NASA Spaceborne Radar Missions – CloudSat and QuikScat – To Observe Clouds and Sea Surface Winds

To be presented in Taiwan during "Symposium on Application of Remote Sensing for Disaster Monitoring and Mitigation"

Chialin Wu
Principal Engineer
NASA / Jet Propulsion Laboratory
Pasadena, CA, 91107 USA

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To JPL/NASA Document Review and Approval:
All slides in this package are assembled from following sources:
1) Paper by E. Im, S. Durden et al, presented in IGRASS 06 Conference, "Early Results on Cloud Profiling Radar Post-launch Calibration and Operations" (JPL Clearance CL#06-1158)
2) NASA Public Information Web Sites on CloudSat and QuikSat Missions. (http://www.nasa.gov/mission_pages/cloudsat/main/index.html and http://winds.jpl.nasa.gov/index.cfm)

Why Active Radar Sensors

- Sensors that can react to or interrogate the objects' physical properties

- Microwave Radar Scatterometer of 13.4 GHz center frequency can see through clouds. By measuring sea surface roughness from several observation angles, one can infer sea surface wind speeds and directions. The QuikScat Satellite has been operating in space for more than seven years, since its launch in 1999.

- The new CloudSat Satellite carries a 94 GHz nadir looking radar. It is capable of detecting clouds' ice particles and water droplets. It can then observe vertical structure profiles of clouds under the sensor path.

- Such sensors are useful in observing and monitor the formation and the three dimensional processes of storms over ocean area.

The QuikScat Scatterometer

NASA's QuikSCAT Scatterometer lofted into space on June 19, 1999, and has been operating in space since then. Results have been reported extensively.

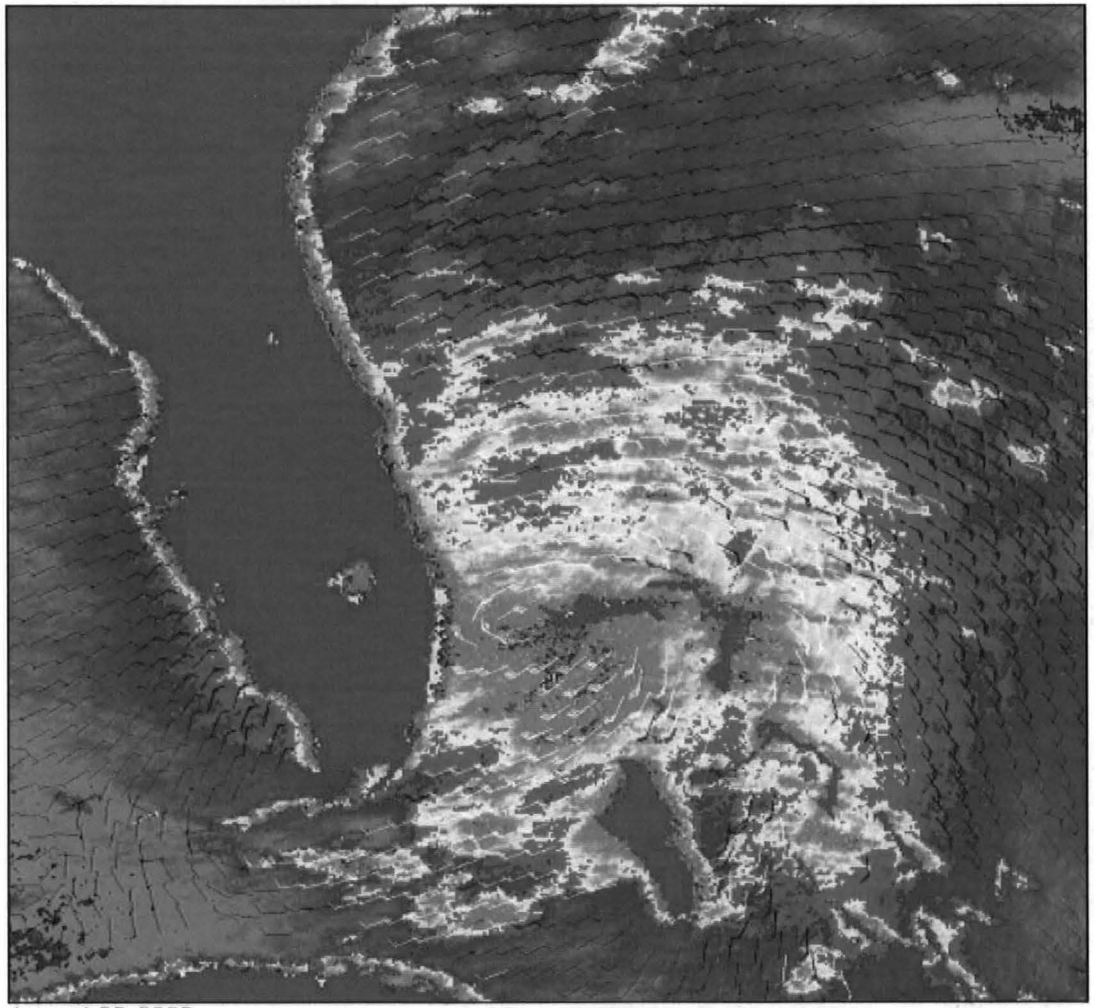
Instrument Description

Radar: 13.4 gigahertz; 110-watt pulse at 189-hertz pulse repetition frequency (PRF)
Antenna: 1-meter-diameter rotating dish that produces two spot beams, sweeping circularly.

Measurements

1,800-kilometer swath during each orbit provides approximately 90-percent coverage of Earth's oceans every day.
Validated wind-speed measurements of 3 to 20 m/sec, with an accuracy of 2 meters/second; Direction accuracy is approximately 20 degrees.
Wind vector resolution cell is 25 km square.

Hurricane Katrina in its early stage



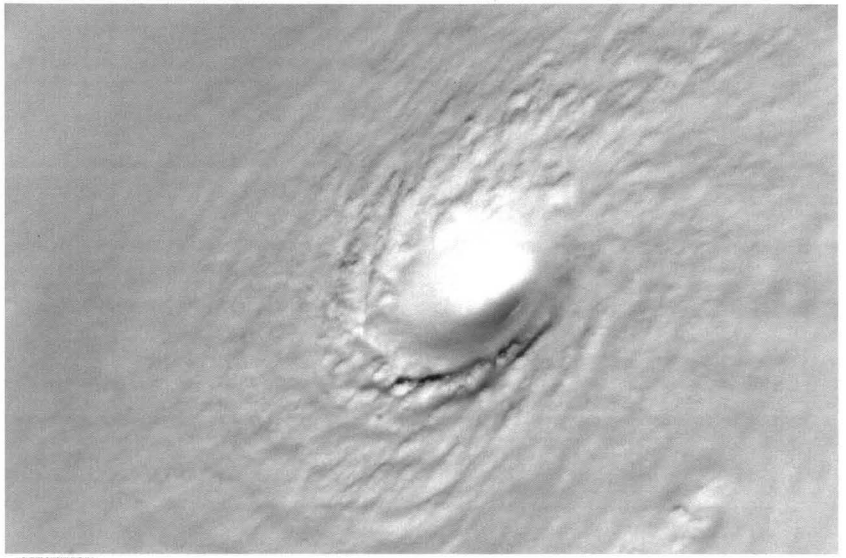
Hurricane Katrina

Tropical Storm Katrina is shown here as observed by NASA's QuikSCAT satellite on August 25, 2005, at 08:37 UTC (4:37 a.m. in Florida). At this time, the storm had 80-kilometer-per-hour (50 miles per hour; 43 knots) sustained winds. The storm does not appear to yet have reached hurricane strength.

Question :
What other information or data could be useful to help us to better forecast the hazards of a storm during its early stage?

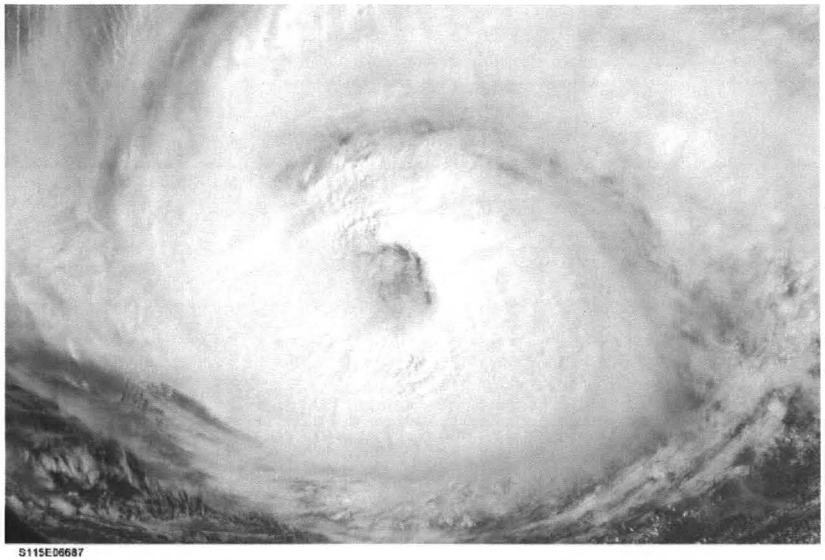
Storms' Clouds - View from Space

Structural Details of Clouds are not present in Conventional Photography



ISS012E05241

ISS012-E-5241 (19 Oct. 2005) --- This image of Hurricane Wilma was taken at 8:22 a.m. CDT Wednesday, Oct. 19, by the crew aboard NASA's international space station as the complex flew 222 miles above the storm. At the time, Wilma was the strongest Atlantic hurricane in history, with winds near 175 miles per hour. The storm was located in the Caribbean Sea, 340 miles southeast of Cozumel, Mexico. (Image credit: NASA)



S115E06687

S115-E-06687 (17 Sept. 2006) --- Hurricane Gordon was captured at 18:17:13 GMT, Sept. 17, 2006 with a digital still camera, equipped with a 20-35mm lens, by one of the crewmembers aboard the Space Shuttle Atlantis. The center of the storm was located near 34.0 degrees north latitude and 53.0 degrees west longitude, while moving north-northeast. At the time the photo was taken, the sustained winds were 70 nautical miles per hour with gusts to 85 nautical miles per hour. 22

With Clouds' role in Earth's Energy and Water Cycles, we must know them well.

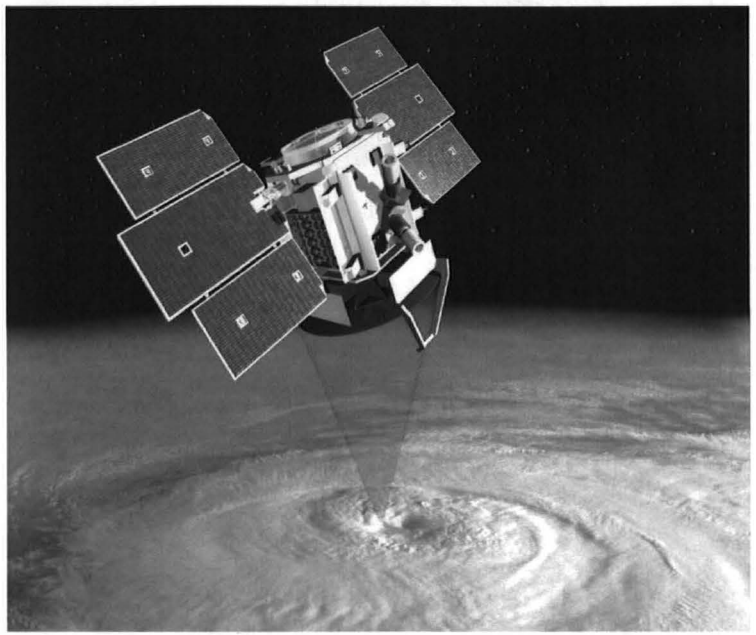
NASA CLOUDSAT
A NASA EARTH SYSTEM SCIENCE PATHFINDER MISSION

CloudSat Mission Overview

JPL

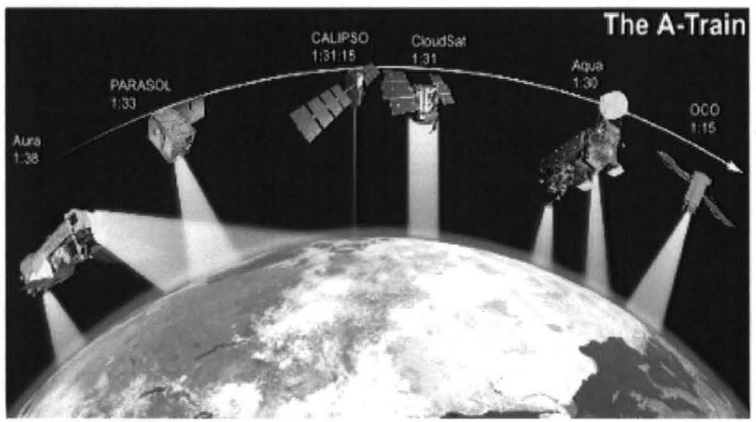
Mission Features

- First spaceborne 94-GHz Cloud Profiling Radar (CPR)
- Ball Aerospace's RS-2000 spacecraft bus
- Flies in formation with EOS Aqua and Calipso
  - 705 km altitude, sun sync orbit
- Launch date: April 28, 2006
- Mission duration: 22 months
- CloudSat Mission PI: Graeme Stephens (CSU)
- CPR is jointly developed by NASA JPL and Canadian Space Agency (CSA)
- USAF Kirkland AFB provides Missions Operations
- CSU's Cooperative Institute for Research in Atmosphere (CIRA) processes CloudSat science data



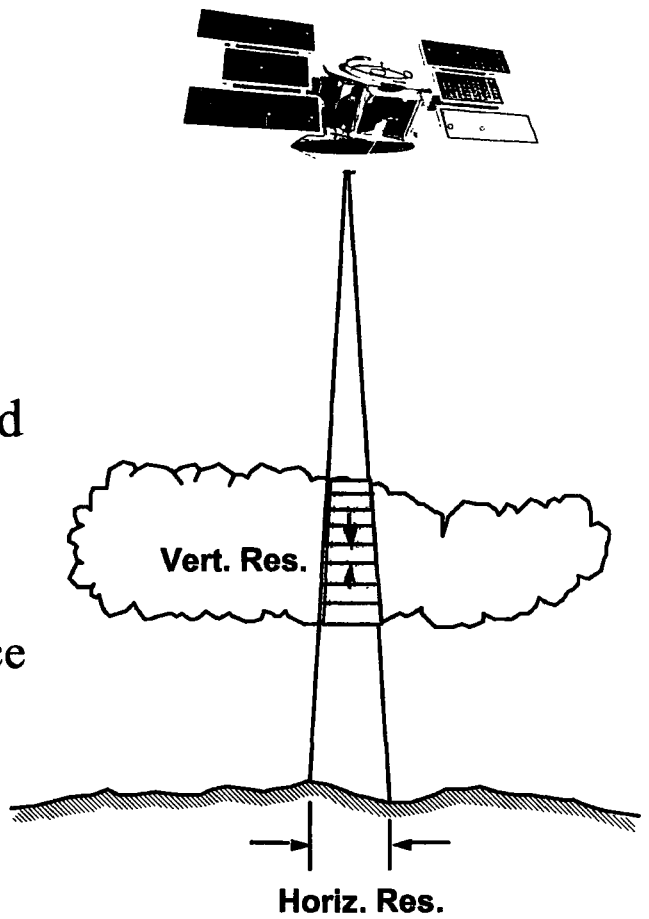
Objectives

- Measure vertical structure of clouds and quantify their ice and water content
- Improve weather prediction and understanding of climatic processes
- Investigate effect of aerosols on clouds and precipitation
- Investigate the utility of 94 GHz radar for spaceborne remote sensing



Cloud Profiling Radar(CPR) Overview

- **Nadir-pointing 94-GHz radar**
  - Measure cloud reflectivity vs. altitude profile along nadir track
- **One science operation mode**
  - Vertical resolution ~500 m
    - Transmits 3.3-μs monochromatic pulses
  - Horizontal resolution ~1.4 km
    - Uses 1.85-m dia. antenna
  - Sensitivity of -28 dBZ (nominal) is achieved by:
    - High peak power, large antenna, low-noise receiver, and pulse-averaging
    - To capture low reflectivity clouds and surface return
  - Height window: 25 km
- **Technical resource allocations:**
  - Mass: 250 kg
  - Power: 230 W
  - Data rate: 25 kbits/sec
  - Share with spacecraft within DPAF envelope



CPR: The First-Ever Cloud Radar in Space for Earth Science Applications

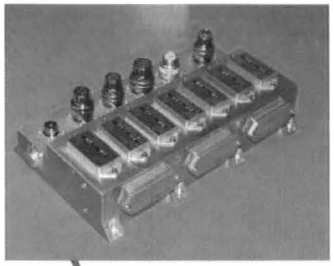
- **Global, uniformly-calibrated data set provided by CPR is unique. It contributes to:**
  - understanding of the microphysics and processes of clouds
  - understanding of radiative heating
    - balance between incoming IR radiation and outgoing longwave radiation
  - measuring light rain and its variability for latent heat budget
  - improving general circulation models (GCMs) for long-term climate change studies
  - improving numerical weather prediction (NWP) models for weather prediction

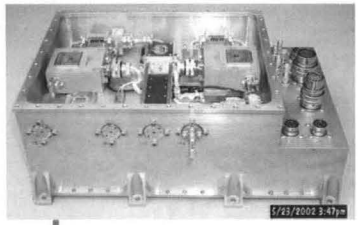
- **CloudSat CPR instrument is unique. It is:**
  - the highest frequency spaceborne earth-science radar ever flown in space
  - the most sensitive remote sensing radar instrument in space
    - Approximately 4 order of magnitude more sensitive than the TRMM radar

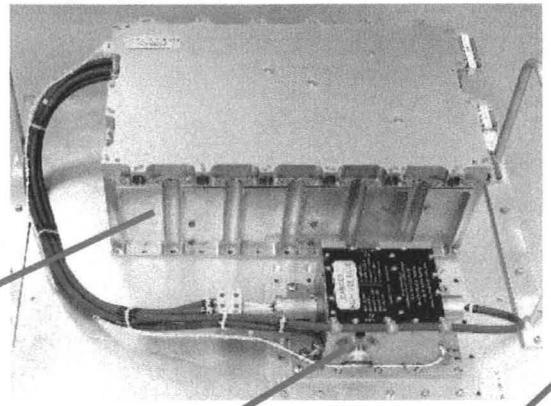
Cloud Detection Sensitivity is The Key CPR Design Driver

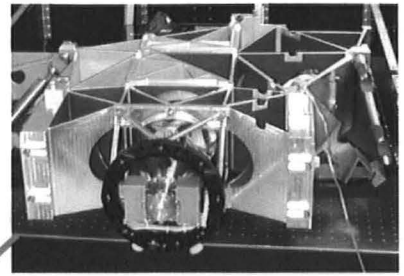
- **Required minimum detectable reflectivity is -26 dBZ.**
  - As a reference:TRMM radar sensitivity for rain measurements: approx. +15 dBZ
- **This requirement drives the following design and technology choices**:
  - W-band frequency (94 GHz)
    - An optimal choice for cloud measurements from backscattering strength and signal absorption considerations
  - 94-GHz transmitter amplifier
  - 1.85-m, high gain antenna
  - Quasi-optical (free space) front end to minimize RF loss
  - Noise subtraction
    - Detect signals that are ~15 dB below noise floor

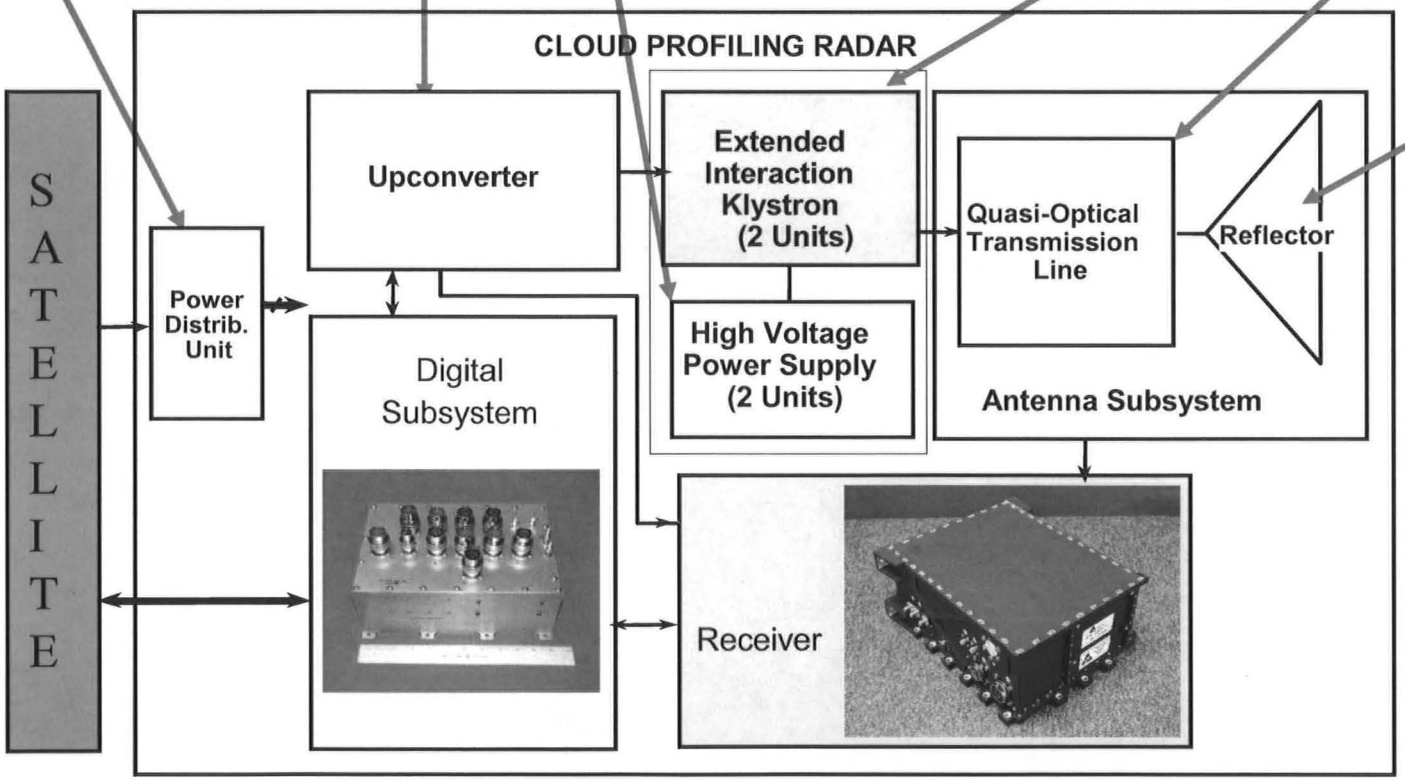
CPR Subsystems and Assemblies









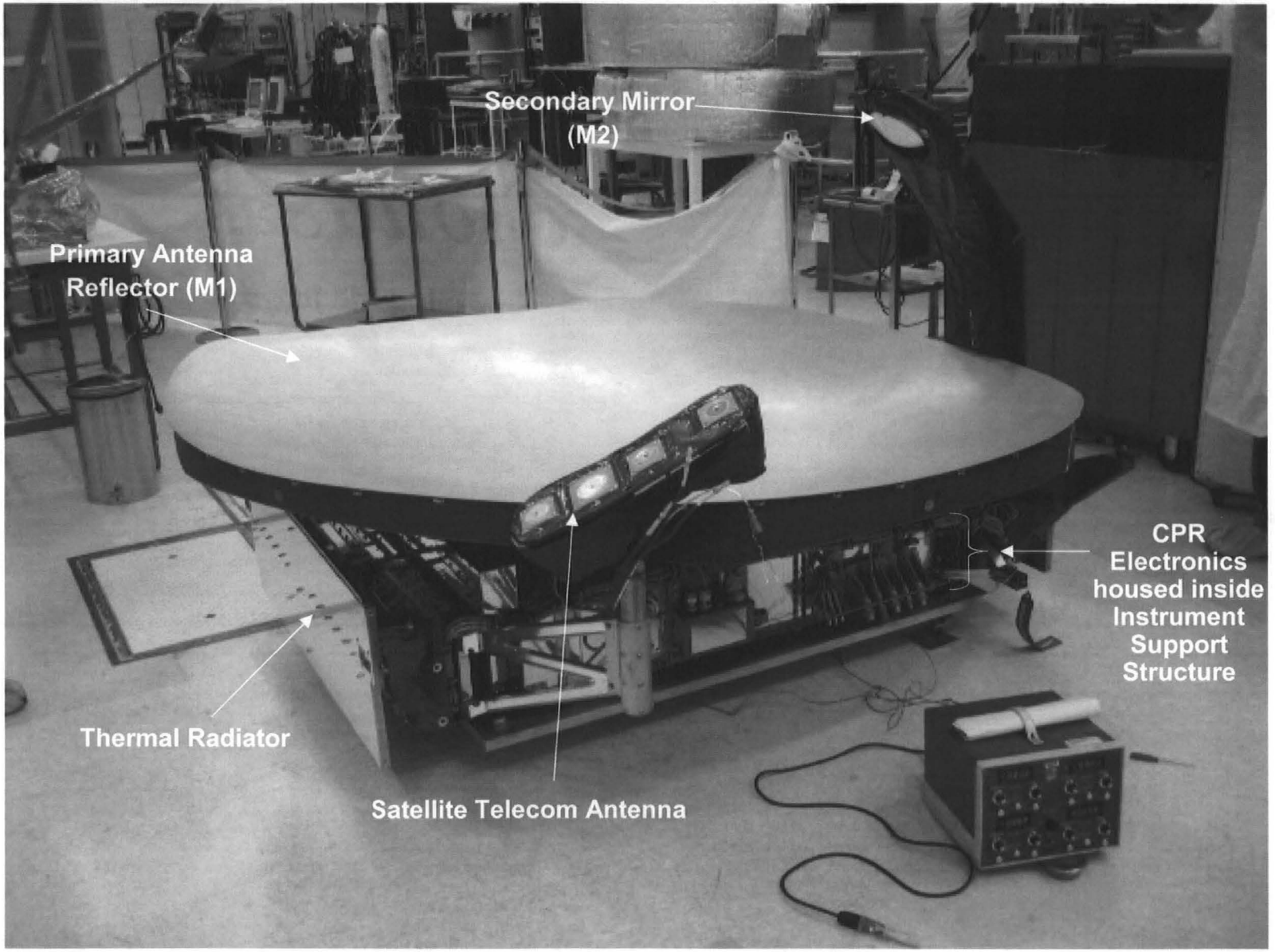


NASA/JPL

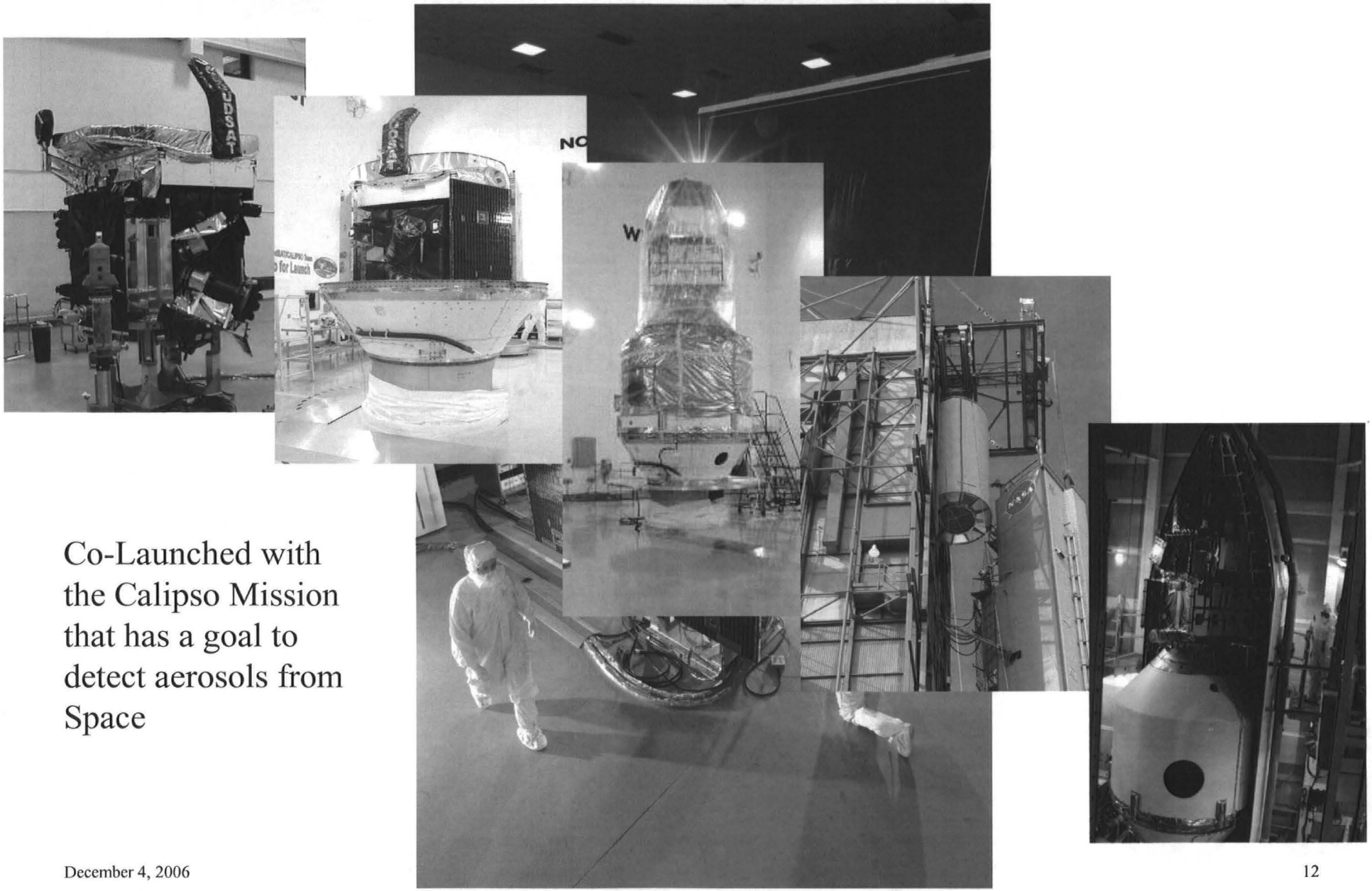
Canadian Space Agency

Ball Aerospace Co.

Integrated CPR Instrument



CloudSat Integration Process



Co-Launched with the Calipso Mission that has a goal to detect aerosols from Space

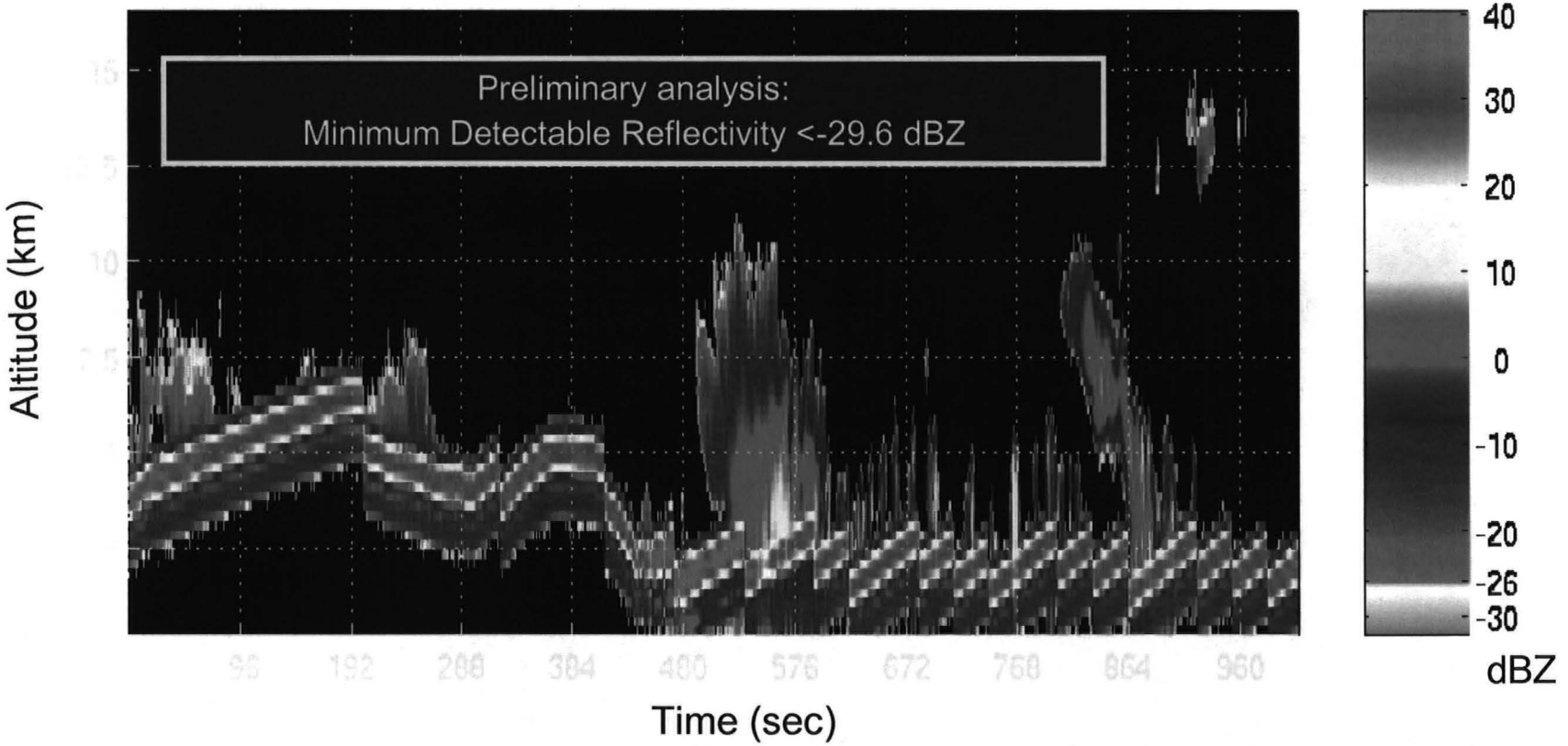
CloudSat Launch, April 28, 2006

CPR In-flight Operation History

- May 20, 2006 - CPR switched to Operate Mode for the first-time to check out science data collection functions and performance
- June 2, 2006 - CPR switched to Operate Mode permanently
  - CloudSat science data acquisition phase began
- June 6, 2006 - First CPR 10° clear-ocean Calibration exercise

Preliminary Assessment on Cloud Detection Sensitivity

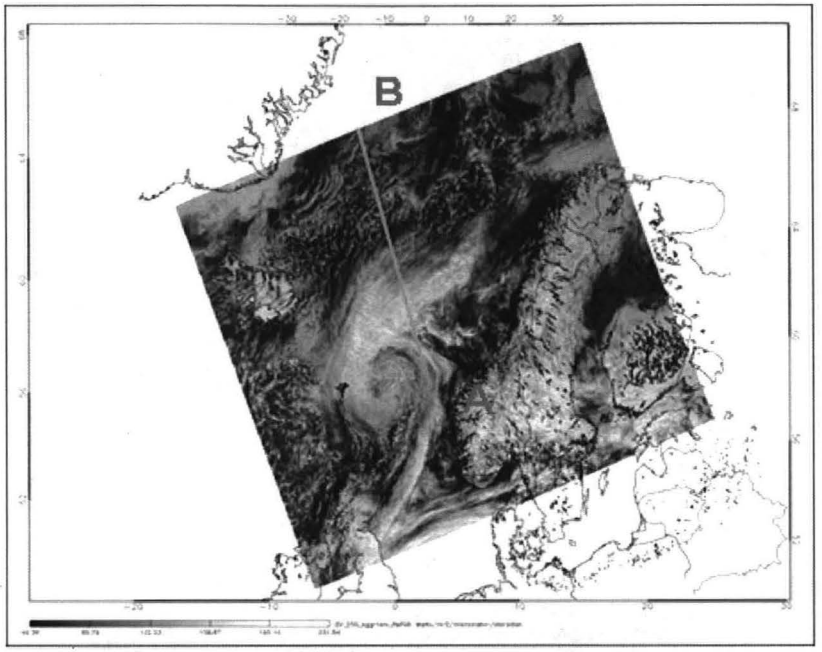
- Minimum Detection Sensitivity Requirement:
  - Detection Sensitivity to -26 dBZ cloud targets at EOL (i.e., at the end-of-life of 22-month primary mission)
- Pre-launch estimates: BOL -29.6 dBZ; EOL -28.4 dBZ
- Post-launch results are consistent with pre-launch estimates

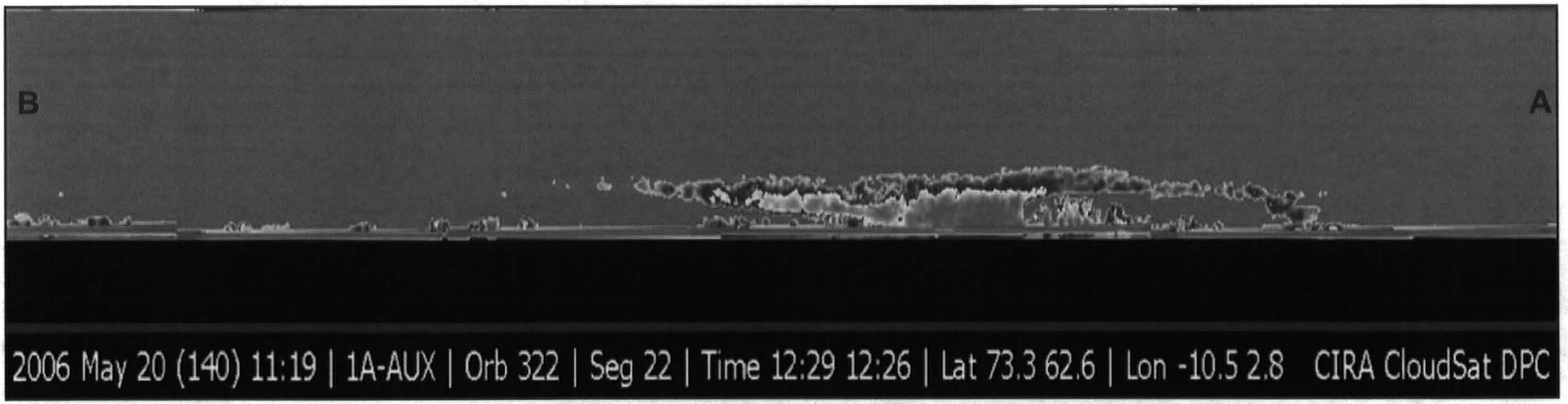


First Images of CPR on May 20, 2006 (1)

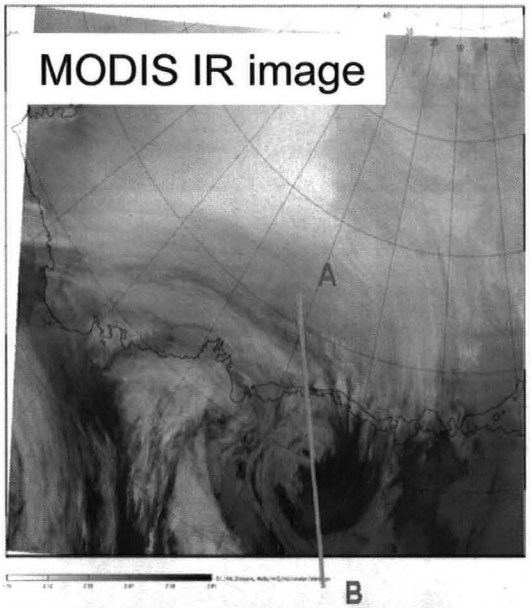
Warm Front Storm Over the Norwegian Sea: 12:26-12:29 UTC

MODIS Visible image



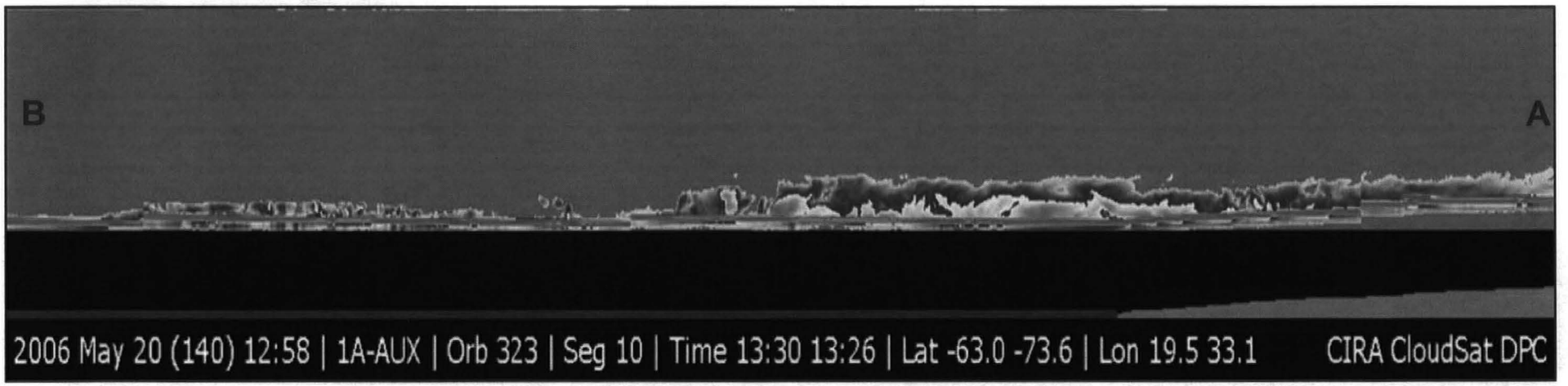


First Images of CPR on May 20, 2006 (2)



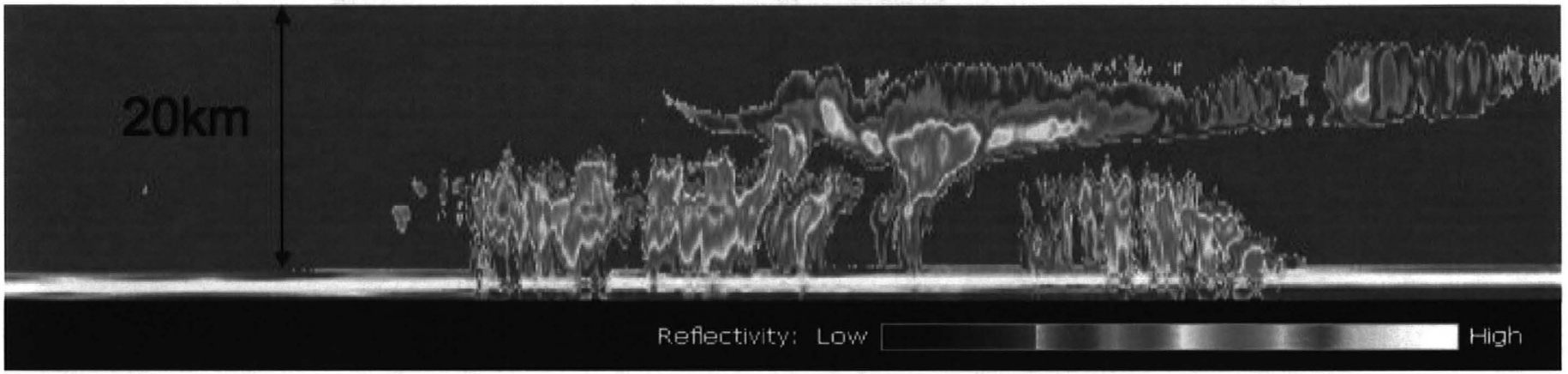
Polar Night Storm Near Antarctica: 13:26-13:30 UTC

CloudSat image of a horizontal cross-section of a polar night storm near Antarctica. Until now, clouds have been hard to observe in polar regions using remote sensing, particularly during the polar winter or night season.



CPR measured "Hidden" Precipitation
June 10, 2006

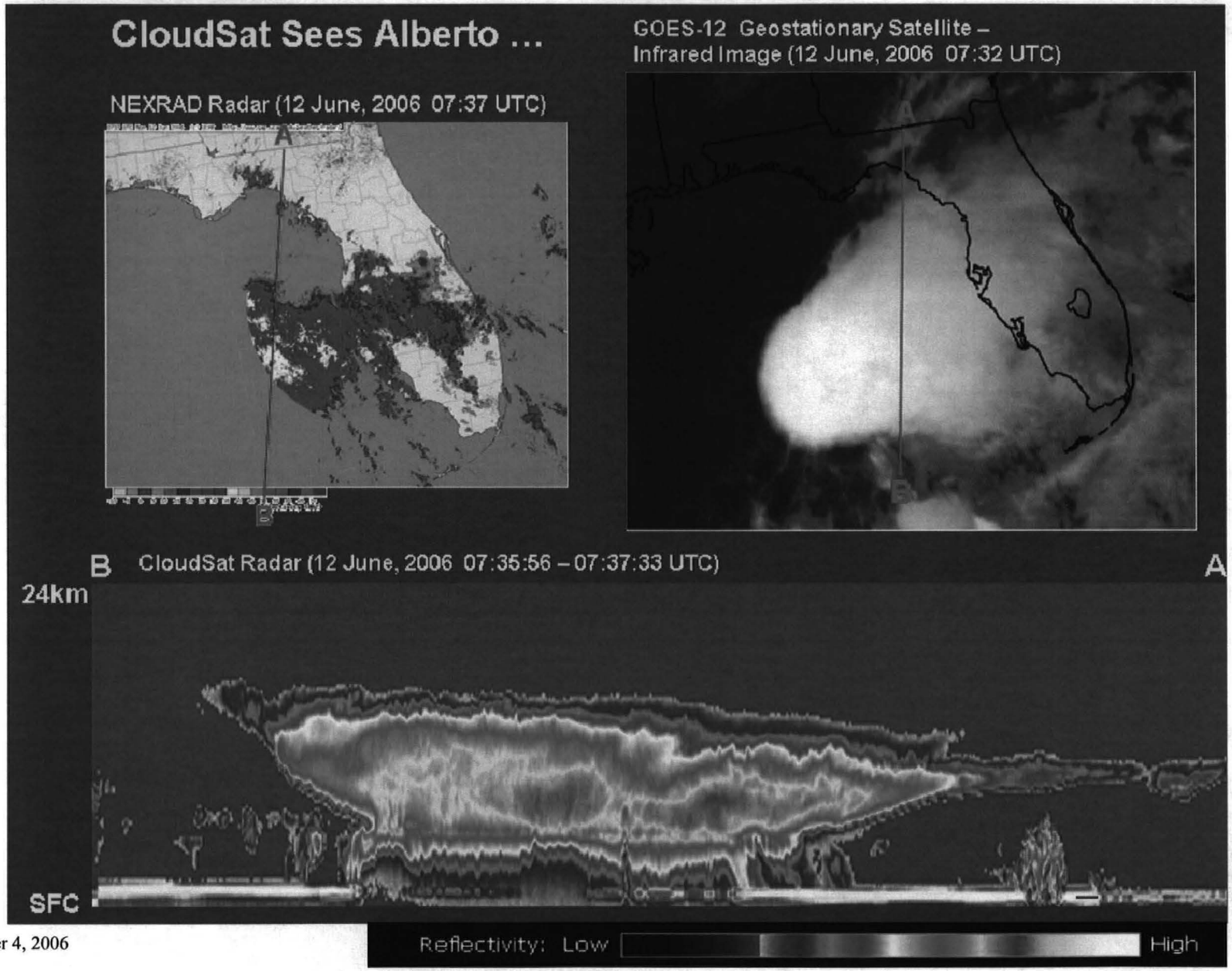
Tropical convection over equatorial mid-pacific, 6/10/2006



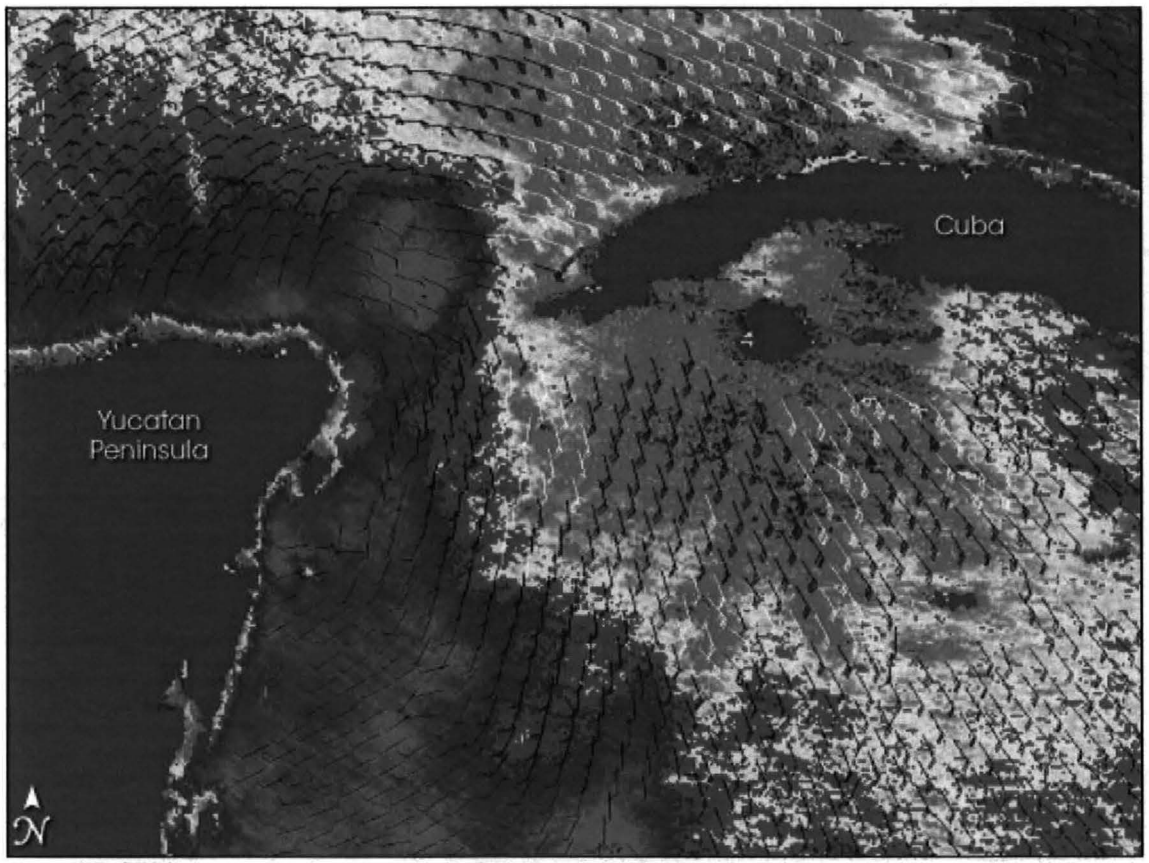
800 km

This image shows the CPR view of both clouds and precipitation. A thick layer of cirrus cloud was observed above about 10 km overlying shallow convection. This cirrus was generated as outflow from a deeper thunderstorm.

CPR Observations in Tropical Storm Alberto June 12, 2006

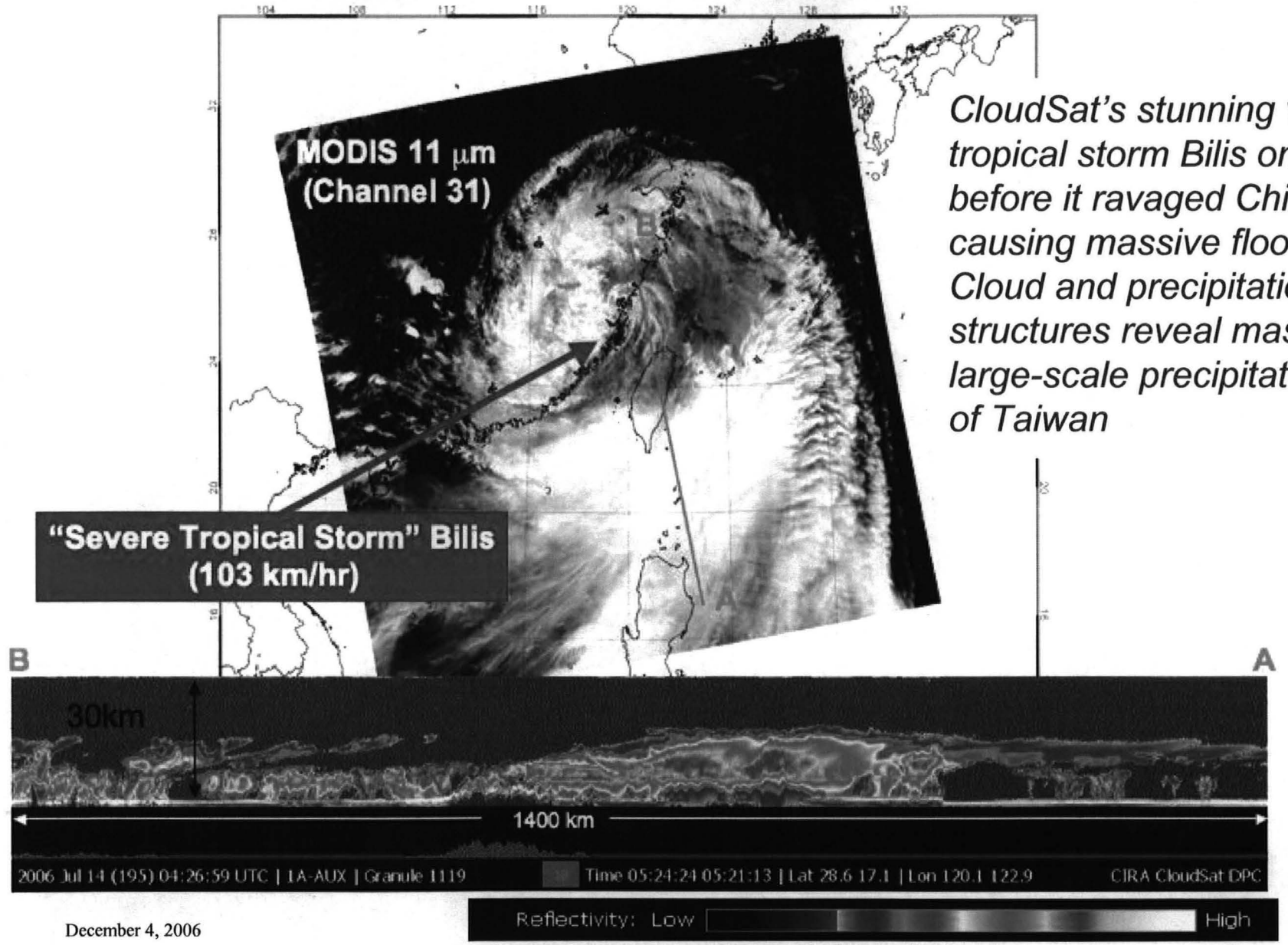


Tropical Storm Alberto as seen by QuikScat



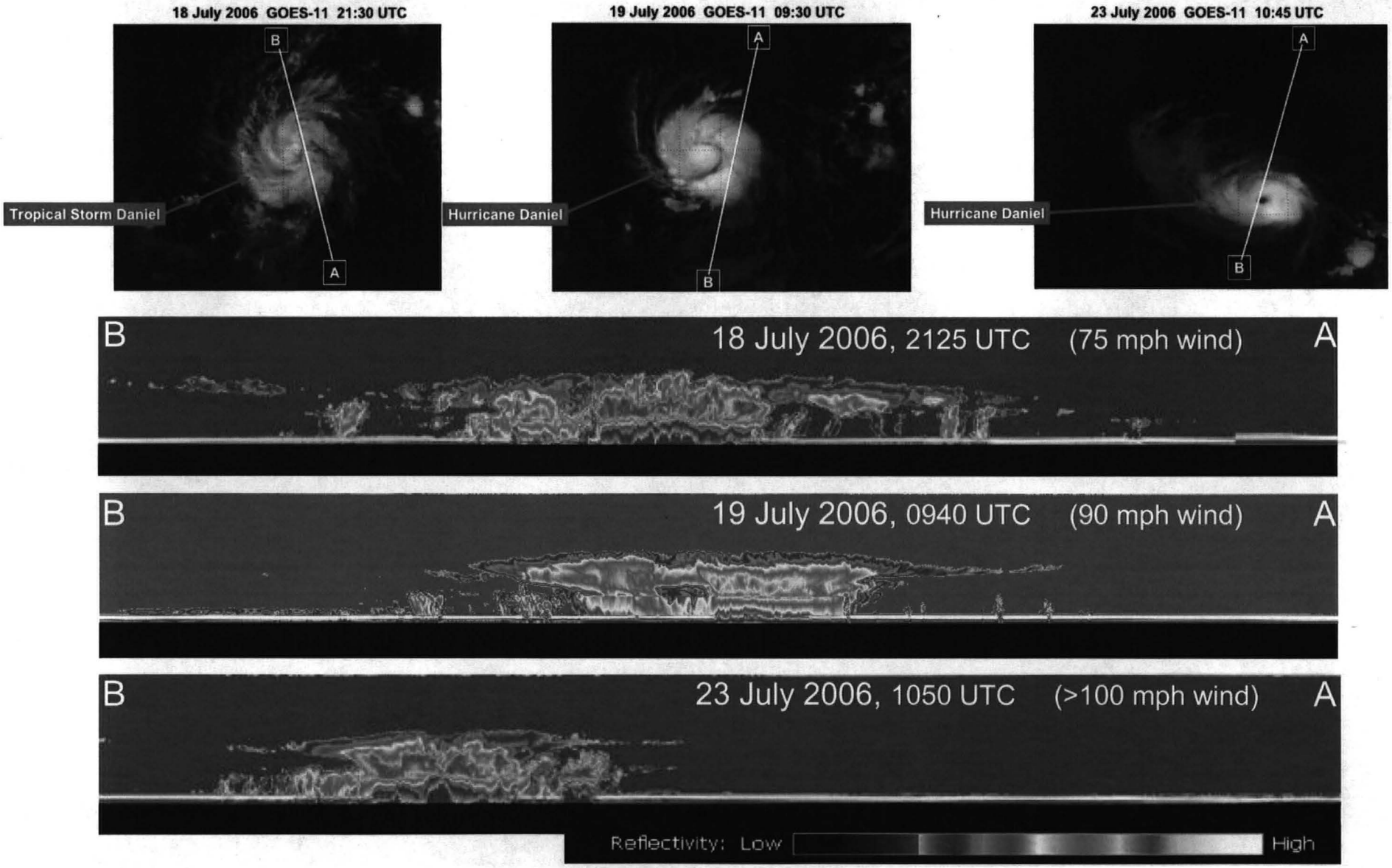
Tropical Storm Alberto
Tropical Storm Alberto formed as a tropical depression early in the morning on June 10, 2006, in the Yucatan Channel.

CPR Observation of Tropical Storm Bilis
July 14, 2006



CloudSat's stunning view of tropical storm Bilis on July 14th before it ravaged China causing massive flooding. The Cloud and precipitation structures reveal massive large-scale precipitation south of Taiwan

CPR Observations of Hurricane Daniel July 18-23, 2006



CPR Observation of Mushroom Cloud in Storm 06W, July 24, 2006

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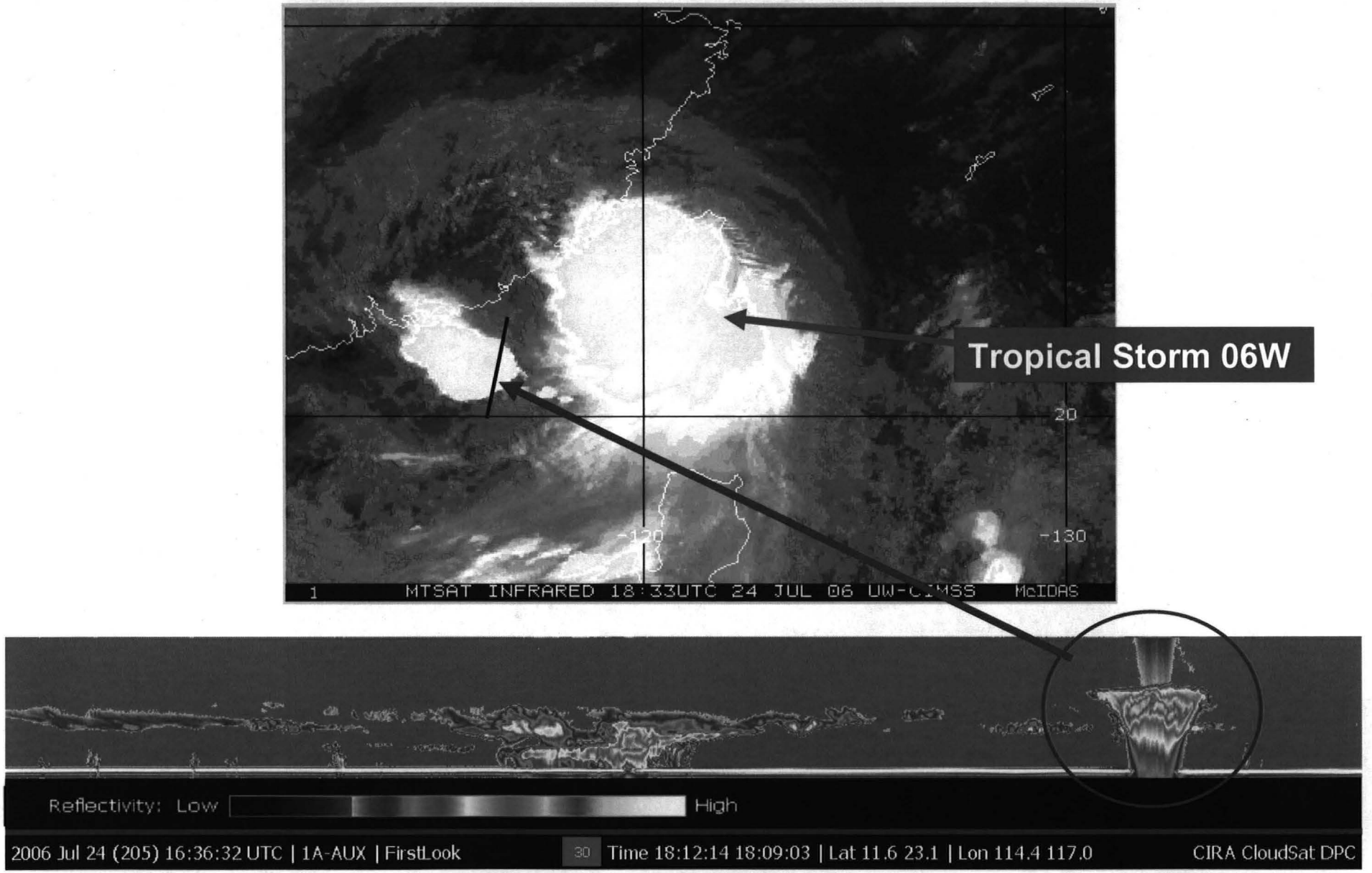
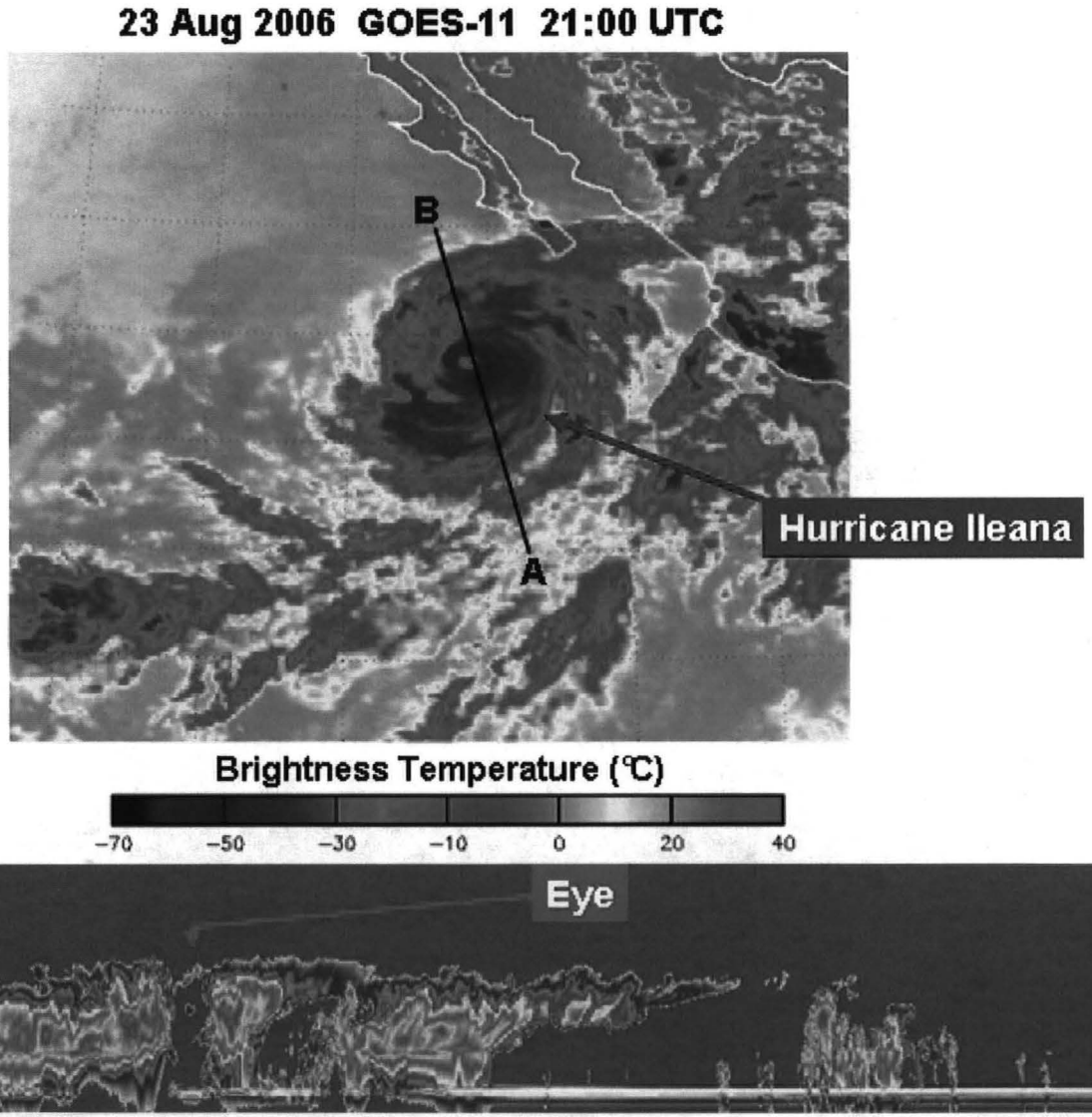


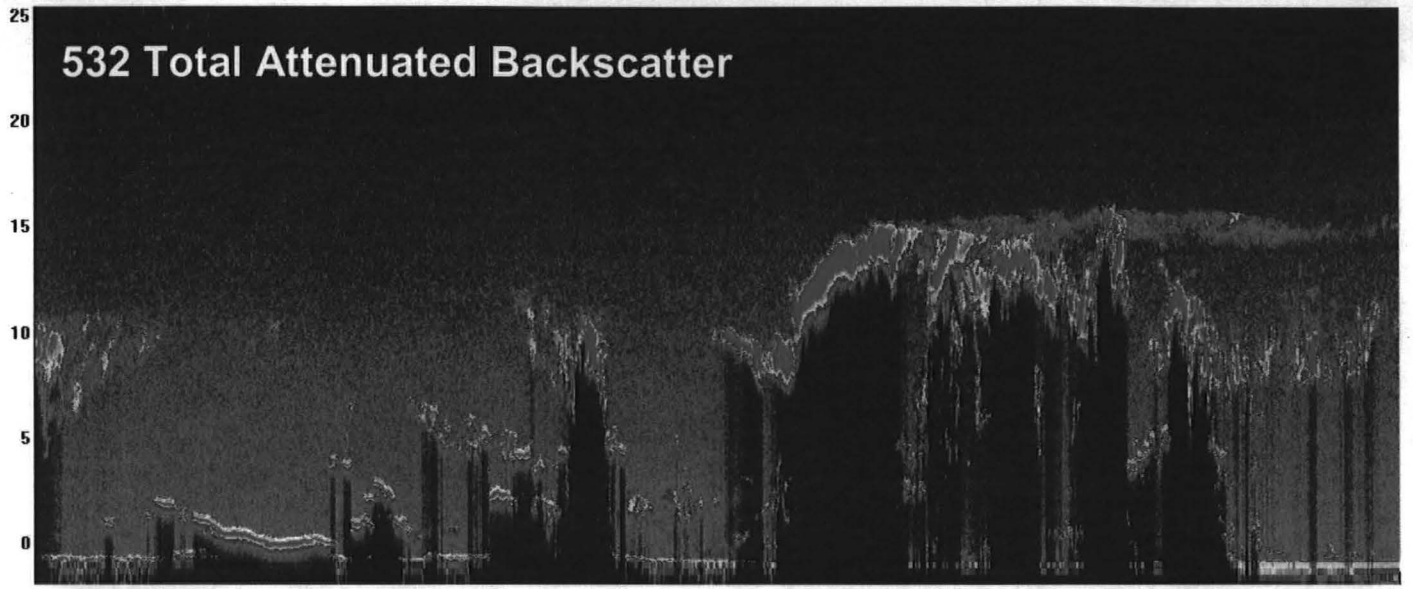
Satellites Catch Eye of Ileana

08.25.06 - These two images are from two different satellites, giving a top-down and sideways view of Hurricane Ileana as she spins in the eastern Pacific on Aug. 23, 2006.

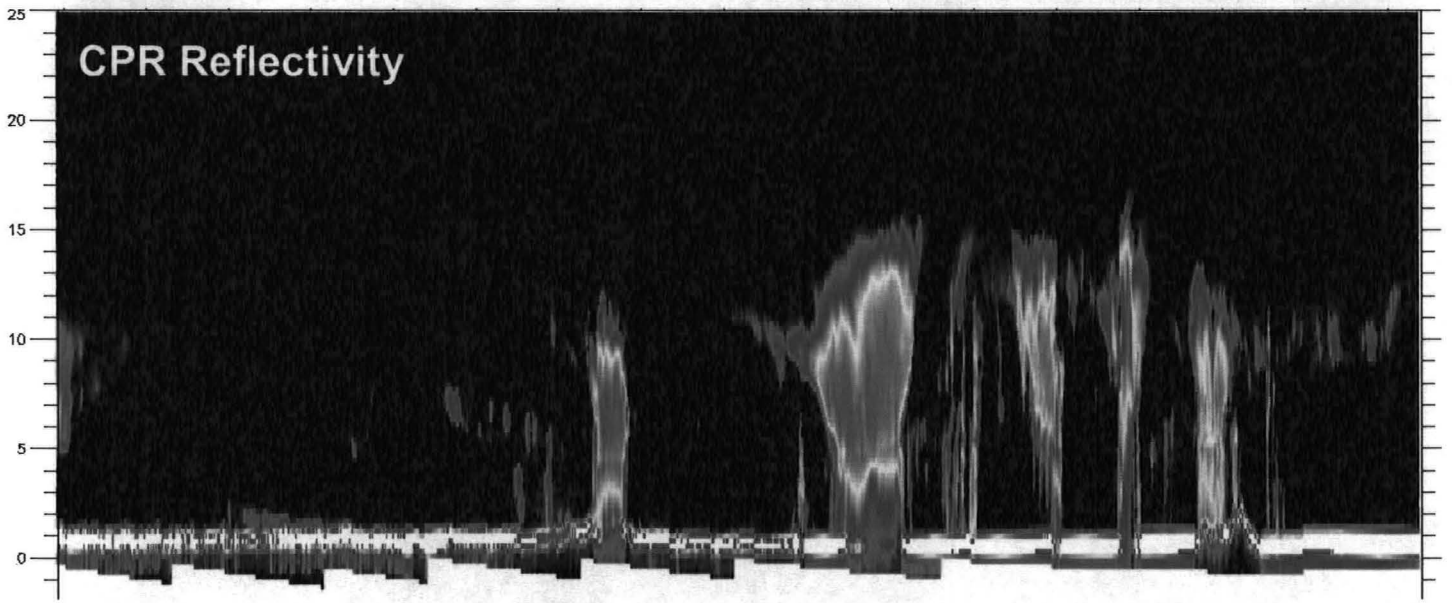


Early Comparison Between CloudSat Radar and Calipso Lidar Observations

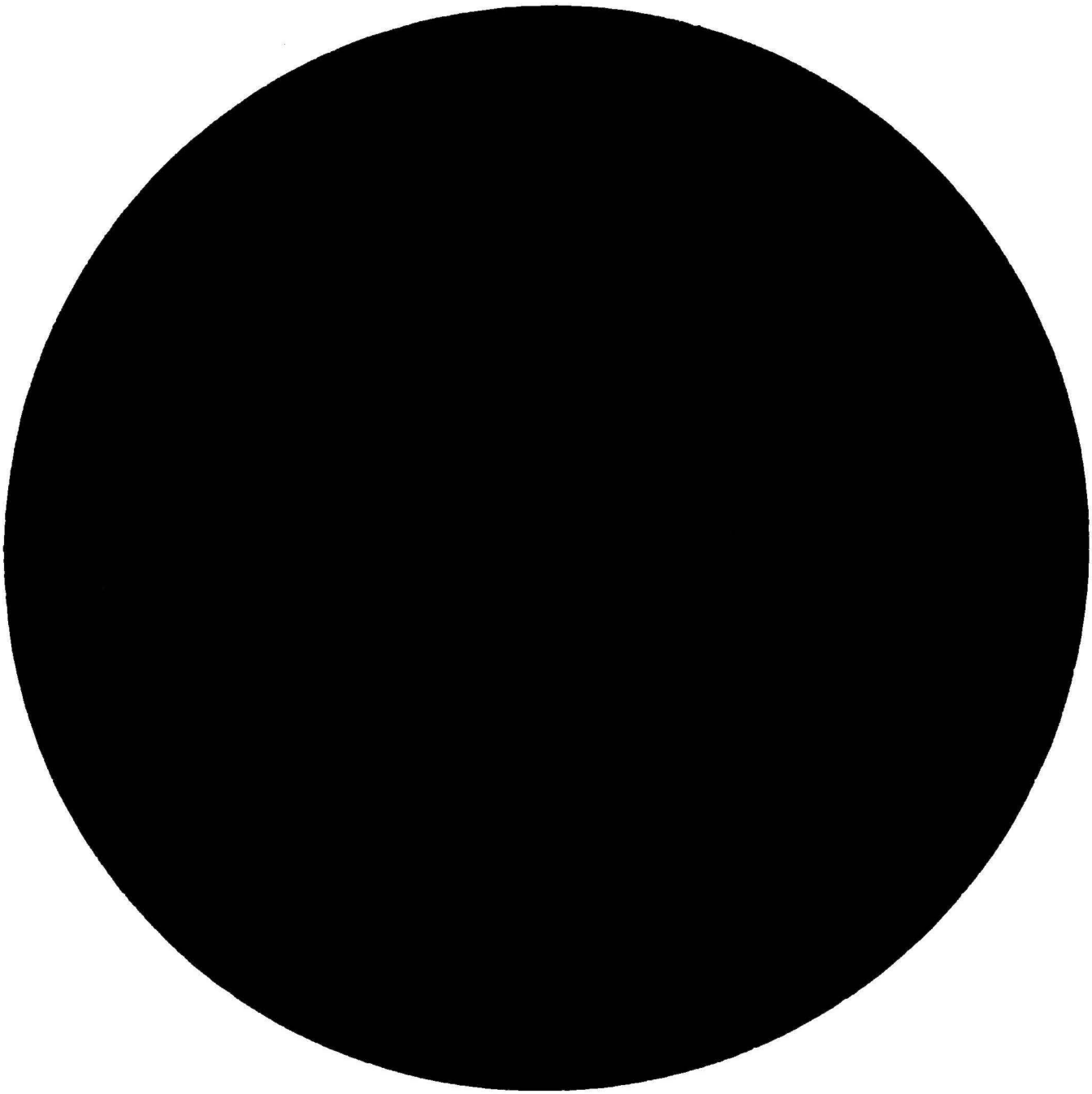
CALIPSO



CloudSat



Concluding Remarks on CloudSat

- CloudSat is a joint US/Canadian spaceborne science mission for global measurements of atmospheric cloud structures
- After a brief checkout period, the CloudSat payload, the Cloud Profiling Radar (CPR), has been acquiring science data continuously
- Engineering assessment thus far indicates that CPR has achieved the required measurement sensitivity
- The measured ocean surface NRCS from the first clear-ocean calibration exercise appears to be consistent with published airborne results
- CPR has already captured many stunning profiles of cloud/precipitation structures, some have not been seen before
- Observation of storms' cloud formation, in conjunction with data from other remote sensors, will hopefully improve quality of natural hazards' forecasts.

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