In-Flight Performance of the CloudSat Radar

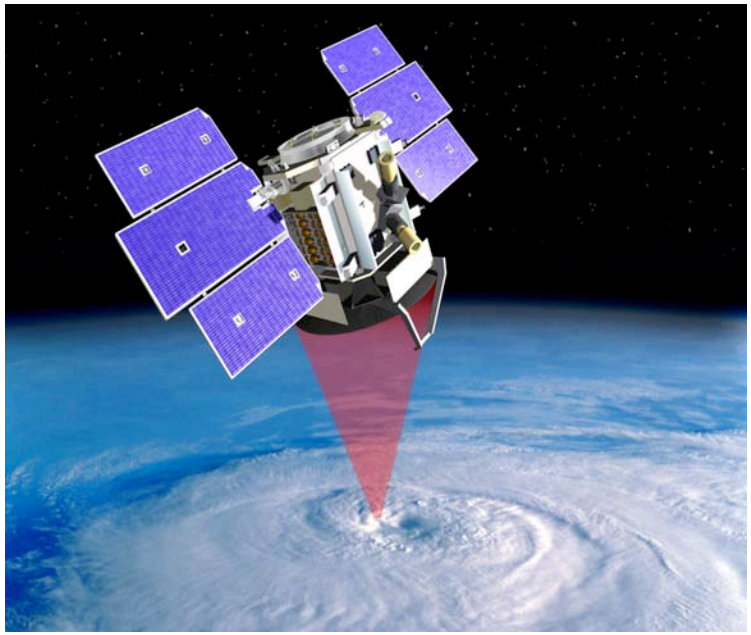
E. Im, S. Tanelli, S.L. Durden , K. Pak
Jet Propulsion Laboratory
EarthCARE Workshop, May 7-9, 2007

CloudSat Mission Overview

A NASA EARTH SYSTEM SCIENCE PATHFINDER MISSION

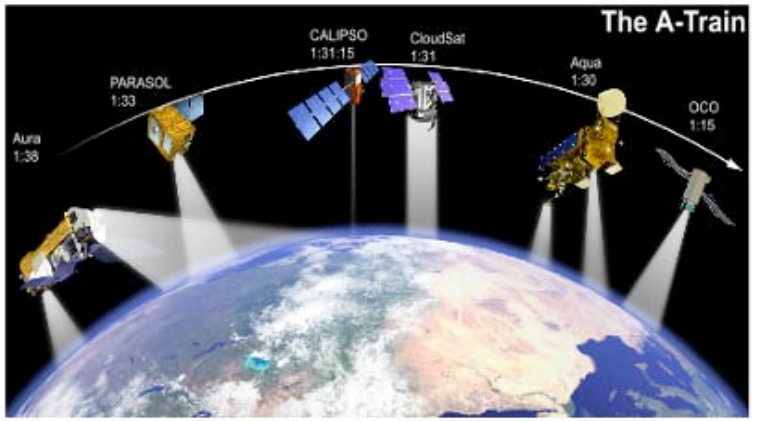
Mission Features

- *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*
- *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*



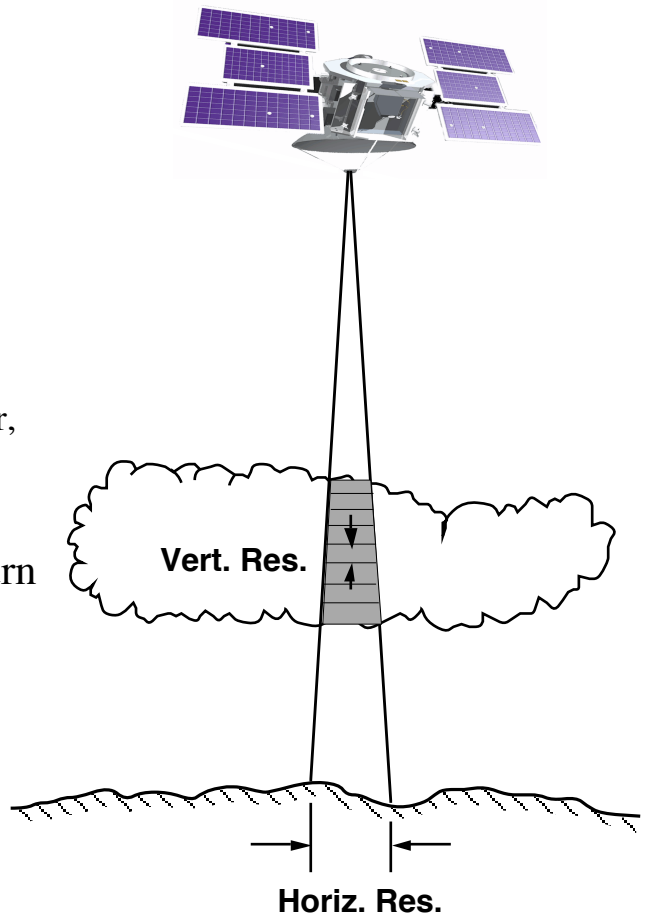
Objectives

- *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*



CPR Overview

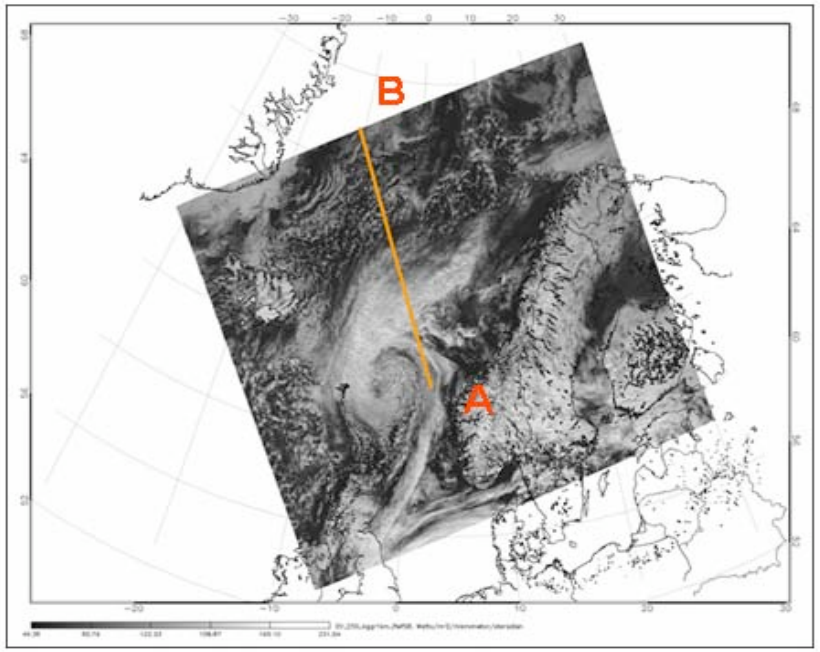
- Nadir-pointing 94-GHz radar
  - Measure cloud reflectivity vs. altitude profile along nadir track
- One science operation mode
  - Vertical resolution ~500 m
    - Transmits 3.3-μs monochromatic pulses
  - Horizontal resolution ~1.4 km
    - Uses 1.85-m dia. antenna
  - Sensitivity of -28 dBZ (nominal) is achieved by:
    - High peak power, large antenna, low-noise receiver, and pulse-averaging
  - Dynamic range: 80 dB
    - 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

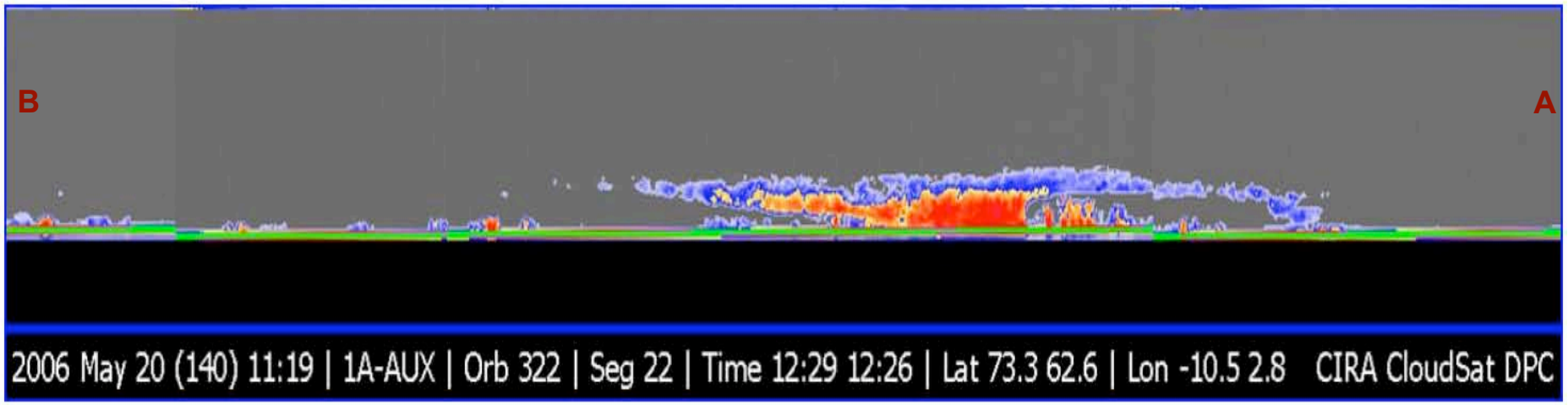


First Image of CPR on May 20, 2006

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

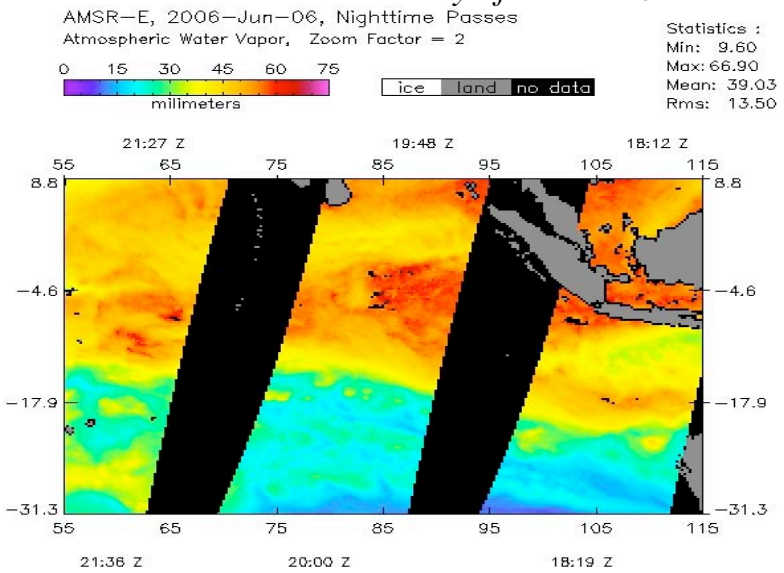
MODIS Visible image

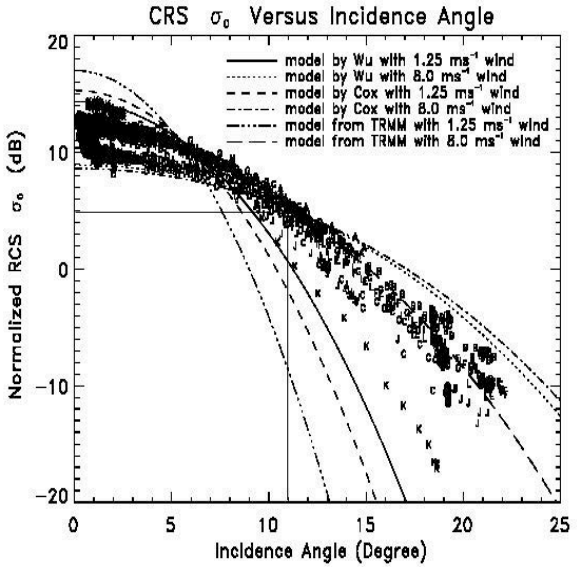




External Calibration

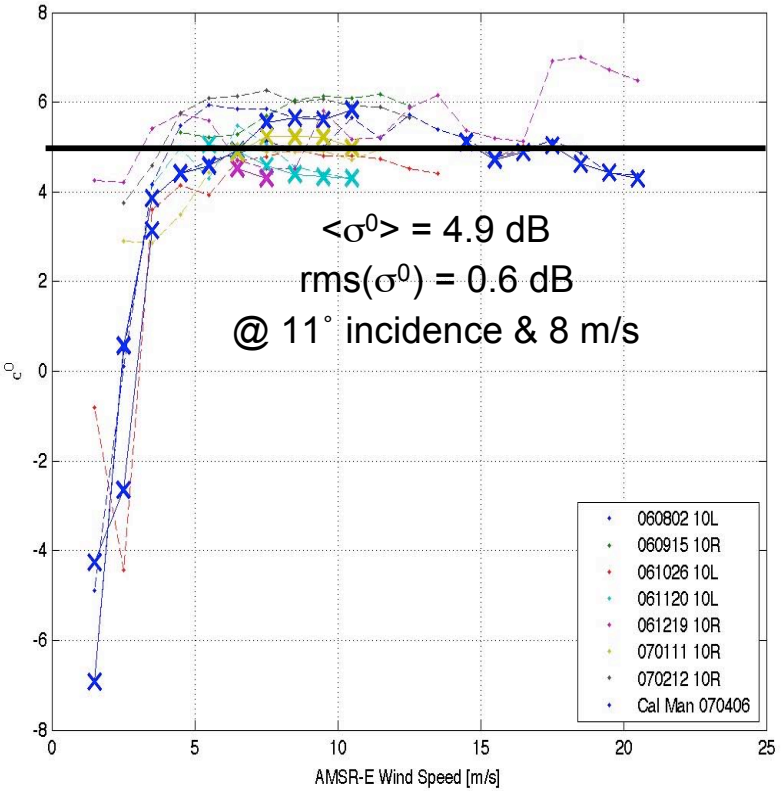
AMSR-E data: Courtesy of F. Wentz



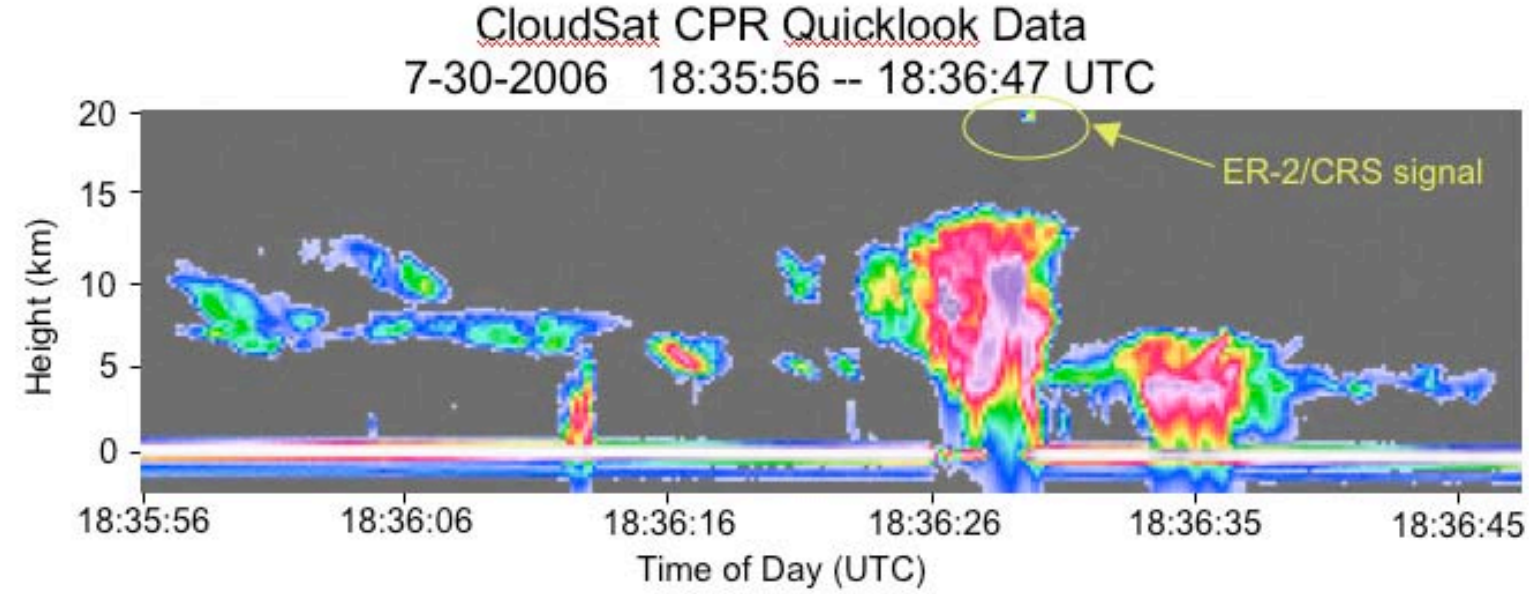


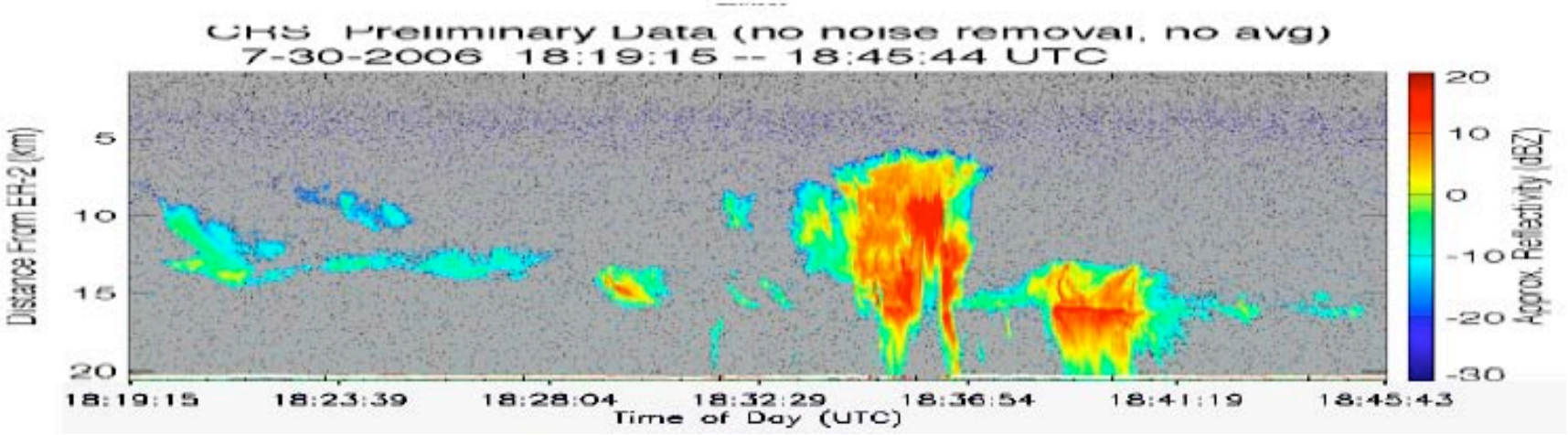
(Li et al., JTECH, 2005)

- Requirement: 2 dB
- CPR Pre-launch Calibration budget: 1.8 dB
- Monthly calibration maneuvers: the antenna points 10˚ cross-track (resulting in 11˚ incidence angle) for 5 minutes over ocean and clear air
  - Correct for surface range sampling error in surface backscatter power
  - Correct for gaseous attenuation based on AMSR-E retrievals

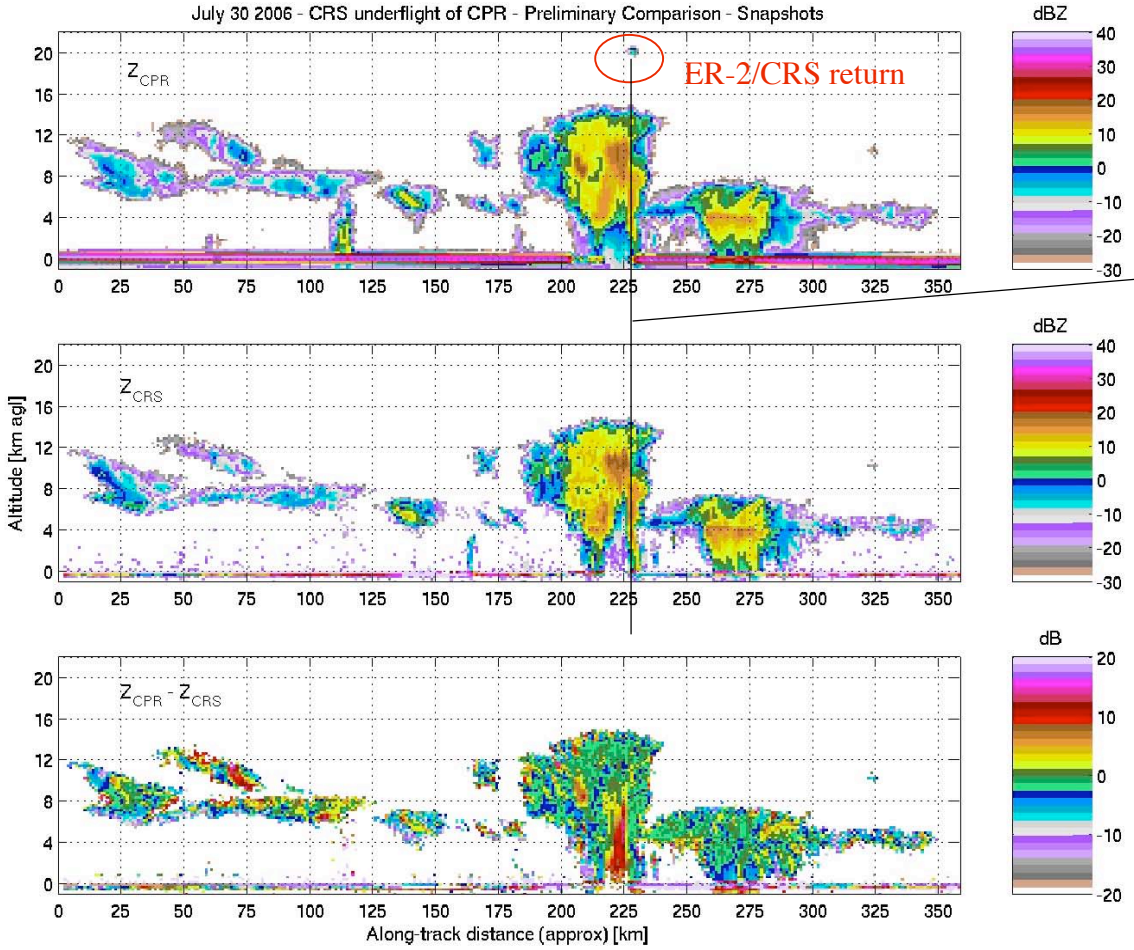


Preliminary Comparison of CPR and Airborne Cloud Radar Measurements (1)

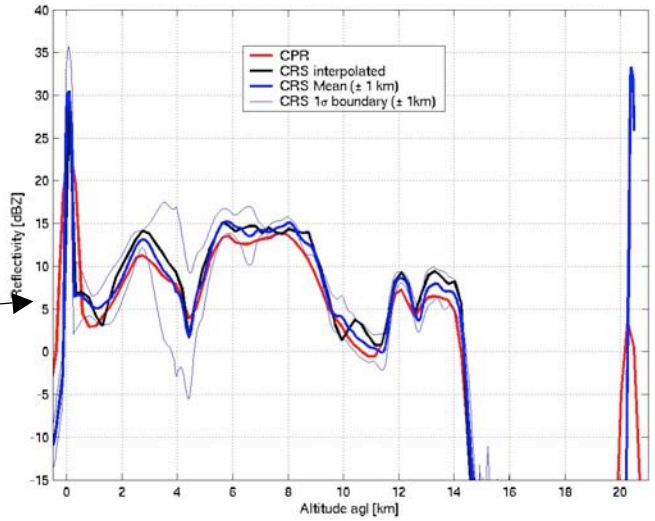




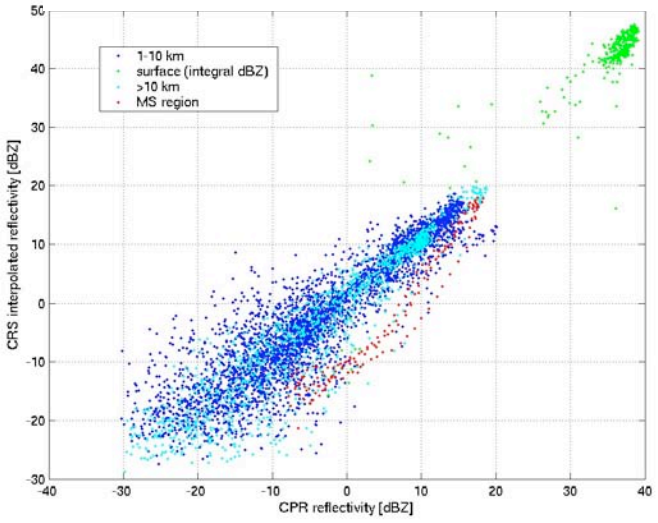
Preliminary Comparison of CPR and Airborne Cloud Radar Measurements (2)



Co-located profiles



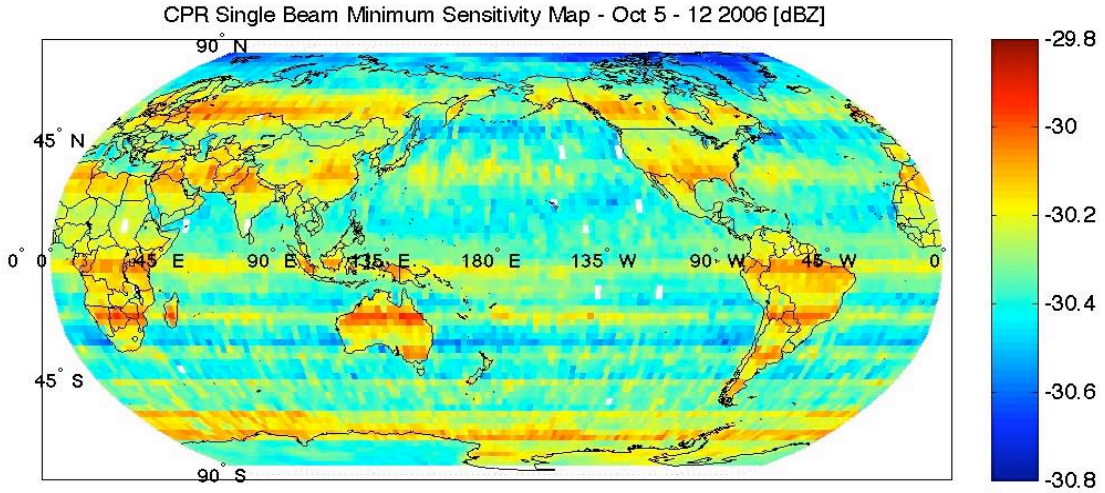
Scatter plot of entire scene



CPR Minimum Detectable Reflectivity Factor

- Minimum detectable Z is not constant over the globe and across the seasons. It depends on:
  - Radiometric temperature of the observed scene (~0.8 dB swing)
  - Number of pulses per averaging period (latitude dependent)
  - Algorithm used to estimate noise floor
  - System overall performance (no hardware degradation so far)

- Example: Pre-launch tuning & calibration coefficients, 2.4-km along-track integration
  - Minimum detectable reflectivity in the -30 to -31 dBZ range

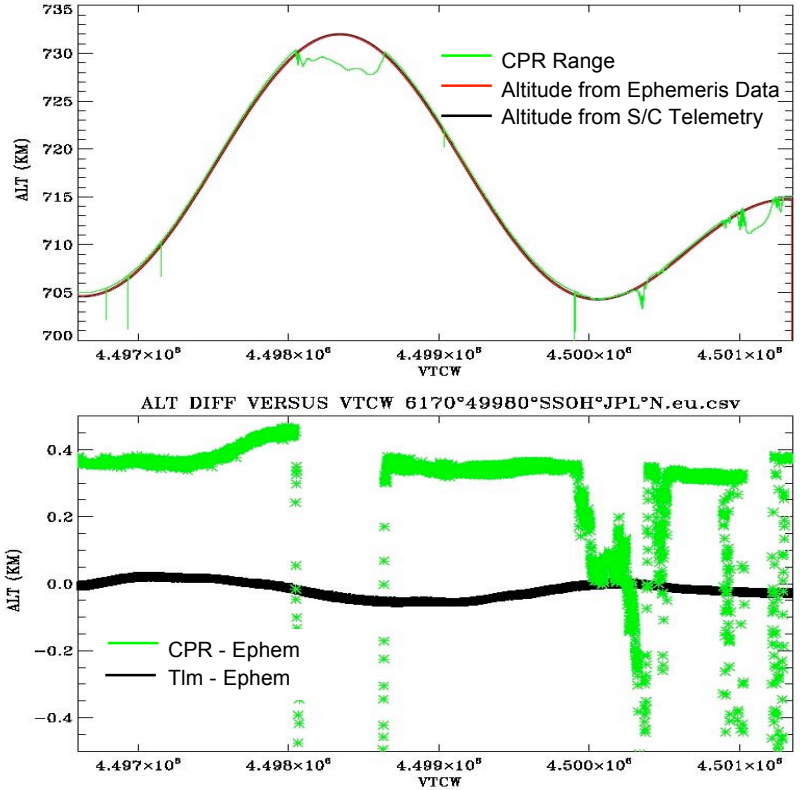


  - Scaled for EarthCARE scenario: -36.8 to -37.8 dB
    - 450-km altitude: 3.8 dB
    - 10-km integration: 3 dB

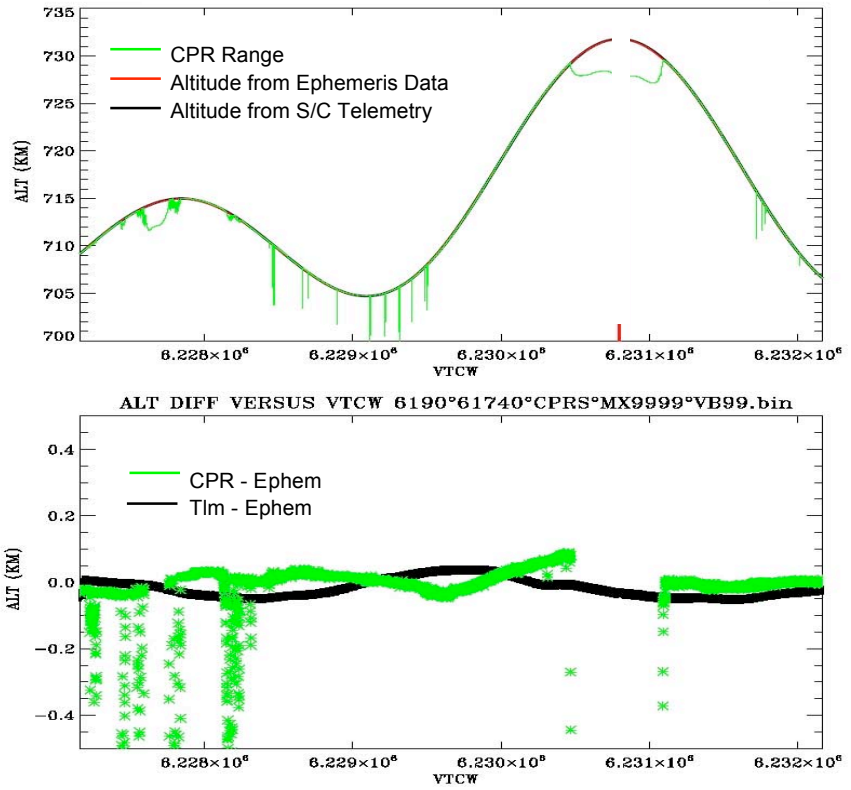
Correction of Pointing Error and "3-sec" offset

- Soon after CPR was in operations, a "3-sec" offset between CPR-deduced land topography and reference topographic database was detected
- Using CPR ranging ("nadir" & 10° calibration) and spacecraft ephemeris data, CPR Team determine the offset was duw to radar beam pointing: 1.707° along-track and 0.128° cross-track
- Shortly afterward, Spacecraft Team discovered a "sign" error in quaternion matrix calculation, resulting in 1.707° along-track and 0.127° cross-track point errors
- Later, CPRsurface ranging/backascttering data confirmed the correction of the pointing errors.

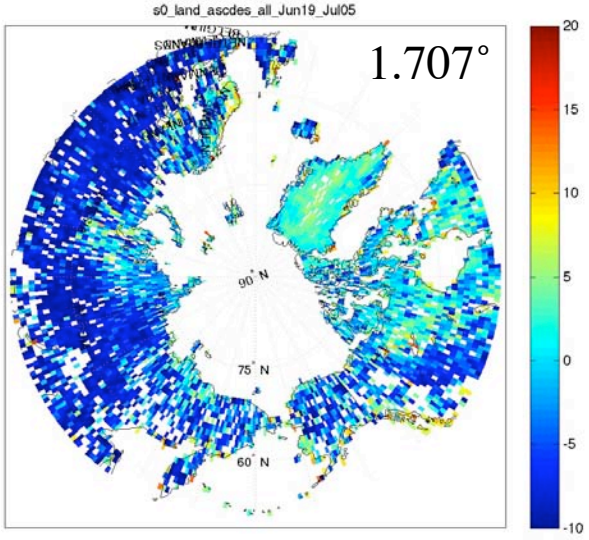
Before Pointing Correction



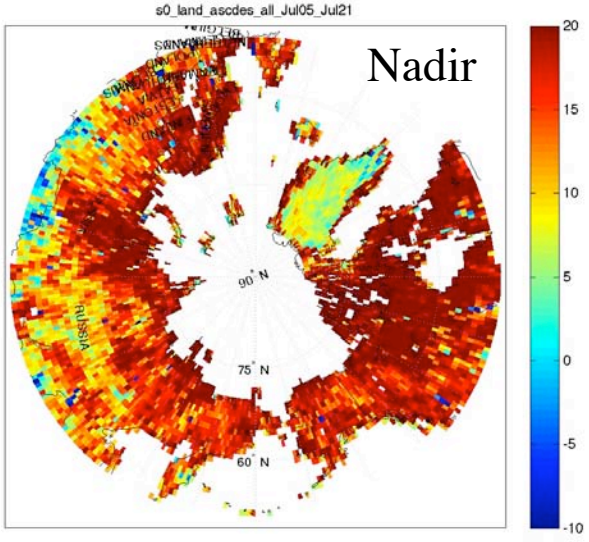
After Pointing Correction

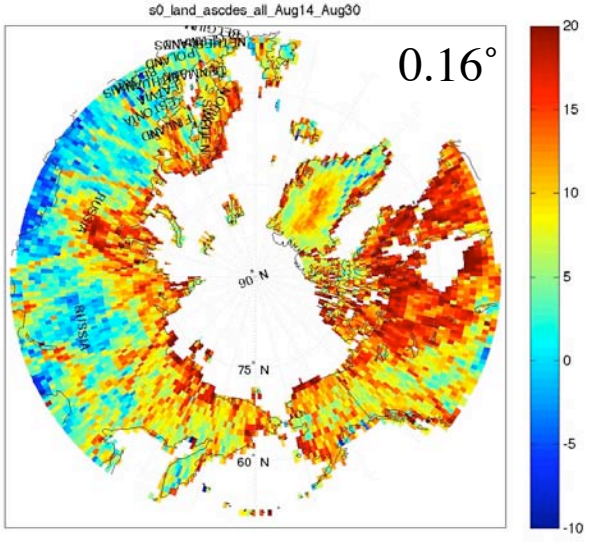


CPR Pointing and Specular Returns



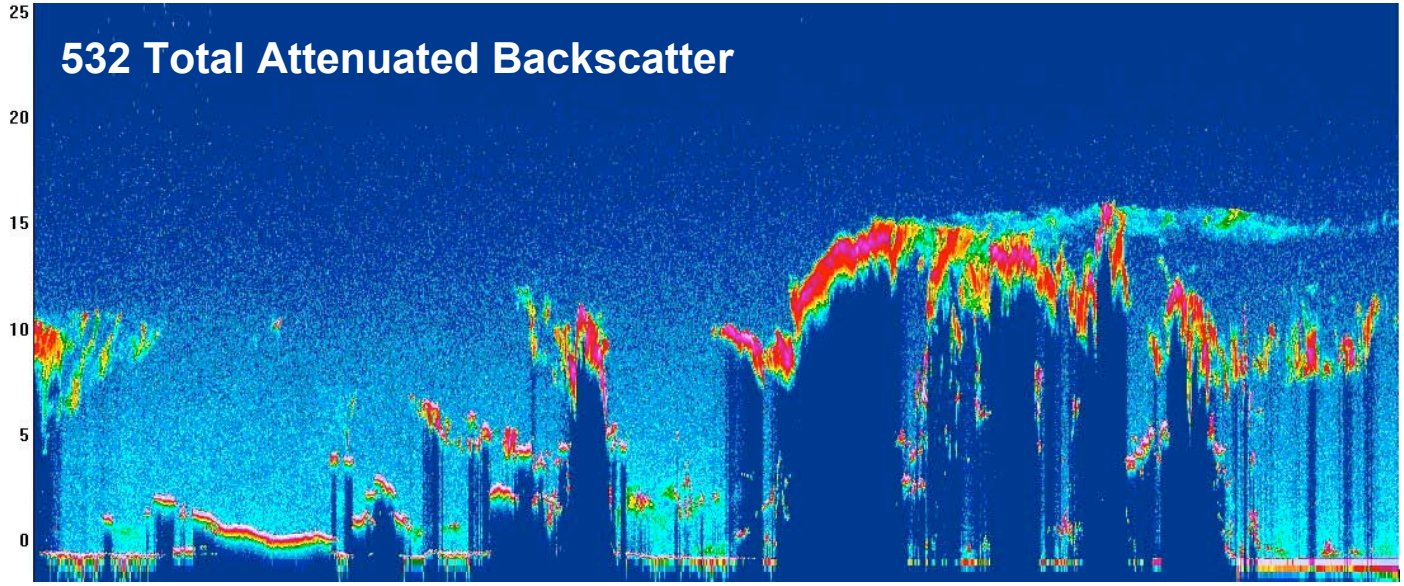
- Pointing is verified by presence of specular returns
  - 1.707° -- During pointing offset
  - Nadir
  - 0.16° -- Final pointing
    - This angle corresponds to the first null of antenna pattern



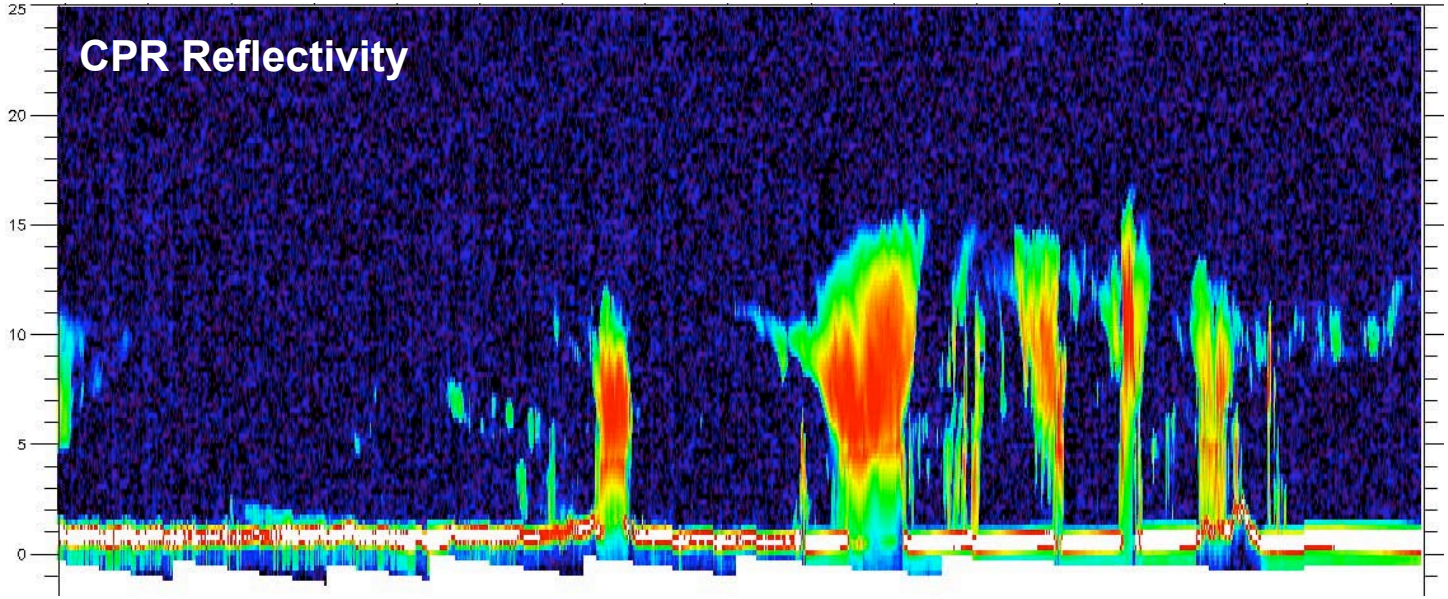


Early Comparison Between CloudSat Radar and Calipso Lidar Observations

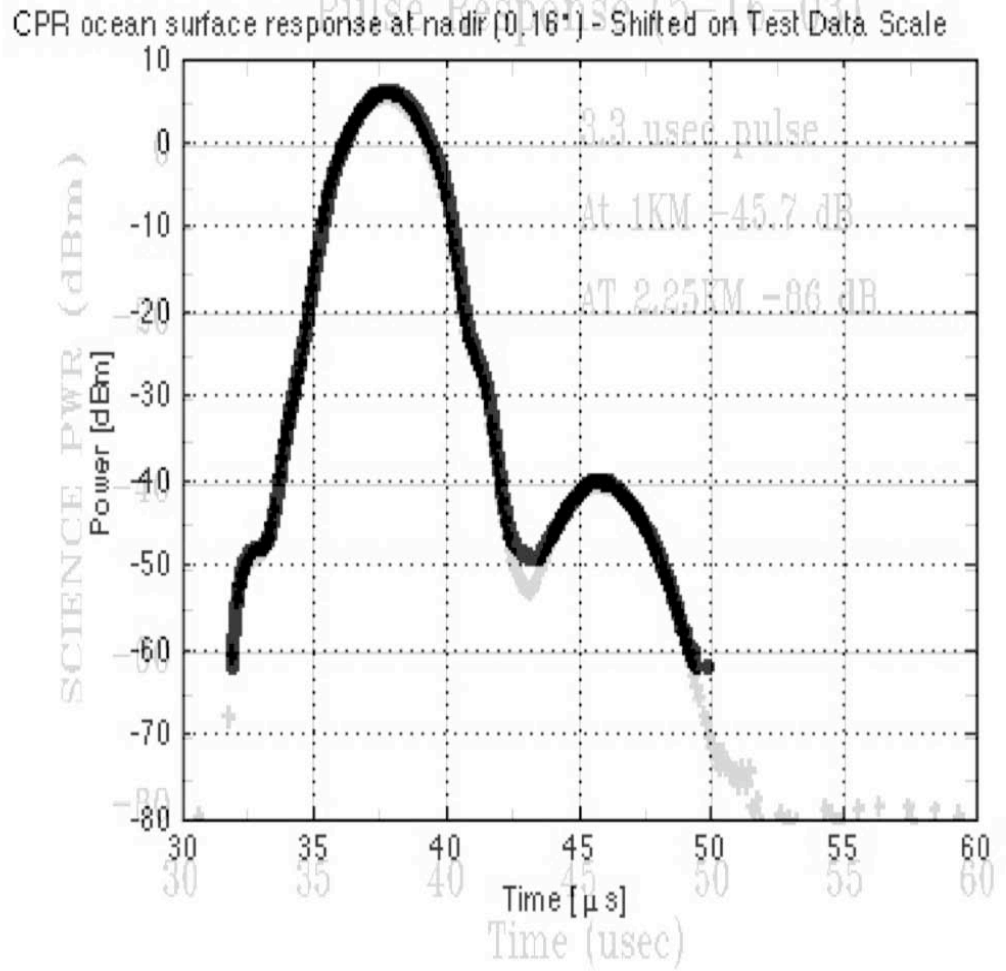
CALIPSO



CloudSat



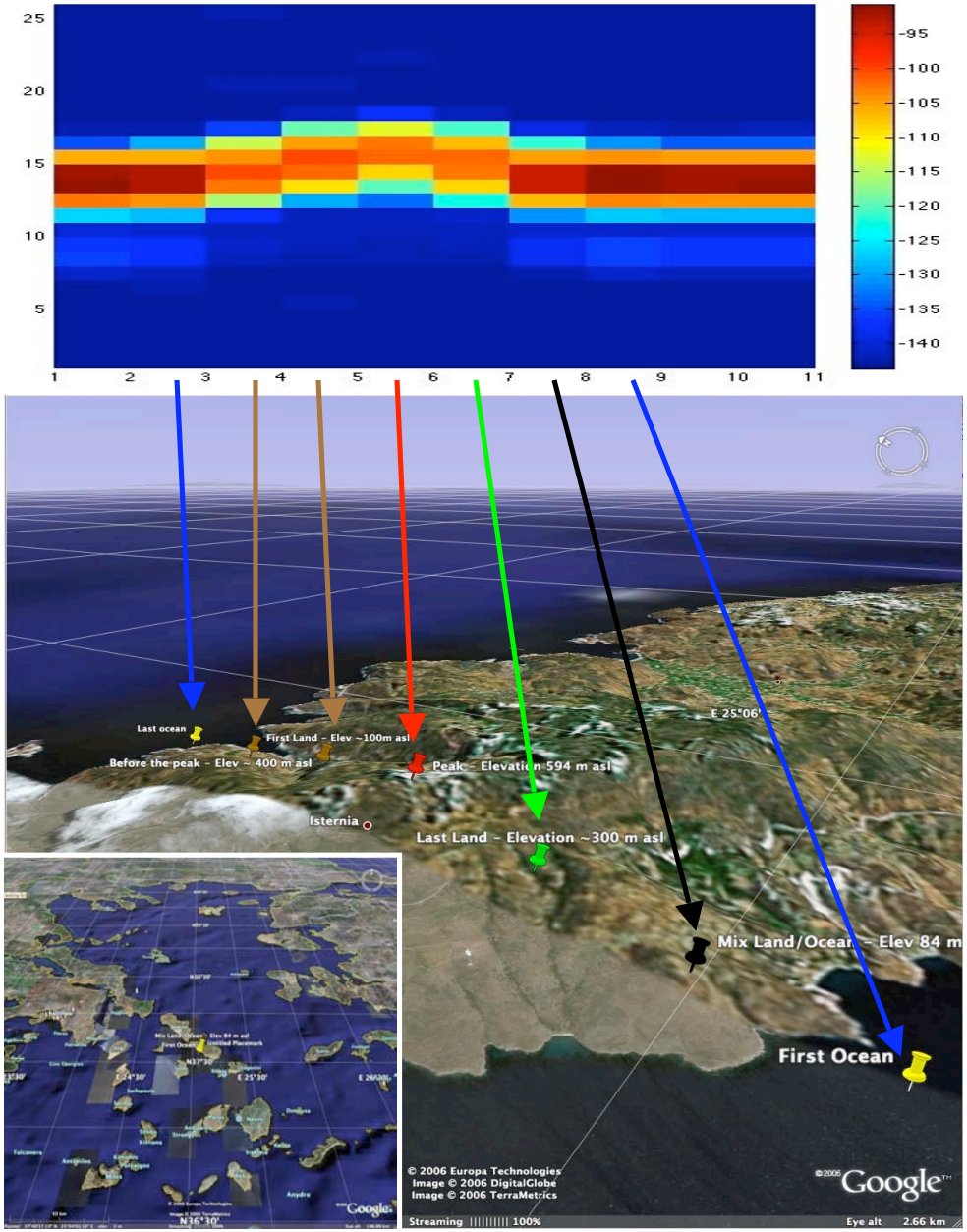
CPR Sea Surface Response



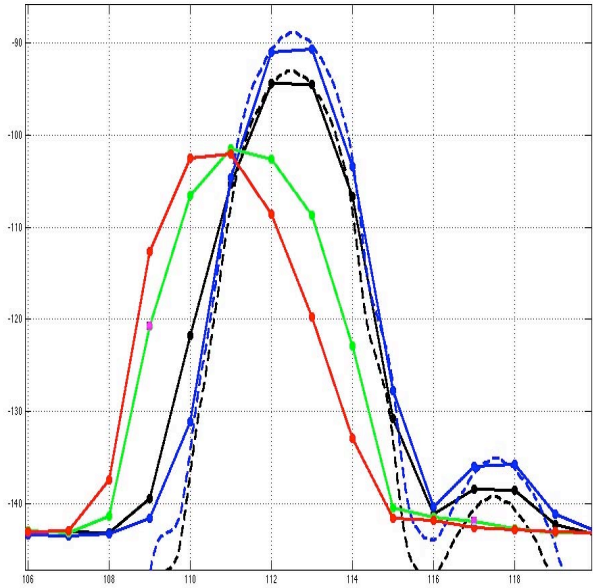
Grey: prelaunch measured point response
Black: flight-measured surface response

- Sea surface response was reconstructed from data at 1/100 bin resolution (~2.4m)
- Shape matches pre-launch measured impulse response

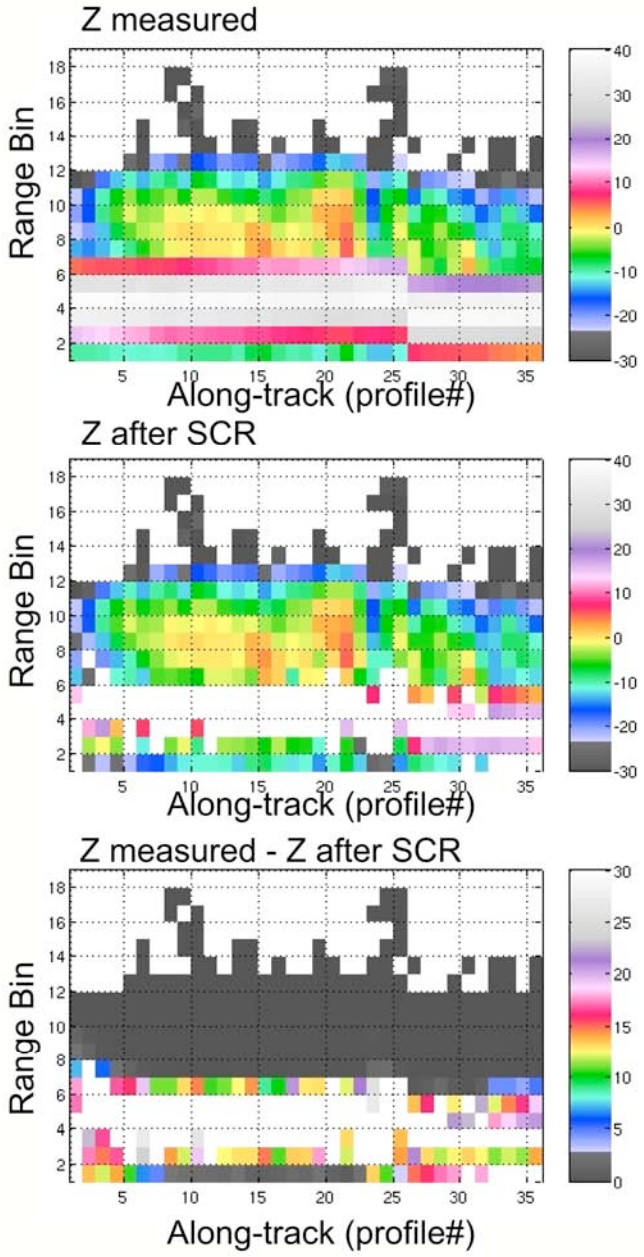
Surface Clutter over land

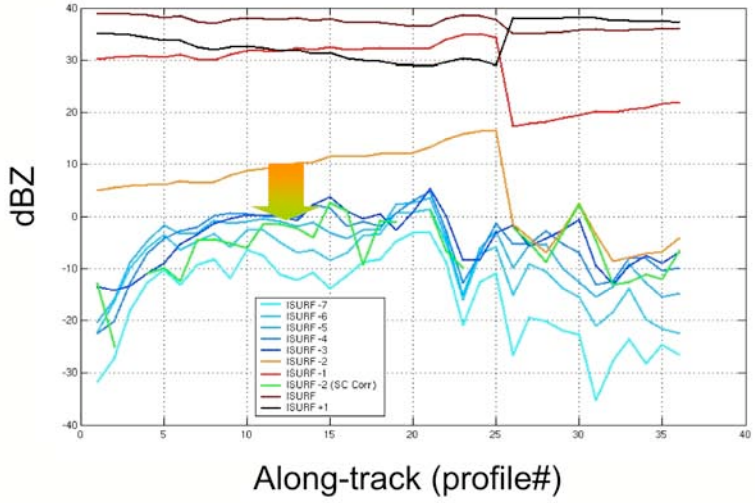


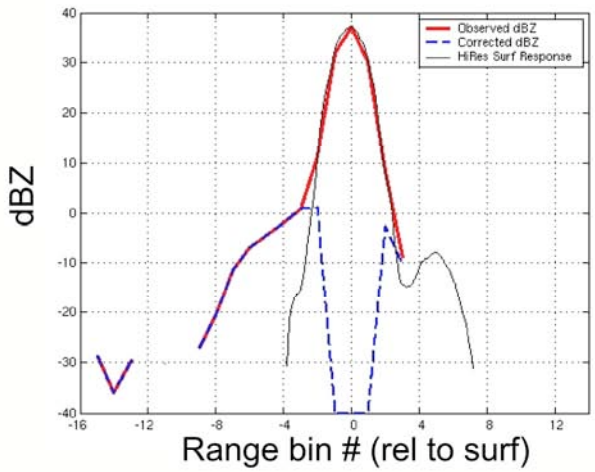
- L1B geolocated surface response compared to topgraphy
- Further verification of pointing
- Surface Clutter spread due to orographic features is consistent with expectations (qualitative spot checks)



Surface Clutter Removal (I)

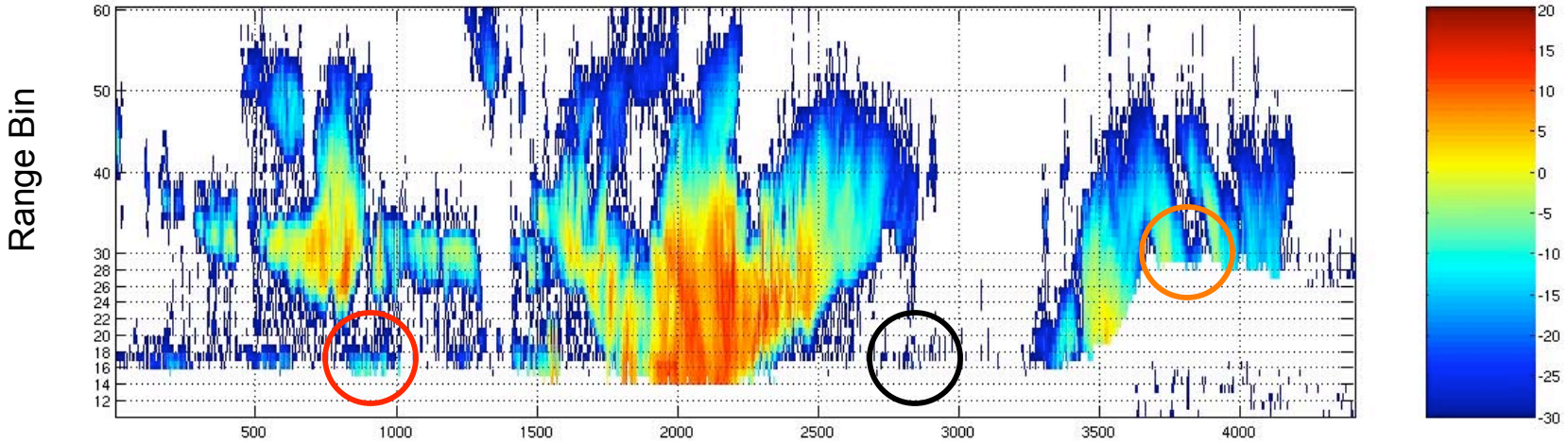




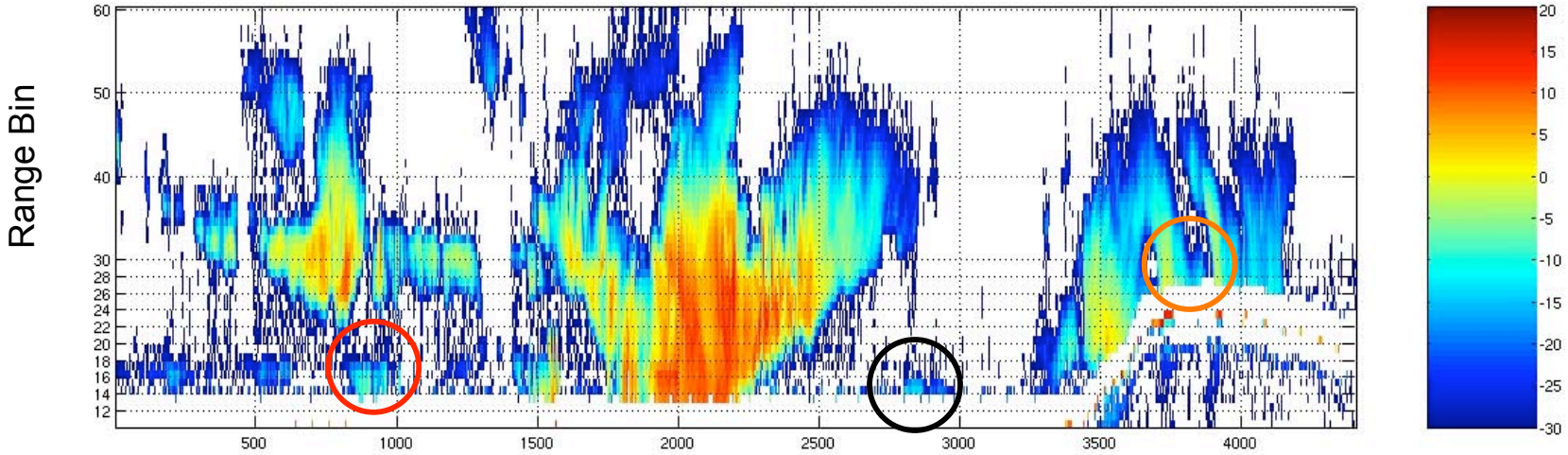


Clutter Removal Test Case (I)

Z measured with CLDCLASS R03 mask: 3-4 range bins above the surface are masked



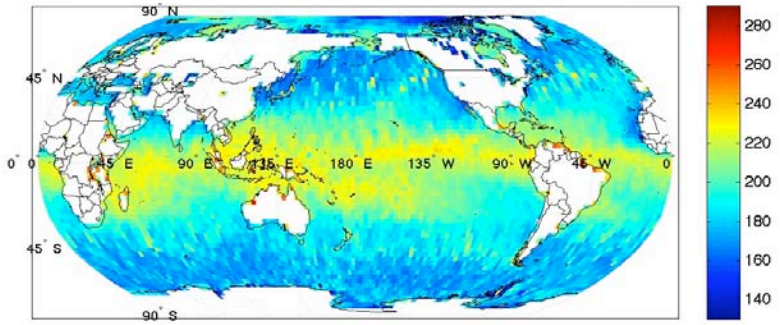
Z post-SCR with post_SCR mask: 1-3 range bins above the surface are masked



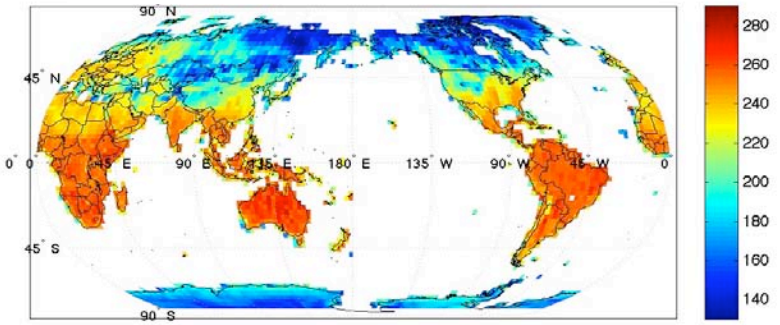
CPR as Radiometer

- CPR noise power converted into brightness temperature using relationship obtained by comparing with AMSR-E 89-GHz TB
- Preliminary estimation of NEΔT ≅ 5K

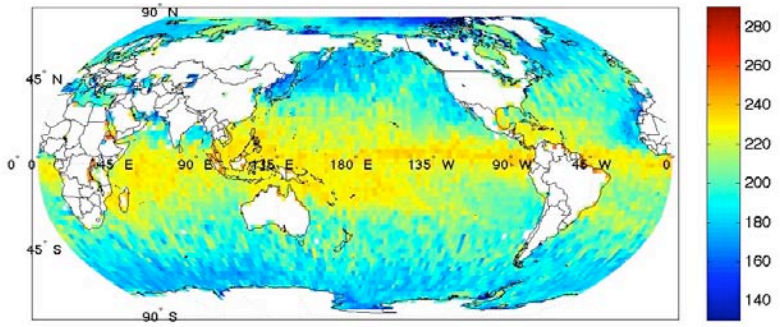
Ocean, clear sky (Jan 1-17, 2007)



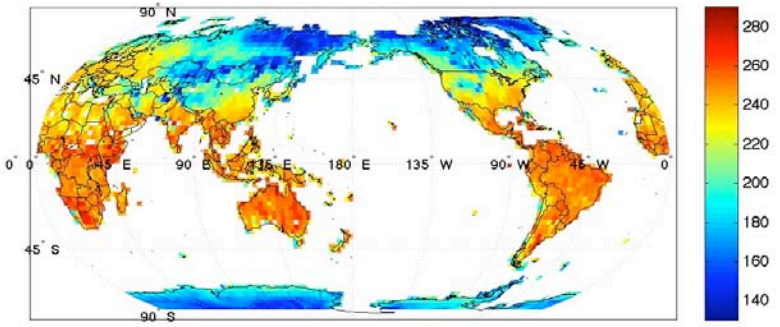
Land, clear sky (Jan 1-17, 2007)



Ocean, cloudy sky (Jan 1-17, 2007)



Land, cloudy sky (Jan 1-17, 2007)



- Cold background (ocean) appears warmer in the presence of water cloud

Summary & Concluding Remarks

- CloudSat has just celebrated the first-year anniversary on April 28, 2007
- Since beginning of June 2006, the CloudSat payload, the Cloud Profiling Radar (CPR), has been acquiring science data almost continuously (98.7% of time)
- End-to-end in-flight performance of CPR has met or exceeded requirements.
  - The achieved minimum detection sensitivity is better than -30 dBZ
  - The measured clear-ocean NRCS's are consistent with published airborne results, indicating good calibration and system stability over time
  - CPR pointing is excellent, allowing co-aligned measurements with CALIPSO lidar
  - CPR's system impulse response before and after launch are almost identical, suggesting excellent system stability and enabling a new scheme to reduce surface clutter effects
- CPR flight system is in very good health. No sign of aging and/or degradation
  - High-power Amplifier (EIK/HVPS) have performed better, and with fewer trip-offs, than predictions
- Based on in-flight performance, CPR is expected to operate well beyond the primary mission duration of 22 months.