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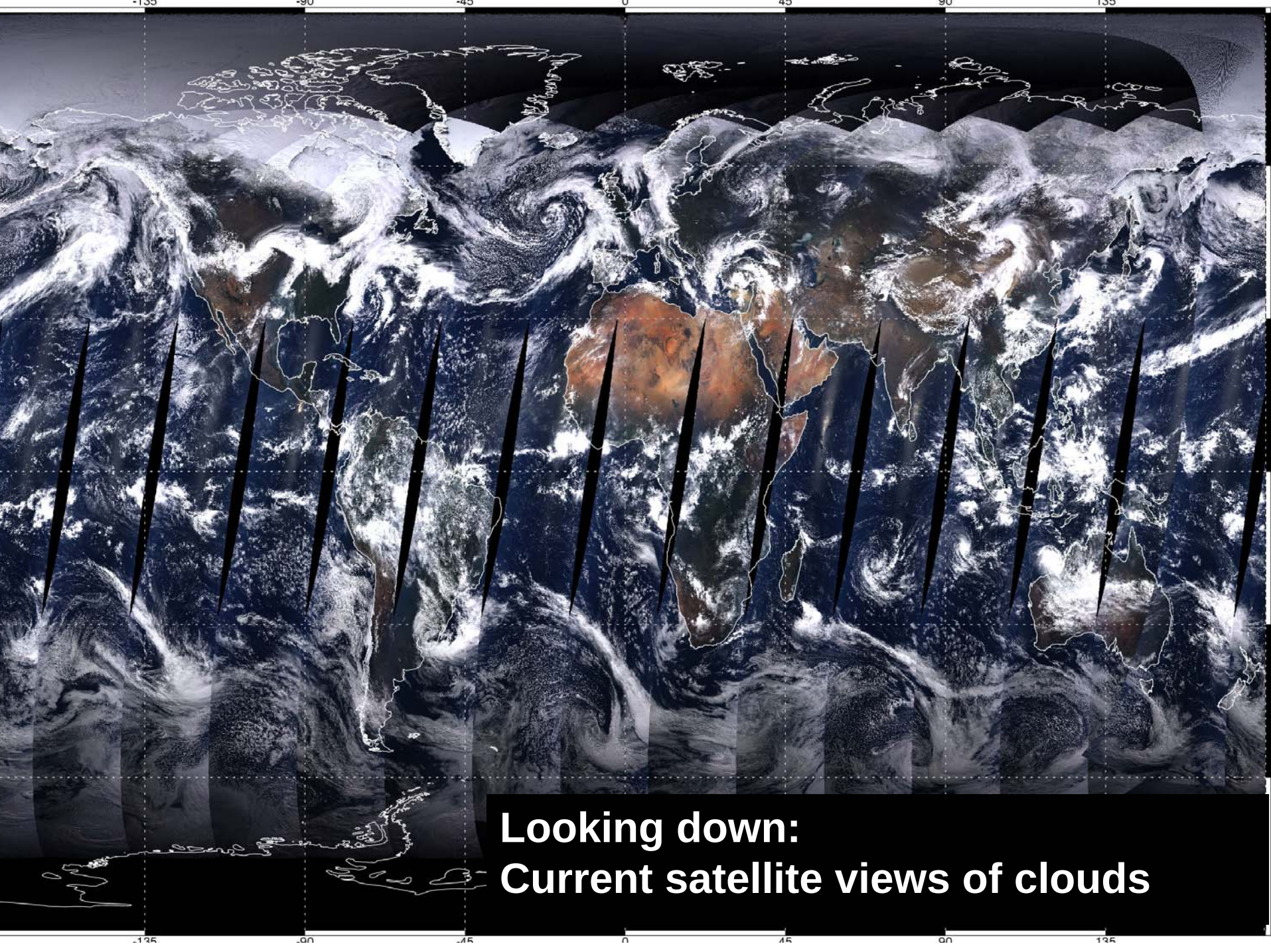
Challenges of cloud-prone and rainy areas remote sensing for First International Symposium on Cloud-prone and Rainy Areas Remote Sensing (CARRS2005)

October 6, 2005

Charles Elachi, Director
Jet Propulsion Laboratory
California Institute of Technology


-135
-90
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Looking down:
Current satellite views of clouds

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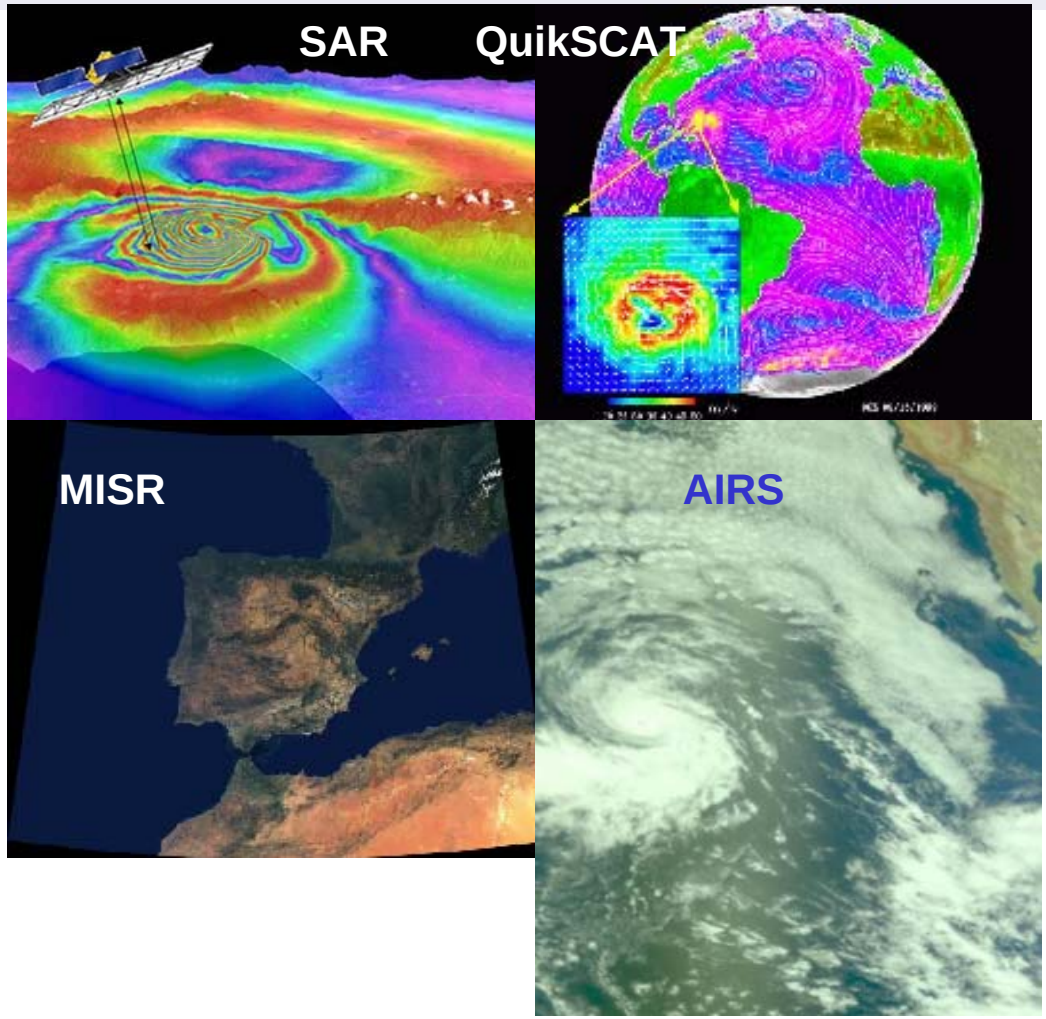
From “clouds as noise” to “clouds as research subject”

- **Clouds transparent to:**
  - **Synthetic aperture radars (SARs)**
  - **Scatterometers**
    - **NASA Scatterometer**
    - **QuikSCAT**
  - **Ocean altimetry**
    - **Topex/Poseidon**
    - **Jason 1**
- **Clouds obscure:**
  - **Multi-angle Imaging SpectroRadiometer (MISR) on Terra**
  - **Atmospheric Infrared Sounder (AIRS) on Aqua**
- **Clouds are research subjects for:**
  - **Tropical Rainfall Measuring Mission (TRMM)**
  - **Airborne Rain Mapping Radar (ARMAR)**
  - **Airborne Cloud Radar (ACR)**
  - **Cloudsat**



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Clouds transparent to Shuttle Radar Topography Mission (SRTM) synthetic aperture radar (SAR)

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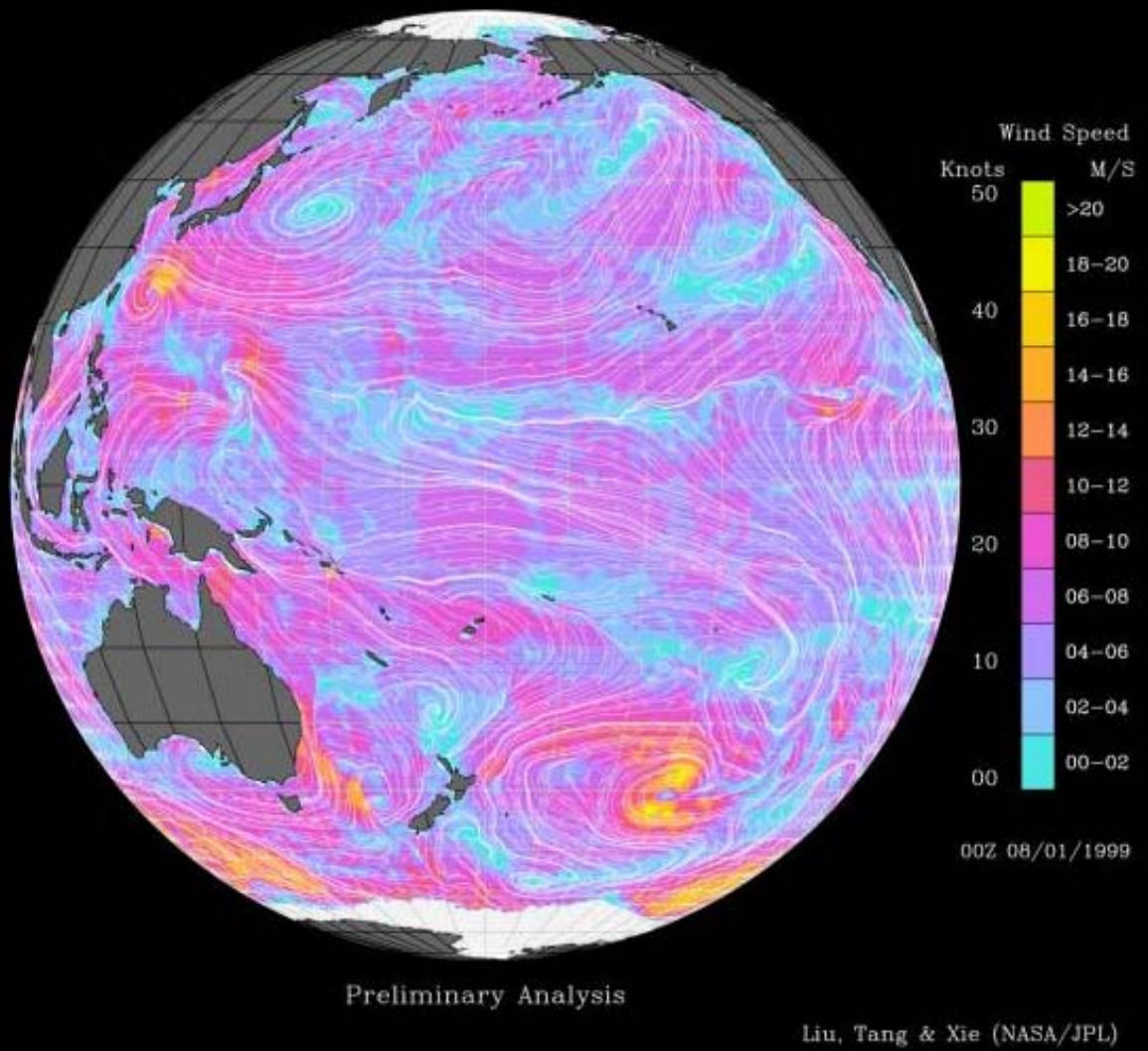
Clouds transparent to QuikSCAT scatterometer



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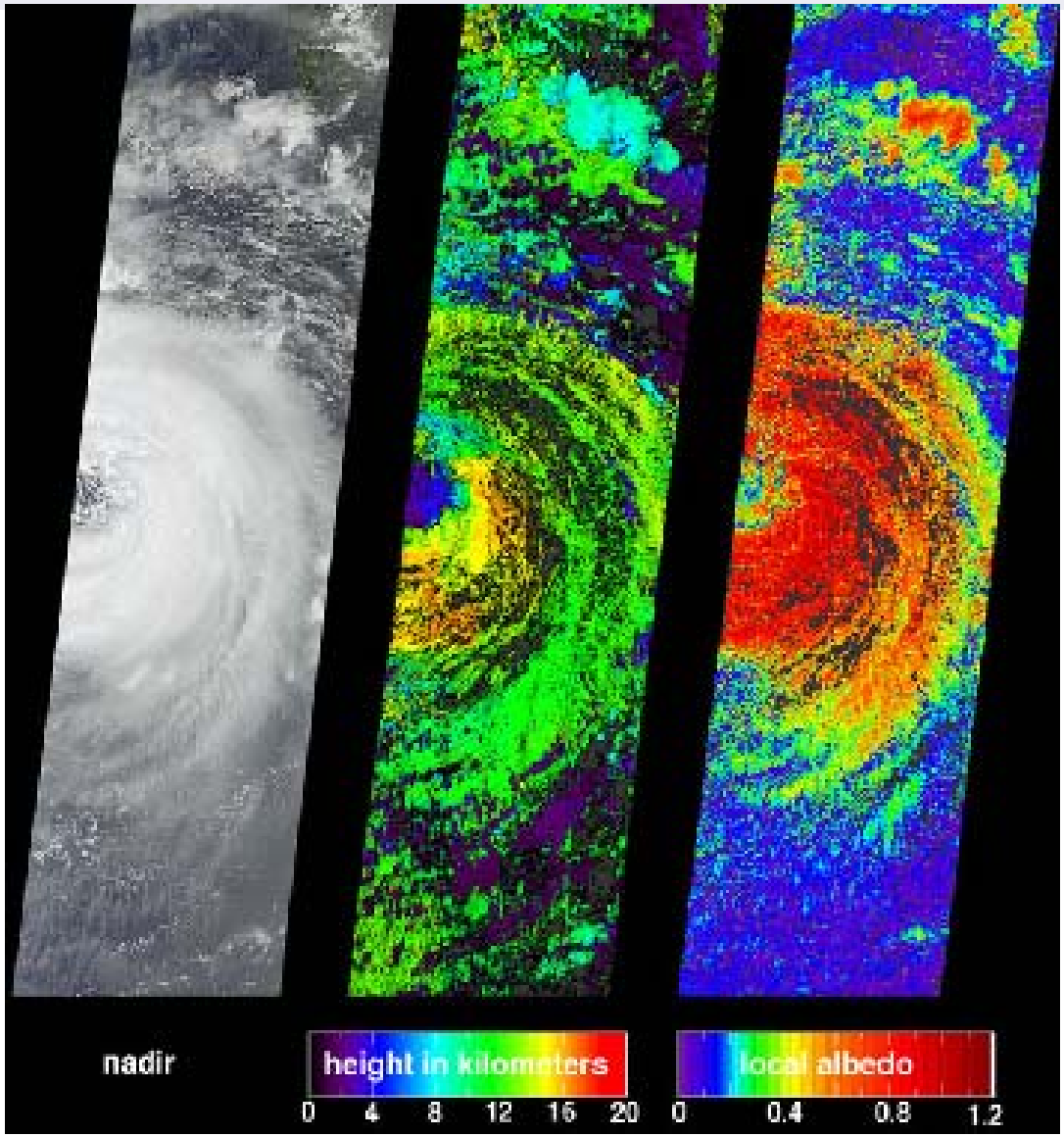
Multi-angle Imaging SpectroRadiometer (MISR) on Terra observes clouds of Typhoon Sinlaku over Okinawa 5 Sept 2002.

- **Cloud structure by height in middle image.**
- **Cloud albedo for energy balance studies in right hand image**



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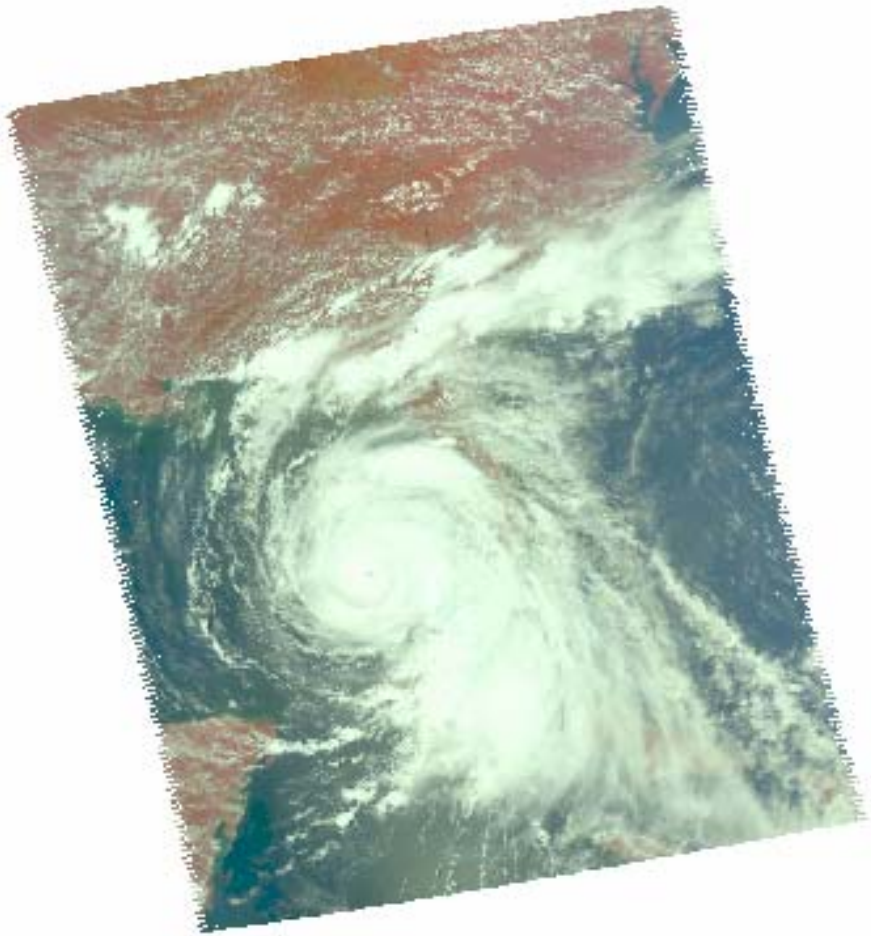
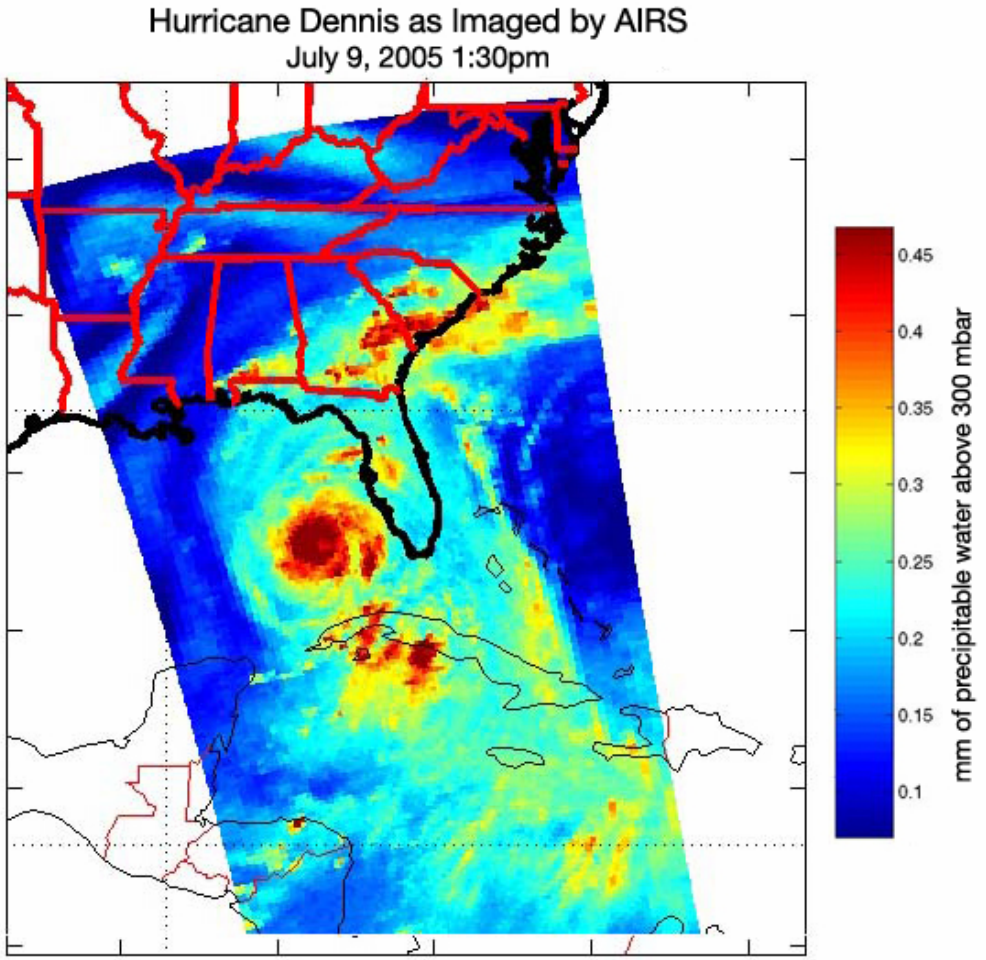
AIRS observes clouds of Hurricane Dennis July 9, 2005

- **Visible and infrared precipitable water images**





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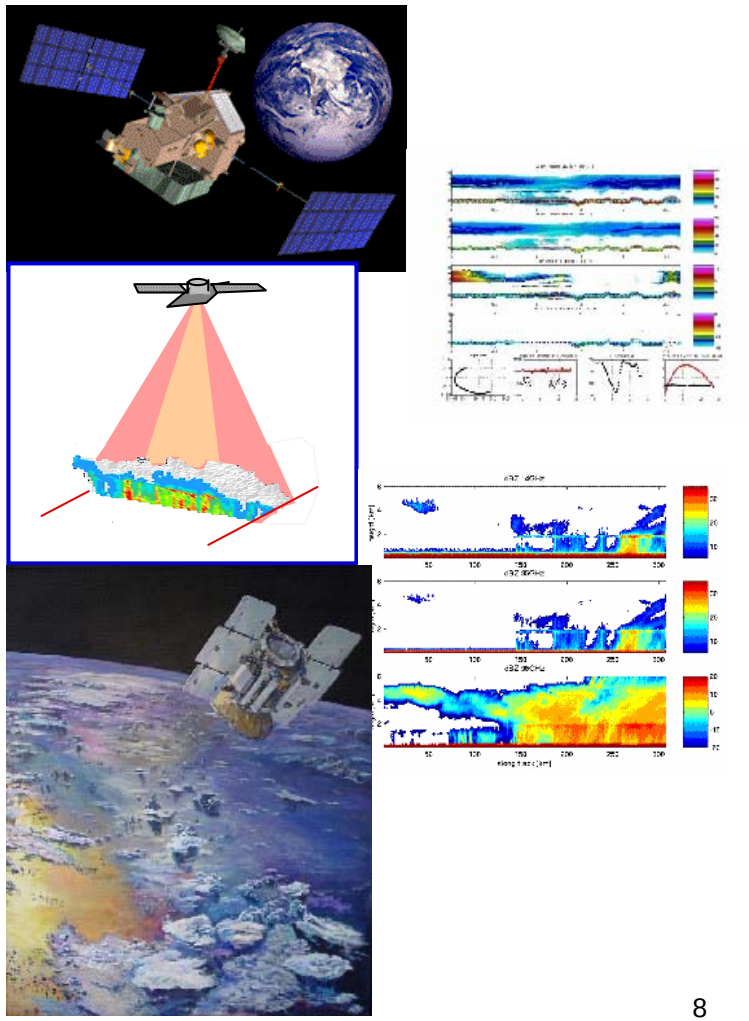
Past and current cloud and precipitation monitoring missions

- **Tropical Rainfall Measuring Mission (TRMM)**
- **Airborne Rain Mapping Radar (ARMAR)**
- **Second generation precipitation radar (PR-2)**
- **JPL/UMass Airborne Cloud Radar (ACR)**
- **Cloudsat**



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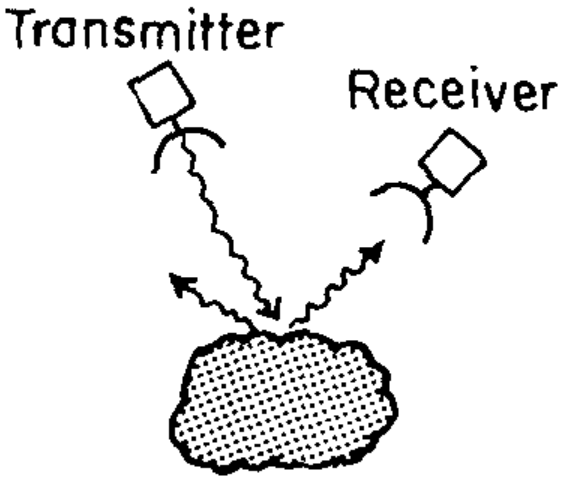
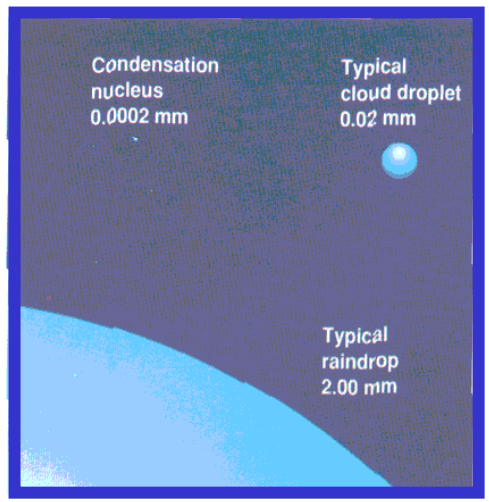
Active sensing of clouds and precipitation using radar

1. Transmit pulses of electromagnetic radiation and receive reflected energy scattered by particles in air.

2. The received power contains information about particle properties.

3. Particles in air vary in size over several orders of magnitude.





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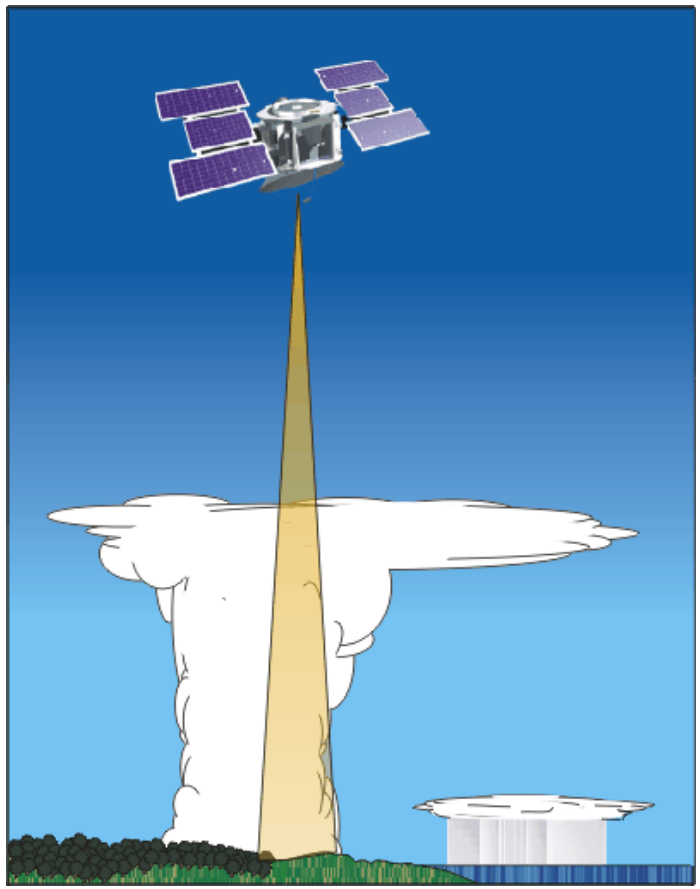
Comparison of cloud and precipitation technologies

Transmitter	Advantage	Disadvantage
Laser (visible, infrared wavelengths; 0.5-10 X 10^{-6} m)	Sees* all particles of a few 0.1 X 10^{-6} m and greater, able to provide high resolution	Attenuates heavily in moderately thick cloud, multiple scattering confuses ranging (from space)
Microwave mm wavelength (e.g. 3mm)	Sees* all particles of a few ~5 X 10^{-6} m (most cloud particles) and greater. No multiple scattering effects	Attenuation in moderate to heavy rainfall
cm wavelength (1-10 cm)	Less attenuated under heavy rain	Unable to see majority of cloud

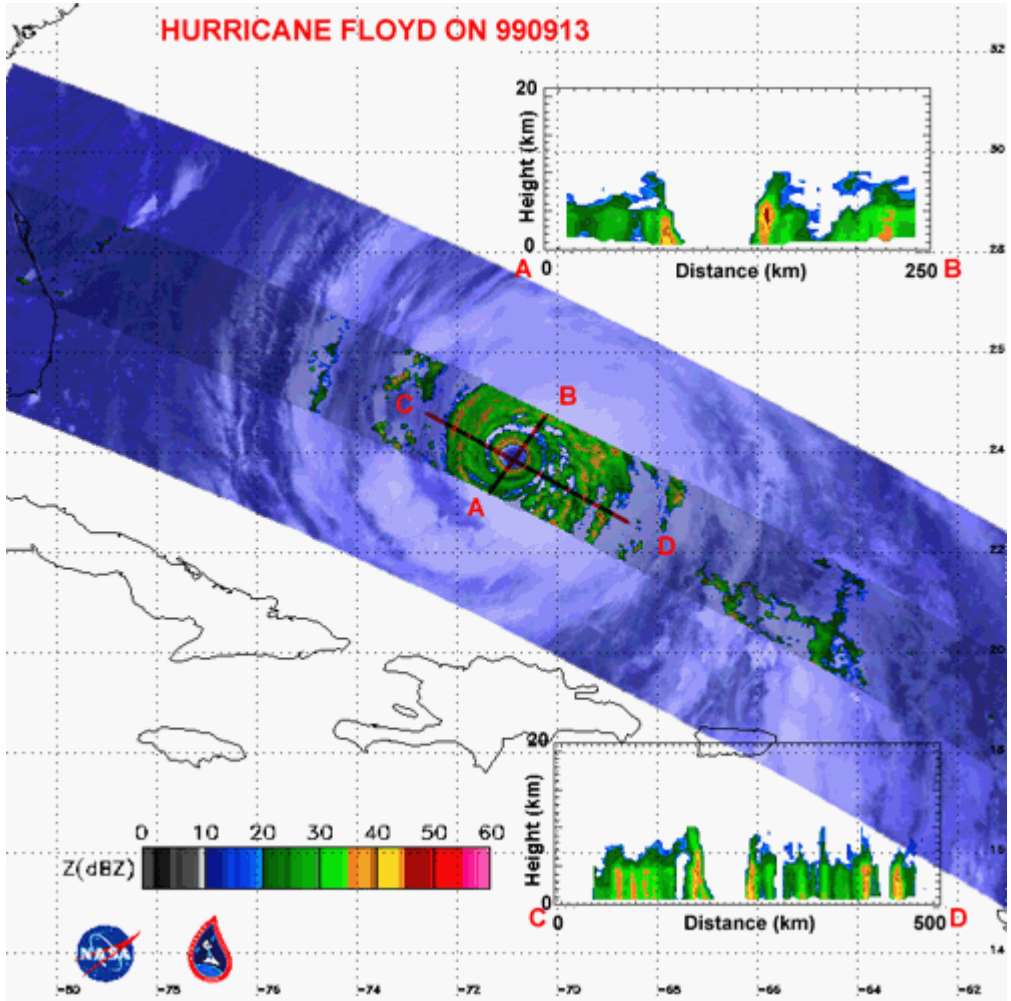


* Depends also on volume concentration of particles

Tropical Rainfall Measuring Mission (TRMM)

- TRMM includes 1st spaceborne weather radar

- performs cross-track scan to get 3-D view of rain



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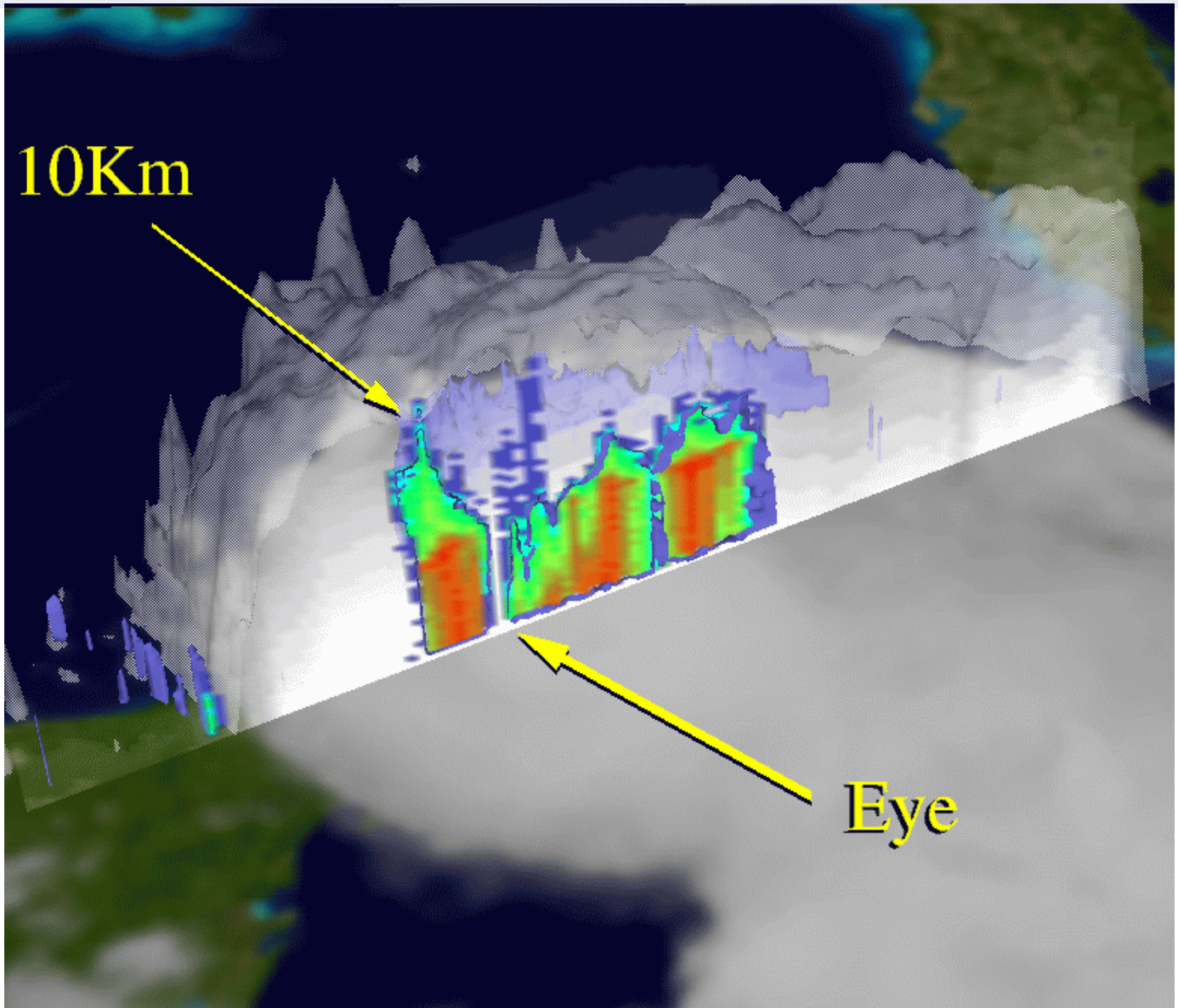
TRMM radar vertical slice through hurricane Isidore 2002



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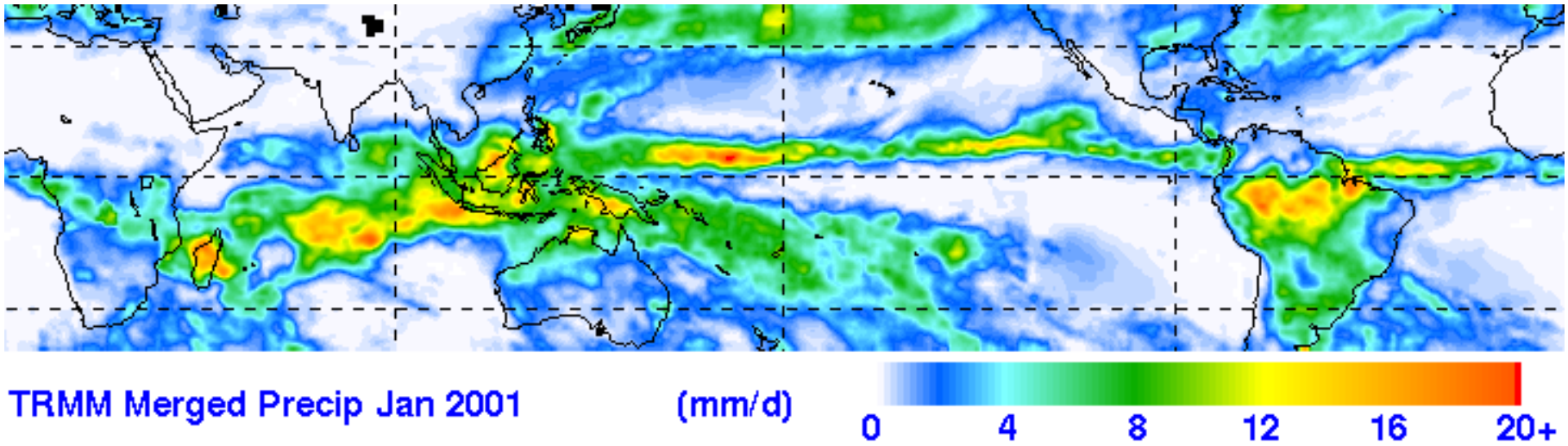
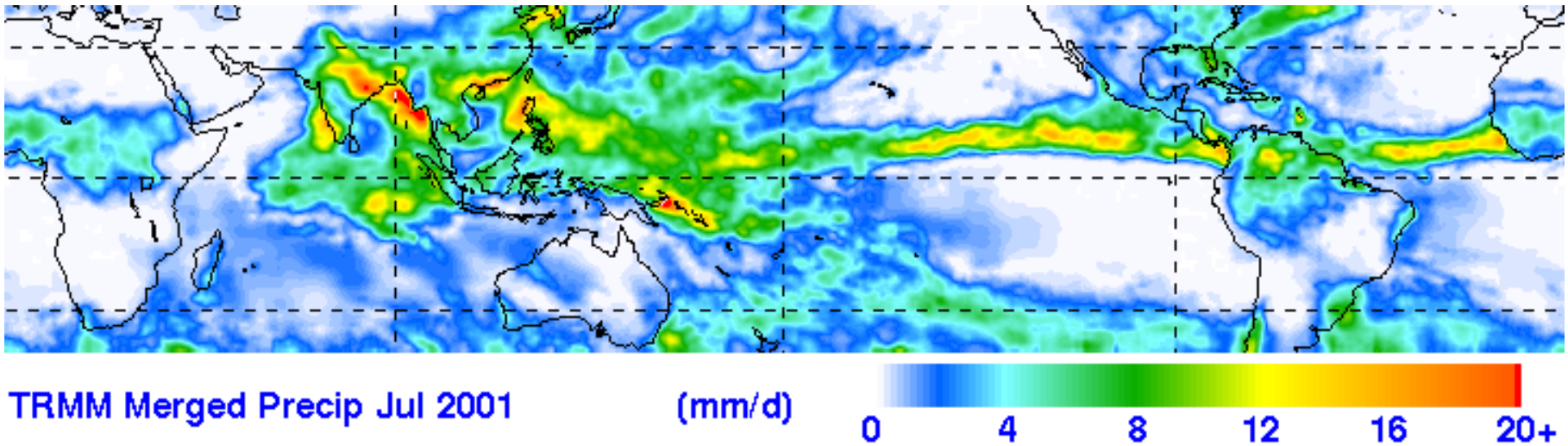
TRMM global rainfall

(TRMM microwave imager merged with radar, geostationary IR and rain gauges)





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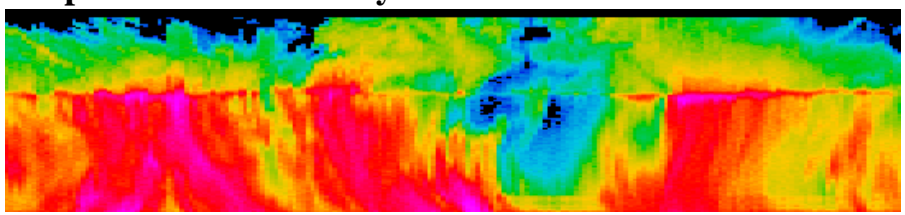
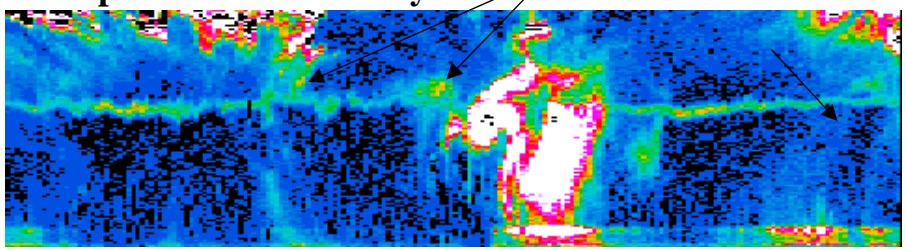
Airborne Rain Mapping Radar (ARMAR) measurements and science results

- **The Airborne Rain Mapping Radar (ARMAR) was developed by JPL under NASA funding in the early 1990's**
  - **operated on DC-8 with TRMM precipitation radar (PR) geometry and frequency**
  - **also provided dual-polarization and Doppler capabilities**
- **ARMAR was used in several field campaigns prior to and during the TRMM mission to obtain data for development and validation of TRMM precipitation radar rainfall retrieval algorithms.**

Co-polarized reflectivity



Dual-polarized reflectivity



Vertical axis is altitude above ocean; horizontal axis is distance along aircraft track. Hurricane eye is blue area to right of center in upper image, corresponding white area in lower image.

CAMEX-3 Observations of Hurricane Bonnie

- **TRMM PR makes co-polarized measurements so some assumptions about location of melting ice are made in retrieving rain.**
- **ARMAR's dual-polarization measurements have been used to investigate assumptions.**
- **ARMAR on the NASA DC-8 observed Hurricane Bonnie near North Carolina during CAMEX-3**
- **Lower panel is dual-polarization data, showing areas of possible melting ice.**

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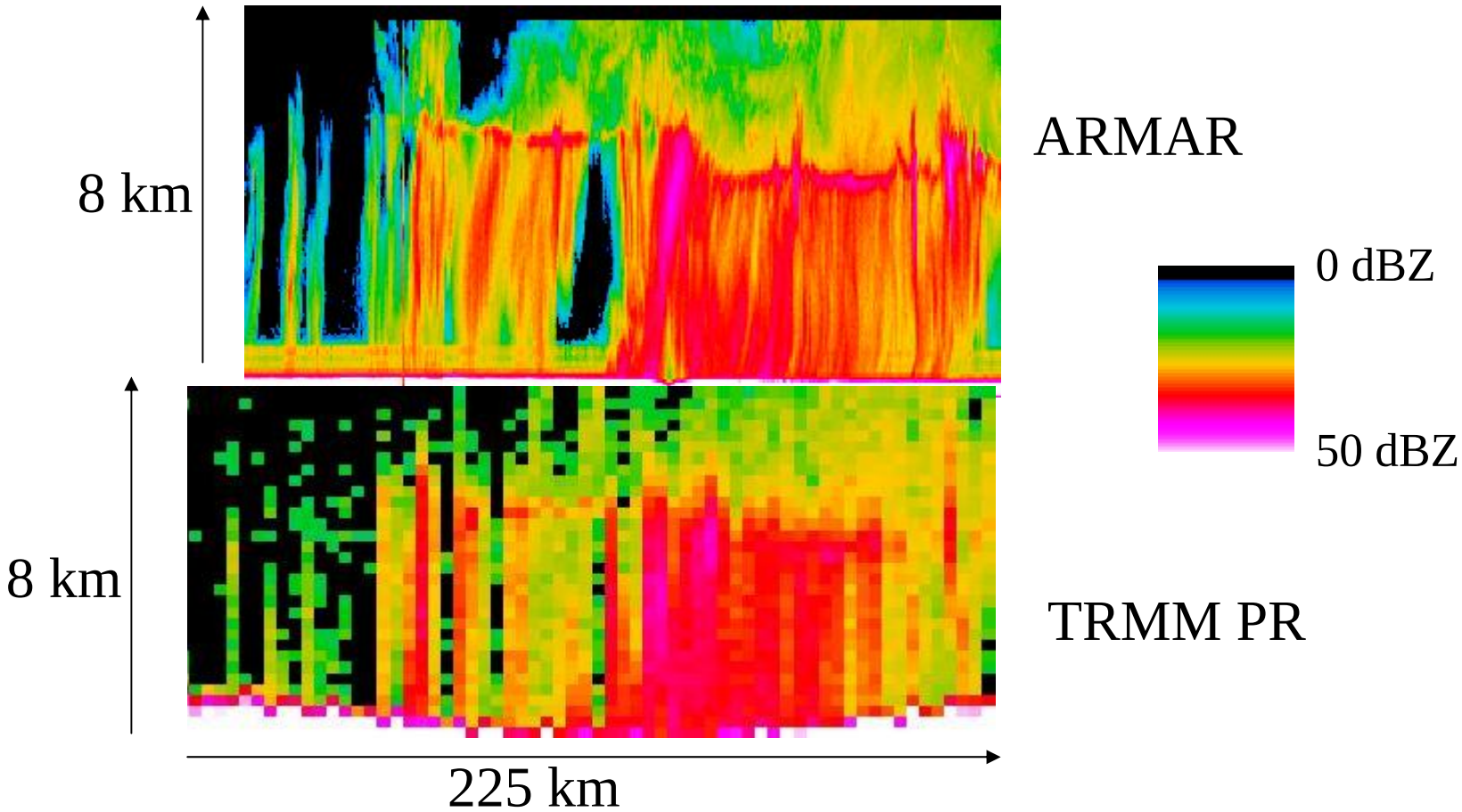
ARMAR reflectivity comparison for Hurricane Bonnie



Images show that precipitation radar (PR) can detect much of the reflectivity structure seen by ARMAR. The same color scale applies to both images.

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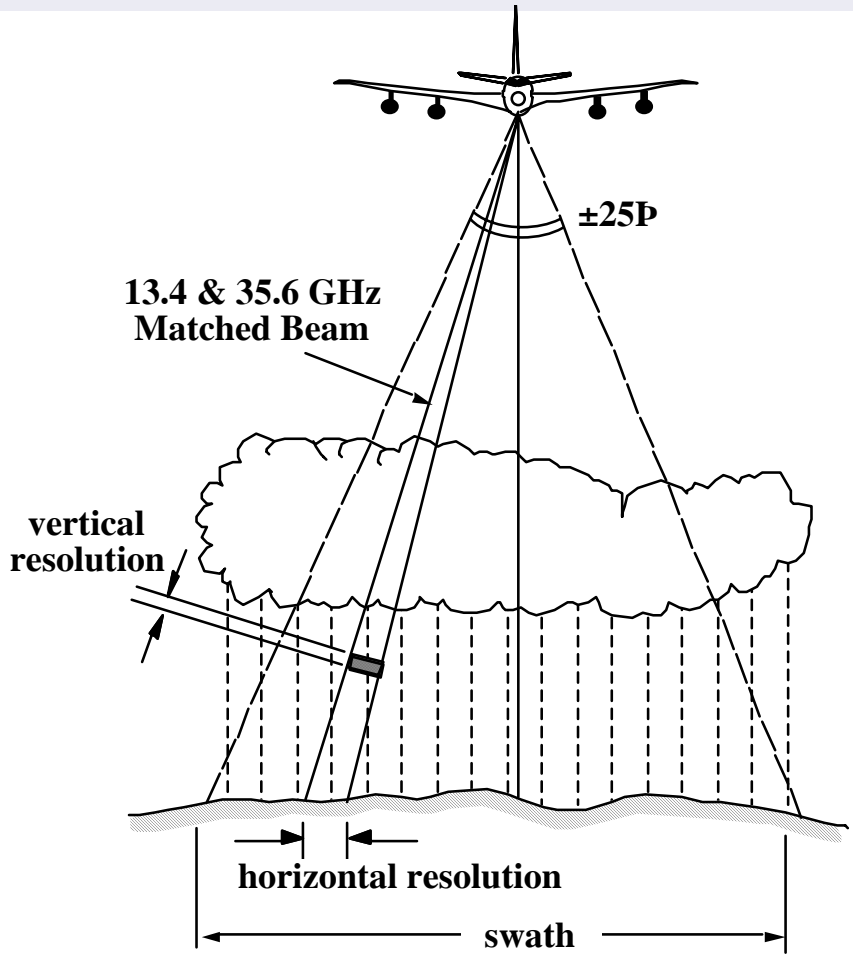
APR-2 background

- A second-generation precipitation radar (PR-2) has been designed, and could be flown on a DC-8 or P-3.
- A PR-2 airborne simulator has been developed (APR-2).
  - It is the PR-2 prototype model that has most PR-2 capabilities, including real-time pulse compression and compact (flight-like) LO/IF module.
- APR-2 measurement capabilities:
  - Co-polarized (HH) radar reflectivity at 13.4 and 35.6 GHz (Ku- and Ka-bands);
  - Cross-polarized (HV) radar reflectivity at 13.4 and 35.6 GHz;
  - Doppler velocity at 13.4 and 35.6 GHz;
- APR-2 was completed summer of 2001, participated in CAMEX-4, AMSR/Wakasa Bay, and LRR engineering tests, but is no longer flying.



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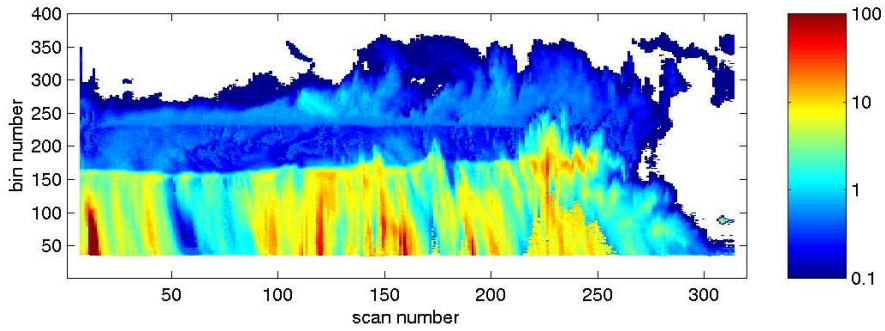
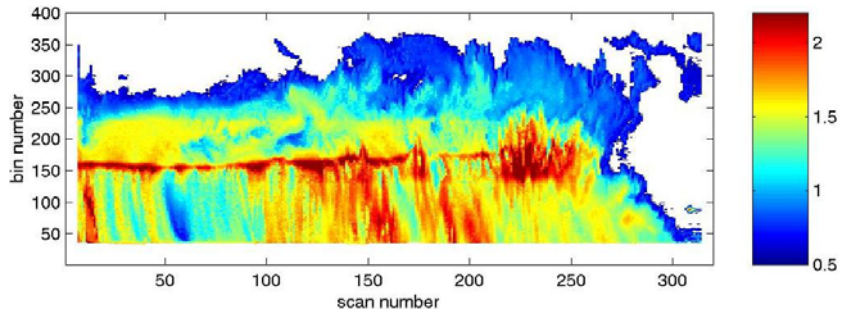
Dual-frequency (13 and 35 GHz) rainfall retrieval with Airborne Precipitation Radar-2 (APR-2)

- **Second generation precipitation radar (PR-2) innovations and capabilities:**
  - **Dual frequency (14/35 GHz) to improve rain measurement dynamic range and sensitivity;**
  - **Dual polarization to differentiate between liquid and frozen hydrometeors;**
  - **Doppler capability to obtain vertical motion structure;**
  - **Large, light-weight deployable antenna to provide 2 km horizontal resolution;**
  - **Cross-track adaptive scan over ±37° to increase swath coverage;**
  - **Mass reduction of factor of 2 to 3 from TRMM PR using deployable antenna.**





Rain rate (upper) and mean drop size (lower) from Hurricane Humberto (in CAMEX-4, 9/24/01)

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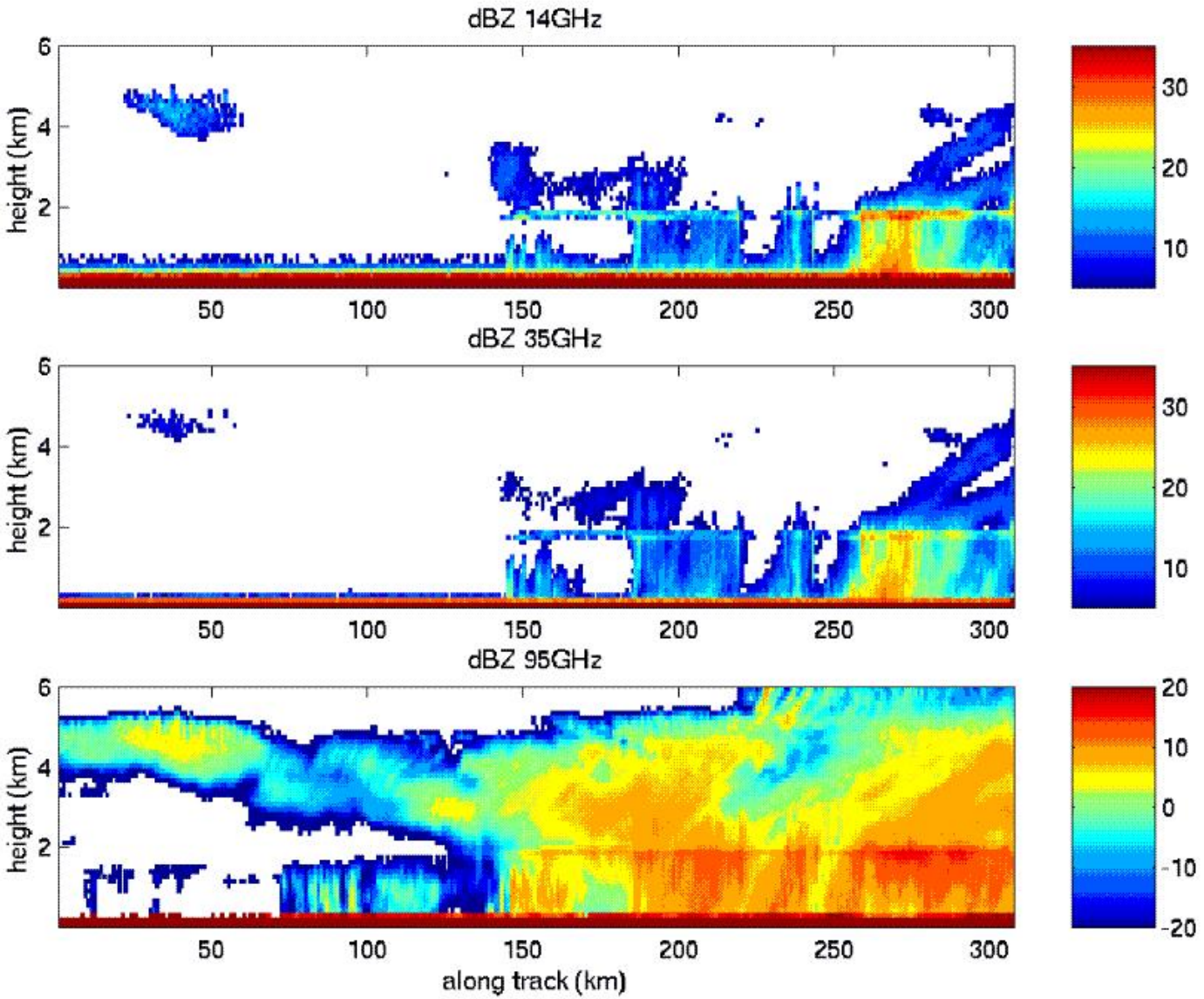
Addition of 94 GHz to 14 GHz and 35 GHz permits seeing clouds in addition to precipitation.



The 14 and 35 GHz channels primarily see precipitation.

The 94 GHz channel sees both precipitation and the cloud in which it is embedded.

The combination should allow retrieval of particle sizes and improved representation of precipitation processes.

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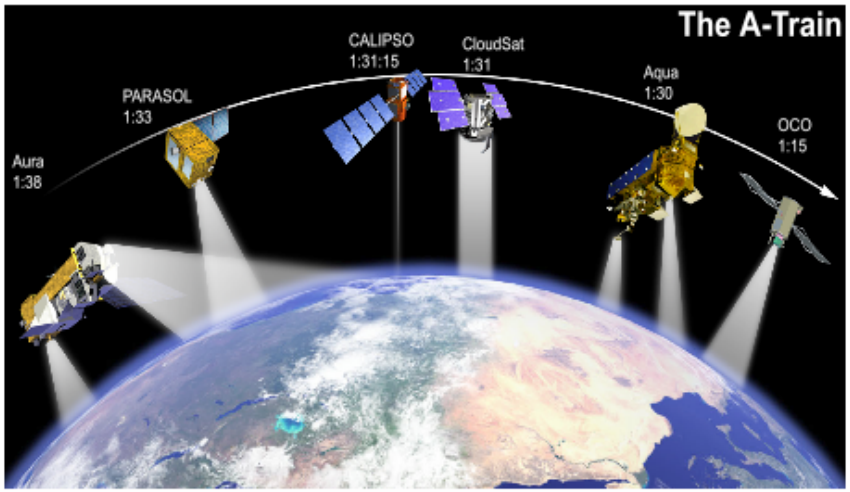
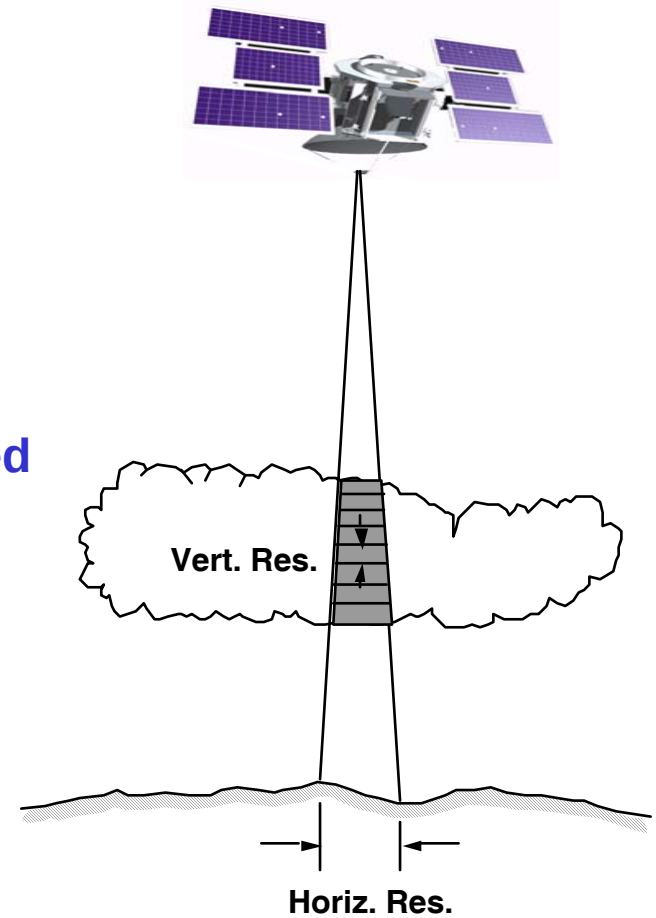
CloudSat Mission Objective:

Provide, from space, the first global survey of cloud profiles (height, thickness) and cloud physical properties (water, ice, precipitation) needed to evaluate and improve the way clouds, moisture and energy are represented in global models used for weather forecasts and climate prediction.



The CloudSat radar, as part of the "A-train" satellites, will penetrate into and through clouds, providing a three-dimensional view of clouds (in addition to precipitation) that fills a critical gap in existing and planned spaceborne observational systems.

- Nadir-pointing 94-GHz radar:
  - Measure cloud reflectivity vs. altitude.
- One science operation mode:
  - Vertical resolution ~500 m
    - Transmits 3.3-ms monochromatic, linearly-polarized pulses;
  - Horizontal resolution ~1.4 km
    - Uses 1.85-m diameter antenna
  - Sensitivity of -28 dBZ (nominal) is achieved by:
    - High peak power, large antenna, low-noise receiver, and pulse-averaging
- Joint collaboration between NASA/JPL and Canadian Space Agency (CSA) with COMDEV and CPI



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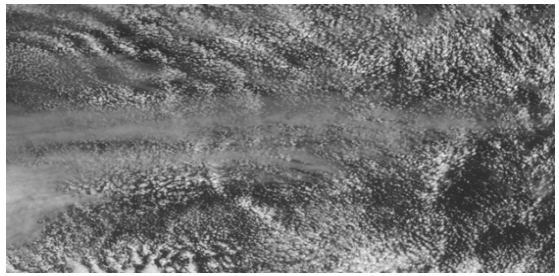
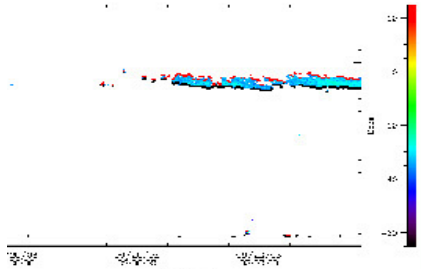
CloudSat data examples

What we see

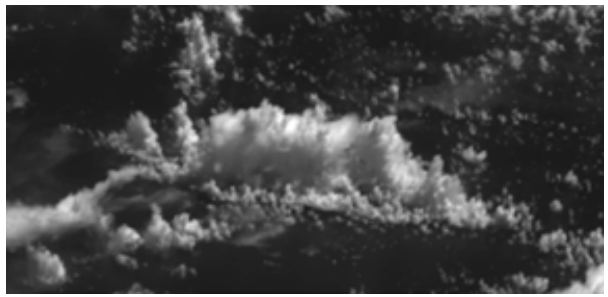
What MISR sees (slant view)

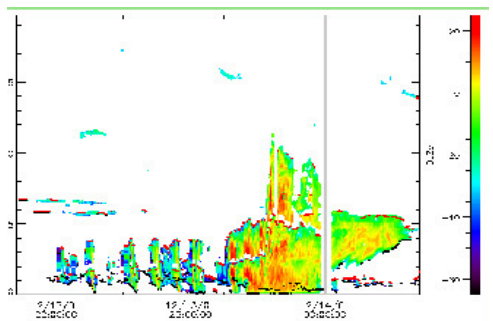


What CloudSat sees

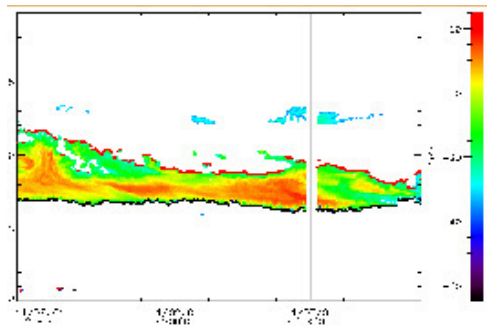


High level 20,000 feet (6,000 meters) **cirrus** clouds are composed of ice crystals





Vertically developed **cumulonimbus** clouds grow to heights in excess of 39,000 feet (12,000 meters) and are a mixture of water droplets and ice crystals



Low-level—6,500 feet (2,000 meters)—**stratus** clouds can be accompanied by light to moderate precipitation

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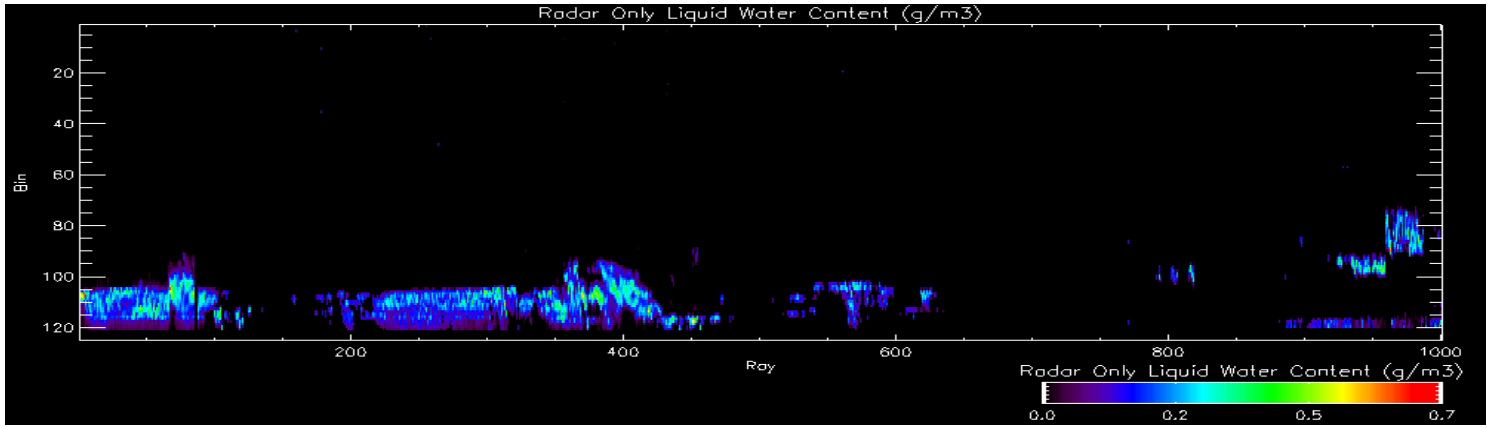
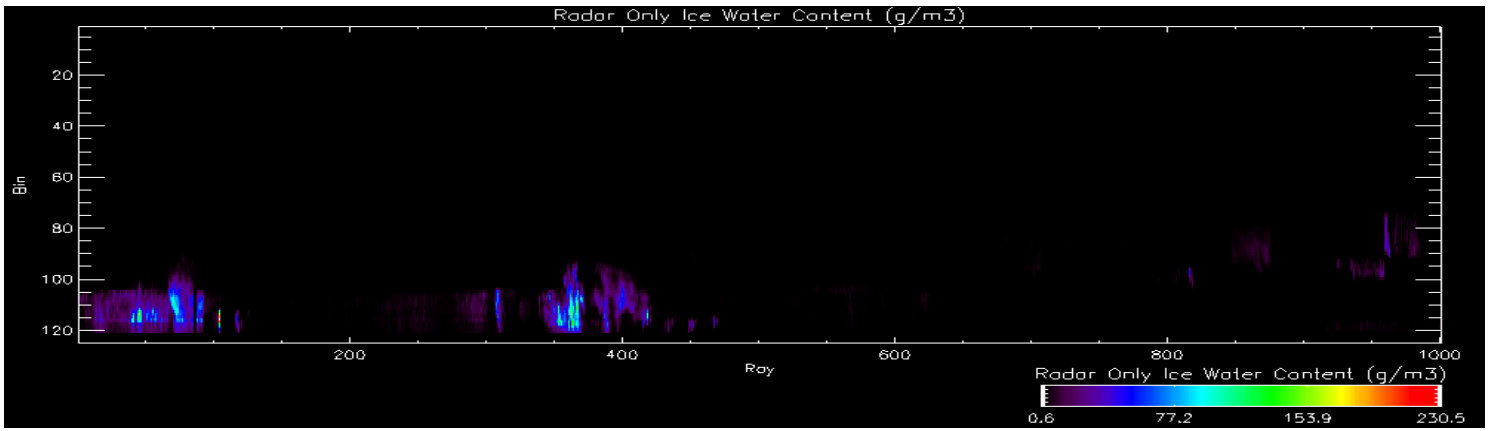
CloudSat will produce the first vertically-resolved estimates of cloud ice and liquid water content.



Cloud liquid water content



Cloud ice water content

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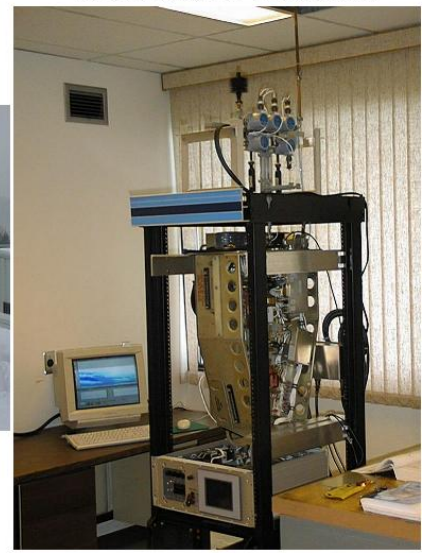
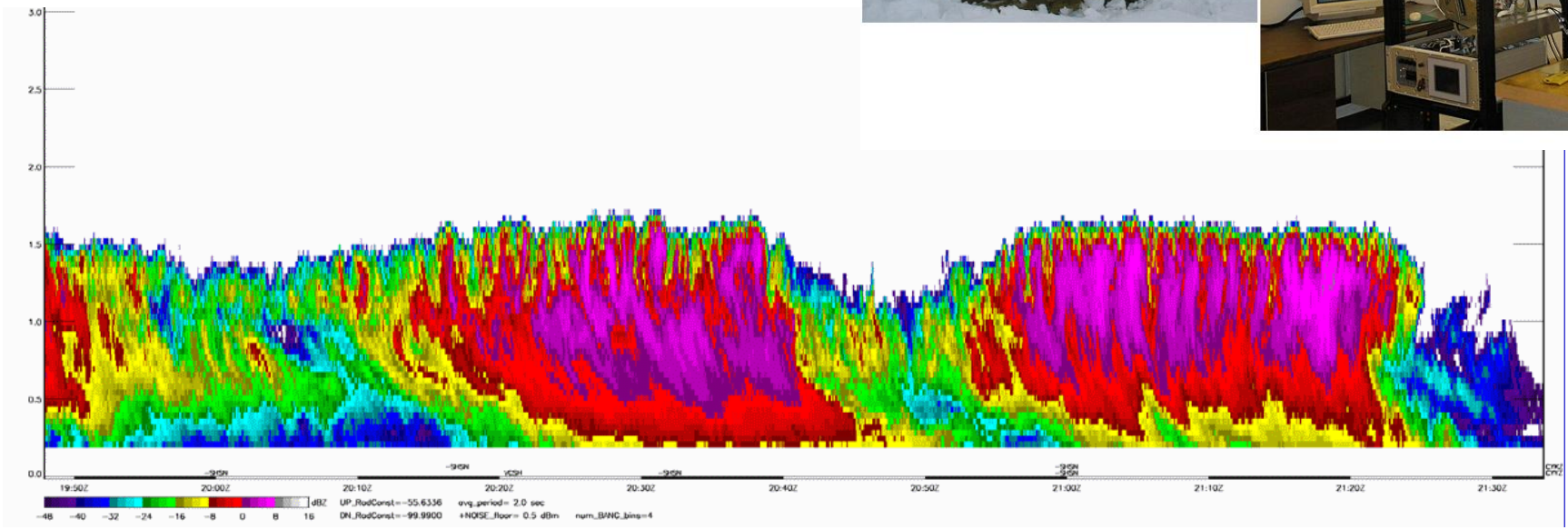
Example of 35 GHz radar snowfall detection

35 GHz radar R/T unit and DAS



Ground Antenna (2.1 m dish)

Example of a Low Level Snow Event



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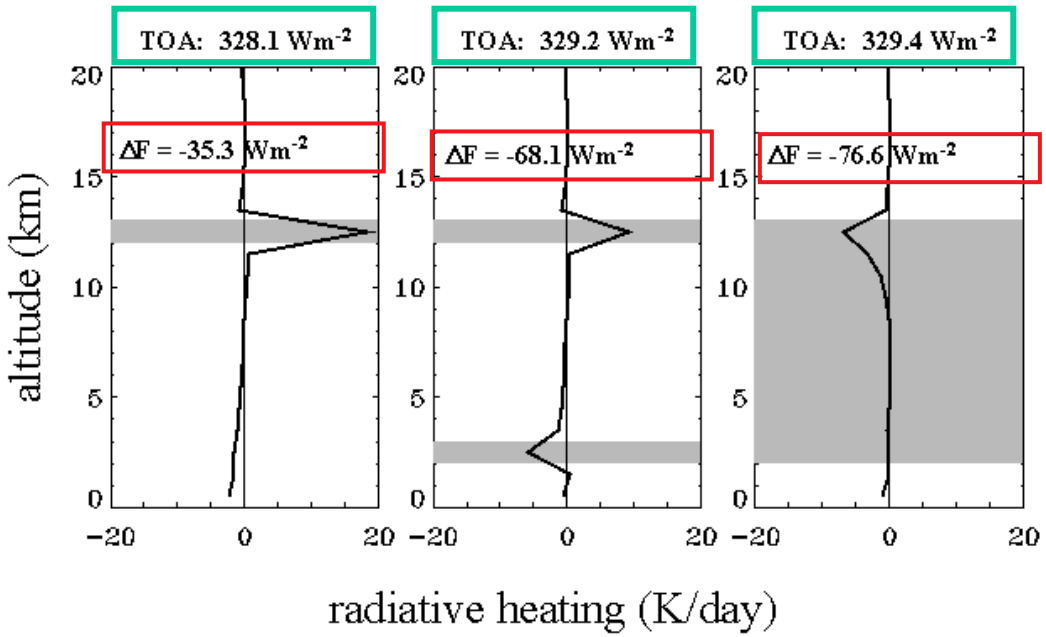
What we have now: Measurement of the top-of-atmosphere (TOA) radiation, which is nearly the same in the three cases below.



Slingo and Slingo, 1988

What CloudSat will provide:

Vertical profiles of radiative heating of the atmosphere and the net flux absorbed in the atmosphere, which are significantly different for the three cases above. Other A-Train sensors (e.g. lidar) help discriminate between ice, water, and mixed-phase clouds.

Radiative heating of the atmosphere drives the atmospheric circulation

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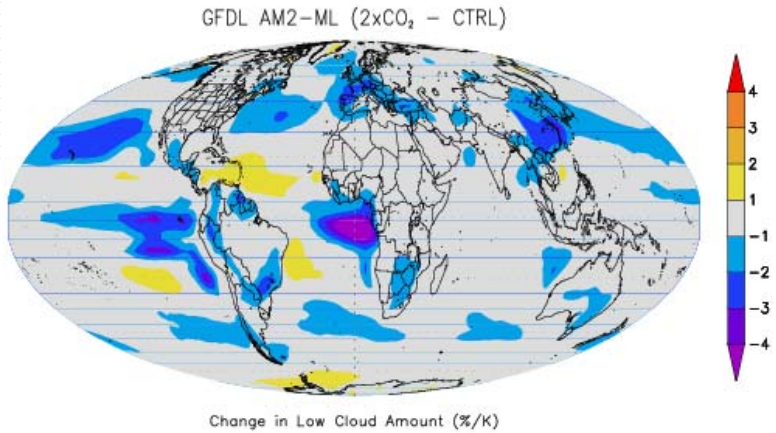
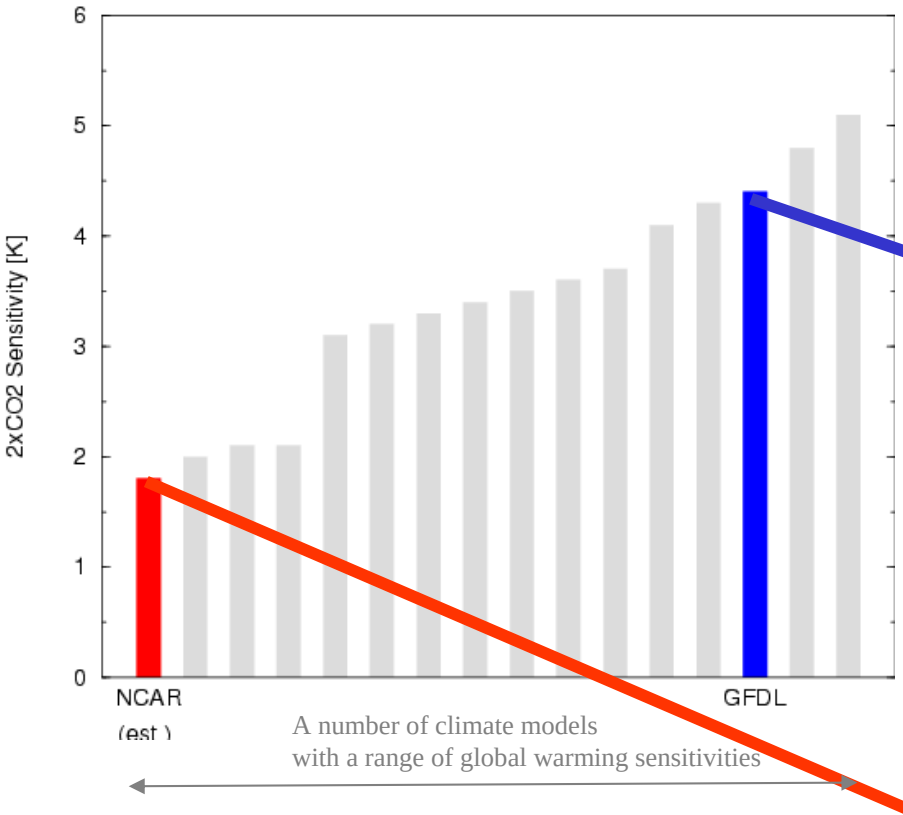
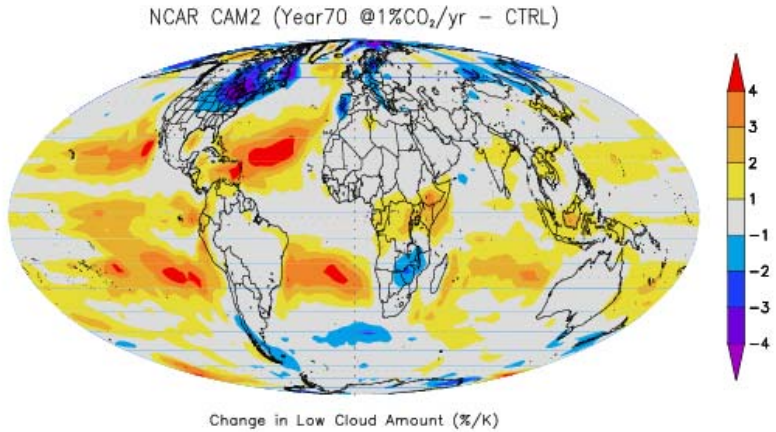
Influence of clouds on global warming

The amount of low cloud predicted in these two climate models is connected to the large difference in their global warming predictions

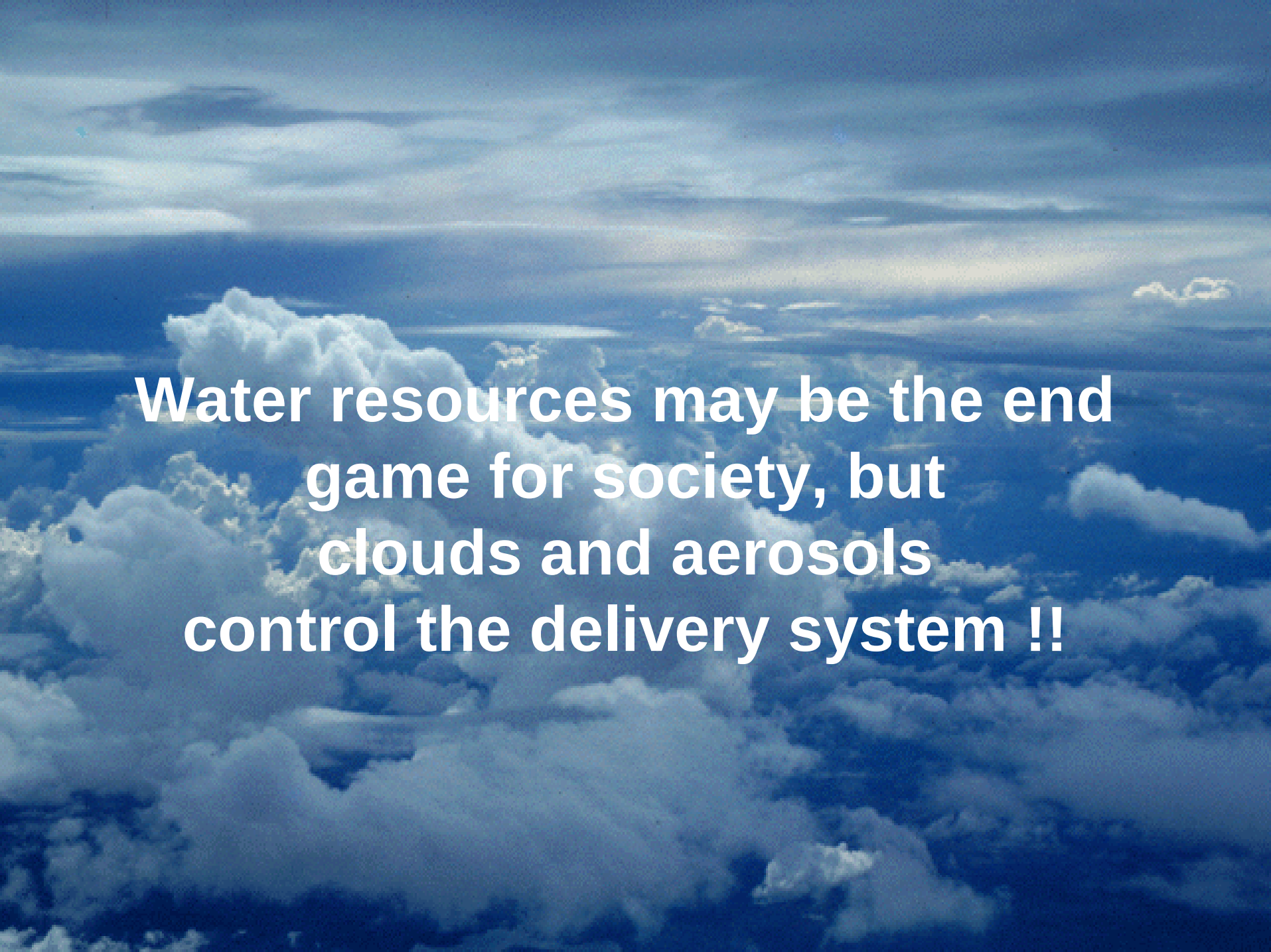


Fewer low clouds =more warming





More low clouds =less warming


Water resources may be the end
game for society, but
clouds and aerosols
control the delivery system !!