AN OVERVIEW OF THE CLOUD-AEROSOL TRANSPORT SYSTEM (CATS) PROCESSING ALGORITHMS AND DATA PRODUCTS

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ABSTRACT

The Cloud-Aerosol Transport System (CATS) was launched on 10 January 2015 to the International Space Station (ISS), where it was installed on the Japanese Experiment Module – Exposed Facility (JEM-EF). CATS is an elastic backscatter lidar designed to provide a combination of operational science, in-space technology demonstration, and technology risk reduction for future Earth Science missions. This paper outlines the CATS science goals, data products, and processing algorithms. Furthermore, initial data will be presented that demonstrates the utility of CATS for cloud and aerosol studies.

1. INTRODUCTION

The Cloud-Aerosol Transport System (CATS) payload is based on existing instrumentation built and operated on the high-altitude NASA ER-2 aircraft, including the Cloud Physics Lidar (CPL) [1] and the Airborne Cloud-Aerosol Transport System (ACATS) [2]. The instrument consists of two high repetition rate (4-5 kHz), low energy (1-2 mJ) Nd:YVO4 lasers operating at three wavelengths (1064, 532, and 355 nm), a receiver subsystem with a 60 cm beryllium telescope that has a 110 microradian field of view, photon-counting detectors, and a data system to provide timing of the return photon events.

The instrument is located on the Japanese Experiment Module – Exposed Facility (JEM-EF) on the International Space Station (ISS). The ISS orbit is a 51-degree inclination orbit at an altitude of about 405 km (Figure 1). This orbit provides more comprehensive coverage of the tropics and mid-latitudes than sun-synchronous orbiting sensors, with nearly a three-day repeat cycle. CATS is intended to operate on-orbit for at least six months, and up to three years. Data from CATS is used to derive properties of cloud/aerosol layers including: layer height and thickness, backscatter, optical depth, extinction, and depolarization-based discrimination of particle type.

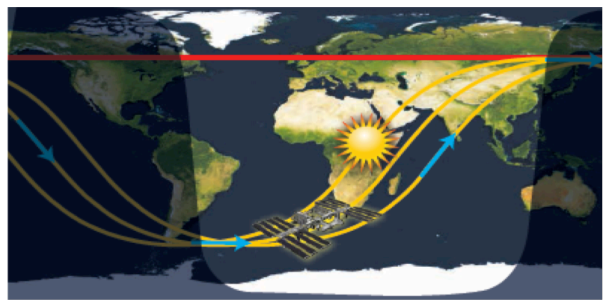

Figure 1. The ISS orbit is a 51-degree inclination orbit that passes over the same location on Earth nearly every 3 days at a different local time.

The measurements of atmospheric clouds and aerosols provided by the CATS payload are used for three main science objectives, which include:

1. Extend global lidar climate observations to include measurements at various local times and promote studies of diurnal changes in clouds and aerosols.
2. Provide near real time observational data to improve operational aerosol model forecasts.
3. Advance technology in support of future space-based lidar mission development, such as high-rep rate lasers, photon counting detection, high spectral resolution lidar (HSRL) and 355 nm capabilities.

To meet these three science goals, CATS operates in three different modes using four instantaneous fields of view (FOV) as detailed below:

- ***Mode 1: Multi-beam backscatter detection at 1064 and 532 nm, with depolarization***

measurements (Left and Right FOV). This mode will be used to ensure that minimum science requirements can be met.

- ***Mode 2: Demonstration of HSRL aerosol measurements (Fore FOV)***. This mode uses the injection-seeded laser to demonstrate an HSRL measurement using the 532-nm wavelength.
- ***Mode 3: Demonstration of 355-nm profiling (Aft FOV)***. This mode uses the injection-seeded laser operating at 1064, 532, and 355 nm to demonstrate 355-nm laser performance.

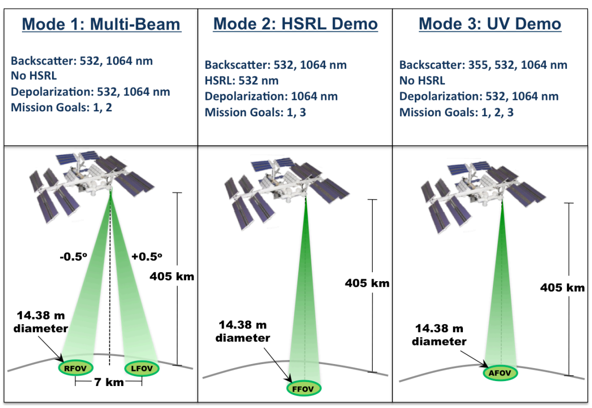

Figure 2. CATS will operate in one of three modes to achieve all three science goals.

2. DATA PRODUCTS AND ALGORITHMS

Raw CATS data, with 60 m vertical resolution and about 350 m horizontal resolution (20 Hz), is received from the ISS in near real-time with the exception of loss-of-signal (LOS) periods that can range from 1 to 50 minutes. Due to these LOS periods, 3-hour segments of data are collected, corrected for communication artifacts (i.e. duplicate or missing data) and sorted to produce granules that denote night or daytime operation. The raw data is then geo-located, corrected for detector nonlinearity and instrument artifacts, normalized to laser energy, and annotated with ancillary information to create the normalized relative backscatter (NRB).

The data products generated from the CATS measurements are produced to support the three main science goals. The nearly instantaneous data downlinking provided by the ISS allows CATS data to be processed as quickly as 3-6 hours after collection. This allows CATS data to be incorporated into the data assimilation process of aerosol forecast models. Processing of the CATS data products in Mode 1 began in February 2015 and include:

- **Level 1B**: Data that have been calibrated, annotated with ancillary meteorological data, and processed to sensor units. The CATS Level 1B data (attenuated total backscatter and depolarization ratio) is archived as Level 1 data at the raw CATS resolutions.
- **Level 2**: Geophysical parameters derived from Level 1 data, such as the vertical feature mask, profiles of cloud and aerosol properties (i.e. extinction, particle backscatter), and layer-integrated parameters (i.e. lidar ratio, optical depth).

These products and corresponding browse images will be available starting in June 2015 at the CATS website (cats.gsfc.nasa.gov).

The CATS Level 1B and 2 data processing algorithms rely heavily on heritage from existing airborne and space-based lidar systems, such as CPL, ACATS, and the Cloud-Aerosol Lidar Infrared Pathfinder Spaceborne Observations (CALIPSO) satellite [3]. Due to a failure in the optical path of Mode 3, data from this mode will not be available. The HSRL data processing algorithms will be very similar to those used for the ACATS instrument [2], with much longer turnaround times expected.

The processing algorithms for Level 1B in Modes 1 and 3 consist mainly of the backscatter and depolarization calibrations. The 532 nm CATS data is calibrated by normalizing the NRB signal to the 532 nm molecular backscatter signal in a set calibration region [4,5]. The CATS calibration region is 23-27 km, starting 1 km below the top of the CATS data frame (28 km). The aerosol loading in this region is computed using CALIPSO data and applied to the calibration. The CATS NRB signal is averaged to 3 minutes at night and 20 minutes during daytime operation to reduce uncertainty in the calculation. During nighttime data collection, the 1064 nm calibration constant can be computed using an identical approach as the 532 nm calculation. However during daytime operation, the 1064 nm signal is calibrated using the 532 nm signal and backscatter from ice clouds, similar to CALIPSO at 1064 nm [6]. The depolarization gain ratio, which describes the relative gain between polarization channels, is computed for both 532 and 1064 using the solar radiation scattered by ice clouds [7].

The CATS Level 2 products consist of two different types of products. The CATS Heritage L2 product is produced by running CATS L1B data through the CALIPSO L2 algorithms to provide continuity in the algorithms used for the lidar climate record [8,9]. The CATS Operational L2 product uses the new operational CATS L2 algorithms. More details on the CATS Operational L2 product will be presented at a later date, but the processing algorithms are based on those from previous lidar sensors [10,11,12], tailored to the CATS instrument design.

3. INITIAL RESULTS

The CATS laser was first operated on 5 Feb. 2015. After initial telescope alignment procedures, semi-continuous CATS operation in Mode 1 began on 10 Feb. 2015, with occasional interruptions due to spacecraft dockings at the ISS. One of the first orbits of CATS data collection occurred as the ISS flew over Africa on 11 Feb. 2015 during local nighttime hours (00:59 to 01:19 UTC). The CATS 1064 nm attenuated total backscatter (km^{-1} sr^{-1}) shows Saharan dust as high as 5 km (30N to 5N), cirrus clouds that extend above 17 km (12N to 20S), and smoke from biomass burning (20S to 30S) in South Africa (Figure 1a). The 1064 nm depolarization ratio values of about 0.30 for dust and 0.50 for

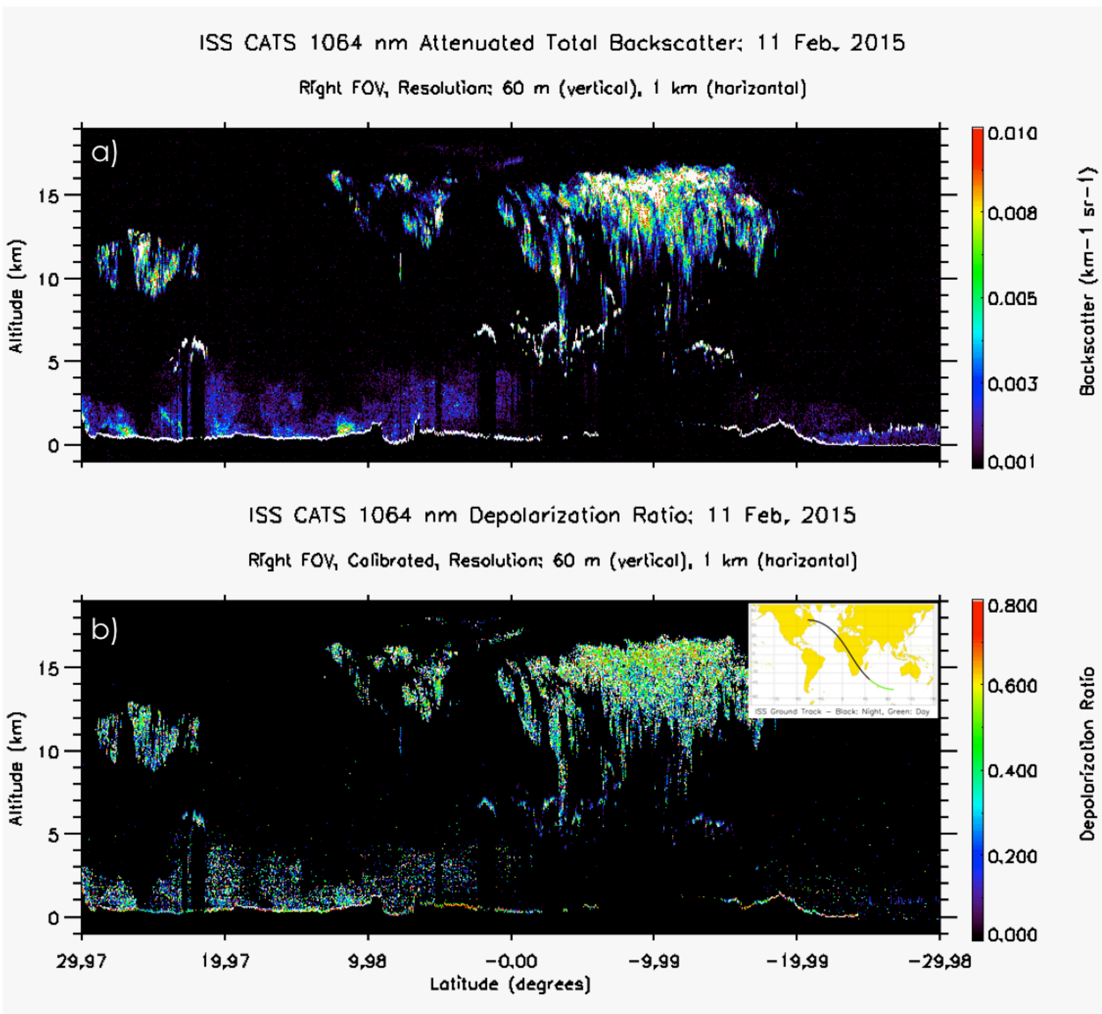

Figure 3. CATS 1064 nm attenuated total backscatter (a) and 1064 nm depolarization ratio (b) for the right field-of-view (FOV) from 11 Feb. 2015 as the ISS passed over Africa.

cirrus are consistent with CALIPSO and CPL historical data.

During the time of initial CATS operations, the CPL instrument was flying on the NASA ER-2 out of Palmdale, CA. Several CATS validation flights were coordinated in which the ER-2 flew the expected ISS track for about 30 minutes centered on the direct coincidence of the aircraft and ISS. Validation flights were conducted during local twilight hours (10 Feb.), daytime hours (17 and 20 Feb.) and night (22 Feb.). Cirrus clouds were present during the 10 and 22 Feb. flights, while low-level stratocumulus clouds were observed during the two daytime flights. Comparisons between CPL and CATS cloud spatial properties are forthcoming.

4. CONCLUSIONS

The Cloud-Aerosol Transport System (CATS), built at NASA Goddard Space Flight Center as a payload for the International Space Station (ISS), launched in January 2015 and began semi-continuous operations in Feb. 2015. CATS is an elastic backscatter lidar operating in one of three science modes with three wavelengths (1064, 532, 355 nm) and HSRL capability at 532 nm. Initial CATS data products in Mode 1 operation demonstrate the utility of CATS to measure thin cirrus clouds and aerosol layers.

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