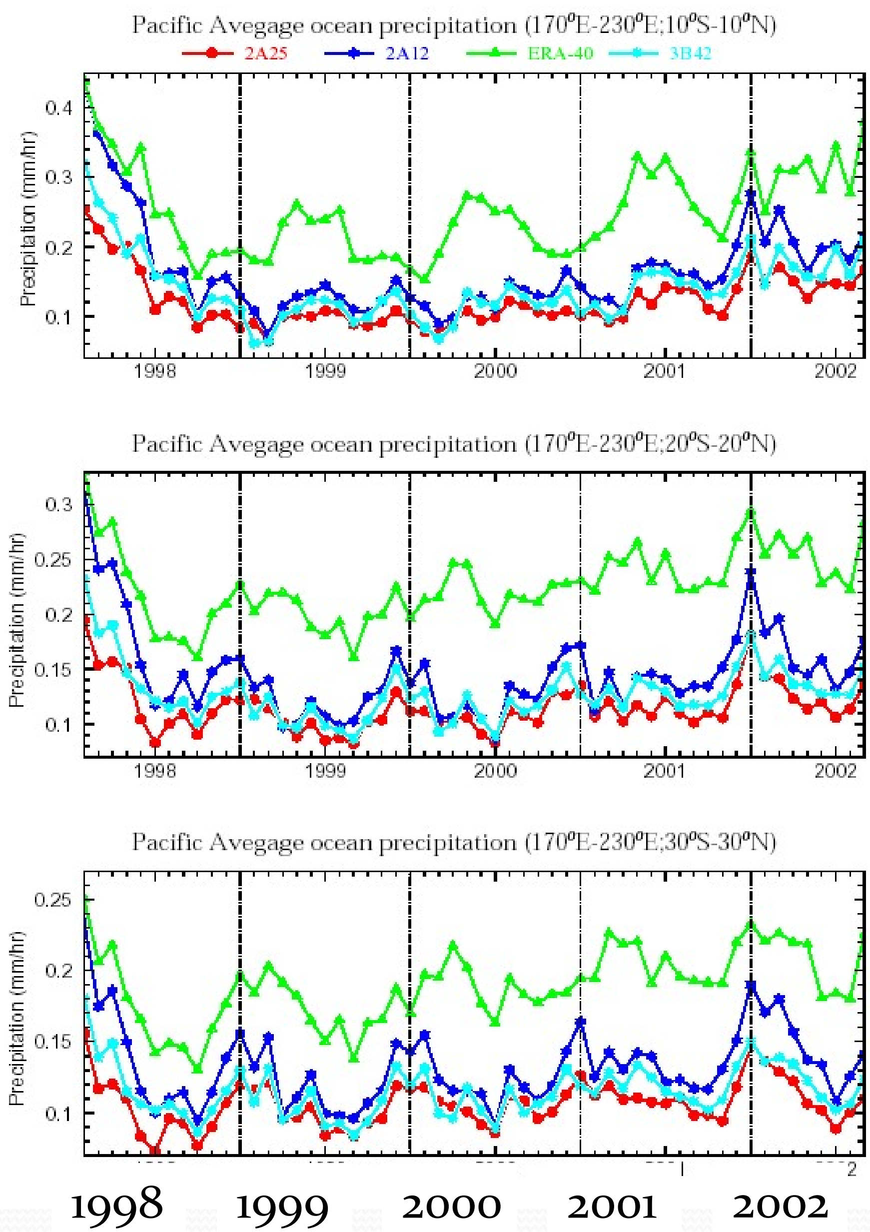
Differences in Rain Estimates

170E-230E

10S-10N

20S-20N

30S-30N



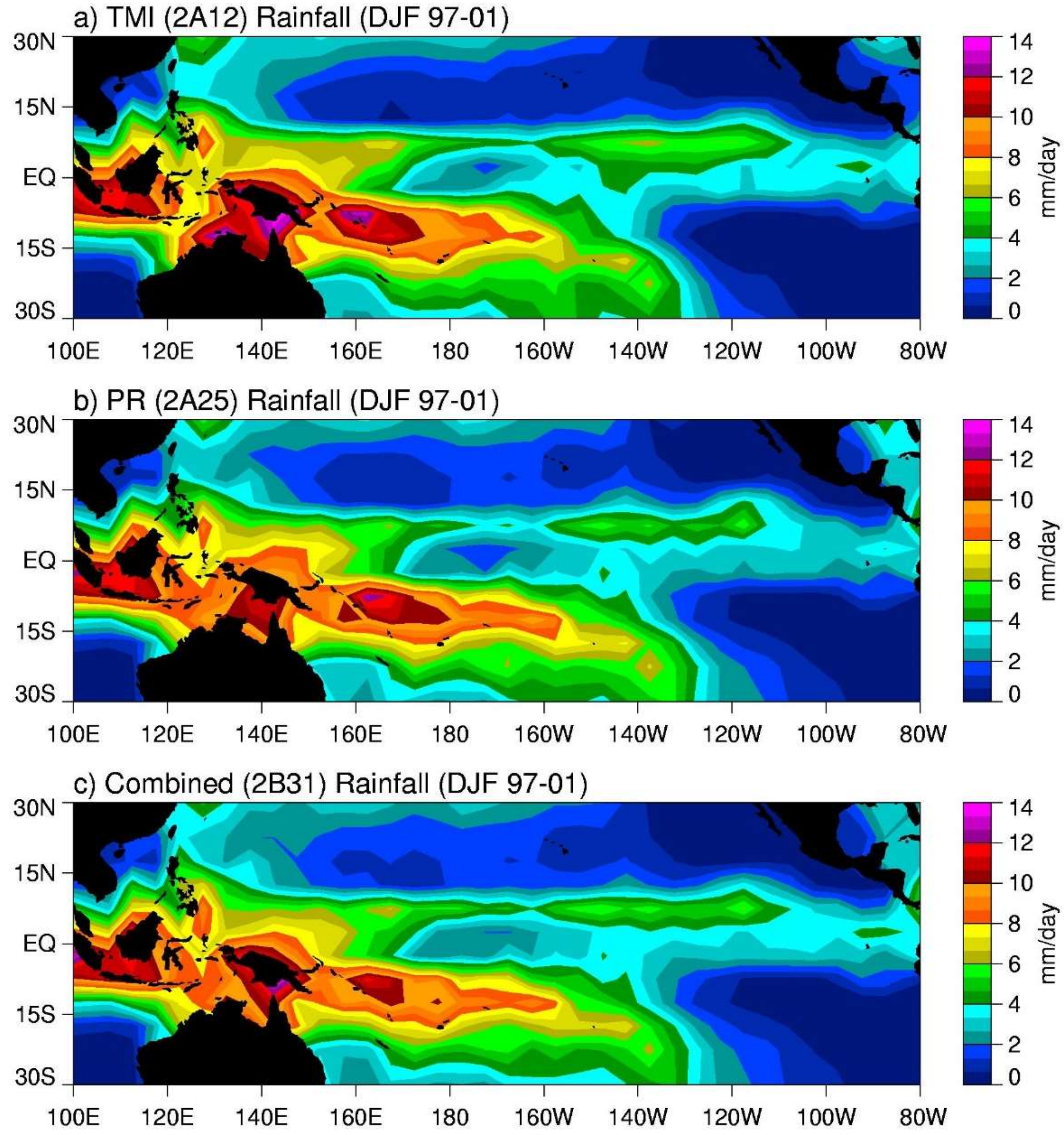
2A25

2A12

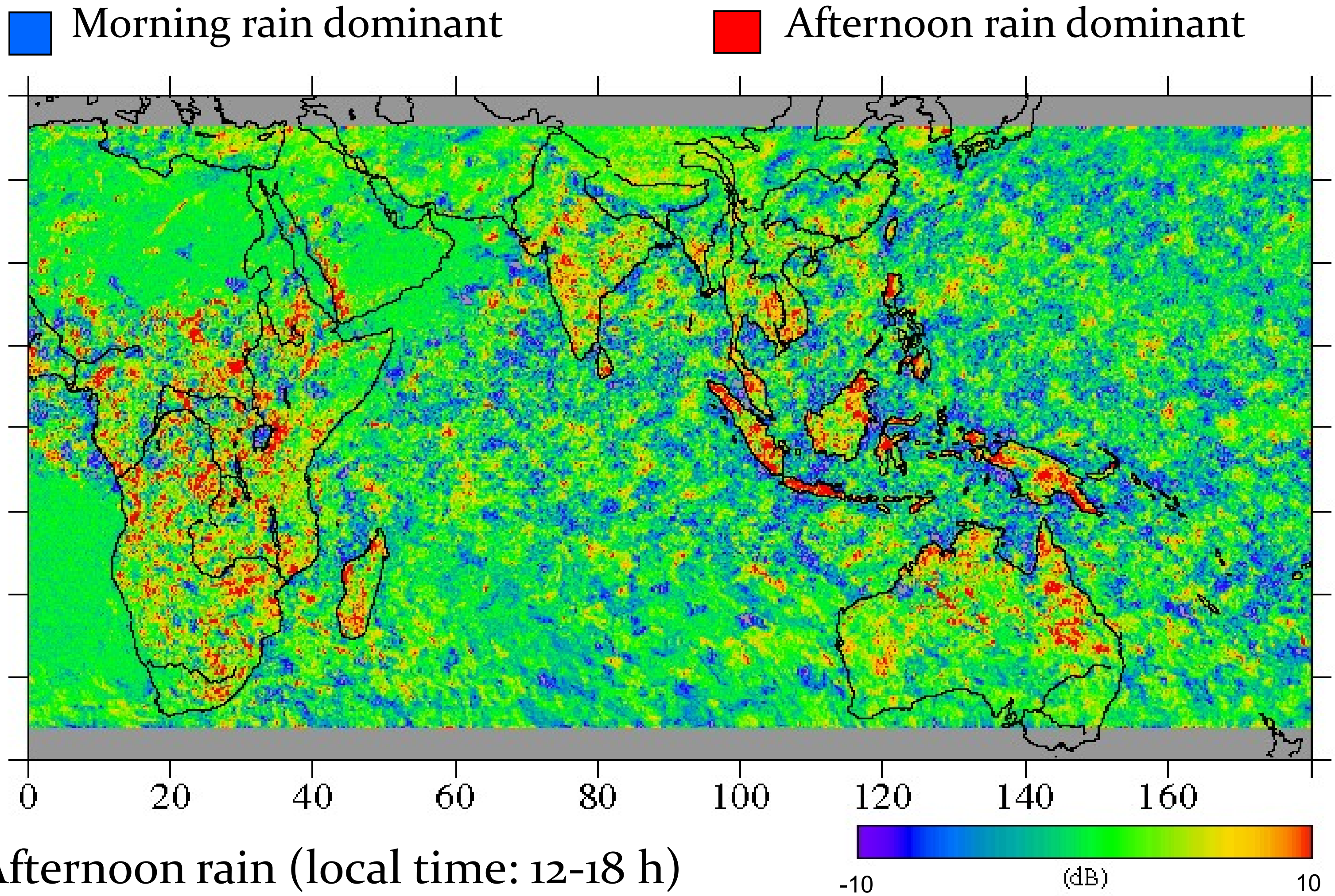
ERA-40

3B42

Bias Adjusted Mean DJF Rainfall



Diurnal Variation of Rain from PR



$$\frac{\text{Afternoon rain (local time: 12-18 h)}}{\text{Morning rain (local time: 6-12 h)}}$$

(March 1998 - February 1999)

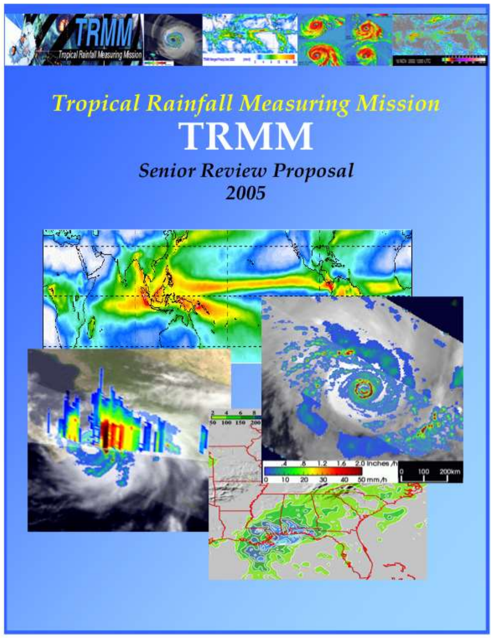
PR Summary

- **TRMM PR uses three kinds of calibration methods.**
  - internal calibration
  - external calibration with ARC (active radar calibrators)
  - calibration with natural targets
- **All calibration methods indicate an extremely stable performance of PR.**
  - Housekeeping data are all very stable
  - overall long-term stability < 0.05dB
- The largest error in rain rate estimation probably comes from the **retrieval algorithms** and not from the **radar calibration**.

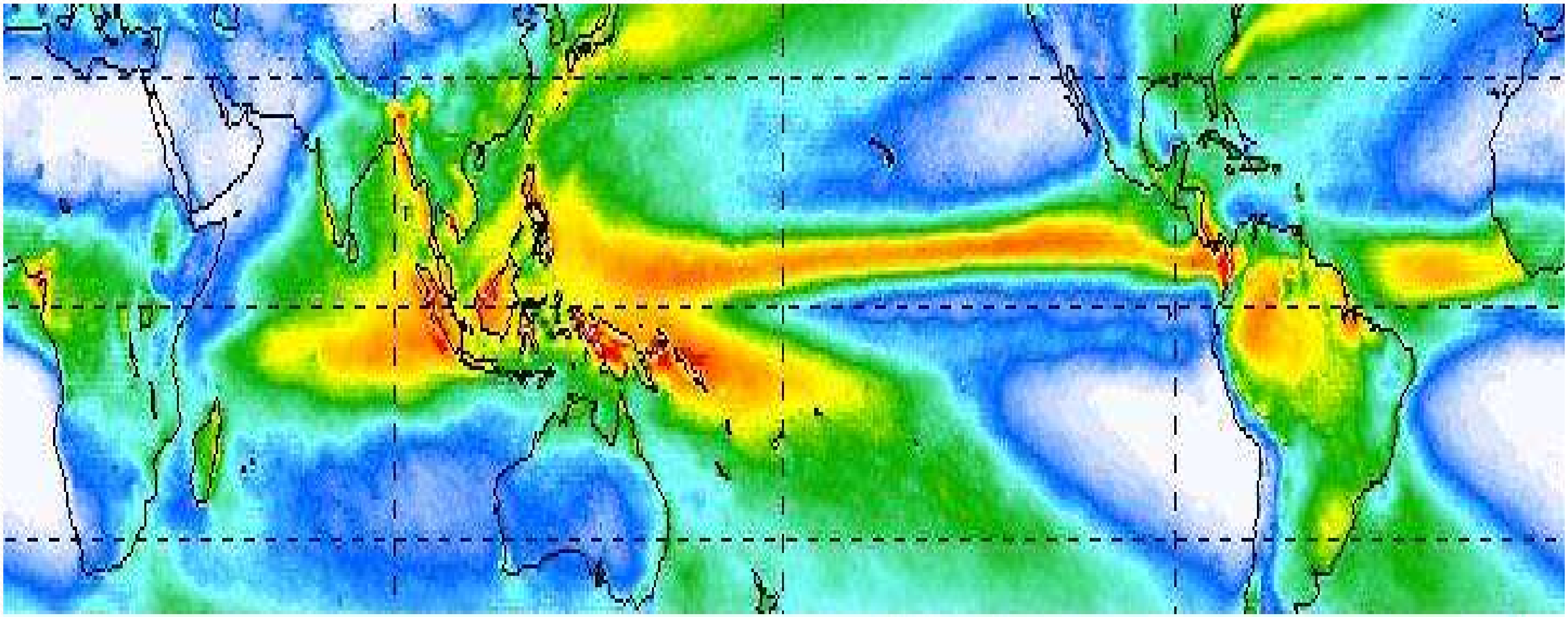
TRMM Major Science Results

- **Space standard** for measuring precipitation
- **Improved climatology** of tropical rainfall and variations
- **Convection intensity** observations and variations
- **Climatology of lightning** over land and ocean
- **Vertical heating structure** and **diurnal variations**
- **Improved** climate and weather **modeling**
- **Impact of humans** on precipitation
- **Hurricane**/typhoon structure/evolution
- **Multi-satellite (~3-hr) rainfall analyses** using TRMM+other satellites
- Flood and agricultural **applications**
- **Operational use** of data by weather agencies.

Senior Review Proposal



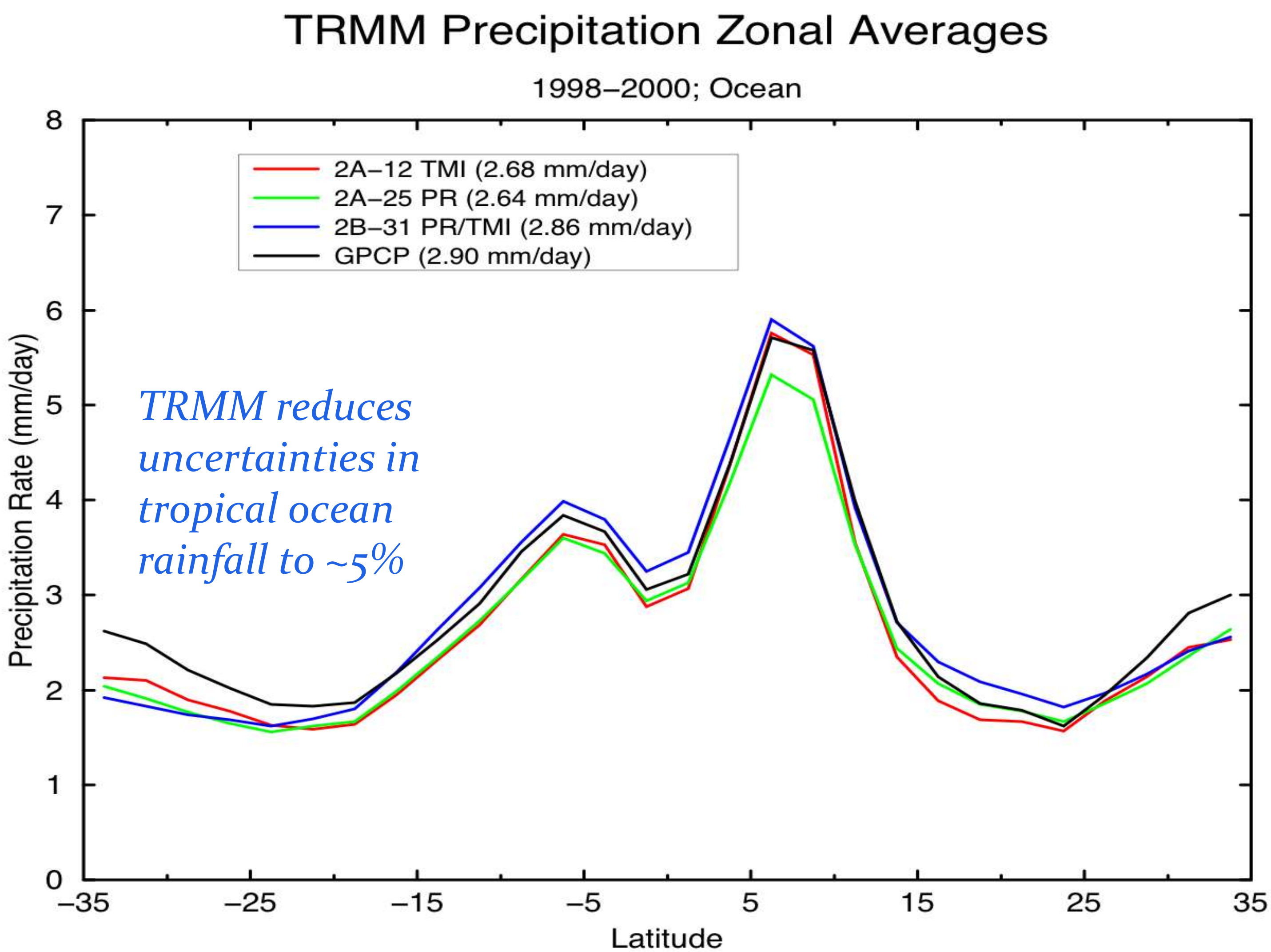
Eight-Year TRMM Climatology January 1998-December 2005



Precip (mm/d)

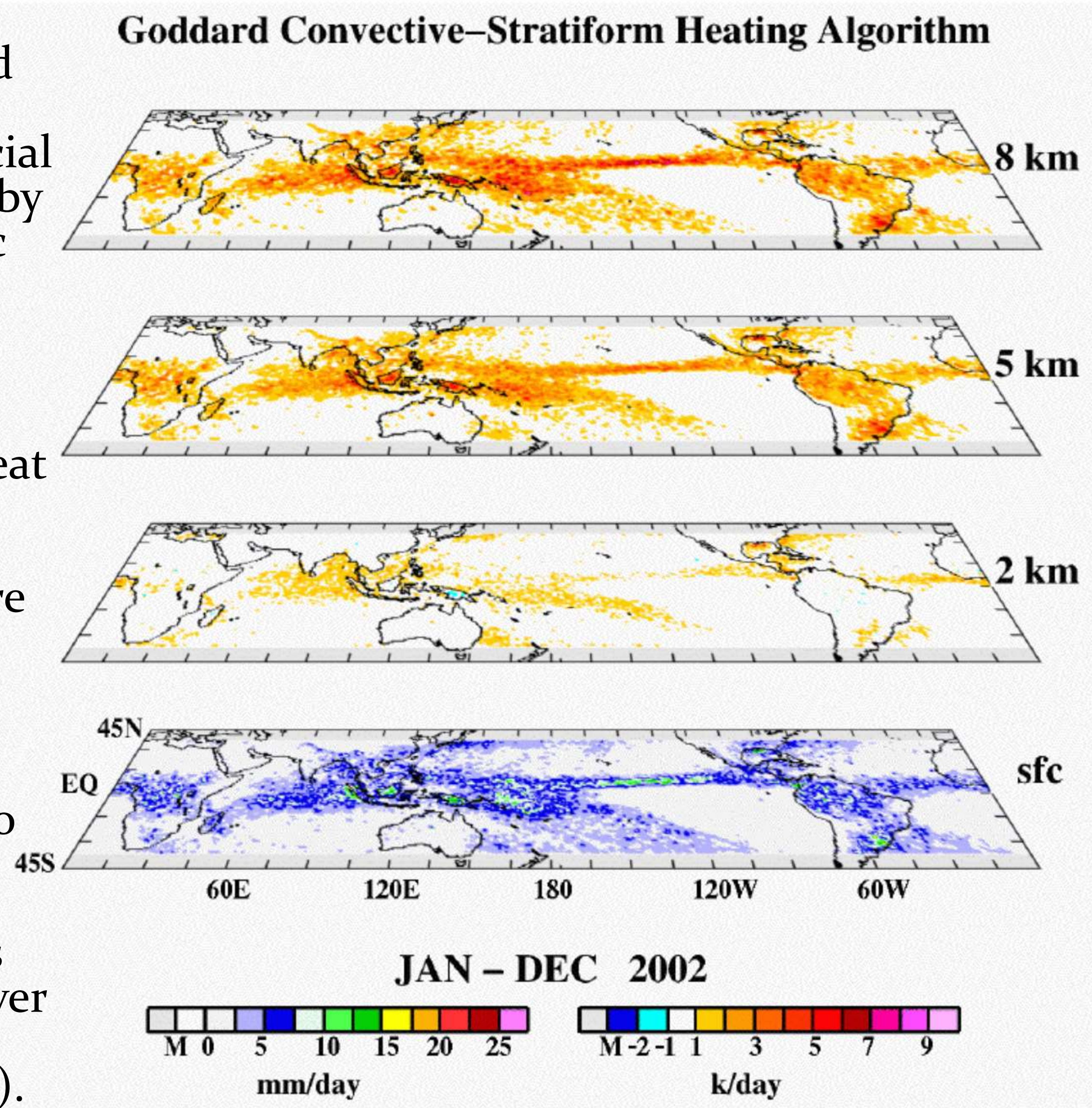
TRMM Multi-satellite product
(TMPA--3B43)

TRMM Precip Zonal Averages



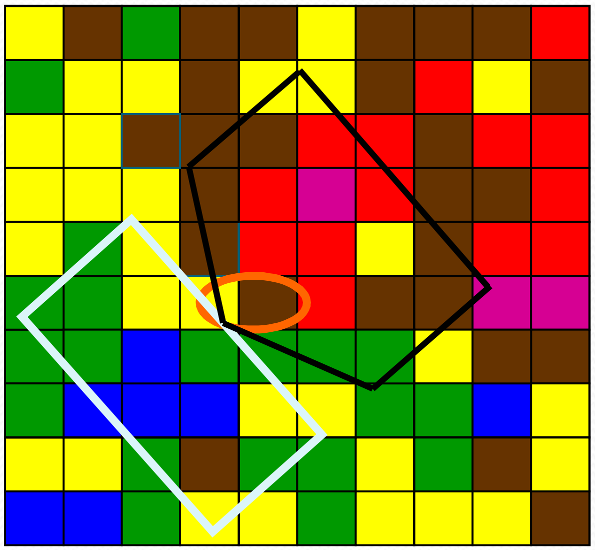
TRMM Derived Latent Heating Distribution

- Latent heating in convective and stratiform clouds drives the tropical Hadley Cell – plays crucial role in poleward heat transport by Earth's atmospheric and oceanic fluid system.
- A primary mission objective of TRMM is to quantify the 4D distribution of tropical latent heat release.
- Accurate estimates of heating are crucial for climate models and their cumulus parameterization schemes.
- Areas of largest rain rates map to the greatest in-cloud heating.
- Annual average latent heating is maximized across the Pacific, over the Maritime Continent, and is largest at high altitudes (~ 8 km).



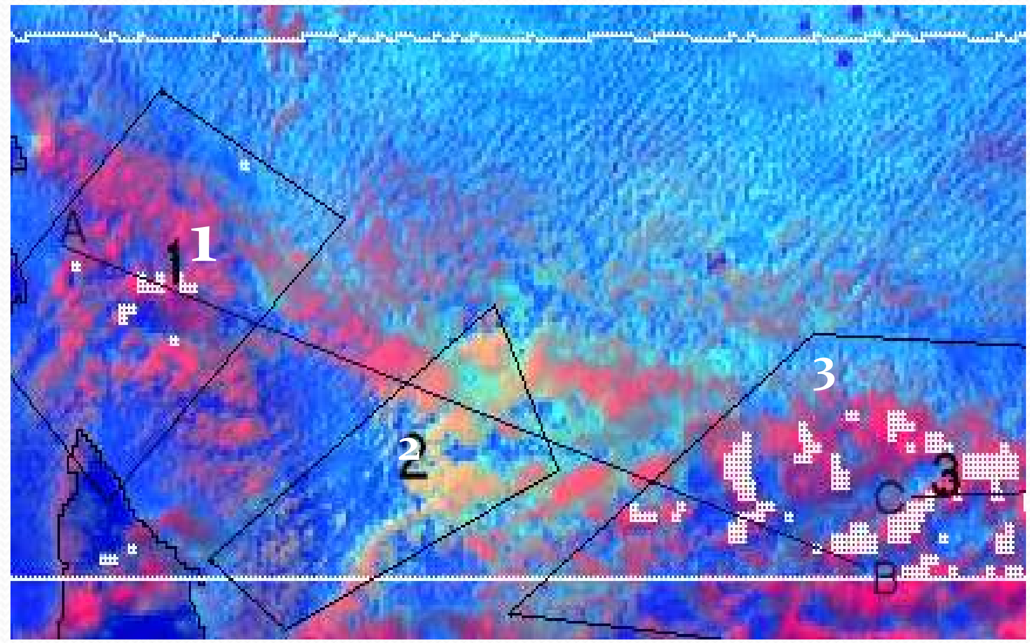
Impact of Humans of Precipitation

Impact of Cities on Rainfall

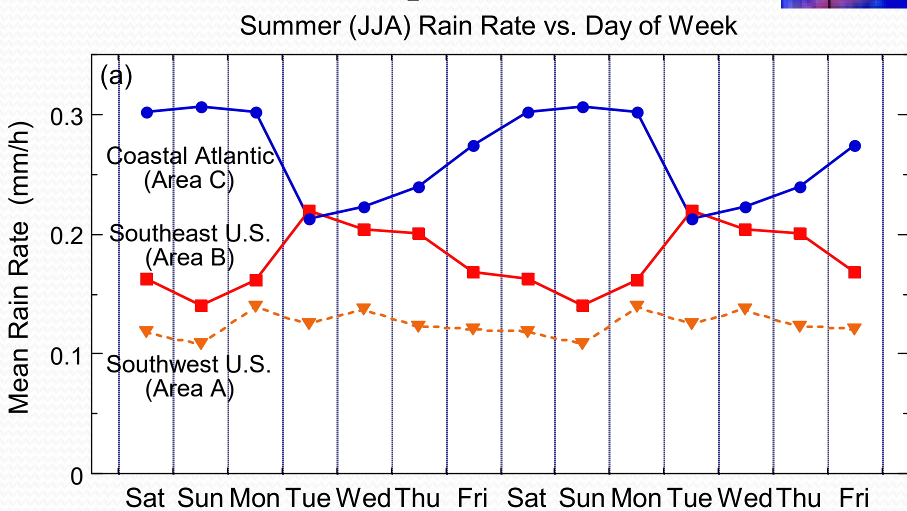


Houston downwind rainfall maximum (Shepherd)

Effect of Pollution on Rainfall Over Ocean



Lack of PR-detected rain in polluted clouds (Rosenfeld)

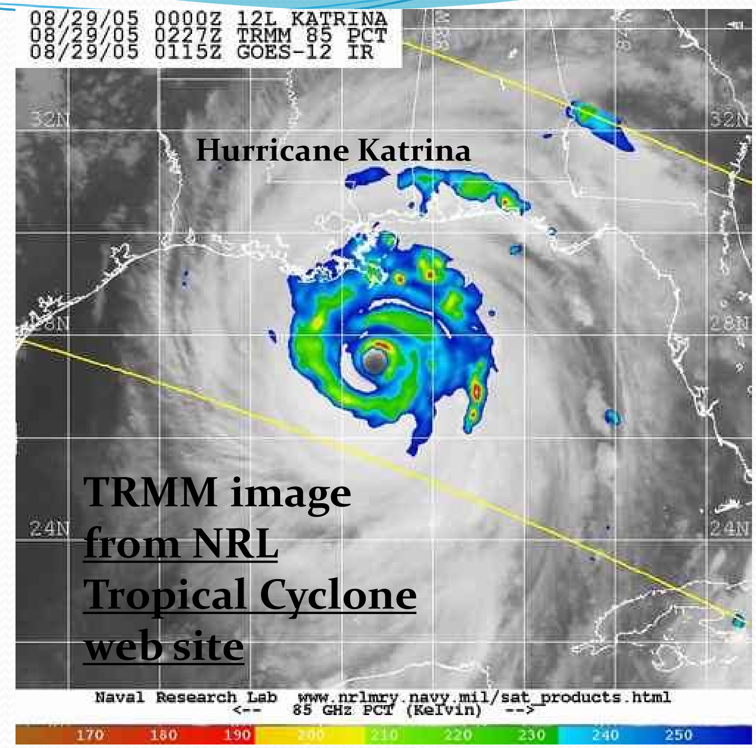


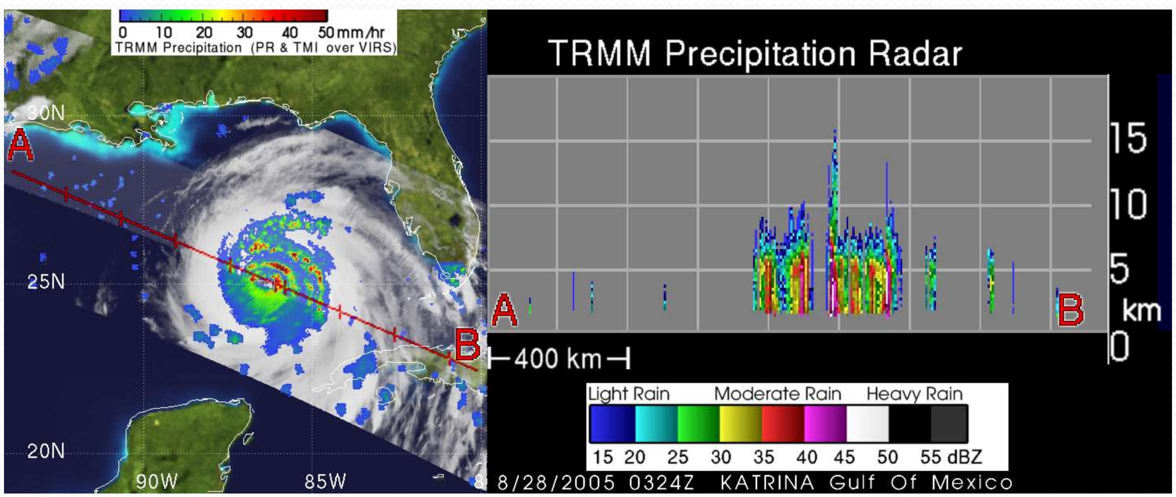
Pollution Impact on Land Rainfall

Increase in Summer Rain over SE U.S. during week (red curve)--Increase offshore on weekend (blue curve)--(Bell)

TRMM & Hurricanes

- TRMM orbit advantageous for tropical cyclone monitoring
- despite narrow swath it is always in tropics
- **TRMM sampling best in 10-35º latitude storm band**.
- TMI resolution twice as good as SSM/I, about same as AMSR.
- Precessing orbit provides **off-time observations relative to sun-synchronous microwave observations**.



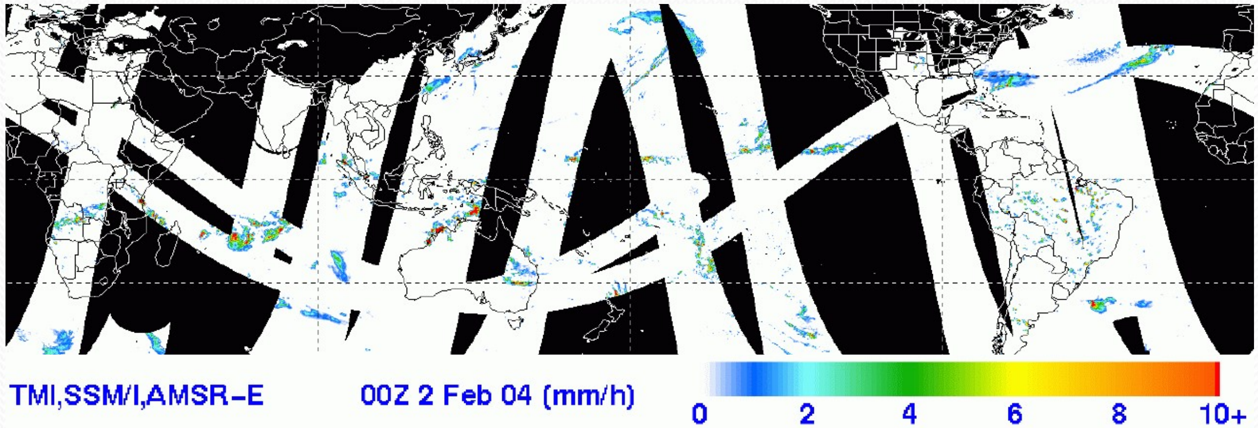


TRMM radar (PR) cross-sections of hurricanes used to be available in real time via operational analysis from TRMM website

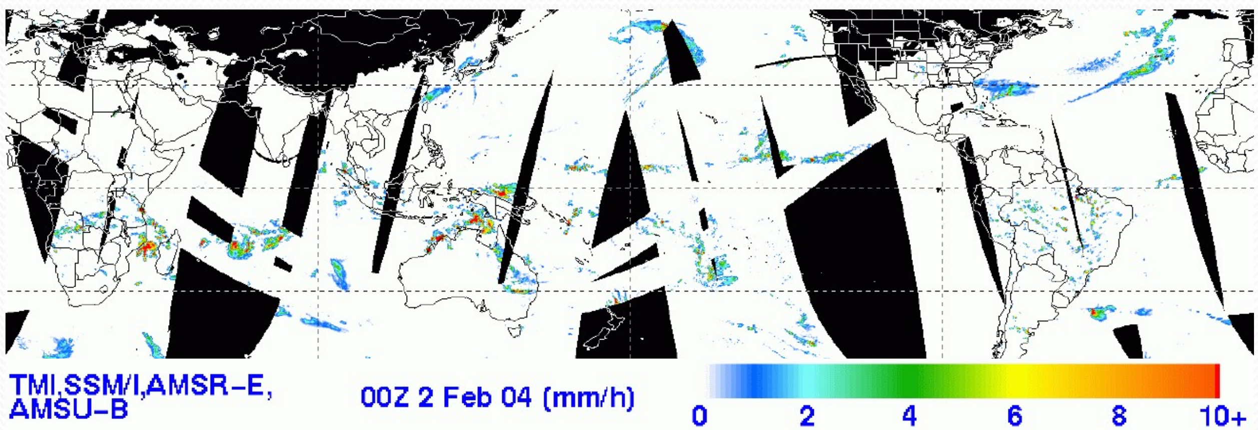
TRMM Calibrating Other Satellites

(TRMM Multi-satellite Precipitation Analysis (TMPS 3-hr)

Combined "high quality" (conical scanning) microwave data coverage: Averages 55% with TRMM, AMSR-E and 3 SSM/I's



Addition of 3 AMSU-B's (lower quality over ocean): Total coverage averages ~ 85%



Remaining gaps filled by Geo-IR precipitation estimates

Version 6 3B42: Eight year, 3-hr data set

TRMM – Past, Present, Future

- **TRMM Experimental Phase** (Jan. 1998-August 2001*[~3.5 years]*). 350 km altitude. (better PR sensitivity)

- **TRMM Extended Phase** (August 2001-April 2015). 402 km altitude. (reduced PR sensitivity*[5+ years]*). Fuel sufficient to ~2012

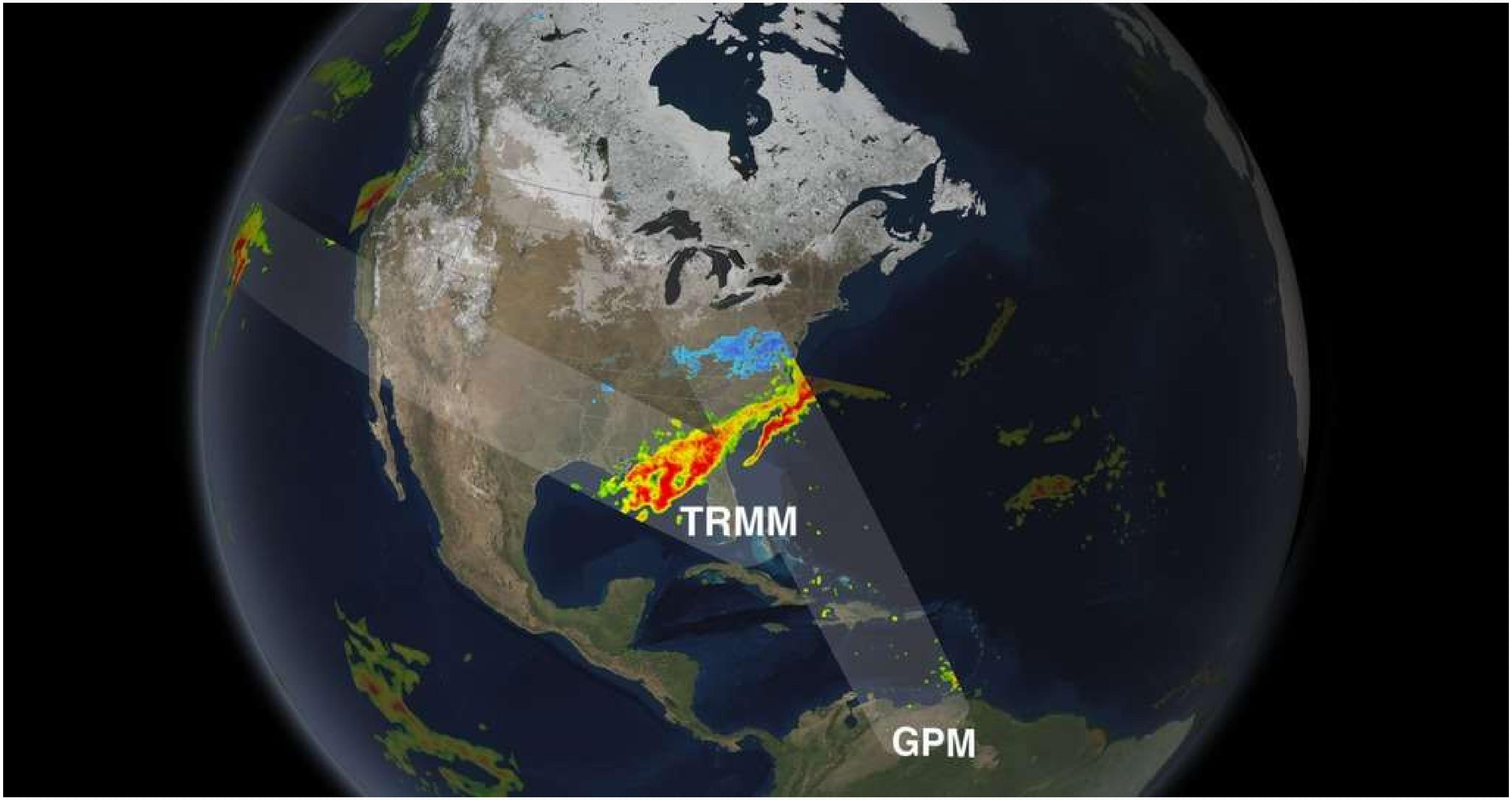
- Version 6 TRMM products improved, but **impact of boost evident**;

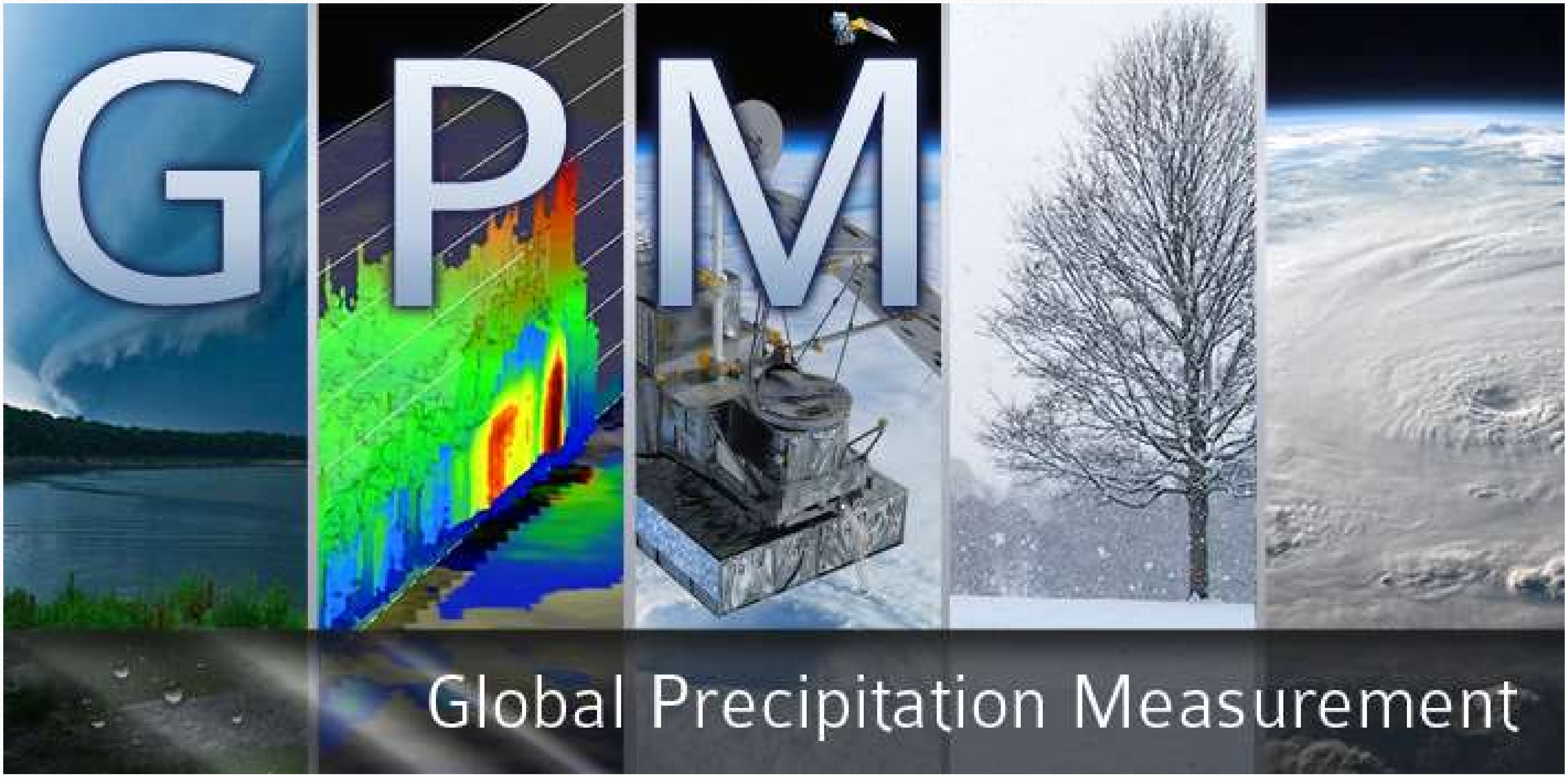
- **Version 7** will address boost issue and **transition toward GPM era as TRMM has been decommissioned (in 2015)**

- TRMM extension decision allowed for continuation of TRMM-based science and applications, **up to and overlapping GPM core (also at ~400 km altitude).**

- **GPM** will add **critical microphysical information**, **expand latitude range** to middle and high latitudes, provide **improved microwave sampling**, and **lengthen important radar/radiometer record** started by TRMM.

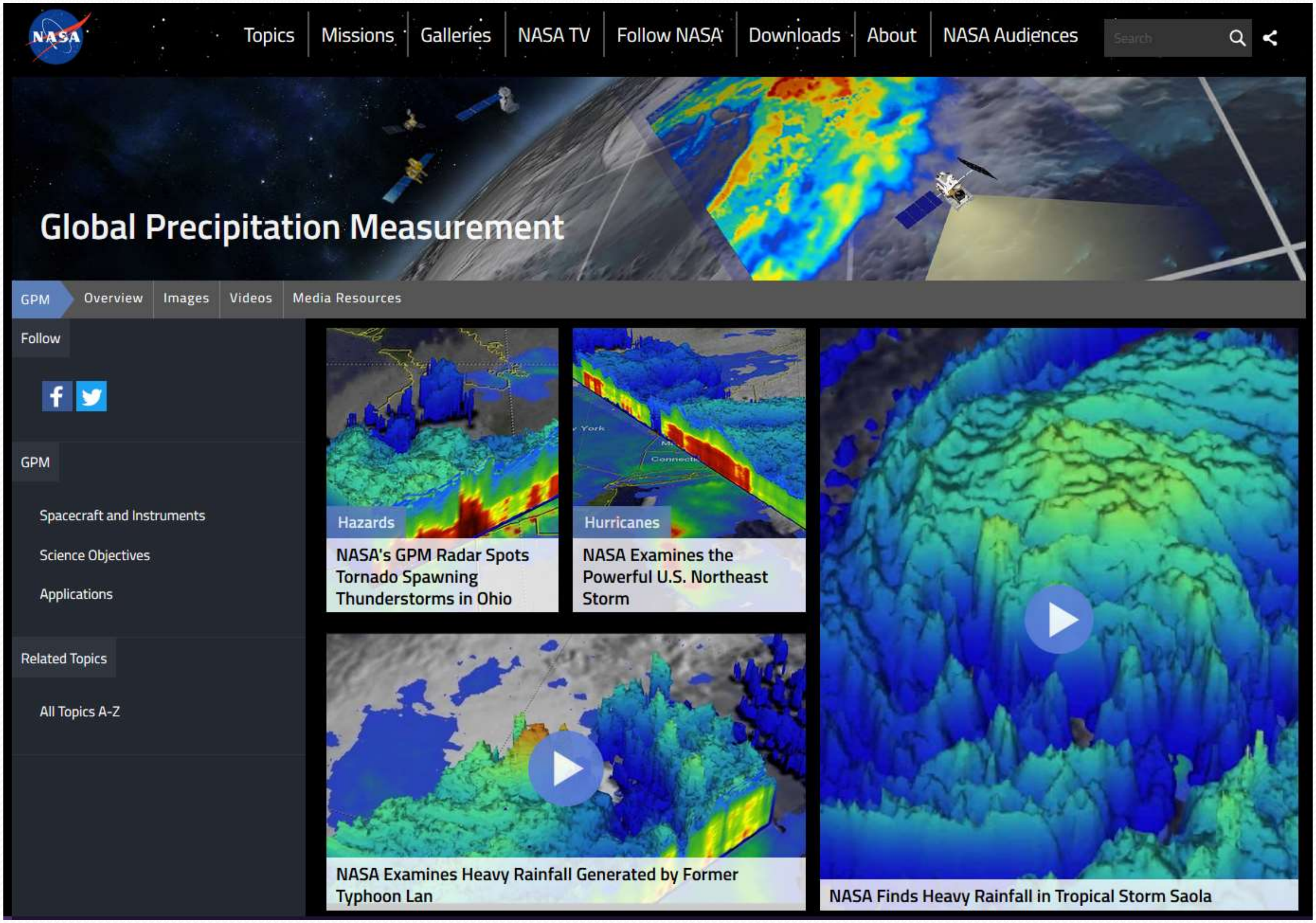
From TRMM to GPM




GPM
Global Precipitation Measurement

GPM Main Description Page

https://www.nasa.gov/mission_pages/GPM/main/index.html



GPM Objective

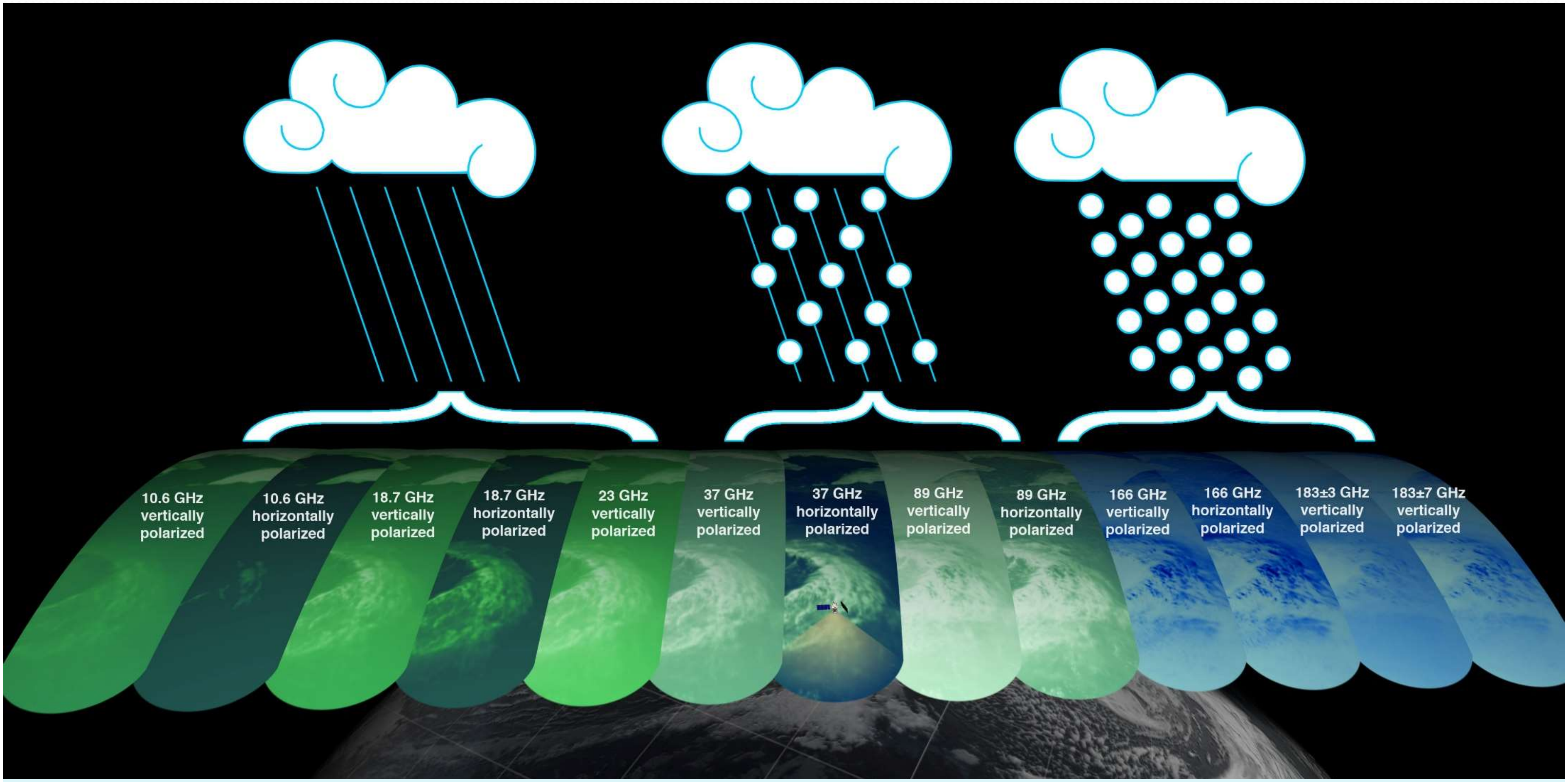
- The **Global Precipitation Measurement mission** is an international network of satellites that provide the next-generation global observations of rain and snow to advance our understanding of Earth's water and energy cycle, improve forecasting of extreme events, and provide accurate and timely information to directly benefit society.

- **Improve ongoing efforts to predict climate**
  - by providing near-global measurement of precipitation

- **Improve the accuracy of weather and precipitation forecasts**
  - through more accurate measurement of rain rates and latent heating.

- **Provide more frequent and complete sampling of the Earth's precipitation.**
  - This will provide better prediction of flood hazards and management of life-sustaining activities dependent upon fresh water

GPM Channels

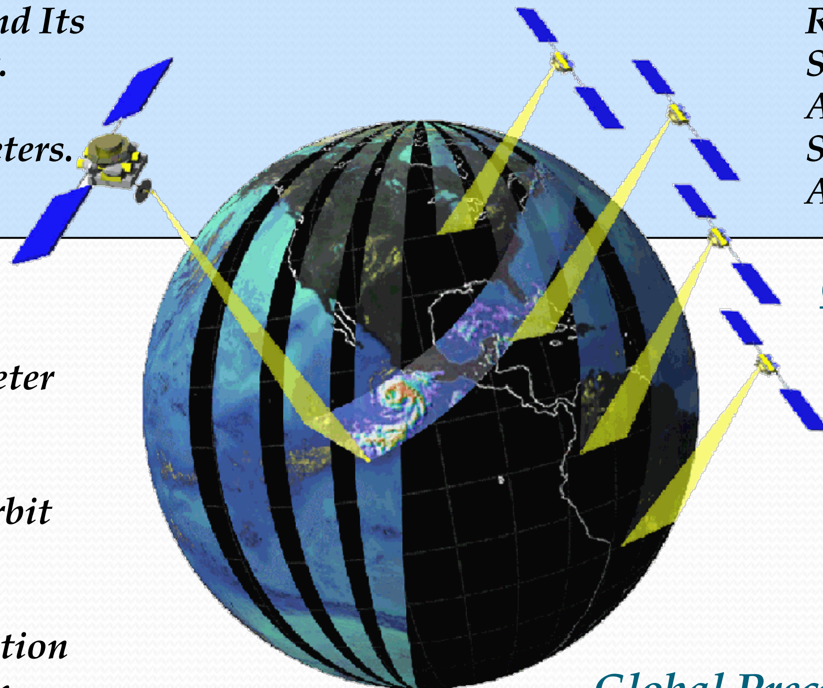


The GPM Microwave Imager has 13 channels, each sensitive to different types of precipitation. Channels for heavy rain, mixed rain and snow, and snowfall are displayed of the extra-tropical cyclone observed March 10, off the coast of Japan. Multiple channels capture the full range of precipitation.

GPM Reference Concept

OBJECTIVE: Understand the Horizontal and Vertical Structure of Rainfall and Its Microphysical Element. Provide Training for Constellation Radiometers.

OBJECTIVE: Provide Enough Sampling to Reduce Uncertainty in Short-term Rainfall Accumulations. Extend Scientific and Societal Applications.



Core Satellite

- *Dual Frequency Radar*
- *Multi-frequency Radiometer*
- *H2-A Launch*
- *TRMM-like Spacecraft*
- *Non-Sun Synchronous Orbit*
- *~70° Inclination*
- *~400 - 500 km Altitude*
- *~4 km Horizontal Resolution*
- *250 m Vertical Resolution*

Constellation Satellites

- *Small Satellites with Microwave Radiometers*
- *Aggregate Revisit Time, 3 Hour goal*
- *Sun-Synchronous Polar Orbits*
- *~600 km Altitude*

Global Precipitation Processing Center

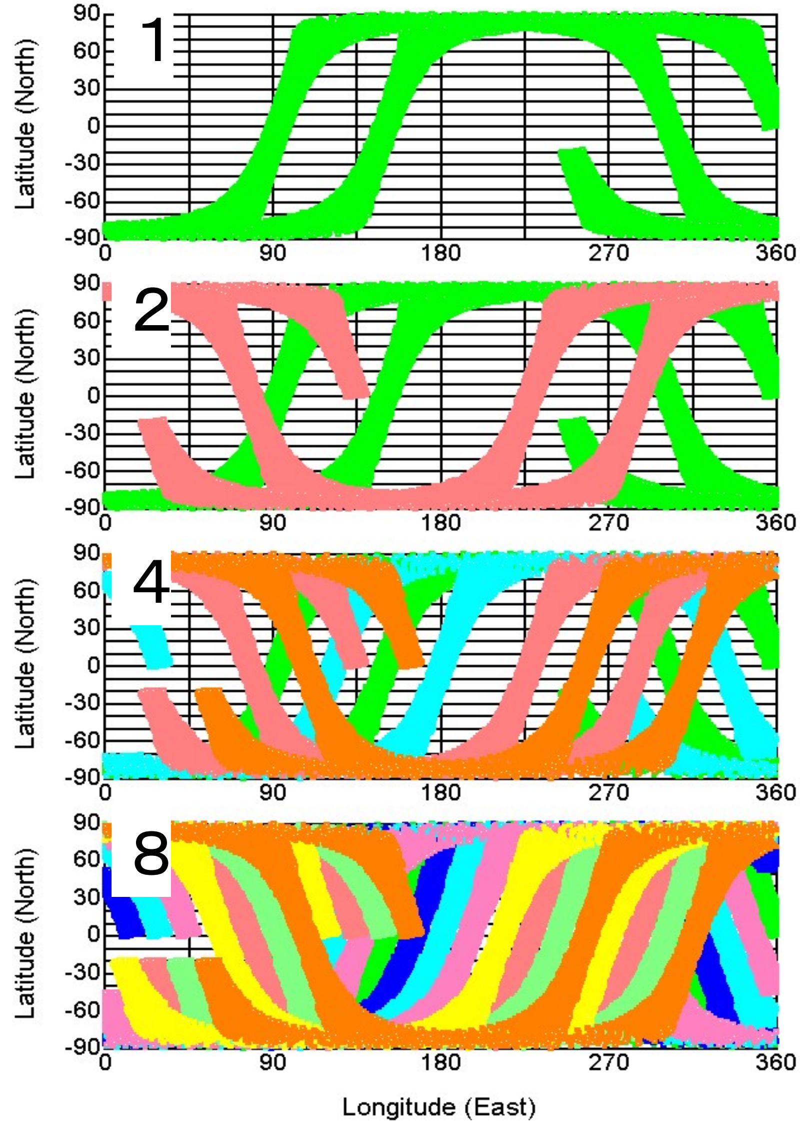
- *Capable of Producing Global Precip Data Products as Defined by GPM Partners*

Precipitation Validation Sites

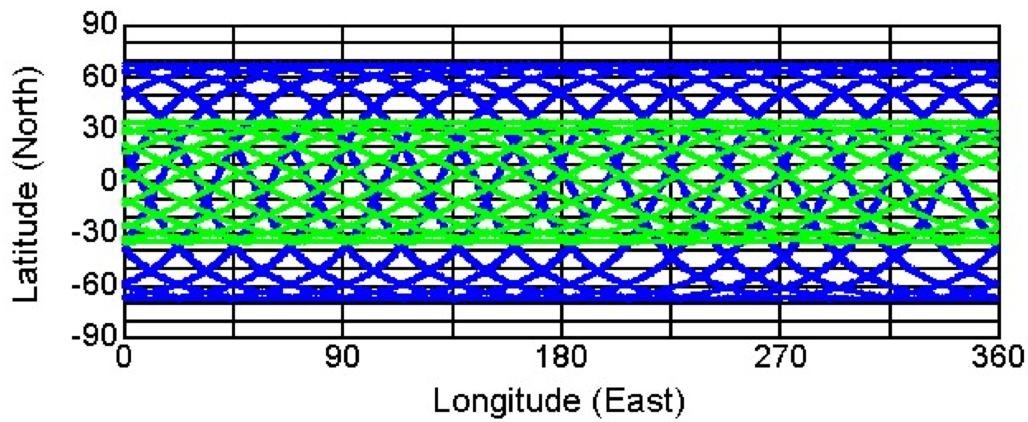
- *Global Ground Based Rain Measurement*

Observation by a fleet of satellites with microwave radiometer

Observation area with MWRs in 3 hours (1, 2, 4 and 8 satellites from top to bottom)



Coverages by **TRMM PR** and **GPM DPR** in a day



3-hour Global Coverage

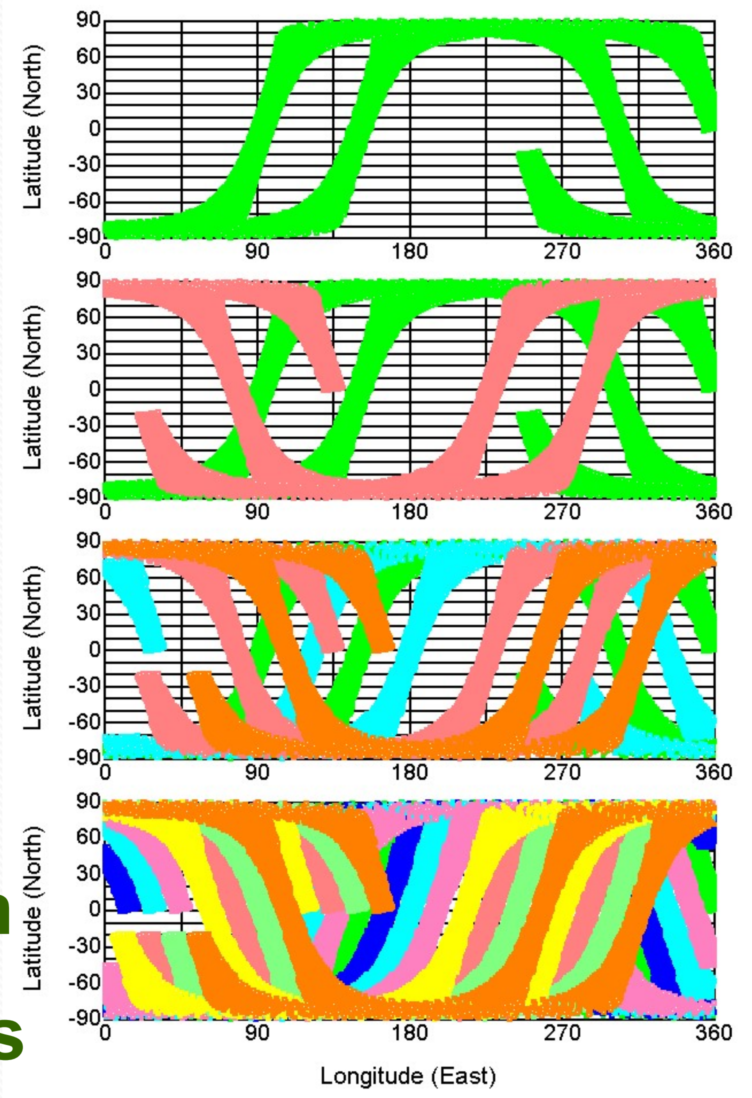
- The observation area covered in 3 hours by

Single satellite

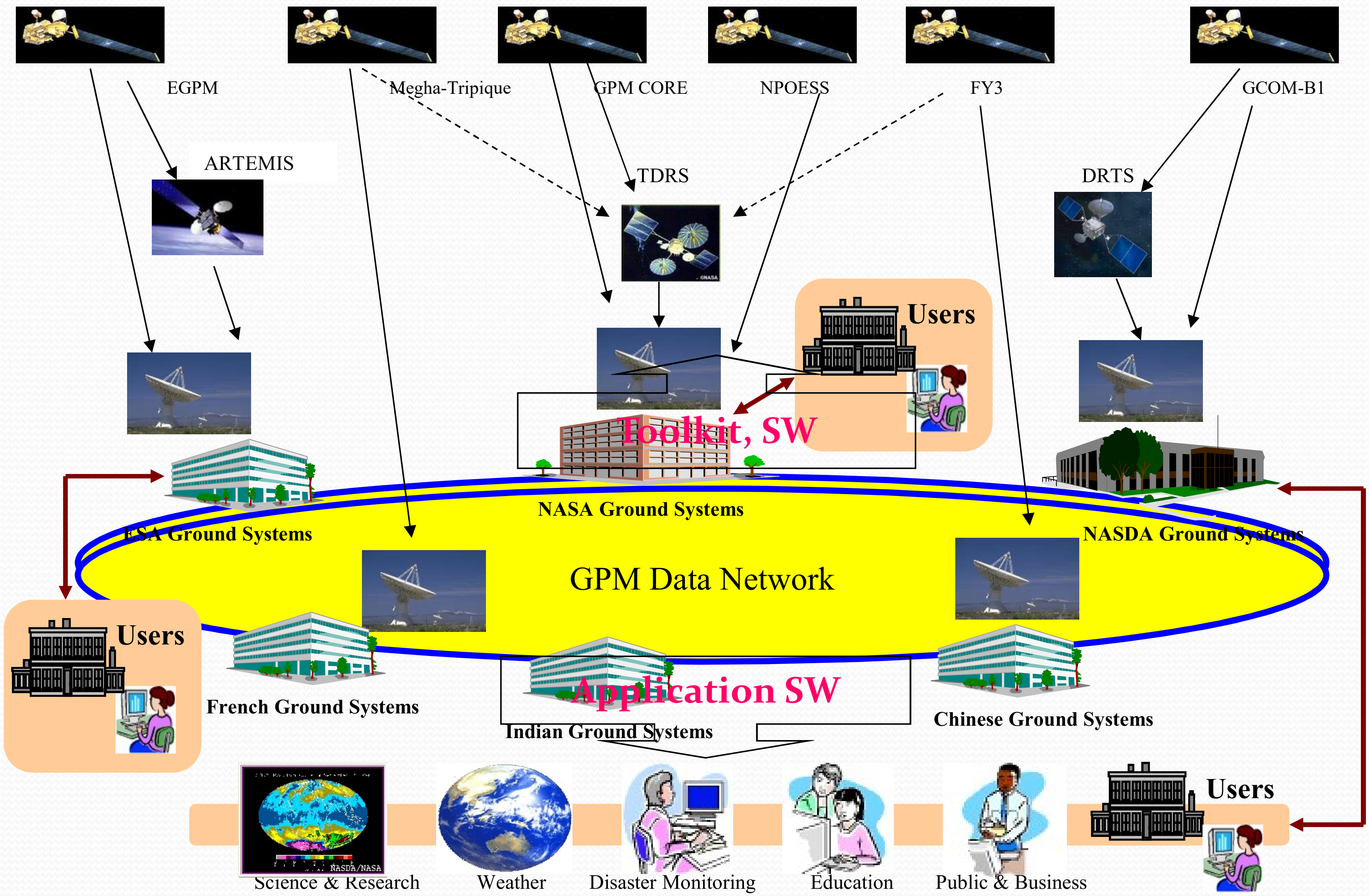
Two Constellation

Four Constellation

Eight Constellation satellites

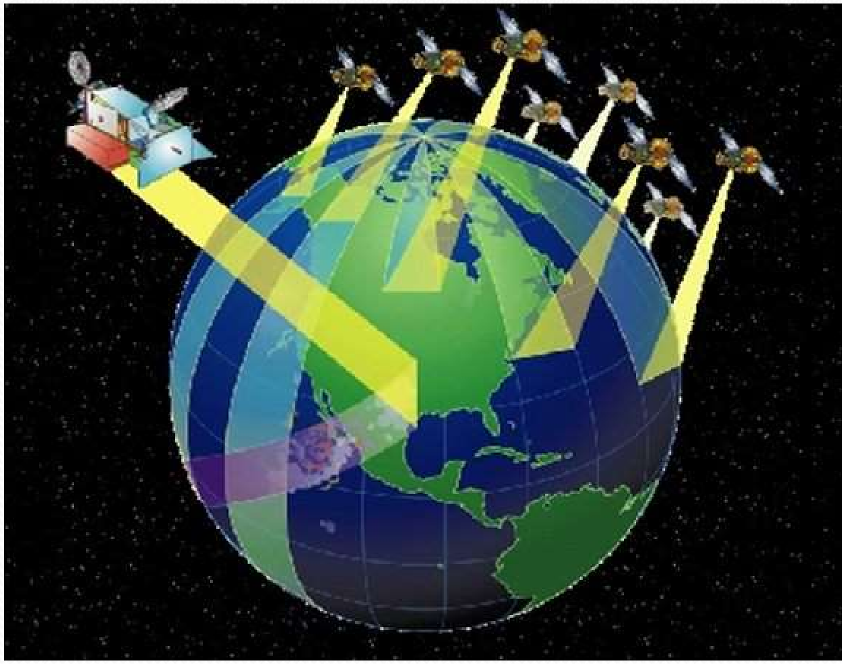


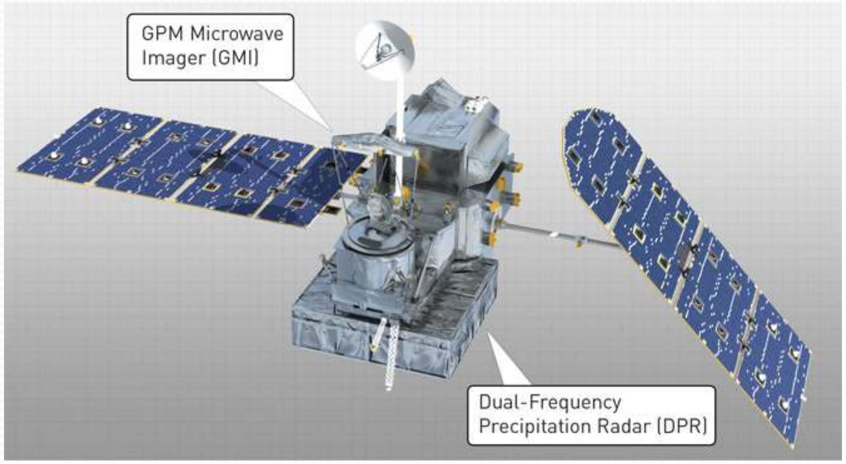
Concept of GPM Data Network



Brief GPM Summary

- **GPM important key is Data Utilization**
  - Important : data exchange
    - High performance network
      - To collect high-frequent observation data immediately
      - To distribute them for users
  - **Easy Utilization**
    - To standardize for handling MWRs data which have different characteristics for their data mapping and their statistics.
    - Varied and diverse user group





GPM Data Downloads

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