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New Capabilities for Space-Based Cloud and Aerosols Measurements: The Cloud-Aerosol Transport System (CATS)

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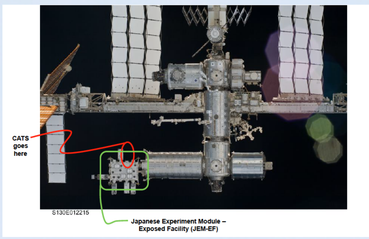
Introduction

- Current uncertainties in cloud and aerosol properties limit our ability to accurately model Earth's climate system and predict climate change
  - Due to difficulties in measuring aerosols/clouds on a global scale
- NASA's A-Train satellites provide an unprecedented opportunity to address these uncertainties
  - CALIPSO satellite provides vertical profiles of cloud and aerosol properties
  - CALIOP lidar has reached its 7th year of operation, well past its expected lifetime
- ATLID lidar on EarthCARE not expected to launch until 2016 or later
- If CALIOP lidar fails before a new mission is operational, there will be a gap in global lidar measurements.

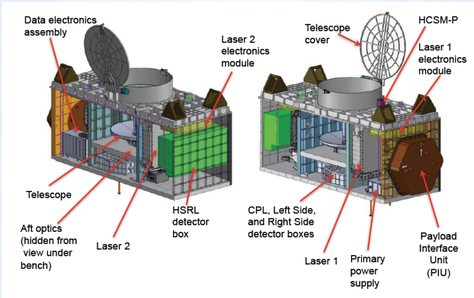
CATS Instrument Overview

- CATS is a lidar remote sensing instrument being developed for deployment to International Space Station (ISS)
- CATS will provide vertical profiles of cloud and aerosol properties at 3 wavelengths (355, 532, 1064 nm)
- Planned launch in mid-2014
- CATS will be installed on the Japanese Experiment Module – Exposed Facility (JEM-EF)

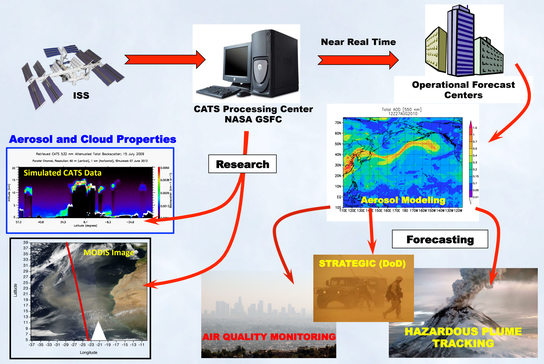


- CATS payload is based on existing instrumentation built and operated on high-altitude NASA ER-2 aircraft
- Intended to operate on-orbit for at least 6 months, and up to 3 years
- Operates in 1 of 6 science modes to meet mission goals
- Utilizes 2 high repetition rate lasers and 4 instantaneous field of view (IFOV)

Laser1 Type	Nd: YVO_4
Laser1 Wavelengths	532, 1064 nm
Laser1 Rep. Rate	5000 Hz
Laser1 Output Energy	~1 mJ/pulse
Laser2 Type	Nd: YVO_4, seeded
Laser2 Wavelengths	355, 532, 1064 nm
Laser2 Rep. Rate	4000 Hz
Laser2 Output Energy	~2 mJ/pulse
Telescope Diameter	60 cm
View Angle	0.5 degrees
Telescope FOV	110 microradians
IFOVs	4
Etalon Spacing	3 cm
Etalon Reflectivity	90%
Orders Imaged	1.2
HSRL Channels	10

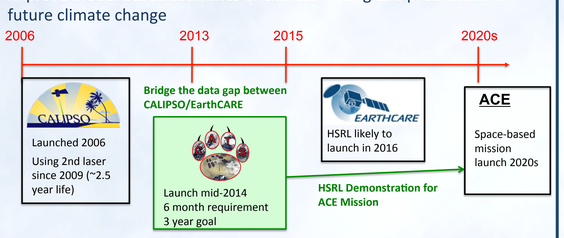


CATS Science Overview

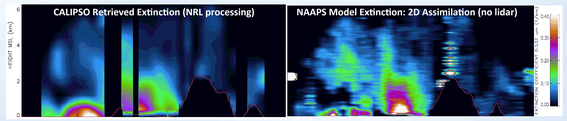


Science Goals

1. **Extend CALIPSO data record for continuity of Lidar Climate Observations**
   - Continue record of vertical profiles of cloud/aerosol properties
   - Improve our understanding of cloud/aerosol properties and interactions
   - Improve model based estimates of climate forcing and predictions of future climate change

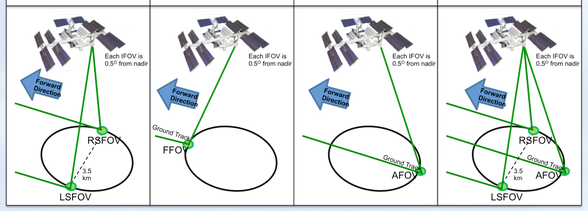


2. **Improve Operational Aerosol Forecasting Programs**
   - Improve model performance through assimilation of near-real-time cloud/aerosol data
   - Enhance air quality monitoring and prediction capabilities by providing vertical profiles of pollutants
   - Improve strategic and hazard warning capabilities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



3. **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)

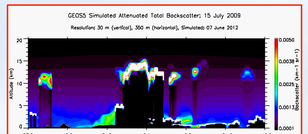
Science Mode 1	Science Mode 2	Science Mode 3	Science Modes, 4,5,6
• Backscatter: 532, 1064 nm • No HSRL • Depolarization: 532, 1064 nm • Mission Goals: 1, 2	• Backscatter: 532, 1064 nm • HSRL: 532 nm • Depolarization: 1064 nm • Mission Goals: 1, 3	• Backscatter: 355, 532, 1064 nm • No HSRL • Depolarization: 355, 532, 1064 nm • Mission Goals: 1, 2, 3	• Backup Mode • Use laser 2 and receiver from mode 1



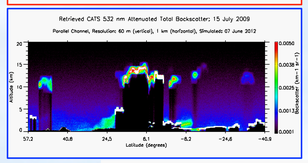
CATS Simulations

Science Simulations

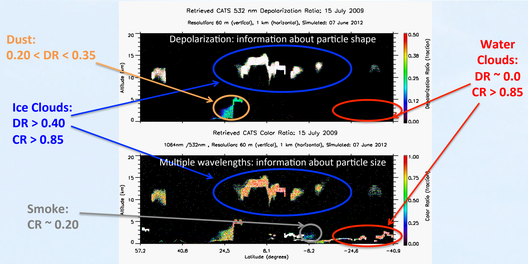
- Designed to enable development of CATS algorithms and data products
- Input: GEOS-5 Modeled Atmosphere w/ aerosols and estimated clouds (red)
- CATS signal simulated at all wavelengths and all modes (blue)
  - Level 1A data products/algorithms complete
  - Level 1B data products/algorithms ongoing (early 2014 completion)



GEOS-5 Modeled Atmosphere with:
- Meteorological Data
- TOA Radiance
- Surface Albedo & Type
- Backscatter, extinction for aerosols
- Clouds estimated (less accurate)
- Dust fully polarized
- All 3 Wavelengths



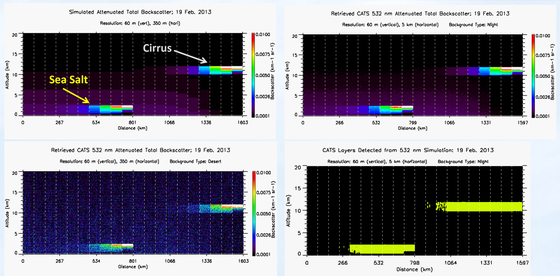
Simulated CATS Data includes:
- Interpolated Met Data
- Solar Background
- Surface Return Signal
- Aerosol backscatter
- Cloud backscatter (estimated)
- Depolarization in dust/cirrus
- All 3 Wavelengths
- All Modes (including HSRL mode)



Performance Simulations

- Designed to evaluate CATS performance similar to CALIPSO approach (ATBD)
- Attenuated Backscatter signal constructed at raw resolution (350 m hor., 60 m vertical) for all wavelengths and modes
- Four Types of Simulations: Night, Day over ocean, land, desert (SZA=20 degrees)
- Data is averaged to 4 horizontal res.: 1, 5, 20, 80 km
- Layer detection algorithm applied to each layer and segment based on Yorks et al. (2011) and Palm et al. (2002) but not the operational algorithm

Seg	Distance	Height	532 ATB	OD
1	0-80 km	0.5-2.5 km	1.12E-03	0.0020
2	80-160 km	0.5-2.5 km	1.15E-03	0.0040
3	160-240 km	0.5-2.5 km	1.19E-03	0.0080
4	240-320 km	0.5-2.5 km	1.33E-03	0.0200
5	320-400 km	0.5-2.5 km	1.56E-03	0.0400
6	400-480 km	0.5-2.5 km	1.98E-03	0.0800
7	480-560 km	0.5-2.5 km	3.00E-03	0.2000
8	560-640 km	0.5-2.5 km	4.30E-03	0.4000
9	640-720 km	0.5-2.5 km	5.69E-03	0.8000
10	720-800 km	0.5-2.5 km	6.58E-03	2.0000
11	800-880 km	10-12 km	5.00E-04	0.0020
12	880-960 km	10-12 km	5.30E-04	0.0040
13	960-1040 km	10-12 km	5.90E-04	0.0080
14	1040-1120 km	10-12 km	7.70E-04	0.0200
15	1120-1200 km	10-12 km	1.07E-03	0.0400
16	1200-1280 km	10-12 km	1.60E-03	0.0800
17	1280-1360 km	10-12 km	2.88E-03	0.2000
18	1360-1440 km	10-12 km	4.68E-03	0.4000
19	1440-1520 km	10-12 km	6.67E-03	0.8000
20	1520-1600 km	10-12 km	8.20E-03	2.0000

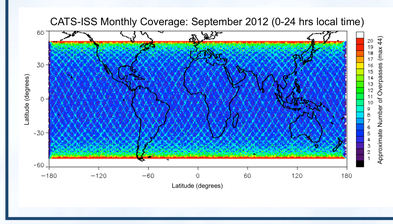


CATS ATB Uncertainties: Res 5 km (hor), 60 m (vert)

Type	532 ATB	532 ATB Uncertainties for Background Types			
		Night (%)	Ocean (%)	Land (%)	Desert (%)
Aerosol	> 1E-03	5.13	15.70	21.06	30.11
Cirrus	> 1E-03	4.37	12.97	16.12	22.97
Type	**1064 ATB**	**1064 ATB Uncertainties for Background Types**			
		Night (%)	Ocean (%)	Land (%)	Desert (%)
Aerosol	> 1E-03	14.91	31.54	52.61	64.83
Cirrus	> 1E-03	14.47	29.84	47.86	58.79

ISS Orbit

- ISS orbit is a 51° inclination orbit at an altitude of about 405 km
  - Provides more comprehensive coverage of tropics and mid-latitudes than sun-synchronous orbiting sensors
  - Primary aerosol transport paths frequently observed
  - Nearly a 3 day repeat cycle
  - Permits study of diurnal (day to night) changes in aerosol/cloud effects
  - Cannot be achieved with other Earth Science satellite orbits



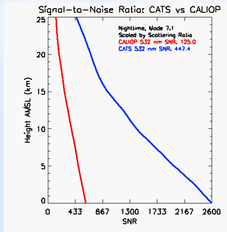
CATS and CALIPSO

- CATS MDB based on Performance Simulations
- CALIPSO MDB from McGill et al. 2007
- Resolutions: 60 m vert. and 5 km hor.
- For cirrus: CALIPSO (15 km) and CATS (12 km)
- Nighttime SNR is averaged horizontally over 1500 km, vertically over 5 km and centered at an altitude of 30 km (CALIPSO) and 25 km (CATS)

CATS-CALIOP 532 nm Minimum Detectable Backscatter

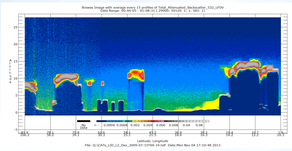
Simulation	Type	Backscatter (km-1 sr-1)
CATS	Night	5.90E-4 ± 0.54E-4
CALIOP	Night	8.00E-4 ± 1.00E-4
CATS	Day* (Land)	1.60E-3 ± 0.35E-3
CALIOP	Day	1.70E-3 ± 0.30E-3

*Daytime solar zenith angle is set to 20 degrees



CATS-CALIPSO Collaboration

- CALIPSO provides 532 nm scattering ratios in CATS calibration zone (24-28 km)
- CATS will use same 1064 nm calibration technique as CALIPSO
- CATS data products will include same variables as CALIPSO data products
- CALIPSO team will run CATS L1B data through their L2 algorithms
- Collaboration will create continuity in lidar climate record



Summary

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  - Will provide vertical profiles of cloud and aerosol properties at 3 wavelengths (355, 532, 1064 nm)
  - Planned launch in mid-2014
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- Science goals include:
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  2. Improve Operational Aerosol Forecasting Programs
  3. NASA Decadal Mission Pathfinder: Lidar for the Aerosols, Clouds, Ecosystems (ACE) Mission
- Simulations have been conducted to test performance and develop processing algorithms
  - CATS performance should be similar to CALIPSO during daytime, better than CALIPSO at night

Acknowledgments

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- CATS science algorithm development is funded by NASA Science Mission Directorate (SMD) under direction of Hal Maring.
- V. Stan Scott (GSFC), Andrew Kupchock (SSAI) and all engineers involved in building CATS.

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