



ISS021E030638

Japanese Experiment Module-Exposed Facility (JEM-EF) attached payload for the International Space Station (ISS)

CATS-ISS (Cloud-Aerosol Transport System for ISS) Science Overview

Directed Opportunity
Payload Delivery Date: April 2013
Planned Launch Readiness Date: mid-2013



CATS is a directed opportunity funded directly by NASA Science Operations Mission Directorate (SOMD). Total budget \$10M (w/ contingency)

Project initiated in April 2011, on 24-month rapid schedule to launch

Pathfinder for future US Science payloads



CATS-ISS Organizational Chart

Matthew McGill: CATS PI

Judd Welton: Project Scientist

CATS Project Science Team:

Stephen Palm

William Hart

Dennis Hlvaka

John Yorks

Modeling Support:

Pete Colarco

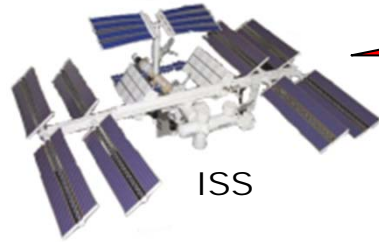
Arlindo da Silva

Virginie Buchard

No Competed Science Team at the moment (ROSES NRA under discussion)



CATS-ISS Science Overview: Research & Operational Goals



ISS



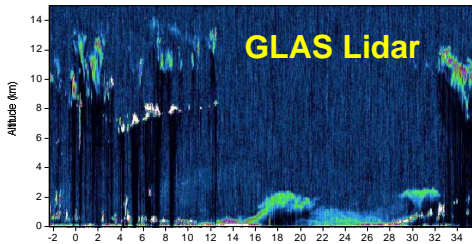
CATS Processing Center
NASA GSFC

Near Real Time

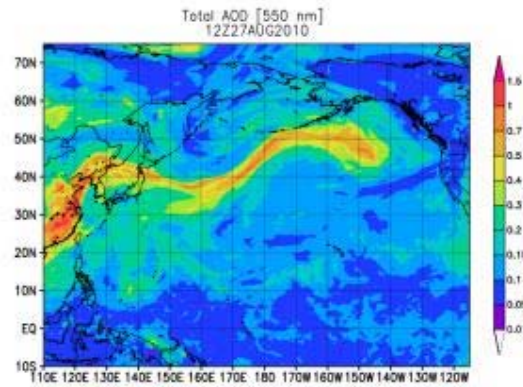
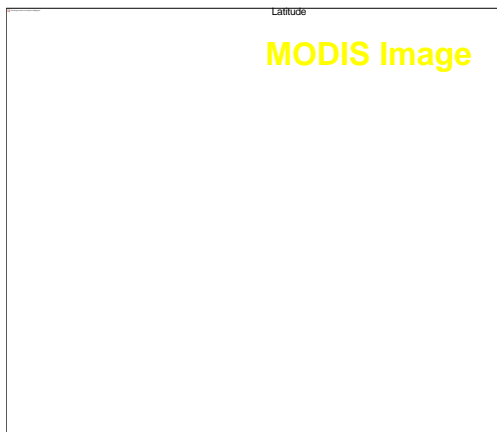


Operational Forecast
Centers

Aerosol and Cloud
Properties



Research

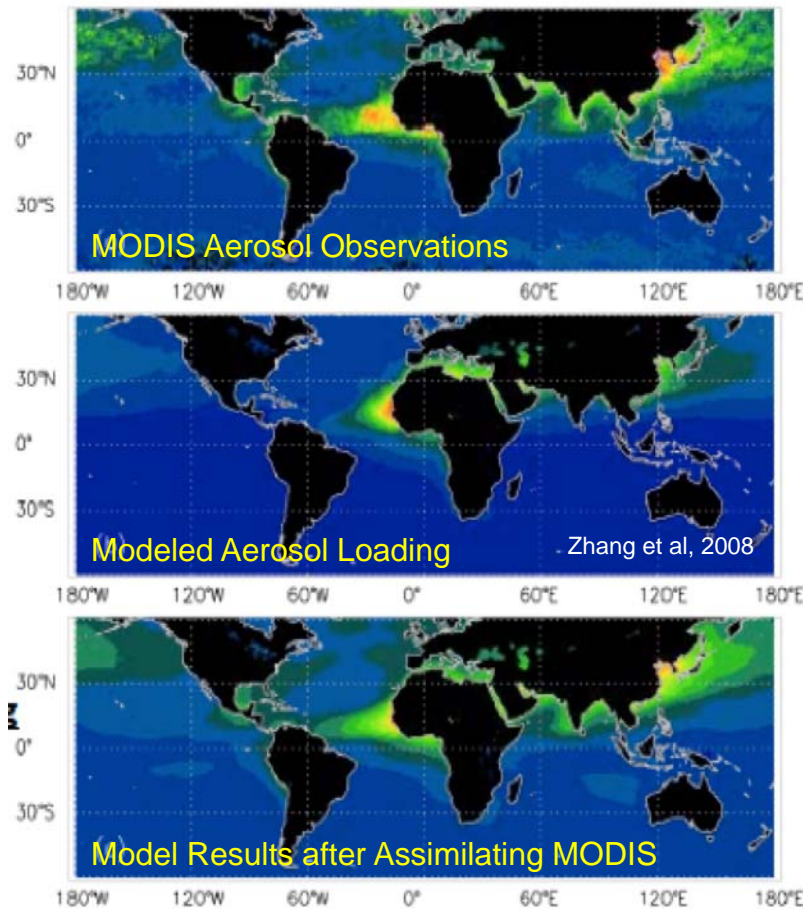


Forecasting





Climate Studies & Aerosol Forecasting



Models are used to determine climate forcing and predict future climate change

Observations provide constraints needed to model aerosol properties and behavior

Even with those constraints, modeling aerosol distribution and loading is difficult

- Aerosol climate impacts are proportional to loading!

Model aerosol loading improves significantly after assimilating coincident observations, but only for 2D total loading (as shown)

Despite agreeing on total loading, current models diverge significantly on vertical distribution and aerosol type (ie pollution vs dust)

As a result, it is difficult to attribute aerosol loading to human vs nature (ie pollution vs dust)

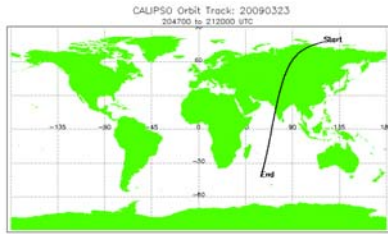
- Determining human induced portion of aerosol climate impact is the primary goal!

Aerosol climate forcing is dependent on vertical location: are aerosol below, mixed with, or above clouds?

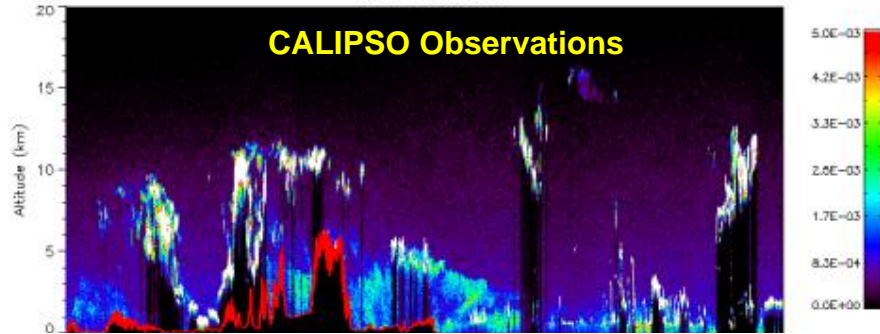
- Aerosol-Cloud interactions comprise the largest uncertainty in climate forcing



Climate Studies & Aerosol Forecasting



CALIPSO Attenuated Backscatter (V3.01): Signals
Date: 20090323



CALIPSO Vertical Feature Mask (V3.01): Aerosols
Date: 20090323 (QA Settings - CAD: 3, Type: 1, Cloud: 0)

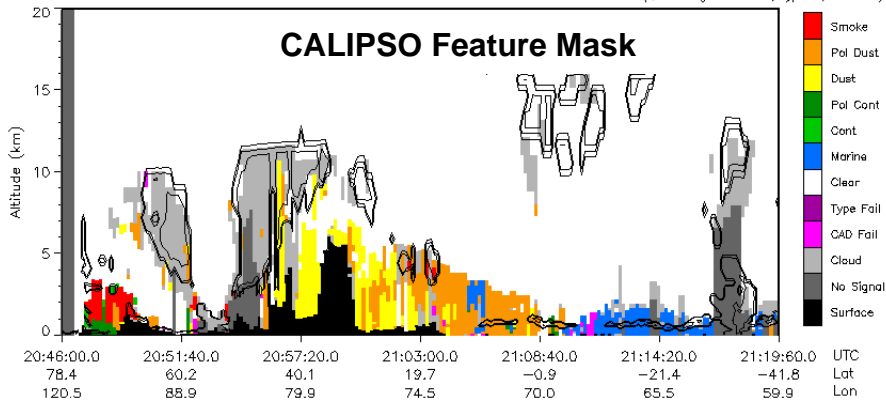


Image Created: Mon Jun 13 12:07:09 2011

Lidar provides:

(1) information on the vertical profile of aerosol type, and properties (ie loading)

- similar information on clouds

(2) heights of aerosols and clouds, and improves our understanding of how and when aerosol-cloud interactions occur

CATS will provide data to constrain modeled aerosol and cloud properties, and improve model distributions and climate forcing through assimilation

GEOS-5 Aerosols: Vertical Feature Mask
Date: 20090323 (QA Settings - Ext: 0.002, FracCol: 0.0%, TypeFrac: 25.0%)

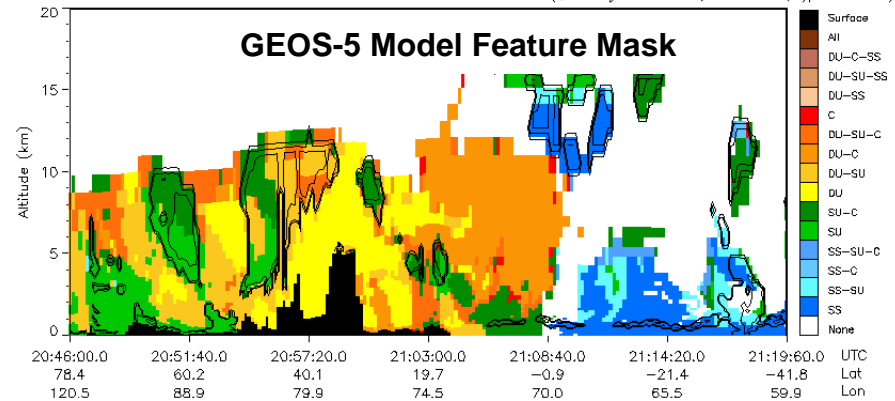


Image Created: Mon Jun 13 12:07:10 2011

Marine Aerosol

Pollution

Dust

Pollution-Dust

Smoke

Welton, et al (2011)



ACE Mission Studies & Tech Demo



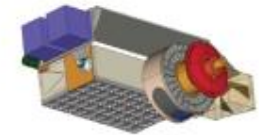
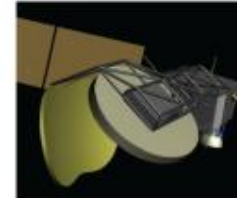
ACE is Societally and Scientifically Relevant

- ✦ ACE is the Tier II Climate Mission (science talks)
- ✦ ACE replaces and will be an advance on much/most of EOS/A-Train including MODIS, MISR, CloudSat, CALIPSO, Glory
- ✦ ACE is building on EOS/A-Train heritage:
 - Instrument design
 - Mission design
 - Algorithms
 - Cal/Val approach
- ✦ ACE is significantly multi/interdisciplinary, bringing together 4+ scientific communities:
 - Aerosol (radiation/energy budget, geochemistry, air quality)
 - Clouds (radiation/energy budget, precipitation)
 - Ocean Ecosystems (biological productivity, carbon cycle)
 - Aerosol-Ocean Interactions (eolian nutrient deposition, aerosol precursor production)



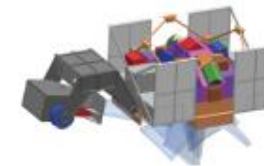
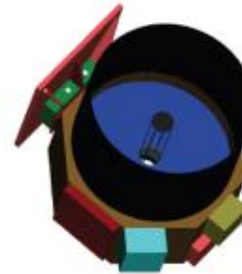
Instruments for Mission Studies

Cloud Profiling Radar



Ocean Radiometer for Carbon Assessment (ORCA)

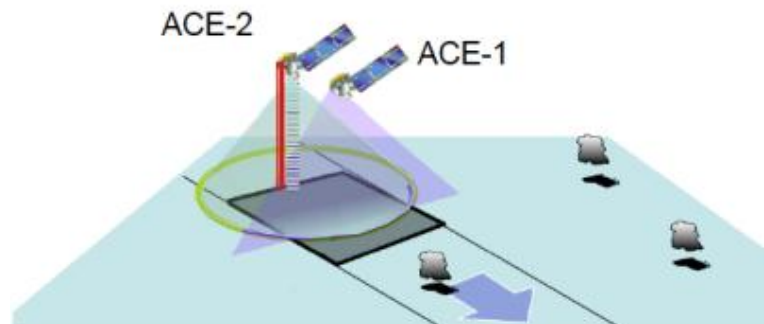
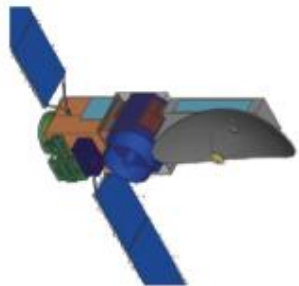
High Spectral Resolution Lidar (HSRL)



Multiangle Spectro Polarimetric Imager (MSPi)

4

ACE Mission Considering Different Mission Options: 1 or 2 Platforms



ACE Mission still in study phase:

If selected launch in 2020's



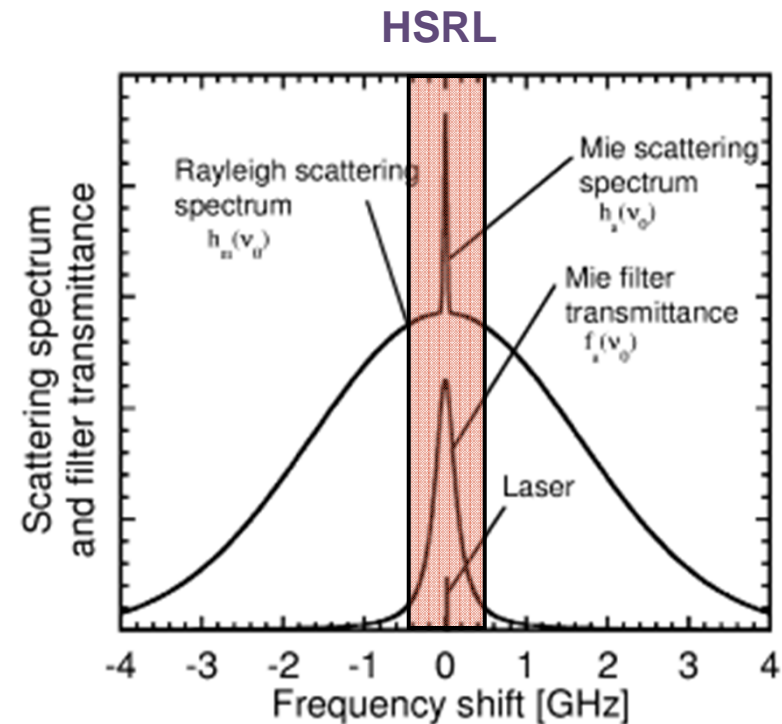
Total Signal, as measured by traditional backscatter lidars

$$P_T(r) = C(\beta_M(r) + \beta_P(r))e^{-2\int_0^z \sigma_M(r')dr'} e^{-2\int_0^z \sigma_P(r')dr'}$$

HSRL techniques provide additional channel containing only molecular backscatter

$$P_M(r) = C\beta_M(r)e^{-2\int_0^z \sigma_M(r')dr'} e^{-2\int_0^z \sigma_P(r')dr'}$$

and more accurate profiles of extinction can be solved directly if an accurate molecular model is used. Profiles of backscatter and the lidar ratio are also generated.



1. Use absorption notch filter to eliminate aerosol signal.

Presence of Doppler shift will preclude measurement (e.g., off-nadir not easy).

Or

2. Use Fabry-Perot etalon to image aerosol/molecular spectrum

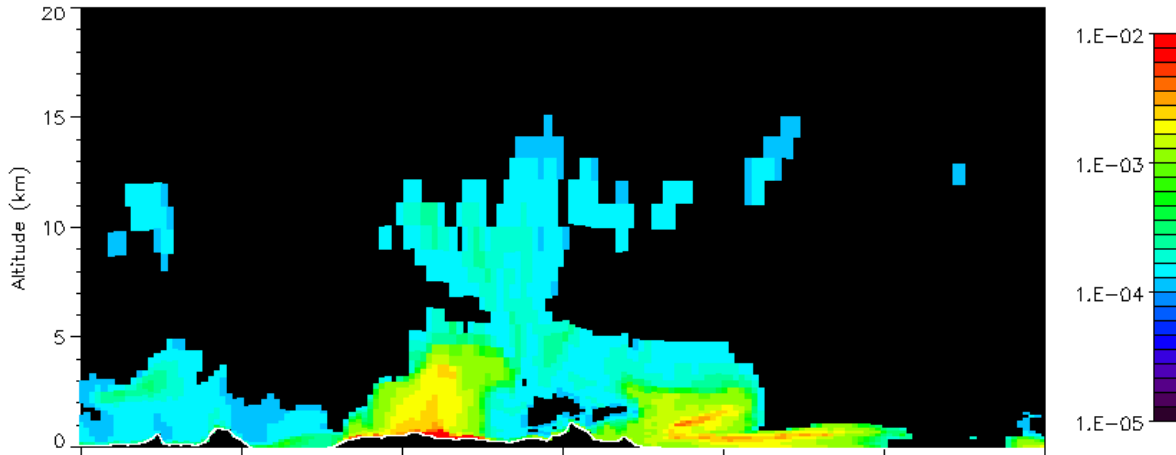
Doppler shift not a problem, but FP has low efficiency



Advanced Lidars: Exploring the Information Content & Simulating CATS



GEOS-5 Aerosols: TOTBKS 532 nm
Date: 20090715



GEOS-5 Aerosols: TOTEXT 532 nm
Date: 20090715

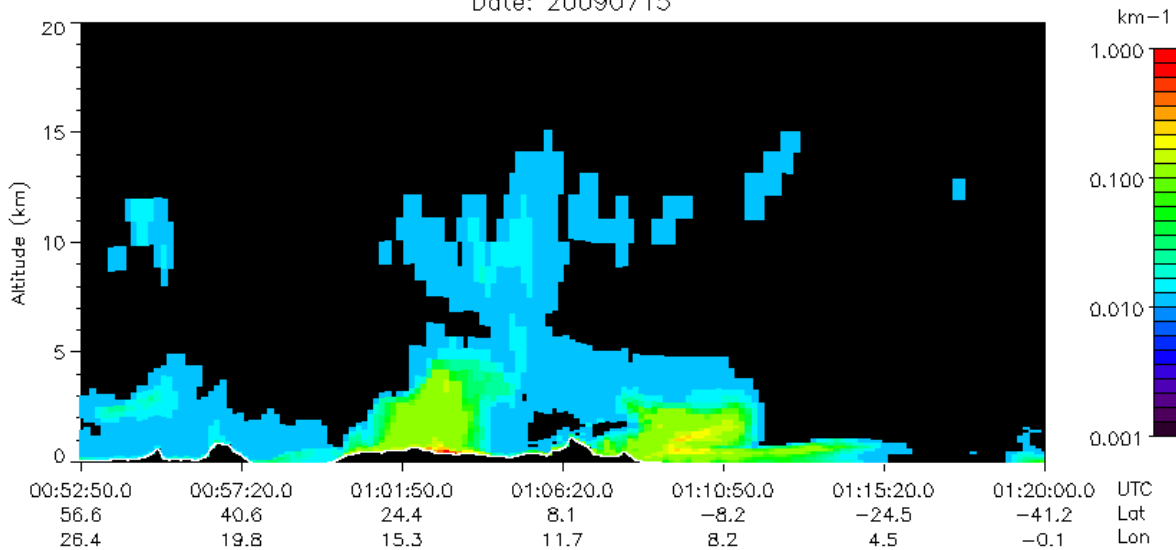
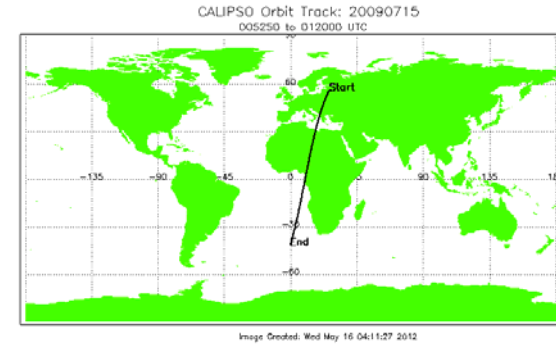


Image Created: Wed May 16 04:41:46 2012



GEOS-5 Inputs:

Met Data

Solar Stokes TOA (I,Q,U)

Surface Albedo & Type

Aerosol:

BKS, EXT, Depol, SSA for sulfate, sea salt, dust, black & organic carbon

Dust aerosols fully polarized

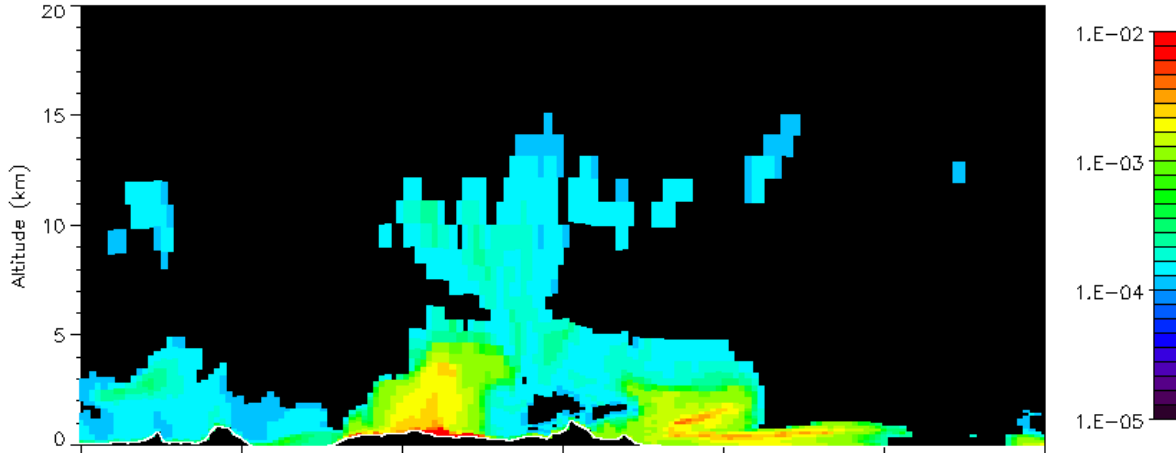
No Clouds, yet



Advanced Lidars: Exploring the Information Content & Simulating CATS



GEOS-5 Aerosols: TOTBKS 532 nm
Date: 20090715



GEOS-5 Aerosols: Vertical Feature Mask
Date: 20090715

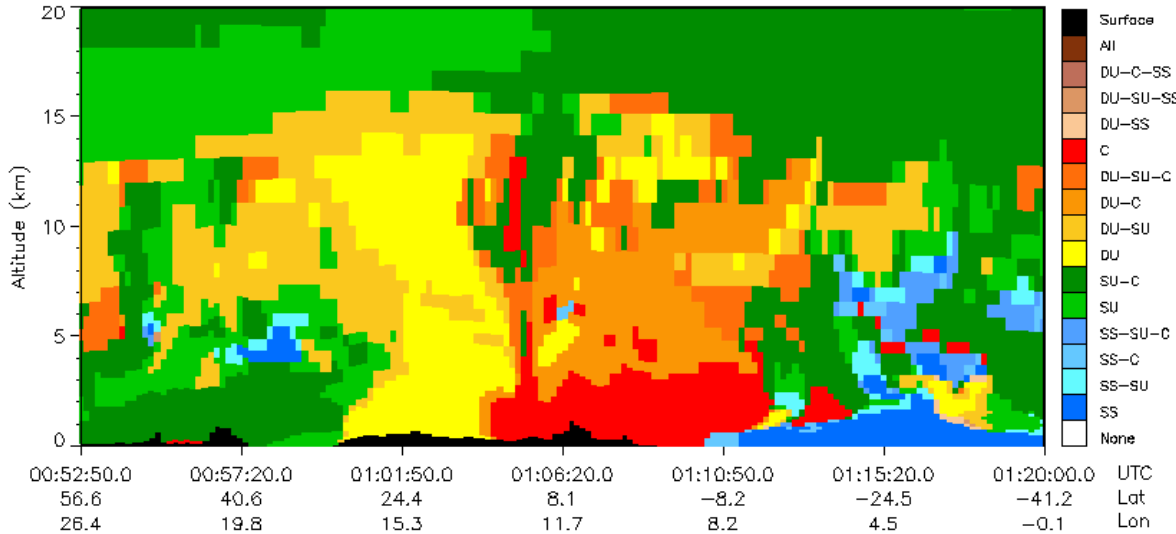
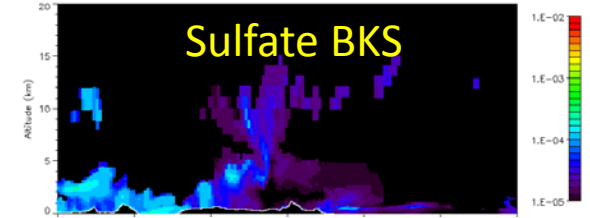
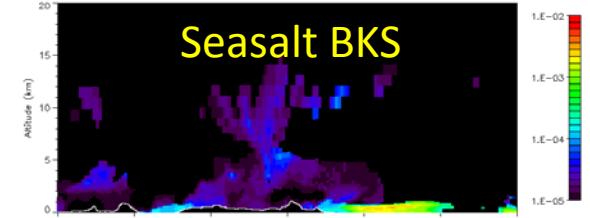


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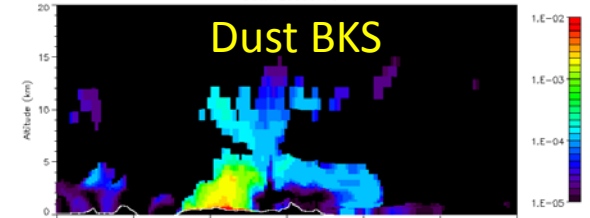
GEOS-5 Aerosols: SUBKS
Date: 20090715



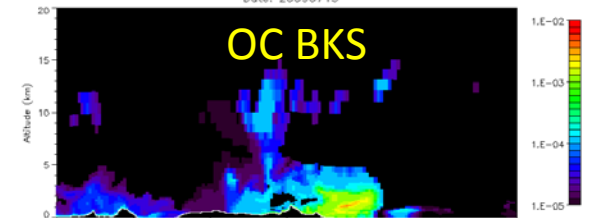
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Date: 20090715



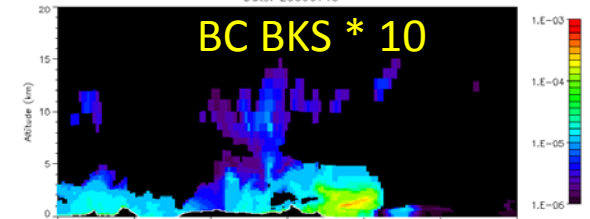
GEOS-5 Aerosols: DUBKS
Date: 20090715



GEOS-5 Aerosols: OCBKS
Date: 20090715



GEOS-5 Aerosols: BCBKS
Date: 20090715



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Lat: 56.6, 40.6, 24.4, 8.1, -8.2, -24.5, -41.2

Lon: 26.4, 19.8, 15.3, 11.7, 8.2, 4.5, -0.1

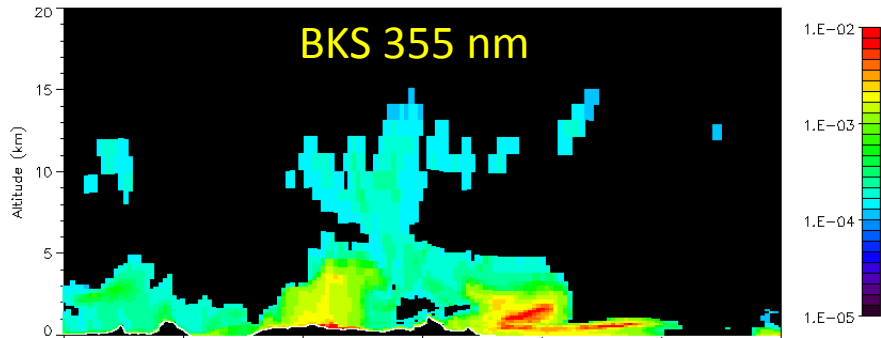
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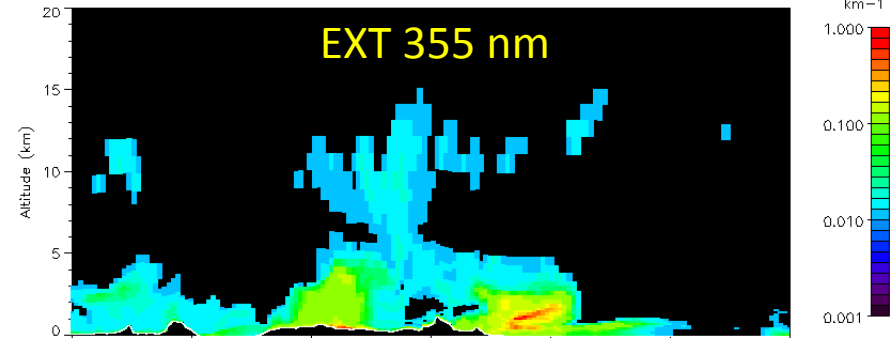
Advanced Lidars: Exploring the Information Content & Simulating CATS



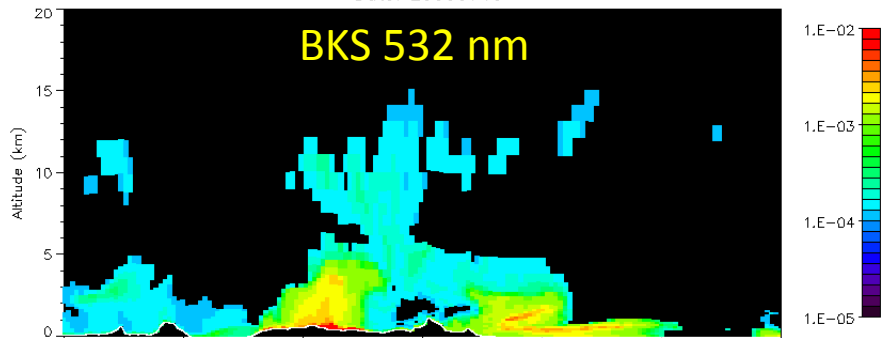
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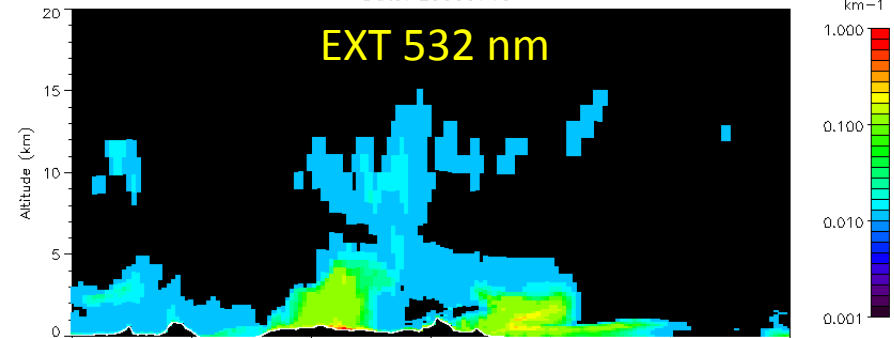
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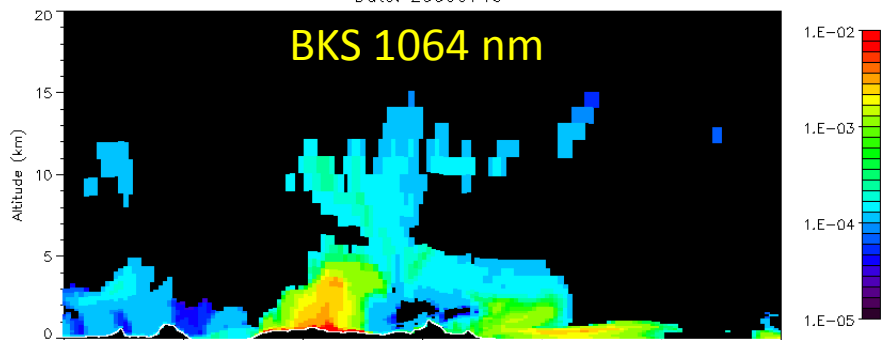
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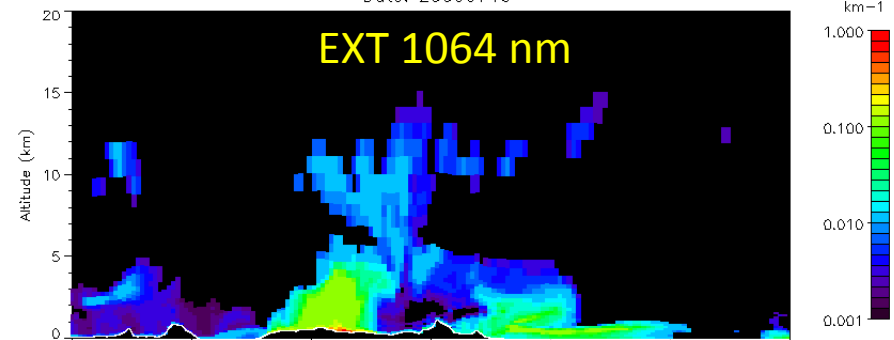
GEOS-5 Aerosols: TOTEXT 532 nm
Date: 20090715



GEOS-5 Aerosols: TOTBKS 1064 nm
Date: 20090715



GEOS-5 Aerosols: TOTEXT 1064 nm
Date: 20090715



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56.6 40.6 24.4 8.1 -8.2 -24.5 -41.2 Lat
26.4 19.8 15.3 11.7 8.2 4.5 -0.1 Lon

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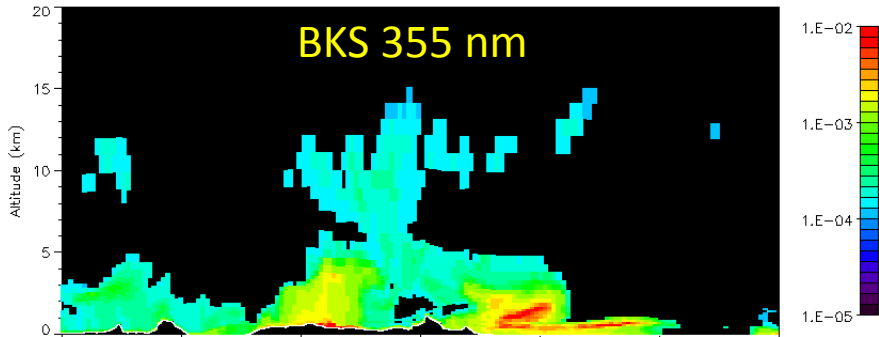
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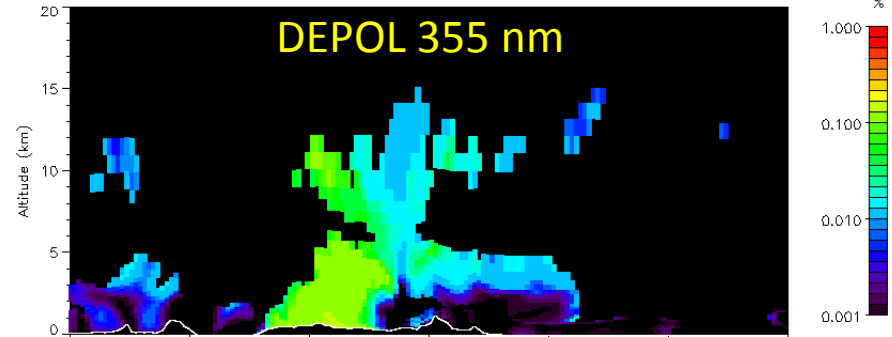
Advanced Lidars: Exploring the Information Content & Simulating CATS



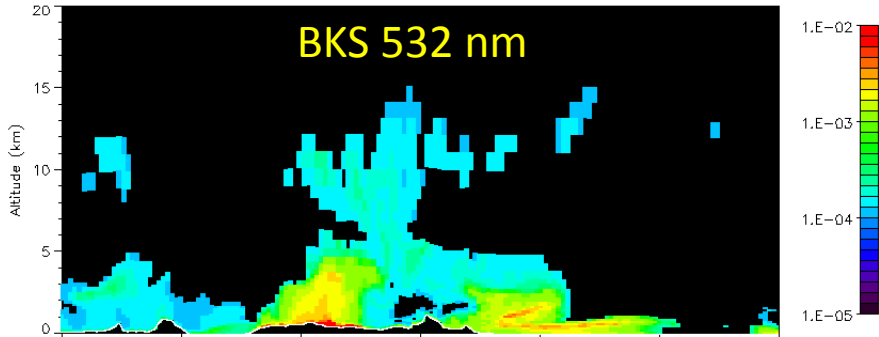
GEOS-5 Aerosols: TOTBKS 355 nm
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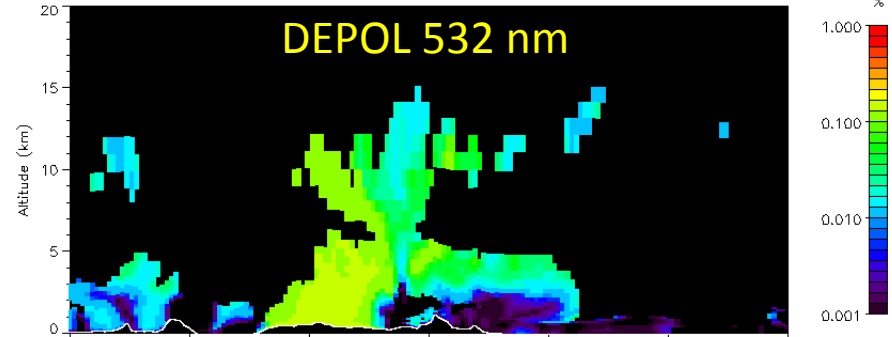
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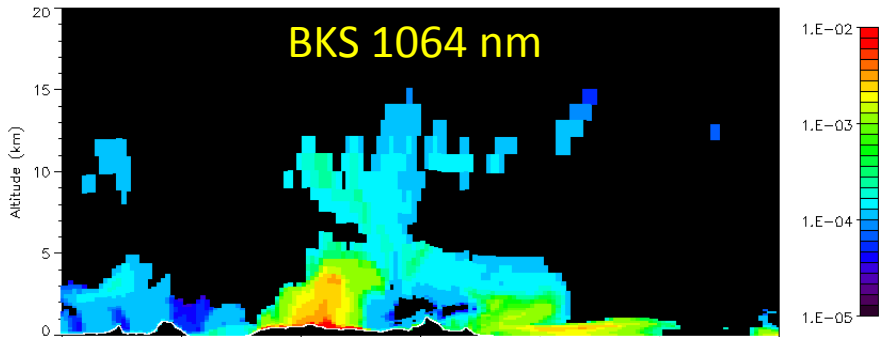
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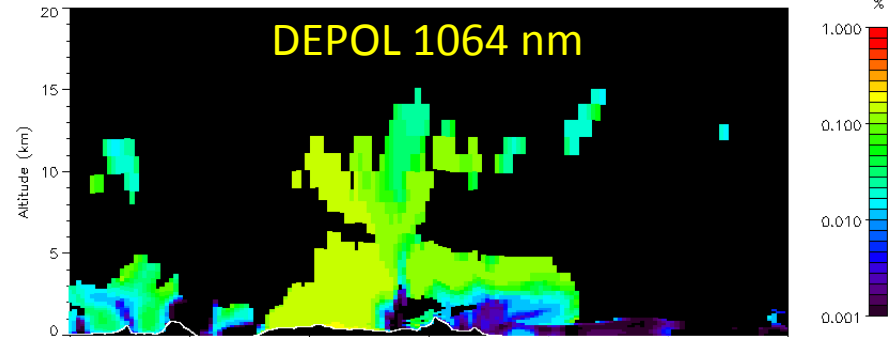
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Date: 20090715



GEOS-5 Aerosols: TOTBKS 1064 nm
Date: 20090715



GEOS-5 Aerosols: TOTDEPOL 1064 nm
Date: 20090715



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26.4 19.8 15.3 11.7 8.2 4.5 -0.1 Lon

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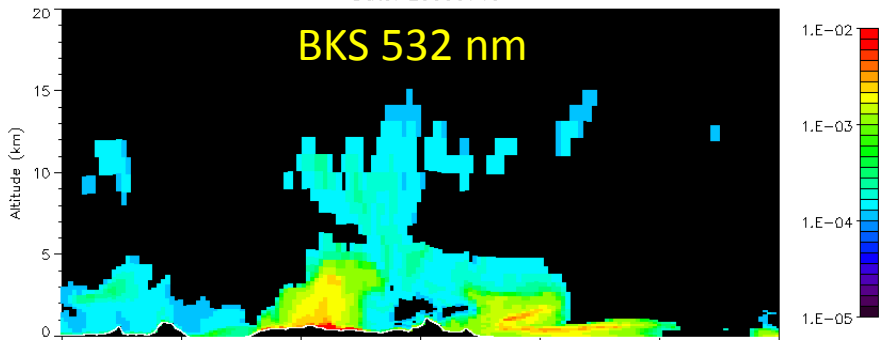
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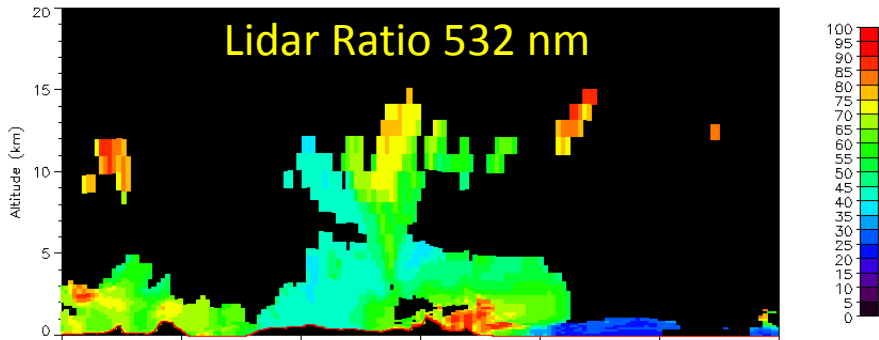
Advanced Lidars: Exploring the Information Content & Simulating CATS



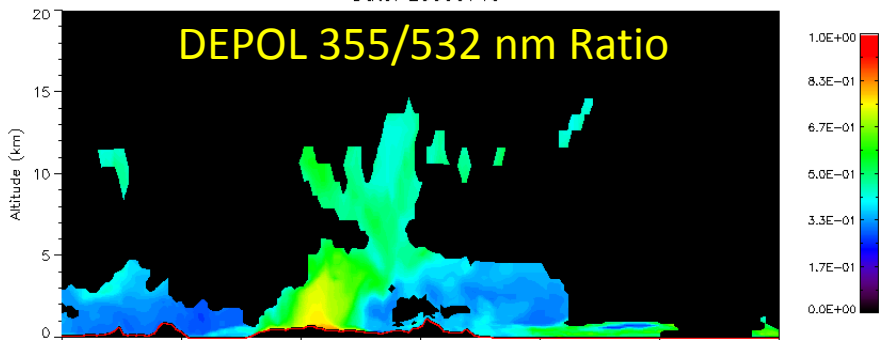
GEOS-5 Aerosols: TOTBKS 532 nm
Date: 20090715



GEOS-5 Aerosols: 532 nm Lidar Ratio
Date: 20090715



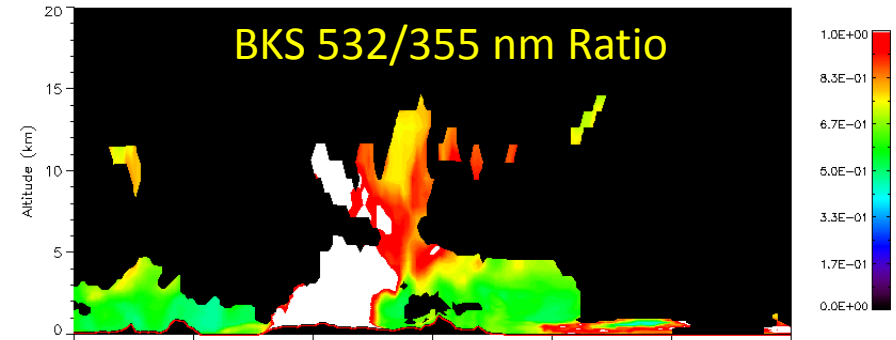
GEOS-5 Aerosols: TOTDEPOL 355/532 nm Ratio
Date: 20090715



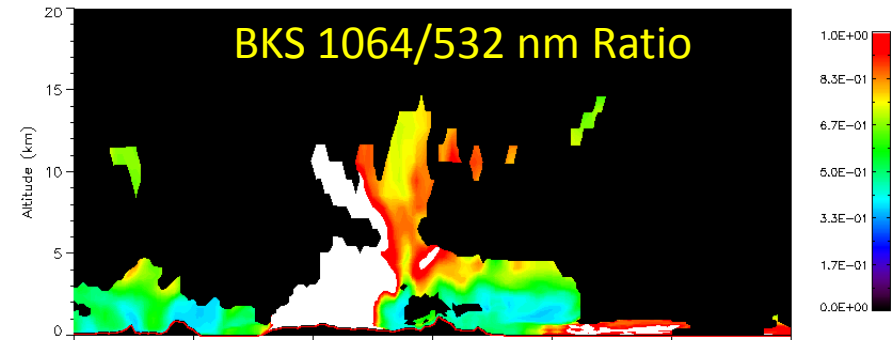
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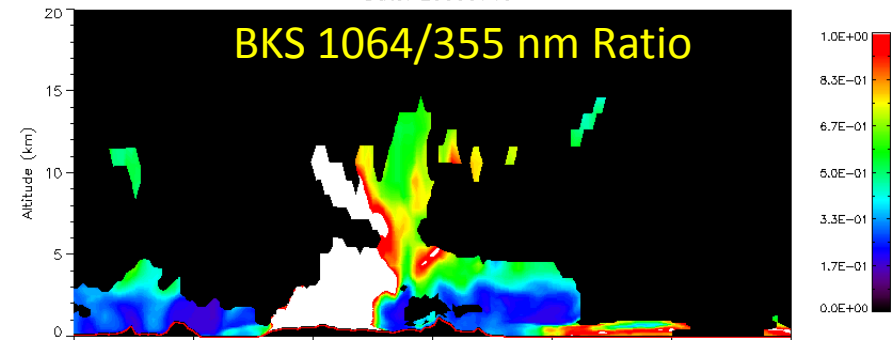
GEOS-5 Aerosols: TOTBKS 532/355 nm ratio
Date: 20090715



GEOS-5 Aerosols: TOTBKS 1064/532 nm ratio
Date: 20090715



GEOS-5 Aerosols: TOTBKS 1064/355 nm ratio
Date: 20090715

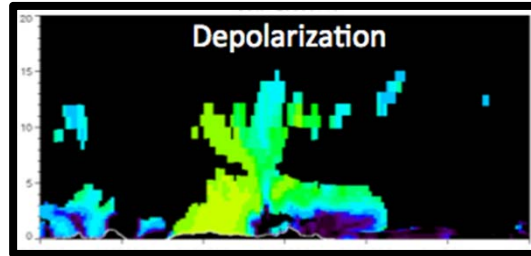
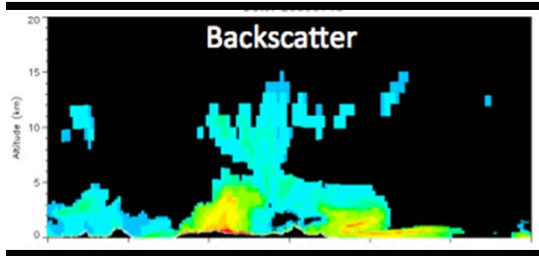


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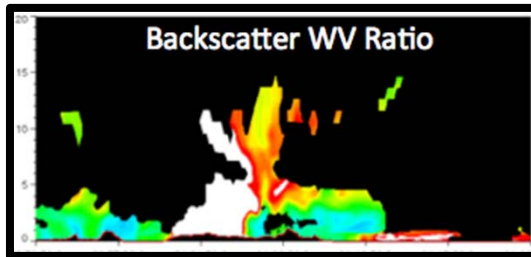
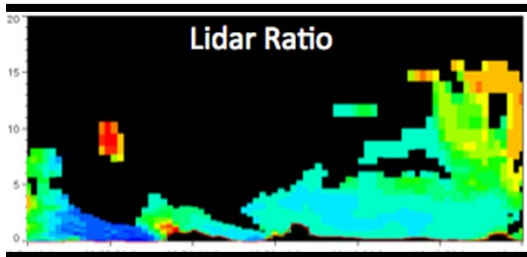
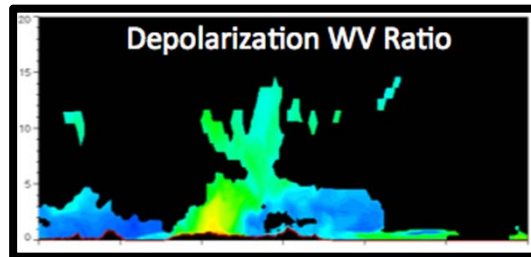
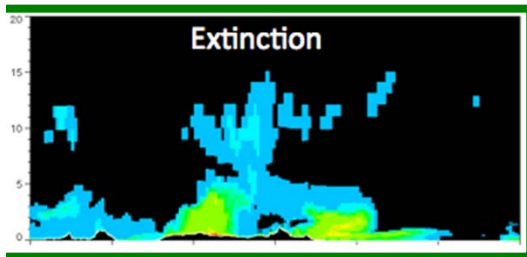
Image Created: Wed May 16 05:30:09 2012



Parameters of Interest for Lidar



Considering only parameters that are observed or retrieved directly





Lidar Capabilities



ACE Lidar Requirements:

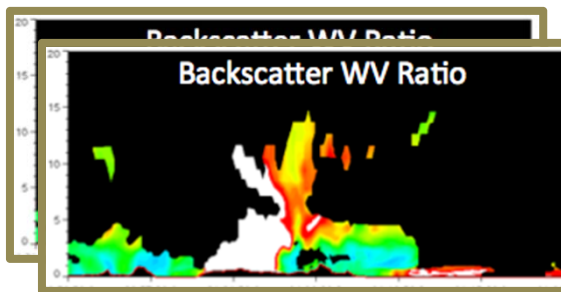
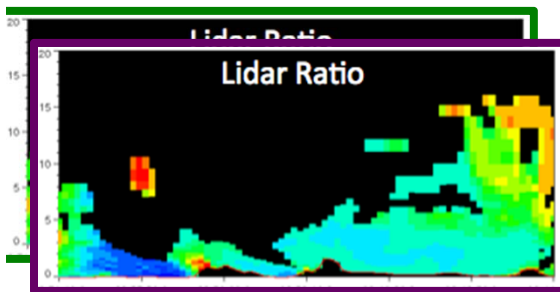
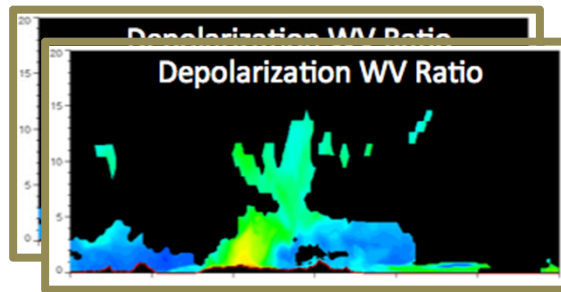
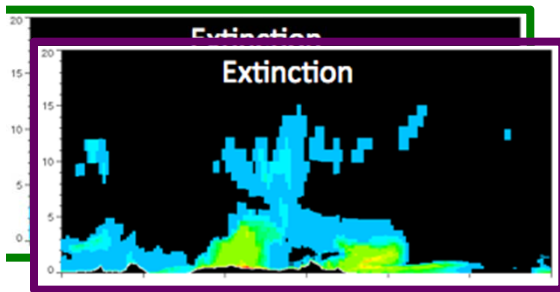
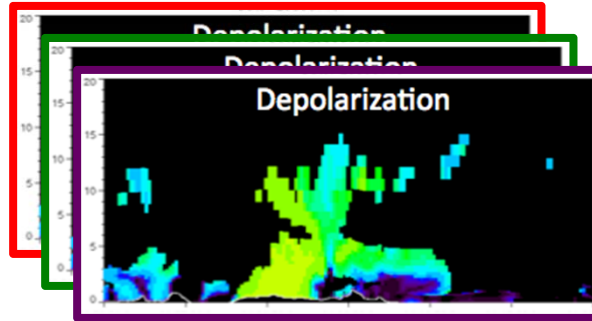
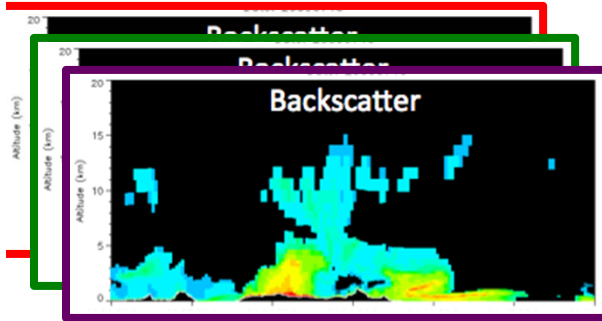
1064, 532, 355 nm backscatter lidar
Depolarization at least 2λ , pref 3λ
HSRL Extinction & Lidar Ratio at 355, 532 nm

This is so-called $3\beta + 2\alpha$ lidar, with multiple depol.

Considered minimum information content to retrieve microphysics.

The color of data plot outline denotes wavelength:

- 355 nm
- 532 nm
- 1064 nm





Lidar Capabilities



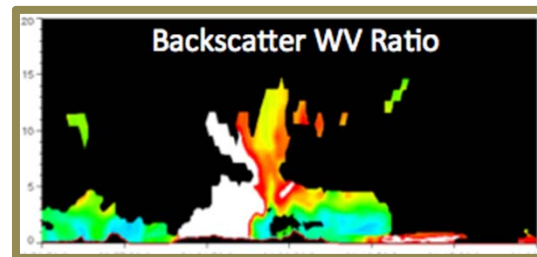
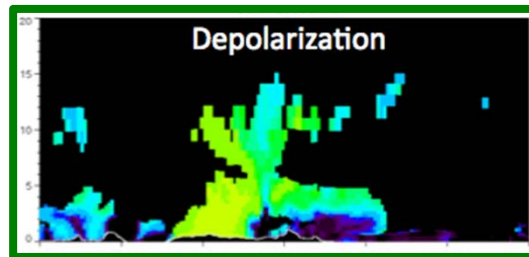
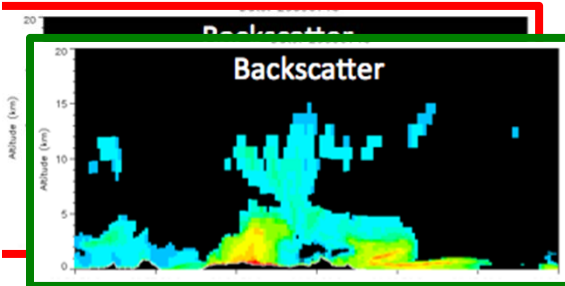
CALIPSO Capability:

1064, 532 nm backscatter lidar
Depolarization at 532 nm

No independent extinction or lidar ratio

No multi-wavelength depol

Backscatter wavelength dependence (WV) is
NOT used for aerosol typing





Lidar Capabilities



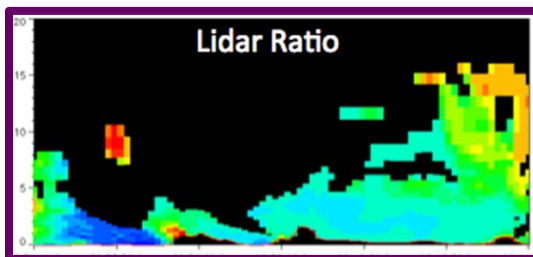
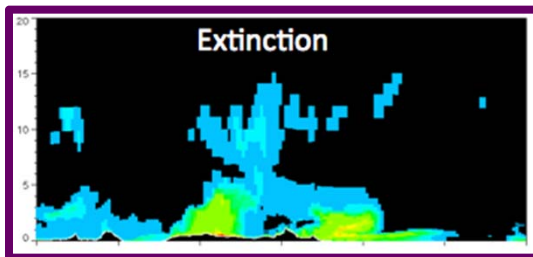
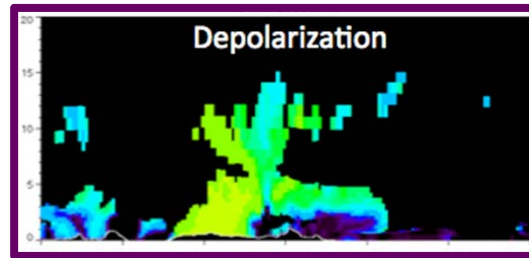
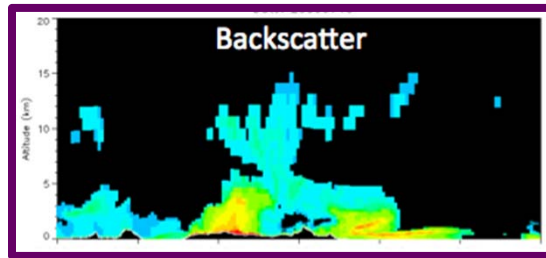
EarthCare AT-LID Capability:

355 nm Backscatter
HSRL extinction & lidar ratio at 355 nm
Depolarization at 355 nm

No multi-wavelength depol

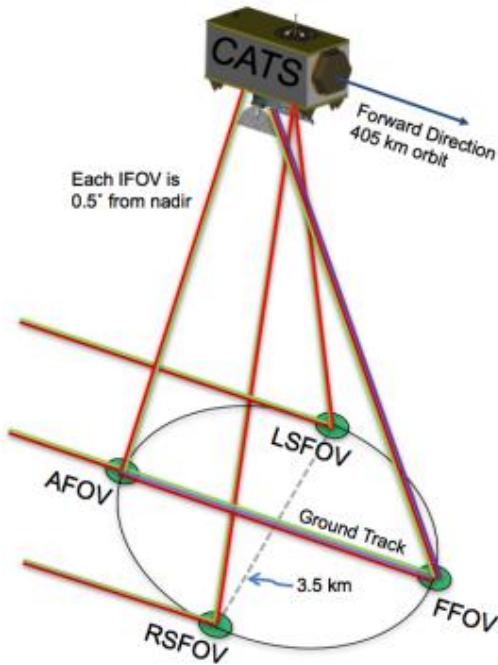
No wavelength dependence (WVD)

Due to the wavelength difference, EarthCare cannot provide climate observation continuity with CALIPSO.





The ISS Cloud Aerosol Transport System (CATS) Lidar: Launch mid-2013



The Cloud-Aerosol Transport System (CATS) is a lidar remote sensing instrument currently being developed for deployment to the International Space Station (ISS). The CATS lidar will provide range-resolved profile measurements of atmospheric aerosol and cloud distributions and properties at three wavelengths (355, 532, and 1064 nm). Retrieved properties include: layer height and thickness, backscatter, optical depth, extinction, depolarization, and discrimination of aerosol type and cloud ice/water phase. CATS operates in one of six science modes to meet mission goals, utilizing various configurations of two high repetition rate lasers and four instantaneous field of view (IFOV).

CATS Mission Goals:

(A) Extend CALIPSO data record for continuity of Lidar Climate Observations

- Continue record of vertically resolved aerosol and cloud distributions and properties
- Improve our understanding of aerosol and cloud properties and interactions
- Improve model based estimates of climate forcing and predictions of future climate change

(B) Improve Operational Aerosol Forecasting Programs

- Improve model performance through assimilation of near-real-time aerosol and cloud data
- Enhance air quality monitoring and prediction capabilities by providing vertical profiles of pollutants
- Improve strategic and hazard warning capabilities of events in near-real-time (dust storms, volcanic eruptions)

(C) NASA Decadal Mission Pathfinder: Lidar for the Aerosols, Clouds, Ecosystems (ACE) Mission

- Demonstrate HSRL aerosol retrievals and 355 nm data for ACE mission development
- Laser Technology Demo/Risk Reduction: high repetition rate, injection seeding (HSRL), and wavelength tripling (355 nm)

Science Mode	Laser	Wavelength (nm)							IFOV				Mission Goals		
		1064		532			355		LSFOV	RSFOV	FFOV	AFOV	(A) Continuity of Lidar Climate Observations	(B) Improve Operational Forecasting	(C) ACE Mission Development, Laser Tech Demo
			⊥		⊥	HSRL		⊥							
1	1	X	X	X	X				X	X			All	All	
2	2a	X	X	X		X						X	Partial, no 532 ⊥	All	ACE HSRL
3	2b	X	X	X	X		X	X			X		All	All	ACE 355 nm
4	2c	X	X	X	X				X				All (backup)	All (backup)	
5	2c	X	X	X	X					X			All (backup)	All (backup)	
6	2c	X	X	X	X						X		All (backup)	All (backup)	

* CATS utilizes two lasers. Laser 1 and Laser 2. Laser 2 has three internal configurations: 2a, 2b, and 2c. The laser output for each configuration is shown above.

** Science Modes 4, 5, 6 all utilize Laser 2c directed to one of three IFOV. Thus, they are not separate, independent backup modes for Goals (A) and (B). If Laser 2 were to fail then all these modes fail.

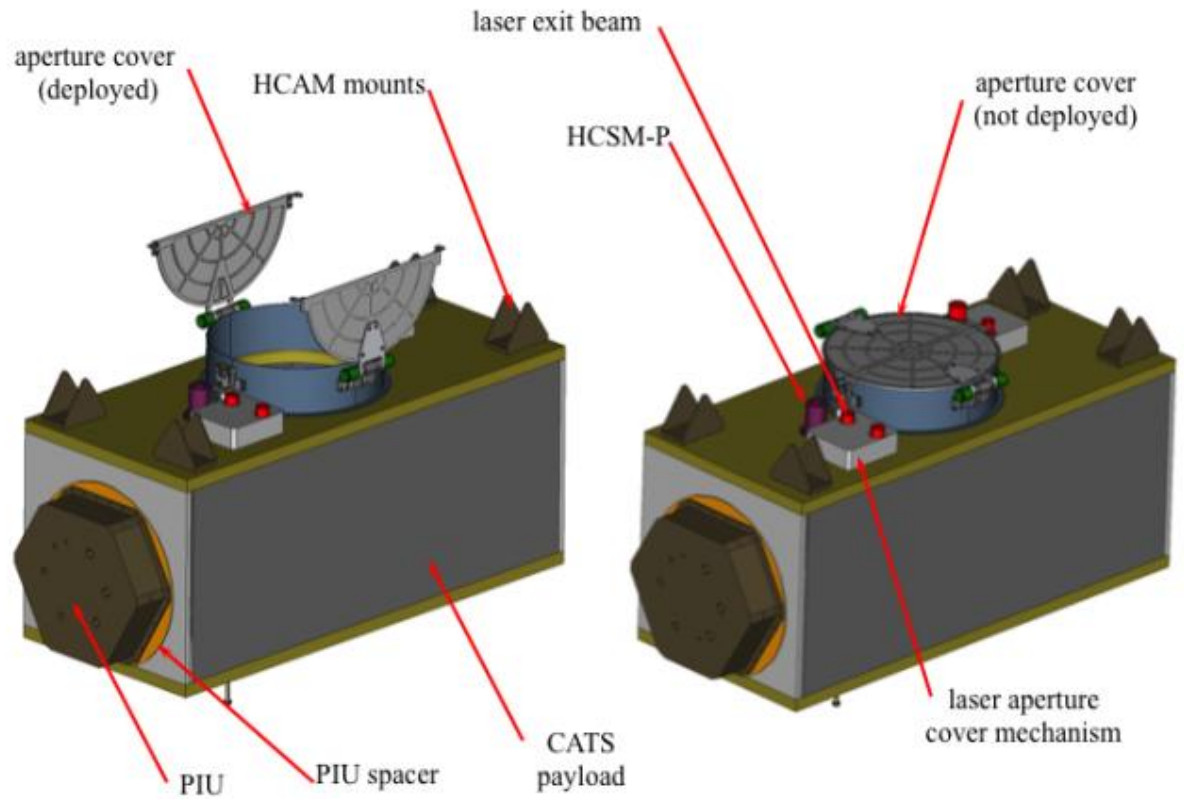
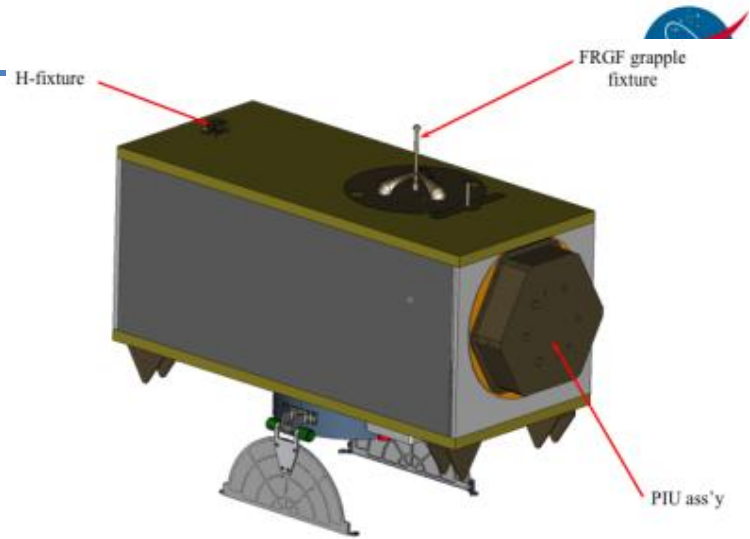
*** Science Modes 1 and 3 provide inherent redundancy for Goals (A) and (B).

**** Science Mode 2 does not provide depolarization measurements at 532 nm, and thus does not map directly to CALIPSO. As a result this mode only partially supports Goal (A).



CATS Instrument

- Instrument
 - Lidar, multi-wavelength (1064, 532, 355 nm)
 - Mass: < 500 kg
 - Power: < 1000W
 - Data rate: ~ 2 Mbits/second via HRDL



CATS Airborne Instrument



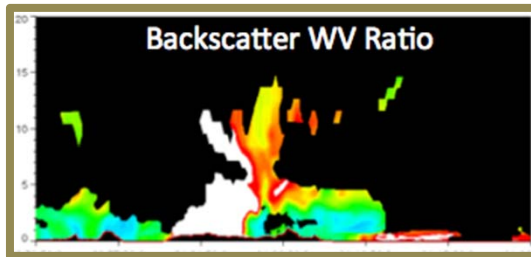
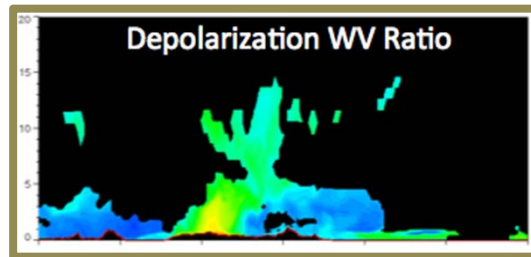
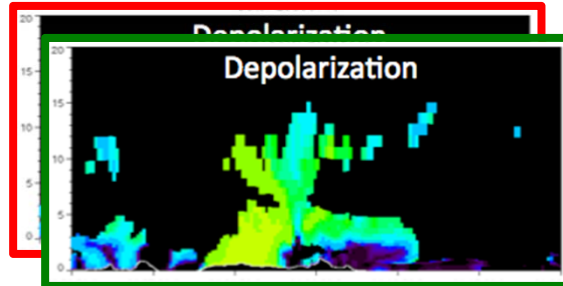
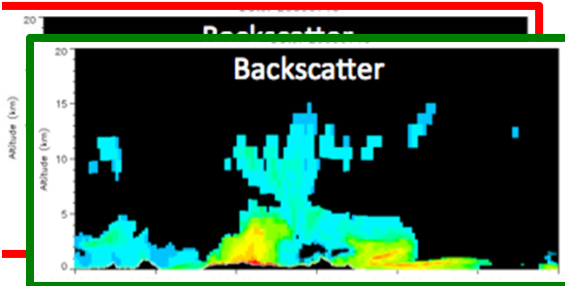
HSRL receiver subsystem, will be used in CATS-ISS

Complete instrument, ready for aircraft installation





CATS Science Modes



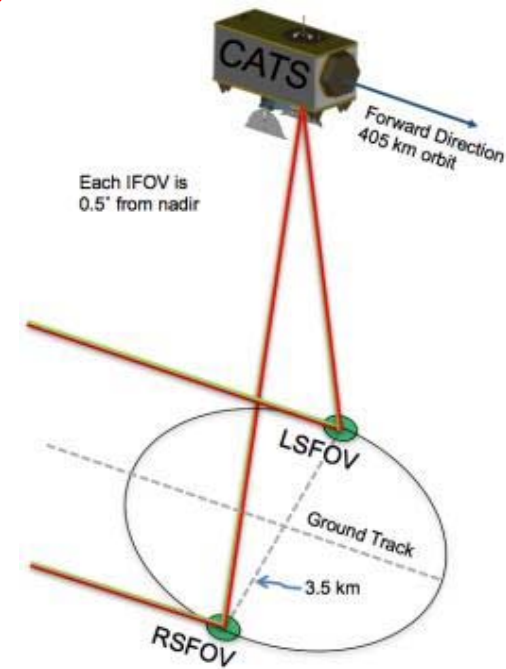
CATS Science Mode 1 Capability:

1064, 532 nm backscatter lidar
Depolarization at 532, 1064 nm

No independent extinction or lidar ratio

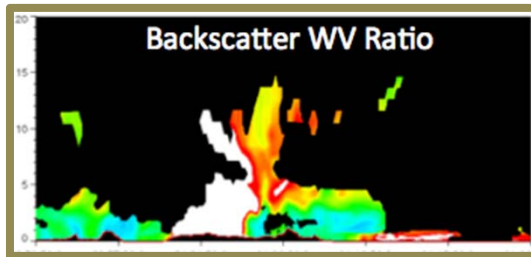
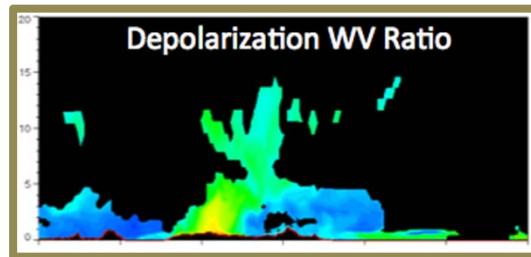
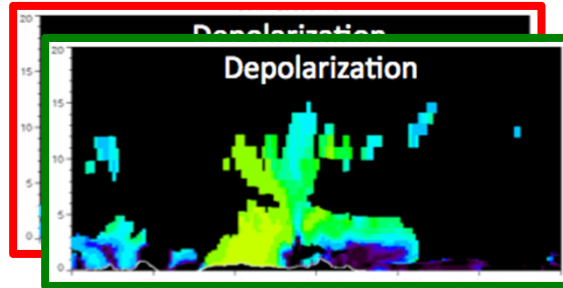
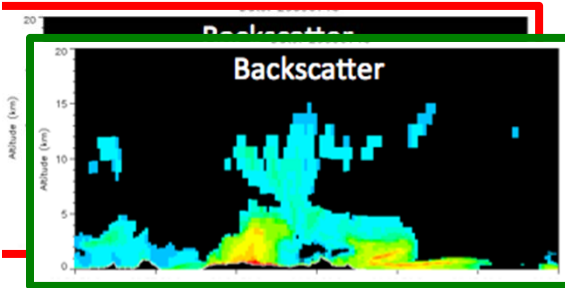
* Basic mode for goal (A) and (B), yet more capability than currently provided by CALIPSO

** Same capability as backup science modes 4,5,6





CATS Science Modes



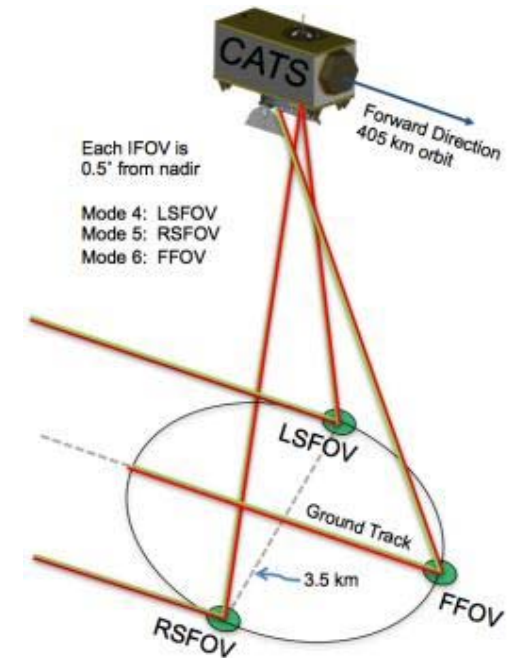
CATS Science Mode 4,5,6 Capability:

1064, 532 nm backscatter lidar
Depolarization at 532, 1064 nm

No independent extinction or lidar ratio

* Basic mode for goal (A) and (B), yet more capability than currently provided by CALIPSO

** Same capability as science mode 1, but using laser 2 and different FOV selections





CATS Science Modes



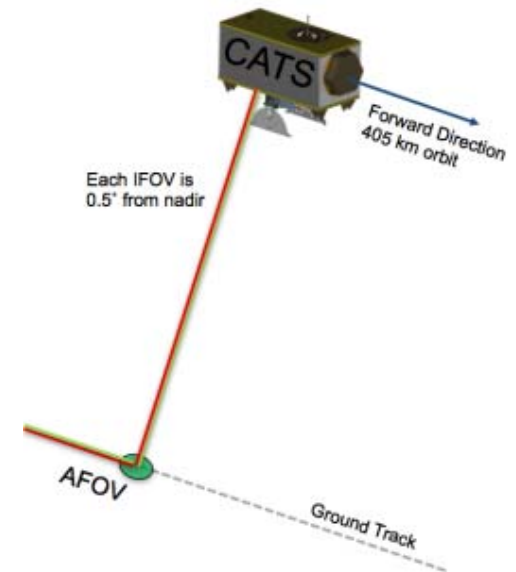
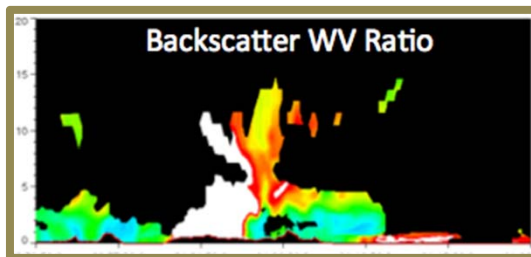
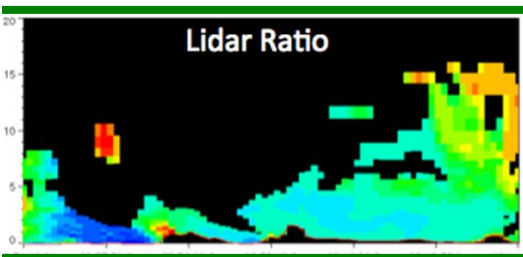
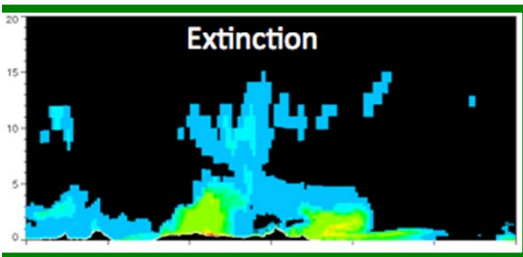
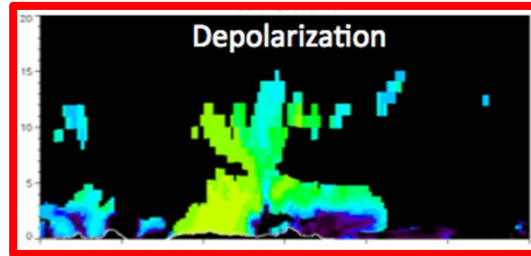
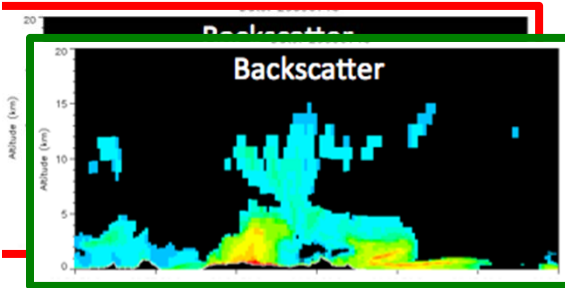
CATS Science Mode 2 Capability:

1064, 532 nm backscatter lidar
532 nm HSRL
Depolarization at 1064 nm

No multi-wavelength depol

* Mode 2 provides best capability for goals (A) and (B), and addresses HSRL objectives of goal (C)

** Caveat: HSRL retrievals from space are untested, this is primarily a tech and data demo mode. Objectives of Goal (B) include hindsight and model evaluation, not forecasting.





CATS Science Modes



CATS Science Mode 3 Capability:

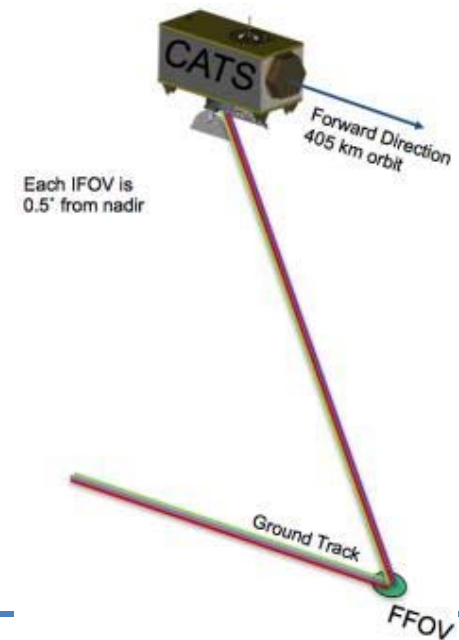
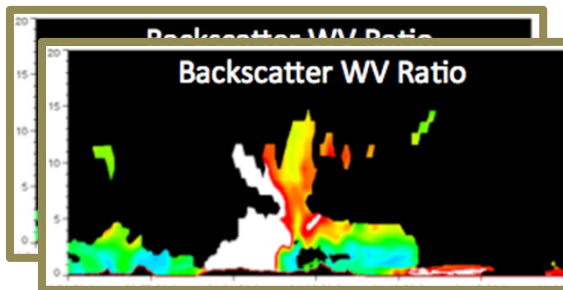
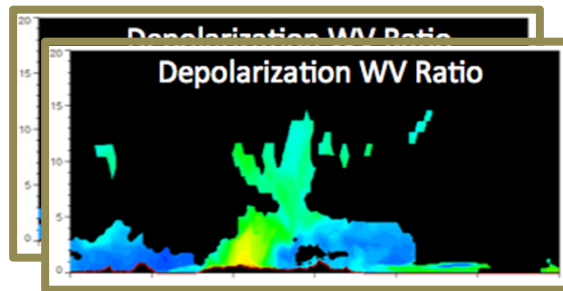
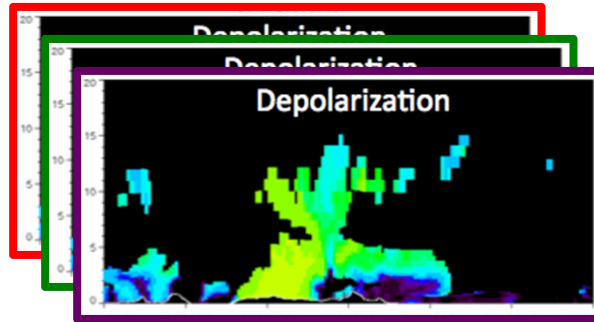
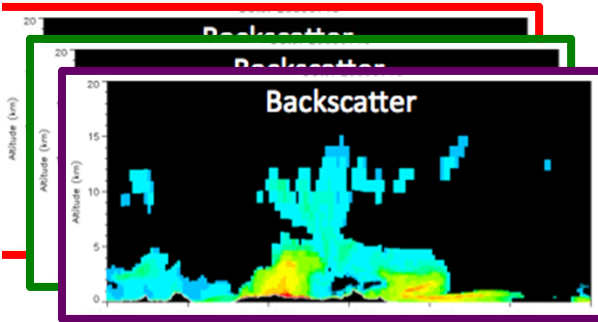
1064, 532, 355 nm backscatter lidar
Depolarization at 1064, 532, 355 nm

No independent extinction or lidar ratio

Depolarization ratio 532/355 is desired for ACE

Backscatter WVD now includes 3λ , should be better for fine mode aerosols

* Mode 3 provides excellent capability for goals (A) and (B), and addresses 355 nm objectives of goal (C)

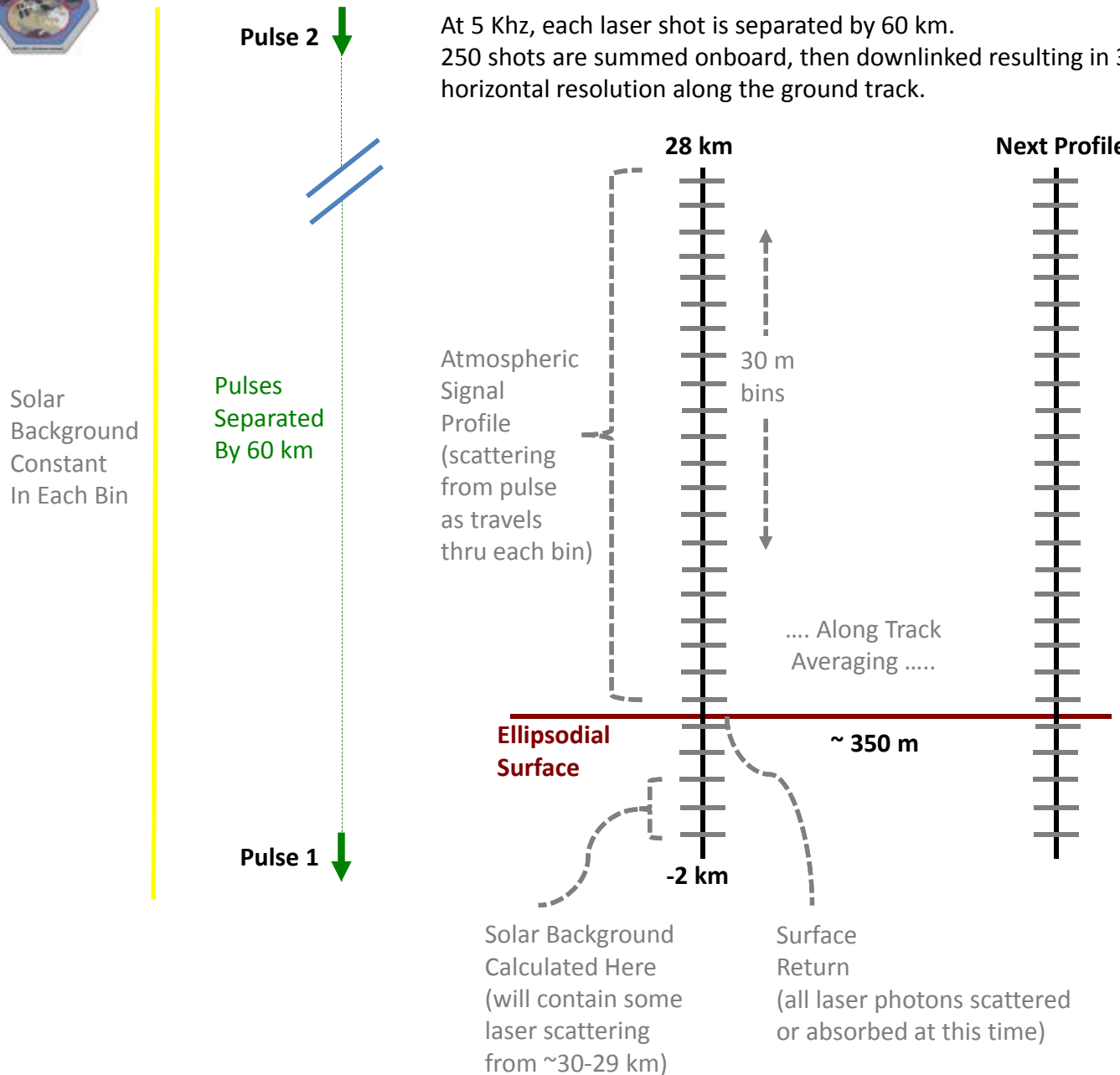




CATS Observations: Raw Data



At 5 KHz, each laser shot is separated by 60 km.
250 shots are summed onboard, then downlinked resulting in 350 m horizontal resolution along the ground track.



Data frame extent is fixed at 30 km

Data frame top/bottom and resolutions shown here are nominal values for start of mission. Values may be changed via ground commands during the mission, with the following limitations:

Data frame top/bottom values must equal 30 km extent, and allow sufficient sub-surface data for solar background corrections



High Repetition Rate Side Effect: Simultaneous Pulse Signals (SPS)



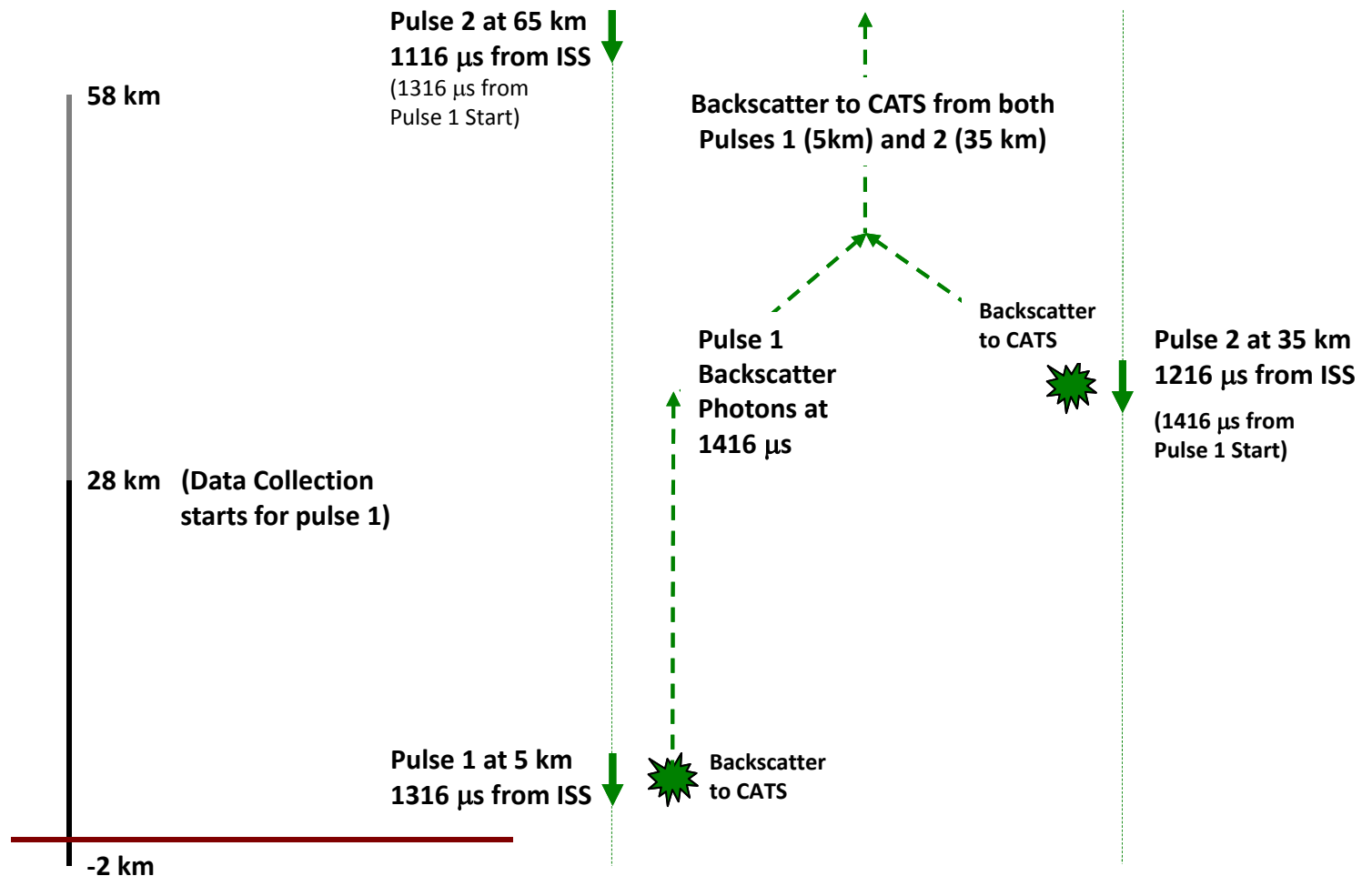
CATS Pulse Repetition Rate is 5 kHz

Pulses separated by 200 μs , or 60 km

SPS from successive pulse scattering in the stratosphere will be present in our lower 28 km data frame

Most likely negligible during day, night time effect under study

CATS calibration and data processing strategy will correct this issue



Stratospheric SPS contribution to solar background calculation and atmospheric profiles will be modeled and characterized prior to launch

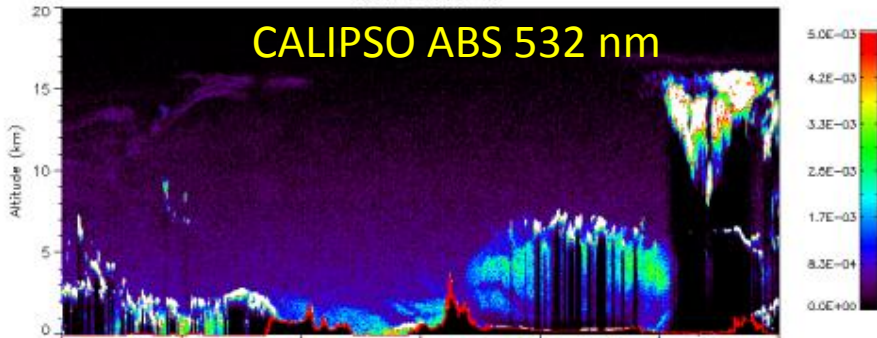
Thick, attenuating clouds in upper troposphere and mountain overpasses (ie, Himalayan plateau) will offer conditions to characterize the stratospheric SPS during the mission



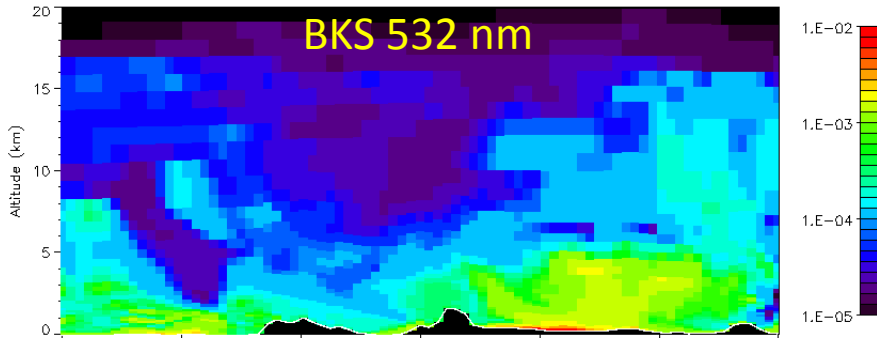
Simulated CATS Signals



CALIPSO Attenuated Backscatter (V3.01): Signals
Date: 20090715



GEOS-5 Aerosols: TOTBKS
Date: 20090715



CATS Total Attenuated Backscatter 532 nm

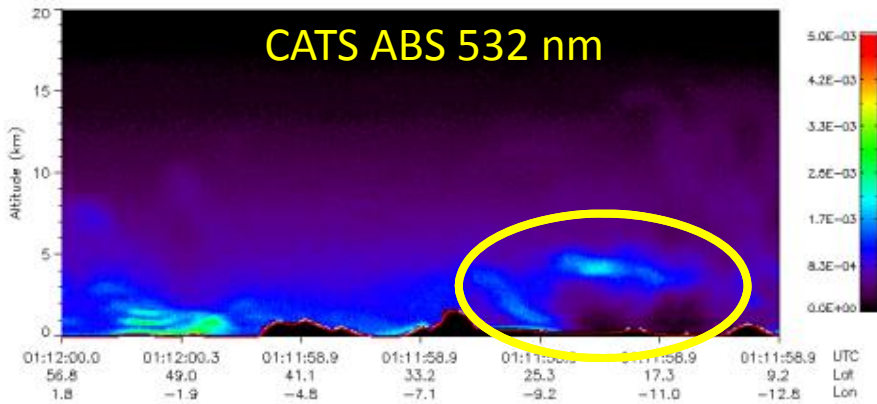
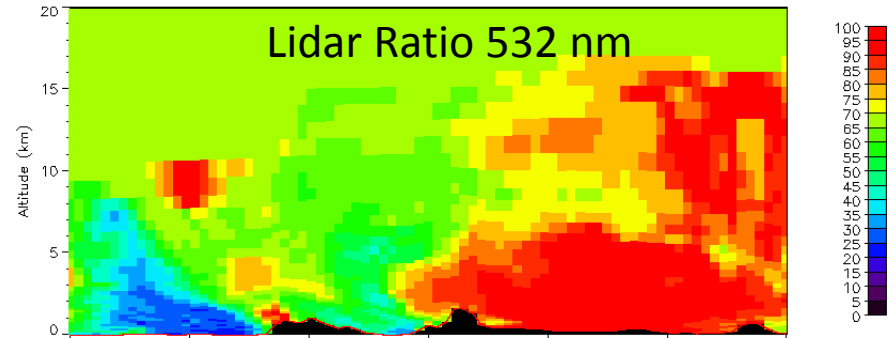
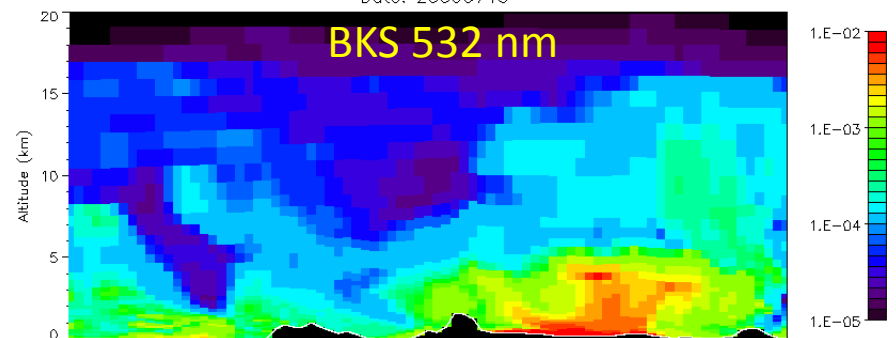


Image Created: Tue May 15 07:23:16 2012

GEOS-5 Aerosols: 532 nm Lidar Ratio
Date: 20090715



GEOS-5 Aerosols: TOTBKS 532 nm
Date: 20090715



GEOS-5 Aerosols: 532 nm Lidar Ratio
Date: 20090715

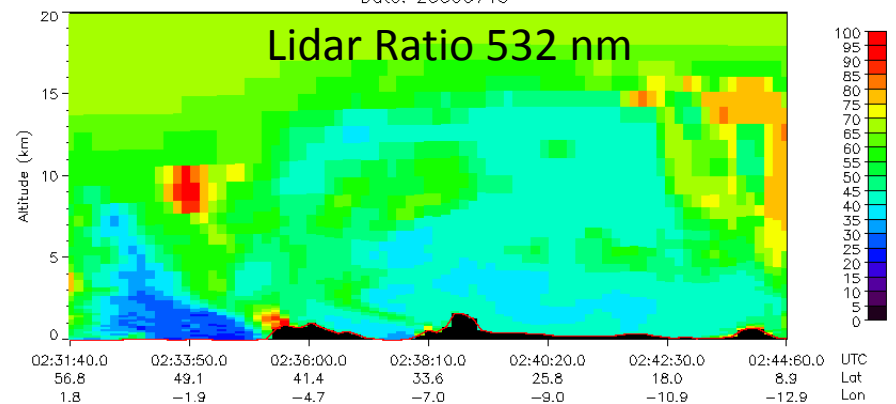
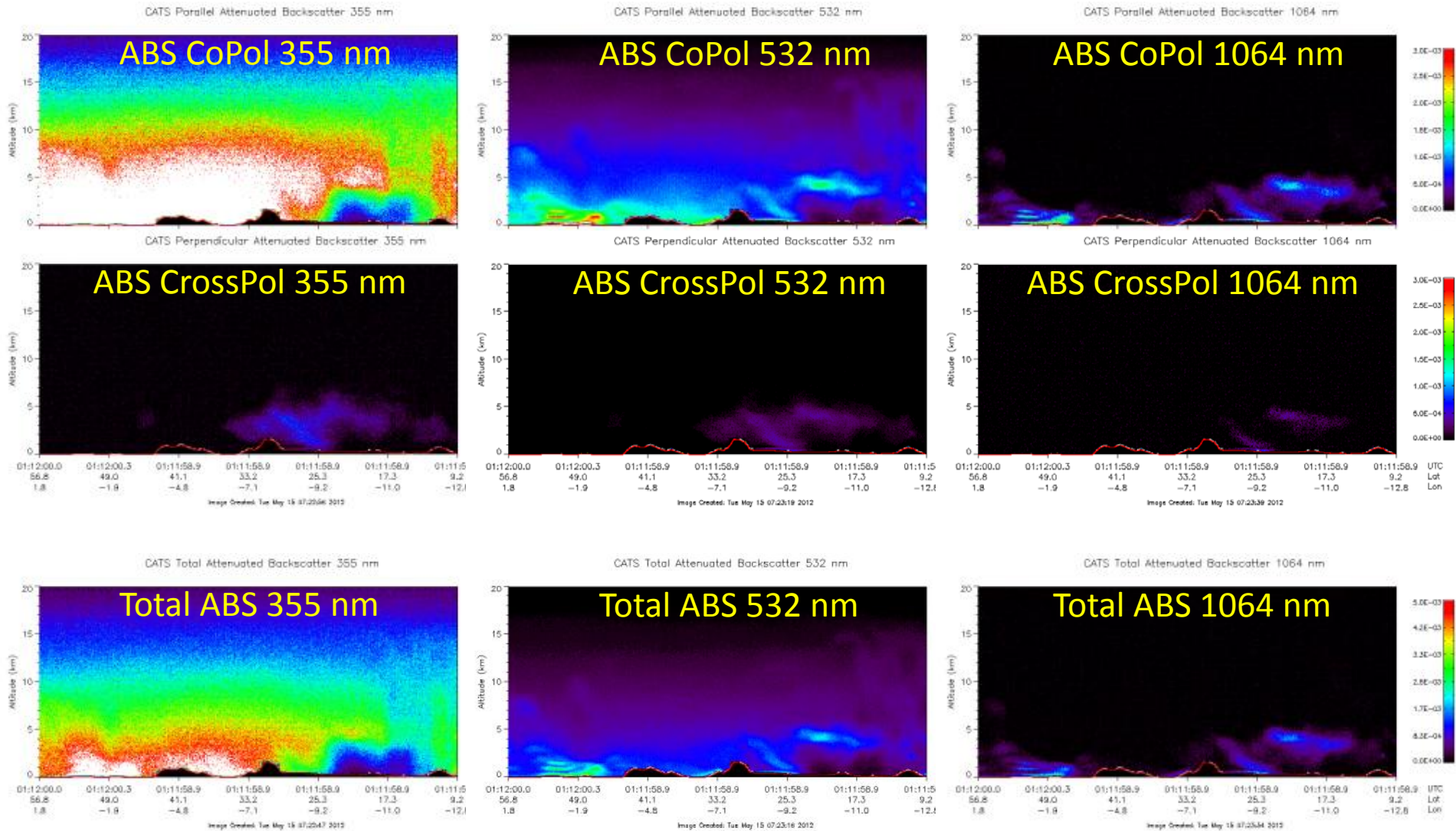


Image Created: Wed May 16 06:08:20 2012

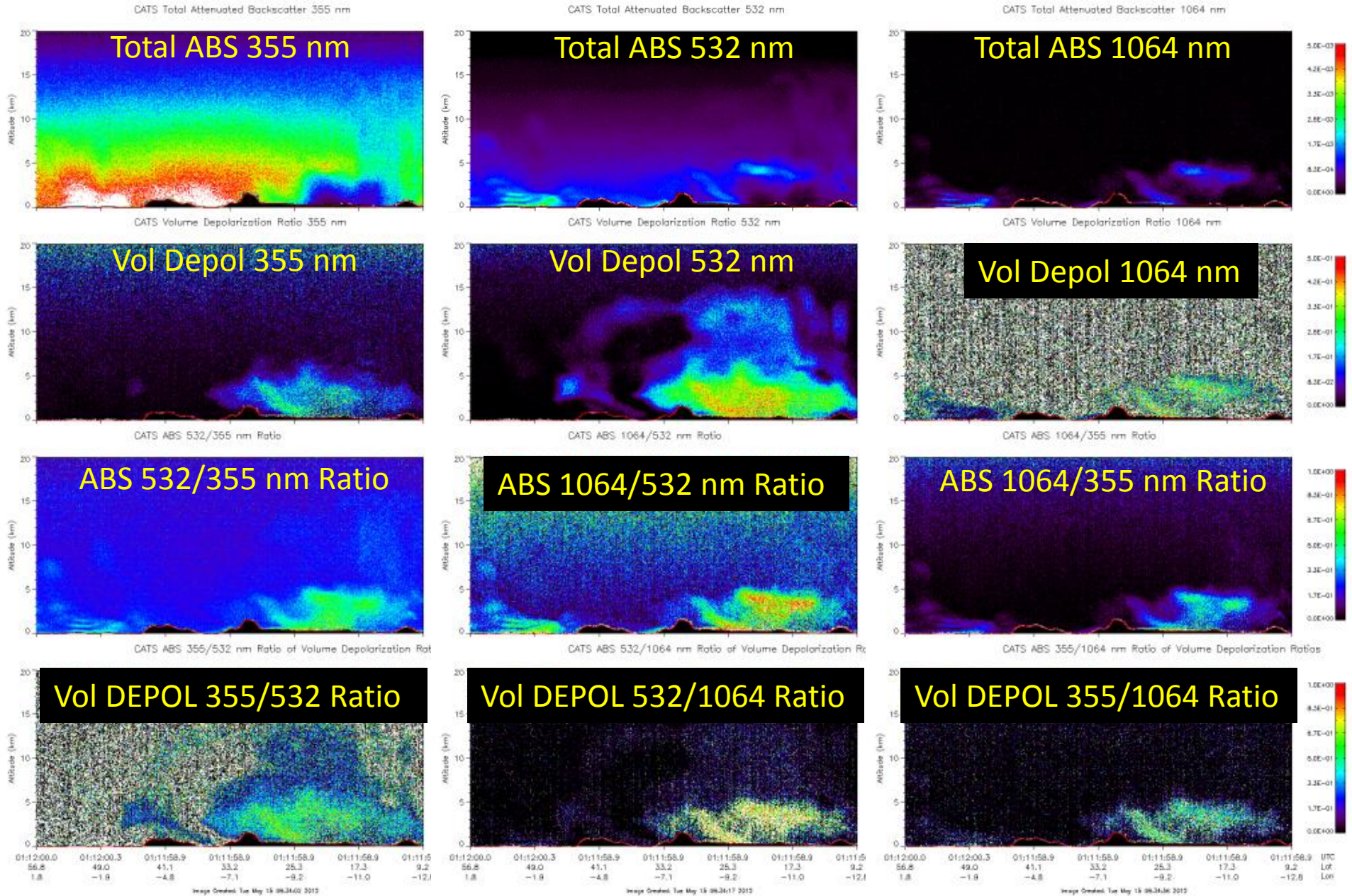


Simulated CATS Signals: 1 sec ave (~7 km along track), 30 m vertical



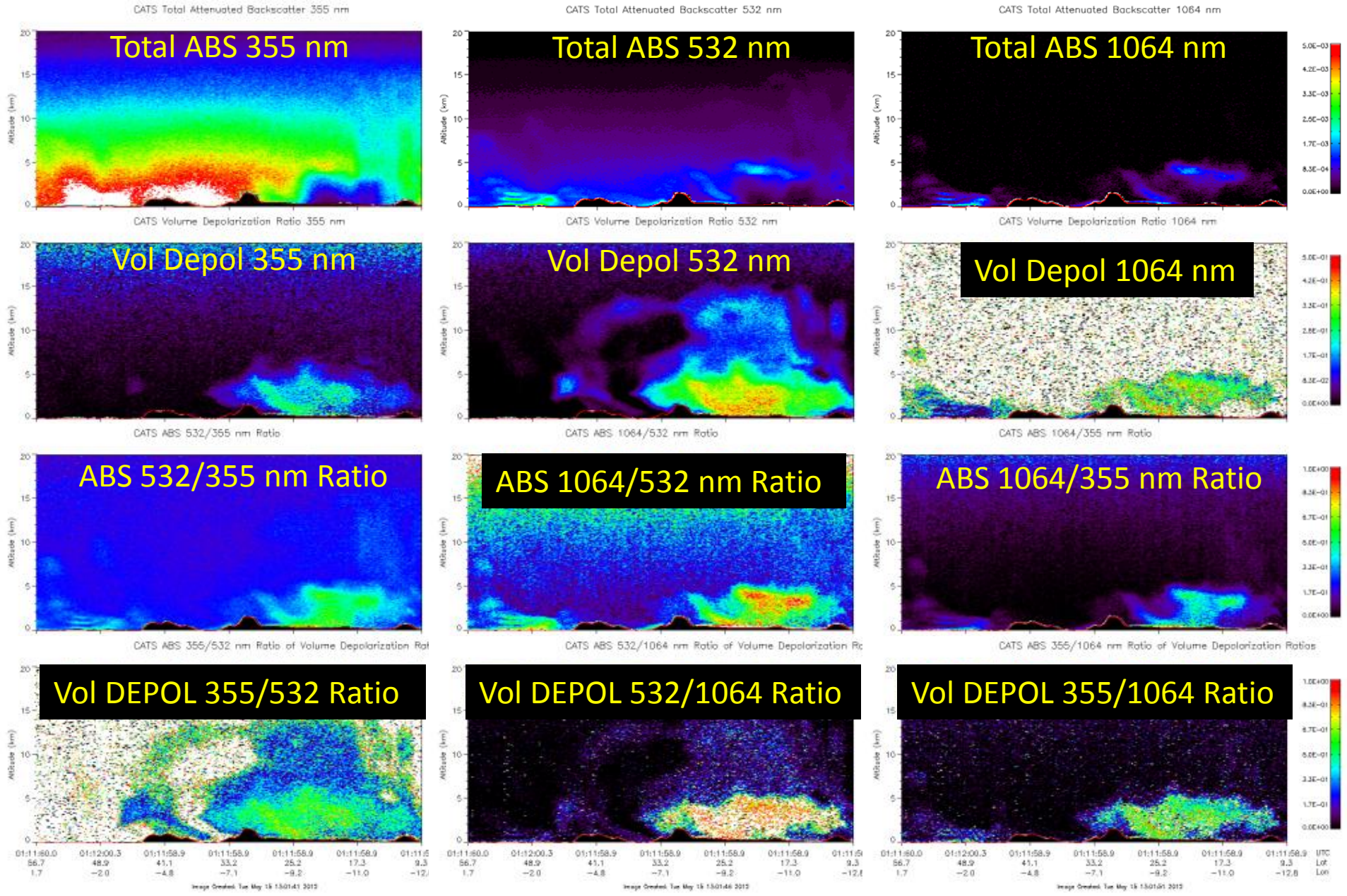


Simulated CATS Signals: 1 sec ave (~7 km along track), 30 m vertical





Simulated CATS Signals: 3 sec ave (~20 km along track), 30 m vertical



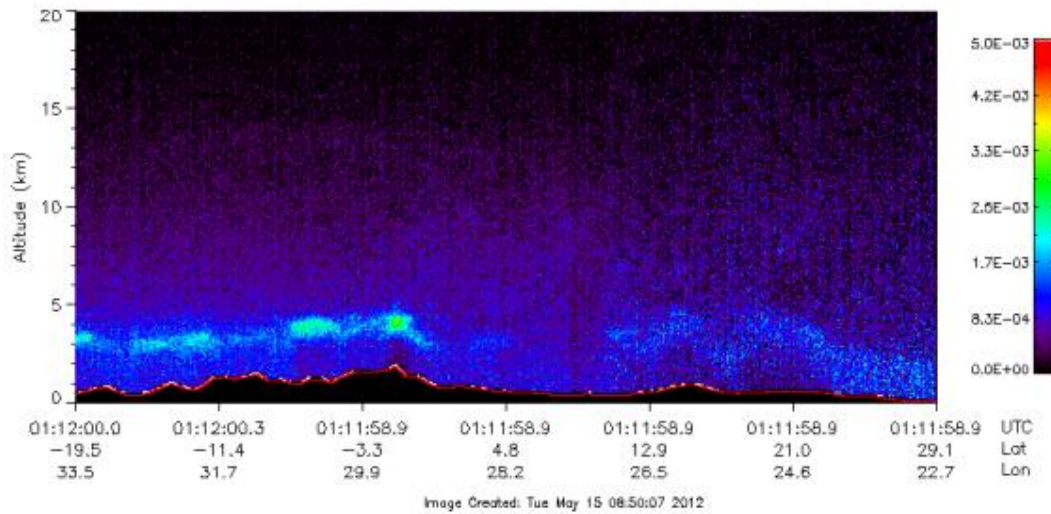
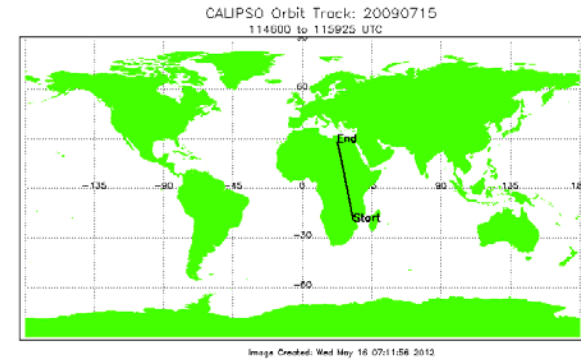
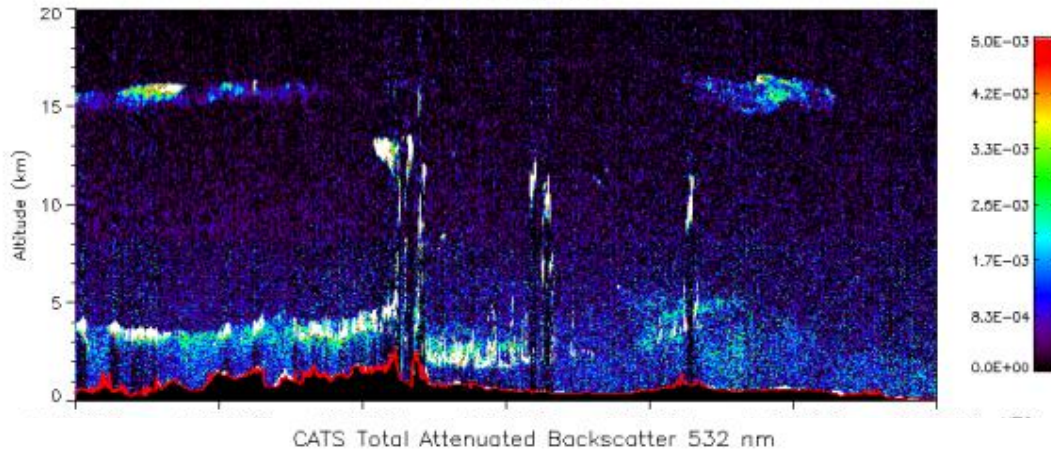


Simulated CATS Signals: 1 sec ave (~7 km along track), 30 m vertical



Daytime

CALIPSO Attenuated Backscatter (V3.01): Signals
Date: 20090715





CATS Performance Simulation: Detection Limits



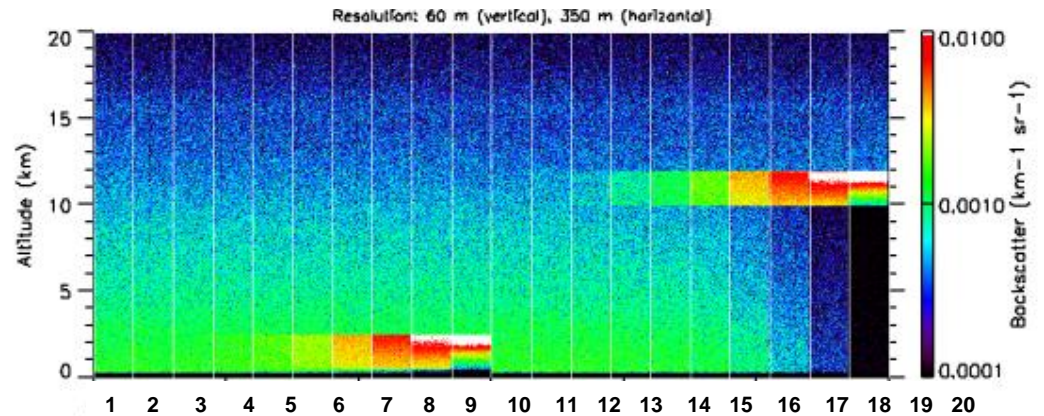
532 nm Results Shown Here, We are working on 355 and 1064 nm

Simulation prepared similar to CALIPSO approach.

Attenuated Backscatter signal constructed at expected Level 0 downlinked resolution (350 m along track, 60 m vertical)

- Aerosol Layer simulated in first 10 segments (lidar ratio = 30 sr, weak sea salt layer)
- Cirrus Layer in segments 11-20 (lidar ratio = 25 sr, typical for thin cirrus)

CATS Simulated Attenuated Backscatter: Night



Detection algorithm applied to each layer and segment based on Yorks et al. (2011) and Palm et al. (2002)

Detection improves as layer concentration/backscatter increases. Find optimum averaging to detect layer.

* These results are preliminary, and operational algorithm will likely do better (as occurred with CALIPSO operational algorithm vs theoretical limits)

Segment	Distance	Height	Backscatter (km ⁻¹ sr ⁻¹)	Optical Depth
1	0-80 km	0.5-2.5 km	3.00E-05	0.002
2	80-160 km	0.5-2.5 km	7.00E-05	0.004
3	160-240 km	0.5-2.5 km	1.30E-04	0.008
4	240-320 km	0.5-2.5 km	3.30E-04	0.020
5	320-400 km	0.5-2.5 km	6.70E-04	0.040
6	400-480 km	0.5-2.5 km	1.33E-03	0.080
7	480-560 km	0.5-2.5 km	3.33E-03	0.200
8	560-640 km	0.5-2.5 km	6.67E-03	0.400
9	640-720 km	0.5-2.5 km	1.33E-02	0.800
10	720-800 km	0.5-2.5 km	3.33E-02	2.000
11	800-880 km	10-12 km	4.00E-05	0.002
12	880-960 km	10-12 km	8.00E-05	0.004
13	960-1040 km	10-12 km	1.60E-04	0.008
14	1040-1120 km	10-12 km	4.00E-04	0.020
15	1120-1200 km	10-12 km	8.00E-04	0.040
16	1200-1280 km	10-12 km	1.60E-03	0.080
17	1280-1360 km	10-12 km	4.00E-03	0.200
18	1360-1440 km	10-12 km	8.00E-03	0.400
19	1440-1520 km	10-12 km	1.60E-02	0.800
20	1520-1600 km	10-12 km	4.00E-02	2.000

Simulation	Layer	Backscatter Detection Thresholds (km ⁻¹ sr ⁻¹)				
		350 m	1 km	5 km	20 km	80 km
Night	0.5 – 2.5 km	1.33 E-3	6.70 E-4	3.33 E-4	3.33 E-4	1.30 E-4
	10 – 12 km	1.00 E-3	4.00 E-4	4.00 E-4	4.00 E-4	1.60 E-4
Day 20° SZA	0.5 – 2.5 km	1.33 E-2	3.33 E-3	1.33 E-3	6.70 E-4	3.30 E-4
	10 – 12 km	8.00 E-3	4.00 E-3	1.60 E-3	8.00 E-4	4.00 E-4

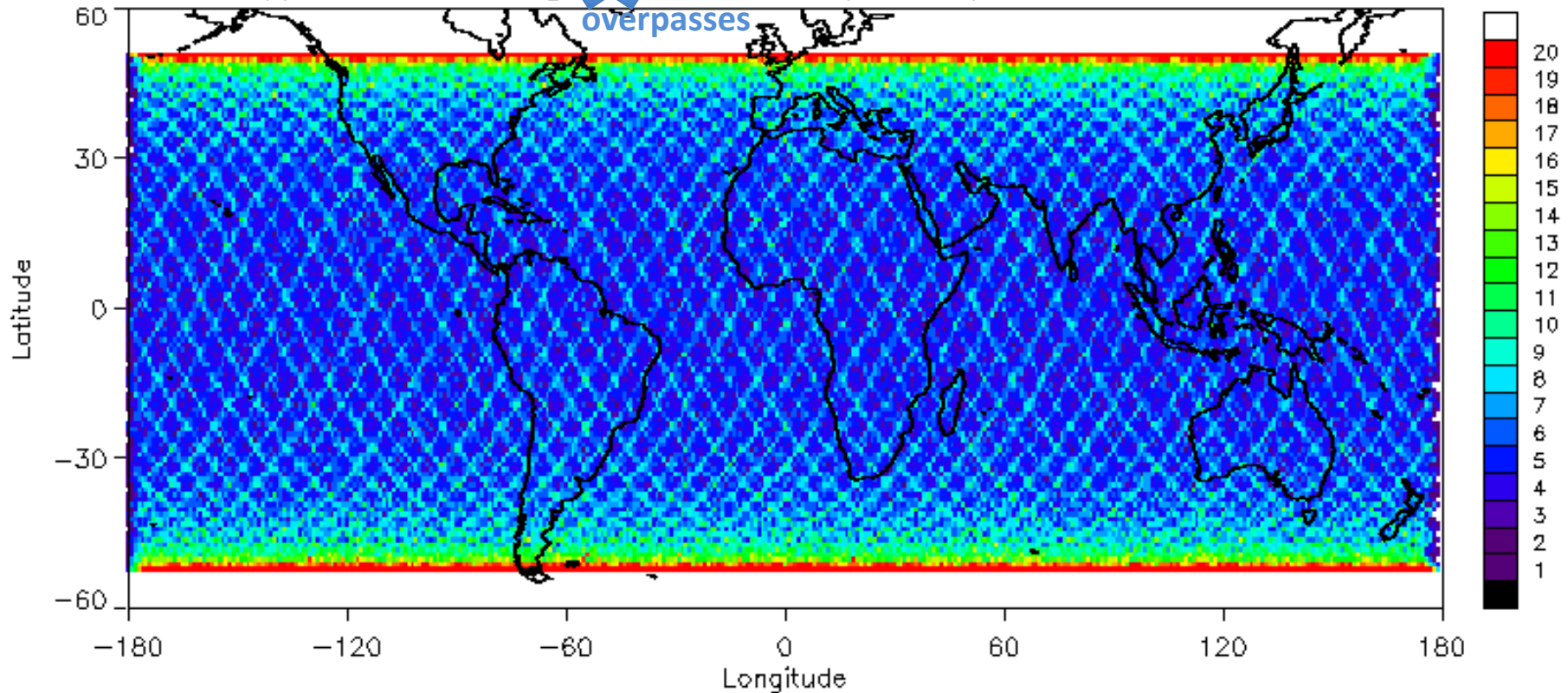


CATS ISS Orbital Coverage



ISS Orbit: 51° inclination (not sun synch), altitude varies between 350 – 410 km
~3 day near repeat cycle, ~60 day solar cycle

CATS-ISS Coverage: 2012/9, 0 – 24 hrs local time
approx number of granules obtained (max 44)



File size (granule) planned at ½ orbit, processing frame size ~ 80 km (same as CALIPSO)

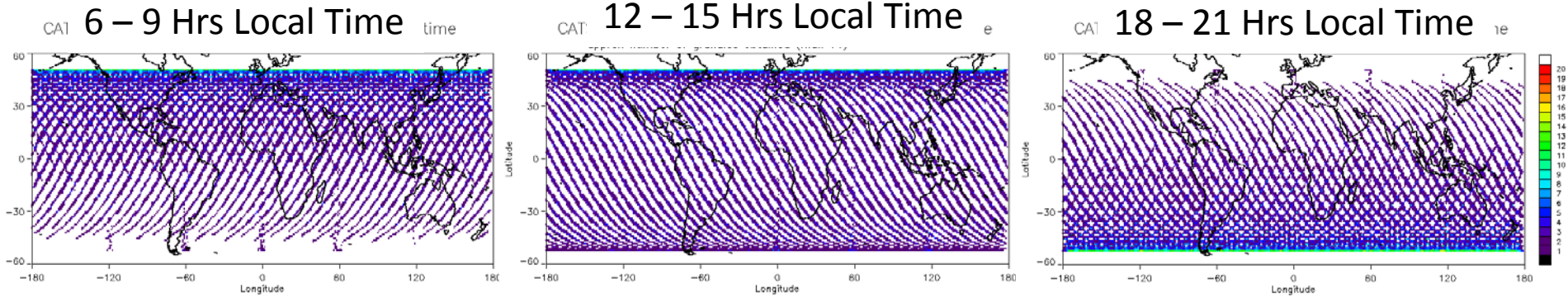


CATS ISS Orbital Coverage

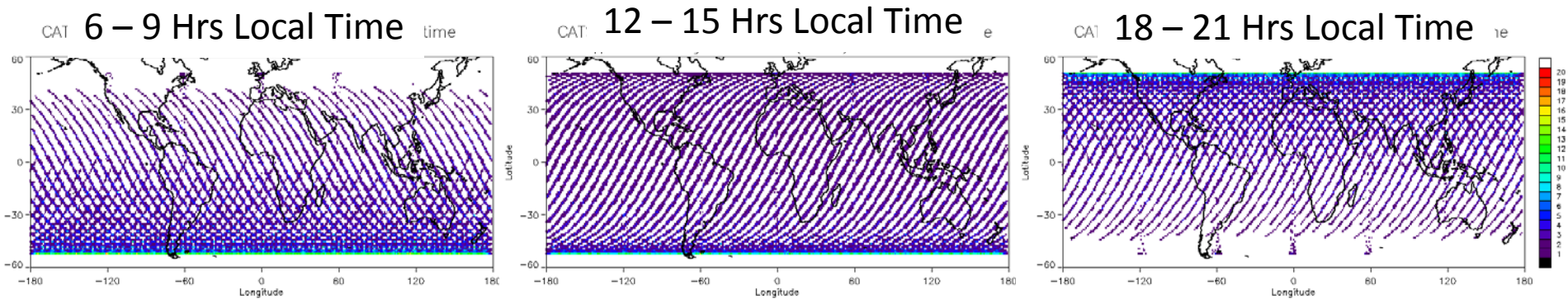


approx number of overpasses

Local Time Coverage: January 2012

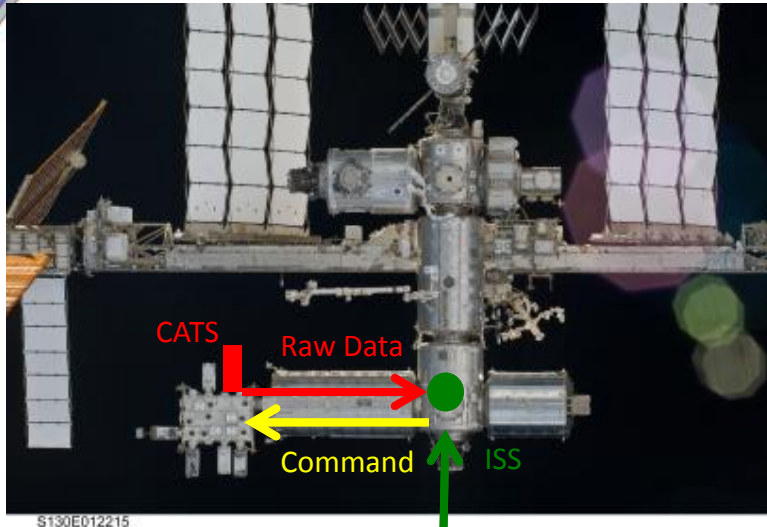


Local Time Coverage: February 2012





CATS Data Comm & Processing System



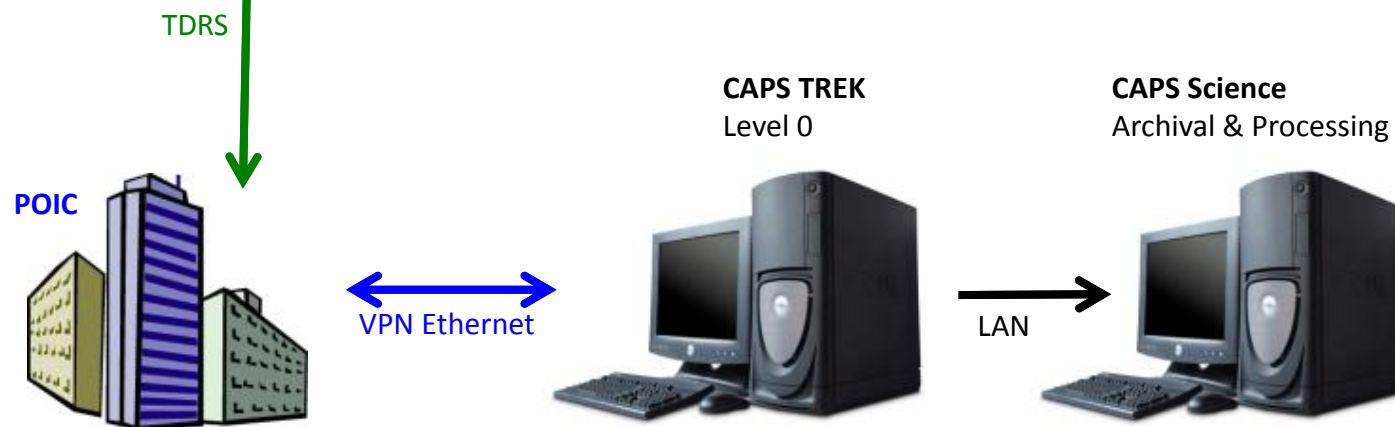
CATS Command/Control and Data Communications

Command Control

Commands initiated from CAPS Trek to POIC via VPN Ethernet
POIC commands to ISS via TDRS
Commands relayed to CATS via 1553 interface?

Science Data

Raw data transmitted to ISS via HRDL
ISS telemetry to POIC via TDRS
POIC transmits data to CAPS Trek via VPN ethernet
CAPS Trek transmits to CAPS Science via LAN
(Final ISS raw data file processing at POIC)



NRT Capability is still unclear, but should be within 3 hours



Conclusion



CATS has a 6 month operational requirement, and 3 year goal (with SOMD/ISS)

- Launch summer 2013
- Launch Vehicle: JAXA HTV

CATS instrument is on track and moving along well toward delivery

- Passed PDR last year, and CDR earlier this year

Algorithm development has begun, using GEOS-5 as simulation base

Performance studies are underway for each channel in each science mode

Currently working with NASA HQ to secure multi year funding for CATS Science team, algorithm development, and operations

- Includes collaboration with LaRC/CALIPSO team to address continuity studies between CALIPSO & CATS (ie, develop methods to run CATS data thru CALIPSO processing)
 - CATS data will follow CALIPSO file conventions to ease strain
 - Other CATS data format for operational use is open for discussion

Algorithm peer review(s) are planned, ~ early 2013

CATS ROSES NRA has been discussed with HQ, if a go then summer 2013 release

Looking for feedback from ICAP community on NRT data for operational support!
