The Cloud-Aerosol Transport System (CATS)

A New Earth Science Capability for ISS with direct applicability to ACE

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Outline

• Why ISS and why CATS?
• The programmatic aspects of CATS
• The science behind CATS
• The CATS payload
• Summary
Why the ISS makes sense for Earth Science:

- Use what we already have (i.e., the ISS) to achieve rapid results within an affordable budget – essential in our cost-constrained environment
- ISS payloads can easily trade mass for cost – the impact on cost can be huge
- Embrace build-to-cost/build-to-schedule mentality to minimize development cycle and cost – multiple lower-cost Class D instruments can accomplish more than one giant Class B instrument
- Incrementally enhance the ISS Earth observing capability, and grow it to become a vital part of the Earth Science system
- Build international partnerships for collaborative climate monitoring and exploration
- ISS orbit covers significant portion of the Earth’s surface, land area, and populated areas

With that rationale, CATS was funded to be a forcing function for Earth Science from ISS and to be a pathfinder for NASA-developed ISS payloads.
The Cloud-Aerosol Transport System (CATS): A New Earth Science Capability for ISS

Programmatic Aspects of CATS
The Cloud-Aerosol Transport System (CATS) instrument is a directed opportunity funded by the ISS Program.

- Payload Developer is NASA-Goddard Space Flight Center
- “customer” is the ISS Program (within HEOMD)
- SMD is assisting with funding algorithm/processing development

**Project was initiated in April 2011**

- 24-month schedule from ATP to instrument ready

**The CATS project has three simultaneous goals:**

- Provide long-term (6 months to 3 years) operational science from ISS
- Prove that low-cost, streamlined project approach can work
- Provide tech demo on-orbit (target ACE mission)
  - high rep rate laser
  - photon-counting detection
  - UV (355 nm) laser operation in space
  - HSRL receiver concept
CATS Program Overview

- CATS is not a “business as usual” project for NASA science or Goddard
  - Not a flight mission – it is an attached payload (think Hitchhiker) launched as cargo
  - Intended as a pathfinder for quick turn-around, low-cost payloads, akin to Hitchhiker payloads
  - Being used as a pathfinder for NASA-developed attached science payloads for ISS
  - Safety is governed by JSC/ISS processes
  - ISS defined the success criteria – not driven by science measurements/products (build-to-cost/build-to-schedule, not build-to-requirements)
  - Heavily streamlined, efficient management and reporting processes

- CATS leverages numerous NASA investments to enable cost effective science:
  - Multiple SBIR/STTR-derived technologies
  - ESTO and technology investments
  - Investments from multiple aircraft instrument developments
Project-level Requirements

1. Develop Cloud-Aerosol Transport System (CATS) instrument for deployment to the ISS

2. CATS shall be an attached payload for the Japanese Experiment Module – Exposed Facility (JEM-EF)

3. Cargo vehicle shall be JAXA HTV or SpaceX Dragon (must be compatible with both)

4. CATS shall not harm ISS or the launch vehicle

5. CATS shall be designed to operate minimum 6 months, with goal of 3 years and option to extend to 5 years (hardware to be certified to 15 years for structural integrity)

Mission Success Criteria

From ISS Program:
“The responsibility to generate and verify functional requirements (science requirements) of what the CATS payload shall do is up to your team.

with general guidance from the ISS program that

– the CATS payload is an attached payload with no flight reliability requirements
– the CATS payload should meet science objectives that both increase readiness for future flight missions and provide operational data related to the phenomenon you are measuring.”
JEM-EF Interfaces

grapple fixture

Payload Interface Unit (PIU)

JEM-EF attached payload
The Cloud-Aerosol Transport System (CATS): A New Earth Science Capability for ISS

CATS Science Overview
CATS Science Applications

ISS

CATS Processing Center
NASA GSFC

Operational Aerosol Forecast Models

Research

AIR QUALITY MONITORING

Forecasting

CLOUD PROPERTIES

AEROSOL PROPERTIES

WILDFIRE DETECTION

VOLCANIC PLUME TRACKING
Improve Operational Aerosol Forecasting Programs

– Enable aerosol transport models by using near real-time data downlink from ISS
– Improve strategic and hazard warning capabilities of events in near real-time (dust storms, volcanic eruptions)
– Demonstrate multi-wavelength cloud and aerosol retrievals
Extend CALIPSO data record for *continuity* of Lidar Climate Observations

- Continue record of vertical profiles of cloud/aerosol properties
- Improve our understanding of aerosol and cloud properties and interactions
- Improve model based estimates of climate forcing and predictions of future climate change

**Bridge the data gap between CALIPSO & EarthCARE**

- **CALIPSO**: Launched 2006, Using 2nd laser since 2009 (~2.5 year life)

- **EarthCARE**: Launch mid-2014, 6 month requirement, 3 year goal

- **HSRL Demonstration for ACE Mission**: HSRL likely to launch in 2016, Space-based mission, launch 2020s
Vertical profiles of backscatter provide important climate information on Earth’s radiation budget. However, layer type (i.e., composition) cannot be determined using backscatter at a single wavelength. Determining layer type is important because:

- Different layers have different microphysical properties which impact radiative balance in different ways.
- Climate models need to know the vertical/horizontal distribution and properties of atmospheric layers.
- Current climate models do not accurately predict the vertical structure of cloud and aerosol layers.
- Lidar data can be used to initialize models for better vertical structure in model output.

We want to take the measured profile data and turn it into a vertically-resolved “feature mask” that identifies the different types of layers.
• Depolarization ratio ($\delta$) provides information about particle shape
• Multiple wavelengths provide information about particle size by ratio of the backscatter (color ratio, $\chi$)
• Both are needed to accurately determine layer type

Ice Clouds: $\delta > 0.40$  $\chi > 0.85$

Dust: $0.20 < \delta < 0.30$

Water Clouds: $\delta \approx 0.0$  $\chi > 0.85$

Smoke: $\chi \approx 0.20$
CATS Data Products

**Level 0 Data:**
- Raw Photon Counts for each channel in sequential order
- Res: 60 m (vert.), 350 m (hor.)

**Level 1 Data:**
- Relative Backscatter (L1A)
- Calibrated Backscatter and Depolarization Ratio (L1B)
- Res: 60 m (vert.), 350 m (hor.)

**Level 2 Data:**
- Vertical Feature Mask
- Backscatter and extinction profiles
- Layer optical depth, lidar ratio
- Res: 60 m (vert.), 1-5 km (hor.)
ACE required parameters for clouds and aerosols that will be provided by CATS*

<table>
<thead>
<tr>
<th>ACE Required Parameters: Clouds</th>
<th>ACE Required Parameters: Aerosols</th>
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<tr>
<td>Cloud Layer Detection</td>
<td>Aerosol Type</td>
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<tr>
<td>Cloud Top Height</td>
<td>Angstrom exponent</td>
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<td>Cloud Base Height</td>
<td>Spectral Column Optical Depth</td>
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<td>Cloud Top Phase</td>
<td>Absorbing Spectral Column Optical Depth</td>
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<td>Precipitation Detection</td>
<td>Effective Radius Profile</td>
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<td>Vertical Motion</td>
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<td>Multilayer Cloud Detection</td>
<td>Single Scattering Albedo</td>
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<td>Cloud Phase Profile</td>
<td>Extinction Profile</td>
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<td>Precipitation Profile</td>
<td>Effective Layer Altitude</td>
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<td>Water Content Profile</td>
<td>Fine Mode Fraction</td>
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<td>Cloud Water Path</td>
<td>Effective Variance</td>
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<td>Cloud Particle Size Profile</td>
<td>Number Concentration</td>
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<td>Precipitation Particle Size Profile</td>
<td>Volume Concentration</td>
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<td>Precipitation Rate Profile</td>
<td>Real Refractive Index</td>
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<tr>
<td>Cloud Column Optical Depth</td>
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<tr>
<td>Layer Effective Radius</td>
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<tr>
<td>Extinction Profile</td>
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<tr>
<td>Radiative Effect</td>
<td></td>
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<tr>
<td>Latent Heating</td>
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</table>

*legal disclaimer: not all products at all times, and not all to the same resolution/accuracy as ACE requirements
Geometry/Operating Modes

Laser #1 Mode
(532/1064 nm)

Laser #2a,b Modes
(532/1064 and 355 nm)

-0.5° +0.5°

14.38 m diameter

7 km

TOP VIEW

SIDE VIEW

7500 m/s

spot separation: 1.5 cm

14.38 m diameter

405 km

TOP VIEW

SIDE VIEW

7500 m/s

spot separation: 1.5 cm
CATS is all about managing expectations.

Please keep your expectations at an appropriate level!

Although we expect CATS to survive launch and collect spectacular data that will advance ACE technology and algorithms, there are many many many unknowns that we cannot control.

CATS is intended to operate as continuously as possible....however, we have to turn off for EVA, EVR, vehicle docking, etc. It turns out, ISS is a busy place – visiting vehicles about once per month, with increasing frequency in coming years. We’ll see how “continuously” we can operate.

Data is supposed to flow continuously down to our ground station. But, CATS is the first “big” payload requiring sustained data flow....we’ll see how it works out.

And so on.
Here’s how it works:

Your Expectation
Setting Expectations

Here’s how it works:

Your Expectation

My Reality

See, and now you won’t be surprised.
The Cloud-Aerosol Transport System (CATS): A New Earth Science Capability for ISS

The CATS Instrument

A Class D Approach To Obtaining Important Earth Sciences Measurements From The ISS
CATS Payload Overview

- Laser 1 Electronics
- Laser 1 Transmitter Sub Assembly (Sealed Container)
- Power Distribution Assembly (PDA)
- Laser Output Filter Assy (Red Tag Item)
- Receiver Telescope & Aft Optics Assy
- Detector Housings (Sealed Containers)
- Laser 2 Exit Port
- Laser 2 Electronics
- Laser 2 Transmitter Sub Assembly (Sealed Container)
- HSRL ASSY
- Data Electronics Assy (DSEM)

- PIU
- FRGF
- H-fixture
- SpaceX FSE
- Telescope aperture cover
As-built, prior to installation of blanketing.

Standard JEM-EF payload volume: 1.855 x 0.800 x 1.299 m.
CATS Payload As-Built

(internal view)

Set up at APL in the EMI chamber (one panel removed for access)
Building the Transceiver

60 cm beryllium telescope, 110 µrad field of view

Laser 1 bench subassembly side

Laser 2 bench subassembly side
Telescope aft-optics assembly
Fiber-coupled to detector boxes

Detector boxes for backscatter channels
Lasers

Laser #1 (1064/532)

Laser #2 with external tripling module (1064/532 and 355, injection seeded)

Laser #1 bench assembly

Lasers are Nd:YVO$_4$, 5 kHz rep rate
HSRL Receiver

HSRL receiver box with etalon

Fringe pattern imaged through etalon
Does anyone know how this goes together?

Cavanaugh, caught in the act

If they’re smiling, that means trouble

Beth aligning optics

Cavanaugh, caught in the act

High school student aligning $1.5M telescope
• CATS will bridge a critical data gap in climate data record from lidar, improve operational aerosol forecasting, and contribute to future NASA mission development.

• CATS will advance ACE technology and algorithms.

• CATS is a spectacular opportunity, and the latitude given by the ISS Program to apply sound engineering and management judgment in the pursuit of generating good science has been demonstrated to work.
  
  • ISS Program trusted the Payload Developer to derive our own science requirements instead of subjecting the project to externally-derived requirements and oversight

• Instrument design and requirements are consistent with the [self-generated] science requirements.

• CATS team is proving that a large attached payload can be built for <$15M and ~2 years development time

• The CATS experience and approach is directly applicable to Earth Venture Instrument (EVi) and Earth Venture Mission (EVm) competitive opportunities

**Launch date: October 3, 2014**

ISS orbit covers significant portion of the Earth’s surface, land area, and populated areas

Monitor effects of climate change

Monitor dynamic events

Astronaut Ops – capability to help assemble/repair instruments

Demonstrate pathfinder instruments and new technologies

Engage the public, the scientific community and decision makers
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<tr>
<th>Mission Objectives</th>
<th>Geophysical Parameters</th>
<th>Measurement Requirements</th>
<th>Approach</th>
<th>Ancillary Data</th>
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<tr>
<td>(A) Extend CALIPSO data record for continuity of Lidar Climate Observations</td>
<td>detection of aerosol and cloud layers from the surface to the atmosphere</td>
<td>Minimum Dual Wavelength Elastic Backscatter Lidar (532 and 1064 nm)</td>
<td>Acquire data set similar to CPL and CALIPSO</td>
<td>Meteorology (molecular calculations and science/analysis)</td>
</tr>
<tr>
<td>(1) Continue record of vertically resolved aerosol and cloud distributions and properties</td>
<td>Attenuated Backscatter, aerosol and cloud backscatter and extinction</td>
<td>Depolarization Ratio at 532 nm</td>
<td>Develop retrieval algorithms based on ICESat and CPL experience</td>
<td>Position/Pointing, and DEM</td>
</tr>
<tr>
<td>(2) Improve our understanding of aerosol and cloud properties and interactions</td>
<td>depolarization ratio</td>
<td>Measured Attenuated Backscatter Resolutions: &lt; 100 m vertical, &lt; 400 m along track (high res for cloud detection/clearing)</td>
<td>In addition to above, apply CALIPSO algorithms to assess data continuity between missions</td>
<td>Column Aerosol Optical Depth 532 nm (Observational or Assimilation Model)</td>
</tr>
<tr>
<td>(3) Improve model based estimates of climate forcing and predictions of future climate change</td>
<td>Aerosol and Cloud Type (feature mask)</td>
<td>Retrieved Backscatter: 1E-4 (km sr)-1 at 100 m vertical, 20 km along track. 30% error.</td>
<td>Utilize model AOD from passive assimilation techniques to provide retrieval constraints, and improved aerosol lidar products</td>
<td>Scene Imagery (context)</td>
</tr>
<tr>
<td>(B) Improve Operational Aerosol and Weather Forecasting Programs</td>
<td>Above parameters, plus:</td>
<td>Above requirements, plus:</td>
<td>Use lidar feature mask and retrieved aerosol properties to assess initial model performance</td>
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<tr>
<td>(1) Improve model performance through assimilation of near-real-time aerosol and cloud data</td>
<td>Planetary Boundary Layer Height (feature mask)</td>
<td>NRT capability: minimum &lt;= 3 hours, max 1 day</td>
<td>Provide vertical profile products and PBL heights for model assimilation</td>
<td></td>
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<tr>
<td>(2) Enhance air quality monitoring and prediction capabilities by providing vertical profiles of pollutants</td>
<td></td>
<td>Observations across the diurnal cycle</td>
<td>Provide a PBL AOD product from extinction profile and PBL height</td>
<td></td>
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<tr>
<td>(3) Improve strategic and hazard warning capabilities of events in near-real-time (dust storms, volcanic eruptions)</td>
<td></td>
<td>Utilize unique ISS orbit to improve studies of longitudinal aerosol transport and diurnal evolution of aerosol and PBL</td>
<td></td>
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</tr>
<tr>
<td>(C) NASA Decadal Mission Pathfinder: Lidar for the Aerosols, Clouds, Ecosystems (ACE) Mission</td>
<td>Above parameters, plus:</td>
<td>HSRL capability at 532 nm (notch filter or interferometric technique)</td>
<td>Provide data for ACE mission studies</td>
<td></td>
</tr>
<tr>
<td>(1) Demonstrate HSRL aerosol retrievals and 355 nm data for ACE mission development</td>
<td>Direct Retrieval of Extinction and Backscatter at 532 nm</td>
<td>Retrieved Extinction Resolutions: &lt;= 1 km vertical, &lt;= 50 km along track</td>
<td>Determine optimum resolution vs extinction limit, and feasibility of retrievals for broken cloud scenes</td>
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<tr>
<td>(2) Laser Technology Demo/Risk Reduction: high repetition rate, injection seeding (HSRL), and wavelength tripling (355 nm)</td>
<td>Lidar Ratio at 532 nm</td>
<td>Depolarization Ratio at 355 nm</td>
<td>Use HSRL extinction and lidar ratio profile products to provide improved aerosol typing for Mission Objectives B1 and B2</td>
<td></td>
</tr>
</tbody>
</table>
Use an imaging detector to resolve aerosol spectrum. True “spectral resolution.”
Results in over-determined set of equations (one per detector element).
Typically use Fabry-Perot etalon as resolving element.
Inherently capable of handling Doppler shift.
Fabry-Perot has fairly low efficiency.
Avionics (data system) for control, data collection, data transfer.
Supports 1553, Ethernet, and FDDI communications links.
Completed payload, with blanketing installed. Entire payload is blanketed.