



The Cloud-Aerosol Transport System (CATS): a new lidar for aerosol and cloud profiling from the International Space Station

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Introduction

Spaceborne lidar profiling of aerosol and cloud layers has been successfully implemented during a number of prior missions, including LITE, ICESat, and CALIPSO. Each successive mission has added increased capability and further expanded the role of these unique measurements in wide variety of applications ranging from climate, to air quality, to special event monitoring (ie, volcanic plumes). Many researchers have come to rely on the availability of profile data from CALIPSO, especially data coincident with measurements from other A-Train sensors. The CALIOP lidar on CALIPSO continues to operate well as it enters its sixth year of operations. However, active instruments have more limited lifetimes than their passive counterparts, and we are faced with a potential gap in lidar profiling from space if the CALIOP lidar fails before a new mission is operational. The ATLID lidar on ESA's EarthCARE is not expected to launch until 2015 or later, and the lidar component of NASA's proposed Aerosols, Clouds, and Ecosystems (ACE) mission would not be until after 2020.

- Launch Date: June 2014
- Launch Vehicle: JAXA HTV
- Mission lifetime: 3 years
- CATS is a directed opportunity from the ISS National Laboratory to improve science utilization of the ISS.
- CATS is an attached payload for the JEM-EF – the first such payload developed by NASA.
- CATS is a low-cost, streamlined approach to developing ISS payloads, akin to the Shuttle Hitchhiker payloads.



The Japanese Experiment Module - Exposed Facility (JEM-EF) on the ISS. Payloads are robotically attached to the JEM-EF.

Here we present the Cloud-Aerosol Transport System (CATS), a new aerosol and cloud lidar that was recently selected to provide profiling data from the International Space Station (ISS). CATS will continue the CALIPSO aerosol and cloud profile data record, ideally with overlap between both missions and EarthCARE. The near real time (NRT) data capability of the ISS will enable CATS to support operational applications such as aerosol and air quality forecasting and special event monitoring. CATS will provide new lidar capabilities from space utilizing advanced technology demonstration laser and receiver components for ACE mission demonstration: high spectral resolution lidar (HSRL) profiles of extinction (more accurate than current backscatter lidar techniques), and lidar profiling at 355 nm.

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

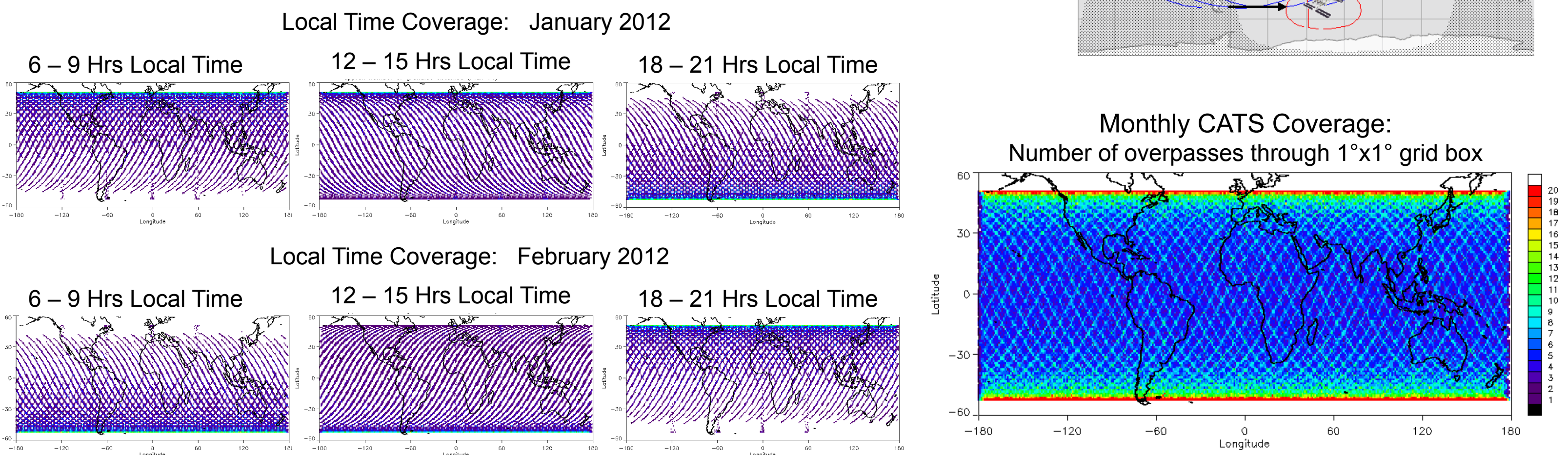
- Improve model performance through assimilation of near-real-time aerosol and cloud data
- Enhance air quality monitoring and prediction capabilities by providing vertical profiles of pollutants
- Improve strategic and hazard warning capabilities of events in near-real-time (dust storms, volcanic eruptions)

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

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

Orbit and Coverage

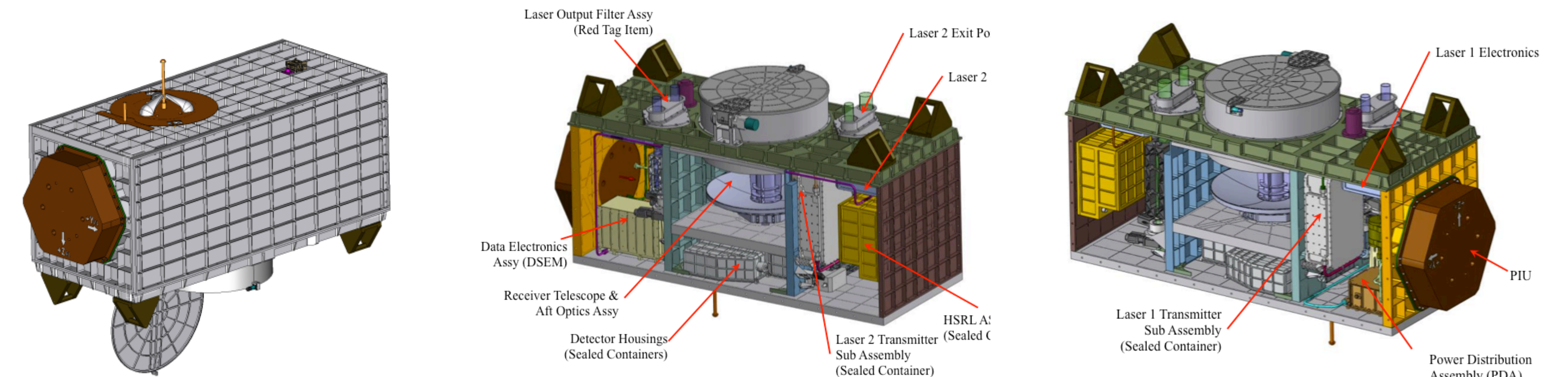
The 51° inclination ISS orbit covers significant aerosol source and transport regions, and areas of important aerosol-cloud interaction. The precessing orbit also captures the full diurnal cycle, allowing for studies that are not possible with CALIPSO in the sun sync A-Train orbit.



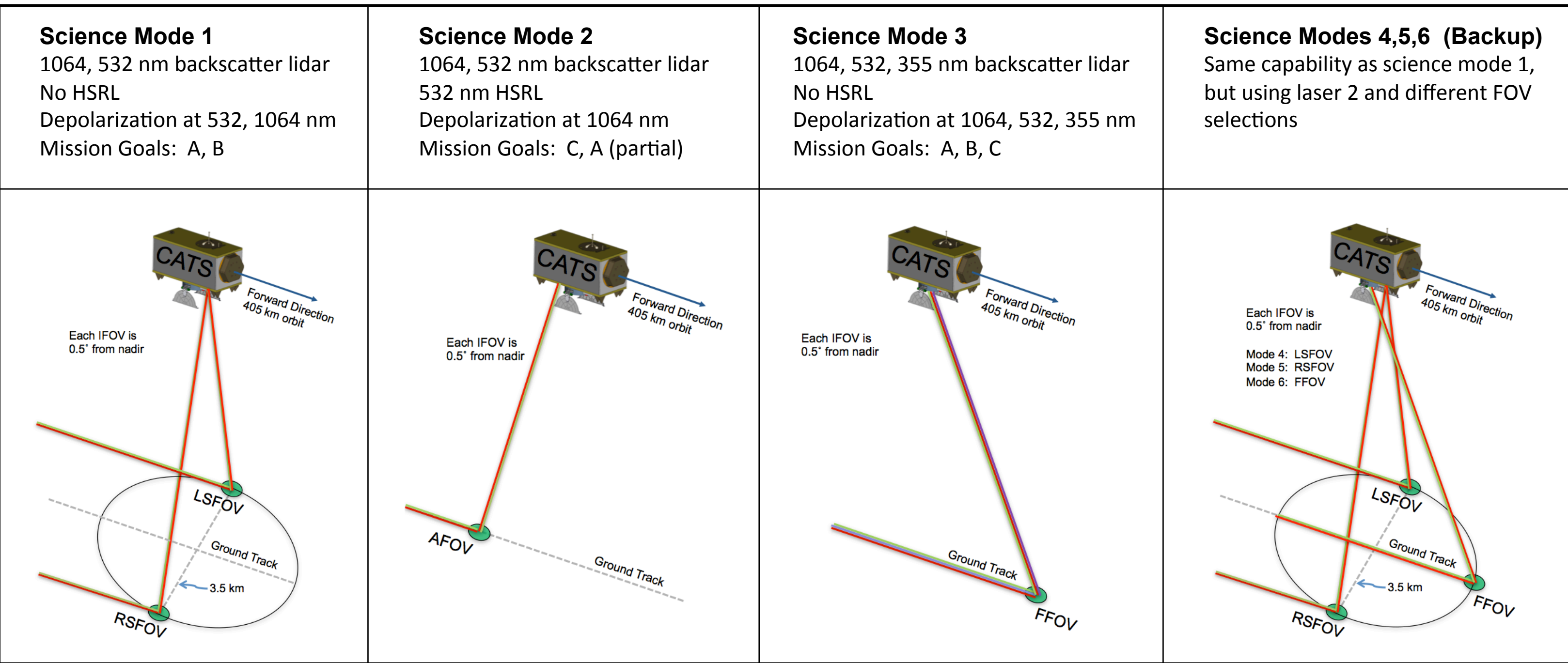
The CATS Instrument

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, four instantaneous field of view (IFOV) and corresponding receiver hardware. The three primary science modes are described in the next section, including modes 4, 5, and 6 which provide backup capability for mode 1.

CATS laser 1 is used in science mode 1, and is derived from proven technology employed onboard CALIPSO and flown on the NASA Cloud Physics Lidar (CPL). CATS Laser 2 is an injection seeded laser with three operational configurations. Configuration 2a emits 532 and 1064 nm narrow line width laser pulses necessary for HSRL observations required in science mode 2. Configuration 2b employs a THG to emit 355 nm laser pulses required for science mode 3. Configuration 2c is a backup for laser 1 if it fails, and is used to provide laser power for backup science modes 4, 5, and 6. All receiver pathways are fiber coupled. Photon counting detectors are utilized for all wavelengths. The HSRL receiver uses a Fabry Perot interferometer at 532 nm. Likewise, only one view path has filters and detectors selected for 355 nm observations. The table below describes the laser and receiver configurations, and corresponding science modes for CATS.



Mode	Wavelength	Laser							Receiver			System
		Config	Energy	Rep. Rate	Divergence	Polarization	Pulse Width	Line Width	Transmission	View Path	Capability	
1	532 nm	1	1.3 mJ	5 kHz	37 µrad	>100:1	4.5 ns	45 pm	20%	LSFOV, RSFOV	Polarized	Telescope Dia: 0.6 m IFOV: 115 µrad Mass: < 500 kg Power: < 1000 W Size: 1.5m x 1m x 0.8m Data Specifications: Rate: 2 Mbits/sec Range: -2 km to 28 km Vertical res: 30 m Along Track res: 350 m (20Hz)
	1064 nm	1	1.2 mJ	5 kHz	59 µrad	>100:1	9 ns	100 pm	30%	LSFOV, RSFOV	Polarized	
2	532 nm	2a	2.7 mJ	4 kHz	49 µrad	>100:1	4.4 ns	< 0.5 pm	8%	AFOV	HSRL	Telescope Dia: 0.6 m IFOV: 115 µrad Mass: < 500 kg Power: < 1000 W Size: 1.5m x 1m x 0.8m Data Specifications: Rate: 2 Mbits/sec Range: -2 km to 28 km Vertical res: 30 m Along Track res: 350 m (20Hz)
	1064 nm	2a	2.5 mJ	4 kHz	72 µrad	>100:1	10.9 ns	< 0.5 pm	30%	AFOV	Polarized	
3	355 nm	2b	2.1 mJ	4 kHz	19 µrad	>100:1	4.4 ns	< 0.5 pm	15%	FFOV	Polarized	Telescope Dia: 0.6 m IFOV: 115 µrad Mass: < 500 kg Power: < 1000 W Size: 1.5m x 1m x 0.8m Data Specifications: Rate: 2 Mbits/sec Range: -2 km to 28 km Vertical res: 30 m Along Track res: 350 m (20Hz)
	532 nm	2b	1.1 mJ	4 kHz	34 µrad	>100:1	4.4 ns	< 0.5 pm	20%	FFOV	Polarized	
4	532 nm	2c	1.7 mJ	4 kHz	72 µrad	>100:1	10.9 ns	< 0.5 pm	30%	FFOV	Polarized	Telescope Dia: 0.6 m IFOV: 115 µrad Mass: < 500 kg Power: < 1000 W Size: 1.5m x 1m x 0.8m Data Specifications: Rate: 2 Mbits/sec Range: -2 km to 28 km Vertical res: 30 m Along Track res: 350 m (20Hz)
	1064 nm	2c	1.1 mJ	4 kHz	72 µrad	>100:1	10.9 ns	< 0.5 pm	30%	FFOV	Polarized	
5	532 nm	2c	1.1 mJ	4 kHz	34 µrad	>100:1	4.4 ns	< 0.5 pm	20%	RSFOV	Polarized	Telescope Dia: 0.6 m IFOV: 115 µrad Mass: < 500 kg Power: < 1000 W Size: 1.5m x 1m x 0.8m Data Specifications: Rate: 2 Mbits/sec Range: -2 km to 28 km Vertical res: 30 m Along Track res: 350 m (20Hz)
	1064 nm	2c	1.7 mJ	4 kHz	72 µrad	>100:1	10.9 ns	< 0.5 pm	30%	RSFOV	Polarized	
6	532 nm	2c	1.1 mJ	4 kHz	34 µrad	>100:1	4.4 ns	< 0.5 pm	20%	FFOV	Polarized	Telescope Dia: 0.6 m IFOV: 115 µrad Mass: < 500 kg Power: < 1000 W Size: 1.5m x 1m x 0.8m Data Specifications: Rate: 2 Mbits/sec Range: -2 km to 28 km Vertical res: 30 m Along Track res: 350 m (20Hz)
	1064 nm	2c	1.7 mJ	4 kHz	72 µrad	>100:1	10.9 ns	< 0.5 pm	30%	FFOV	Polarized	



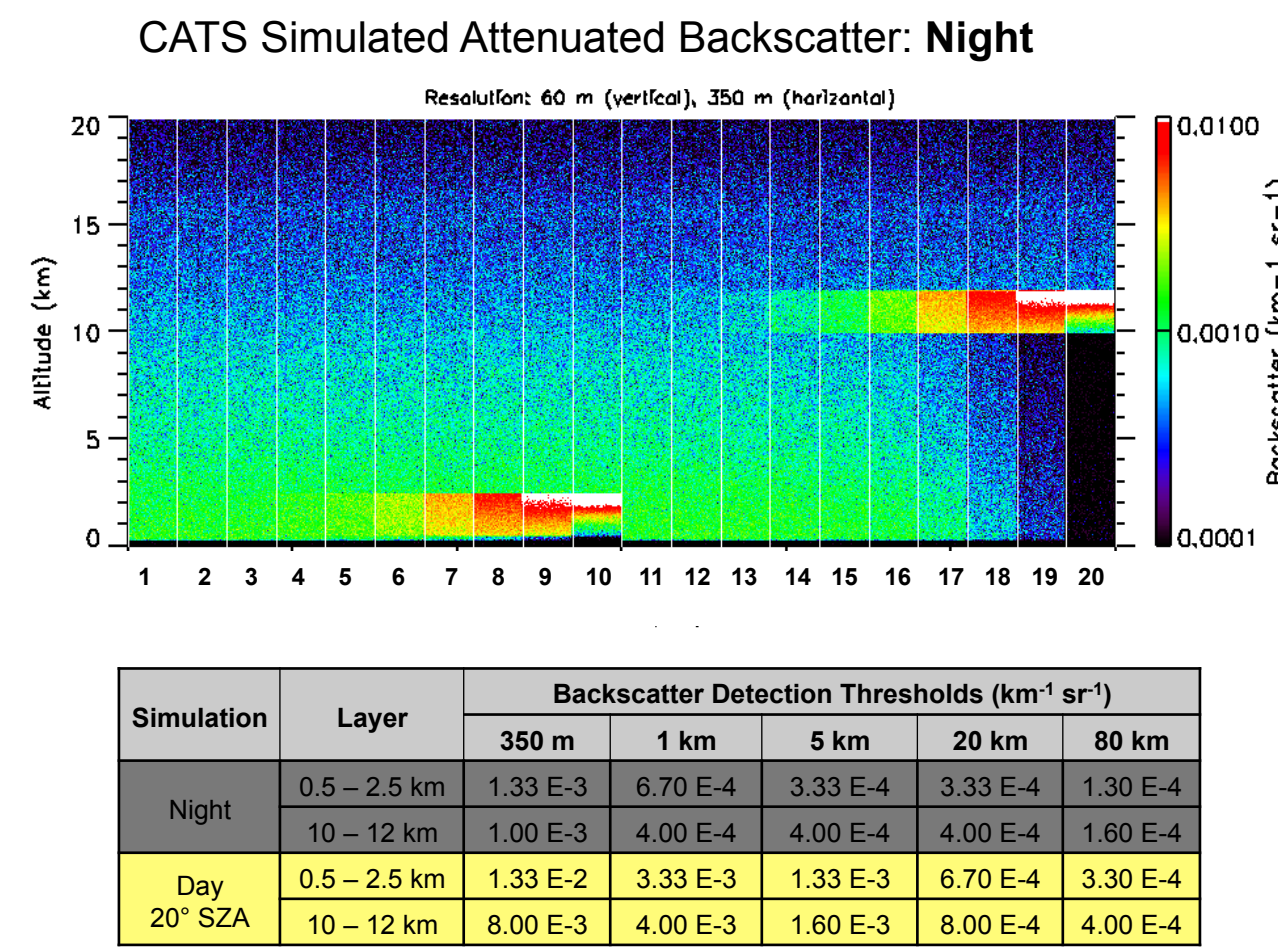
Acknowledgements

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CATS Performance Results

A simulation was prepared to determine CATS detection limits using the same procedure outlined in the CALIPSO Feature Detection and Layer Properties Algorithms ATBD Release 1.01. Attenuated backscatter signals were constructed at native downlinked resolution, and two simple layers were inserted near the surface (sea salt) and the upper troposphere (cirrus). The concentration and thus backscatter in each layer increases along track, and the simulation is used to determine the optimum averaging required to detect weak scattering. VLIDORT was used to simulate polarized solar background for varying SZA. A detection algorithm was applied to each layer and segment based on Yorks et al. (2011) and Palm et al. (2002). The detection capability improves as layer concentration/backscatter increases. Results are shown for Science Mode 1. These results are preliminary, and operational algorithm will likely do better.

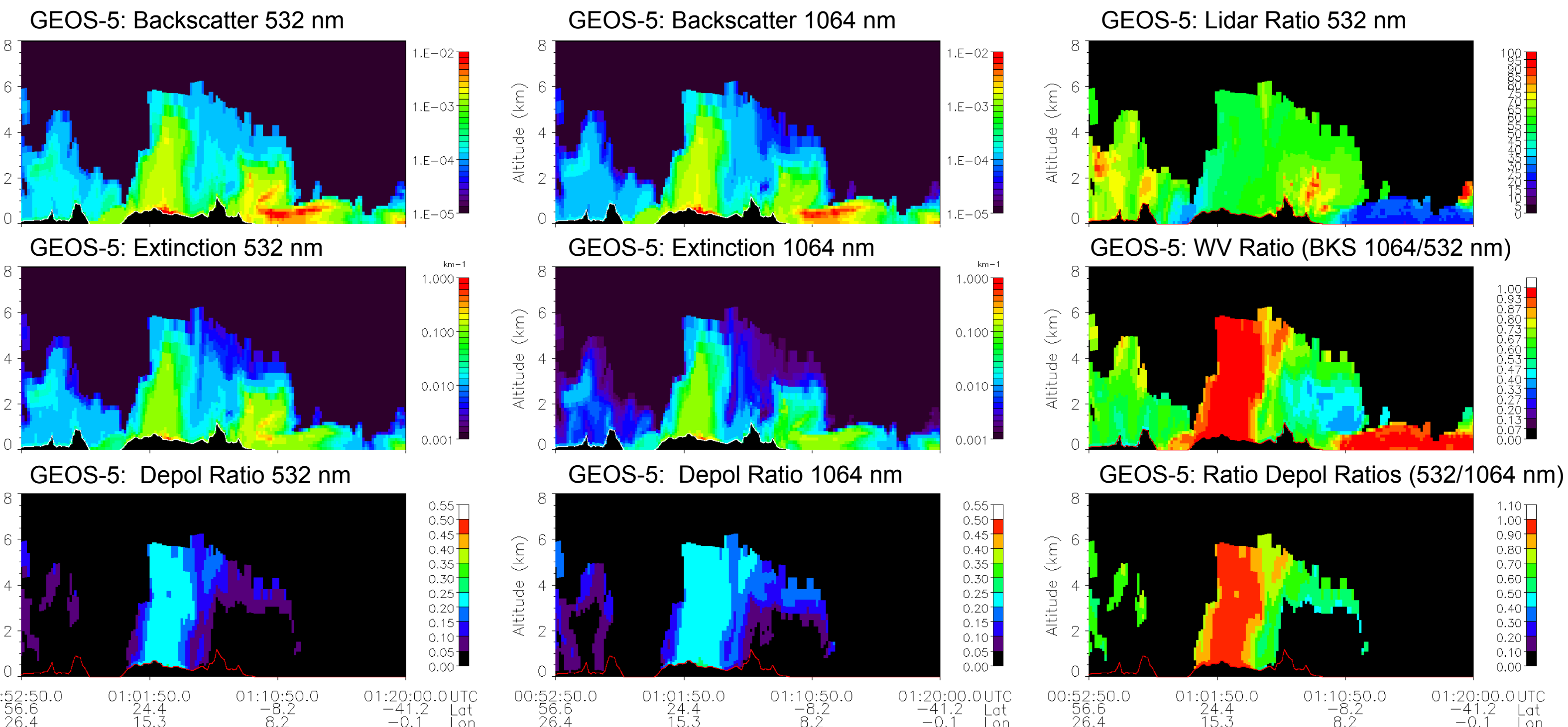
Segment	Distance	Height	Backscatter (km ⁻¹ sr ⁻¹)	Optical Depth
1	0-80 km	0.5-2.5 km	3.00E-05	0.002
2	80-160 km	0.5-2.5 km	7.00E-05	0.004
3	160-240 km	0.5-2.5 km	1.30E-04	0.008
4	240-320 km	0.5-2.5 km	3.30E-04	0.020
5	320-400 km	0.5-2.5 km	6.70E-04	0.040
6	400-480 km	0.5-2.5 km	1.30E-03	0.080
7	480-560 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



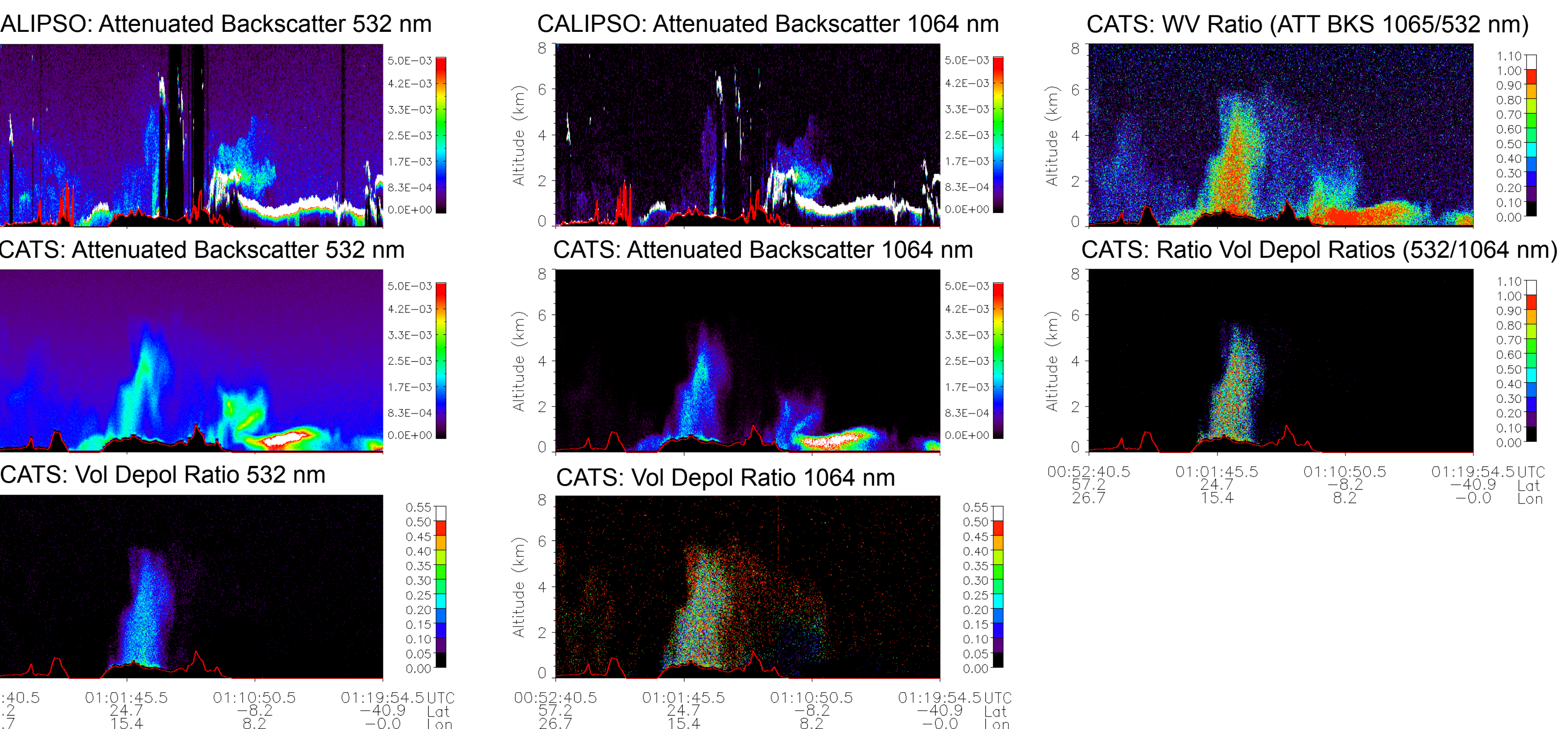
CATS Simulated Data

Results from the NASA Goddard Earth Observing System general circulation model and data assimilation system (GEOS-5) have been used to generate simulated atmospheric and surface properties for orbits along actual CALIPSO tracks from 2009. At present, the simulation does not include clouds. The model results are used to simulate photon count profiles measured by CATS in each of its six science modes. CALIPSO tracks are utilized to provide actual baseline observations for the scenes simulated by GEOS-5 for CATS. The GEOS-5 atmospheric general circulation model runs inside the NASA GEOS DAS meteorological assimilation stream. The GOCART module provides distributions of dust, sea salt, sulfate, and carbonaceous aerosols. Polarized optical profiles at each lidar wavelength are generated using a spheroidal model for dust and Mie for other species. Polarized surface reflectance at each wavelength are also provided, and VLIDORT is utilized to generated polarized solar background signals.

Science Mode 1 examples are shown below (532 and 1064 nm only). Data are plotted from 0 – 8 km to match CALIPSO 30 m resolution.



Simulated CATS signals and volume depolarization ratio are shown, along with CALIPSO signals for example above (night time). CATS and CALIPSO plots below are 1 second along track average (~7 km) and 30 m vertical resolution.



CATS and CALIPSO plots for a day time segment over West Africa. The benefit of increased averaging is shown in plots to the right.

