Observing Precipitation with Radars in Space

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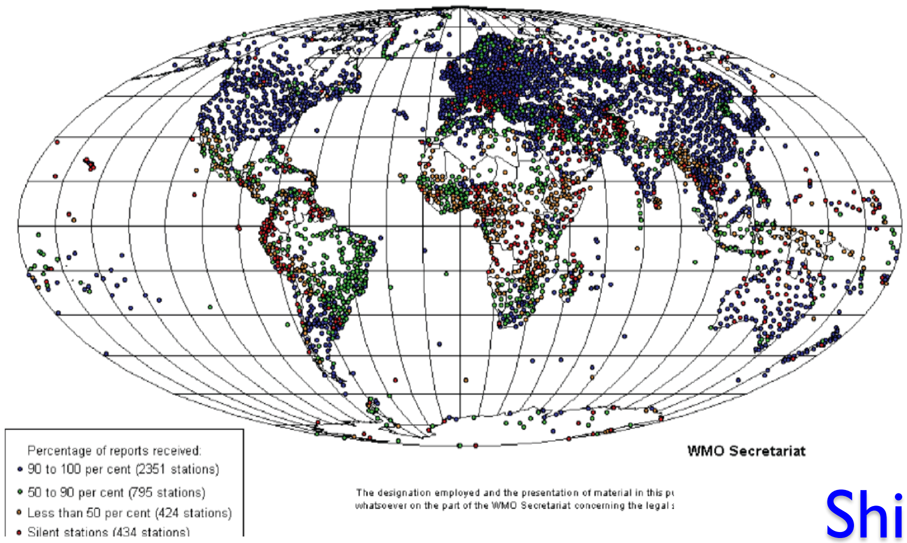
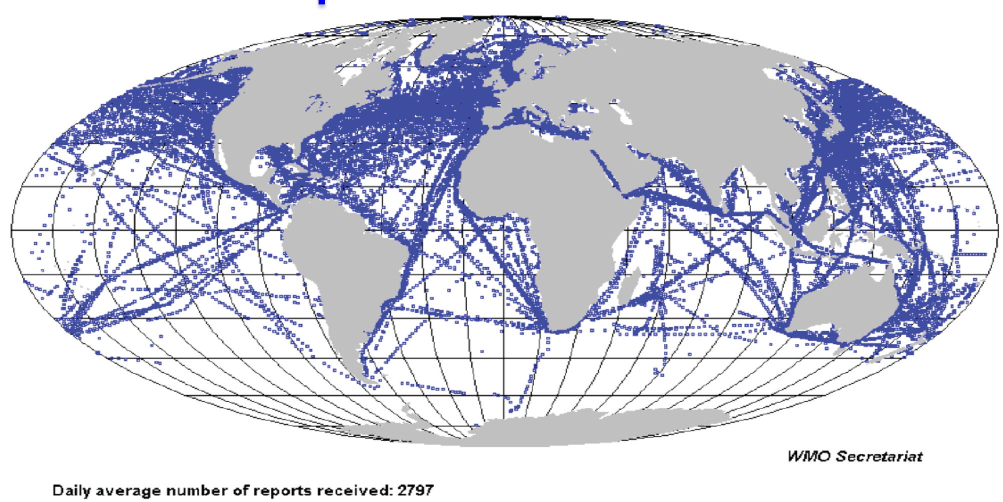
Why Measure from Space?

Surface Observations

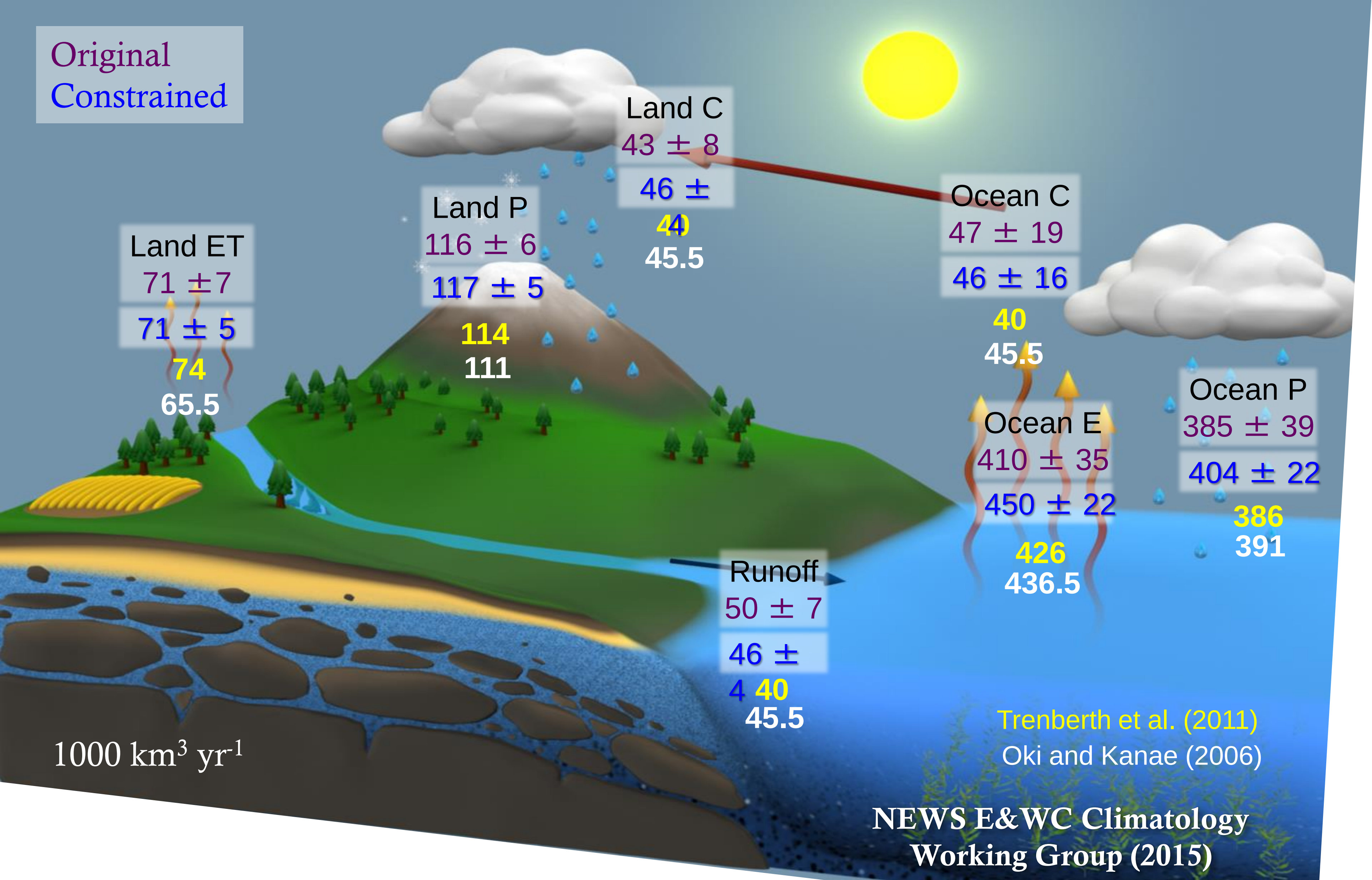


Ship Observations



Specific Applications

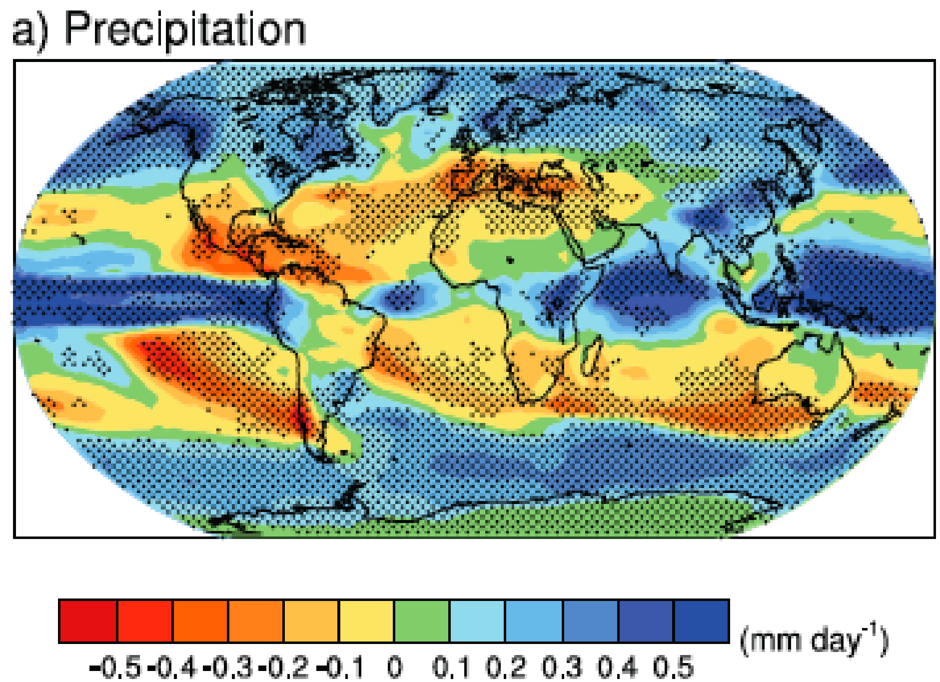
- ✓ Documenting the Global Energy and Water Cycles
- ✓ Monitoring and Predicting Climate Change
- ✓ Understanding Precipitation Processes
- ✓ Forecasting

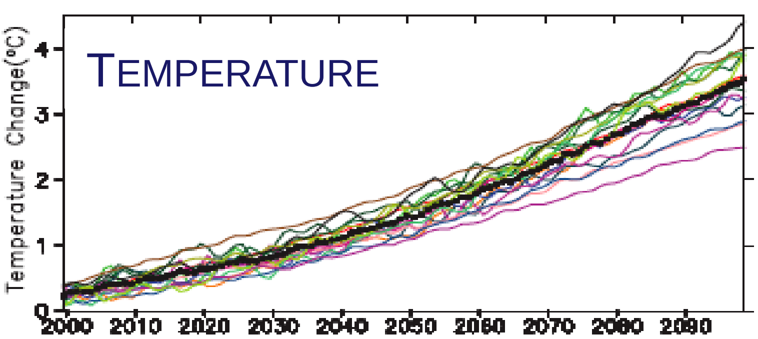


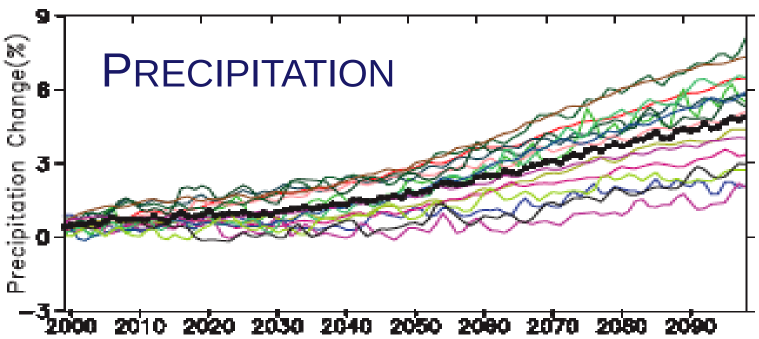
Precipitation is a central player in the Earth's water cycle balancing evaporative losses from the surface.

Rodell et al, *J. Climate* (2015)

Testing Predicted Changes

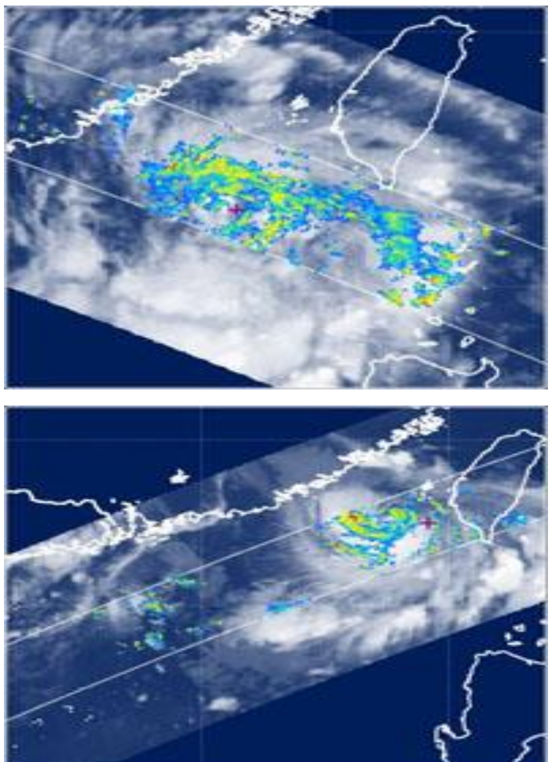




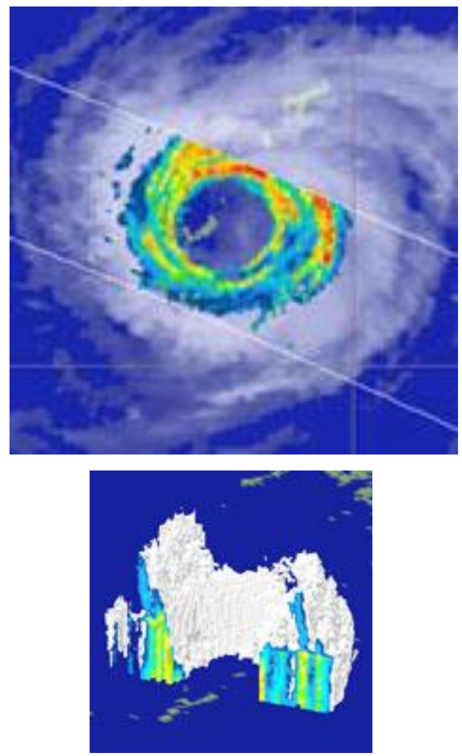


Life-cycle of Tropical Cyclones

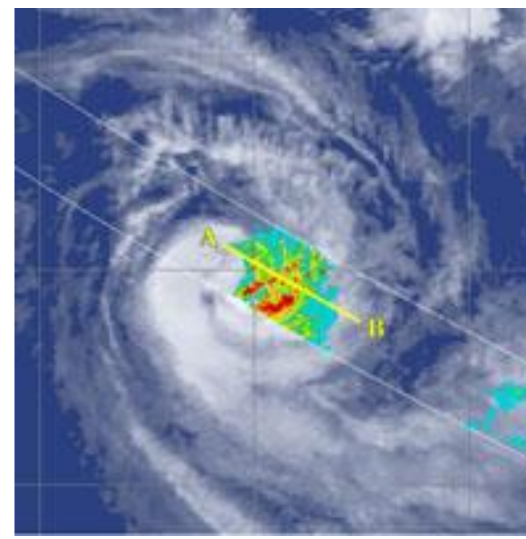
- Satellites provide snapshots of tropical cyclones at various stages in their life-cycle most of which occurs over oceans



Developing

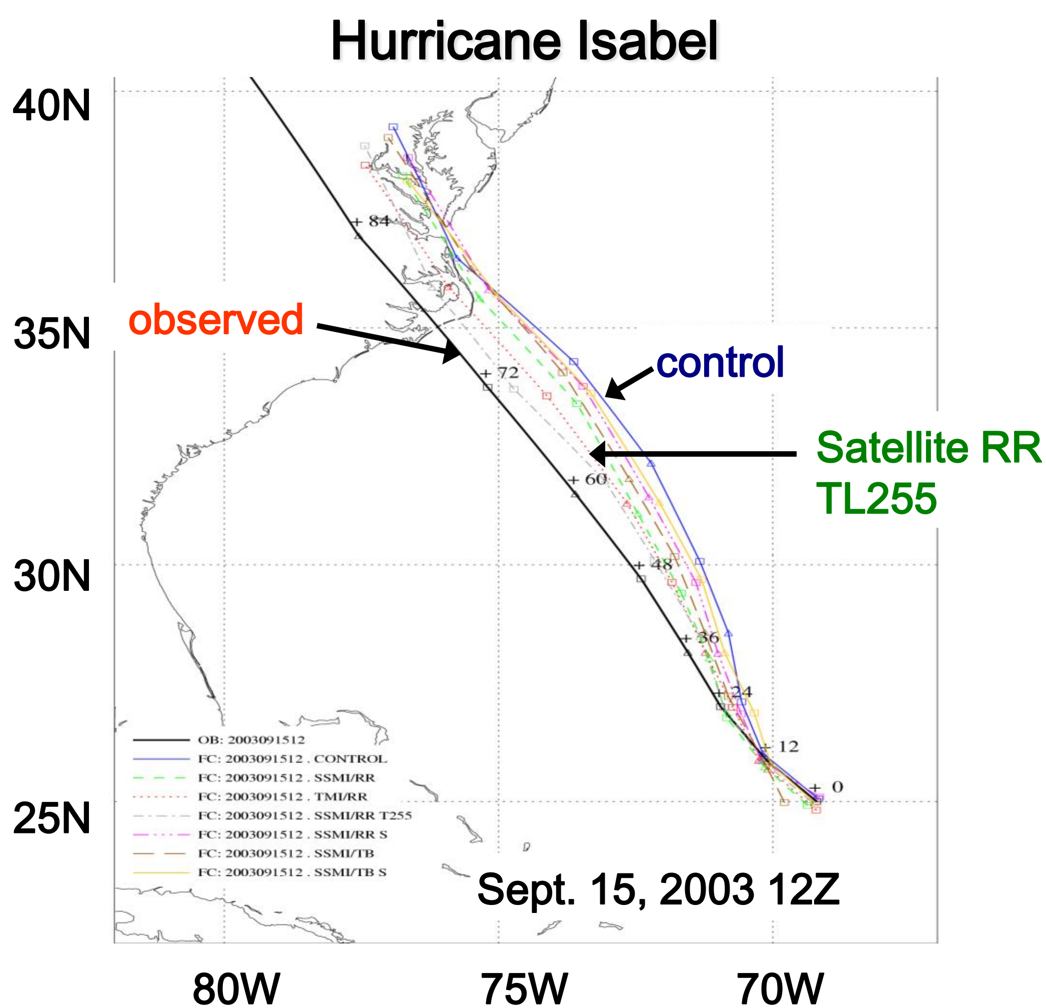


Mature



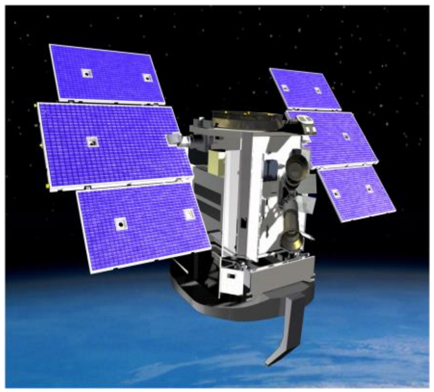
Decaying

Improving Cyclone Forecasts

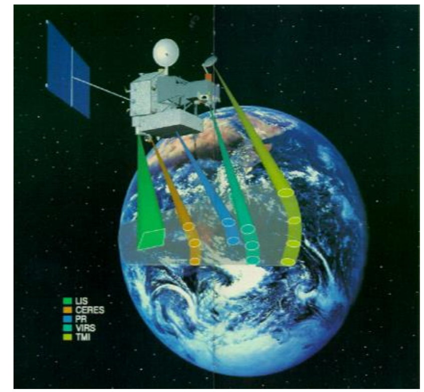


Pioneering Satellite Radar Missions

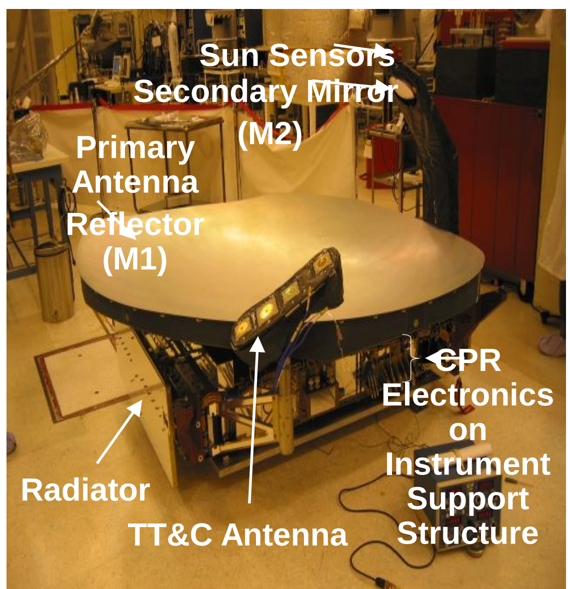
CloudSat

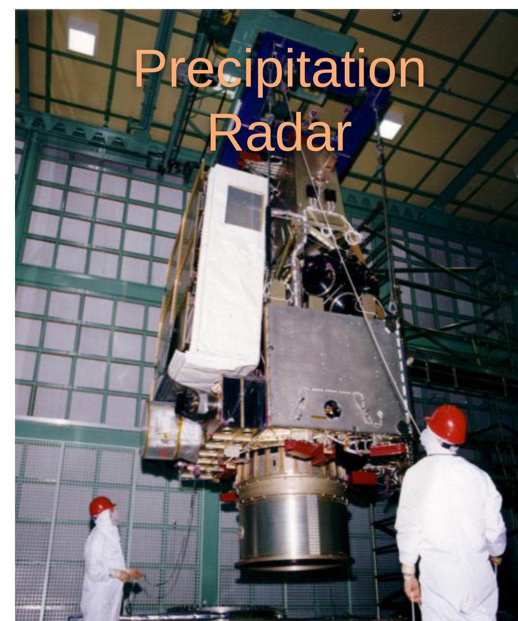


TRMM



Cloud Profiling Radar





Advantages

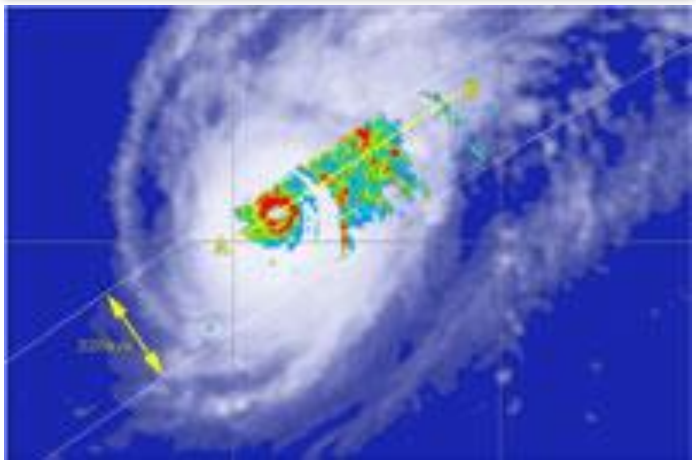
- Advantages relative to ground-based radars:
  - Spatial coverage
  - Access to remote/challenging regions (eg. oceans, jungles, ice sheets, mountains, etc.)
  - No beam-blockage or significant range effects
  - Uniform global calibration
- Advantages relative to conventional space-borne sensors:
  - Higher spatial resolution
  - Very high sensitivity
  - More direct measurement of microphysical parameters and less sensitive to underlying surface than passive microwave

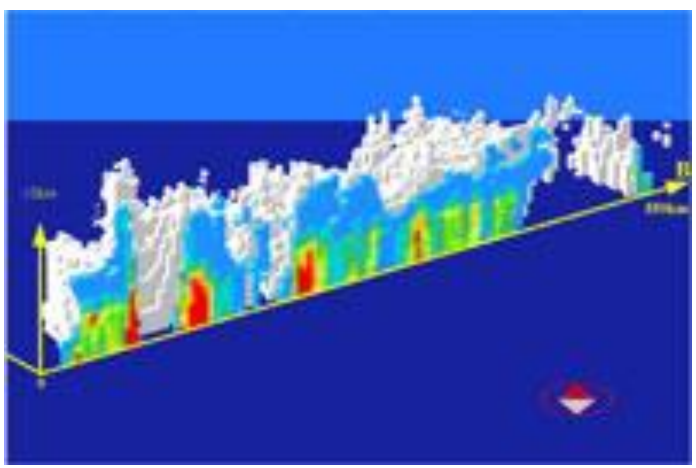
Disadvantages

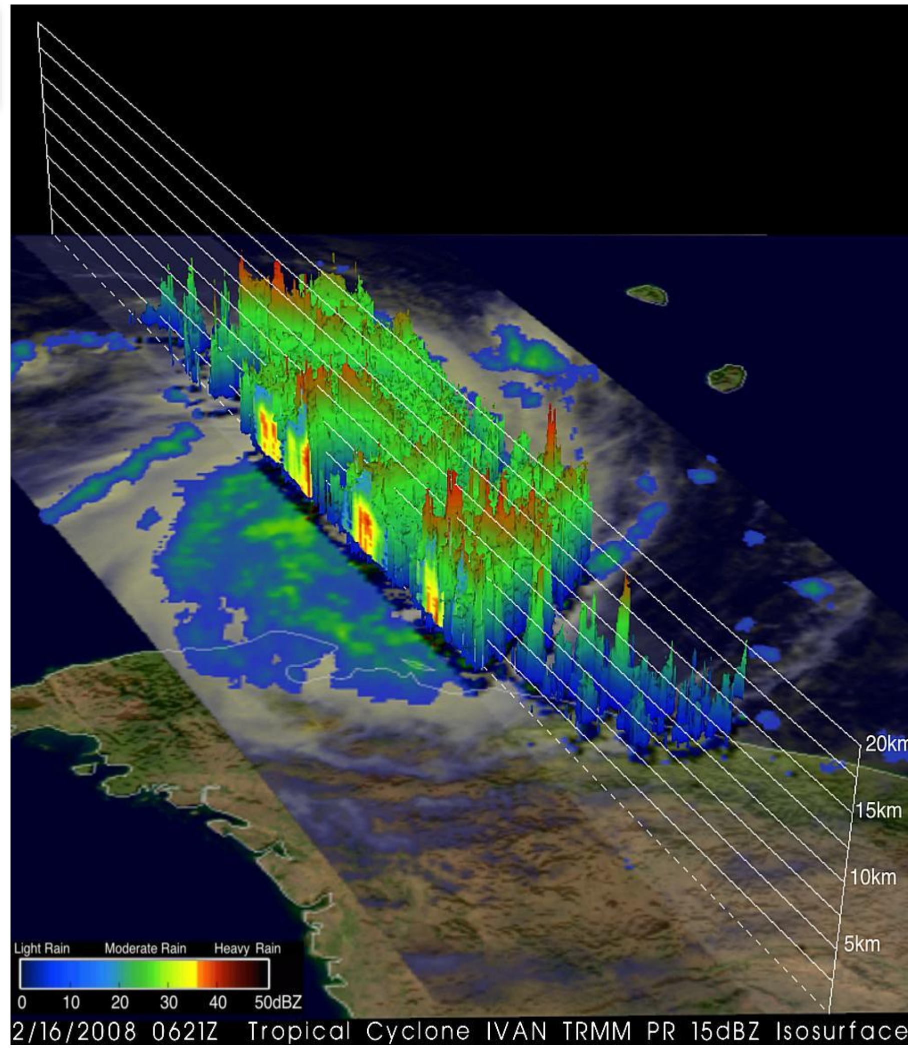
- Single frequency and, unlike ground radars, no Doppler and no polarization is currently available
- Limited time sampling
  - Crude temporal sampling due to polar orbit
  - Narrow swath due to rapid movement of satellite and SNR requirements
- Strong attenuation in rainfall

TRMM Precipitation Radar (14 GHz) Storm Vertical Structure

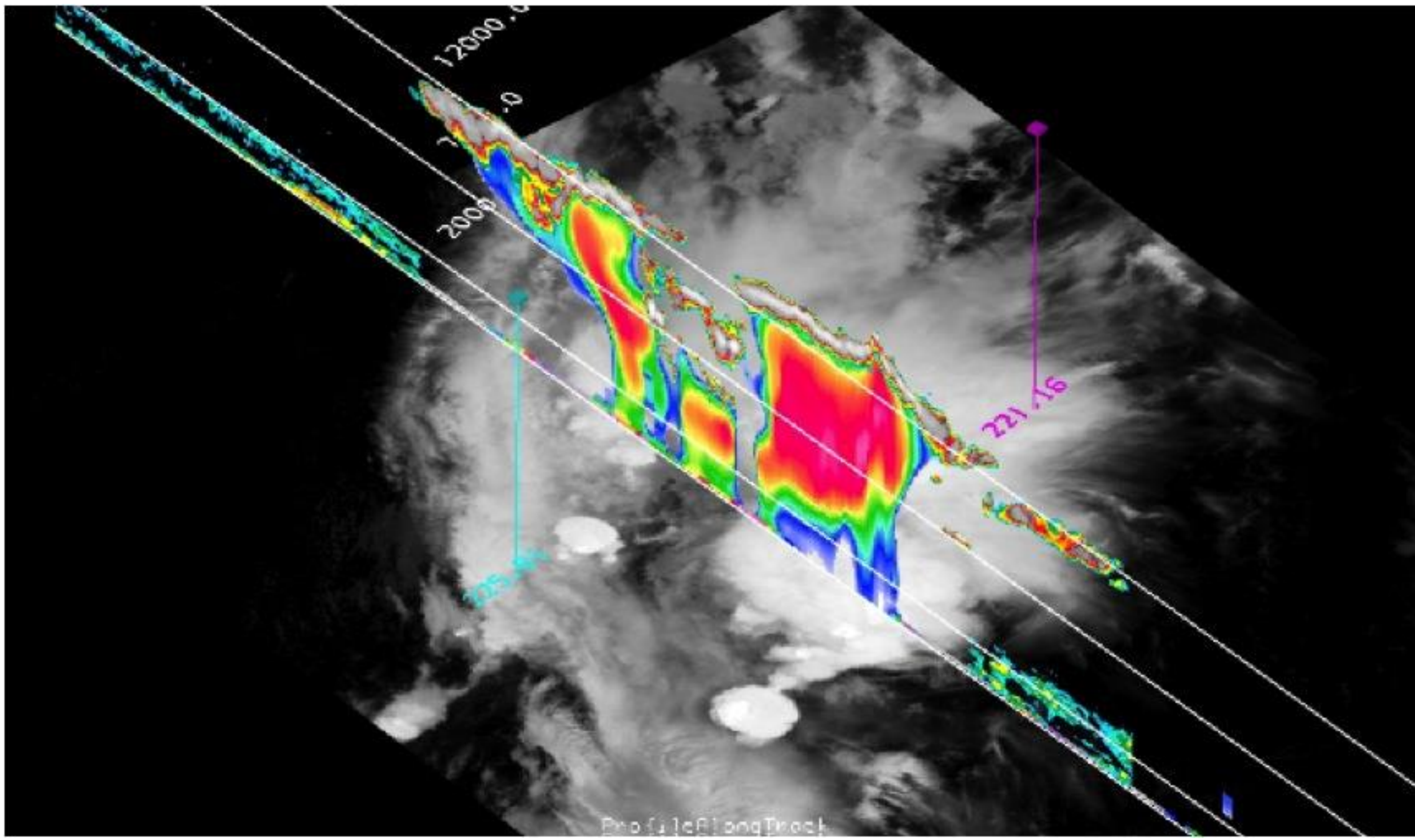
Typhoon Paka (1997)



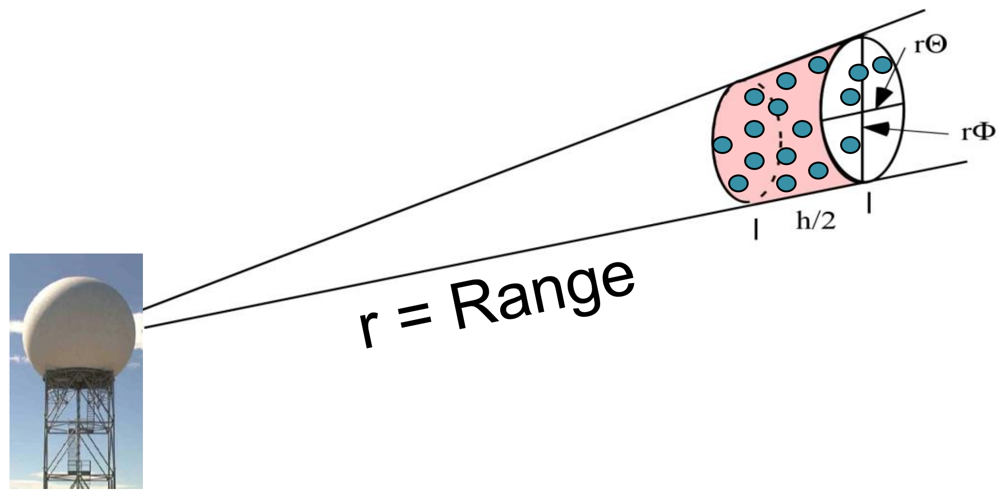




CloudSat Cloud Profiling Radar (94 GHz) Cloud Vertical Structure & Light Rain

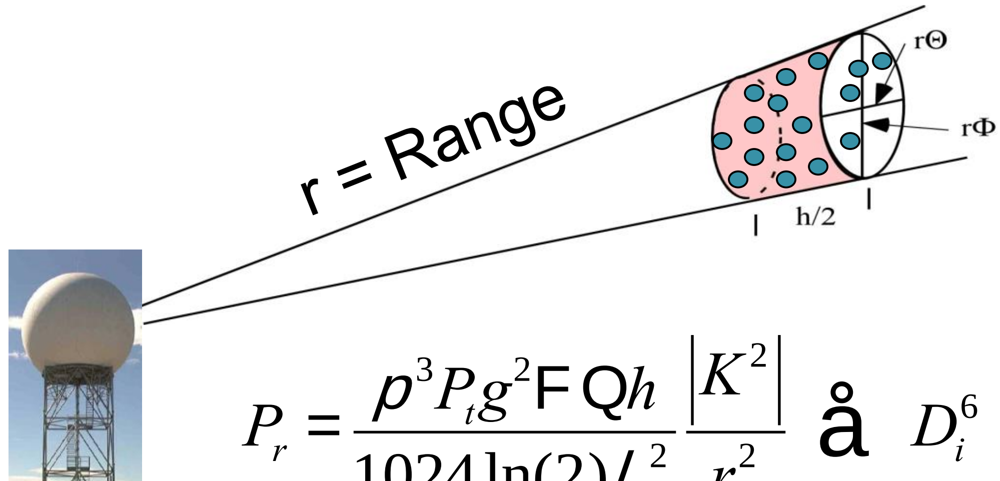


Interpreting the Measurements



$$P_r = \frac{\pi^3 P_t g^2 \Theta \Phi h}{1024 \ln(2) \lambda^2} \frac{|K|^2}{r^2} \sum_{\substack{Unit \\ Volume}} D_i^6$$

The Relationship Between Z and R

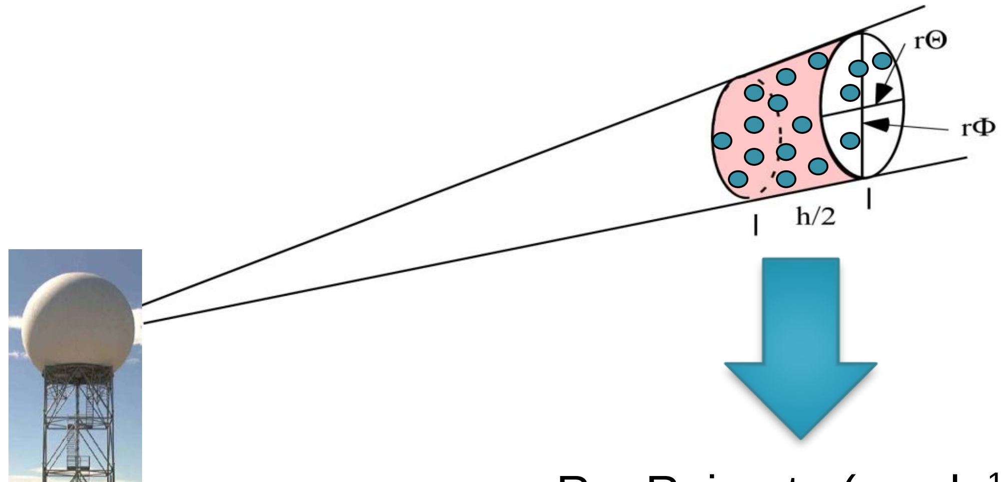


$$P_r = \frac{\pi^3 P_t g^2 \Phi \Theta h}{1024 \ln(2) \lambda^2} \frac{|K^2|}{r^2} \sum_{\substack{Unit\\Volume}} D_i^6$$

$$z = \sum_{\substack{Unit\\Volume}} D_i^6 = c P_r r^2 \qquad c = \frac{1024 \ln(2) \lambda^2}{|K^2| \pi^3 P_t g^2 \Phi \Theta h}$$

r = 0.5 c Δt where Δt is the time delay between transmitting and receiving the pulse

The Relationship Between Z and R



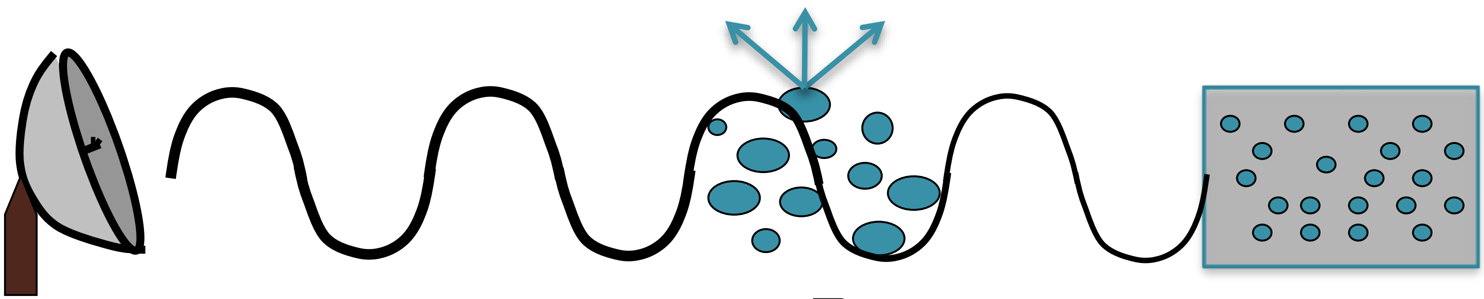
R = Rainrate (mm h^{-1})

$$z = \sum_{\substack{Unit\\Volume}} D_i^6 = c P_r r^2 \qquad c = \frac{1024 \ln(2) \lambda^2}{|K^2| \pi^3 P_t g^2 \Phi \Theta h}$$

$$N(D) = N_0 e^{-\Lambda D} \Rightarrow z = aR^b$$

Attenuation

- Atmospheric gases and hydrometeors also absorb and scatter radiation out of the radar beam as it propagates from the radar to the target volume and back.

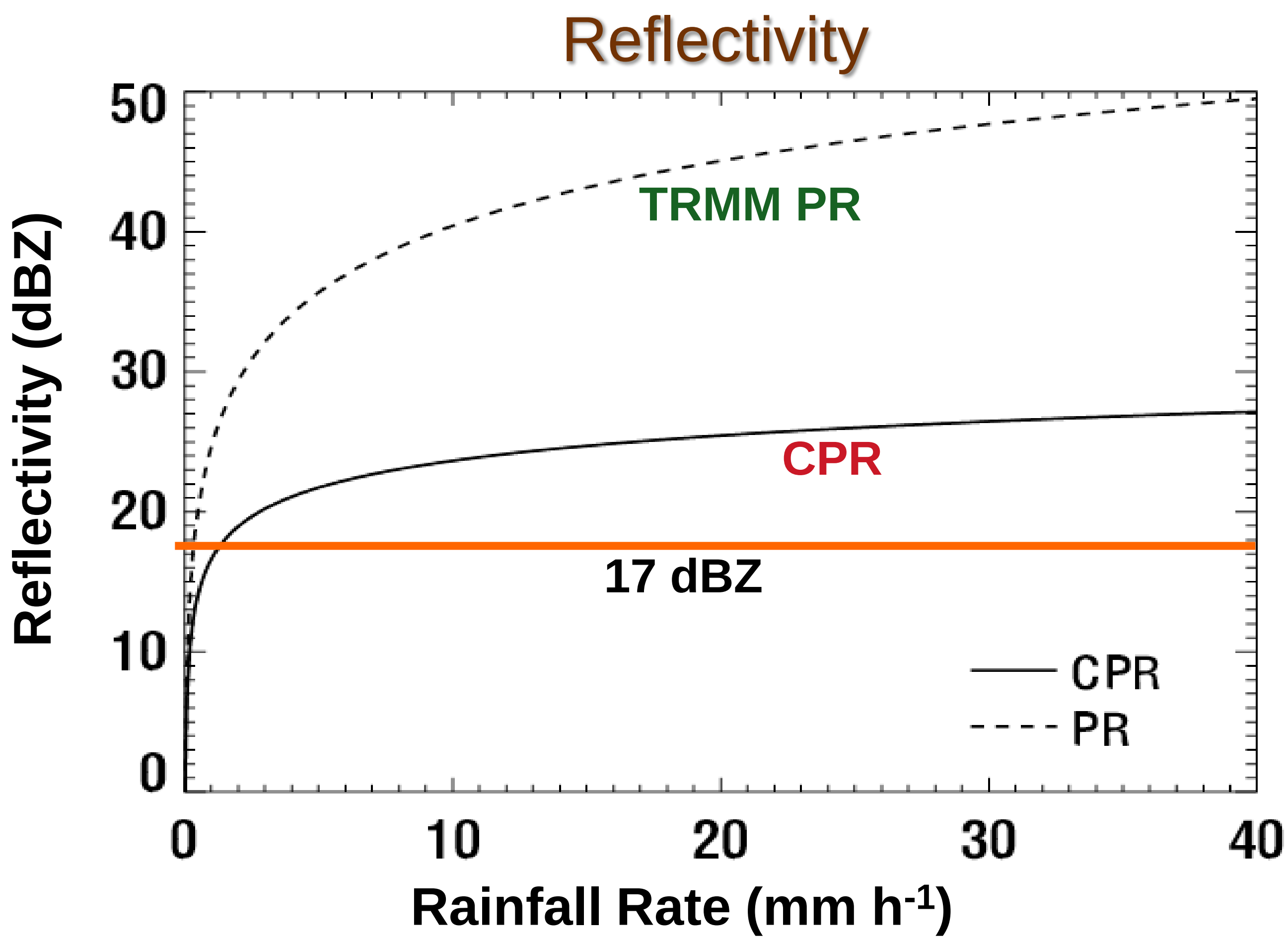


$$P_r = P_{r0} e^{-2\sum k_l \Delta R}$$

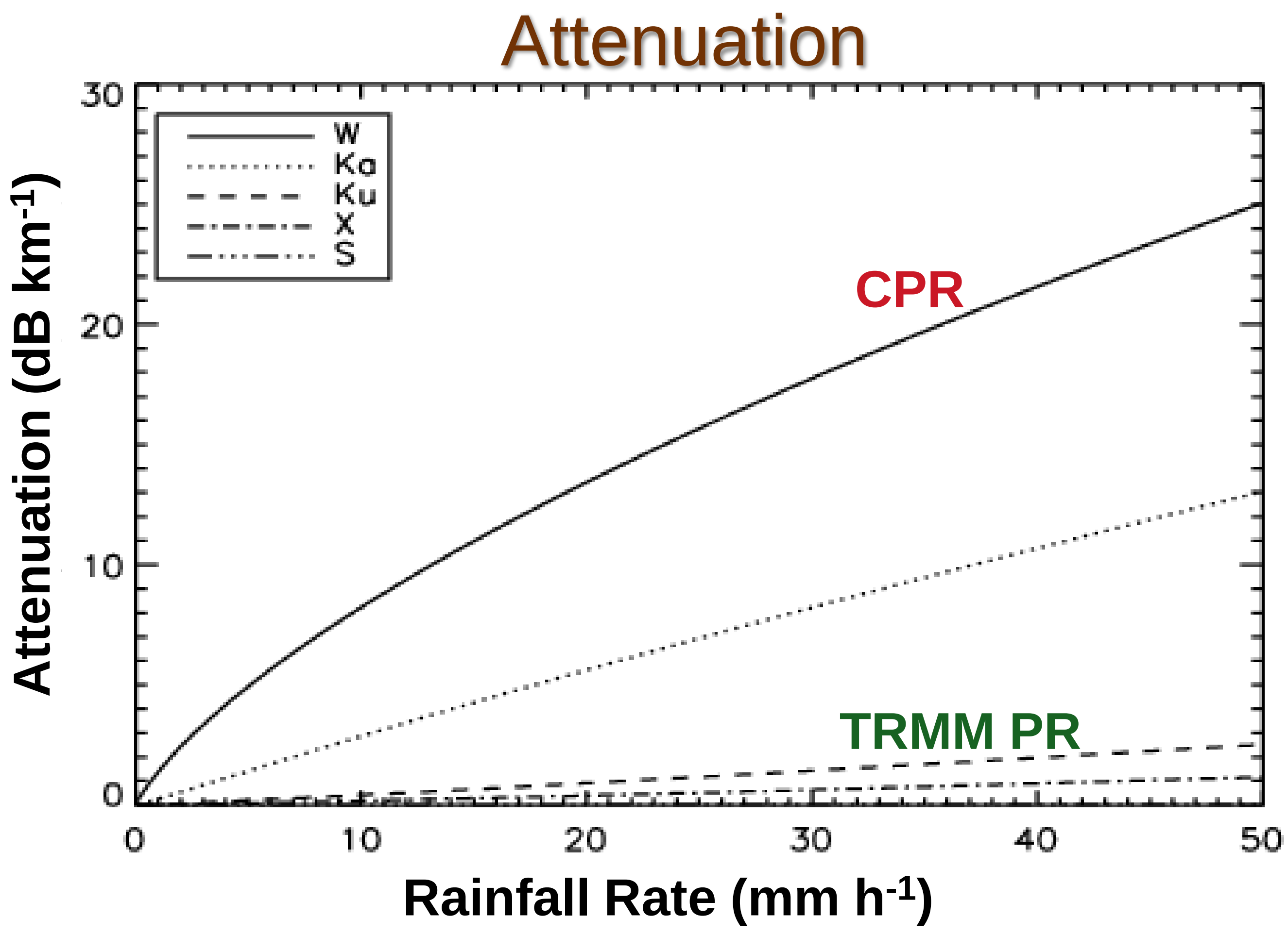
$$z = cP_r R^2 = cR^2 P_{r0} e^{-2\sum k_l \Delta R} = z_0 e^{-2\sum k_l \Delta R}$$

- κ_l is the attenuation coefficient expressed in dB per km
- Attenuation increases with increasing frequency (or decreasing wavelength) and is, therefore, important for all satellite radars

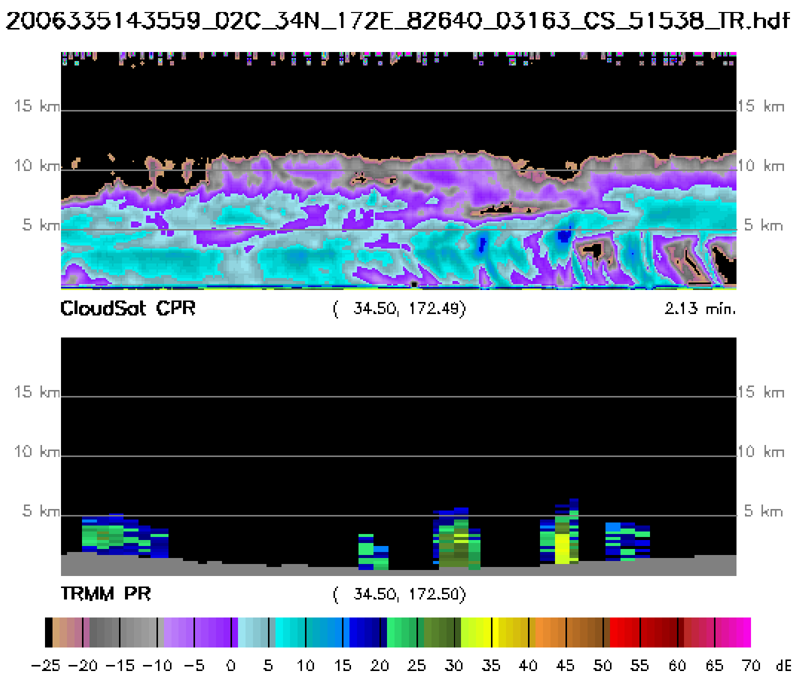
Reflectivity

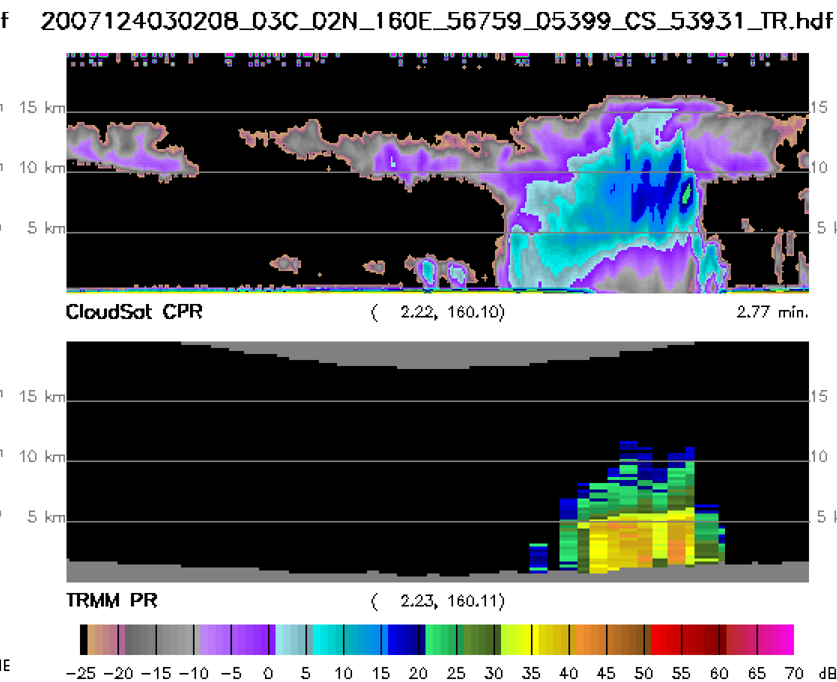


Attenuation



Comparing CloudSat and TRMM

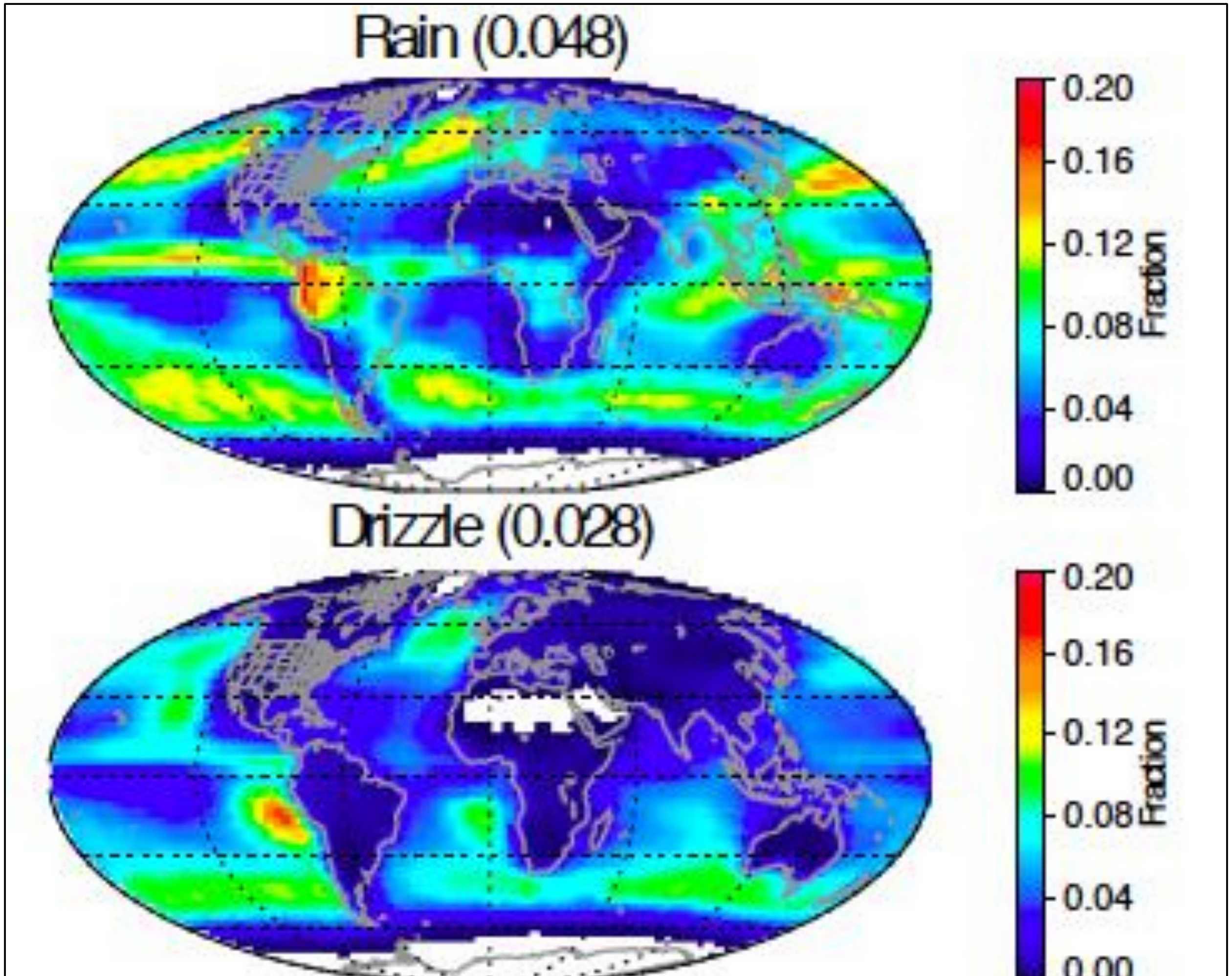




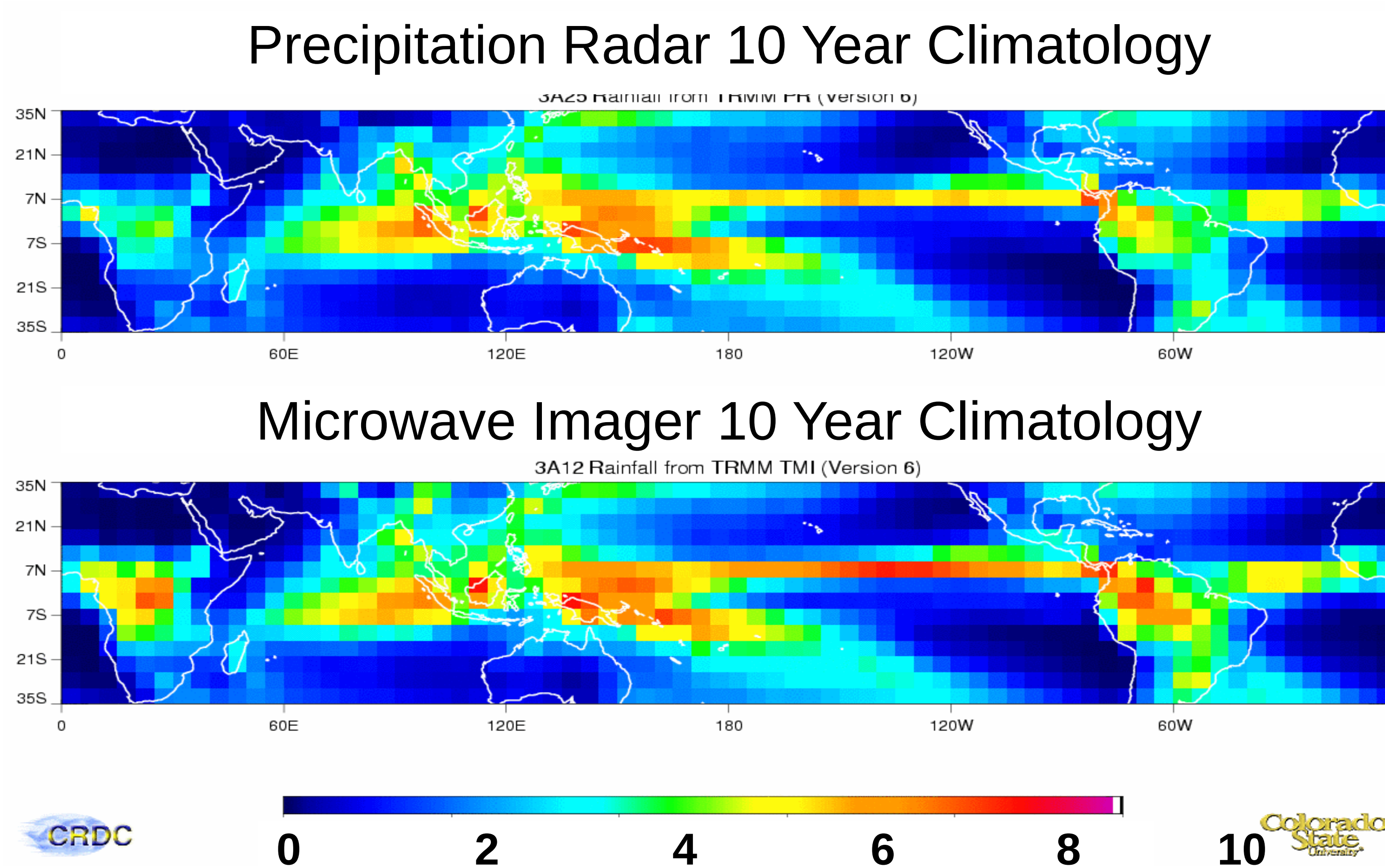
Courtesy: K.-S. Kuo, H. Carty, and E. Smith

A Few Highlights

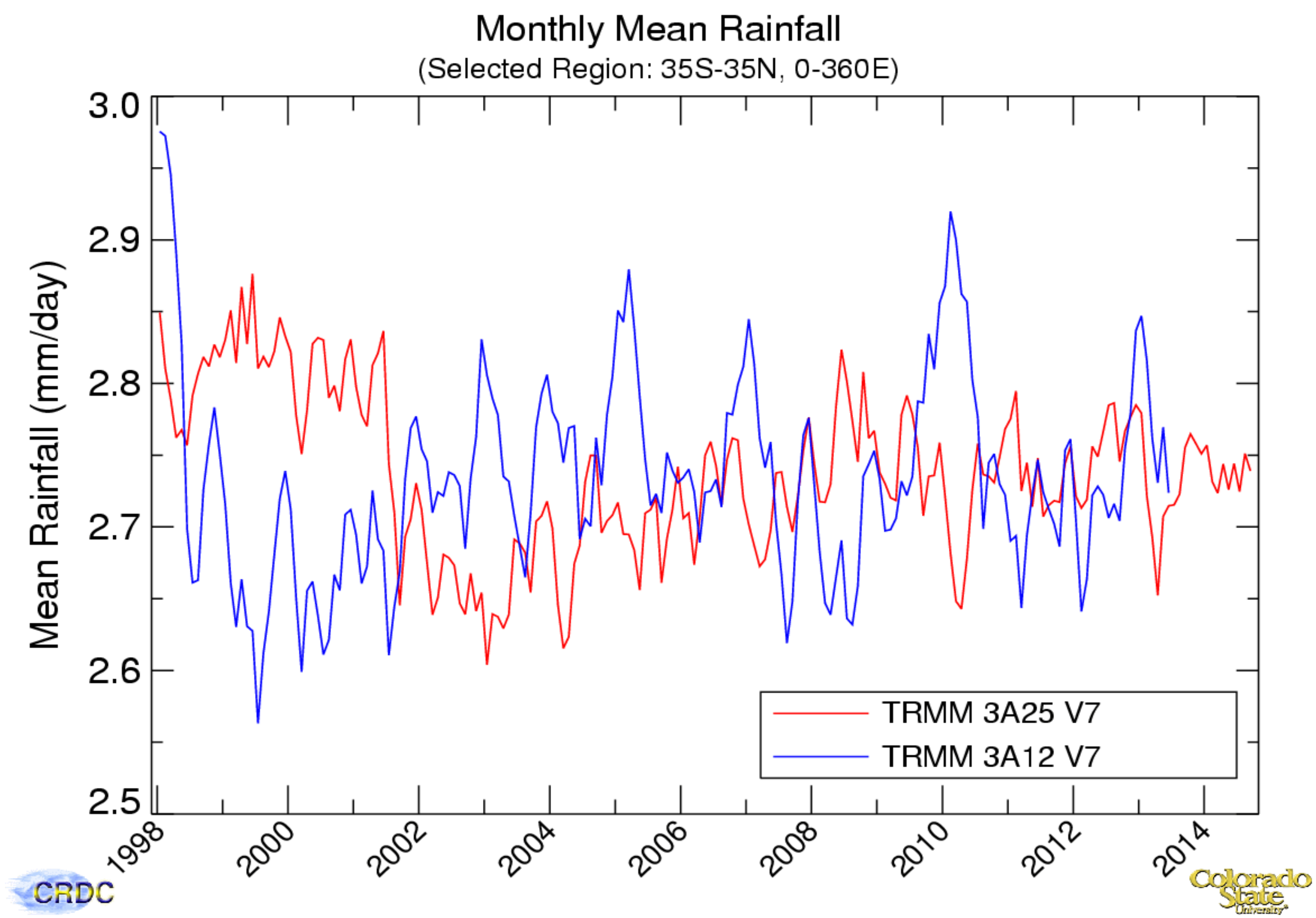
CloudSat: How *Often* Does it Rain?



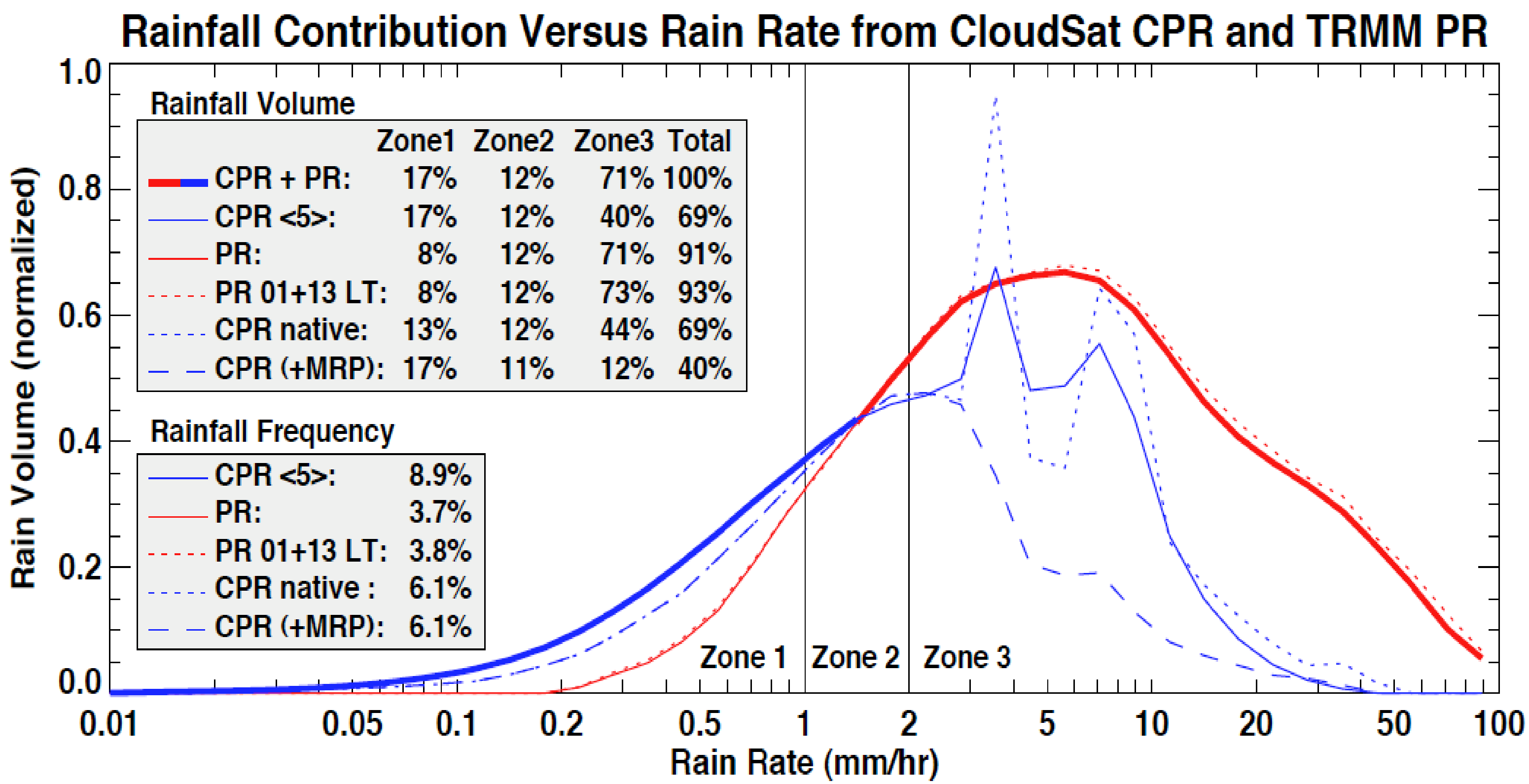
TRMM: How *Much* Does it Rain?



TRMM: How is Tropical Rainfall *Changing*?



CloudSat and TRMM: How *Hard* Does it Rain?

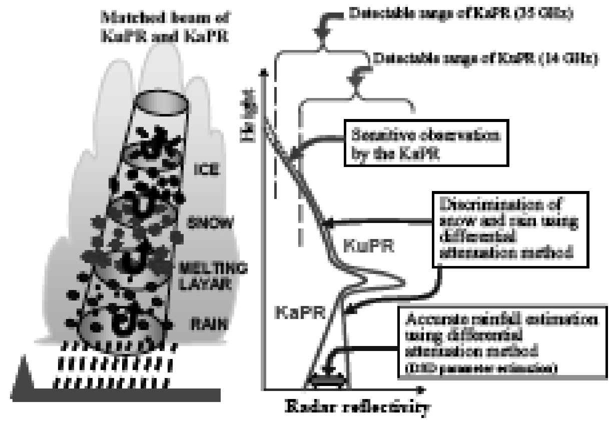


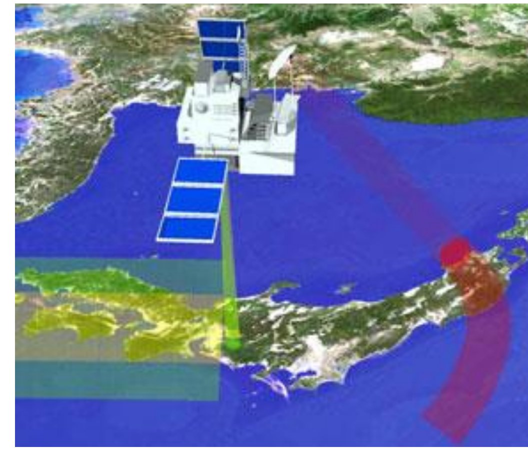
- R < 1 mm h^{-1}: CPR accumulation is 0.47 mm/d, PR's is 0.19
- R > 5 mm h^{-1}: CPR accumulation is 1.35 mm/d, PR's is 1.86

Summary

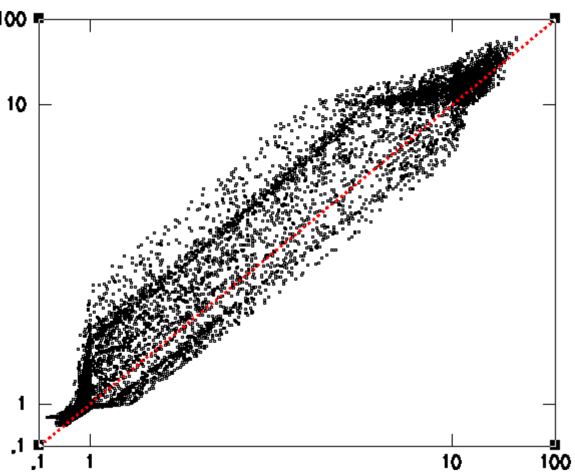
- ✓ Despite some challenges, space-borne radars offer a valuable source of global precipitation measurements.
- ✓ TRMM rainfall estimates are based on reflectivity with an attenuation correction.
- ✓ CloudSat rainfall estimates are based on attenuation with a reflectivity correction.
- ✓ The combination of TRMM and CloudSat are capable of detecting the full spectrum of global precipitation including snowfall.
- ✓ Given their success to date, spaceborne radars with new capabilities (Doppler, multiple-frequencies, and time-resolution) are being proposed for the future.

The Next Generation: GPM

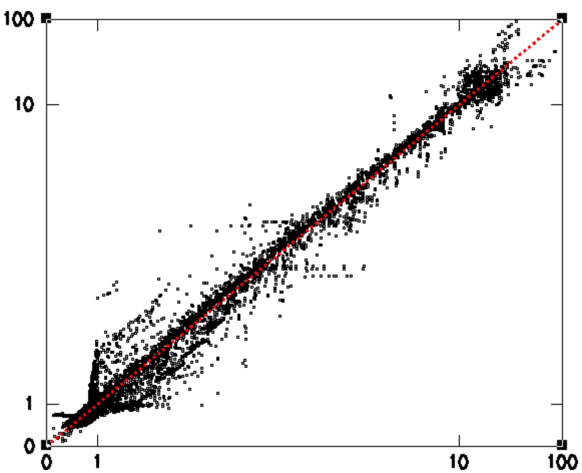




TRMM Single-Frequency



GPM Ka/Ku-band



Differences in attenuation at 14 and 35 GHz allow DSD to be retrieved.

Next Generation: EarthCARE

- The combined ESA/JAXA EarthCARE mission will carry the next generation CPR with a higher vertical resolution (100 m), better sensitivity (-35 dBZ), and crude Doppler capability (~1 m s^{-1} resolution).
- EarthCARE resembles the A-Train on one satellite.