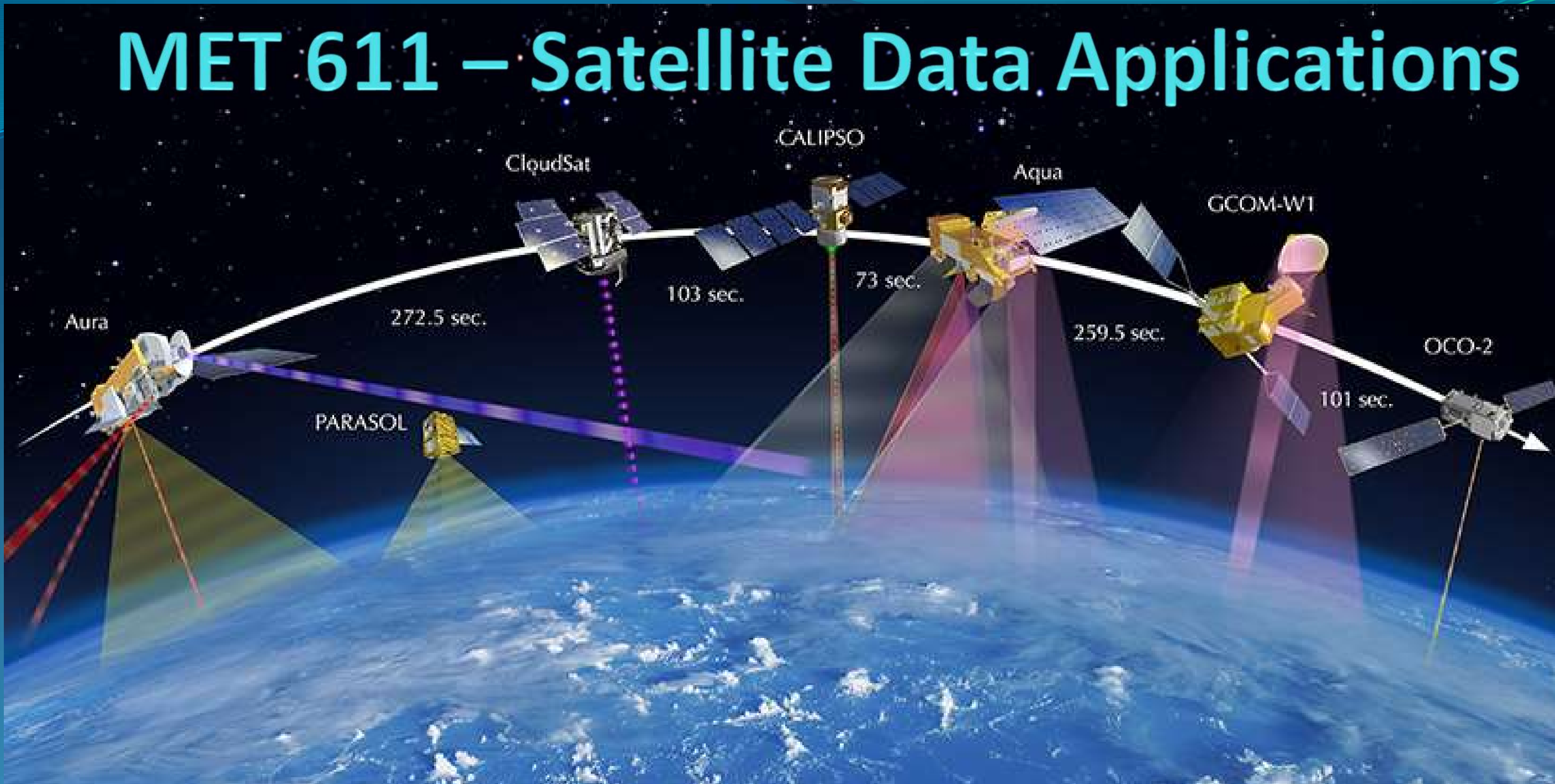
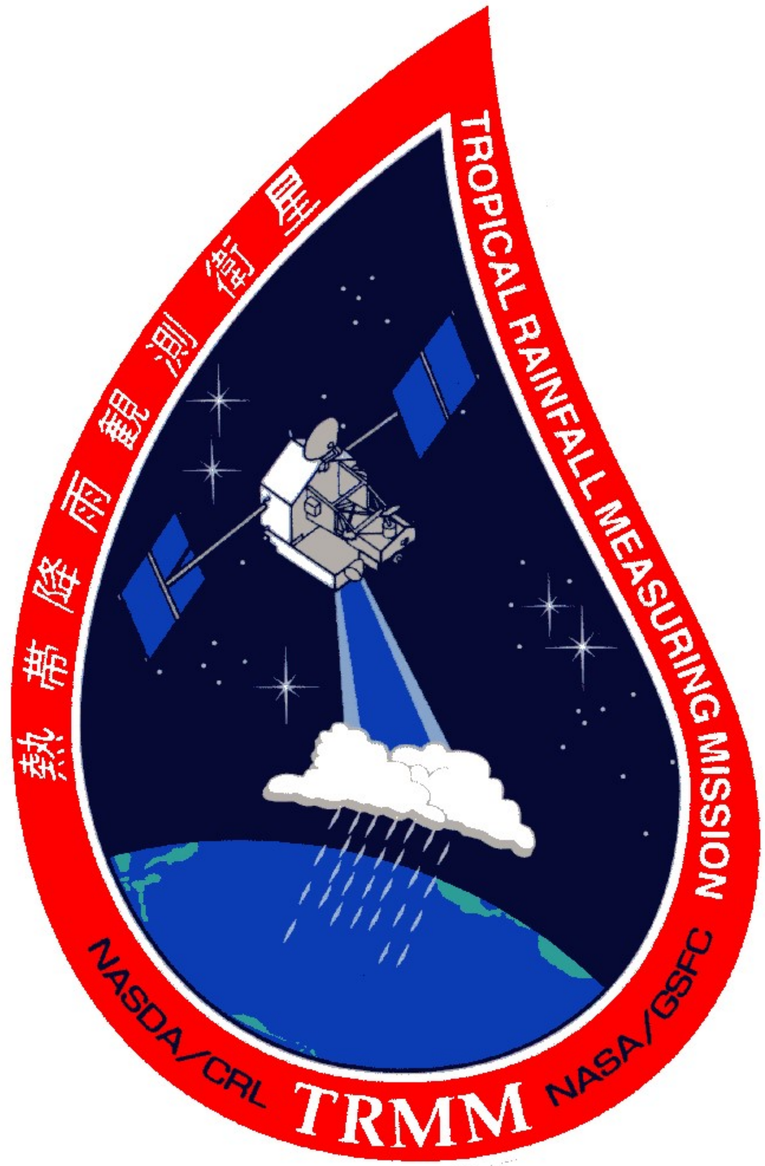


TRMM Introduction

Jennifer D. S. Griswold

TRMM Background

- Joint mission between **NASA** and **JAXA**
- Launched on November 27, **1997** from Tanegashima, Japan
- Monitors rainfall in the **TROPICS**
- Part of the NASA Mission to Planet Earth
- After over 17 years of productive data gathering, the **instruments on TRMM were turned off on April 8, 2015**. The spacecraft re-entered the Earth’s atmosphere on **June 15, 2015**, at 11:55 p.m. EDT, over the South Indian Ocean

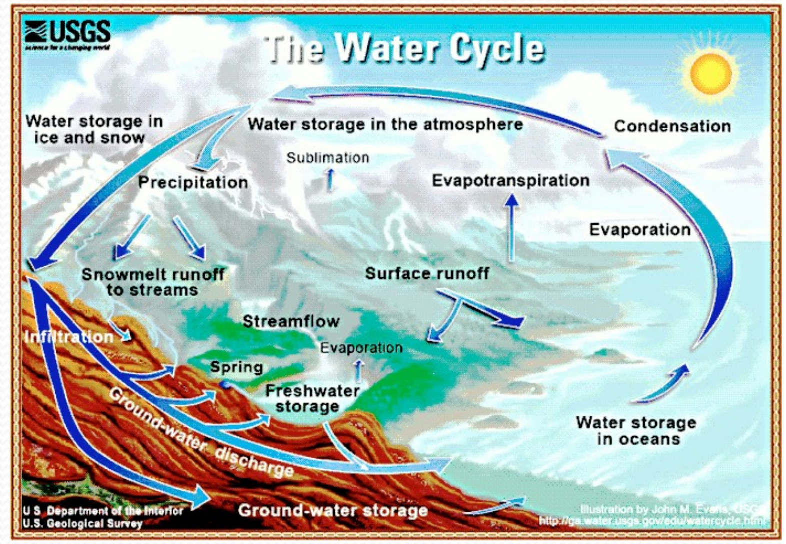


TRMM

Launched November 27, 1997

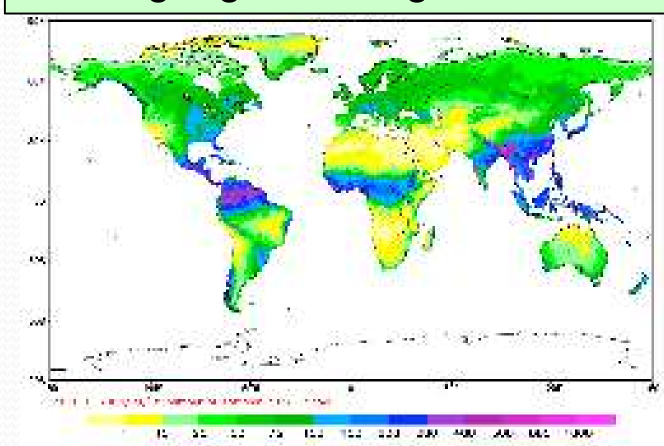
Why TRMM?

- **Accurate measurements of rain are crucial**
  - rain is extremely important for weather, climate, and energy cycle of the earth



- **Tropical rainfall** plays a critical role in driving atmospheric motion releasing latent heating
  - 2/3rd of the global rainfall occurs in the tropics

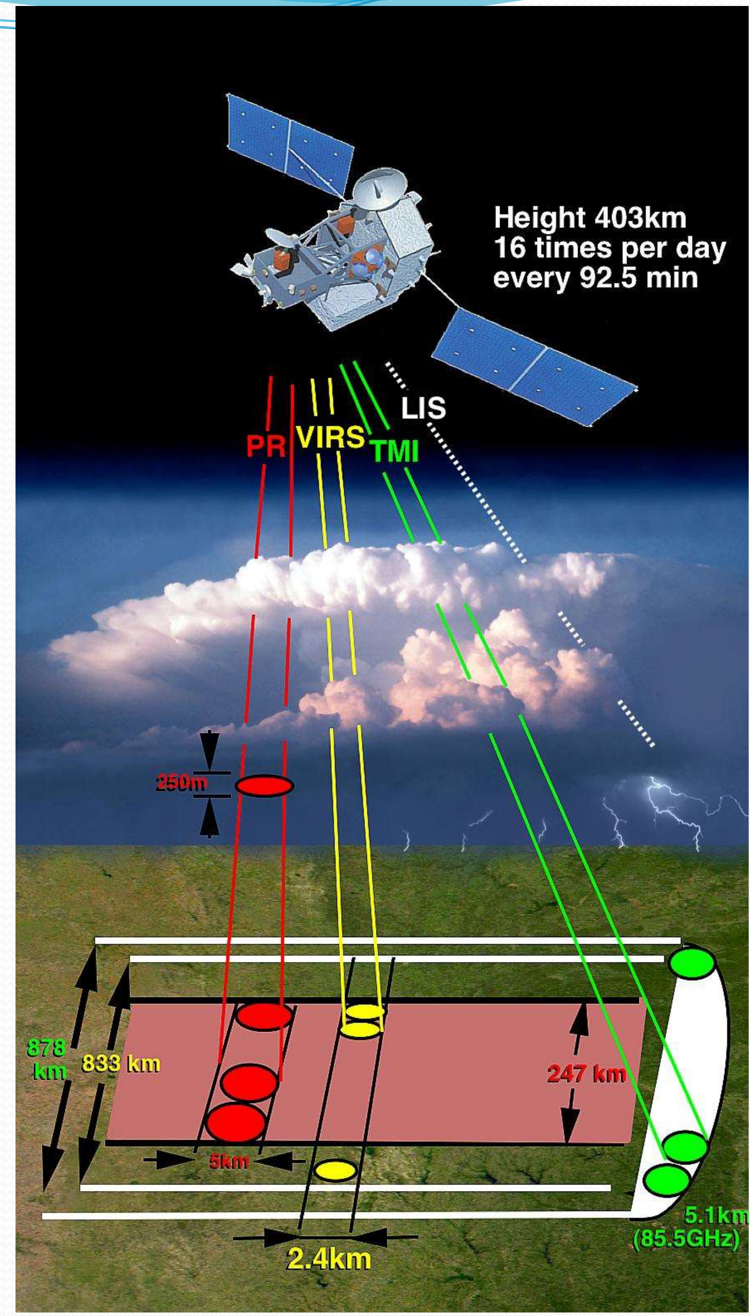
Rain gauge coverage over Land



- Information on **intensity and amount of rainfall** in the tropics was incomplete – especially over oceans prior to satellite coverage

TRMM Specifications

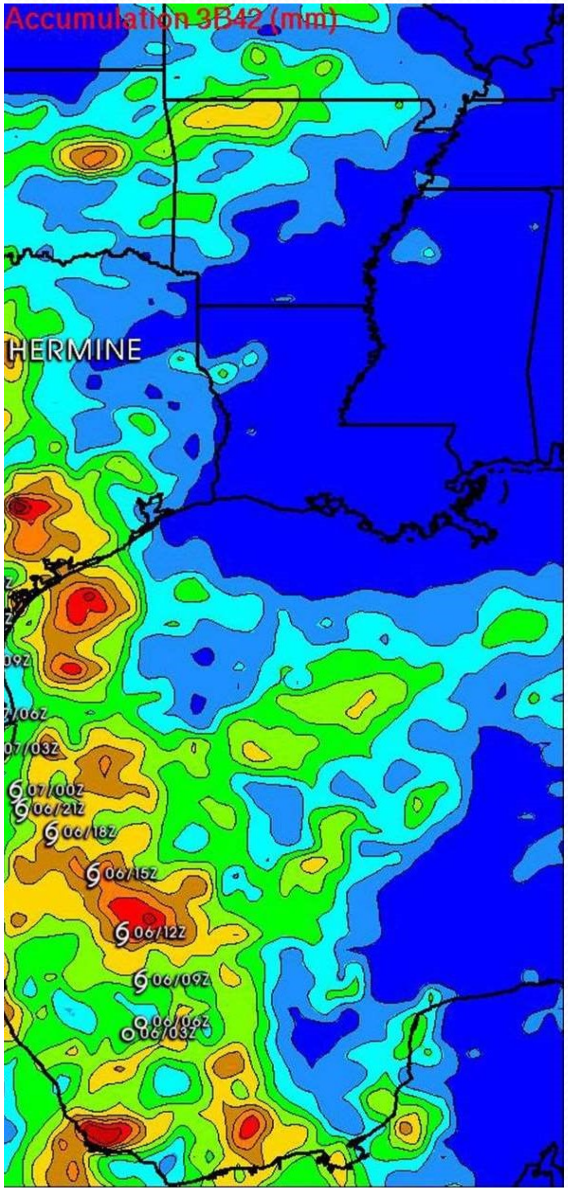
- **Orbit:** 350 km
- **Inclination Angle:** 35˚
- **Non-sun-synchronous**
  - Revisit Frequency: 11-12 hours
- **Track Speed:** 6.9 km/s
- **Area covered:** 35˚N to 35˚S



Active and Passive Microwave Remote Sensing of Precipitation:

- **Overview of tropical rainfall science objectives**
  - The Tropical Rainfall Measuring Mission (TRMM)
- **TRMM sensors and status of TRMM rainfall products**
  - Spacecraft, spatial resolution, swath width, sensor characteristics, and unique characteristics
- **Science results** – Some examples of using TRMM

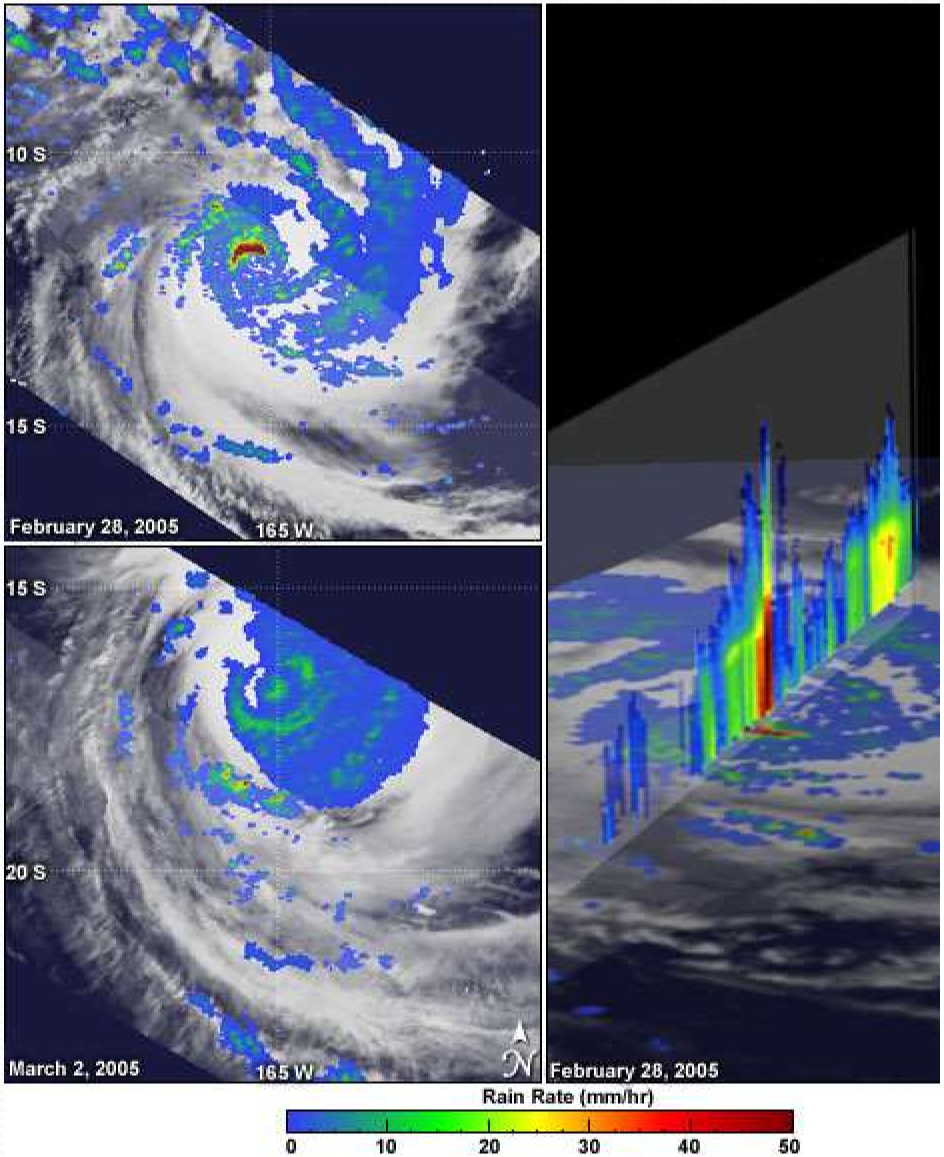
Tropical Rainfall Goals



- Advance the understanding of the **global energy and water cycles, climate and weather** by providing observations of tropical rainfall and latent heating distributions
- Understand the **mechanisms by which tropical rainfall influence global circulation** to
  - improve ability to model these processes and
  - predict global circulation and rainfall variability at monthly or longer time scales
- Obtain a **quantitative description of the diurnal variability** of tropical rainfall

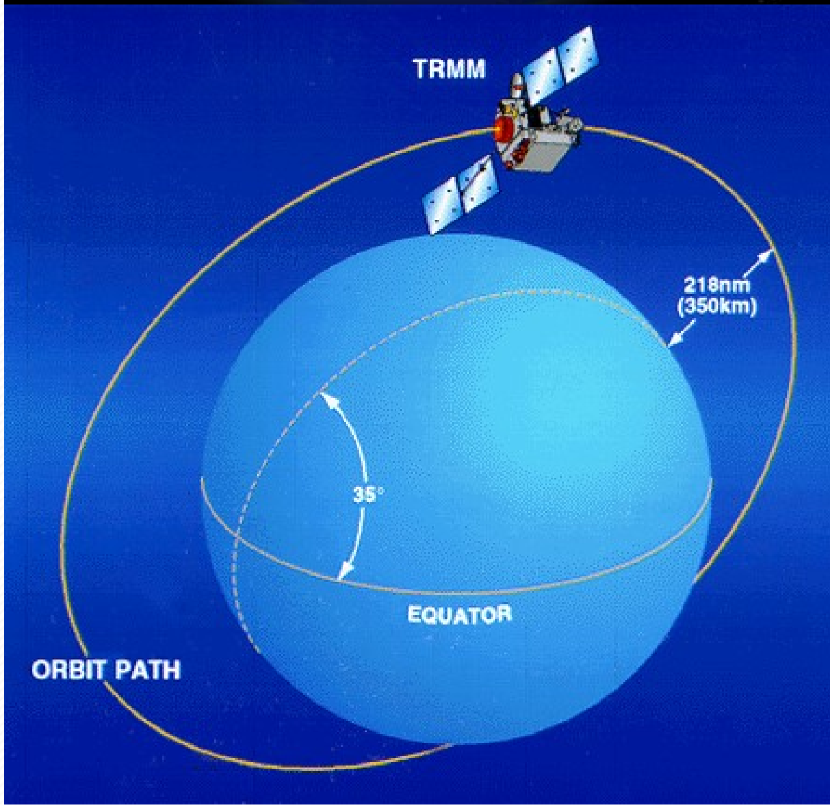
Tropical Rainfall Goals

- Provide **cross-calibration between TRMM and other sensors to produce long-term rainfall analysis**
- Demonstrate the **science benefits of a space-borne system for measuring rainfall** and build strong consensus algorithms for future missions



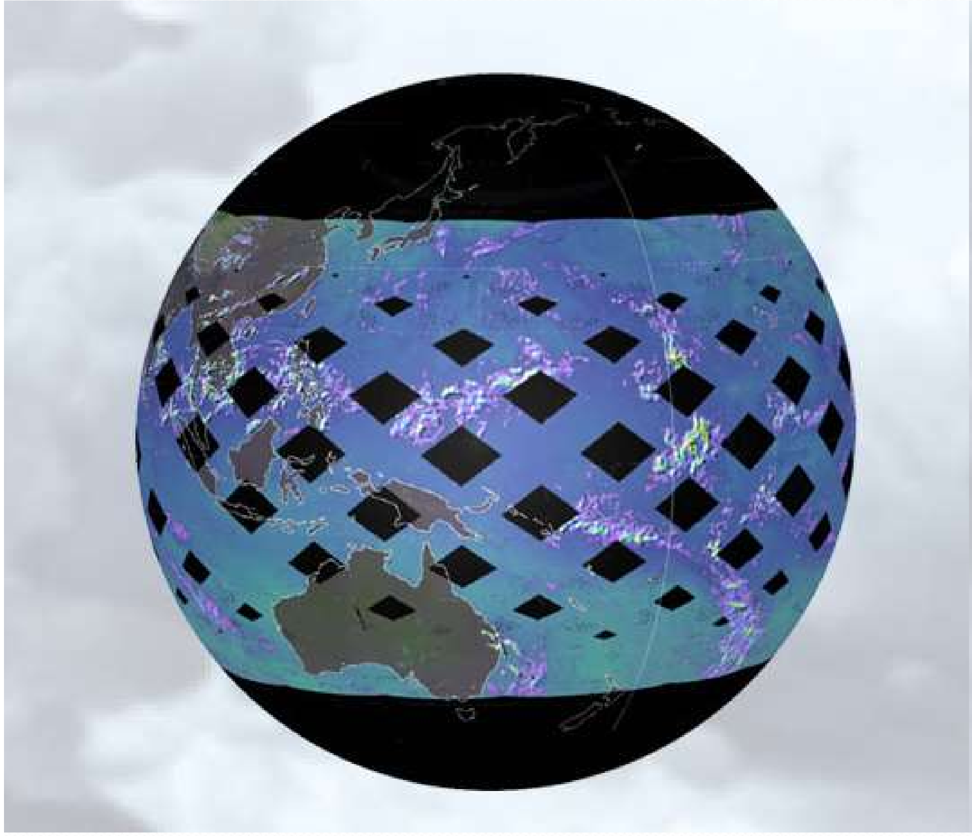
TRMM Orbit

- A precessing Low-Inclination (**35°**)
- Low-altitude (**350 km**) orbit
- Designed to **achieve high spatial resolution** and capture the **diurnal variation** of tropical rainfall

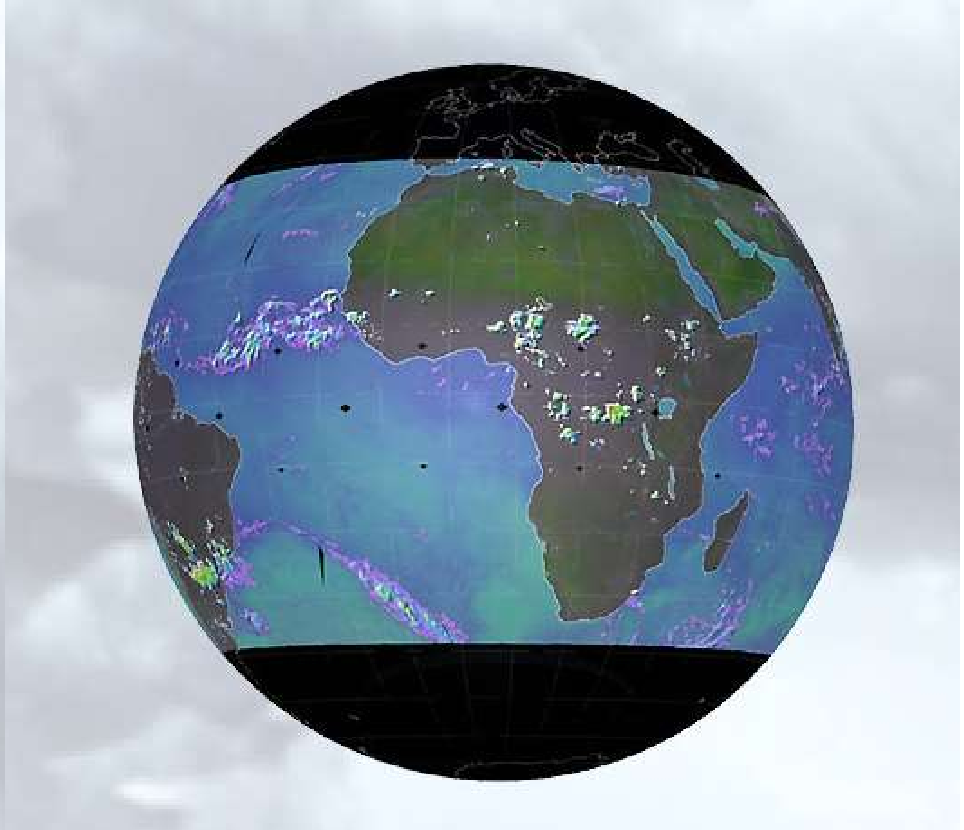


TRMM Coverage

1 day coverage

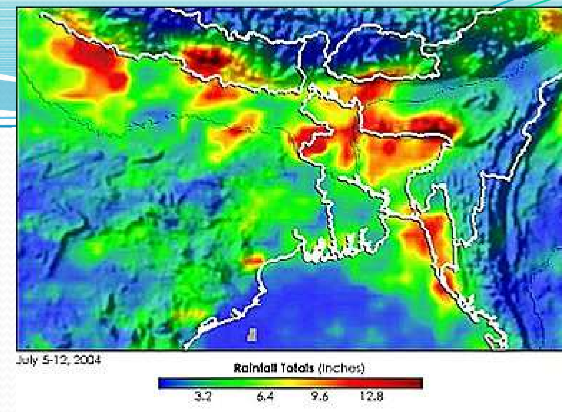


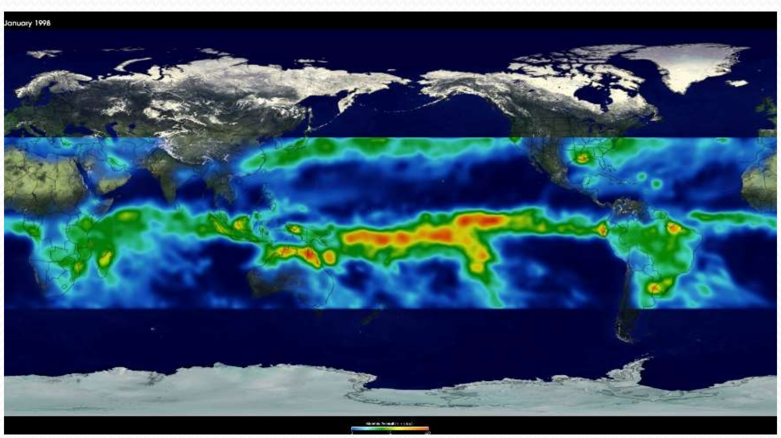
2 day coverage

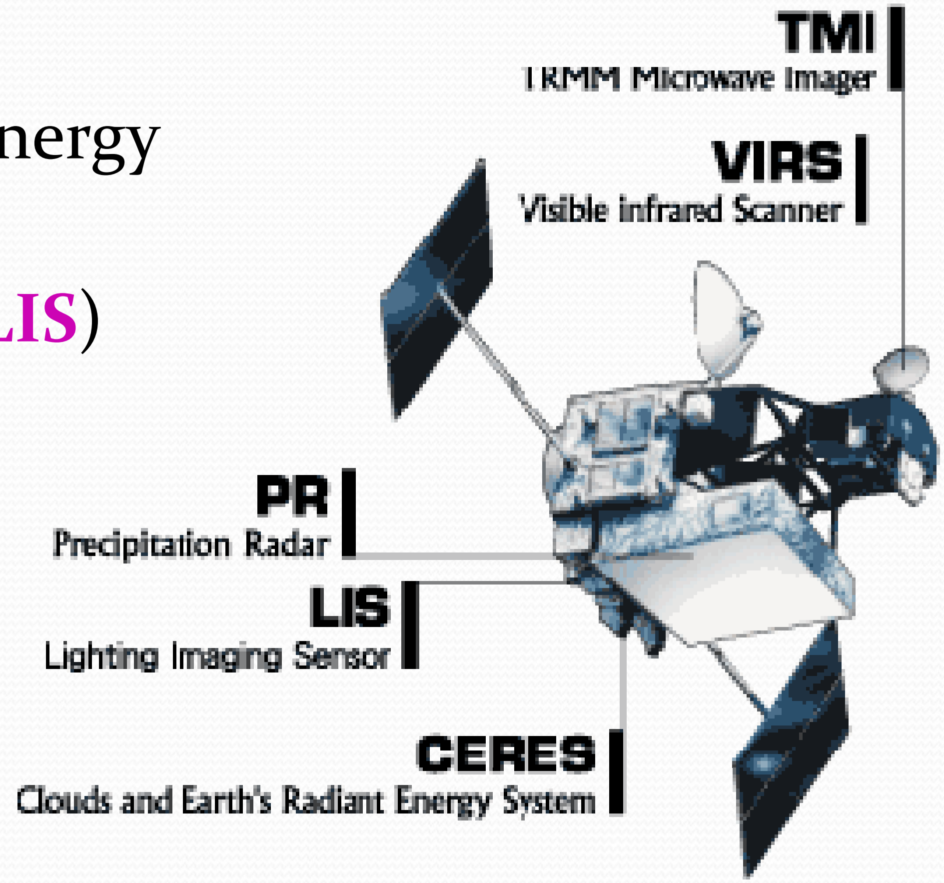


Instruments on Board

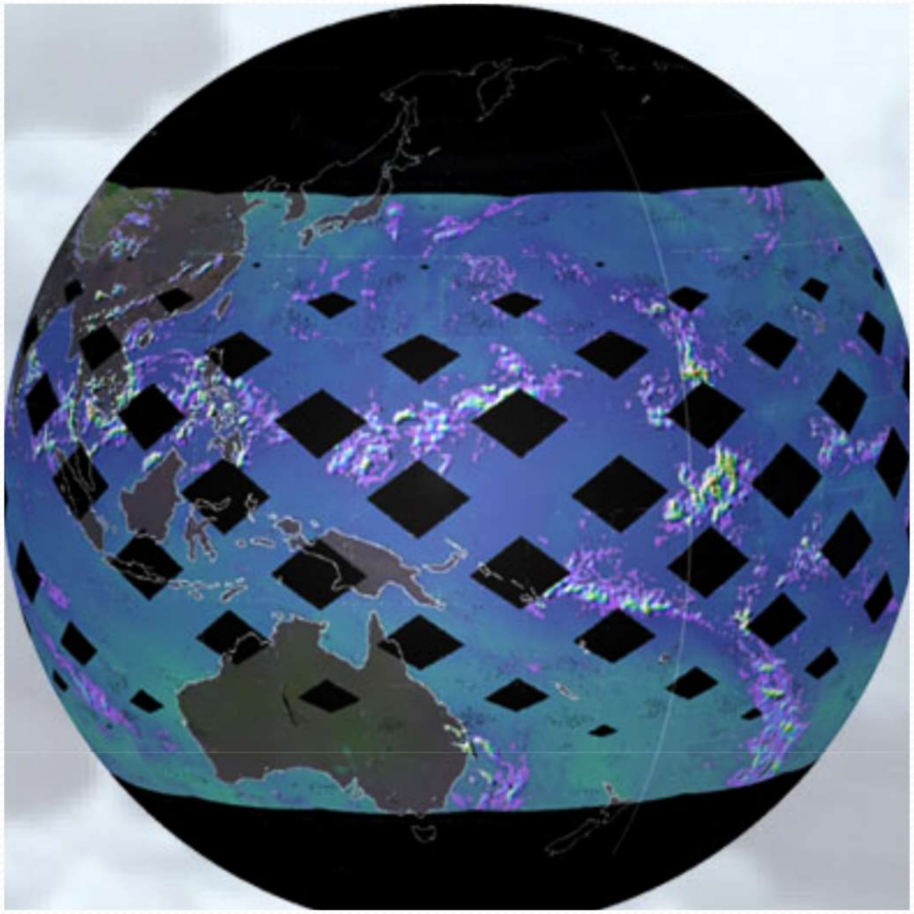
- TRMM Microwave Imager (**TMI**)
- Precipitation Radar (**PR**)
- Visible and Infrared Scanner (**VIRS**)
- Cloud and Earth's Radiant Energy System (**CERES**)
- Lightning Imaging Sensor (**LIS**)





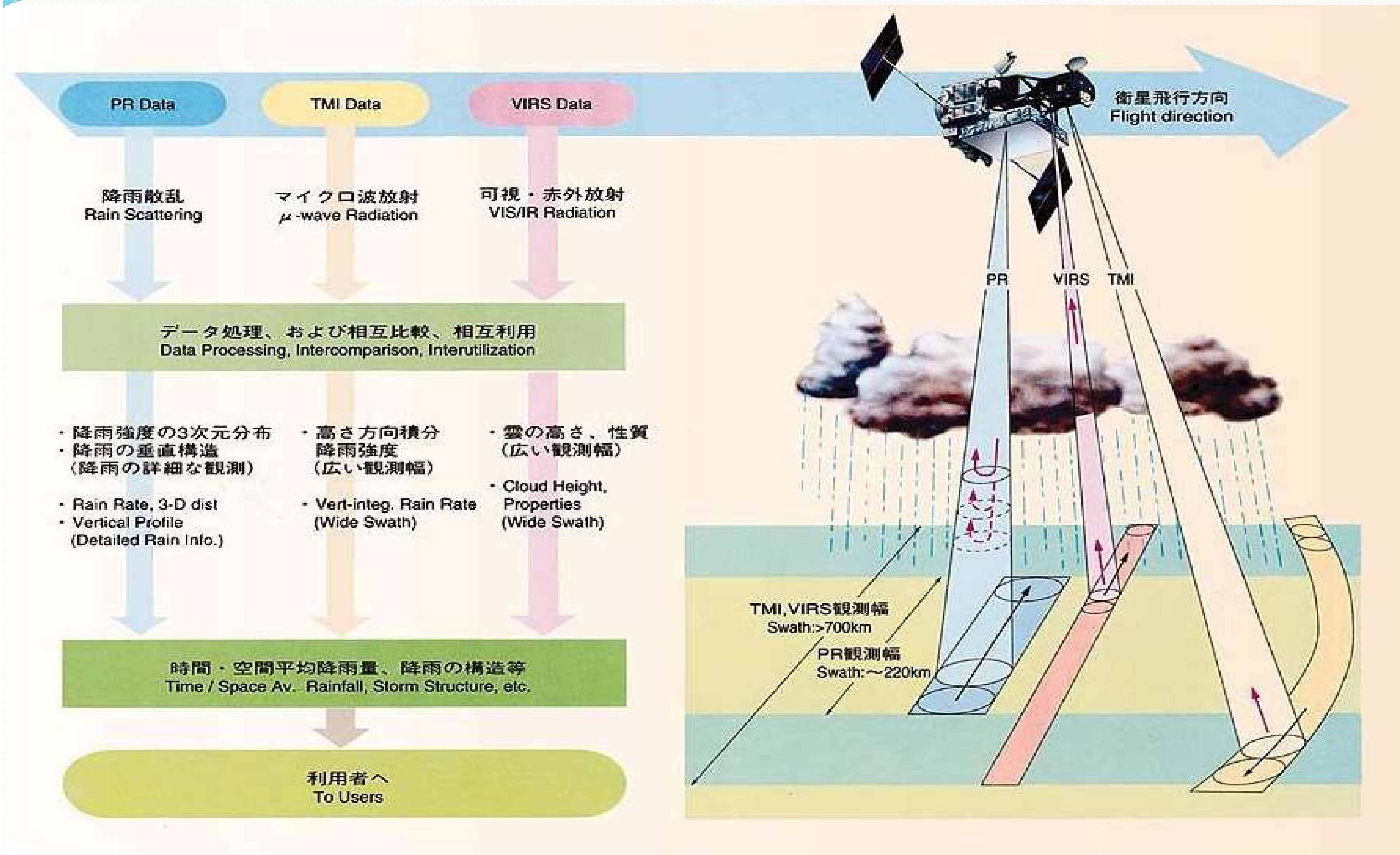


TRMM's Tropical Perspective

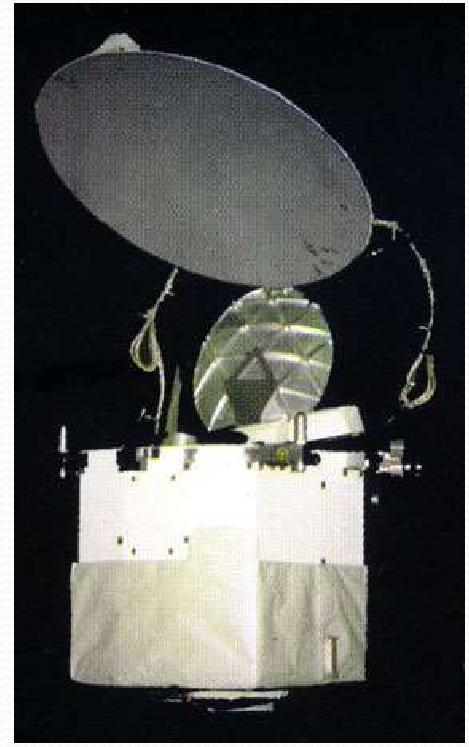


- **Precipitation Radar (PR)**
  - 13.8 GHz radar with 215 km swath width and 4.3 km footprint
- **TRMM Microwave Imager (TMI)**
  - Conically scanning, passive microwave radiometer with 760 km swath (10.7-85.5 GHz)
- **Visible & Infrared Scanner (VIRS)**
  - Medium-resolution, 5 spectral band imager with 2.2 km resolution
- **Lightning Imaging Sensor (LIS)**
  - Rate, location, and radiant energy of lightning flashes
- **CERES**
  - Measures Earth's shortwave, longwave, and net radiant energy budget with a swath width of 720 km

TRMM Sensors



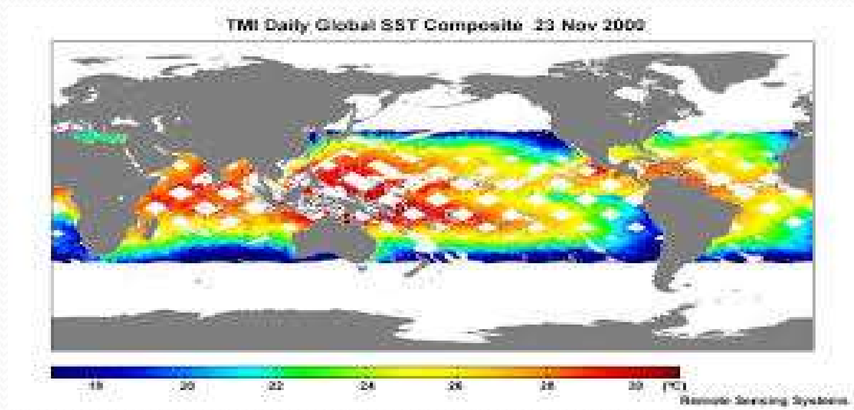
TRMM Microwave Imager (TMI)



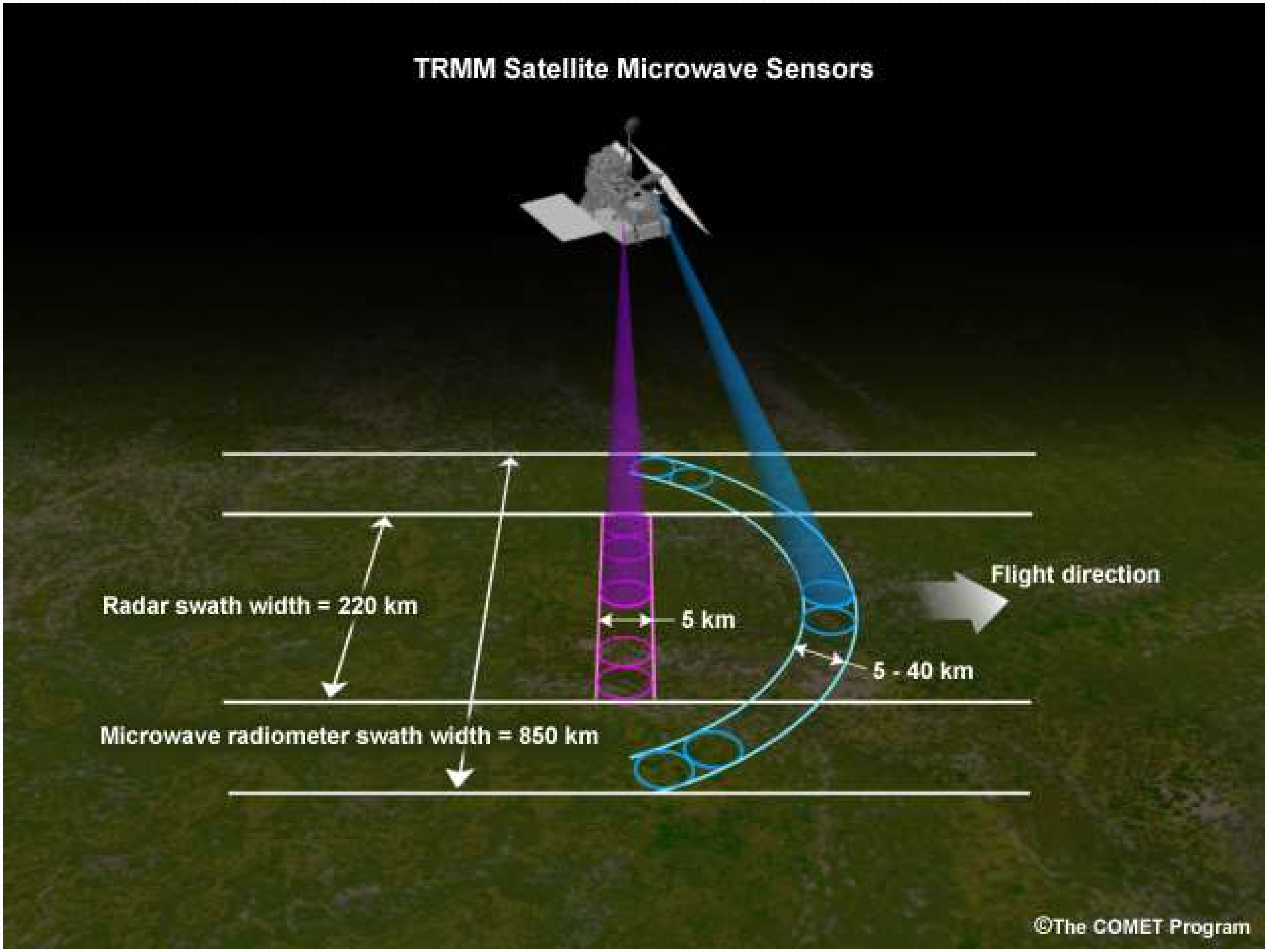
- **9-channel passive microwave radiometer**
  - Frequencies: 10.65, 19.35, 21.3, 37, 85.5 GHz
  - Horizontal and vertical polarizations
  - Reads rainfall, water vapor, and cloud water
  - mass of 65 kg
  - power of 50 W

- **Scan Geometry**
  - Swath: 758.5 km
  - Off-nadir: 52.8 Incident Angle
  - Conical Scan: 130°
    - 55 incident angle at Earth's surface

- **Spatial Resolutions:**
  - 4.4 km (85.5 GHz)
  - 45 km (10.7 GHz)

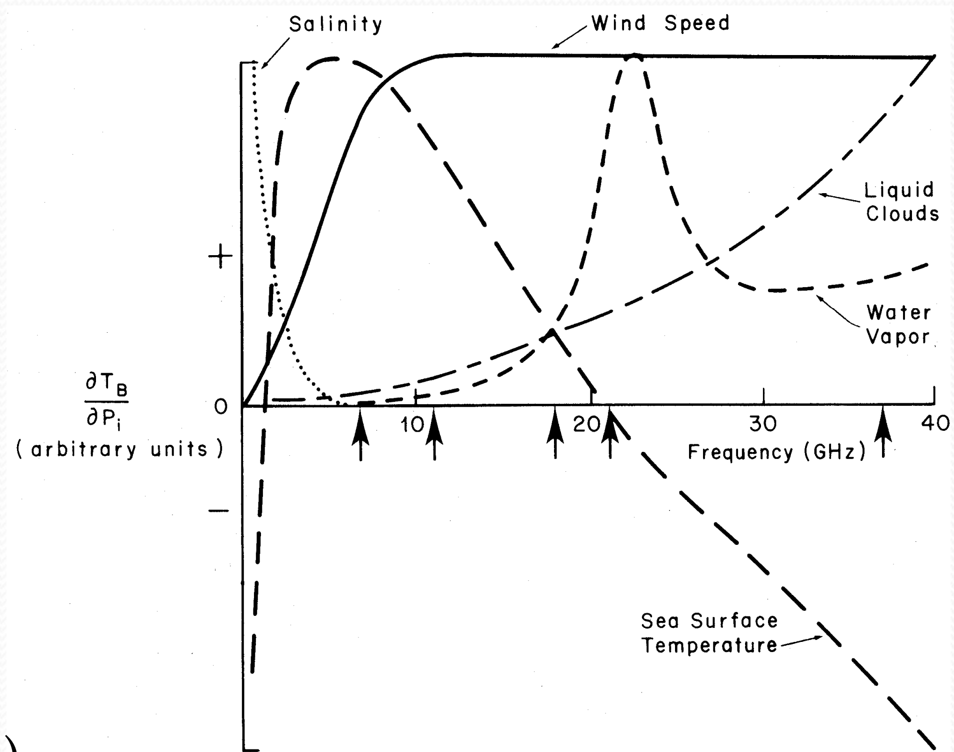


Scan Geometry of TMI



TRMM Microwave Imager

- **Passive microwave imager**
  - Day and night, clear and cloudy
  - Brightness temperature of ocean and atmosphere (“T_b”)
  - SST, roughness, foam, salinity
  - Oxygen, water (vapor, liquid)
- **Multiple frequencies (GHz)**
  - 10.7, 19.35, 37.0, 85.5
  - 10.7 GHz used for SST
- **Geophysical Parameters (accuracy)**
  - Wind speed (~1-1.6 m/s)
  - Column water vapor (~1.2 mm)
  - Column liquid water (~0.025 mm)
  - Column rain rate (0.3 km*mm/hr)



Radiative Transfer in the Microwave

The intensity of radiation I_λ is defined by

$$I_\lambda = \frac{P_\lambda}{\cos\theta_i \, d\lambda \, dA \, d\Omega}$$

where

- P_λ = power within wavelength range $d\lambda$ coming from a surface area dA and propagating into the solid angle $d\Omega$
- θ_i = incident zenith angle with respect to the normal to surface area dA

From blackbody radiation, the emitted radiation follows Planck's law

$$I_\lambda = \frac{2hc^2}{\lambda^5 [\exp(hc/\lambda kT) - 1]} \sim \frac{2kcT_b}{\lambda^4}$$

Rayleigh Jeans Approximation
λ ˘ hc/kT

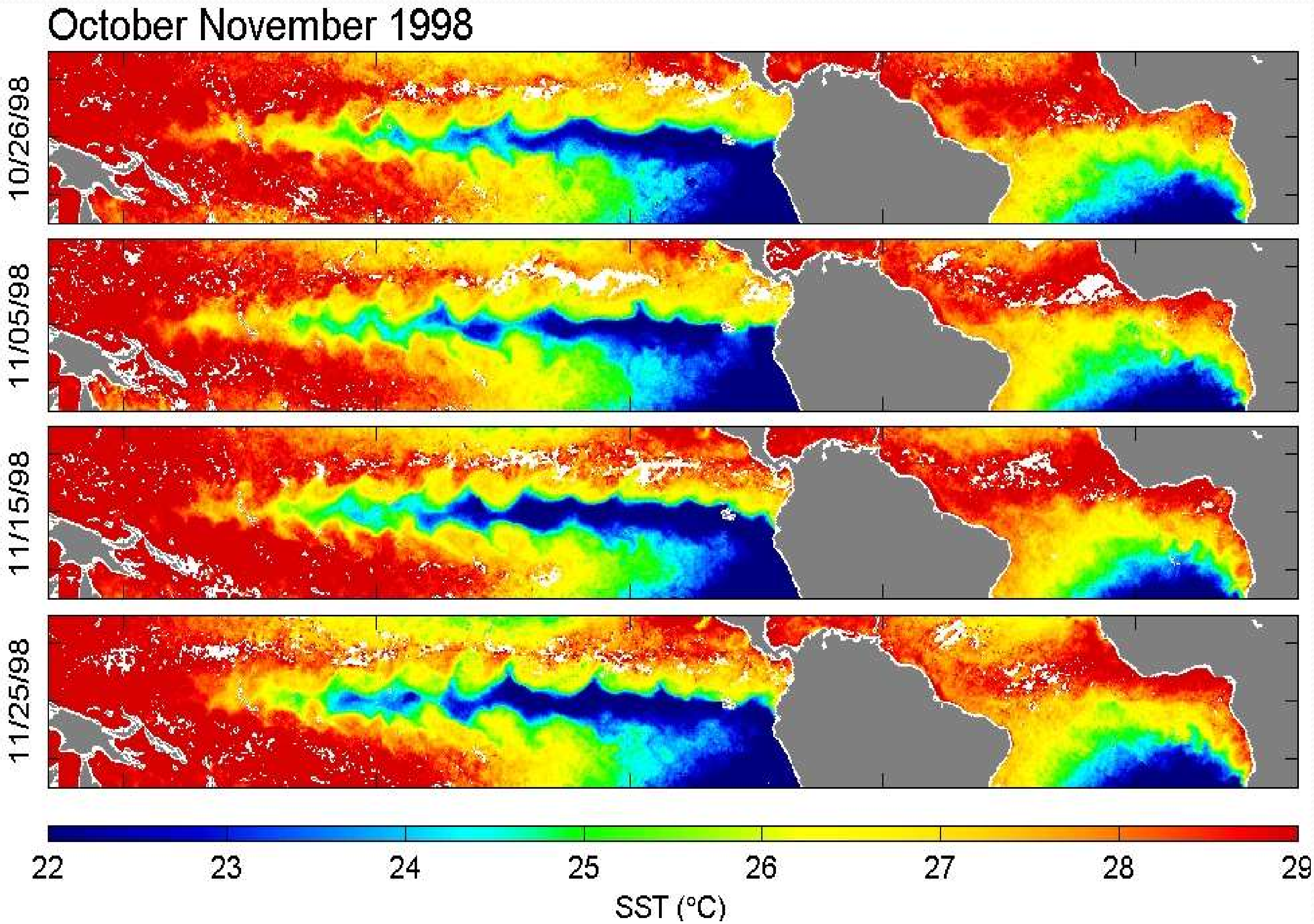
where

- c = speed of light (2.998×10^{10} cm s^{-1})
- h = Planck's constant (6.626×10^{-27} erg s)
- k = Boltzman's constant (1.381×10^{-16} erg K^{-1})

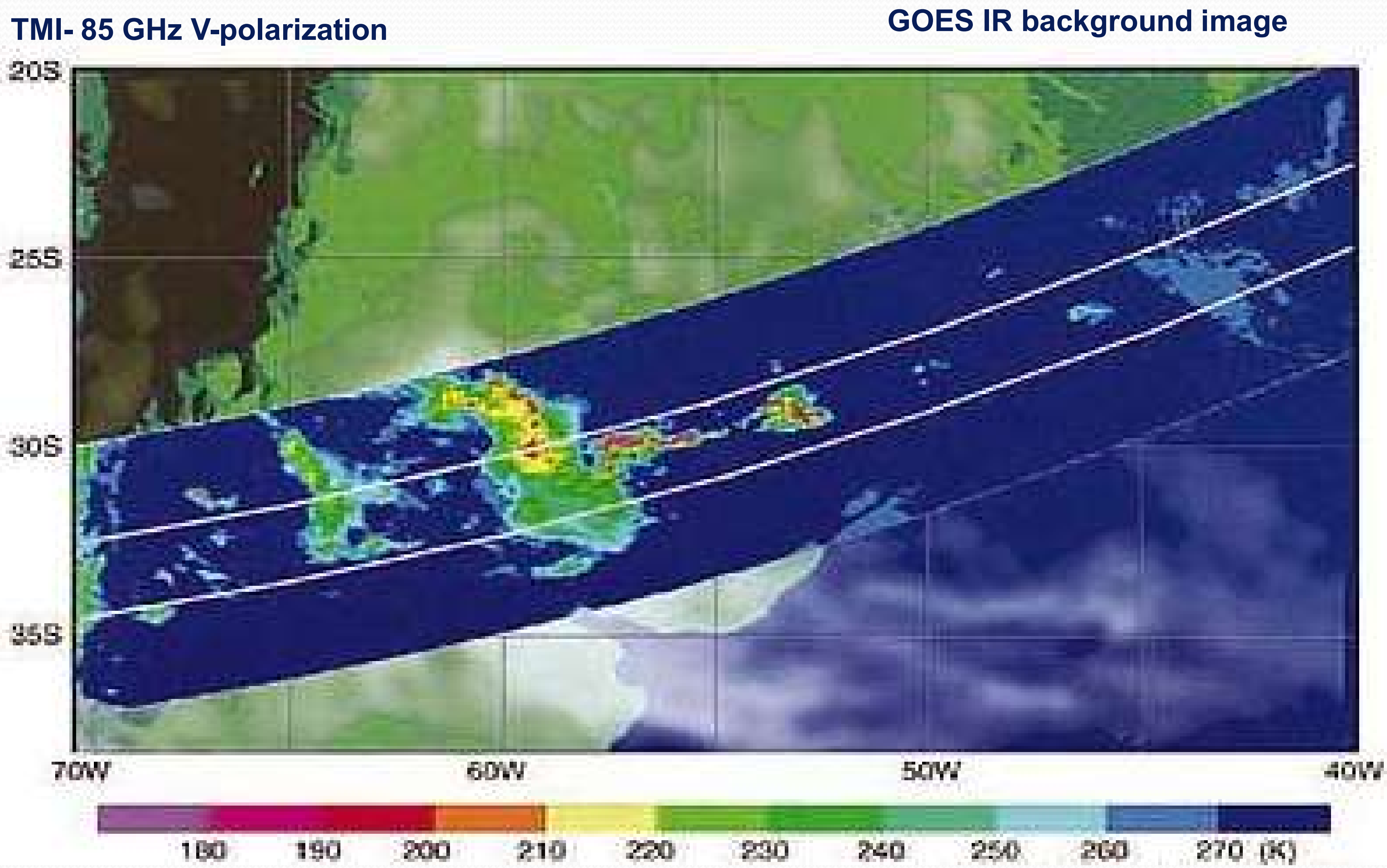
Sea Surface Temperature from TMI

- The measured radiance (**intensity**) is proportional to brightness temperature in the microwave
- At **10.7 GHz (λ = 3 cm)**, the microwave brightness temperature is a strong function of sea surface temperature
- **High-resolution SST** measurements through clouds from TMI data provided early detection of the 1998 La Niña and instability waves (Wentz, *Science*, 1999)
- **Improved prediction of tropical cyclone track**

Sea Surface Temperature from TMI Led to Early Prediction of La Niña

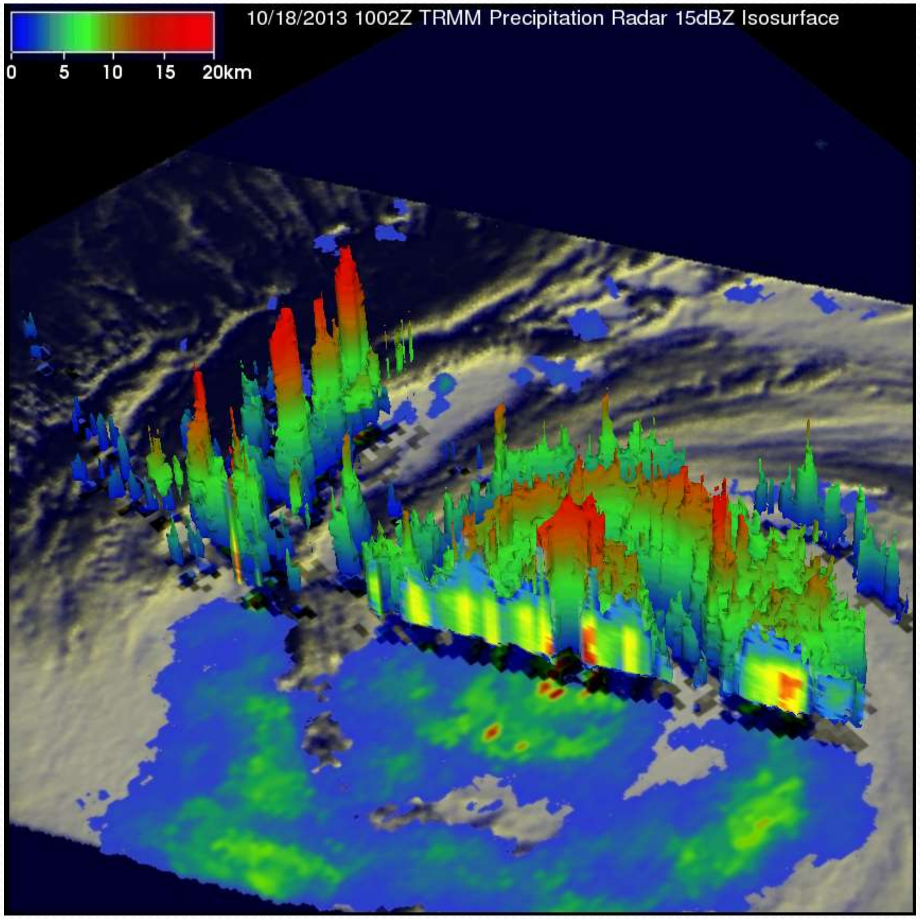


Microwave Brightness Temperature Observed by TMI over Argentina

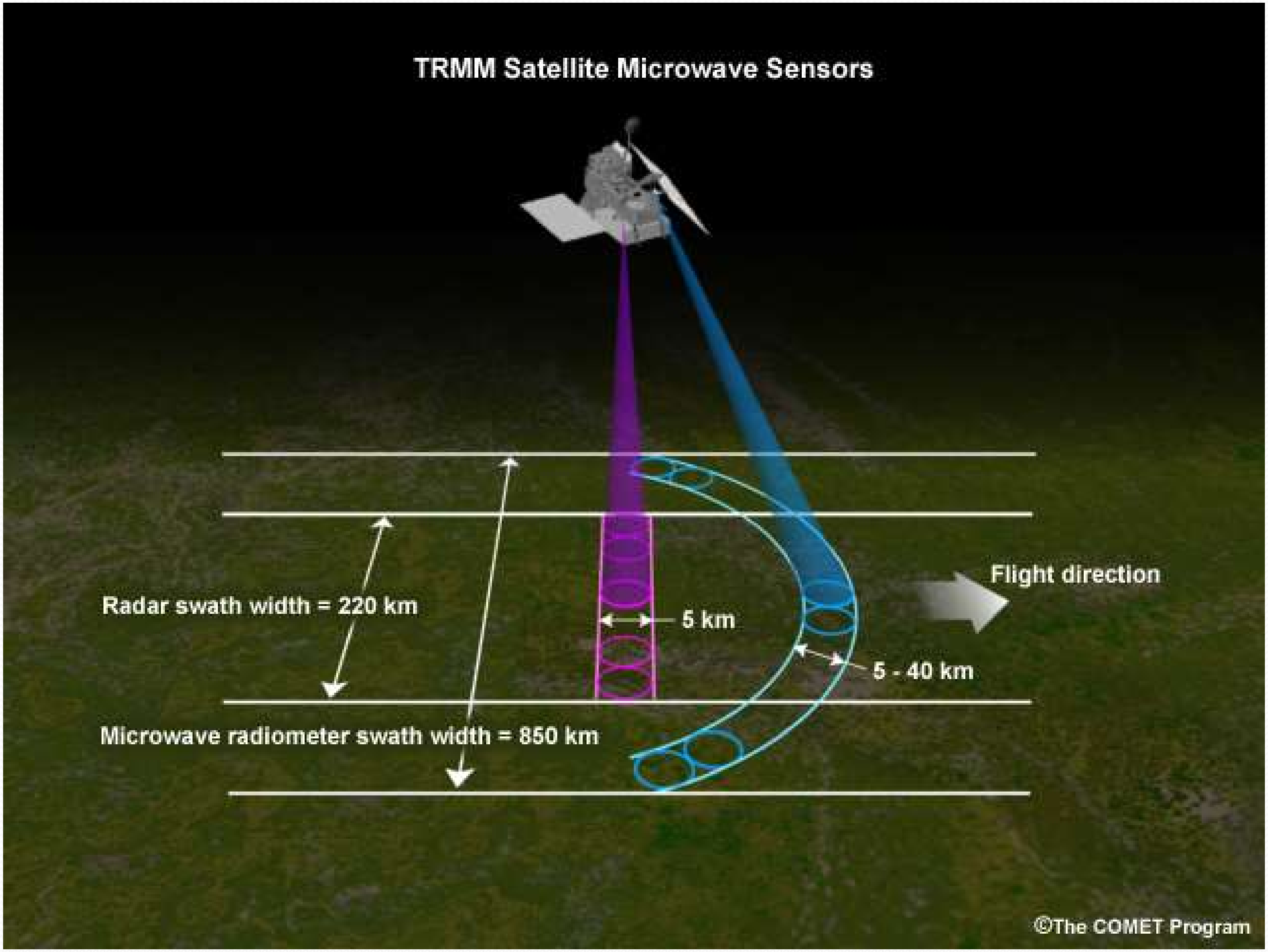


Precipitation Radar (PR)

- **Active Rain Radar**
- **Frequency:** 13.8 GHz
- **Scan Geometry:**
  - Nadir
  - Spatial Resolution: 4.3 km
  - Range Resolution: 250 m
  - Swath: 215 km
  - vertical profile from surface to 15 km
  - 128 element active phased array radar
  - 13.796 and 13.802 GHz
- **Sensitivity**
  - minimum measurable rain rate of 0.5 mm hr^{-1}

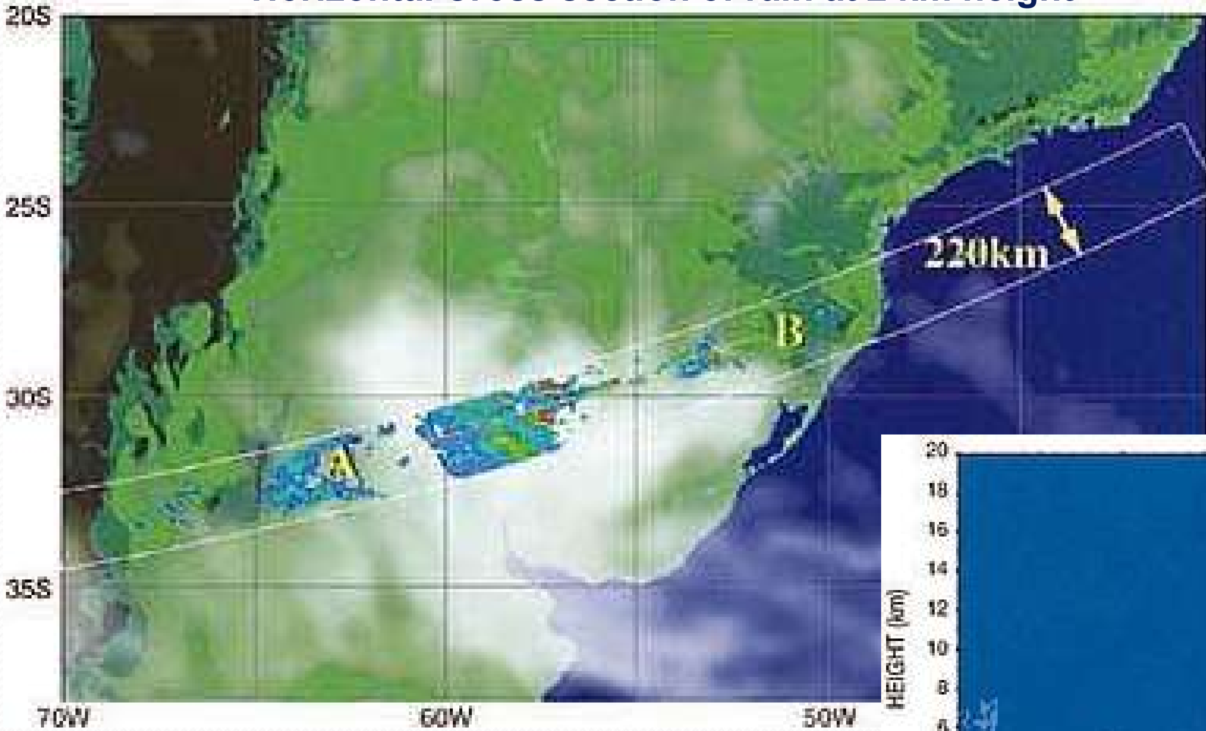


Scan Geometry of PR

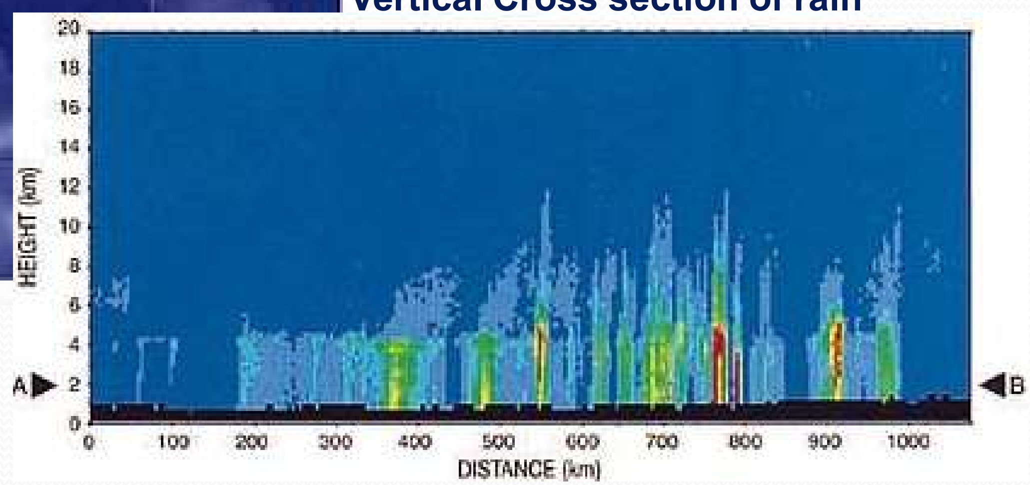


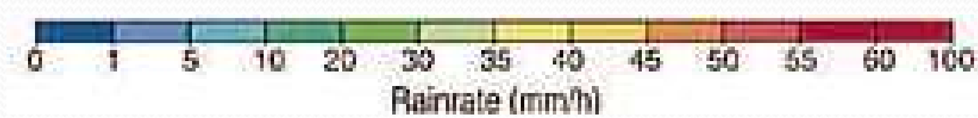
PR Image and Cross Section of Precipitation over Argentina

Horizontal Cross section of rain at 2 km height



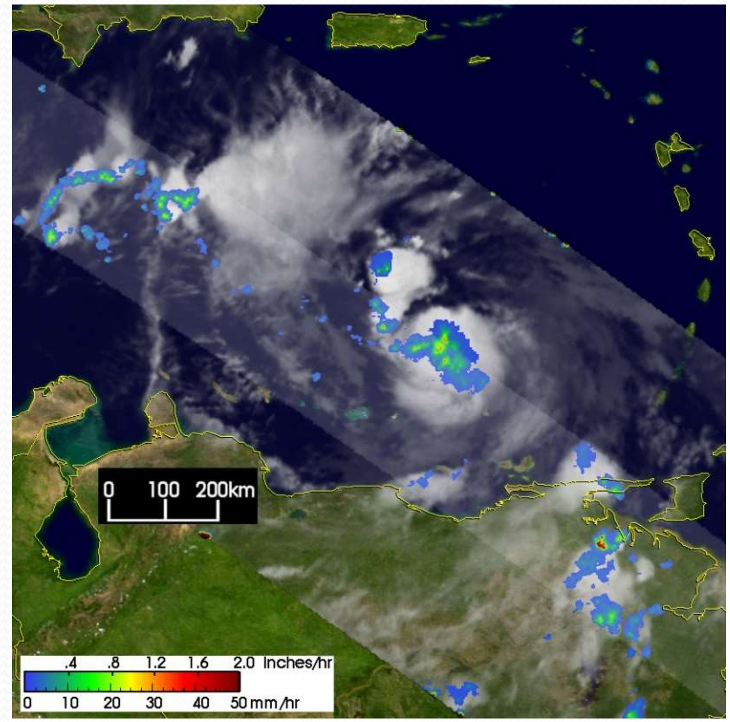
Vertical Cross section of rain





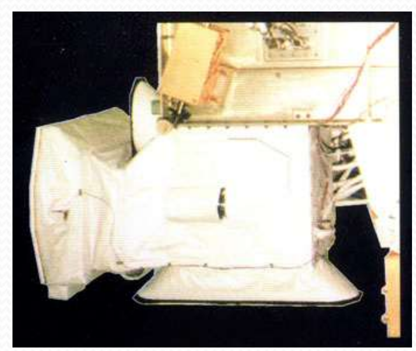
Visible Infrared Scanner (VIRS)

- **5-channel visible and infrared passive radiometer**
  - Wavelengths: 0.6-12μm
  - Reads brightness and temperature



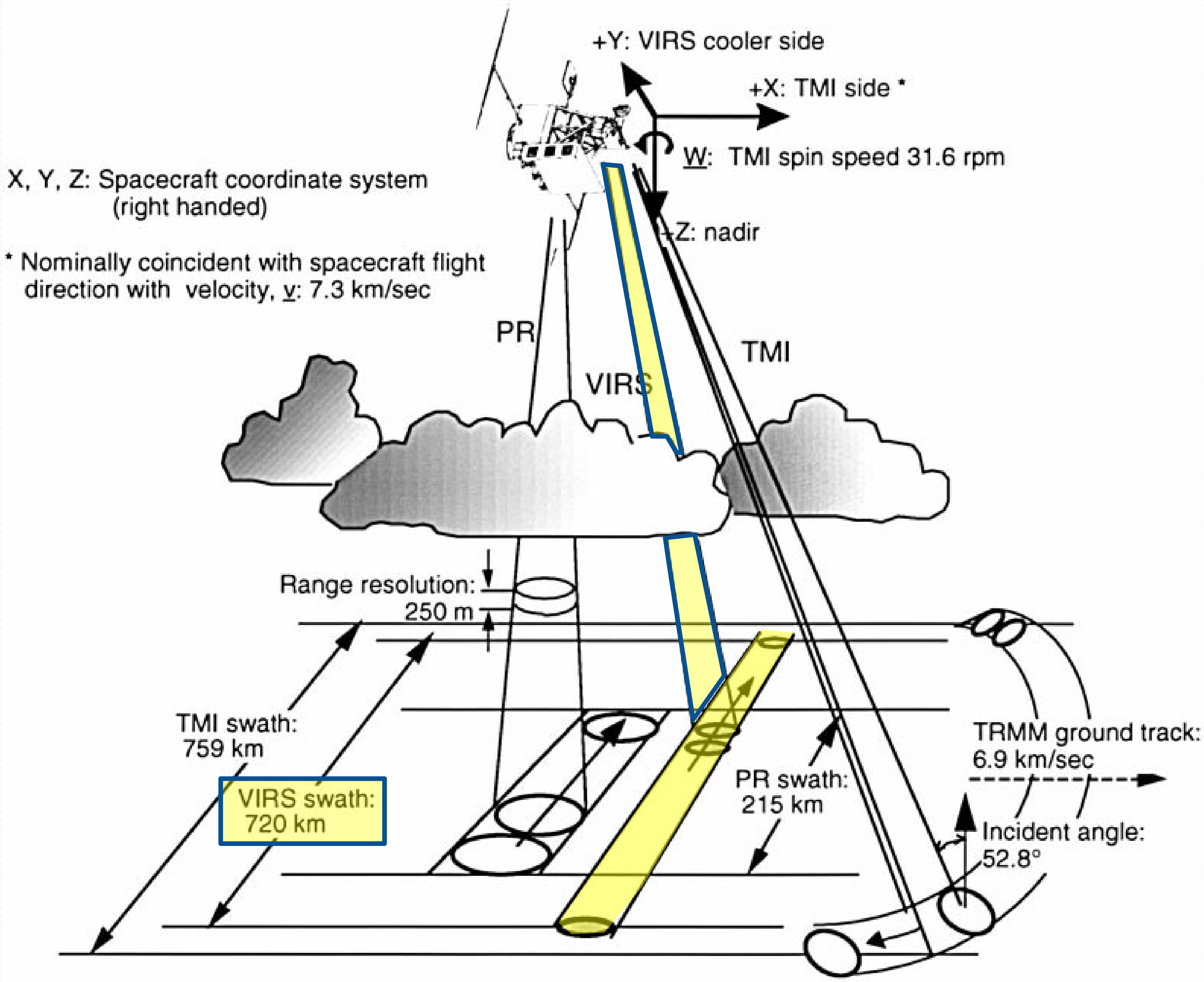
- **Scan Geometry – Cross Track**
  - Swath: 720 km
  - IFOV: 2.11 km nadir
  - Spatial resolution of 2 km

- **Radiometric Properties:**
  - Channels 1 and 2 read solar energy
  - Channels 3-5 read thermal energy



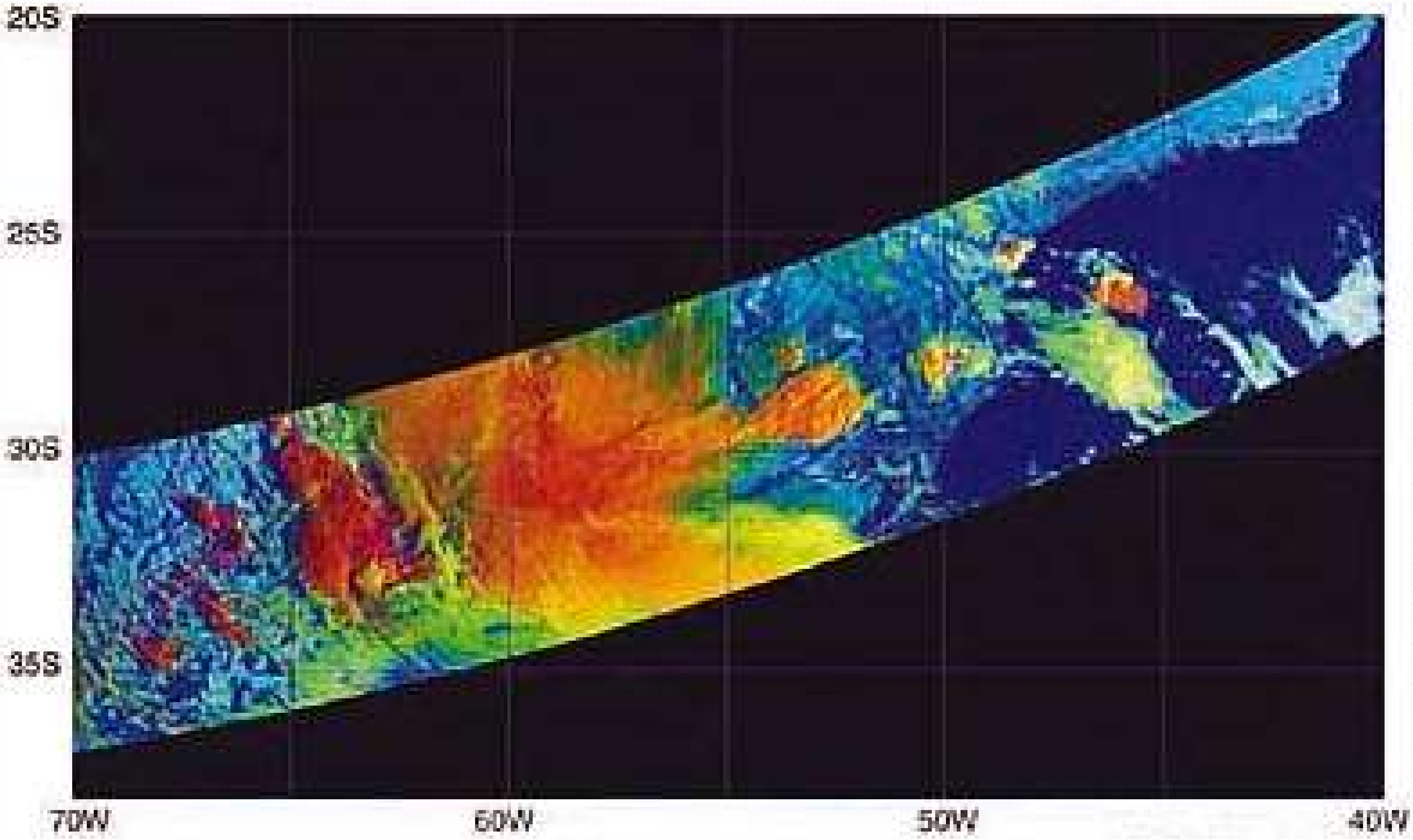
- **Main purposes**
  - Cloud distribution and height
  - Rain estimates from brightness temperature

Scan Geometry of VIRS



Reference: Kummerow et al 1998

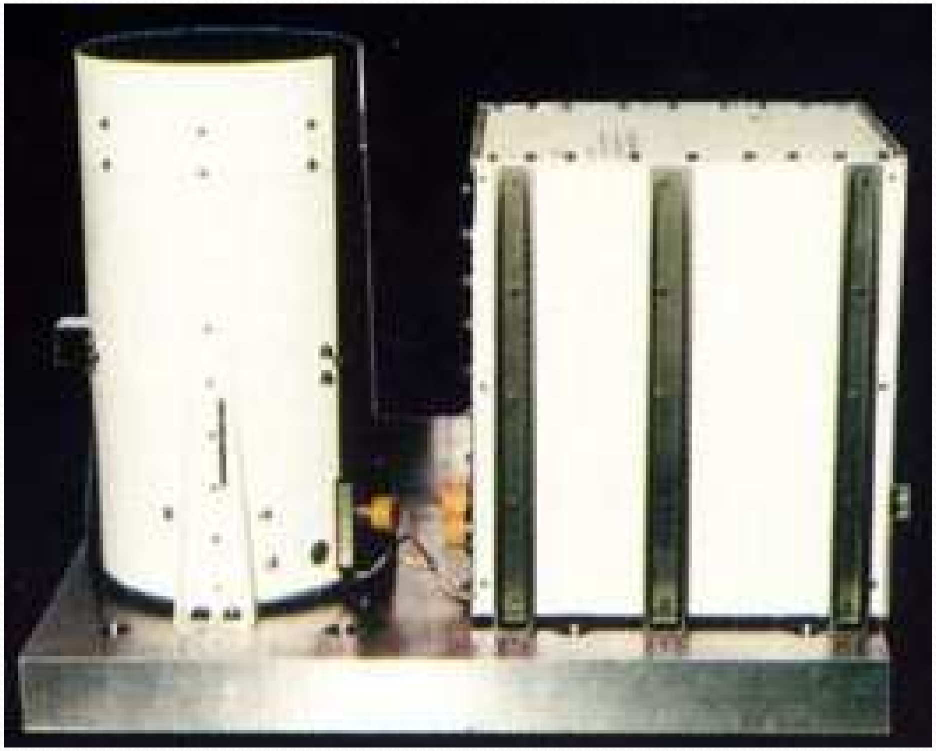
Clouds over Argentina from VIRS

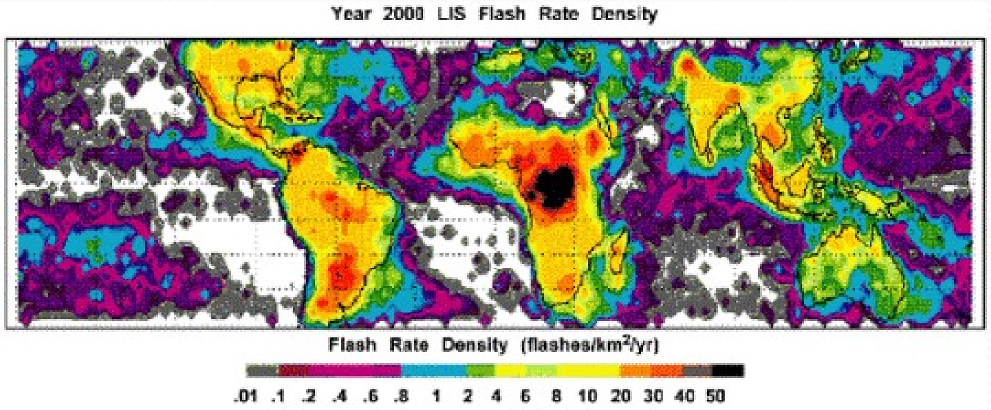


R = 0.63 μm G = 1.6 μm B = 10.7 μm

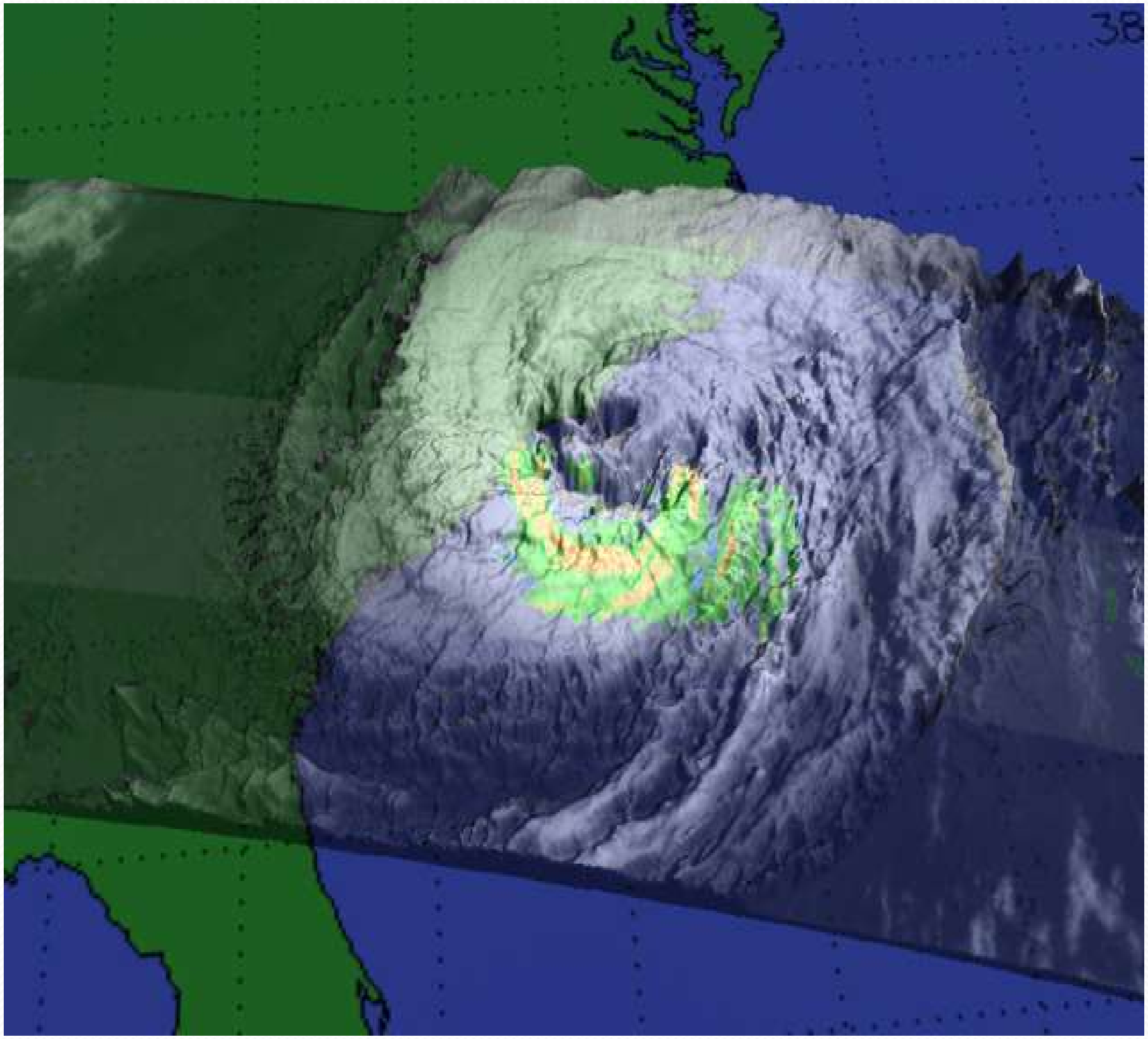
Lightning Imaging Sensor (LIS)

- **Sensor Characteristics**
  - uses 128 x 128 element CCD-based camera
  - one narrow-band filter at 0.777 μm
  - swath of 600 x 600 km
  - spatial resolution of 5 km
- **Lightning detection:**
  - event processor to subtract out the bright background during daylight
    - instrument takes data day and night



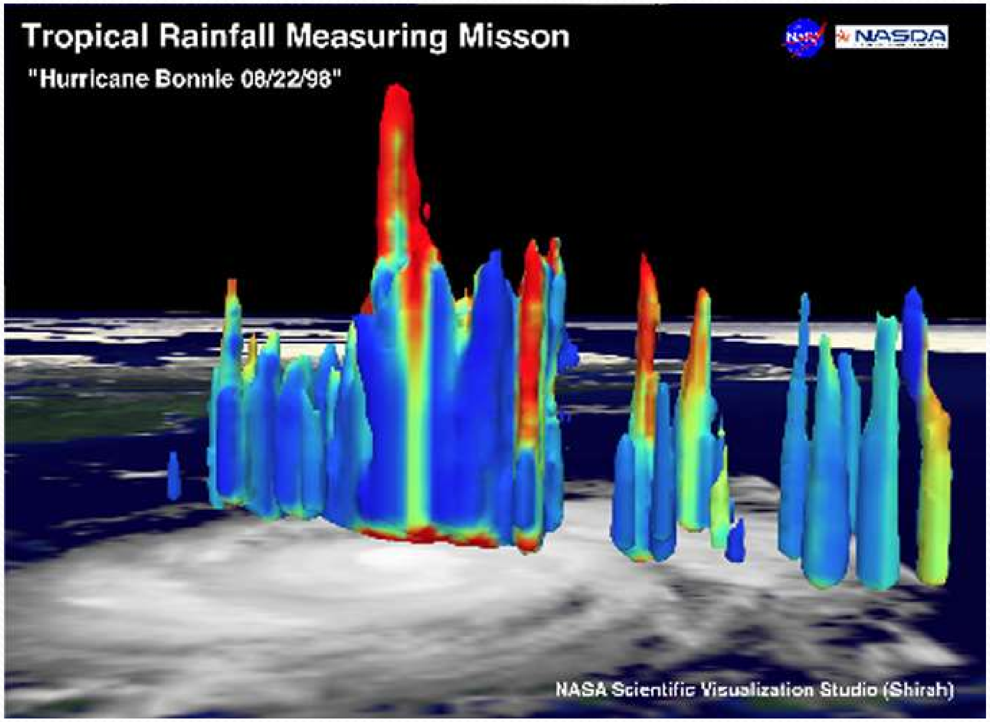


TRMM: Unprecedented Views of Hurricanes



TRMM Provides Unprecedented Insight into Hurricane Structure

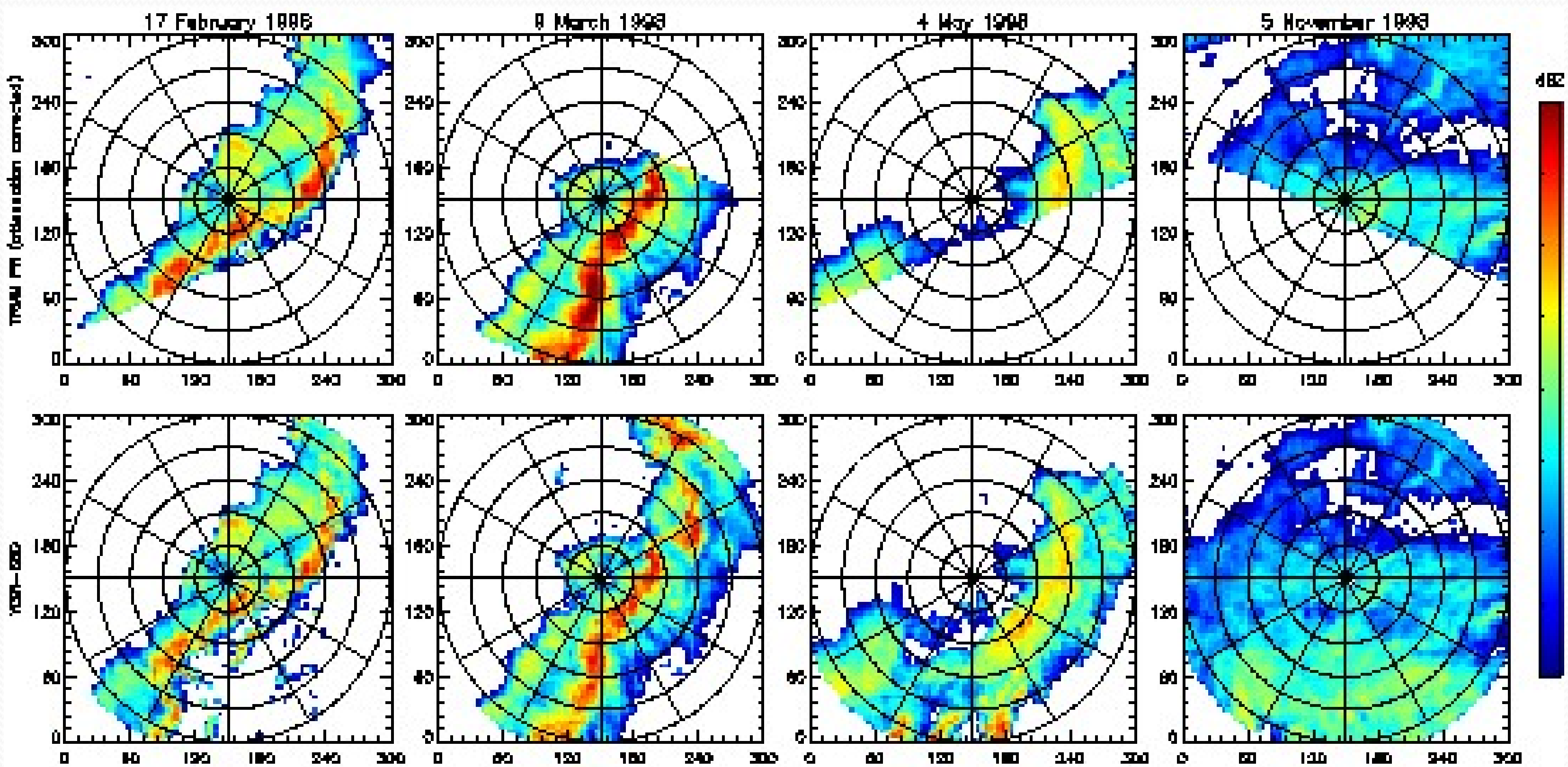
- **Hurricane Bonnie**
  - Tall Clouds (59,000 ft) observed during Hurricane Bonnie
  - These observations were circulated in NY Times & Washington Post
  - Animations played in virtually every television market around the country



PR and Melbourne Radar Comparison

- Reflectivity & RR comparisons over 4x4x1.5 km cells for 24 overpass cases
- Good agreement in area-averaged rain rates with correlation coefficient = 0.95

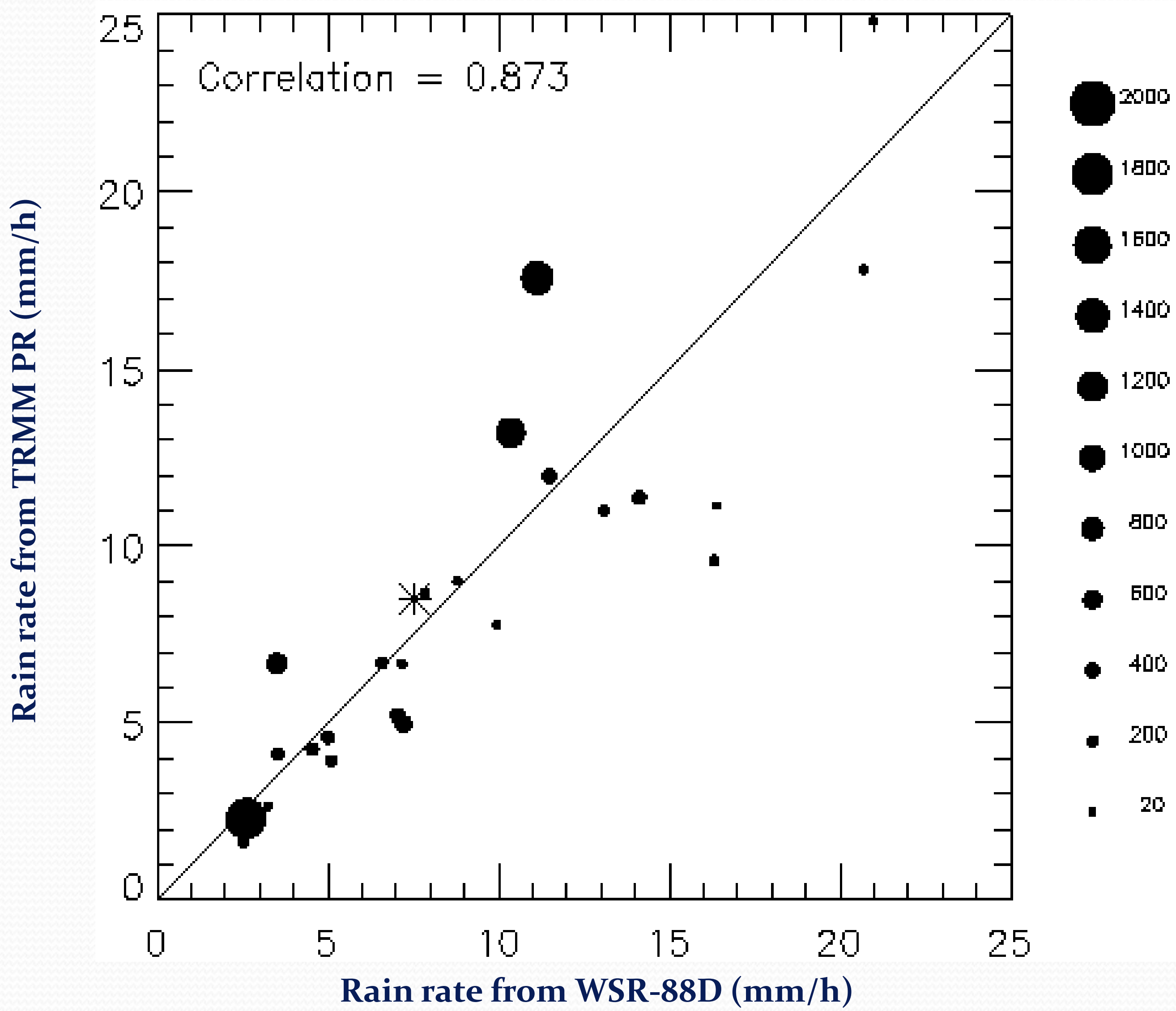
TRMM PR **Pixel-avg. rain rate**



Melbourne, FL radar **Radar Reflectivity (dBZ)**

PR and Melbourne Radar Comparison

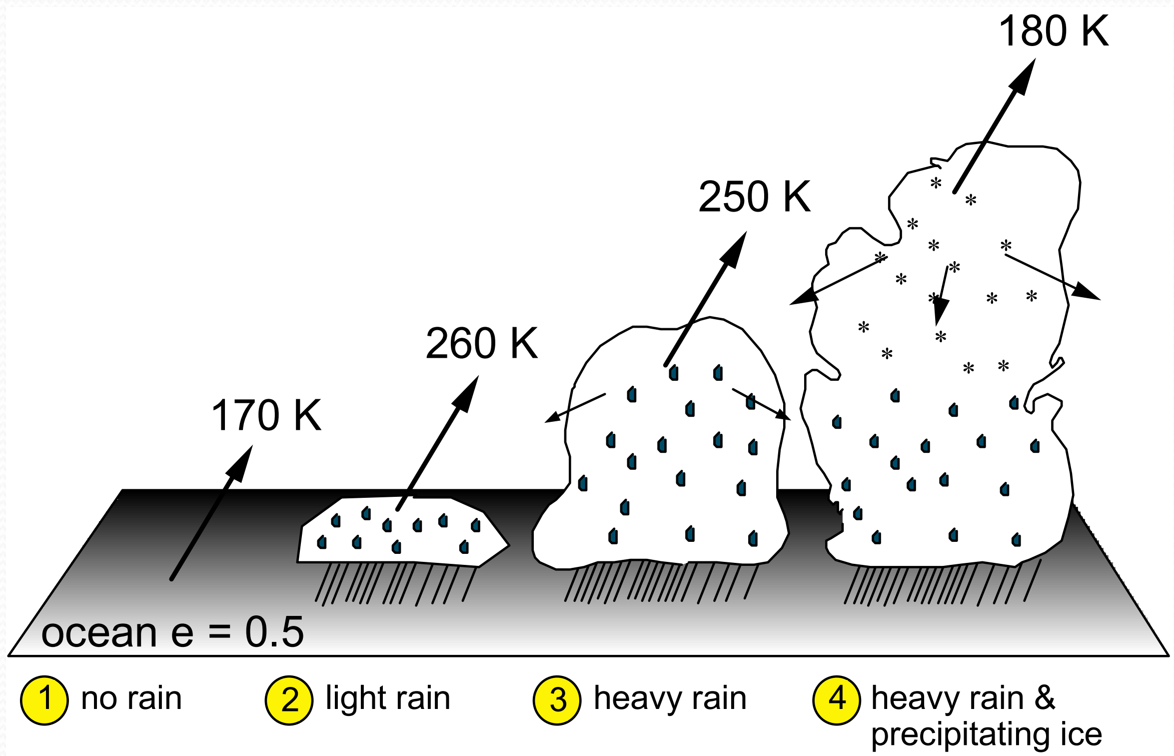
Pixel-averaged rain rate



Passive Microwave Sensing of Rainfall

- In the microwave region, the ocean emits radiation proportional to its temperature and emissivity ($\varepsilon_{37} \sim 0.5$)

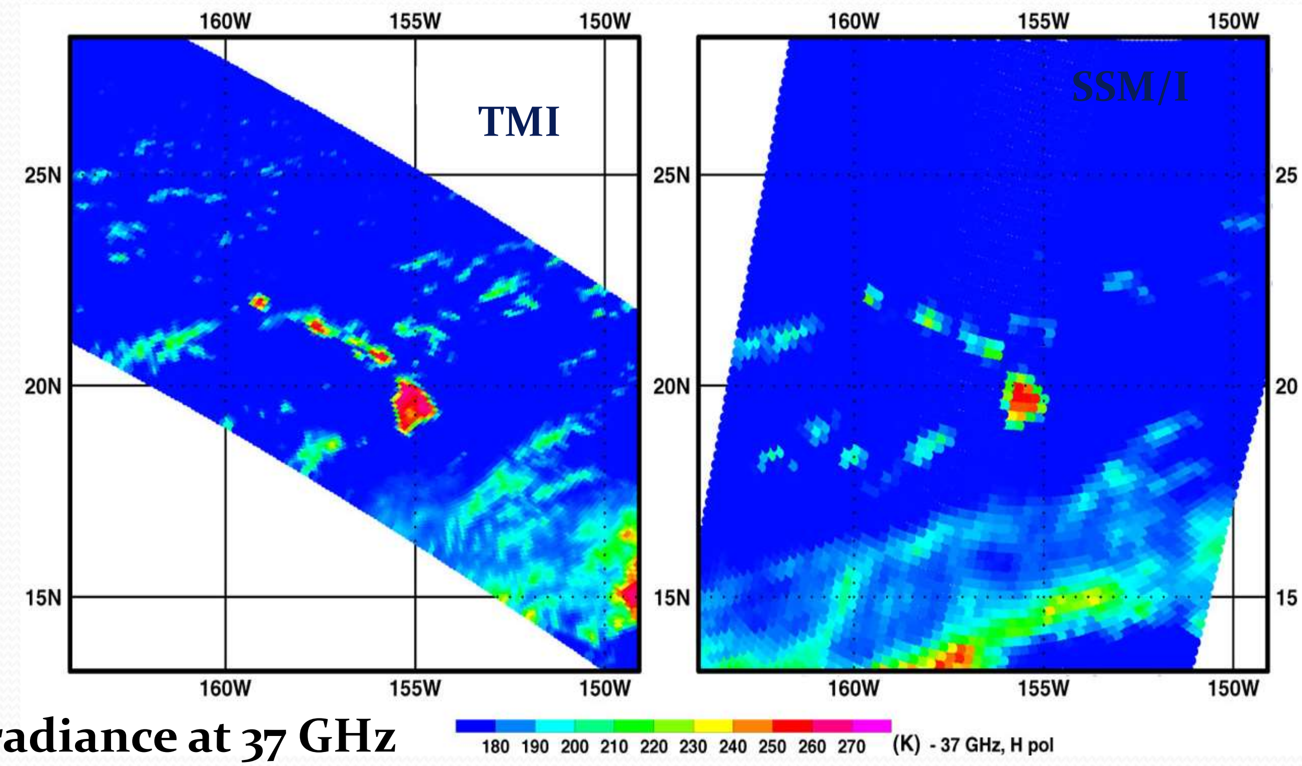
- Cloud water and cloud ice scatter this radiation both upwards to the satellite and backwards to the surface



Microwave radiance at 37 GHz

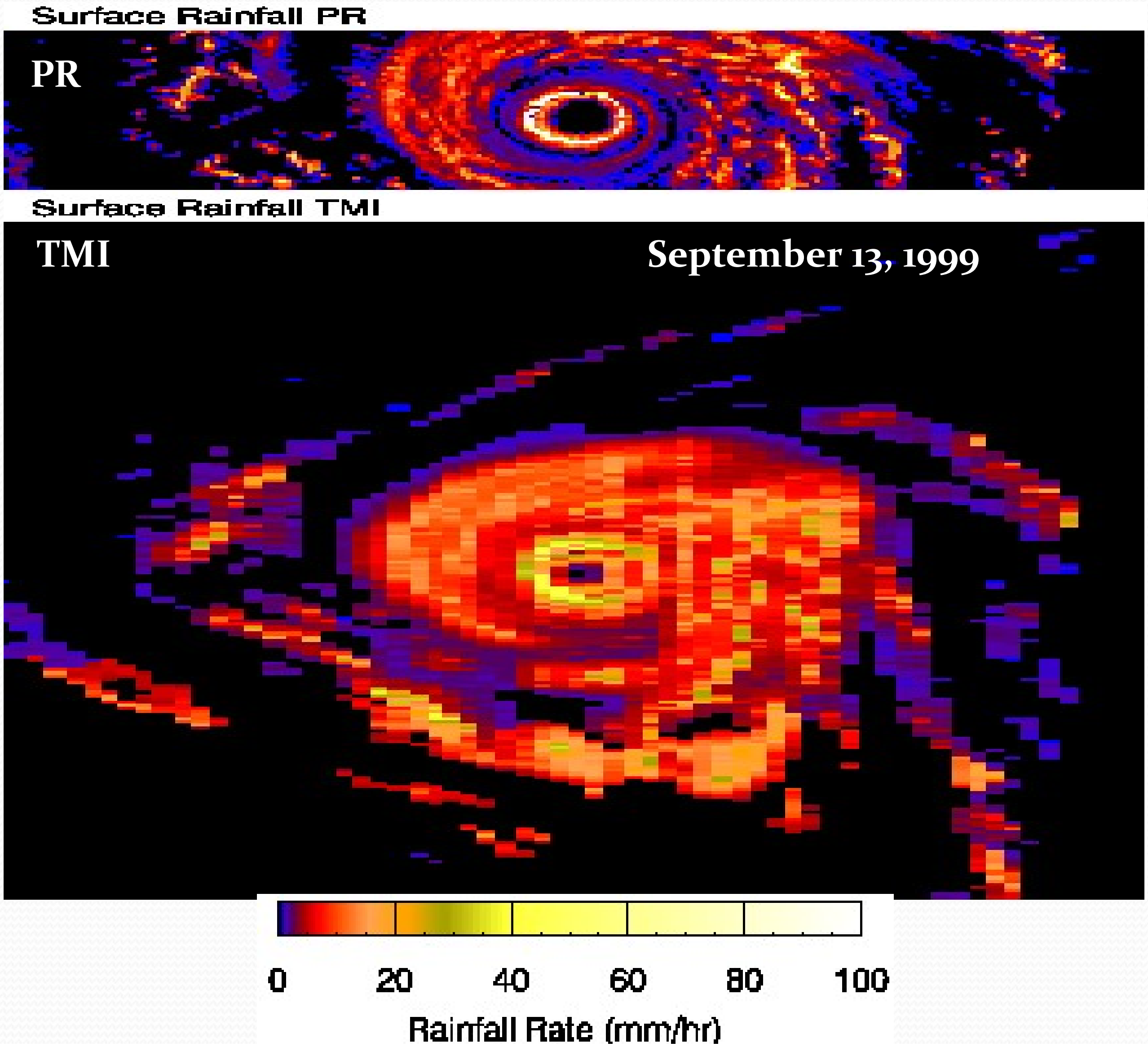
Comparison of TMI and SSM/I Brightness Temperatures at 37 GHz

- Simultaneous images of TRMM Microwave Imager (TMI) and Special Sensor Microwave Imager (SSM/I)
  - The greater spatial resolution of TMI allows higher quality rainfall estimates to be made



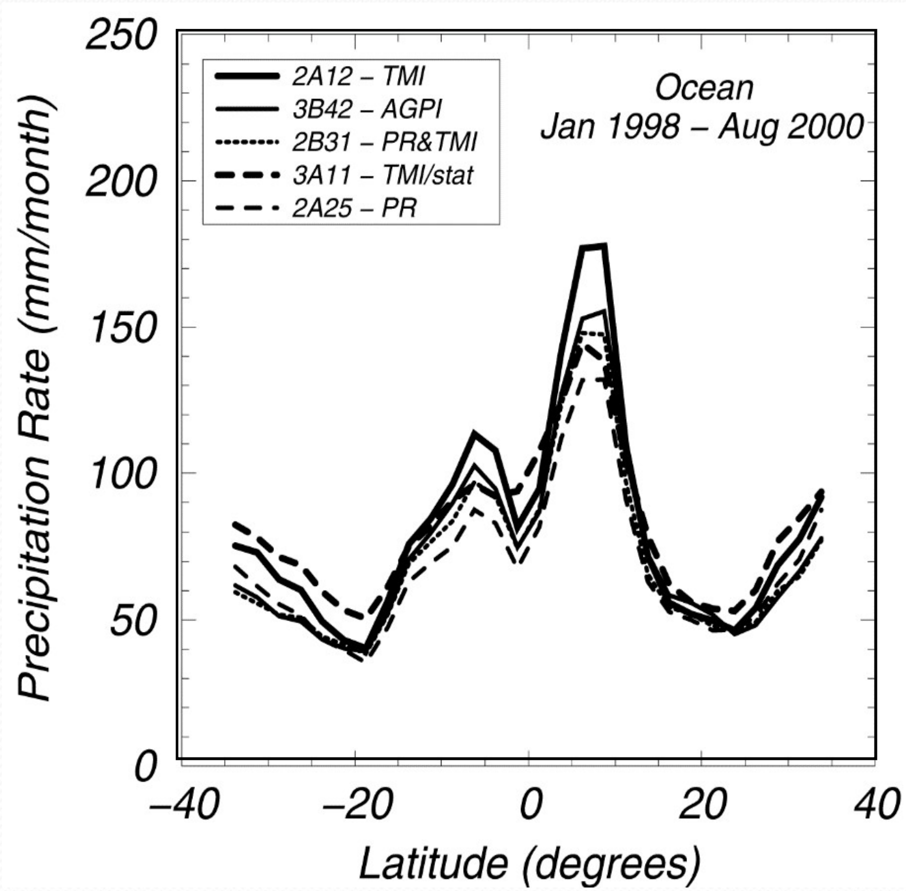
Microwave radiance at 37 GHz

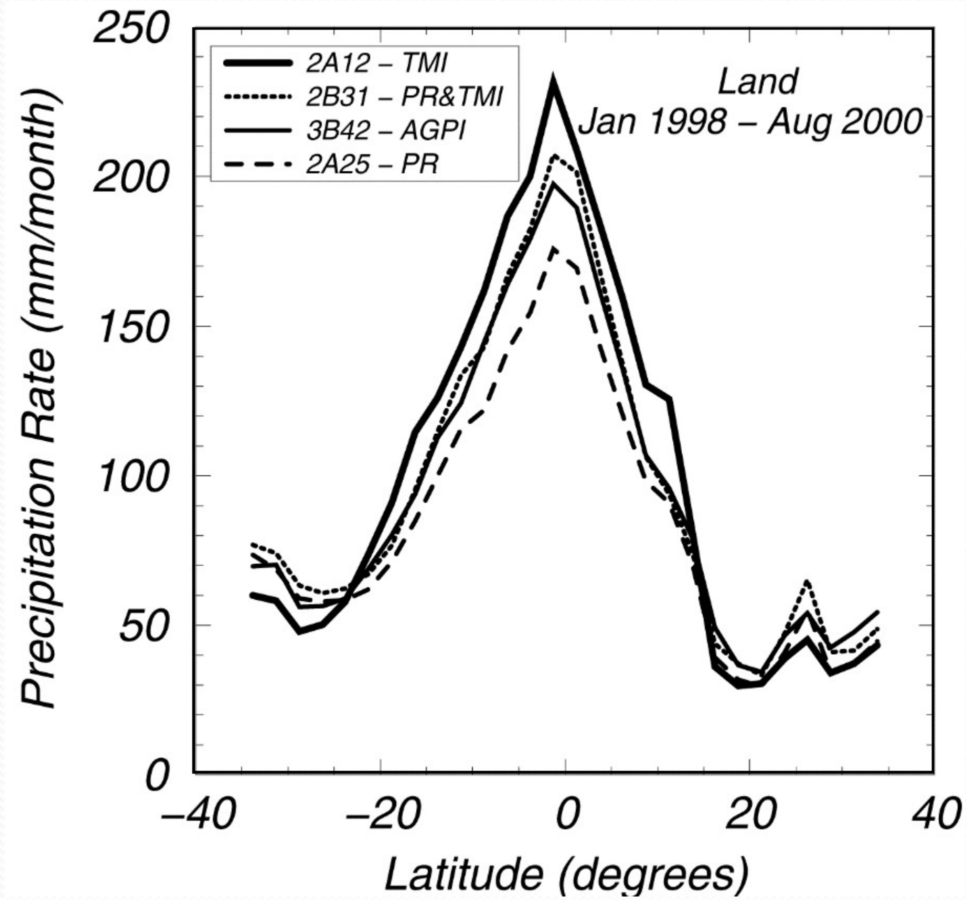
PR and TMI Instantaneous Rain Rate Comparison over Hurricane Floyd



TRMM Zonal Mean Rainfall

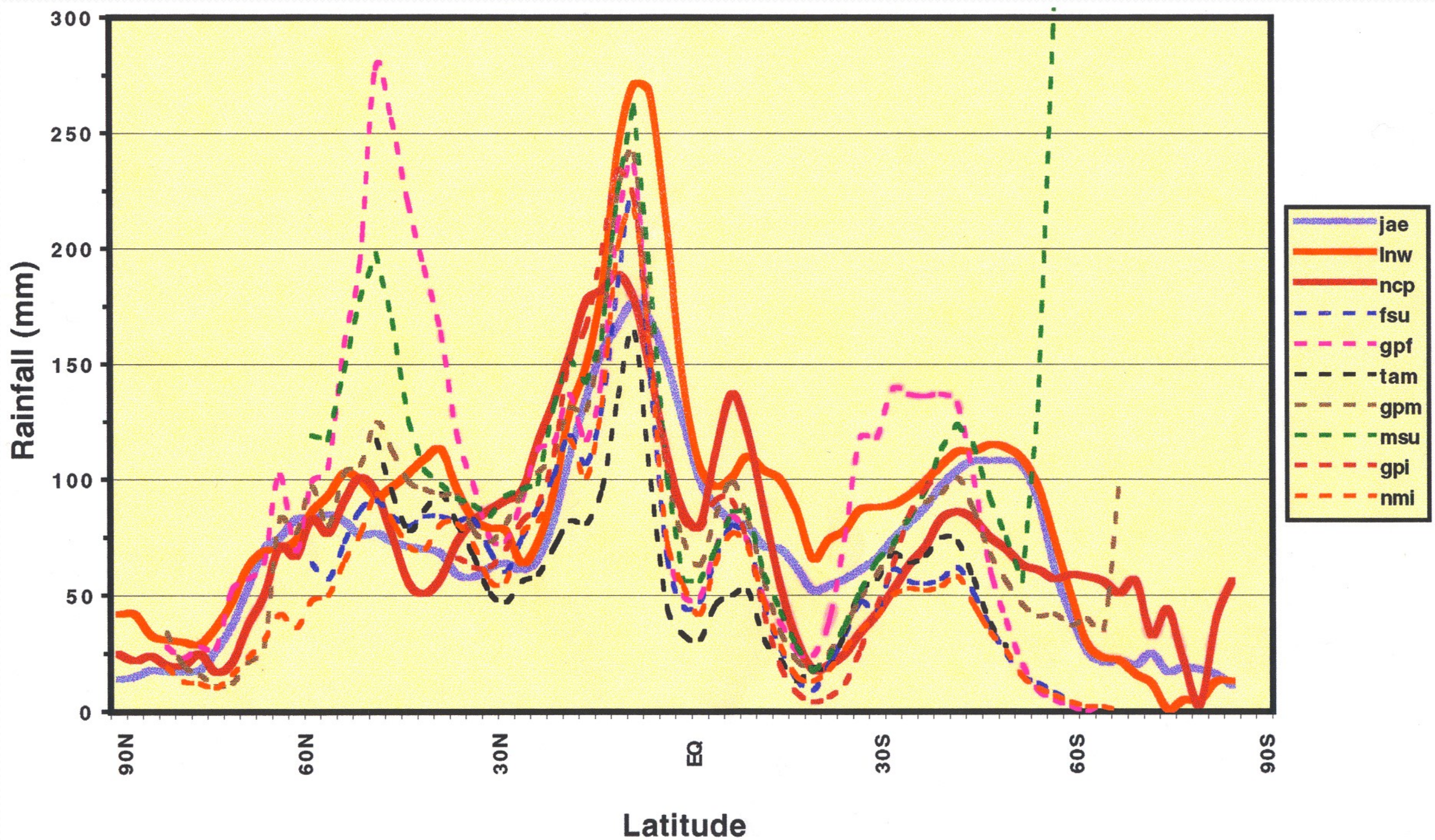
Ocean **Land**



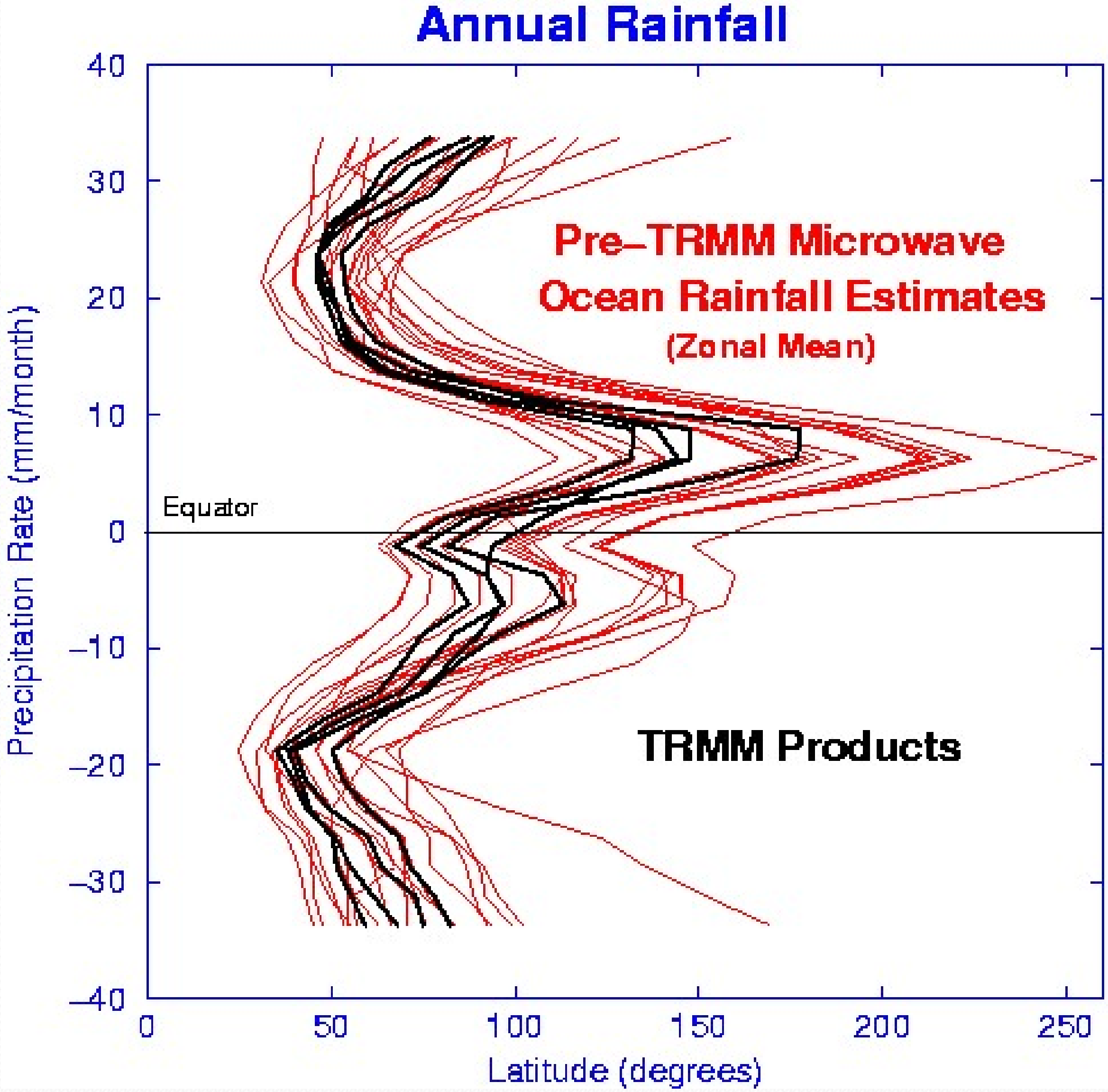


Zonally-Averaged Rainfall over Ocean

September



Ocean Rainfall Estimates with TRMM



Latitude (°)

Precipitation Rate (mm/month)

Status of TRMM Rainfall Products

- **TRMM V5 rainfall algorithms are within:**
  - 24% for tropical monthly averages
  - 20% for zonal-mean averages
  - 30-40% bias for instantaneous rain rates

- The **uncertainty** among TRMM satellite algorithms is comparable to the differences between TRMM rainfall products and ground-based estimates

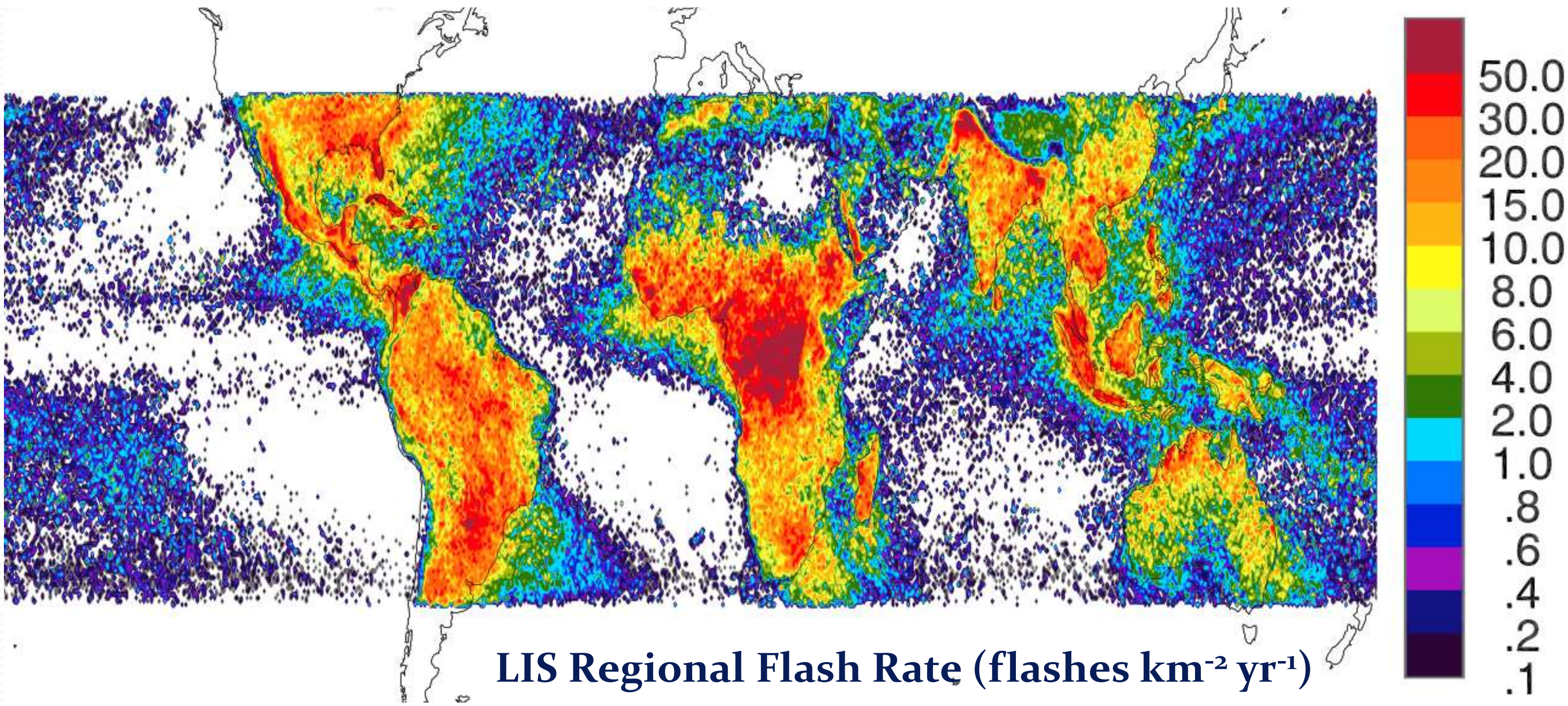
- Ground-based rainfall estimates are not used to evaluate satellite products as uncertainties in **data gaps**, **Z-R relations**, **calibration errors**, **rain-type classification**, and **representativeness errors** need be significantly reduced

- Further **agreement between the spaceborne and ground-based sensors** will require improved understanding of precipitation physics through field experiments

- TRMM Multi-Satellite Precipitation Analysis (TMPA-RT) is currently in **Version 7** and will only be produced until early 2018.

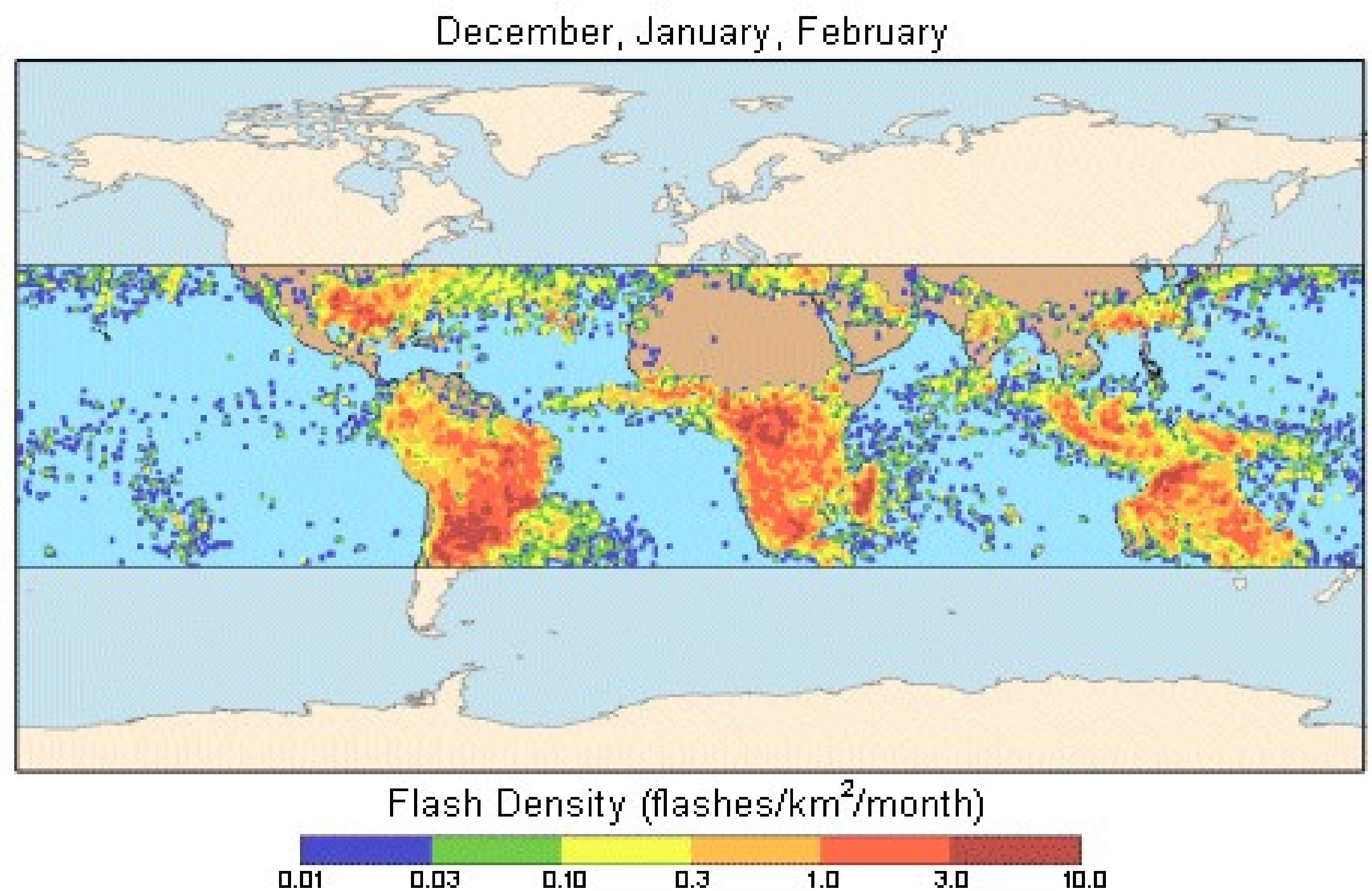
The Lightning Imaging Sensor (LIS) Observes 3 Years of Lightning

- **Land/Ocean** differences are pronounced
- Consistent with **NASA Optical Transient Detection (OTC)** climatology in both spatial distribution and rates
- **Island Effects** are pronounced
- Significant **orographic signals** (Himalayas, Colombia, Congo, Indonesia).



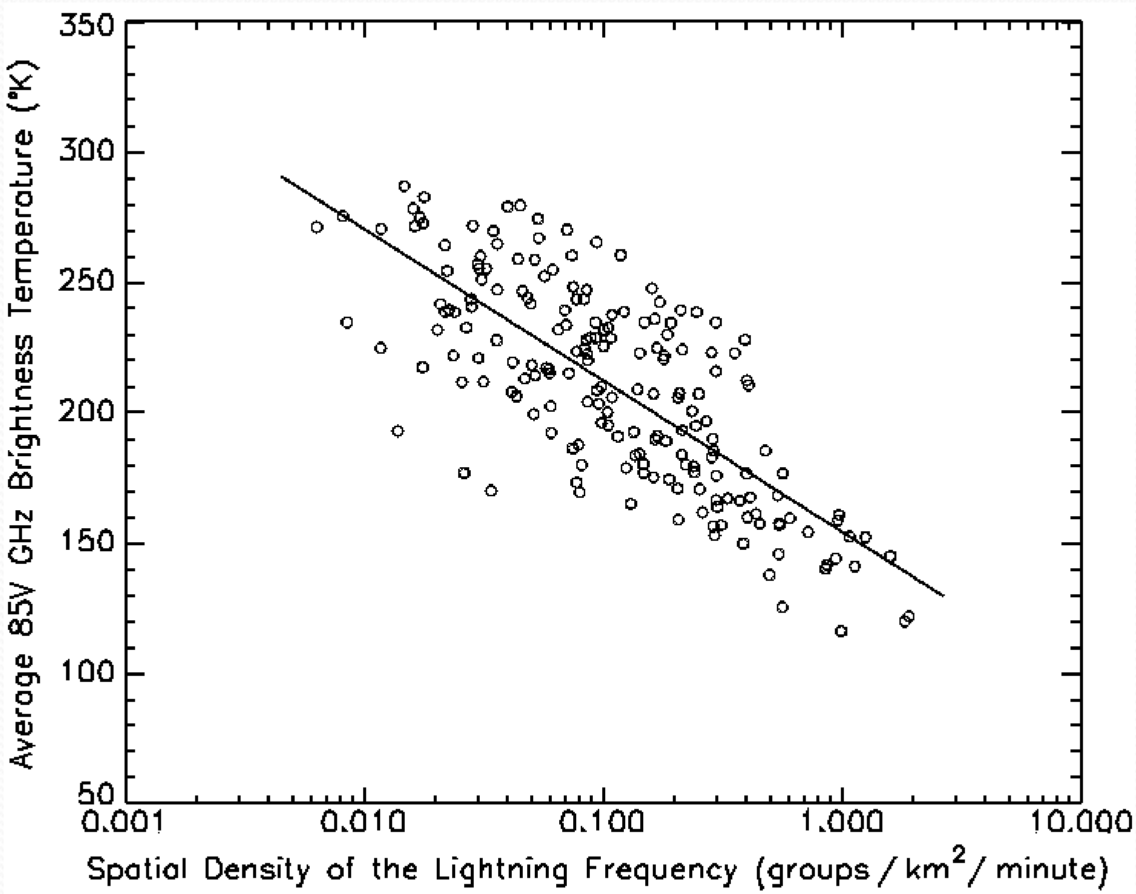
LIS Regional Flash Rate (flashes km^{-2} yr^{-1})

LIS-derived Lightning Rates during the 1997 El Niño-Southern Oscillation Event

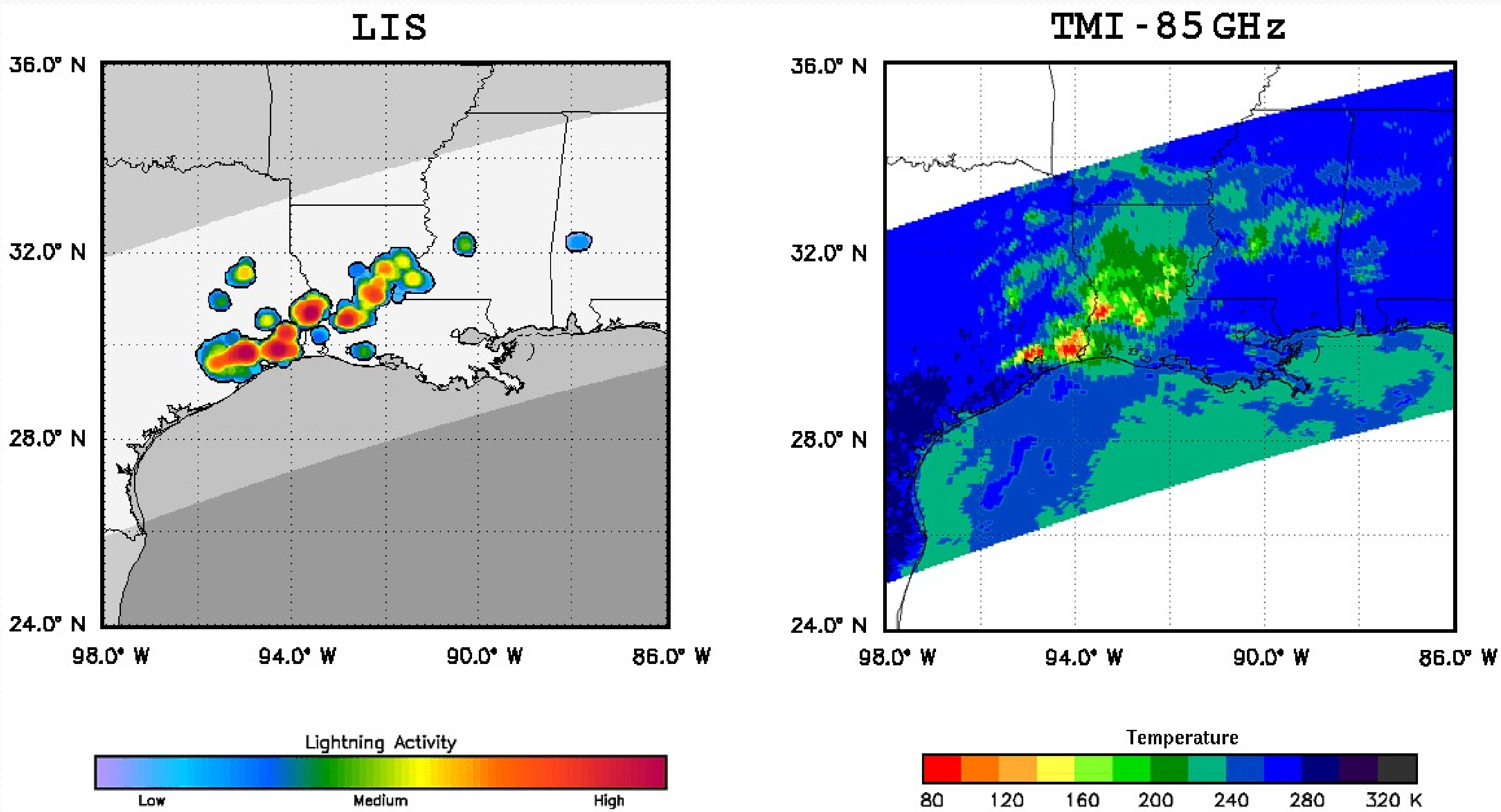


LIS-derived Lightning Rates during the 1997 El Niño-Southern Oscillation Event

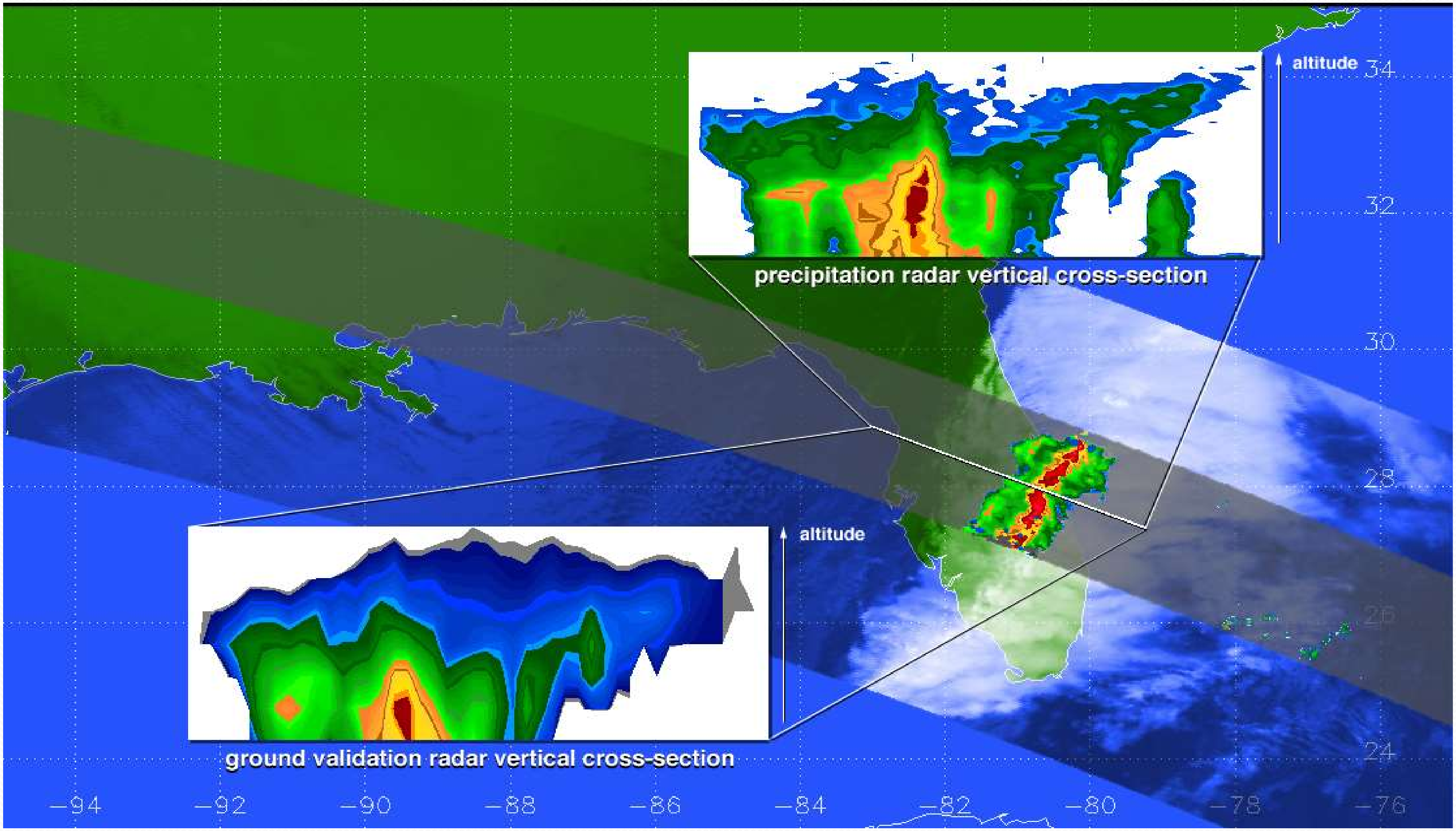
- Lightning/Precipitation Ice relationships demonstrated with (LIS/TMI)



Lightning Events are Associated with Strong Convective Activity in Heart of Severe Storms



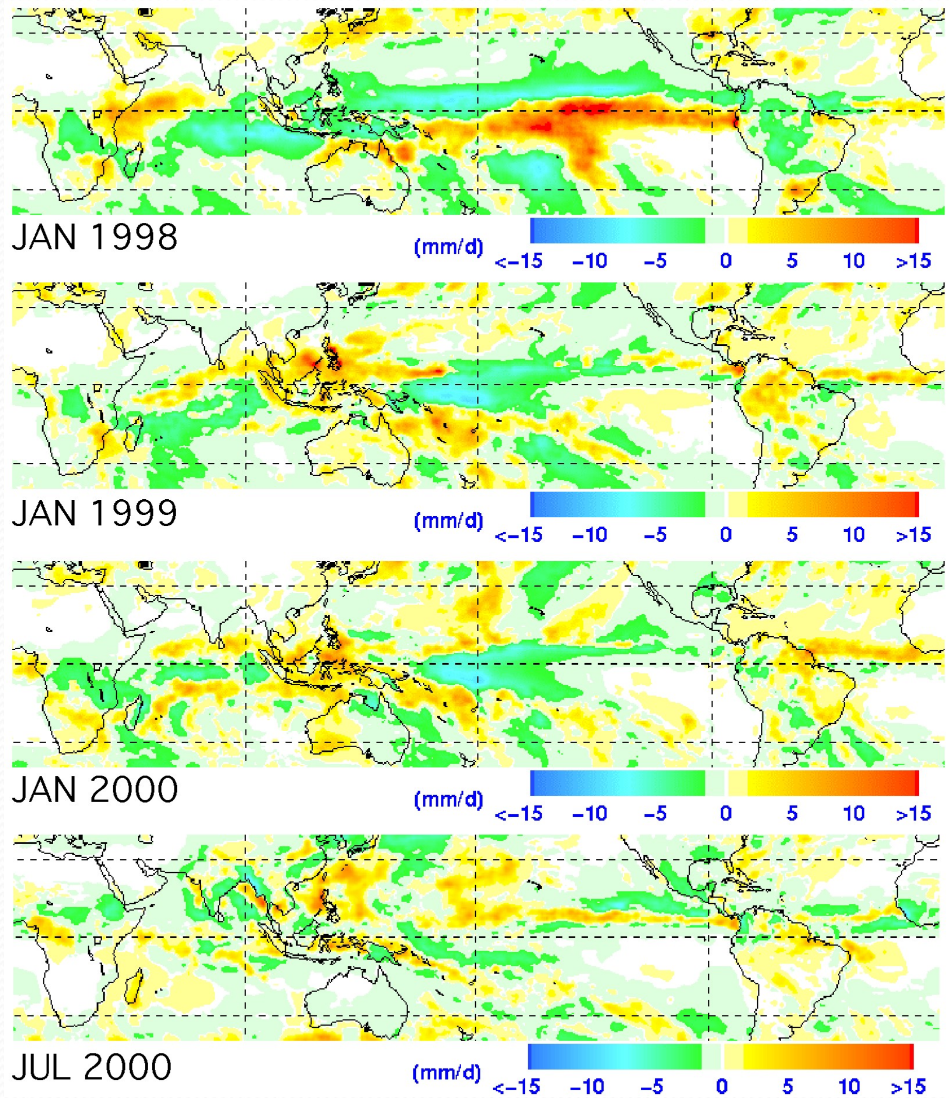
Comparison of TRMM and Ground-based Radars over Florida T-Storm



TRMM Views El Niño/La Niña Evolution (1998-2000)

- **January 1998**
  - Height of El Niño
  - Positive anomalies in the equatorial Pacific
  - Negative values to the north and west

- **January 1999**
  - Height of La Niña
  - Negative anomalies in the western Pacific
  - Positive values over the Maritime Continent



Rainfall Products from TRMM PR

Level 1 & 2: Orbital Data

Swath:	220 km (247 km after orbit change)
Resolution:	4-5 km horizontal, 250 m vertical
Data Format:	Compressed HDF

Name	Quantity
1B21	Radar Power
1C21	Radar Reflectivity
2A21	Radar Surface Cross Section
2A23	Radar Rain Characteristics (rain type, storm, freezing, and bright band heights)
2A25	Radar Rain Rate, Reflectivity, and Attenuation Profile

Rainfall Products from TRMM PR

Level 3: Gridded Data

Resolutions: - 0.5° x 0.5° and 5° x 5° latitude-longitude (for a latitude band from 40° N to 40° S)
- Monthly
- 2, 4, 6, 10, 15 km vertical levels

Data Format: Compressed HDF

Name	Quantity
3A25	Total and **conditional** Rain Rate, Radar Reflectivity, path-integrated attenuation for rain Type, Freezing and Bright Band Heights, and Snow-ice Layer Depth
3A26	Rain Rate Probability Distribution at surface, 2 km, and 4 km

Rainfall Products from TRMM TMI

Level 1 & 2 : Orbital Data

Swath:	760 km (870 km after orbit boost)
Resolution:	5 to 45 km horizontal (channel dependent), 14 vertical levels up to 18 km
Data Format:	Compressed HDF

Name	Quantity
1B11	Microwave Radiances and Brightness Temperatures with Geolocation Information
2A12	Hydrometeor (cloud, rain, ice/snow particles) Profiles, Latent Heating Profiles

Rainfall Products from TRMM TMI

Level 3: **Gridded Data**

Resolutions:- 0.5° x0.5° latitude-longitude, 14 Levels
(for a latitude band from 40° N to 40° S)
- Monthly

Data Format: Compressed HDF

Name	Quantity
3A12	Temperature Profiles, Water Vapor Profiles, Rain, Precipitation Rate, Cloud Liquid Water/Ice Water, Atmospheric Heating

Rainfall Products from Combined PR-TMI

Level 2 :

Resolutions: Swath (5 Km x 247 Km)
(for a latitude band from 40N to 40° S)

Data Format: Compressed HDF

Name	Quantity
2B31	Surface precipitation Rate, Latent heating Profile

Level 3 :

Resolution : 5° x 5° (for a latitude band from 40° N to 40° S), Monthly

Data Format: Compressed HDF

Name	Quantity
3B31	Surface precipitation Rate, Latent heating Profile

TRMM Multi-satellite Merged Product

Level 3: **Gridded Data**

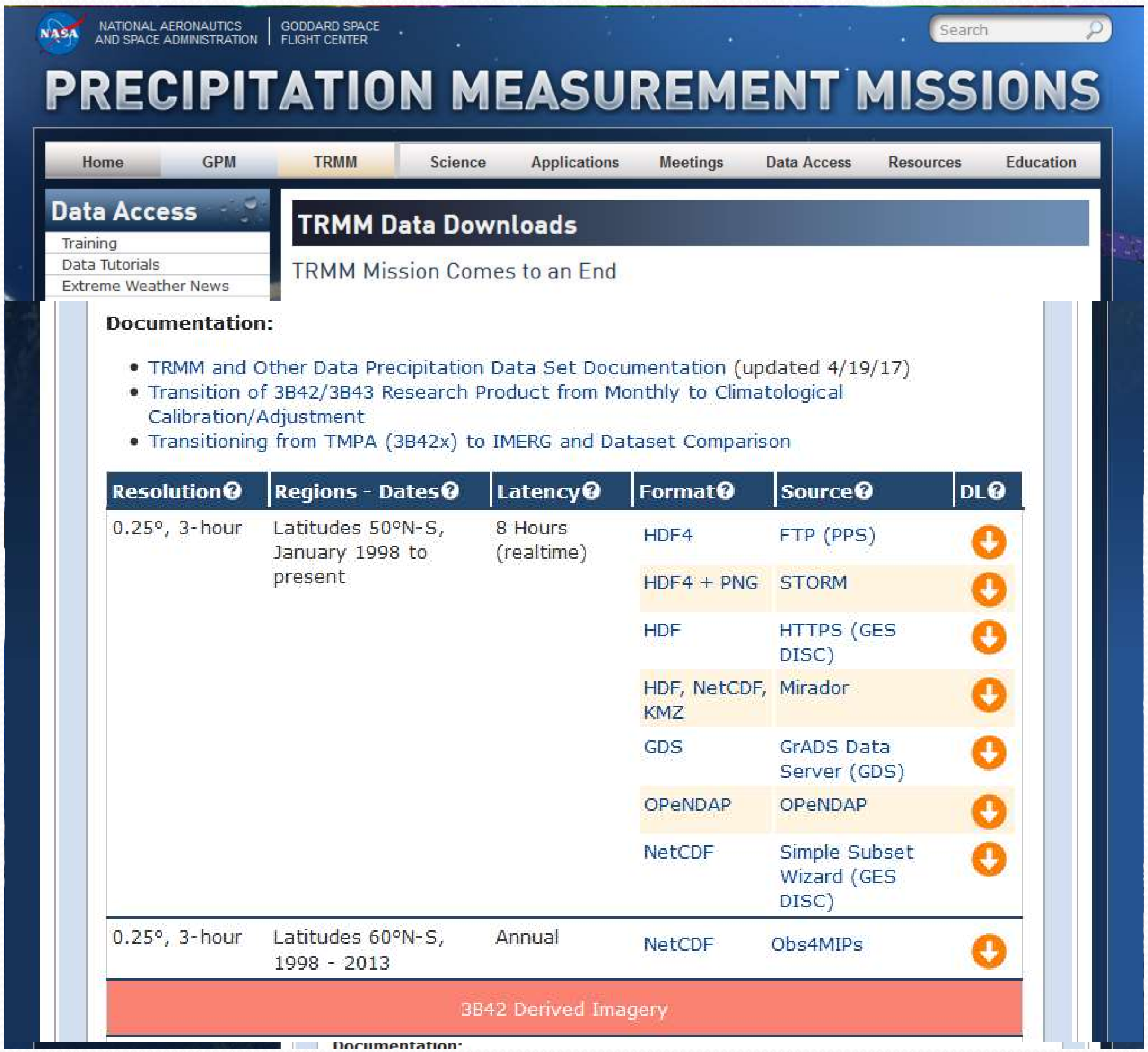
Resolutions: - 0.25° x0.25° latitude-longitude
(for a latitude band from 50° N to 50° S)
- 3-hourly, Daily, Monthly

Data Format: Compressed HDF

Name	Quantity
3B42	3-hourly and daily rain rates(also called TMPA – TRMM Multi-Satellite Precipitation Analysis)
3B43	Monthly averaged rain rates Monthly climatology and anomalies

Obtain TRMM Products

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



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TRMM Mission Comes to an End

Documentation:

- TRMM and Other Data Precipitation Data Set Documentation (updated 4/19/17)
- Transition of 3B42/3B43 Research Product from Monthly to Climatological Calibration/Adjustment
- Transitioning from TMPA (3B42x) to IMERG and Dataset Comparison

Resolution	Regions - Dates	Latency	Format	Source	DL
0.25°, 3-hour	Latitudes 50°N-S, January 1998 to present	8 Hours (realtime)	HDF4	FTP (PPS)	
			HDF4 + PNG	STORM	
			HDF	HTTPS (GES DISC)	
			HDF, NetCDF, KMZ	Mirador	
			GDS	GrADS Data Server (GDS)	
			OPeNDAP	OPeNDAP	
			NetCDF	Simple Subset Wizard (GES DISC)	
0.25°, 3-hour	Latitudes 60°N-S, 1998 - 2013	Annual	NetCDF	Obs4MIPs	

3B42 Derived Imagery

Documentation:

- Here you can download Level 1-3 TRMM data
- Each data product has a description
- And different ways of accessing the data.

TRMM Near-real Time Flood and Landslide Information Tool

(http://trmm.gsfc.nasa.gov/publications_dir/potential_flood_hydro.html)