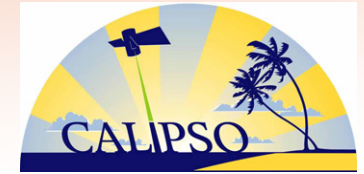
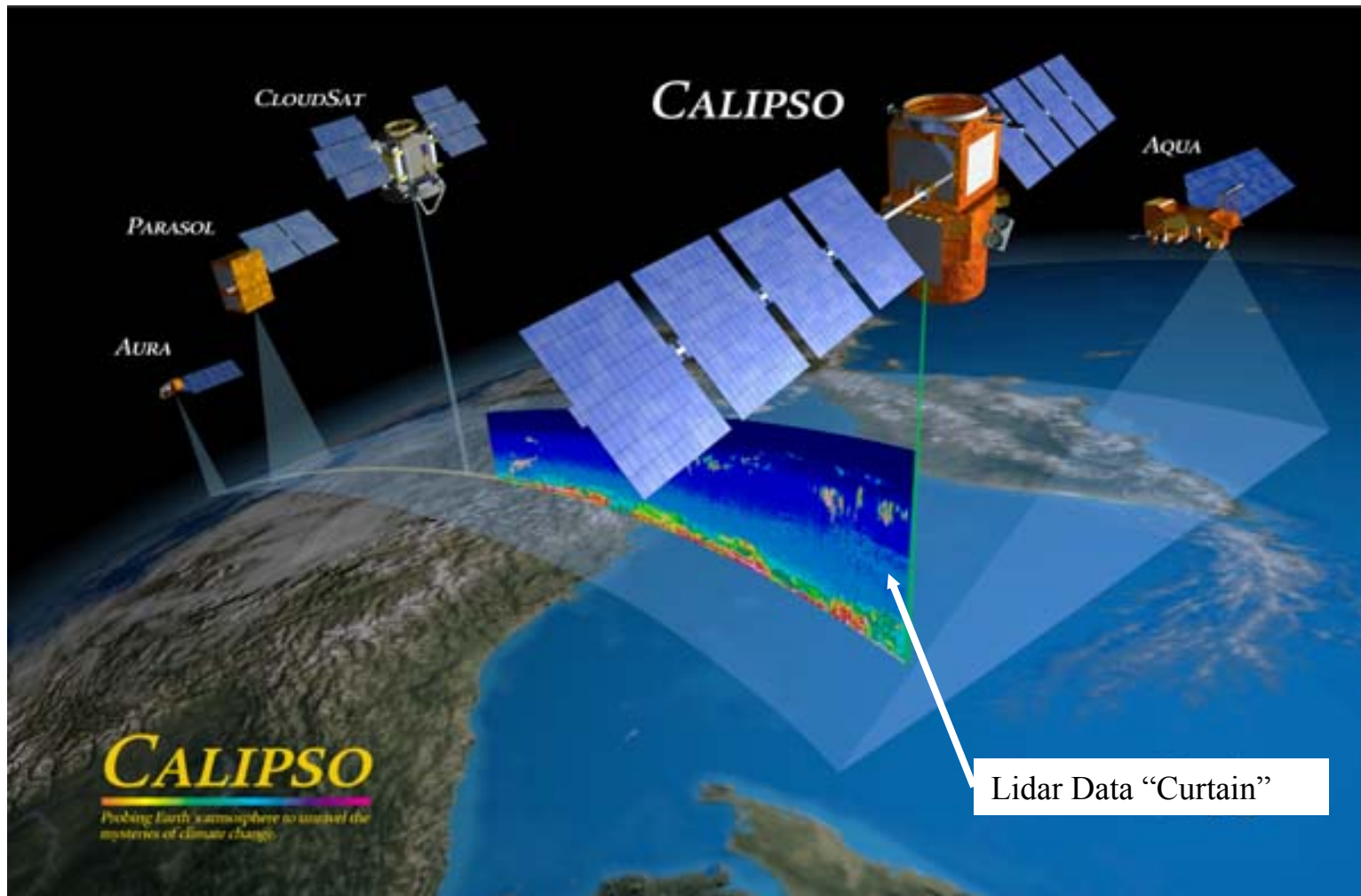




CALIPSO On-Orbit - Lidar



Cloud - Aerosol Lidar and Infrared Pathfinder Satellite Observations



Carl Weimer 3/21/07



Outline



- **Why CALIPSO?**
- **Some Early Science Results**
- **Selected Engineering Results**

Principal Investigator – David Winker – NASA
LaRC

Co-PIs – Patrick McCormick (Hampton
University) and Jacque Pelon (IPSL)

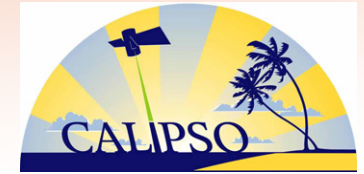
NASA - Ball
Payload

CNES – Alcatel
Proteus
Spacecraft

Summary: The CALIPSO Satellite has three instruments including the CALIOP Lidar. CALIOP is a two-wavelength (532 /1064 nm) polarization-sensitive Rayleigh-Mie lidar. Launched April 29, 2006

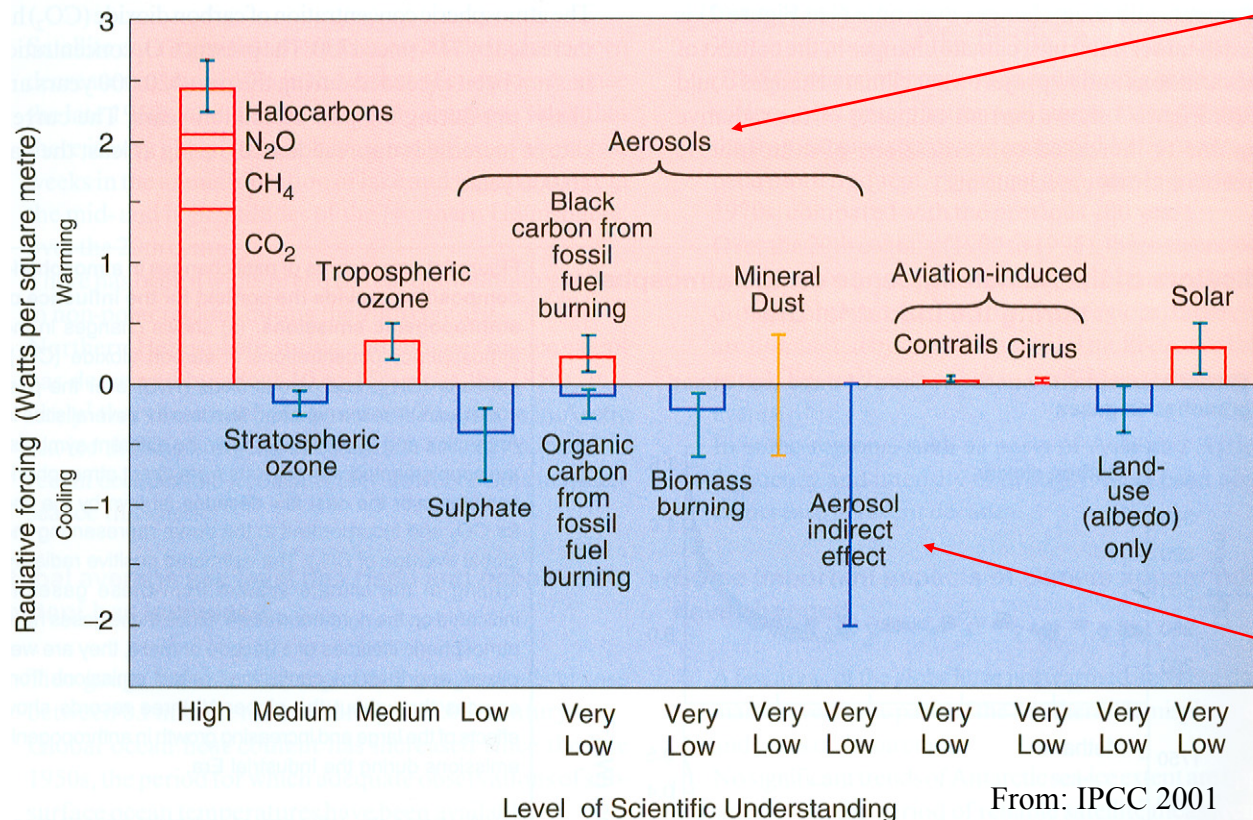


Scientific Need for CALIPSO



Scientists understanding of human impact on the Earth's Radiation Budget - Global Warming

The global mean radiative forcing of the climate system for the year 2000, relative to 1750



CALIPSO Will Help Address

How Aerosols Affect Clouds

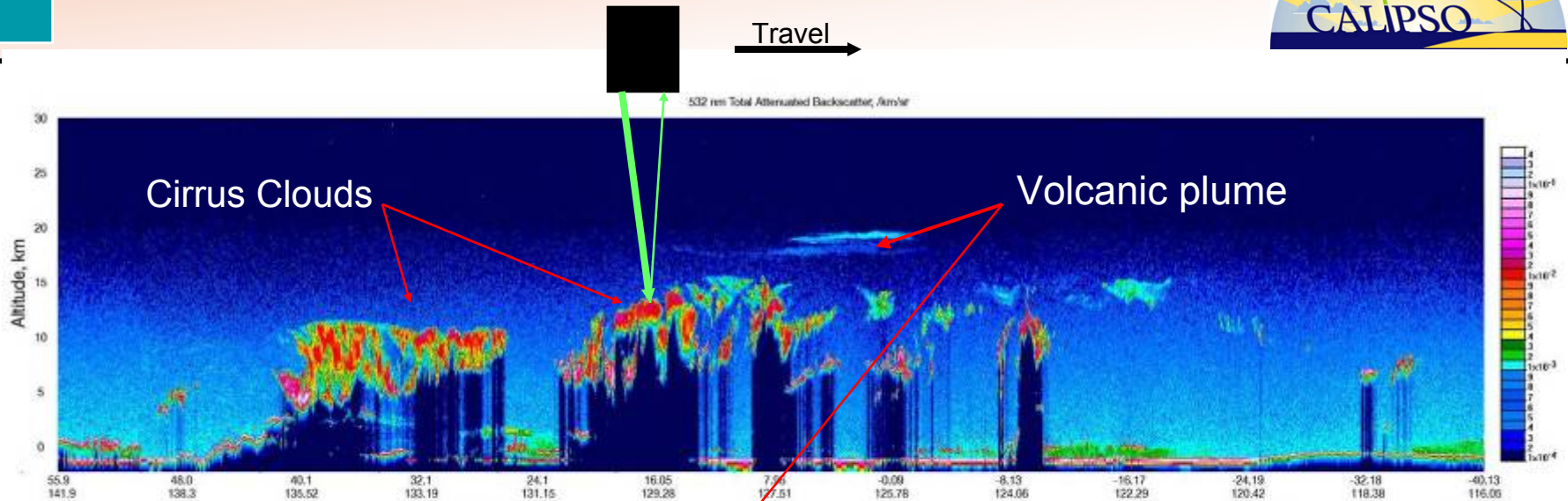
CALIPSO offers unique contributions to help address important questions in climate change and air quality. New applications are being explored (e.g. Ocean)



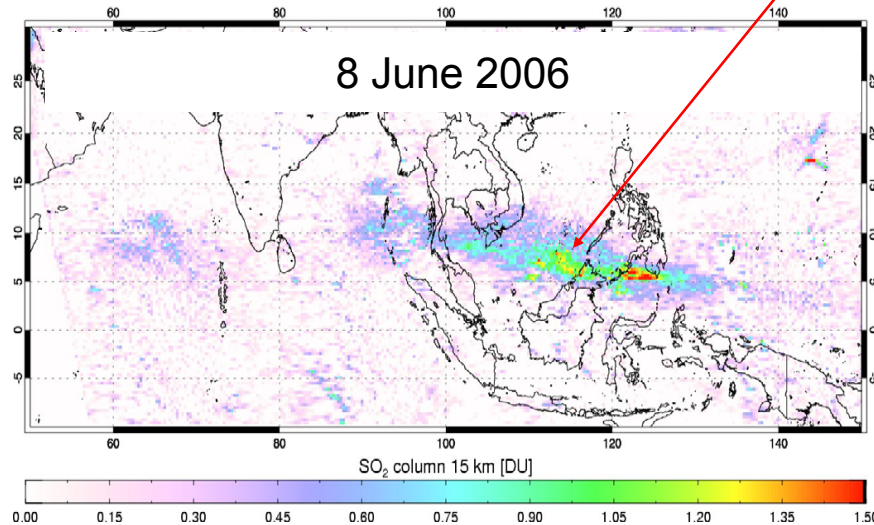
CALIPSO Lidar First Light (from NASA LaRC)



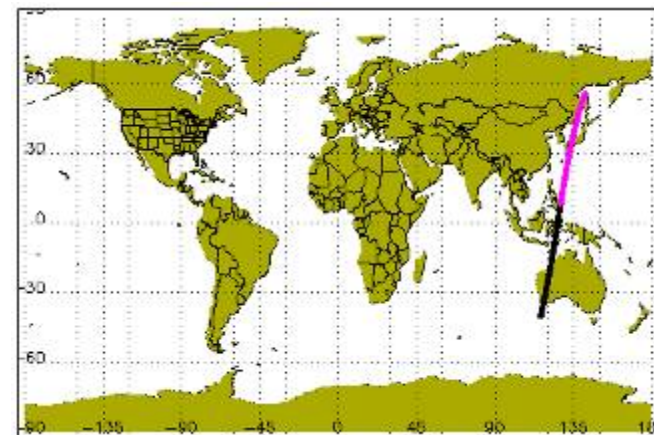
Travel →



Aura/OMI Column SO₂



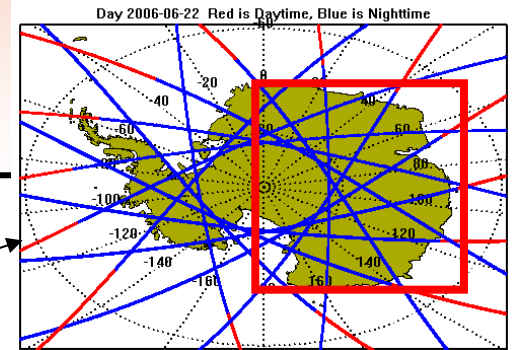
CALIPSO Orbit Track
7 June 2006



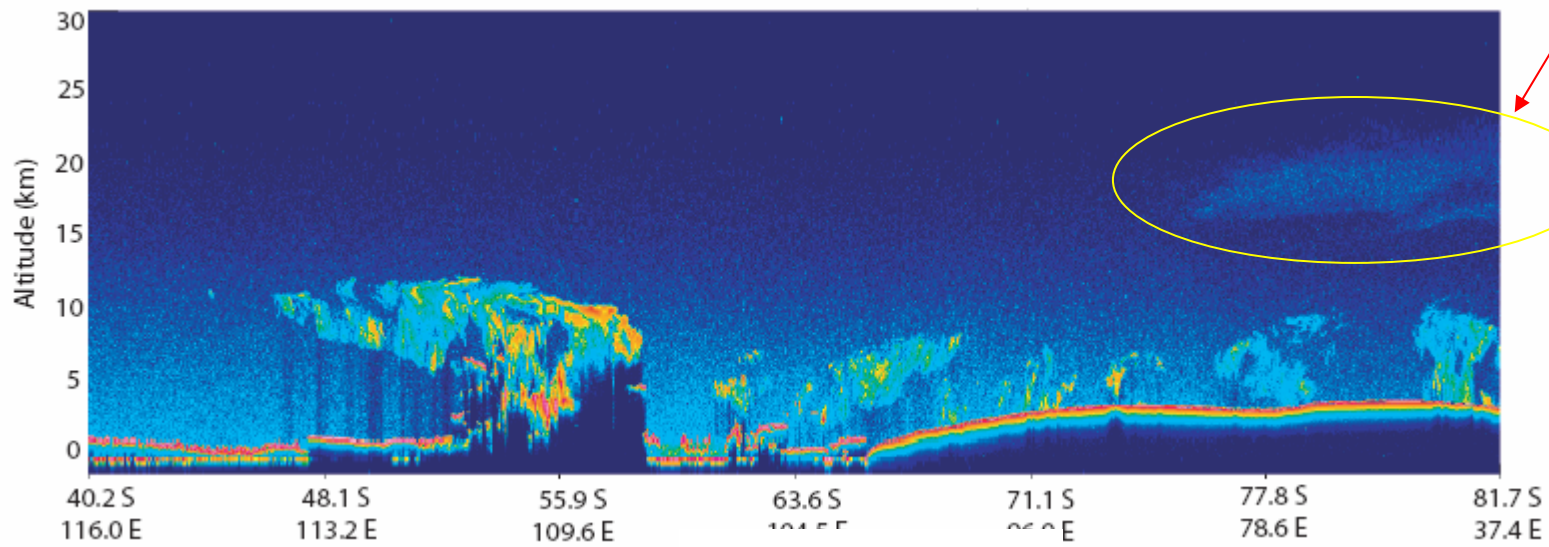
Soufriere (Montserrat – Caribbean) erupted on May 20. Its water droplet/sulfuric acid plume was tracked by OMI and seen crossing over Indonesia by CALIPSO on June 7.



CALIPSO and CloudSat Data

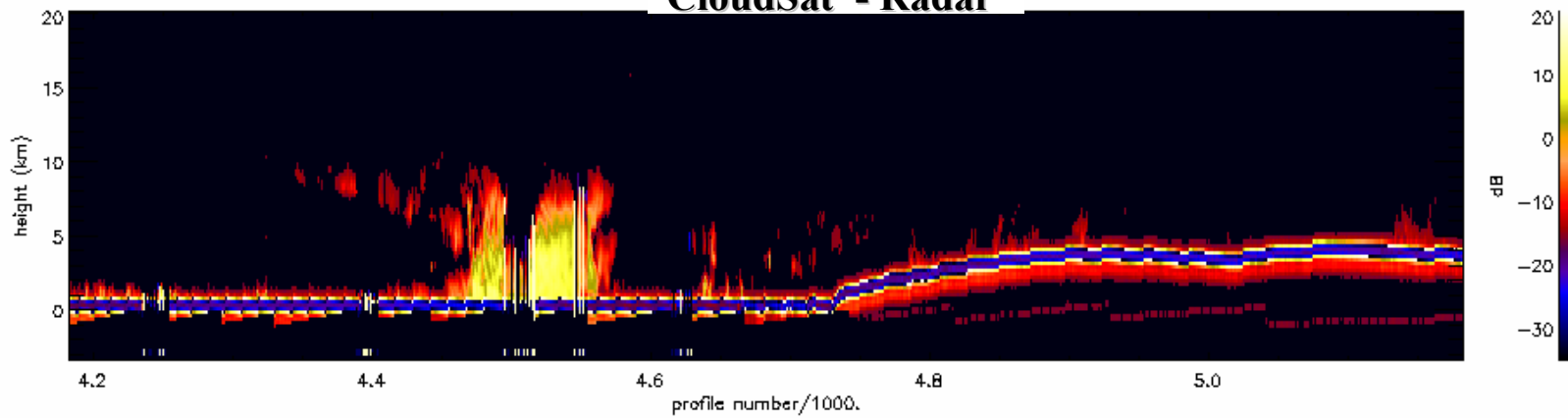


CALIPSO-Lidar



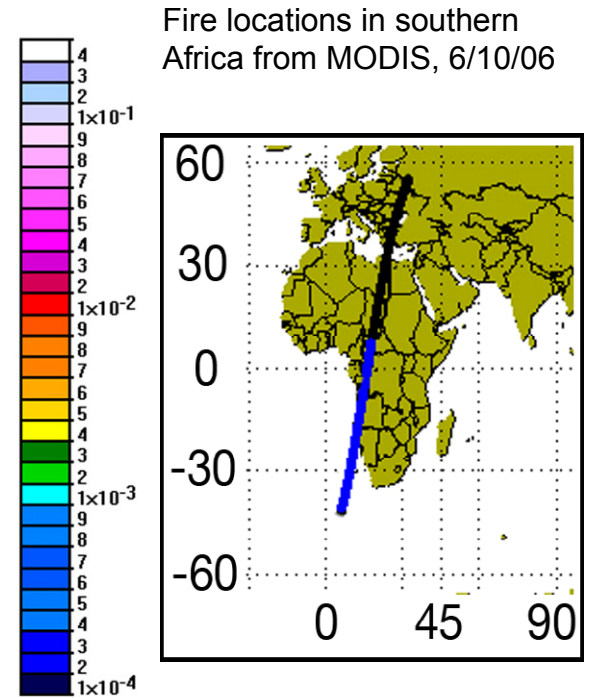
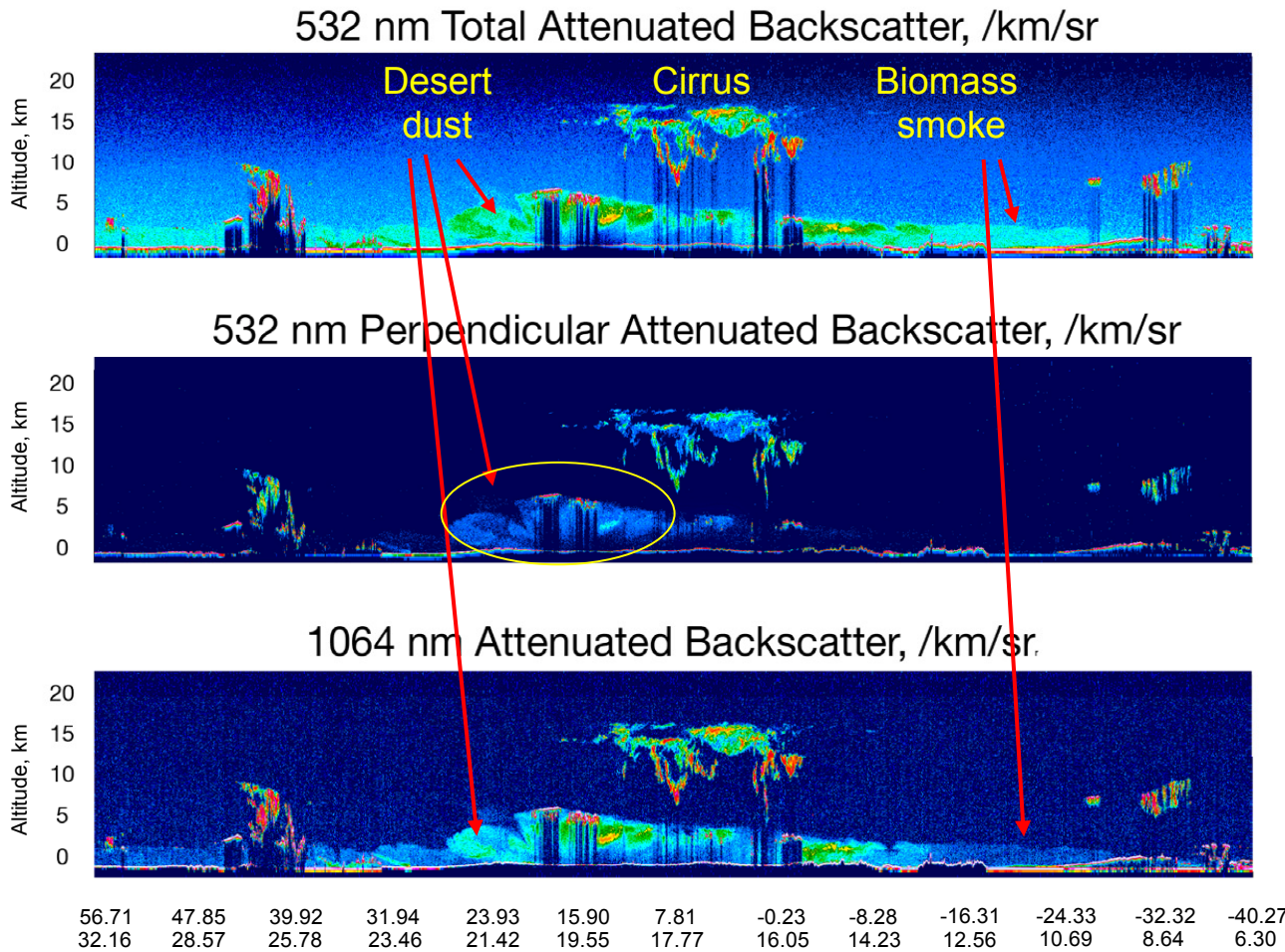
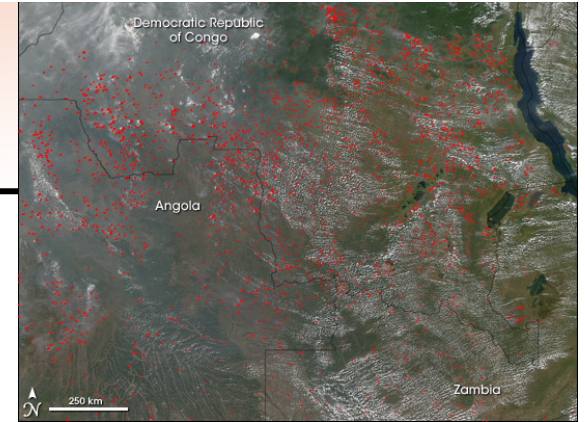
Polar Stratospheric Cloud

CloudSat - Radar





CALIPSO Data – All Three Lidar Channels

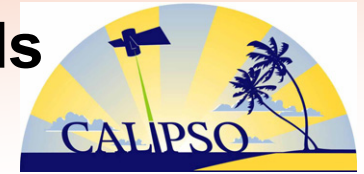


Ratios of Channels give estimate of particle size, particle shape, and differentiate water/ice clouds

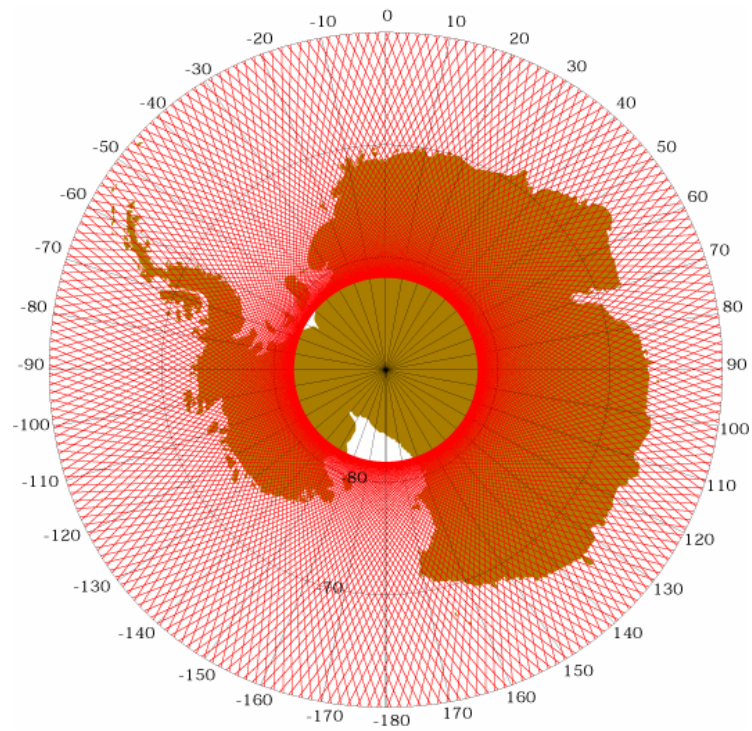


Antarctic Polar Stratospheric Clouds

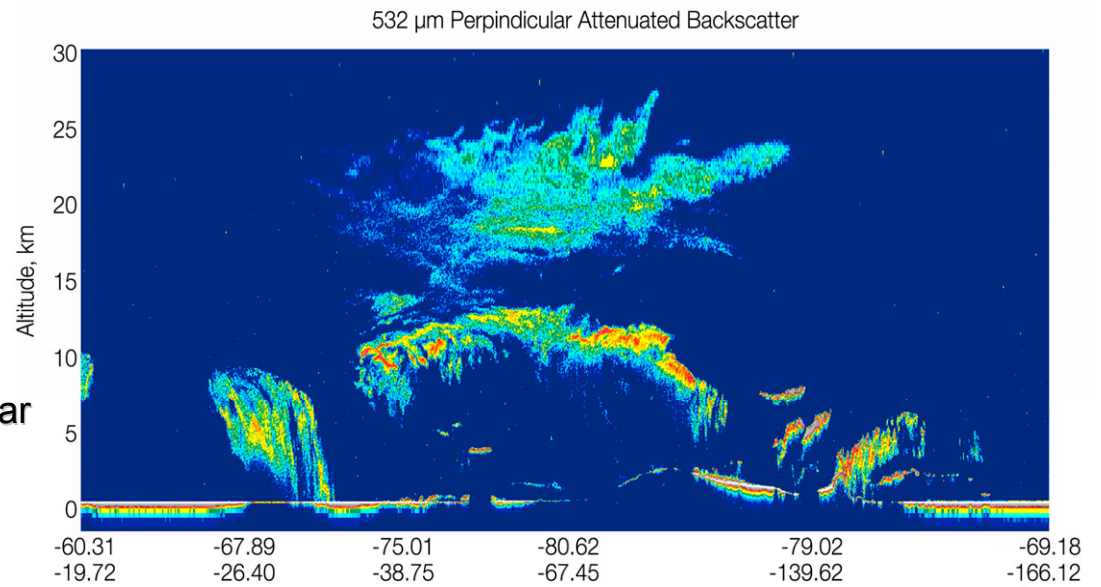
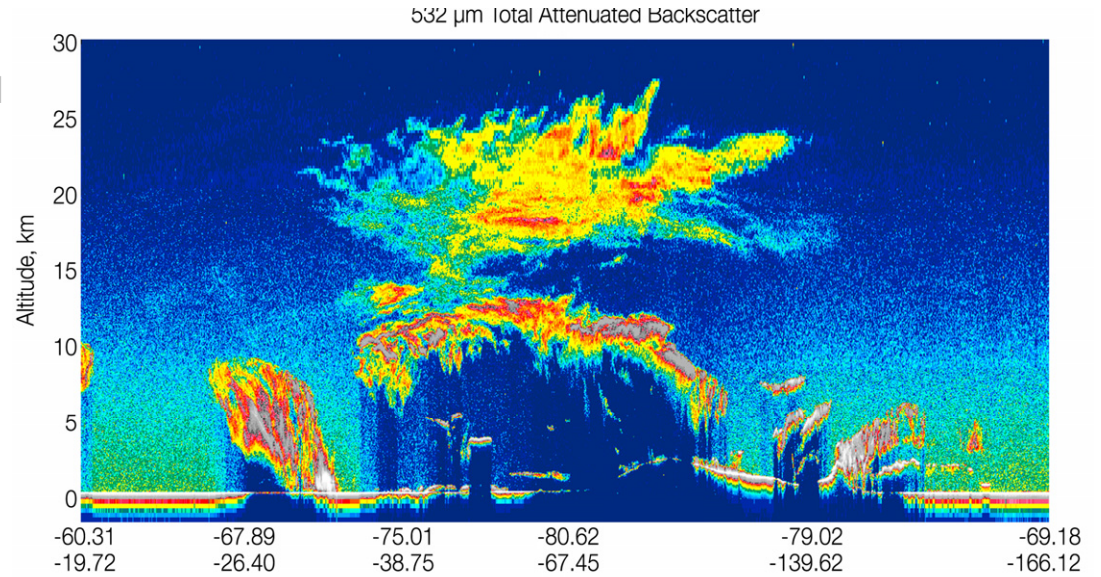
July 24, 2006



532 nm Total Attenuated Backscatter



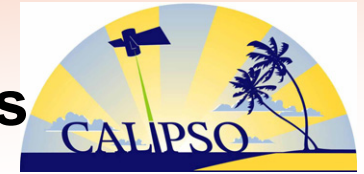
532 nm Perpendicular Attenuated Backscatter



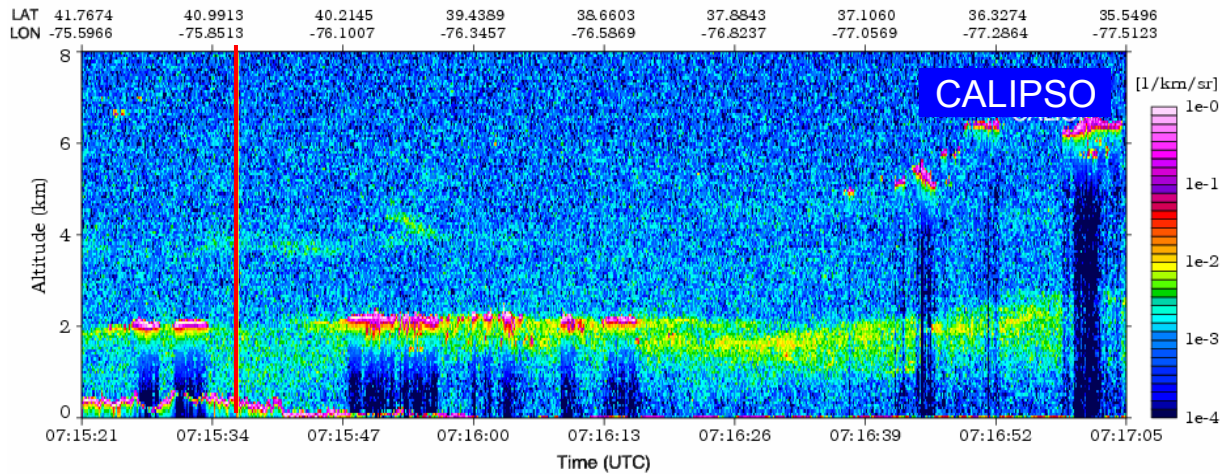
Courtesy: Dave Winker



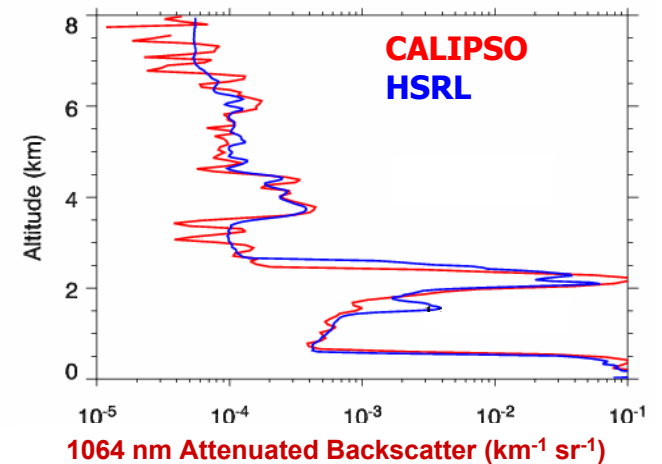
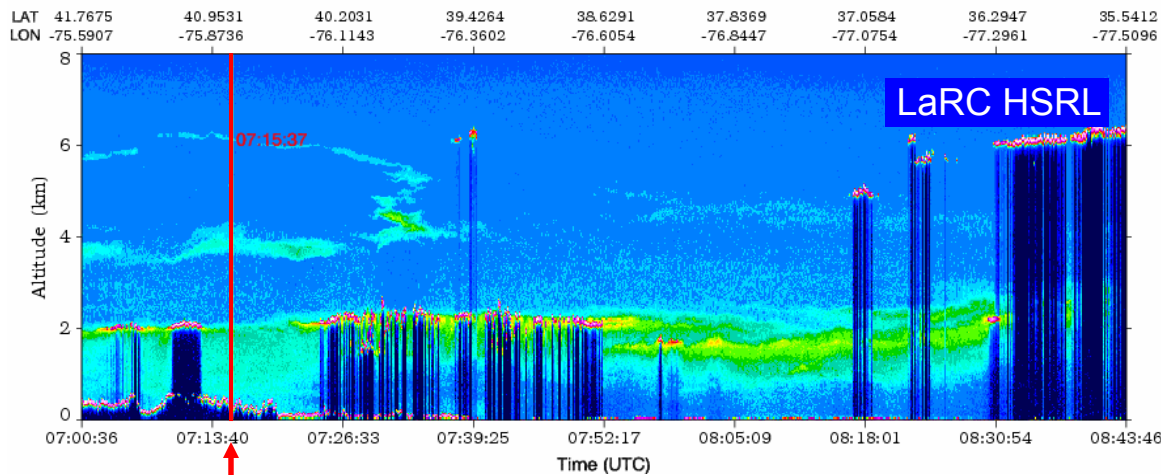
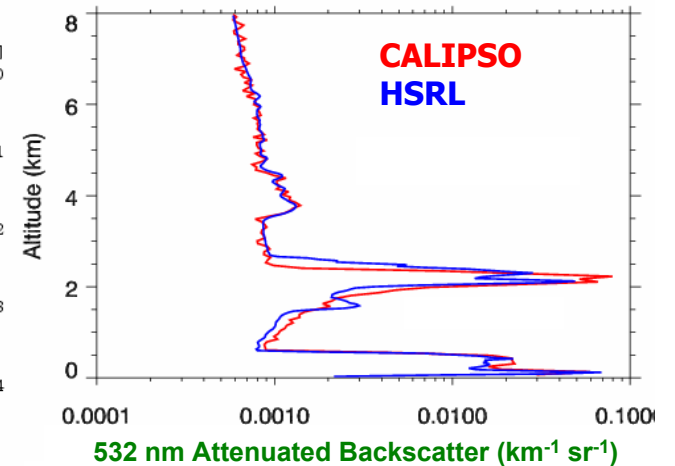
Validation Intercomparisons: Aerosols



August 10, 2006



Coincidence



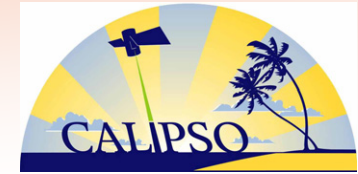
Coincidence

NASA LaRC High Spectral Resolution Lidar is being flown on Aircraft to support validating CALIPSO Data

Courtesy: Dave Winker



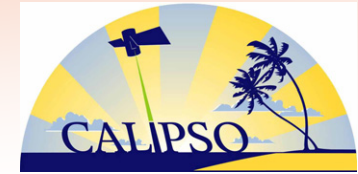
What is different about Lidar from Space?



- **Long distance from atmosphere – 400- 800 km Low Earth Orbit (LEO) –**
 - **Low Signal-to-Noise because of $1/R^2$ term in lidar equation**
 - **Looking down through atmosphere- strongest scatter from furthest distance**
 - **Ground/Ocean scatter sets far boundary condition**
 - **Satellite motion, typical LEO velocity 7000 m/s – limits averaging time**
- **Space Environment**
 - **Radiation (Galactic, Solar, Van-Allen Belts)**
 - **Vacuum – Outgassing and Contamination concerns**
 - **Microgravity – Alignments different than on Earth**
 - **Atomic Oxygen – Erosion and reaction**
 - **Micrometeroids and space junk**
 - **Charging of Surfaces – Corona Discharge**
 - **Thermal environment – Controlled through careful design using radiators and heaters**
- **Launch Environment**
 - **Alignments and structure must withstand vibration and shock**
 - **Limited Weight can be lifted – Typical 100 – 500 kg range for instrument**
- **Limited power available – Typical 100 – 500 W available from solar arrays for instrument**
- **Semi-Autonomous Operation over multiple years – Daily data downlink, weekly uplinks**



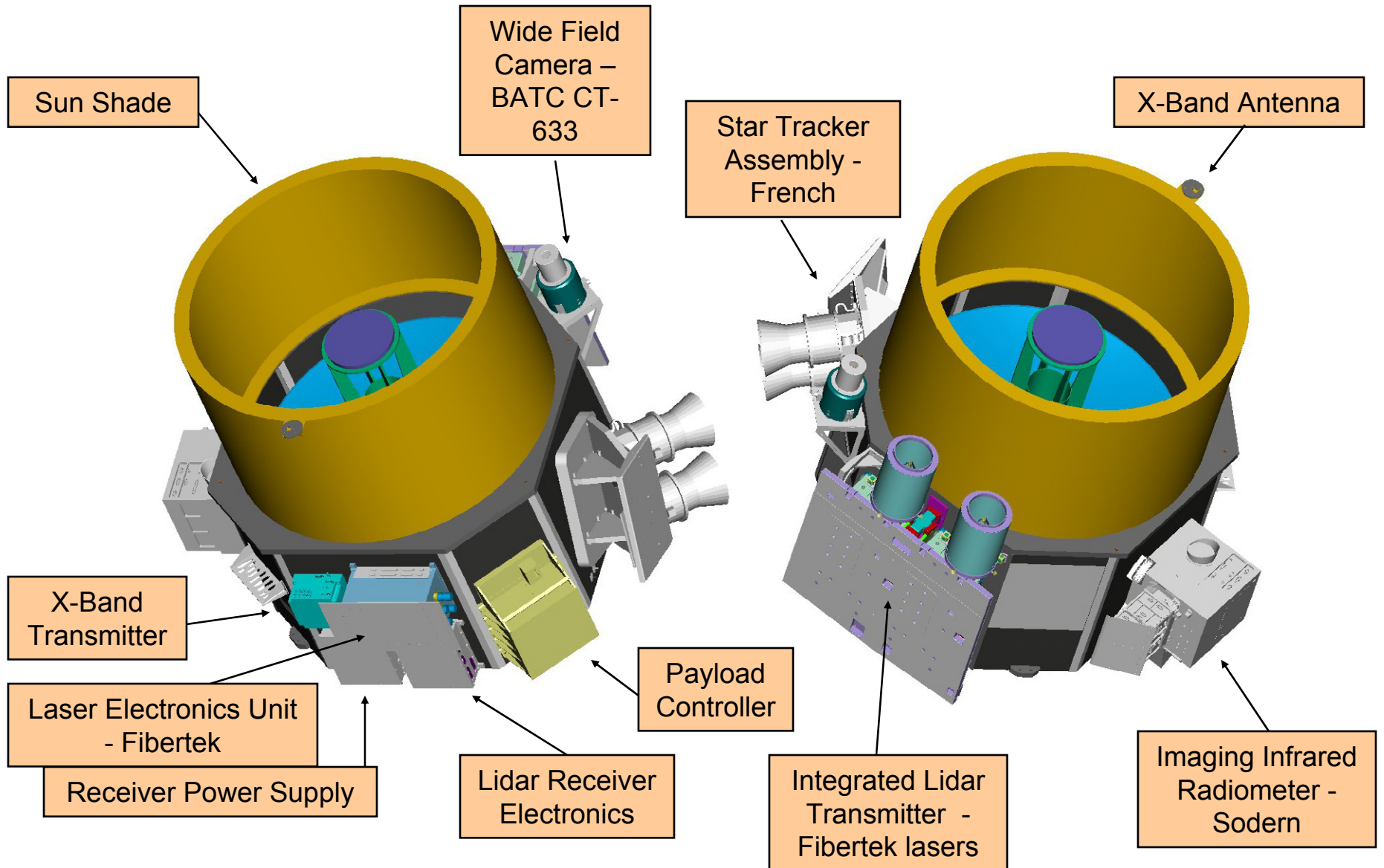
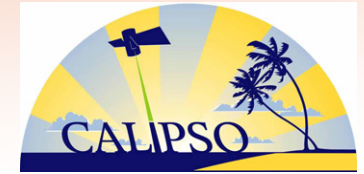
Lidar in Space Building for Reliability



- **High Cost of Space Missions** requires that a space lidar be designed and built to achieve maximum reliability affordable within cost and schedule constraints
- **Standard Aerospace Engineering practices** followed, combined with unique lidar specific techniques
- **High Reliability Parts Program**
 - **Electronic Parts** are all “screened” – tested for lifetime – this limits what parts can be used
 - **All classes of parts** must have passed radiation testing
 - **Optical parts** must be able to withstand radiation, Ultra-violet, laser fluence (if appropriate), vacuum, atomic Oxygen
- **Parts, Sub-assemblies, Assemblies** must pass Qualification Test Program
 - **Thermal-vacuum**
 - **Vibration**
 - **Acoustic**
 - **Shock**
 - **Electromagnetic Interference**
 - **Health/Performance tests** in conjunction with each of the above

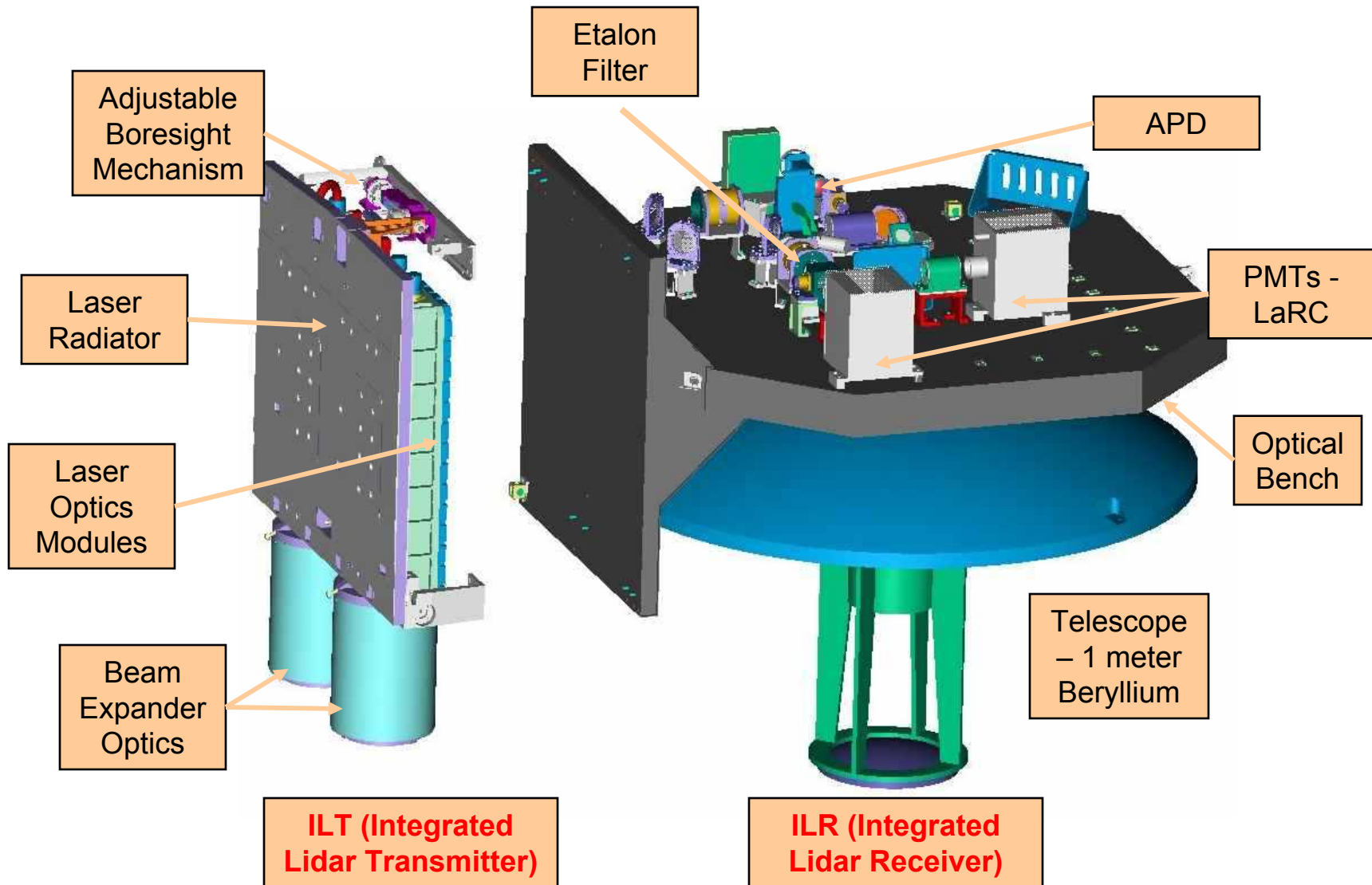


Different Views of CALIPSO Payload



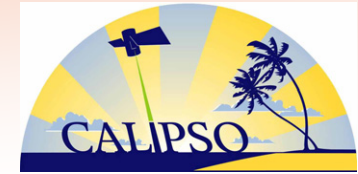


Lidar Core – Transmitter and Receiver





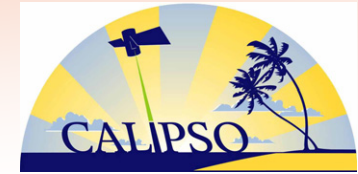
CALIPSO – Random Numbers



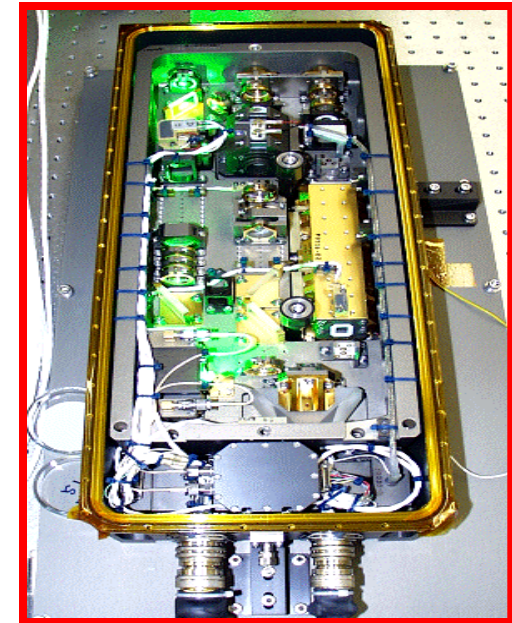
- **Lidar Data “Curtain”**
 - 70 meter diameter footprint
 - 330 meter steps
 - 30 meter (and up) vertical range bins
 - Extends from the ground to 40 km (130,000 ft - clean air)
- **Lasers**
 - 4 Watt average power, 11 MWatt peak (20 nsec pulse), 20 Hz repetition
 - Each laser pulse contains 10^{18} photons
 - All the light is contained in very narrow wavelength bands
 - 0.035 nm at 532 nm (1 part per 15,000)
 - 0.100 nm at 1064 nm (1 part per 11,000)
- **Photomultiplier Detectors used at 532 nm are sensitive to single photons (but not photon counting)**
 - Avalanche Photodiode used for 1064 nm – less sensitive but much more rugged (also 550 V vs 2 kV)
- **To date - on-orbit**
 - 1.1 TByte of science data collected
 - 440 Million laser shots “fired” (1900 Mshots = full mission)



Space Qualified Lasers

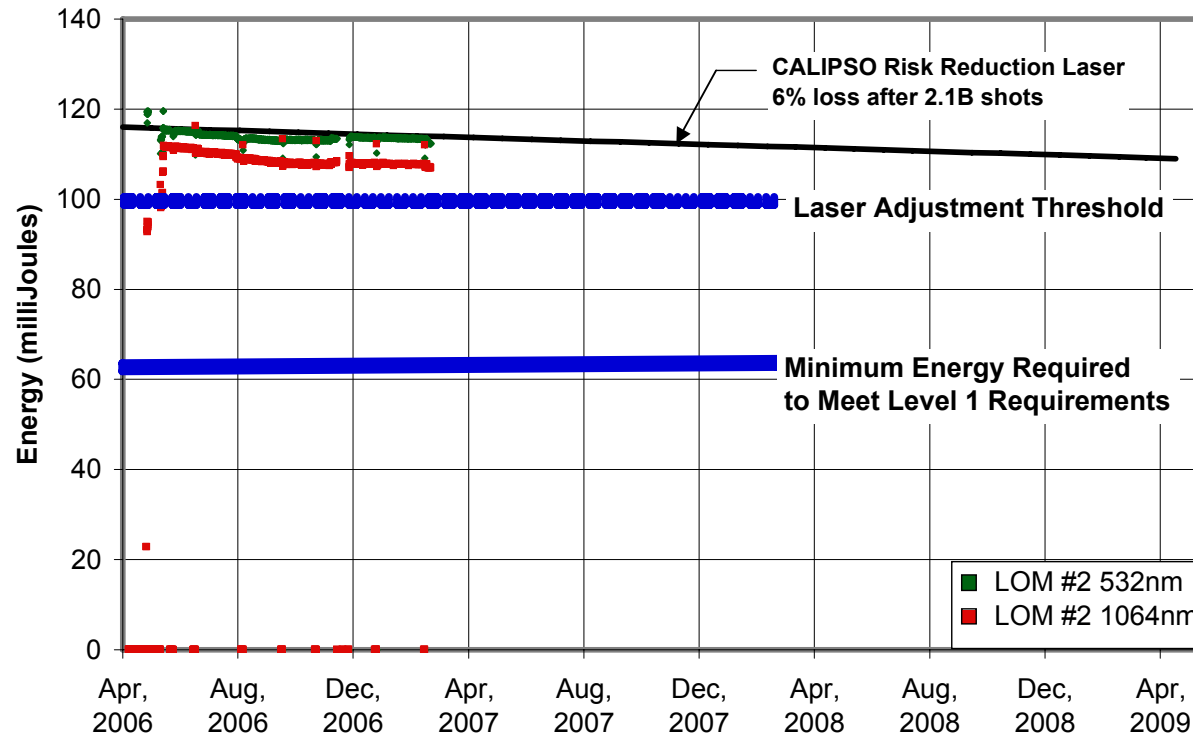
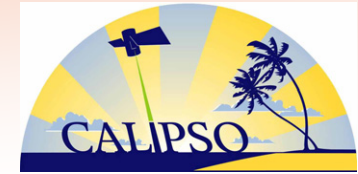


- Built by Fibertek of Herndon VA, with Ball
- Engineering Unit built that demonstrated full mission lifetime (2 billion shots).
- Laser is Nd:YAG in a zigzag slab with 192 diode bar pumps
- Utilizes a KD*P Q-switch (20 ns pulses) and a KTP frequency Doubler
- 110 mJ/pulse for each color @ 20 Hz
- Spectral linewidth (Multi-transverse mode)
- 532 nm Output polarized to > 1000:1
- Conductive Cooling – Heaters/radiators
- Ball designed Beam Expander Optics set laser divergence to approximately 100 microrad
- Weight 35 kg, uses 100 W (incl. Heaters)
- Redundant Lasers used – each designed for full mission life





Laser Energy – Long-term Orbit Trend

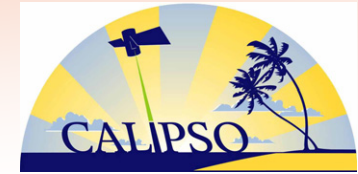


March 15, 2007

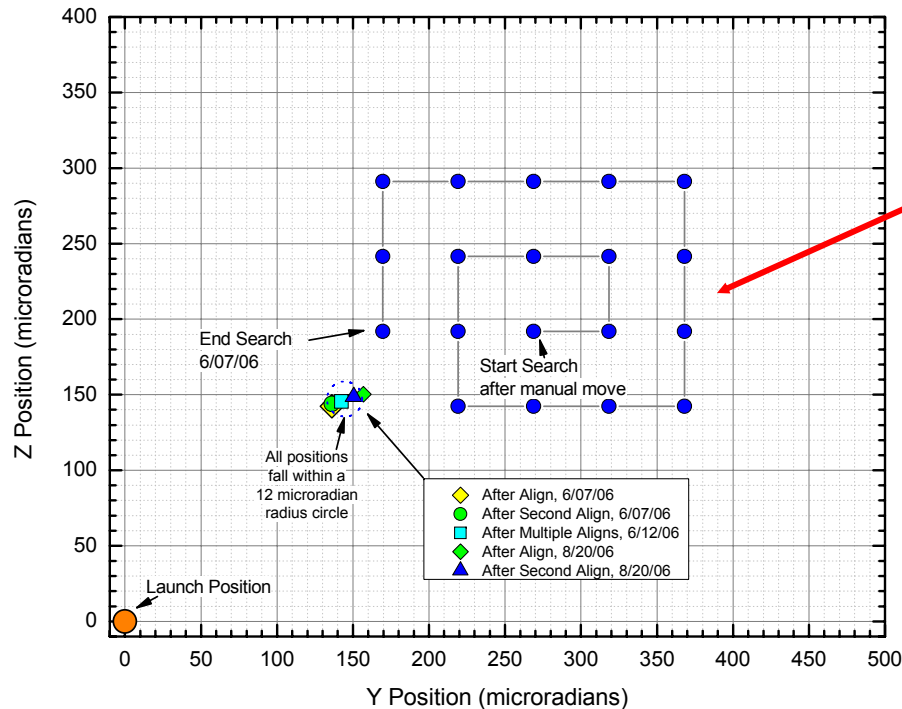
- **Trend is consistent with Risk Reduction Laser (RRL)**
 - **Slow decay is due to the diode lasers degrading – 15,200 used as “pumps”**
- **Redundant second laser hasn’t been turned on, yet**
- **Laser Power is adjustable – Running at 70%, so we still have 30 % margin**
- **Laser Canister pressure decaying but looks acceptable for mission**
- **Current trend indicates only one laser will be needed**



Aligning the Laser and Receiver Pointing

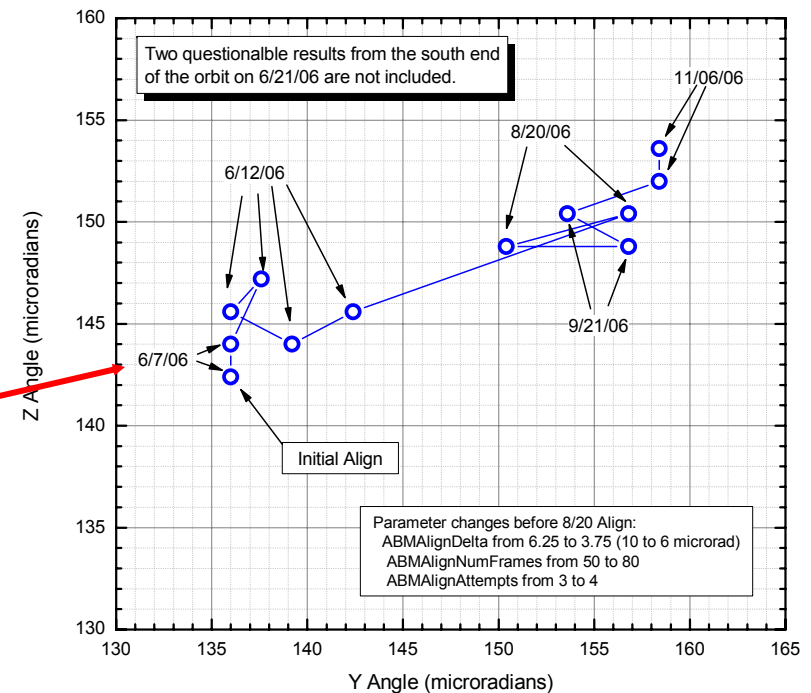


CALIOP Boresight Search and Align



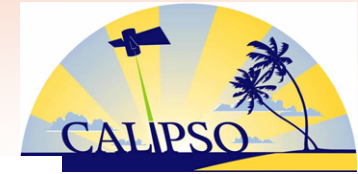
- Ball mechanisms and software autonomously aligned the lidar
 - Search completed in 4 minutes
 - Align completed in 10 minutes
- Predicted align position agreed to 130 μ rad with actual

- Stability of full lidar system checked monthly
 - Relative pointing has been stable to $< 10 \mu$ rad over last three months
 - Signal stability over multiple orbits is better than 1% (night)

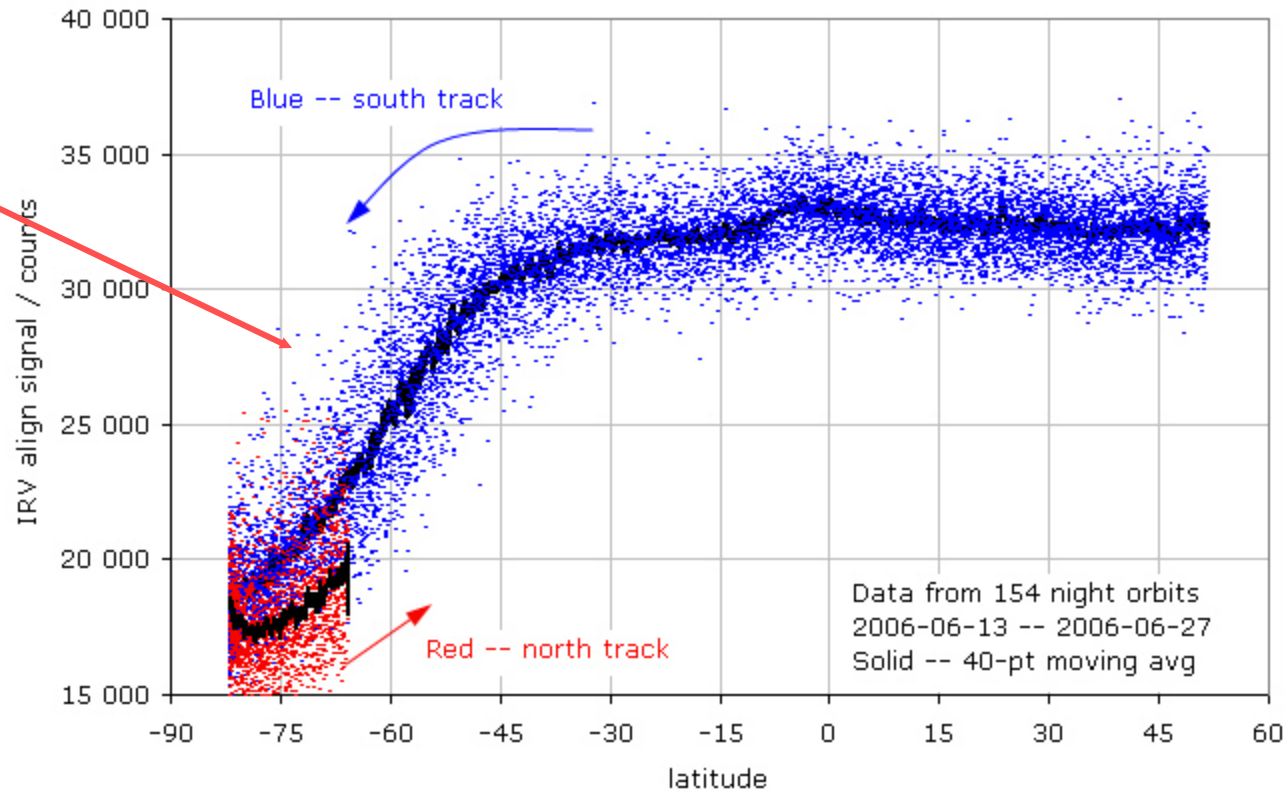




Study of Lidar Stability



CALIPSO stability -- IRV align vs latitude

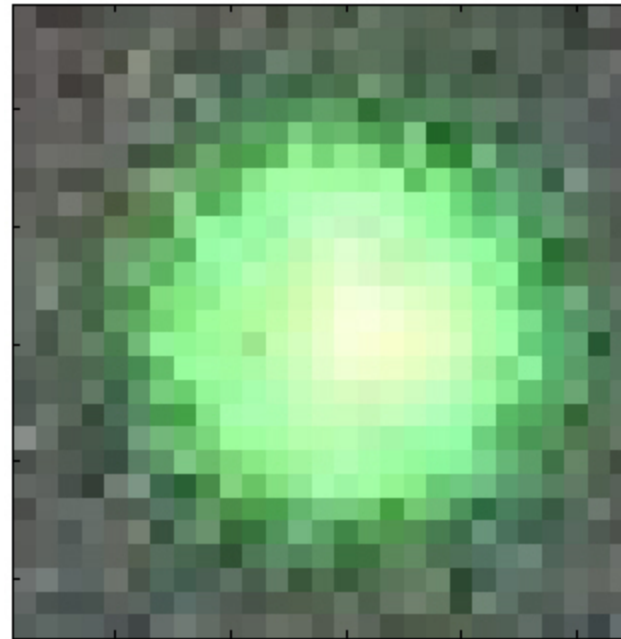
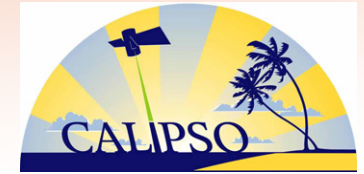


Polar Vortex
over
Antarctica

- **Rayleigh (Molecular) scattering from 27- 40 km altitude (June)**
- **Ground track starts over Northern Hemisphere and goes to Southern**
- **Lidar is temperature cycling – cooling**
- **Signal does not repeat on itself – possible slight alignment shift**



CALIPSO Laser output as it passes over Nederland



Photograph by Gregg Hendry 7/14/06

More Information about CALIPSO at:

<http://www-calipso.larc.nasa.gov>

<http://smc.cnes.fr/CALIPSO/>

<http://calipsooutreach.hamptonu.edu/>

<http://www.n2yo.com/?s=29108>

Also See:

<http://giovanni.gsfc.nasa.gov>

<http://www.nuforc.org/webreports/055/S55212.html>



Some Lidars in Space



• Apollo 15	1971	Ranging
• Clementine	1994	Ranging (Mapped the Moon)
• LITE	1994	Profiling (Shuttle)
• Balkan	1995	Profiling
• NEAR	1996	Ranging
• SLA-01	1996	Ranging
• MOLA II	1996	Ranging (Mapped Mars)
• SLA-02	1997	Ranging
• Icesat/GLAS	2003	Ranging/Profiling (Icesheets)
• MLA	2004	Ranging (Mercury)
• CALIPSO	2006	Profiling of Aerosols/Clouds
• Phoenix	9/2007	Profiling Dust (Mars)
• LOLA	2008	Ranging (Moon)
• ADM-Aladin	2009	Wind Measurements (ESA)