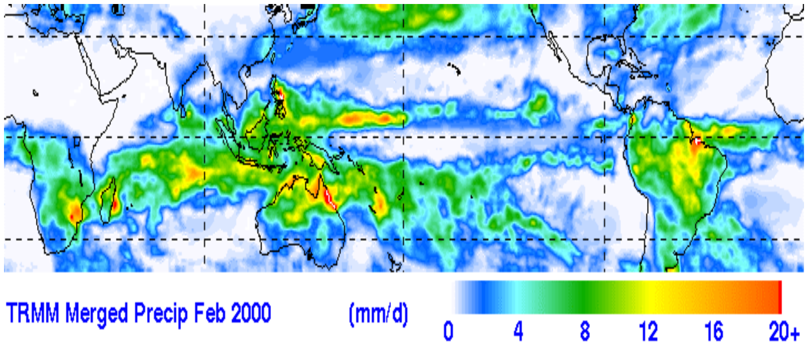
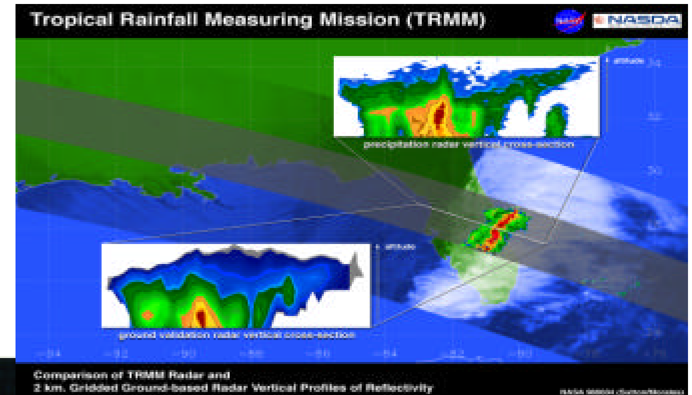
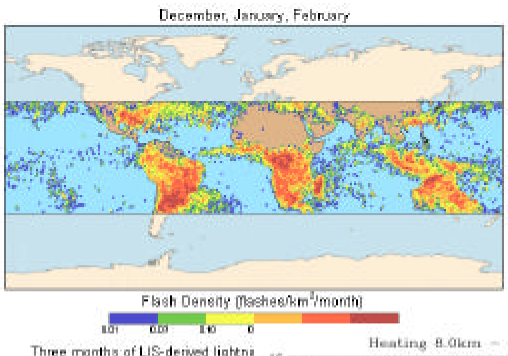
Tropical Rainfall Measuring Mission (TRMM):

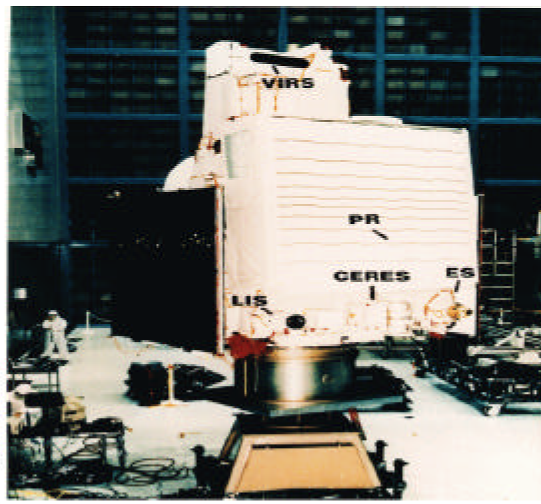
Monitoring the Global Tropics



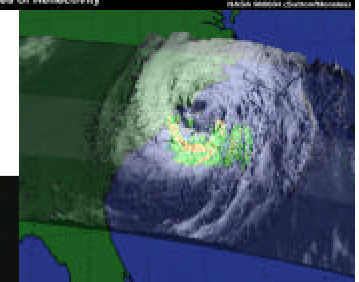
Tropical Rainfall Measurement and Understanding of Climate Processes

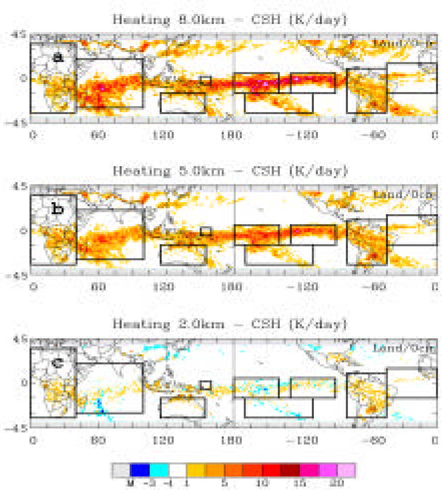






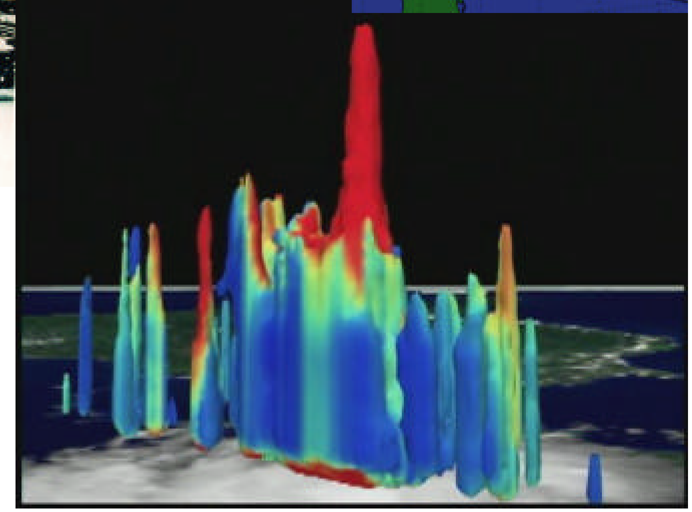
TRMM Observatory





Understanding Latent Heating, Lightning and Other Physical Processes

Assessing Hurricanes and Other Natural Hazards



TRMM Science Overview

- Introduction to TRMM mission
- Science results
- Operational use of TRMM data
- Re-entry issue from science view
- TRMM saves lives?

TRMM Mission

- First science workshop in 1986; launch Nov. 27, 1997
- 35° inclination, 350km altitude, $350M from U.S.
- Joint mission with Japan, approx. equal $$ contribution

- Three-year (1998-2000) set of TRMM data meets Science Team <u>minimum</u> for scientific usefulness of mission--full success requires substantially more data

- U.S. Science Team--70 P.I.s
- Japan Science Team--~20 P.I.s
- EuroTRMM--ESA-funded studies using TRMM data

- Data system produces research products and real-time data

TRMM Sensors

Precipitation radar (PR):

- 13.8 GHz
- 4.3 km footprint
- 0.25 km vertical res.
- 215 km swath

Microwave radiometer (TMI):

- 10.7, 19.3, 21.3, 37.0
- 85.5 GHz (dual polarized except for 21.3 V-only)
- 10x7 km FOV at 37 GHz
- 760 km swath

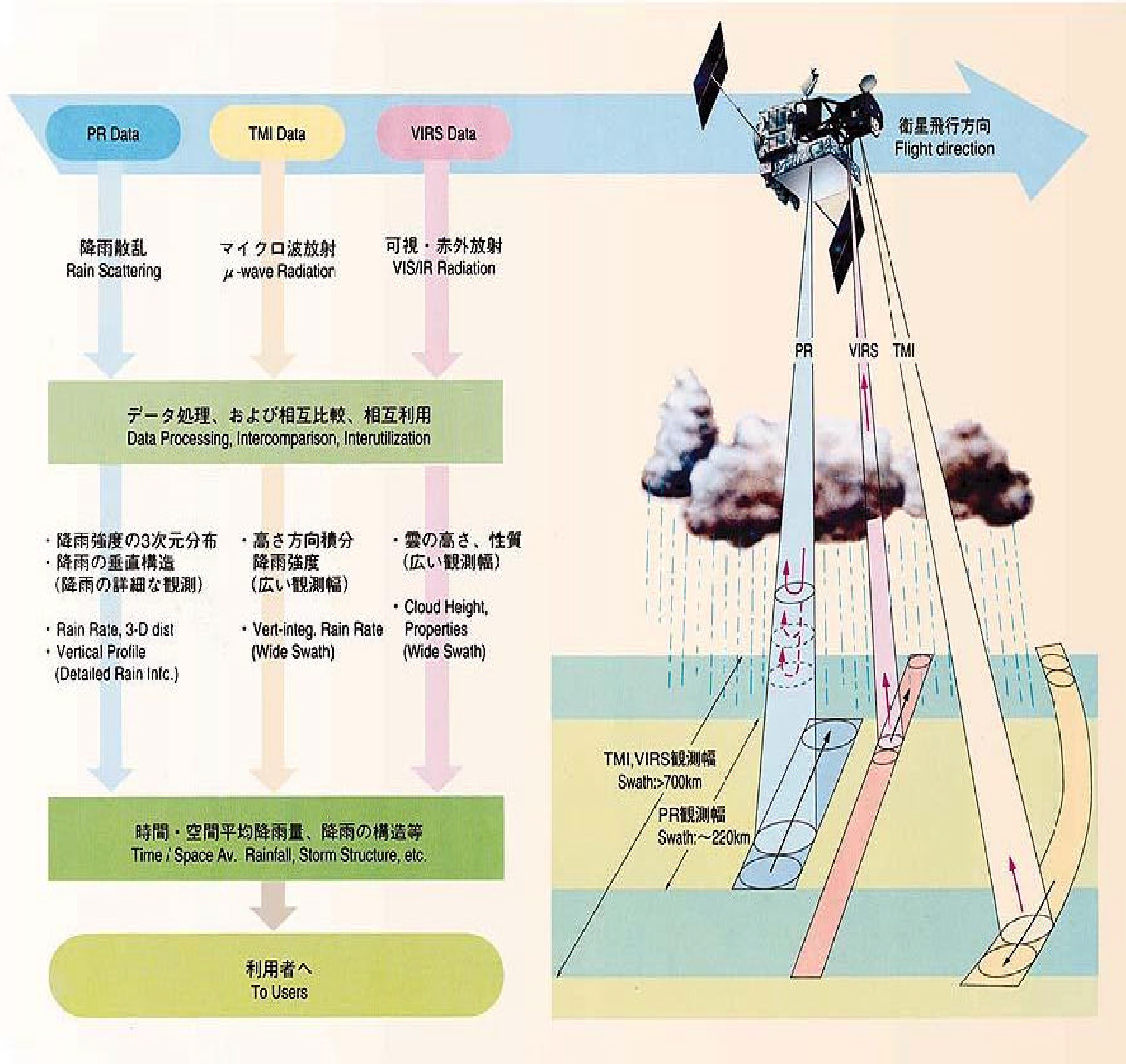
Visible/infrared radiometer (VIRS)

- 0.63, 1.61, 3.75, 10.8, and 12 at 2.2 km resolution

Additional EOS instruments:

CERES (Cloud & Earth Radiant Energy System) 720 km swath

LIS (Lightning Imaging Sensor)



TRMM GOALS

- To advance understanding the global energy and water cycles by providing distributions of rainfall and latent heating over the global tropics.
- To understand the mechanisms through which changes in tropical rainfall influence global circulation, and to improve ability to model these processes in order to predict global circulations and rainfall variability at monthly and longer time scales
- To provide rain and latent heating distributions to improve the initialization of models ranging from 24 hour forecasts to short-range climate variations
- To help understand, diagnose and predict the onset and development of the El Niño, Southern Oscillation and the propagation of the 30-60 day oscillations in the tropics
- To help understand the effect that rainfall has on the ocean thermohaline circulations and the structure of the upper ocean
- To allow cross-calibration between TRMM and other sensors with life expectancies beyond that of TRMM itself
- To evaluate the diurnal variability of tropical rainfall
- To evaluate a space-based system for rainfall measurement

TRMM Re-entry Issue

(Key Points from Science Viewpoint)

- 157 kg fuel level reached in March ‘03; zero fuel in Oct. ‘04
- If orbit raised to 400km dates are Nov. ‘05 and Sep. ‘09

Impact of early re-entry

- Significant loss of science information on climate and storms;
- Loss of operational data used by NWS, AF/Navy, E CMWF and others---one estimate indicates significant loss of lives in tropical cyclones due to absence of TRMM data.

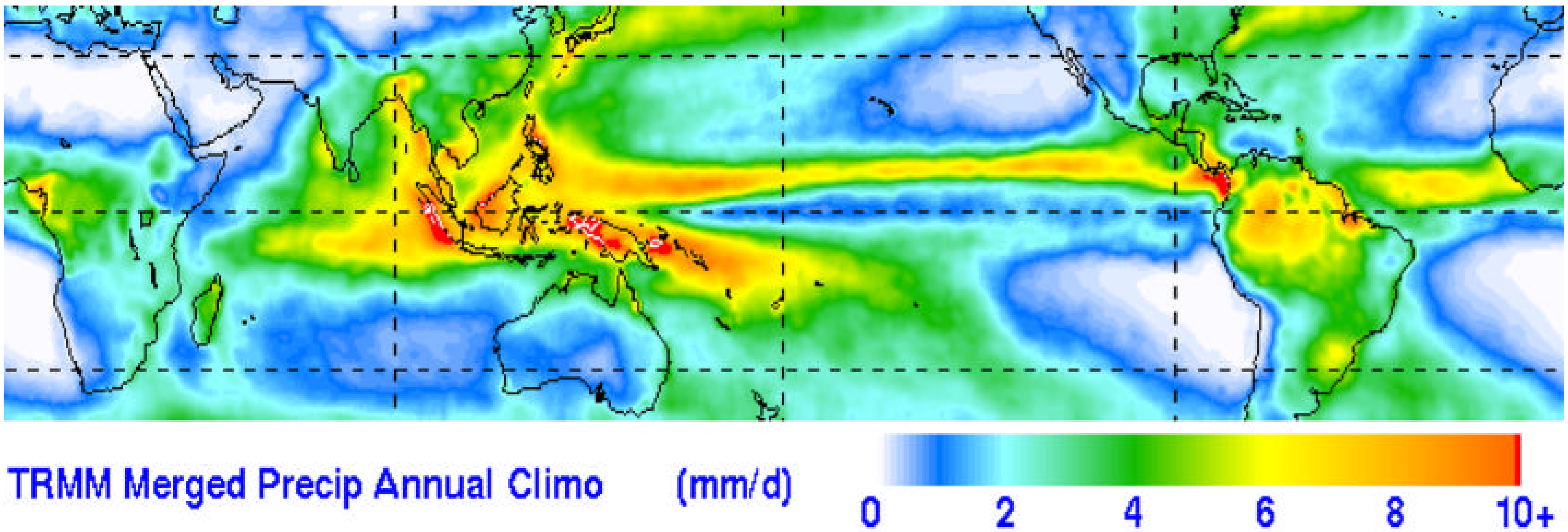
As a safety issue the TRMM re-entry should be considered in a comprehensive manner including both the possible injury by debris and the life-saving use of TRMM data in storm analysis and forecasting.

TRMM Re-entry Dates

	157 kg	0 kg
350 km orbit	March 2003	October 2004
400 km Orbit Aug. '01 boost [Jan '02 boost]	November 2005 [Sep. 2004]	September 2009 [Nov. 2008]

Tropical Rainfall Measuring Mission (TRMM)

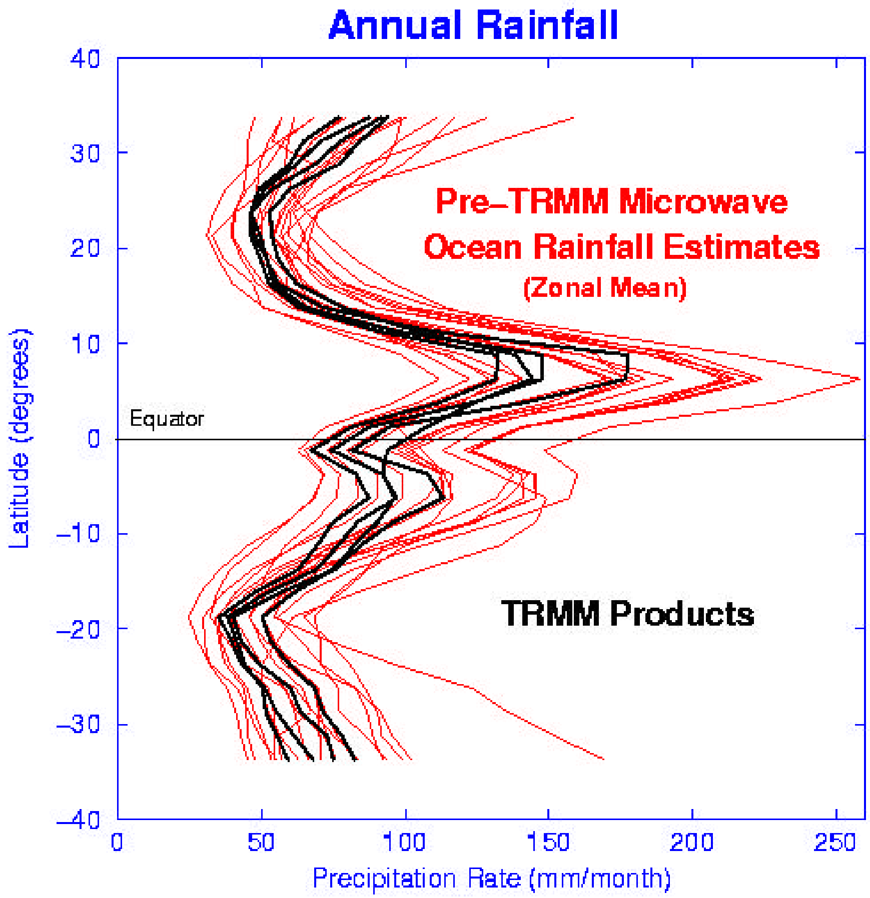
Three-Year TRMM Climatology



January 1998 - December 2000

Tropical Rainfall Measuring Mission (TRMM)

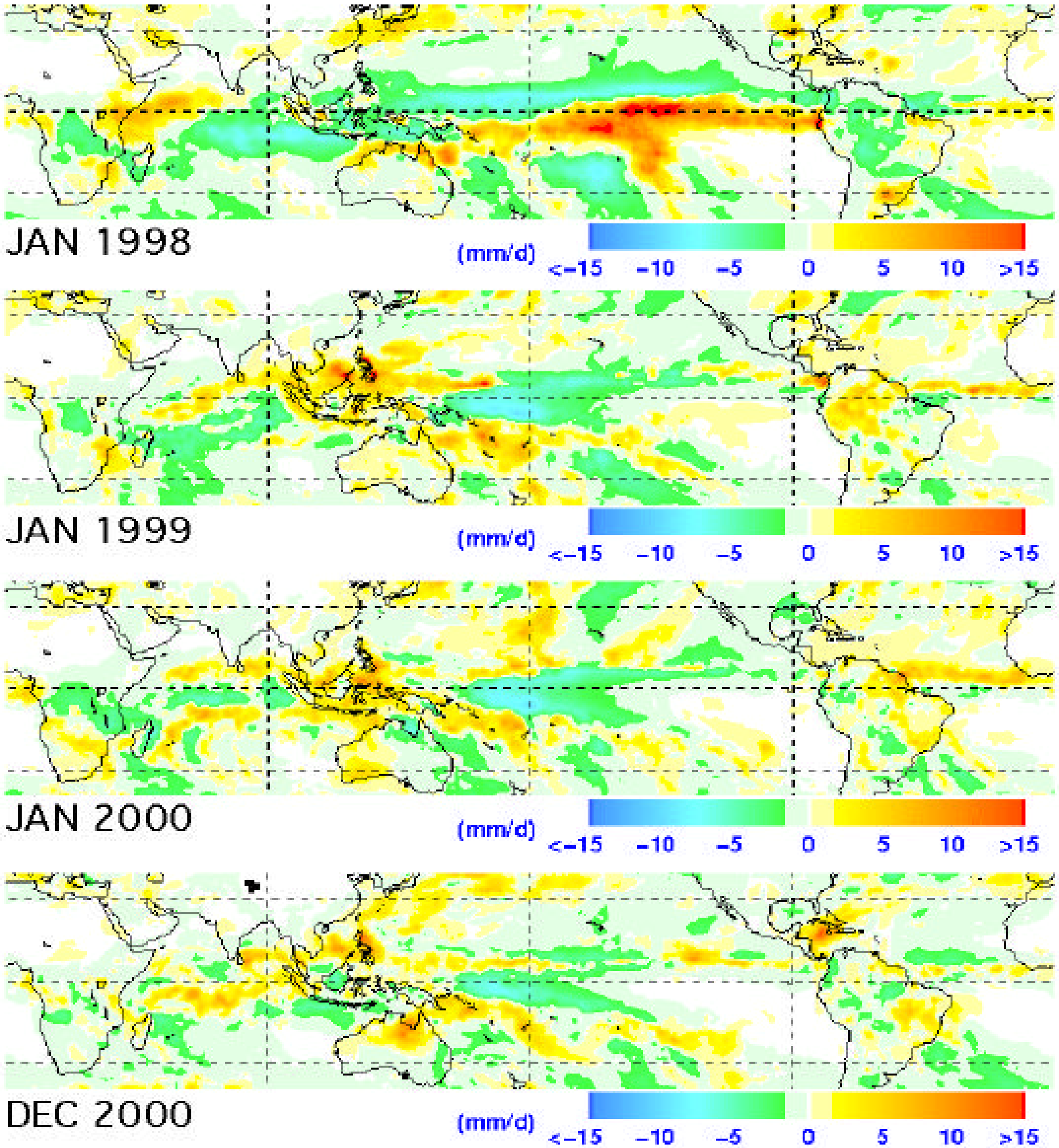
Ocean Rainfall Estimates With TRMM



Tropical Rainfall Measuring Mission (TRMM)

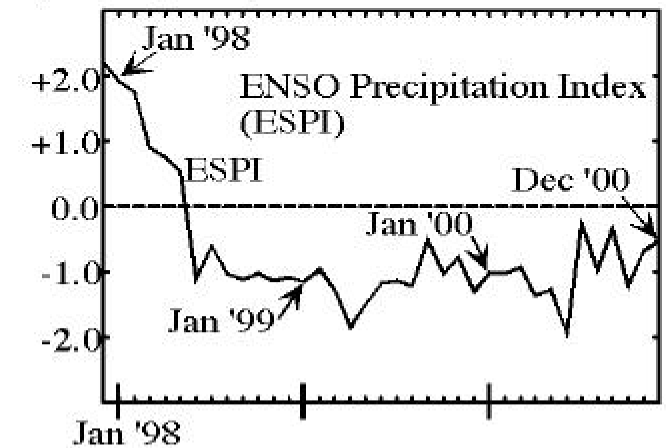
TRMM Views El Niño/La Niña Evolution (1998-2000)

Monthly Rainfall Anomaly Fields
(from TRMM merged analyses)



- Jan 1998 - Height of El Niño, with positive anomalies in the equatorial Pacific; negative values to the north and west
- Jan 1999 - Height of La Niña, with negative anomalies in the western Pacific; positive values over the Maritime Continent

Based on Gradients of Tropical Precipitation Anomalies
Representing Strength of Anomalous Walker Circulation



- Jan 2000 - La Niña continues...
- Dec 2000 - La Niña ending...

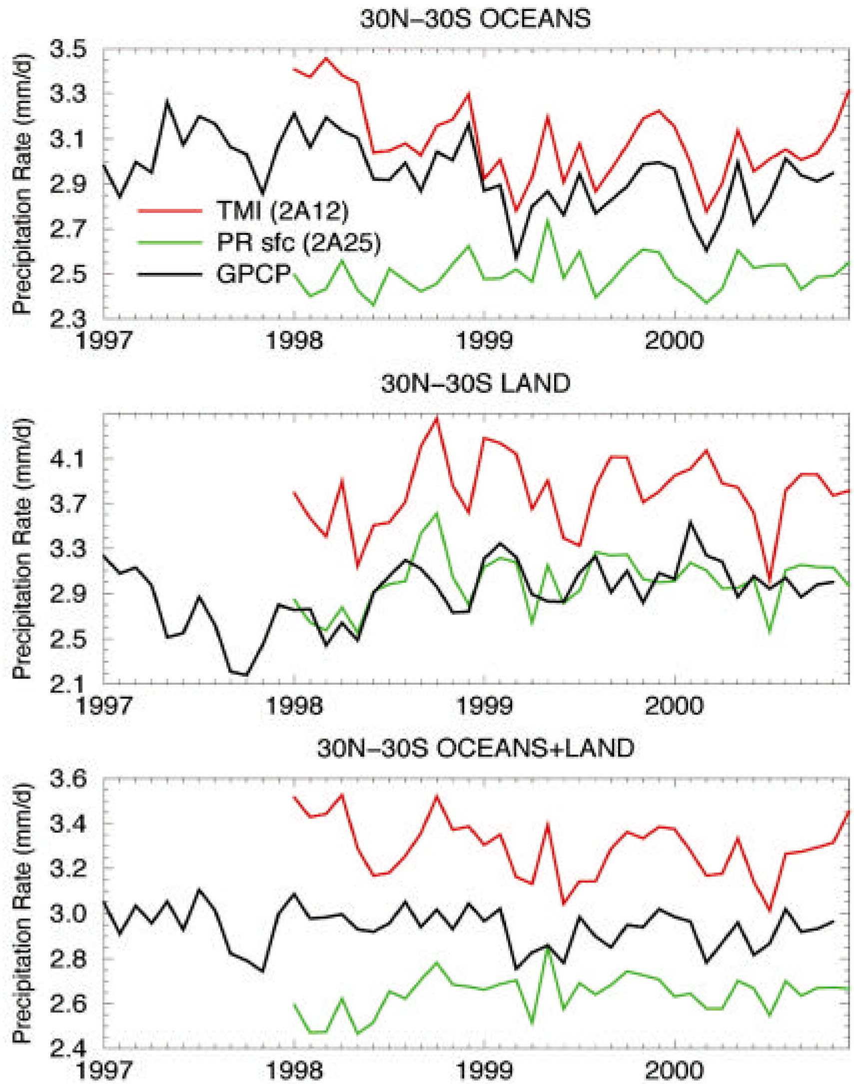
Adler, Huffman, Curtis, Bolvin NASA/Goddard

Tropical Integrated Rainfall (El Nino/La Nina Transition)

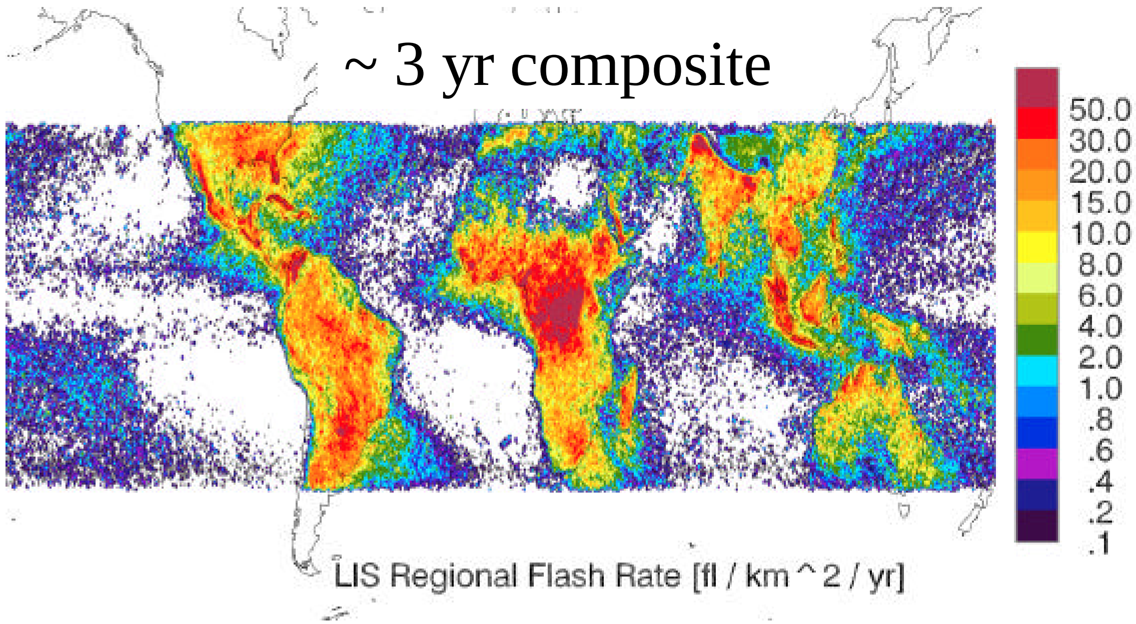
Oceans (30N-30S)

Land (30N-30S)

Oceans+Land (30N-30S)

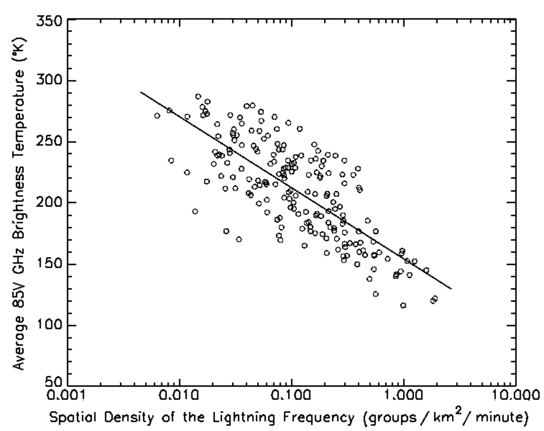


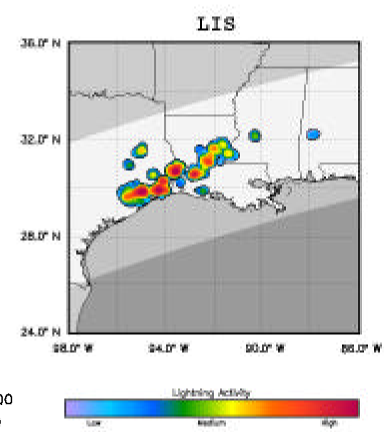
The Lightning Imaging Sensor (LIS) - Key Results

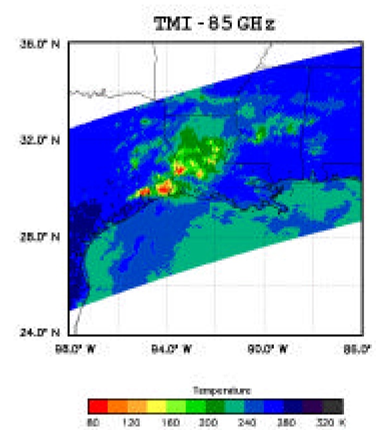


- Land/ocean differences pronounced
- Consistent with NASA OTD climatology in both spatial distribution and rates
- Island effects pronounced
- Significant orographic signals (Himalayas, also in Colombia, Zaire, Indonesia)

- Lightning / precip ice relationship demonstrated (LIS / TMI)



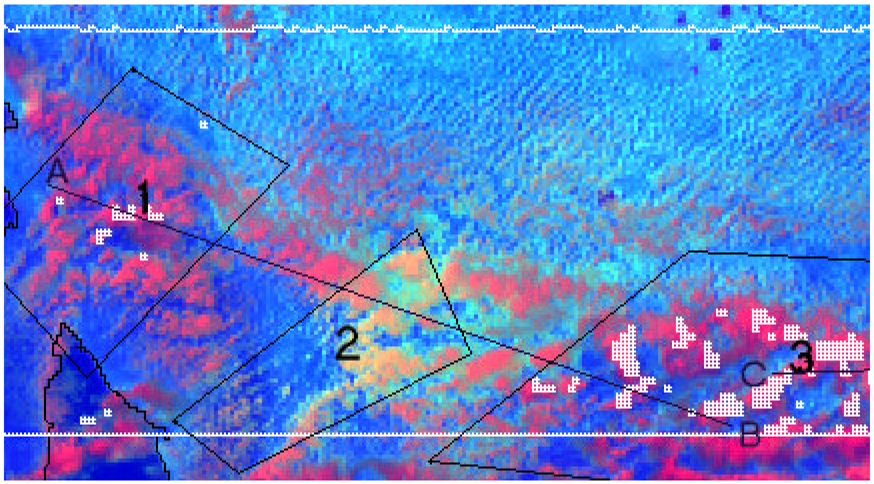




Christian, Blakeslee, Goodman, Mach -- NASA/MSFC, UAH

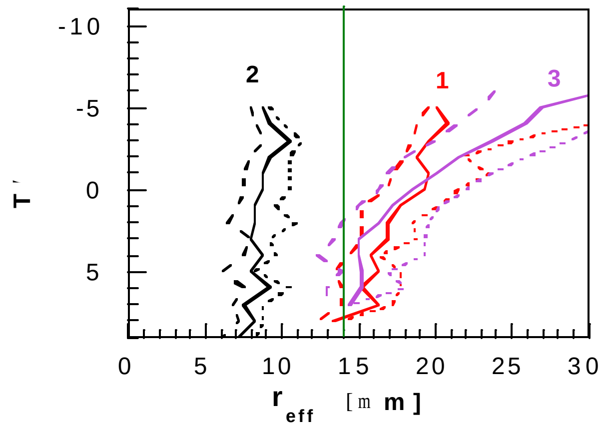
Suppression of Rain and Snow by Smoke and Air Pollution

TRMM VIRS painting yellow pollution tracks in the clouds over South Australia, due to reduced droplets size.



TRMM PR shows precipitation as white patches only outside the pollution tracks, although clouds have same depth.

TRMM TMI shows ample water in the polluted clouds



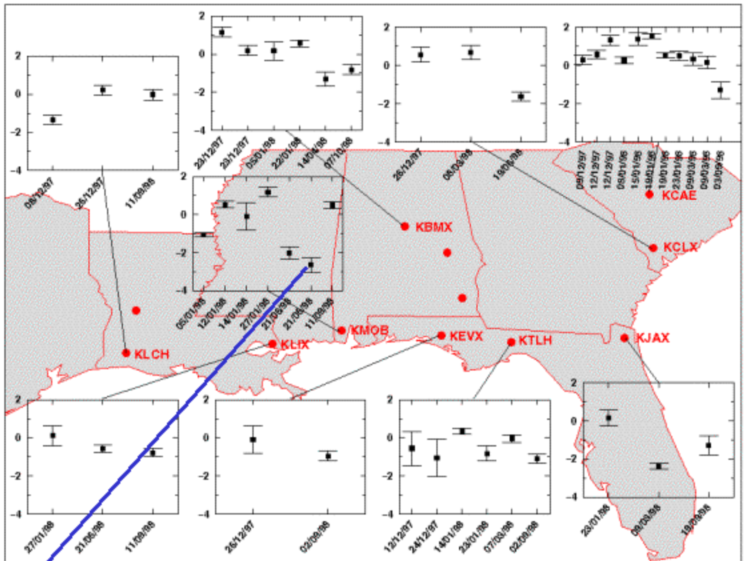
TRMM VIRS retrieved effective radius does not exceed the 14 µm precipitation threshold in polluted clouds within area 2 in the Australia image.

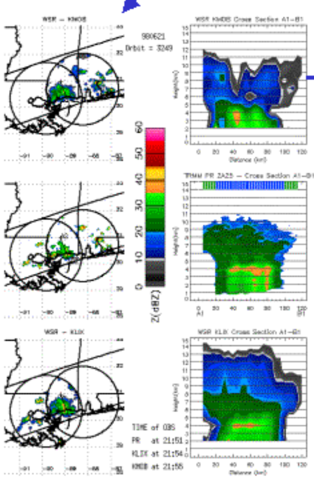
Contact: Prof. Daniel Rosenfeld
The Hebrew University of Jerusalem

TRMM Precipitation Radar Helps Address Calibration Problems of Ground-Based Weather Radar Systems

E.N. Anagnostou, C.A. Morales, and T. Dinku, University of Connecticut

•PR monitors fluctuations in the calibration bias of US WSR-88D systems:

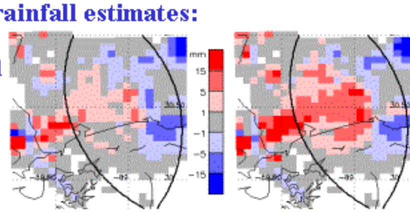




Example showing comparisons of TRMM PR and two WSR-88D observations of a storm cell located in the quantitative range of the two radars: PR identifies a 2.5 dB calibration bias for KMOB, while it agrees within 0.5 dB with KLIX.

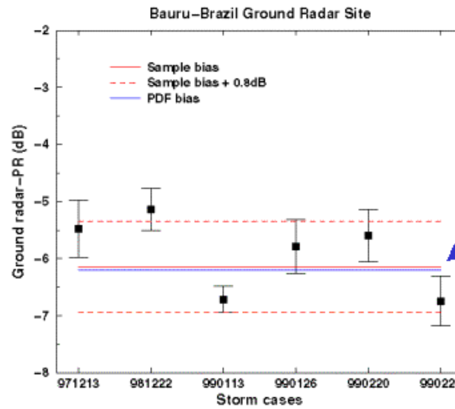
<u>Hudrologic Implications</u>: Adjusting for the bias identified by PR results to removal of the wide divergence in the two ground radar storm total rainfall estimates:

PR based adjusted WSR-88Ds →



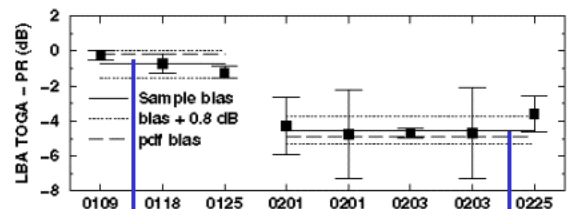
← Unadjusted WSR-88Ds

•PR identifies calibration biases for an operational weather radar used for flood forecasting in the urban area of Sao Paolo, Brazil:



Comparison with PR over the period of 1997 to 1999 shows a calibration bias of ~6dB for the Bauru radar. This bias corresponds to about 3-4 times underestimation in the flow forecasts if driven by radar data left uncorrected.

•PR identifies a 4 dB change in the calibration of the TOGA research radar used in the Large Biosphere Atmosphere Experiment in the West Amazon:



The TOGA-PR systematic difference from data comparisons preceding January 24 1999 was about –0.5 dB

The systematic difference jumps to -4.5 dB from data comparisons following January 24.

Web Page: http://www.engr.uconn.edu/~gracp

Amazon Rainforest Monitoring

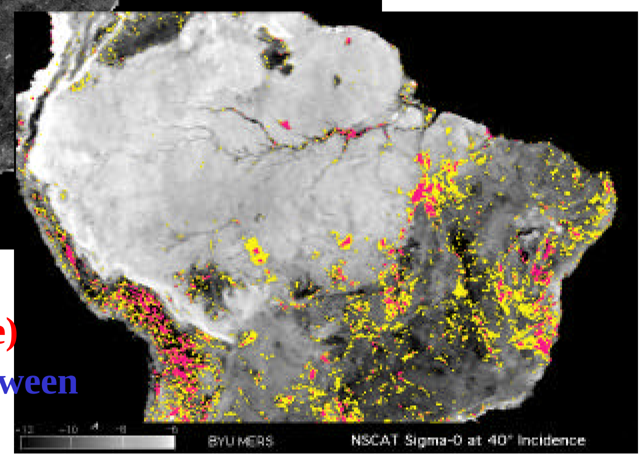
BYU Center for Remote Sensing

JPL

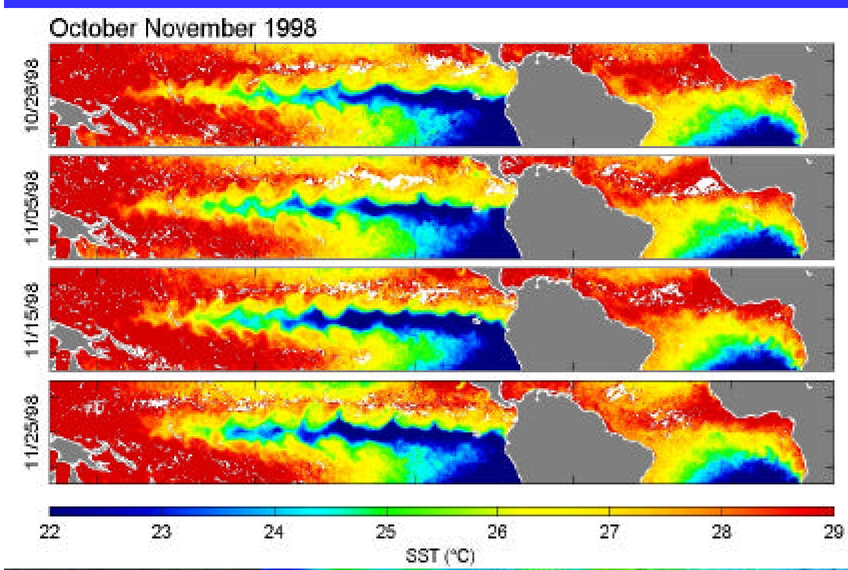
Investigators:
D. G. Long
(BYU)
M. W. Spencer
(JPL)

The TRMM PR and Ku-band wind scatterometers (NSCAT & SeaWinds) provide complementary sigma-0 measurements: River flood plains most evident in low-incidence angle TRMM data. Higher incidence angle scatterometer data best for vegetation mapping.

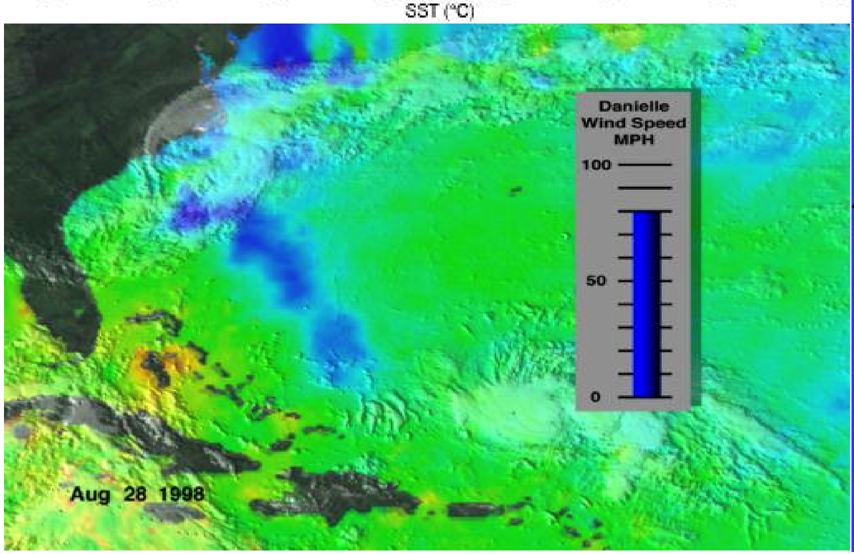
NSCAT sigma-0
(40 deg incidence angle)
Significant changes between 1978 and 1996 in color



Sea Surface Temperature Measurements from TRMM

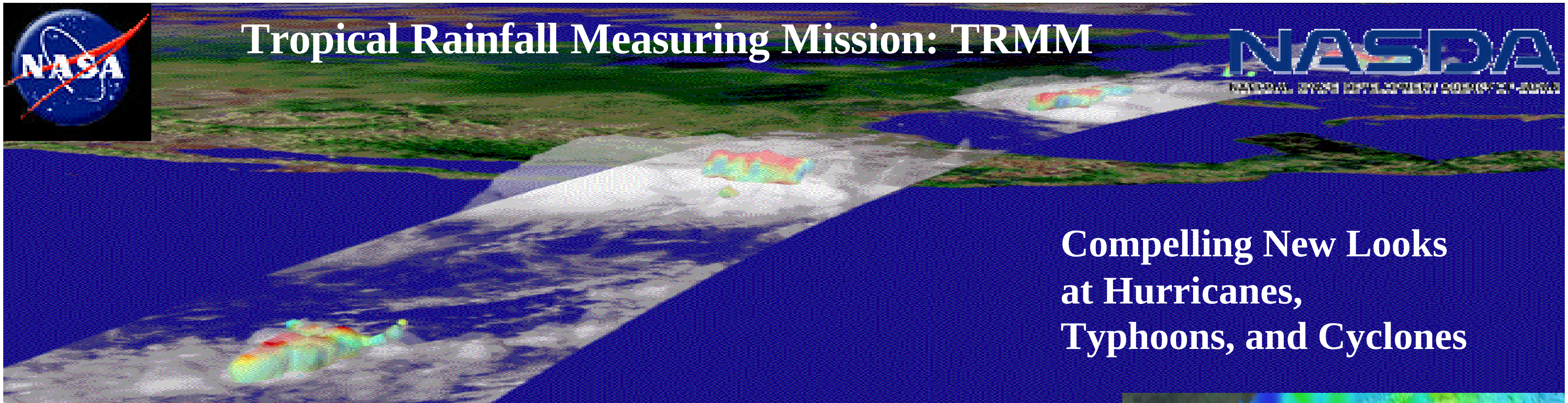


High-resolution SST measurements through clouds from TMI data provided early detection of the 1998 La Nina and instability waves (Wentz, ***Science*** 1999)

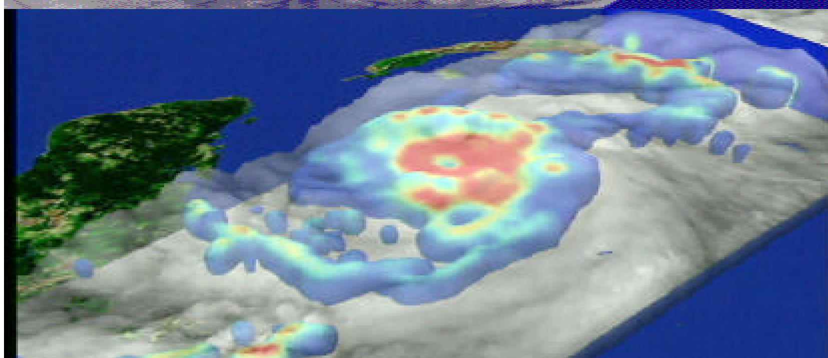


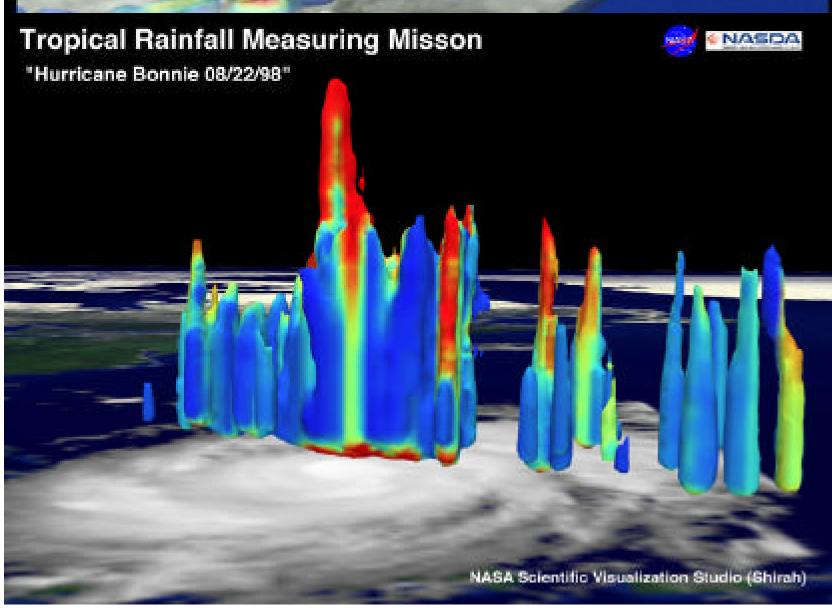
High-resolution SST measurements illustrated the deleterious effect of Hurricane Bonnie's cold wake on the development of Hurricane Danielle

Tropical Rainfall Measuring Mission: TRMM

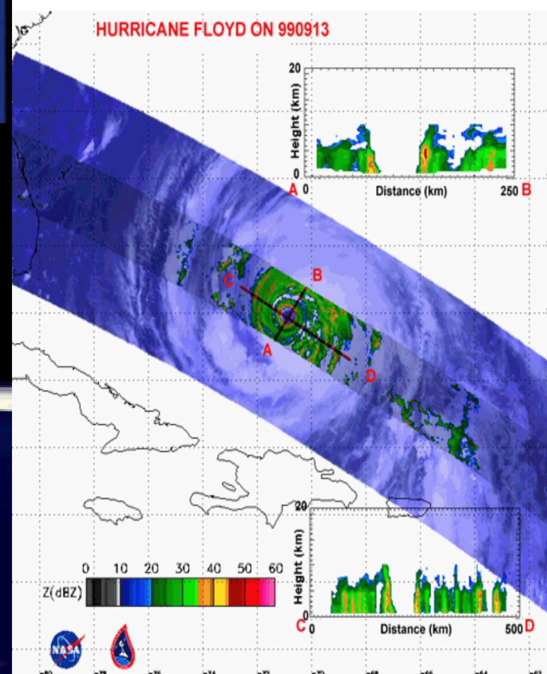


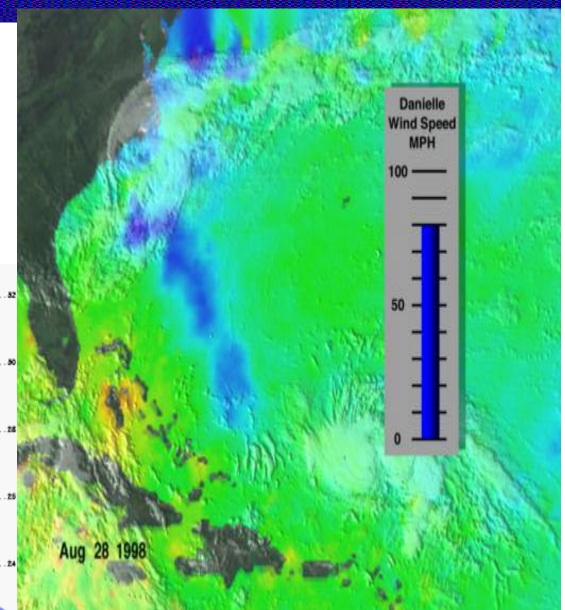
Compelling New Looks at Hurricanes, Typhoons, and Cyclones





TRMM has observed the inner structure of natural hazards like hurricanes Mitch, Bonnie, and Floyd.



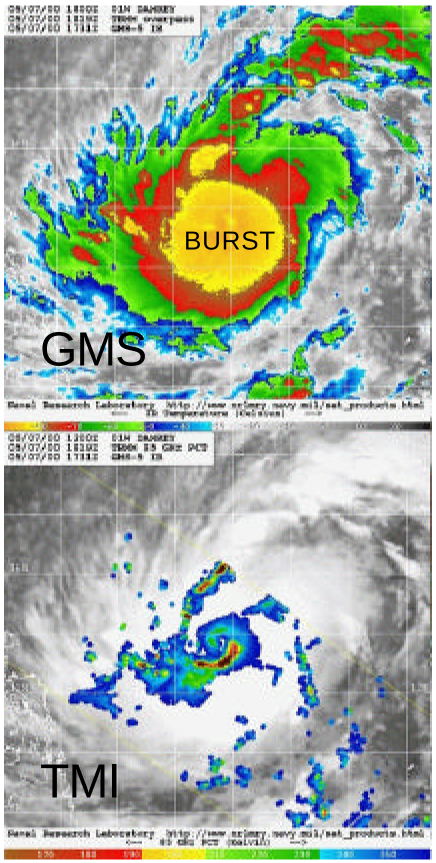


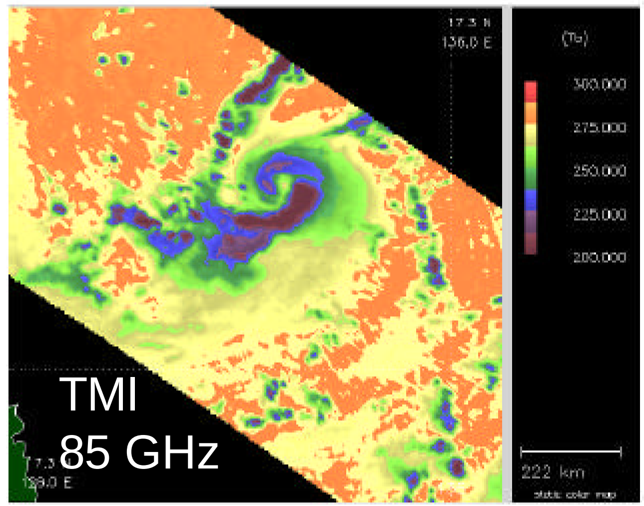
TRMM even provides measurement of sea surface temperature in cloudy tropical cyclone environments.

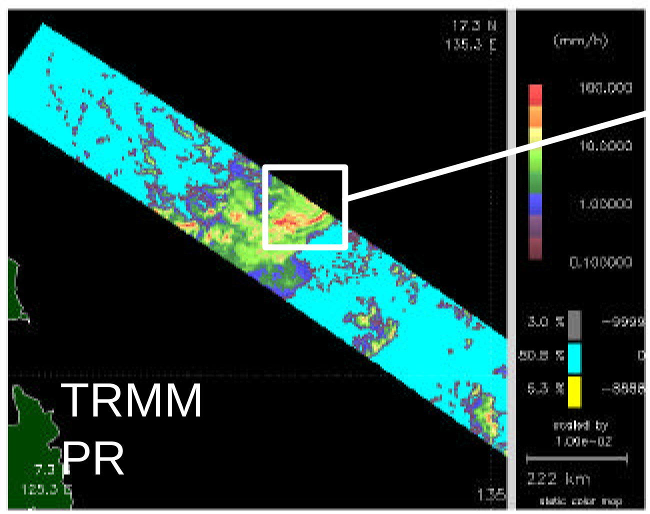
TRMM Views the Anatomy of a Convective Burst

Genesis of STY Damrey (WPAC, 7 May 2000)

Within the center of the convective burst, an intense spiral rainband wraps up into a nearly closed eyewall.

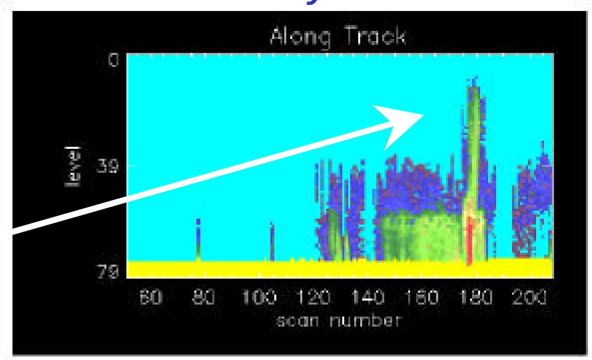






The nascent eyewall features several "chimney clouds", some towering to 18-19 km, and spiraling in toward the center.

Chimney Cloud



Next Step: Compute vertical profiles of latent heat release in the young eyewall.

J. B. Halverson, JCET UMBC

TRMM Workshop. June 18-19, 2001. Boulder, CO.

Summary of TRMM Mission Success

- TRMM science success/*remaining questions or issues*

  3-year rainfall "climatology"/*TRMM algorithms differ by 20%; climatology weighted by La Nina*

  El Nino to La Nina transition monitored/ *TRMM algorithms differ in trend of total tropical rain--implications for hydro. cycle acceleration*

  Improved climate simulations/*implementation in routine global modeling ongoing*

  Improved hurricane and flood analysis and forecasting/*operational transition and testing*

  Aerosol and pollution link to rain/*validation, variations, monitoring*

Science Impact of Shortened Mission

- Critical shortening of climatological record by 1/3
- Lack of El Nino and neutral conditions for comparison
- Loss of critical hurricane analysis and forecasting cases for statistical comparison
- Shortened record of TRMM input into NASA global model-based analysis with TERRA and AQUA data
- Loss of overlap with CLOUDSAT and other data
- Loss of monitoring pollution/precipitation relation

TRMM Real-Time Use in Operations

- In addition to scientific research, TRMM data is used by operational weather agencies in U.S. and internationally and quasi-operational university activities
- Real-time data is available from TSDIS at Goddard; about 20 users (e.g., National Hurricane Center (NHC), Joint Typhoon Warning Center (JTWC), Aviation Weather Center (AWC), European Center for Medium Range Forecasting (ECMWF)
- TRMM data used in analysis and forecasting of hurricanes, typhoons, floods and aircraft turbulence throughout the tropics (~25,000 people die annually due to windstorms and floods in tropics)-*World Disasters Report 2000*

Specific Impacts of Shortened TRMM Mission Related to Injury and Loss of Life

- Loss of improved and earlier identification of tropical cyclones (definition of closed circulation) and improved definition of tropical cyclone locations due to TRMM's higher spatial resolution and additional views (NWS/NHC, USN-AF/JTWC)
- Loss of improved numerical forecasts of hurricane track and intensity due to lack of TRMM rainfall information (FSU, ECMWF, NCEP)
- Loss of improved numerical forecasts of floods due to lack of TRMM rainfall information (FSU , ECMWF, NCEP)
- Loss of lightning data used for aircraft routing over Pacific (NWS/AWC)
- Loss of TRMM radar data for calibration of operational radars
- Loss of improved monitoring of floods and droughts for disaster relief planning
- Loss of improved seasonal to interannual forecasts due to improved global analyses, in turn due to TRMM data

Comments from Users of TRMM Real-Time Data

- "JTWC has been using TRMM data since 1998. On several occasions, TRMM passes over a TC led to storm relocation and changes in intensity for our typhoon warnings. JTWC and the Air Force Weather Agency, which also provides fixes for our AOR, combined to issue over 150 real-time TRMM fixes worldwide during 2000. TRMM data is integral to JTWC's TC reconnaissance and warning mission. We'd like to have this data available as long as possible." Lt. Col. Mark Zettlemoyer (Director, Joint Typhoon Warning Center)
- "Many times, TRMM data proved to be the main tool used to properly locate/relocate the center of tropical cyclones in both the Northeast Pacific and Atlantic basins in areas beyond the range of aircraft reconnaissance. I could cite many cases about how valuable TRMM is/was and how it was used in location and intensity analyses….. The bottom line is that TRMM data is used to a great extent in NHC TC forecasting operations and also by the Tropical Analysis and Forecast Branch (TAFB) forecasters in preparation of high seas forecasts and tropical weather discussions." Max Mayfield(Director, National Hurricane Center); Stacy Stewart (Hurricane Specialist/Warning coordinating Meteorologist, NHC)

Quantification of Impact of TRMM Operational Data on
Tropical Cyclone Mortality in Tropics
(Preliminary Calculation)

- Decrease in deaths related to decreased error in hurricane track forecasts using U.S. data over last 50 years (Willoughby, 2000; McAdie and Lawrence, 1998; Neuman, 1981)
- Assume very conservative (and scalable) 1% improvement in 24-48hr track forecast due solely to TRMM (improved initial locations; assimilation of rainfall info.) [NHC, JTWC, Krishnamurti et al. (2000, 2001] (actual number may be 5%)

(89% decrease in mortality)*(0.5 due to forecast)*(1% error reduction due to TRMM) = 1.6%
(28% decrease in 24 hr error)

- Result is conservative 1.6% decrease in mortality rate for tropical cyclones due to TRMM

Quantification of Impact of TRMM Operational Data on Tropical Cyclone Mortality in Tropics
(Preliminary Calculation)
(cont.)

- Average of 15,000 deaths/year due to tropical cyclones during 1990's (World Disasters Report 2000 has 20,000 global windstorm deaths)

  1.6% * 15,000 deaths/year= 240 lives/year
- Result: estimate of 240 lives/year saved through use of TRMM data in tropical cyclone forecasts
- Calculation has large uncertainty and uncertain cause/effect relations
- Separate calculation can be done for non-cyclone flooding

Summary of Impacts of Shortened TRMM Mission

- Significant science loss in critical length of record, monitoring ENSO/climate relations, statistically important number of cases, monitoring floods and drought, and unique overlap with Aqua and Cloudsat
- Loss of life and property due to TRMM's absence, related to tropical cyclones, floods and climate forecasting

Tropical Rainfall Measuring Mission

TRMM

Summary and Future

Summary:

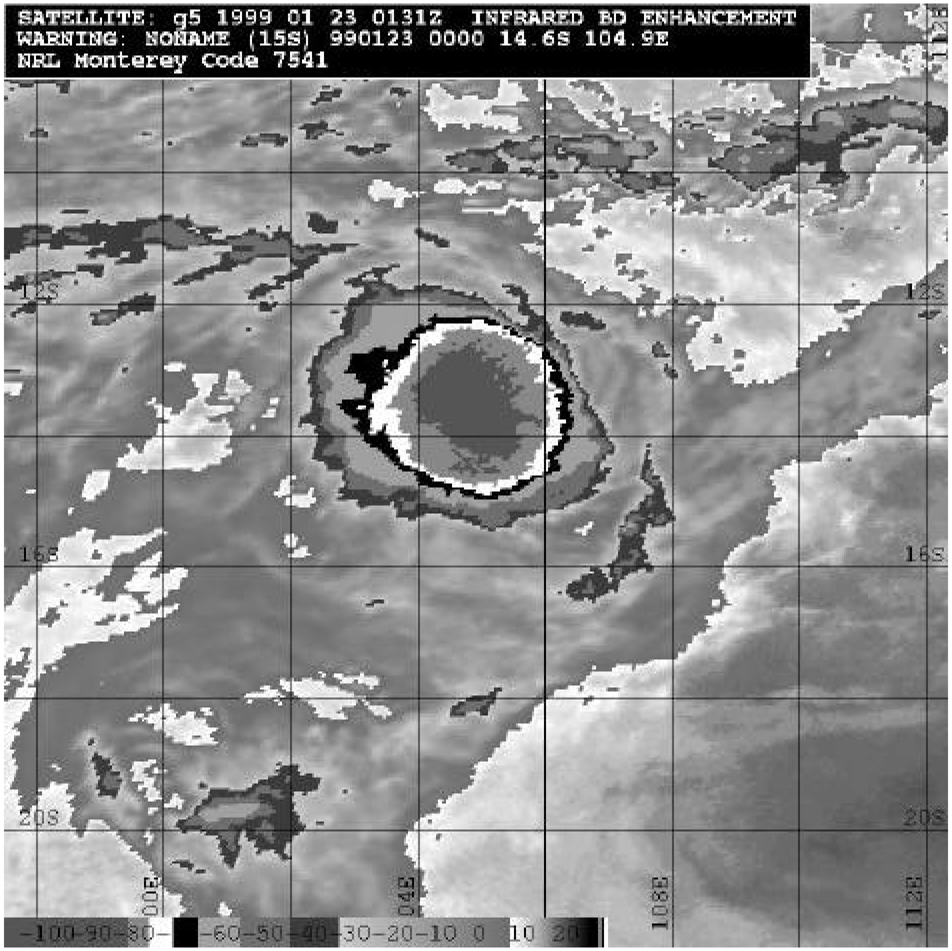
- TRMM has contributed significant knowledge related to the climatology and variation of rainfall, has improved climate and weather simulations, and imroved our understanding of the mesoscale structure of storm systems and the physics of precipitation
- TRMM has also unexpectedly contributed significant information related to operational tropical cyclone analysis and warning, improved monitoring of SST in cloudy and cloud-free environments,and relations between pollution and rainfall.

Future:

- The TRMM rainfall estimates will likely converge to a physically consistent set that will form the basis for reanalysis of the long-term set of satellite rain estimates.
- TRMM is moving to finer time scale (3-hr) rainfall analysis related to possible follow-on missions, *i.e.*, the Global Precipitation Mission (GPM).
- Still much to do and the length of record is important; therefore, we need to keep TRMM flying as long as possible.

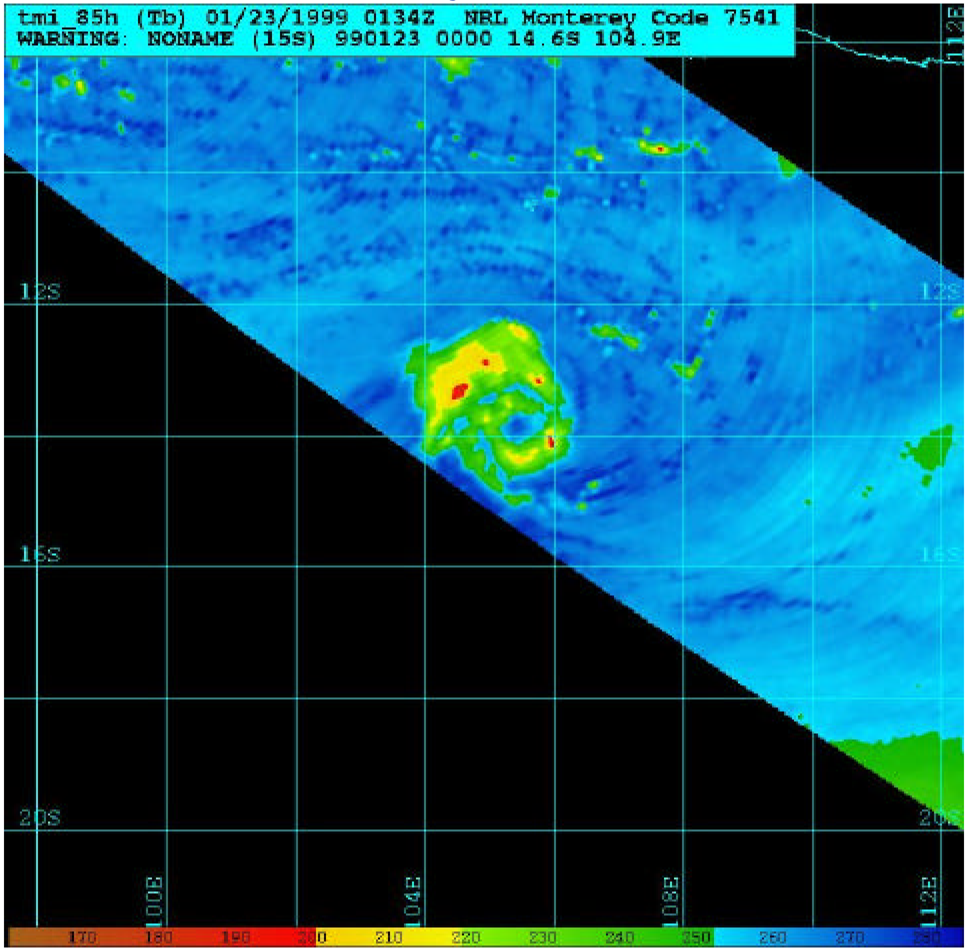
TRMM Microwave Imagery Relocated Tropical Cyclone Position - JTWC

Central Dense Overcast



Dvorak IR Enhanced GMS-5 Image

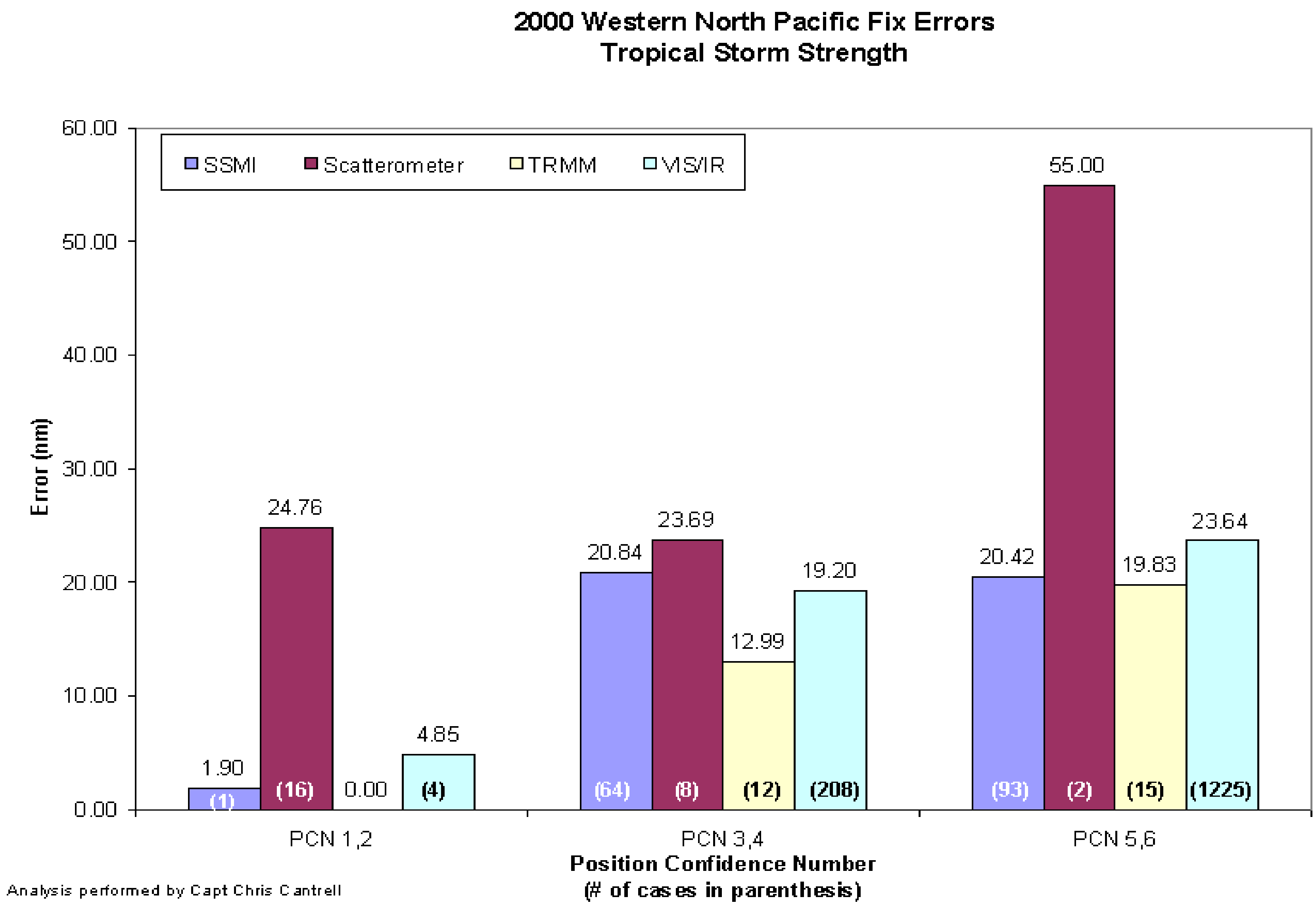
Enclosed Eye with Bands

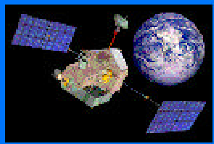


TMI 85 GHz Image: 2 minutes after GMS-5 Image

TRMM data courtesy of NASA/GSFC

Analysis Provided by U.S. Navy/Air Force Joint Typhoon Warning Center





TRMM Data Assimilation for Climate Research

PI: Arthur Y. Hou ***NASA Goddard Space Flight Center***

Assimilation of TMI rainfall and total precipitable water observations improves the hydrologic cycle, clouds, and radiation in global analysis

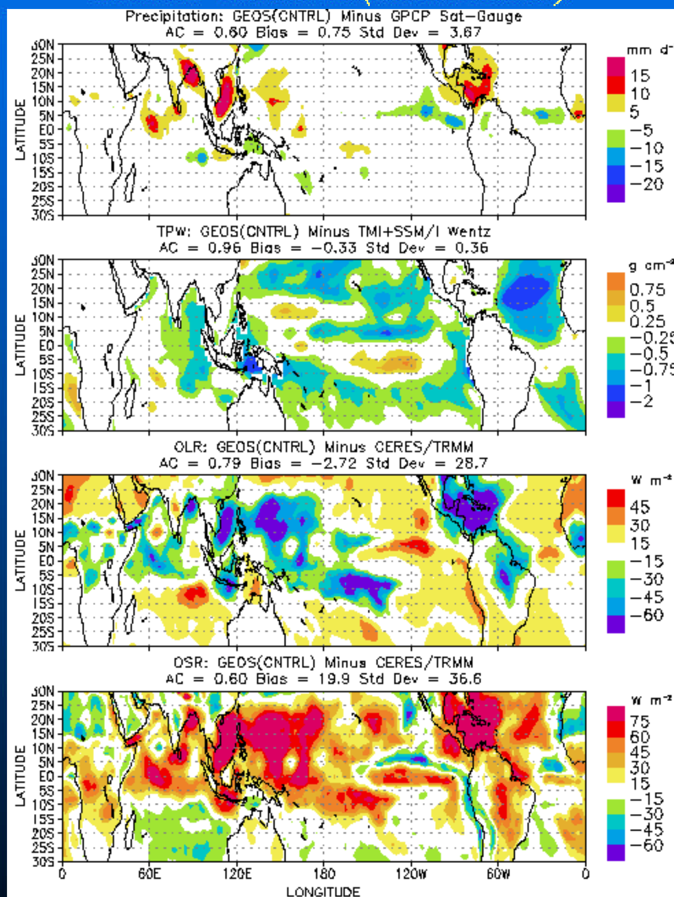
GEOS control (June 1998) | *TMI+SSM/I rainfall and TPW assimilation*

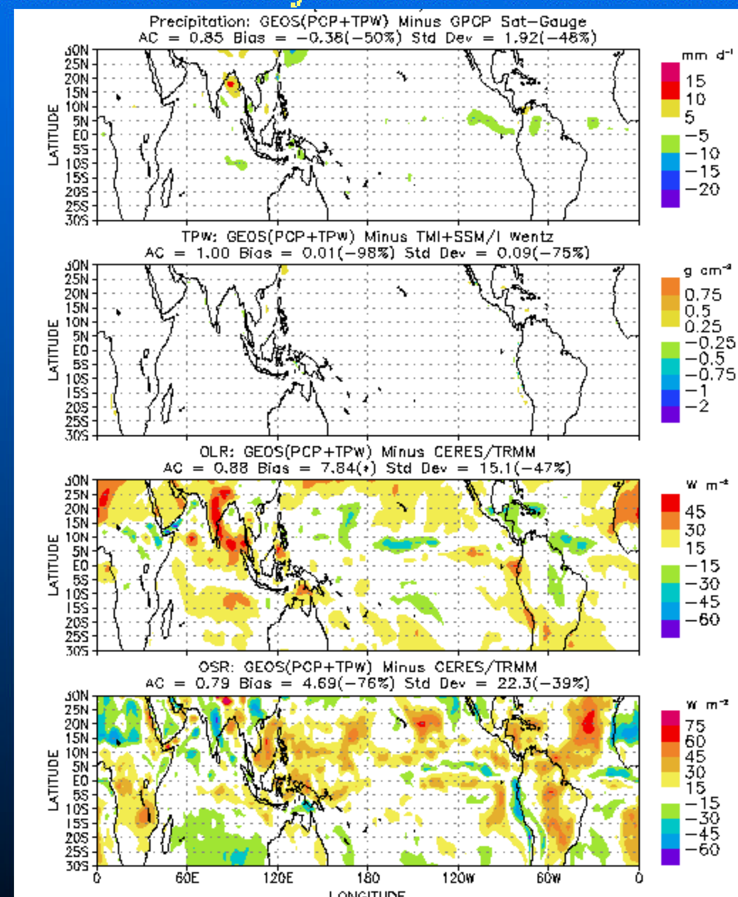
Rainfall minus GPCP

TPW minus Wentz

OLR minus CERES

IR Cloud Forcing minus CERES





1

TRMM Mission Life Increase by Boosting to 400 km

Nominal Schatten Predicts