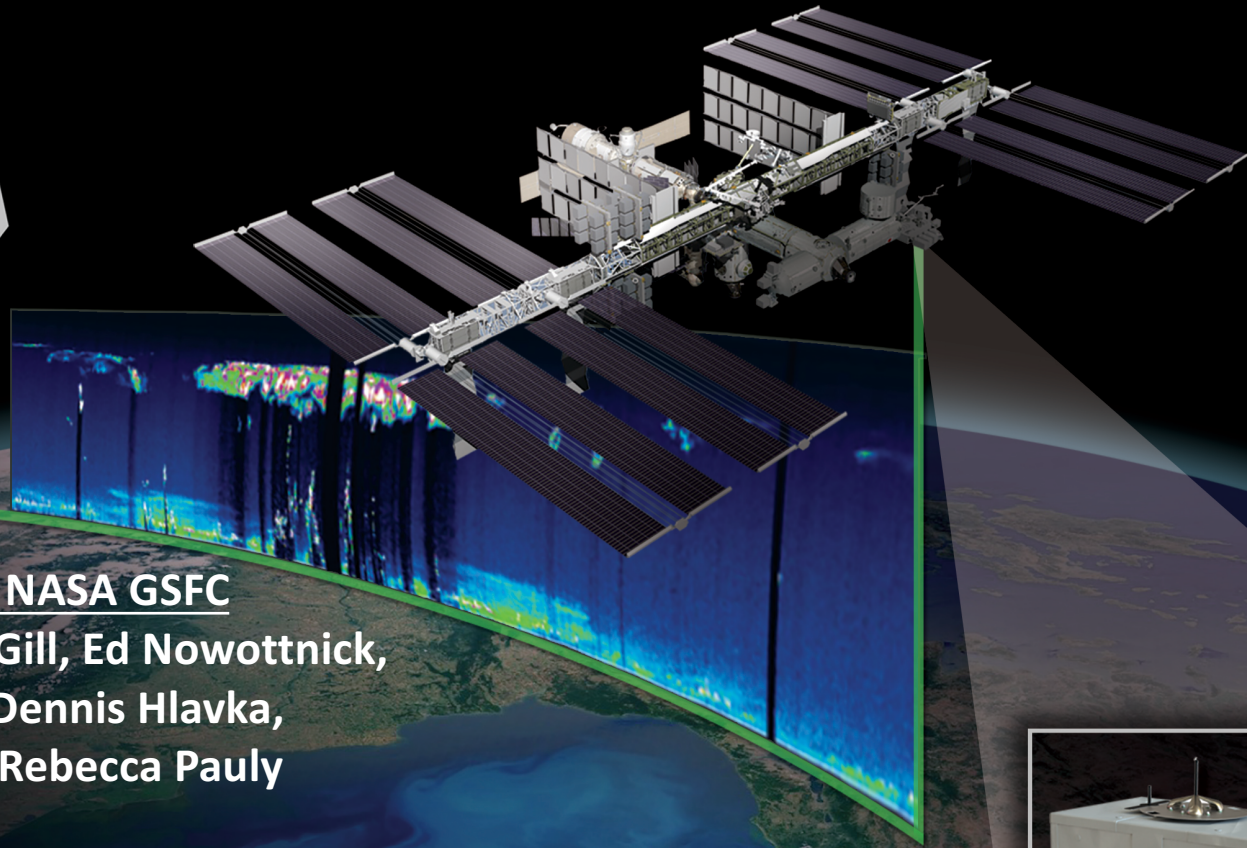# CATS Near Real Time Data and Applications for Aerosol Forecasting

CATS Team – NASA GSFC
John Yorks, Matt McGill, Ed Nowottnick,
Stephen Palm, Dennis Hlavka,
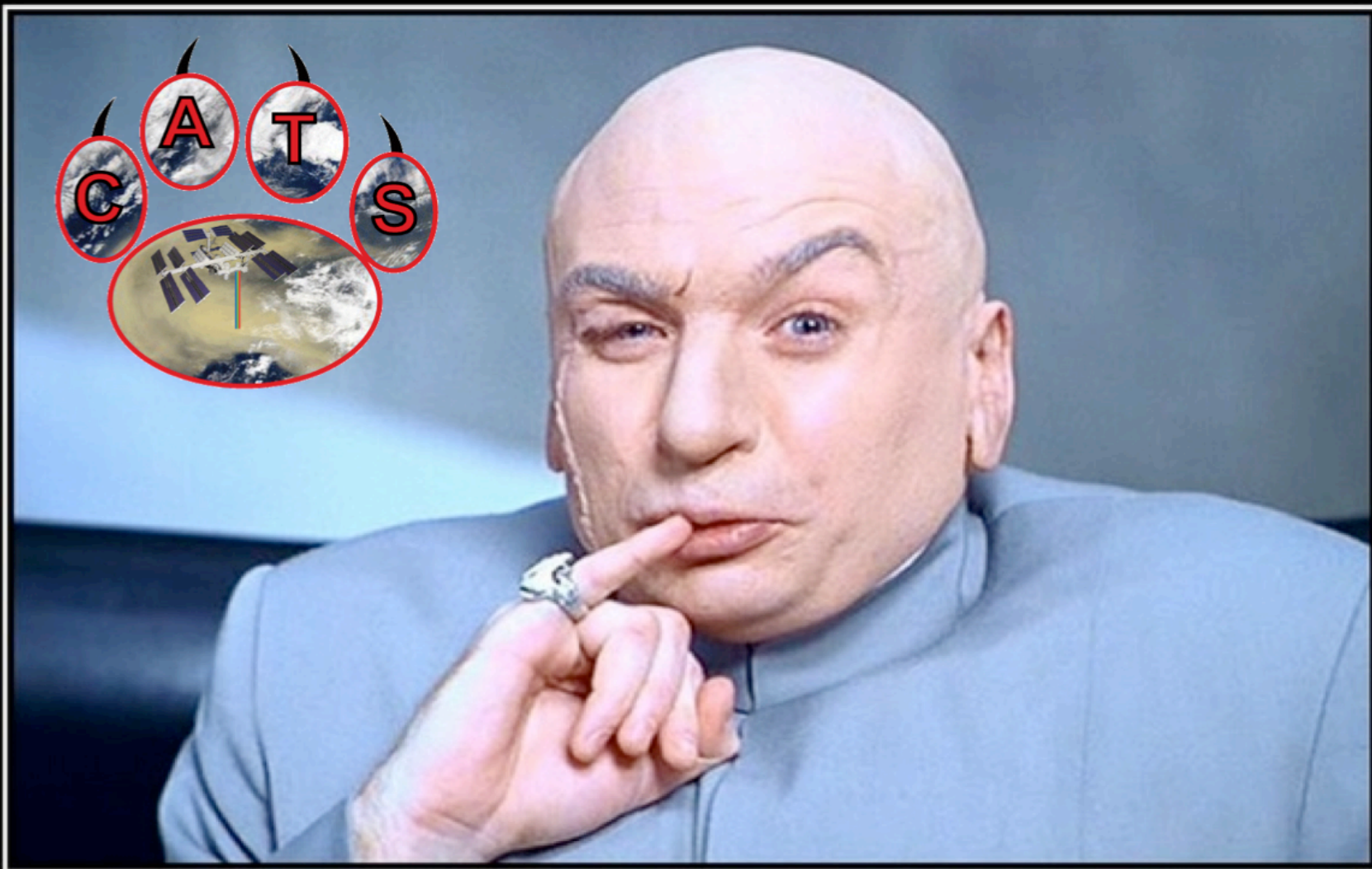**Patrick Selmer, Rebecca Pauly**

CATS Team – NASA LaRC
Chip Trepte, Mark Vaughan, Sharon Rodier

Other Contributors (NASA GSFC)
Hongbin Yu, Eric Hughes, Nick Krotkov

# CATS Overview

- **CATS is a lidar utilizing ISS as an affordable Earth Science platform designed to:**
  - **Monitor effects of cloud and aerosols on climate change**
  - **Monitor dynamic events such as wildfires and volcanic eruptions**
  - **Provide in-space demonstration of technologies for future satellite missions**
  - **Demonstrate build-to-cost project development with streamlined management structure**
- **CATS has now been operating on the ISS for nearly 18 months and has fired 100+ billion laser shots (0.015 cents per laser pulse!)**
- **New L1 (V2-07) and L2 (V1-04) data products released last month**
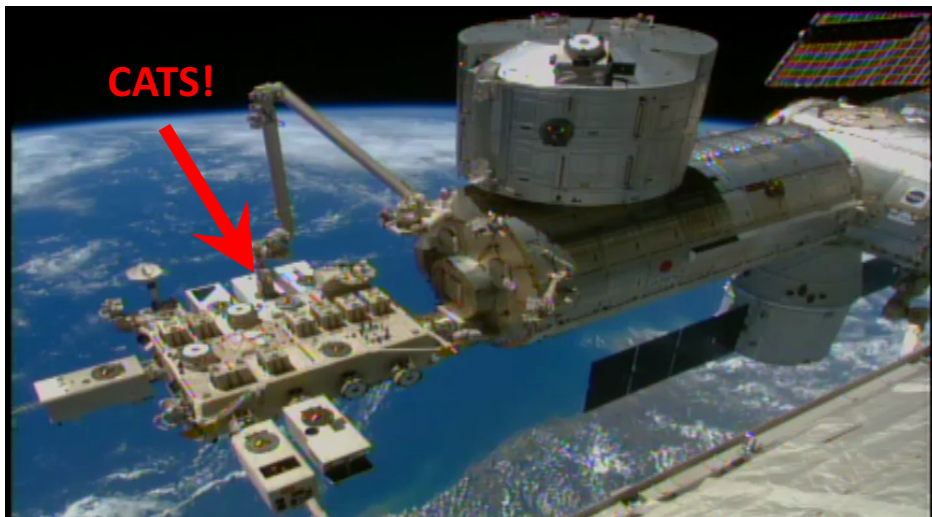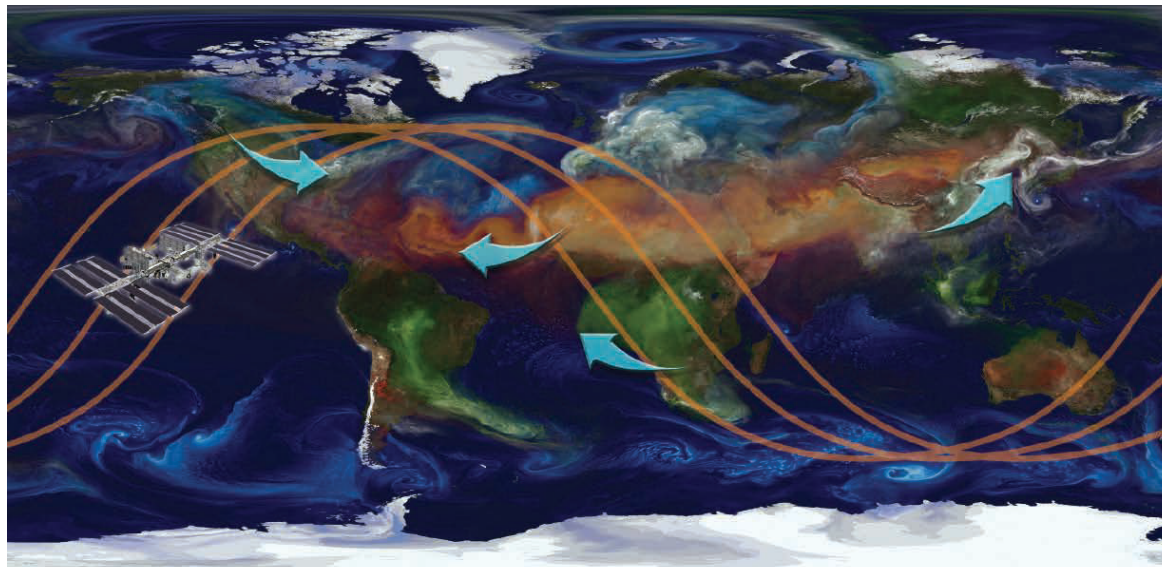
CATS!

TIMELINE:
Jan 10 2015:   CATS launched on SpaceX5
Jan 22 2015:   installed to JEM-EF (left)
Feb 5 2015:   "1st light" with laser 1
Feb 10 2015:   1st continuous 24-hr operation
Mar 25 2015:   1st laser 2 operations
Present: near-continuous laser 2 operations

Laser: 100+ billion shots, 6000+ hours

- **ISS provides a low-cost platform for earth science capabilities and demonstration of new technologies**

- **Near real time data downlinking with loss of signal (LOS) periods that last about 20 minutes**

- **CATS located on Japanese Experiment Module – Exposed Facility (JEM-EF)**

- **Orbit is a 51° inclination orbit at an altitude of about 415 km**
  - **Provides comprehensive coverage of tropics and mid-latitudes**
    - **Primary aerosol transport paths**
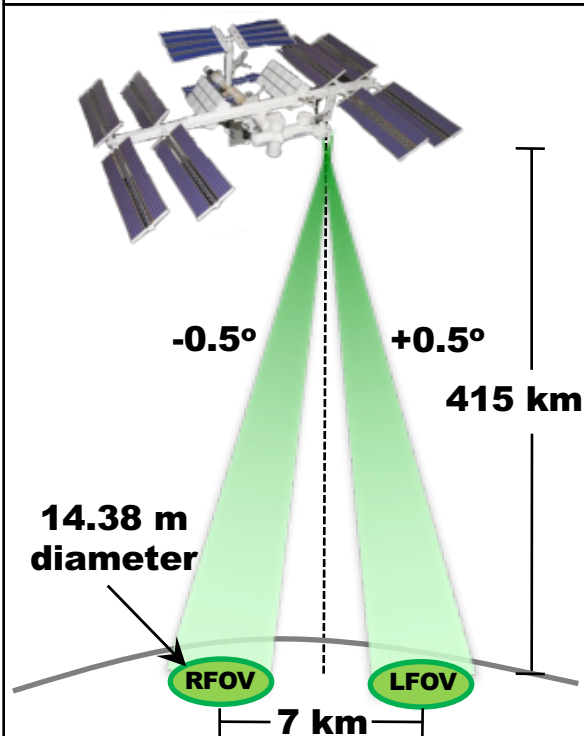 - **Permits study of diurnal changes in clouds/aerosols**

- ## Early bumps in the road:
  - ### Laser 1 failed 3/2015
  - ### Seeded laser cannot be stabilized for HSRL retrievals (Mode 2)

- ## Mode 2 1064 nm data has been very reliable
  - ### Instrument health is good
  - ### Signal strength and laser energy are steady
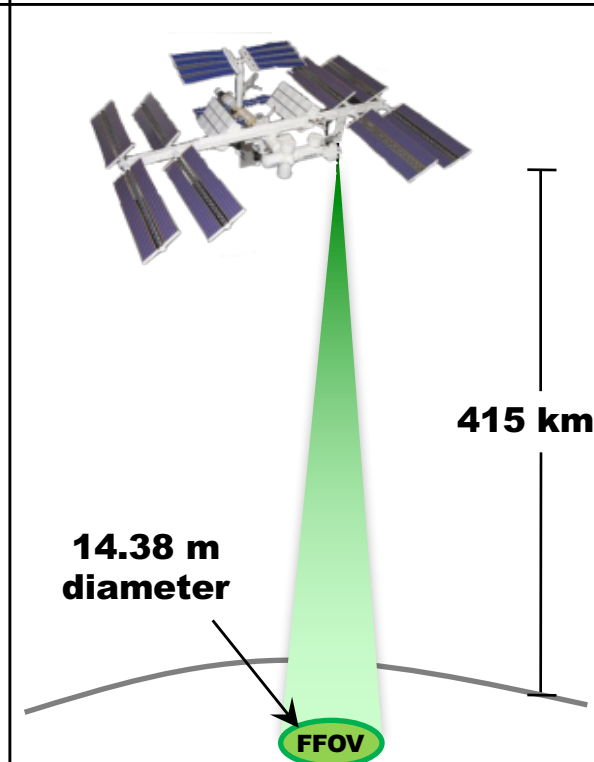 - ### Could operate on-orbit for up to 3 years

Mode 1: Multi-Beam	Mode 2: Laser 2
Backscatter: 532, 1064 nm **Depolarization:** 532, 1064 nm **L2 Products:** 532, 1064 nm	**Backscatter:** 532, 1064 nm **Depolarization:** 1064 nm **L2 Products:** 1064 nm

-0.5°   +0.5°

415 km

14.38 m diameter

RFOV   LFOV

7 km

14.38 m diameter

415 km

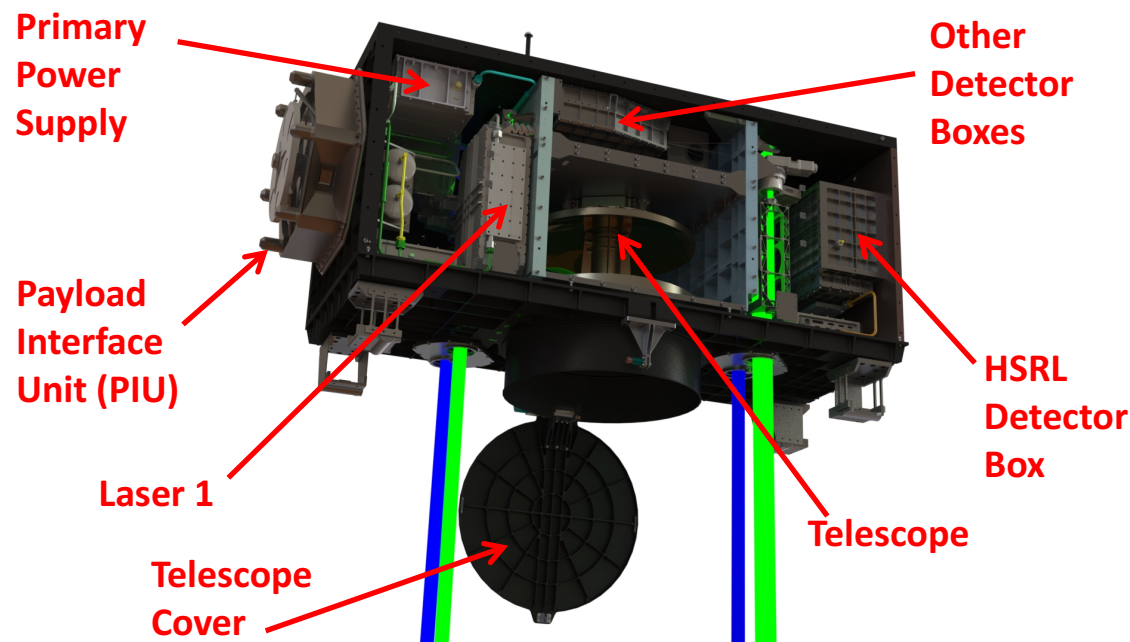FFOV

Semi-continuous operation: Feb. 10 – Mar. 21 (2015)

Semi-continuous operation: 25 Mar. 2015 – Present

CATS Instrument

- ## CATS has demonstrated new technologies in space:

  1. **Photon counting detection with 2 high rep-rate lasers (4 & 5 kHz)**

  2. **Multiple beams separated by 7 km at surface (1.5 months of data in Mode 1)**

  3. **Seeded laser that has been operating for over 1 year (Laser 2)**

 4. **First space-based measurements of depolarization at 1064 nm and 2 wavelengths (532 & 1064)**

Primary Power Supply

Other Detector Boxes

Payload Interface Unit (PIU)

Laser 1

HSRL Detector Box

Telescope

Telescope Cover

V2.07 Now Available:

- Improved geolocation, more accurate calibration
- Updates to calibration and PGR reduce biases in M1 532 nm backscatter and depolarization ratios
- M2 532 nm data is noisy → recommend using 1064 nm data for wavelength-independent analysis
- Corrects for error in vertical remapping of CATS data → more accurate layer top and base heights detection
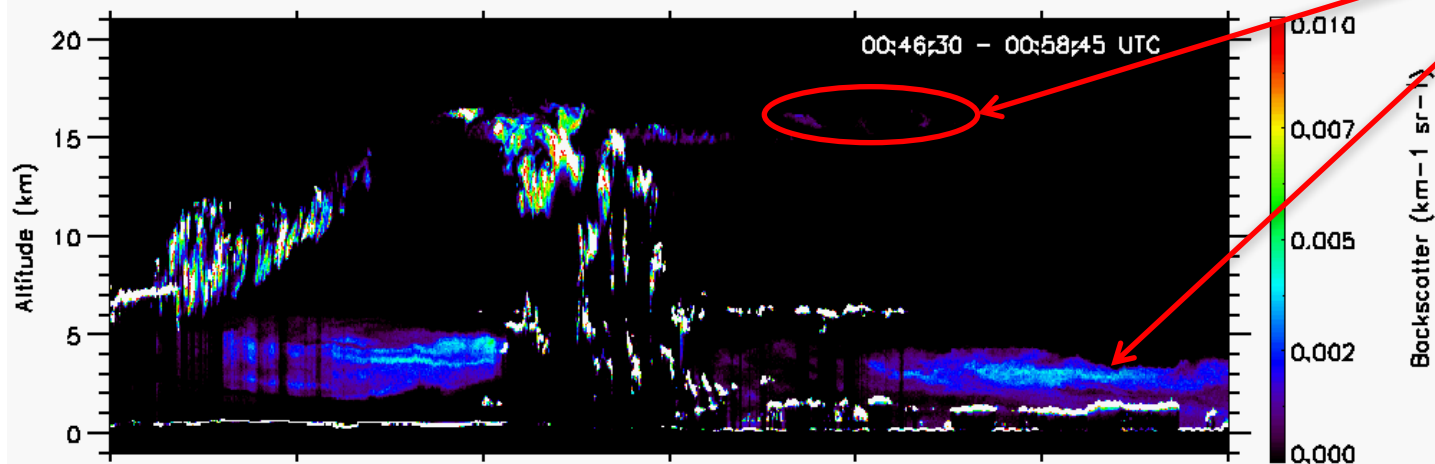

CATS 1064 nm Attenuated Total Backscatter: 12 August 2015

CATS 1064 nm Depolarization Ratio: 12 August 2015
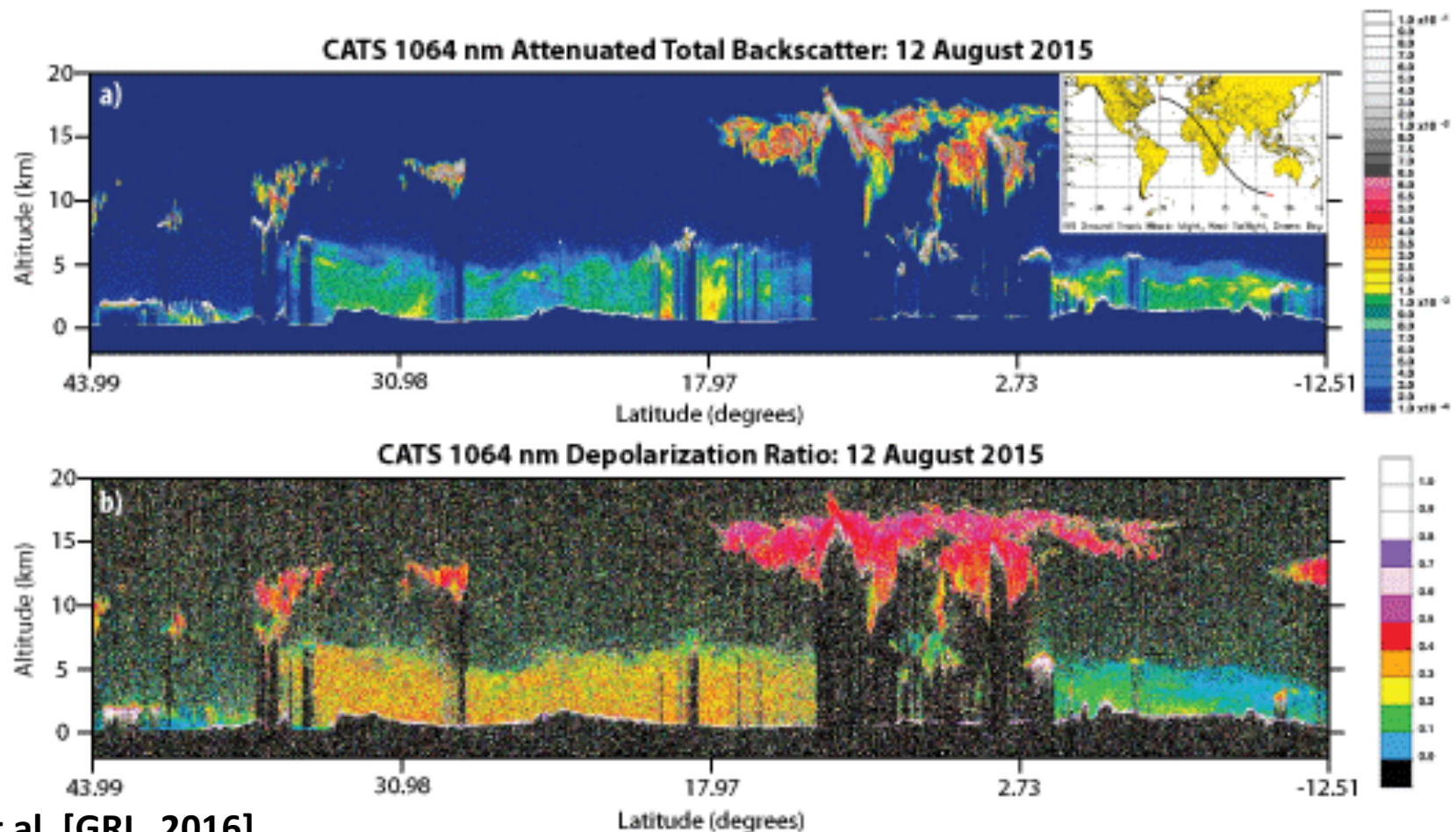
Yorks et al. [GRL, 2016]

ISS CATS 1064 nm Attenuated Total Backscatter; 13 Aug, 2015

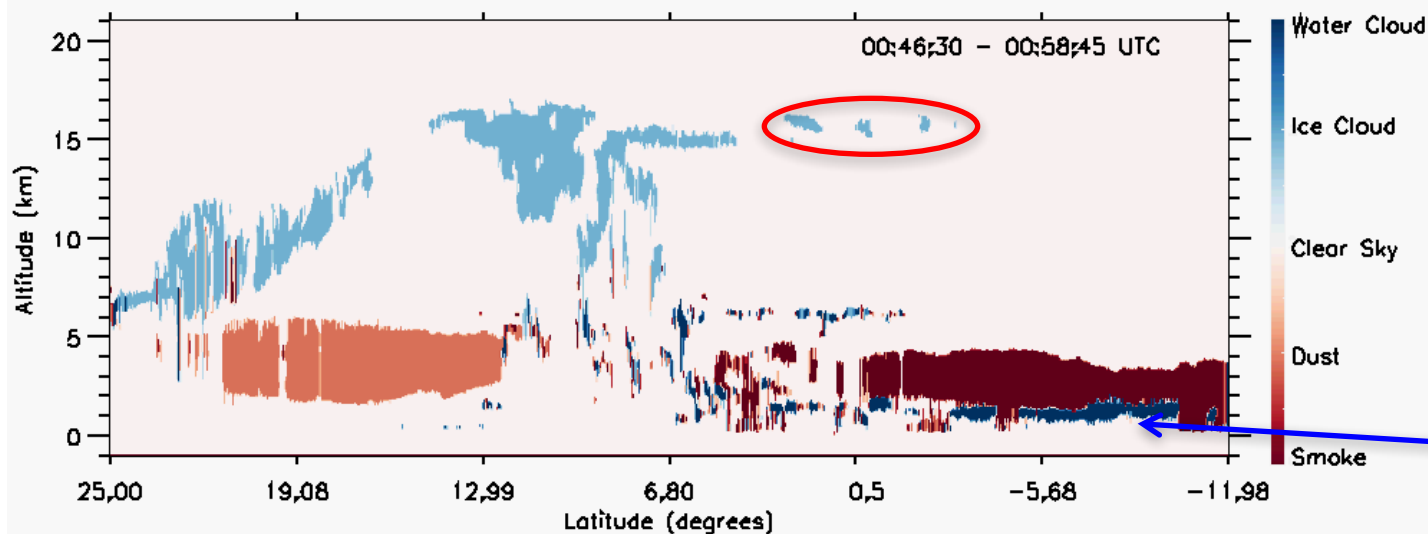### Fore FOV, Resolution: 60 m (vertical), 5 km (horizontal)

00:46:30 – 00:58:45 UTC

CATS L2 Operational uses 1064 nm attenuated scattering ratio for layer detection

Cloud-Aerosol Discrimination using PDFs similar to CALIPSO

ISS CATS Vertical Feature Mask; 13 Aug, 2015

Fore FOV, Resolution: 60 m (vertical), 5 km (horizontal)

00:46:30 – 00:58:45 UTC

Latitude (degrees)

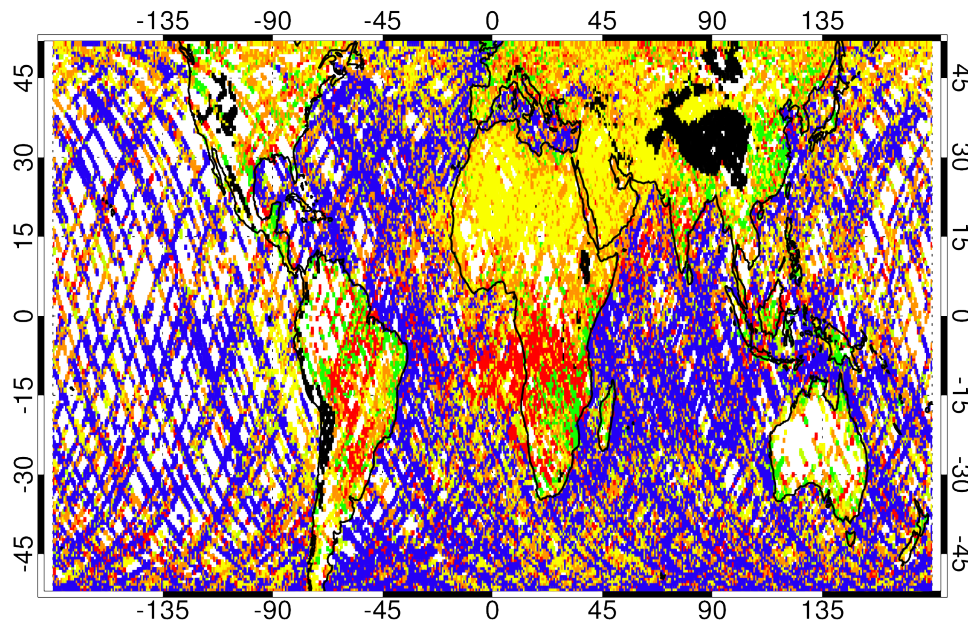**Cloud Phase determined using mid-layer temperature and depolarization ratio**

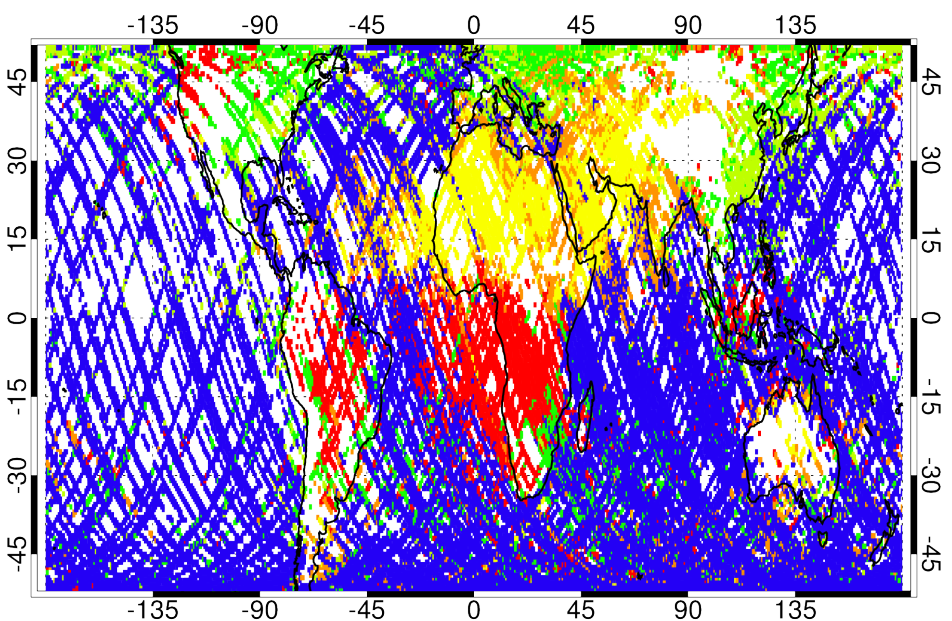**CATS detects clouds embedded in aerosol layers**

Level 2: Aerosol Typing

- **CATS uses different algorithms for each mode**
- **Statistical comparisons to GEOS-5 and CALIPSO are underway**
- **More details in next talk: Ed Nowottnick**

CATS: Aug. – Sep. 2015   GEOS-5: Aug. – Sep. 2015

Smoke   Dust   Dust Mix   Marine   Polluted Marine   Clean Background   Polluted Continental

- **Similar to CALIPSO Products**
    - Vert. resolution = 60 m
    - Hor. resolution = 5 km
- **COD = -1 for opaque clouds**
- **Initial comparisons to CPL are good but show biases**
- **L2 Heritage products (CALIPSO Algorithms) will also be available soon**
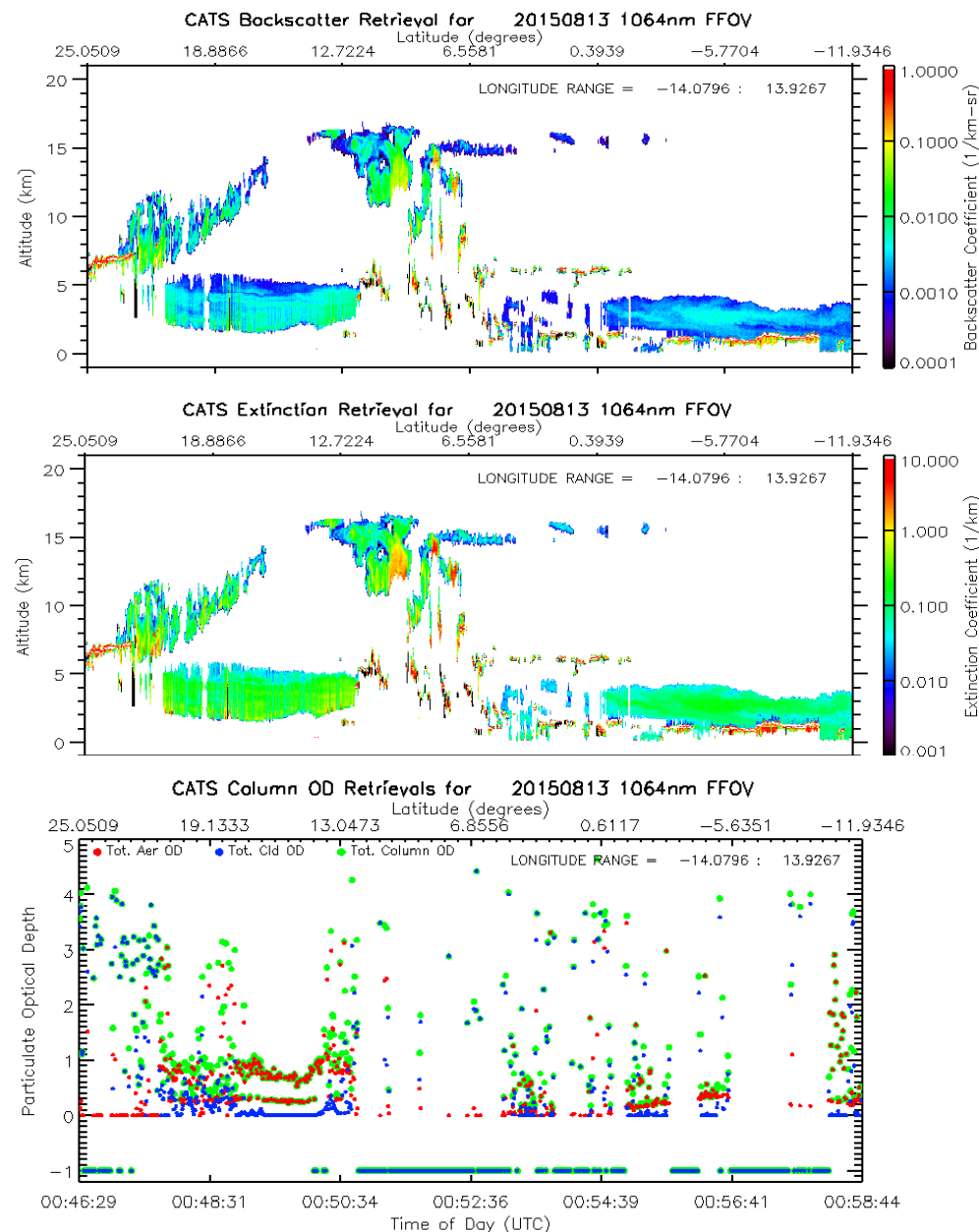
- ## Level 1 Improvements for V2-08:
  - **Assess and improve calibration**
  - **Further reduce 532 nm backscatter and depolarization ratio biases for Mode 1**
  - **Identify and fix files with bias in geolocation**

- ## Level 2 Improvements for V1-05:
  - **Enable L2 uncertainty parameters (currently set to filler values)**
  - **Assess/update multiple scattering factors (1.0 for aerosols)**
  - **Improvements to aerosol typing (Ed will discuss next)**
  - **1064 lidar ratios from CATS and CPL (especially volcanic)**
  - **Detect non-spherical aerosol layers within spherical aerosol layers**
 - **2nd layer detection array that uses same thresholds for night/day**

CATS NRT Data and Applications for Aerosol Forecasting

- **Experimental assimilation of lidar data shows improvements in aerosol forecasts**

- ***Zhang et al.*** **shows CALIPSO extinction profile reduces absolute error in forecasted AOD by 10-20%.**

- ***Sekiyama et al.*** **found hit score (% correct) for surface mass concentrations increases by 40% when CALIPSO data is assimilated.**

- **Models DO NOT assimilate vertical profiles on an *operational* basis because NRT global lidar data have been unavailable.**
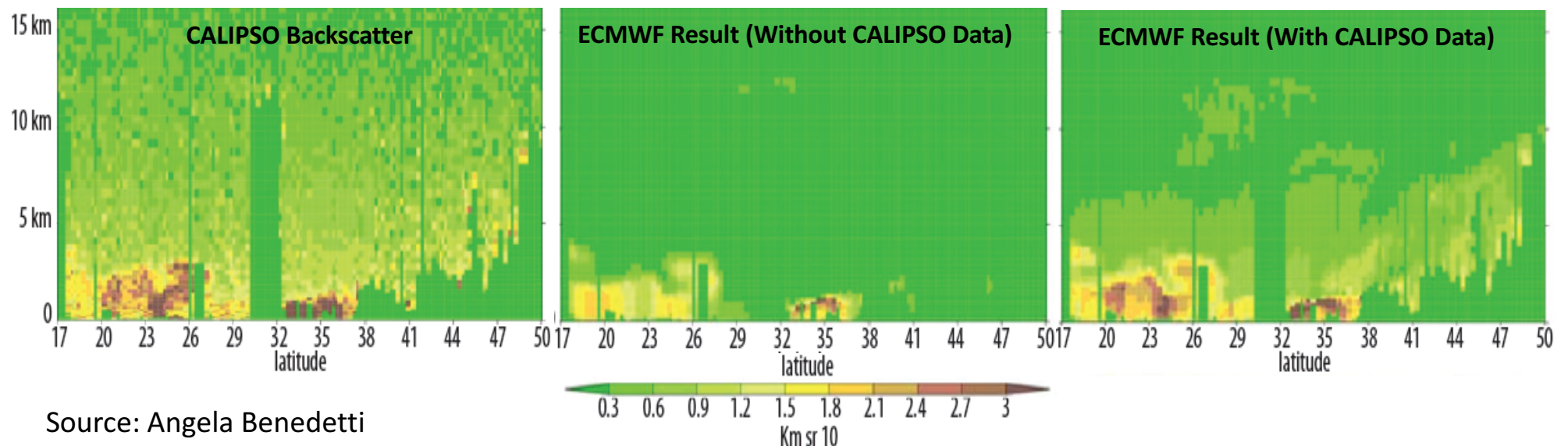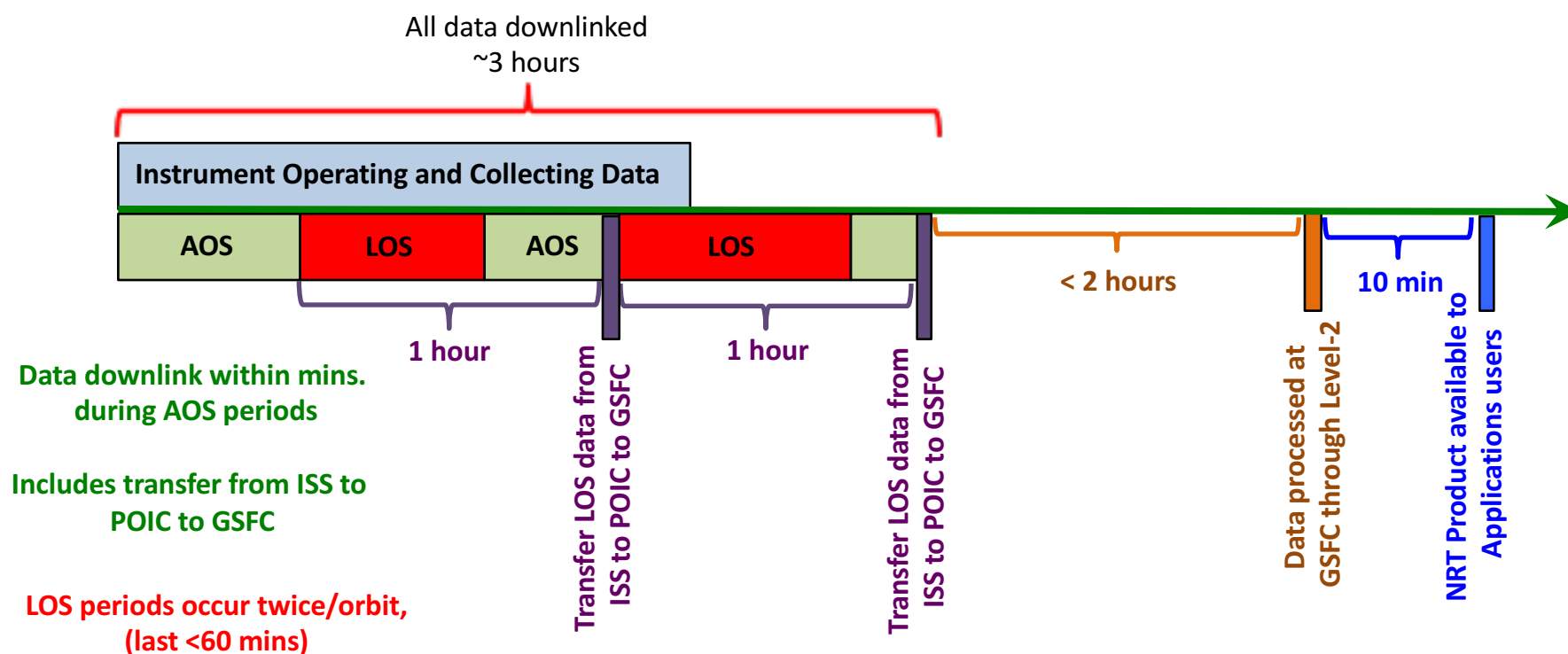

Source: Angela Benedetti

CATS NRT Processing

- **NRT data products created within 6 hours of data acquisition**
  - Includes profiles of backscatter, depolarization ratio and feature mask
- **Work is underway with GMAO (Da Silva/Nowottnick) and NRL (Campbell) to assimilate CATS data.**

Timeline for 1 orbit

All data downlinked ~3 hours

Instrument Operating and Collecting Data

AOS | LOS | AOS | LOS

1 hour

1 hour

< 2 hours

10 min

Data downlink within mins. during AOS periods

Includes transfer from ISS to POIC to GSFC

LOS periods occur twice/orbit, (last <60 mins)

Transfer LOS data from ISS to POIC to GSFC

Transfer LOS data from ISS to POIC to GSFC

Data processed at GSFC through Level-2

NRT Product available to Applications users

Smoke/Fires

ISS passed directly over fire raging near Warm Springs, OR. Plume was observed by CATS, data that can be assimilated into air quality models.
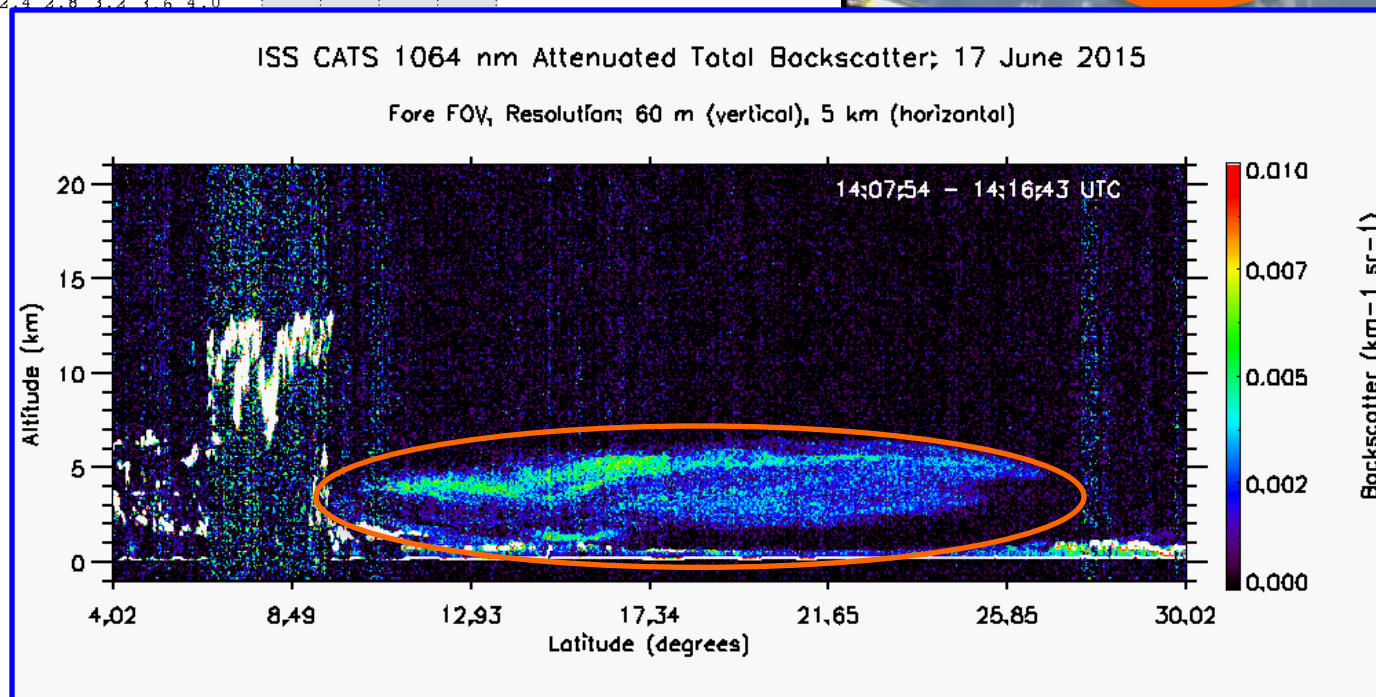
ISS CATS 1064 nm Attenuated Total Backscatter; 18 Aug, 2015
Fore FOV, Resolution: 60 m (vertical), 1 km (horizontal)

04:00:11 – 04:04:22 UTC

Smoke

MODIS TerraCorrected Reflectance: 18 August 2015

Oregon County Line 2 Fire

2016 ICAP Meeting, 12-14 July 2016, College Park MD

Saharan Dust

OMPS Aerosol Index
17 June 2015
0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2 3.6 4.0

Dust blowing off Africa shows clearly in visible imagery from ISS

CATS!

ISS CATS 1064 nm Attenuated Total Backscatter; 17 June 2015

Fore FOV, Resolution: 60 m (vertical), 5 km (horizontal)

14:07:54 – 14:16:43 UTC
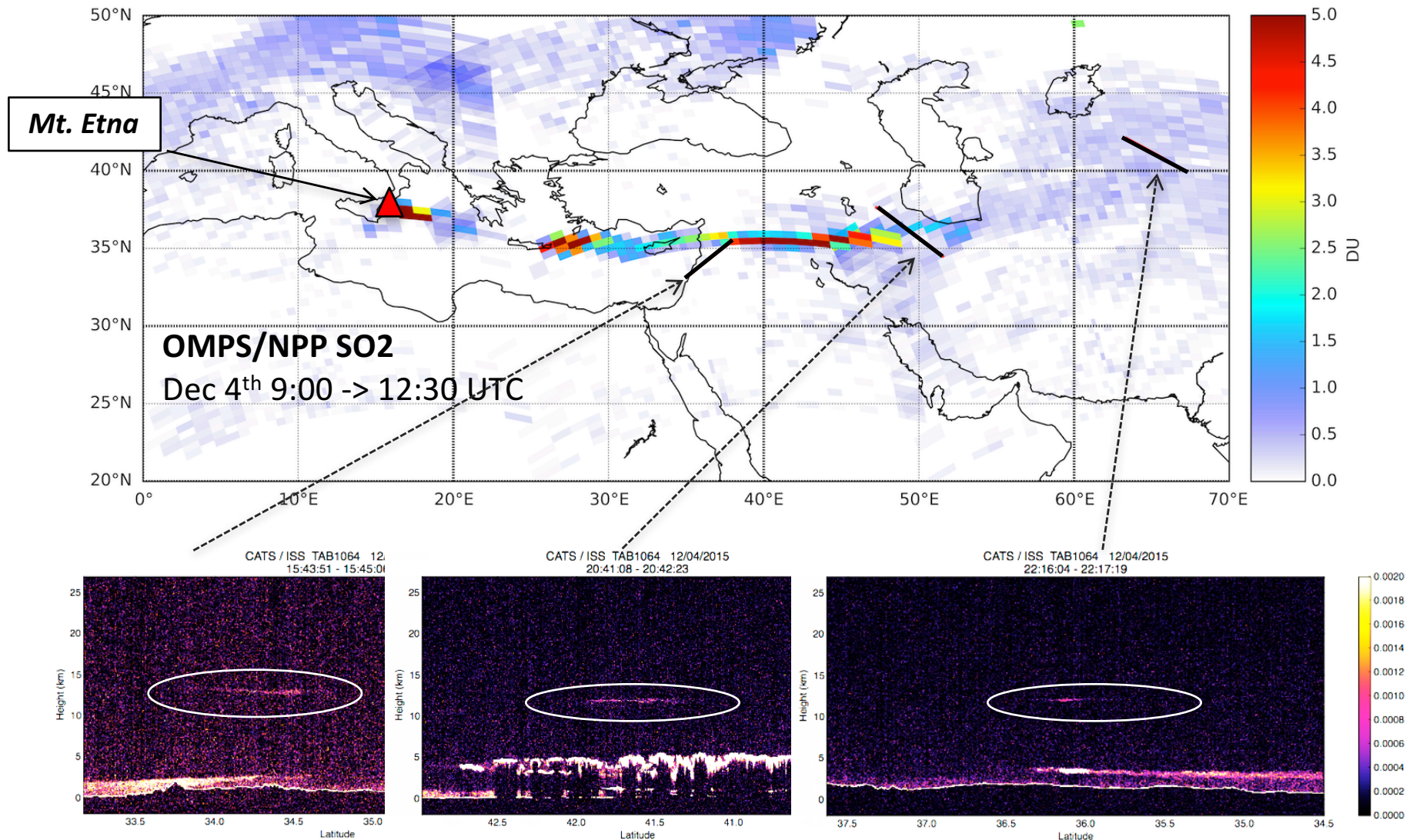

2016 ICAP Meeting, 12-14 July 2016, College Park MD

Volcanic Plumes

- **CATS NRT data observed the Mt. Etna plume on 04 Dec. at altitude of 12-14 km**
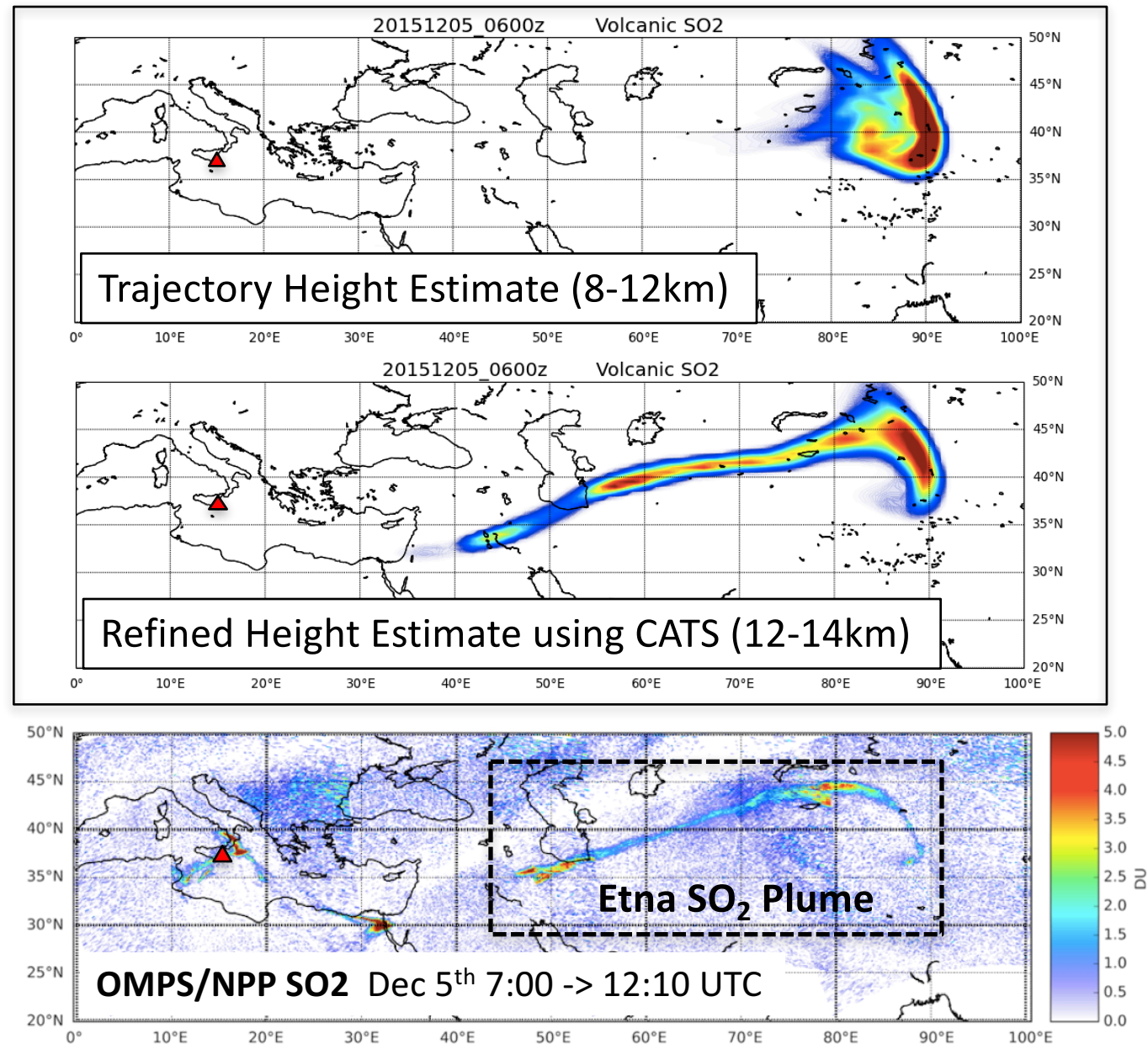 - **Much higher than thought just after eruption (8-12 km)**

Volcanic Plumes

Eric Hughes and Nick Krotkov (GSFC) are forecasting volcanic SO_2 transport using GEOS-5/GOCART

When CATS data is used to initiate volcanic plume injection height, forecast agrees better with observations

CATS NRT data provides an unprecedented opportunity to assimilate global lidar data into aerosol forecast models.

Hughes et al. [GRL, 2016]

20151205_0600z   Volcanic SO2

Trajectory Height Estimate (8-12km)

20151205_0600z   Volcanic SO2

Refined Height Estimate using CATS (12-14km)

Etna SO_2 Plume

OMPS/NPP SO2 Dec 5th 7:00 -> 12:10 UTC

Aerosol Applications

- **CATS provides measurements at different local time every overpass**
  - **Fills in spatial and temporal gaps between NASA A-Train measurements (CALIPSO)**
  - **Improves diurnal statistics of aerosol types and plume heights**
  - **Better track aerosol plume transport**
  - **Greater likelihood of observations of small-scale plumes**

MODIS Aqua Corrected Reflectance (True Color): 17 June 2015

03:48 UTC | **02:15 UTC** | **04:38 UTC**

CATS 1064 nm Attenuated Backscatter | CATS 1064 nm Attenuated Backscatter | CALIPSO 532 nm Attenuated Backscatter

CATS 1064 nm Depolarization Ratio | CATS 1064 nm Depolarization Ratio | CALIPSO 532 nm Depolarization Ratio
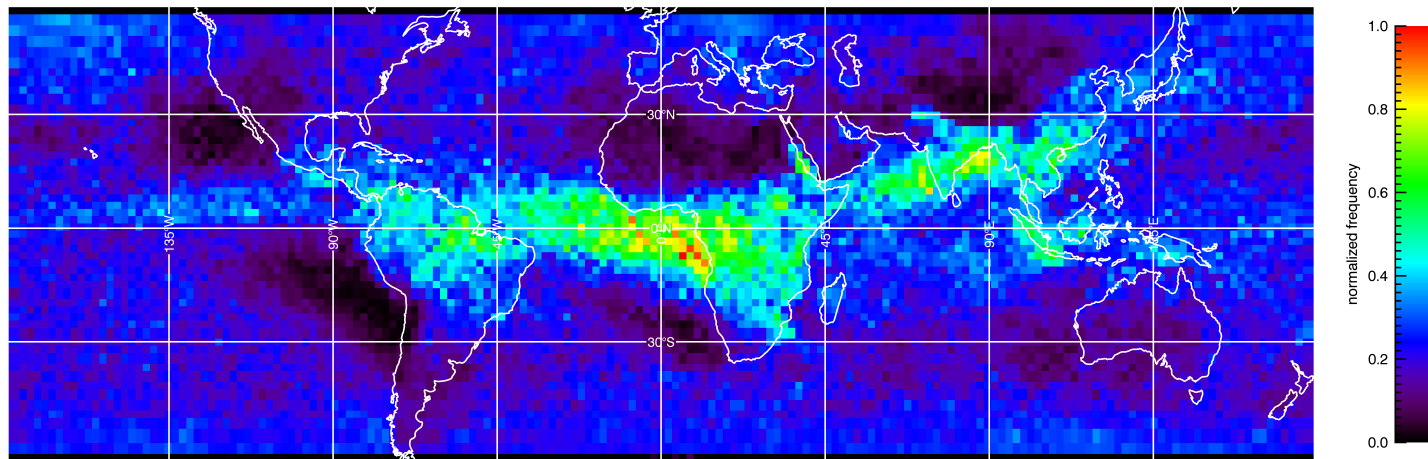
2016 ICAP Meeting, 12-14 July 2016, College Park MD

Model Comparisons
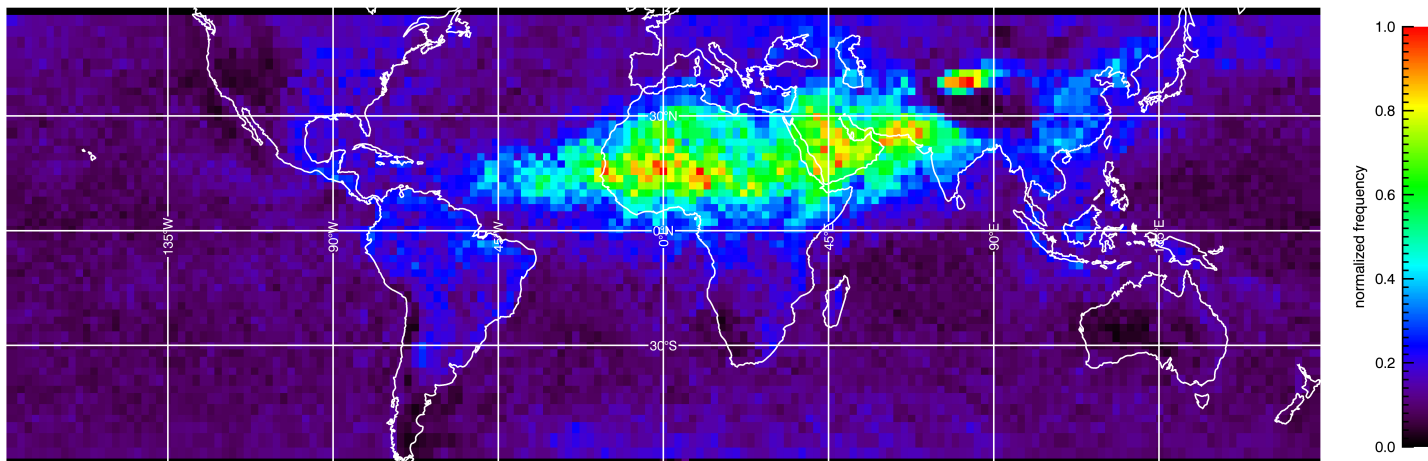
- With nearly a year and a half of data, CATS can now be used to analyze detection frequency of specific aerosol types, aerosol layer heights, aerosols in close proximity to clouds, aerosols above clouds, etc.

CATS Smoke Detection Frequency: March 2015 – March 2016
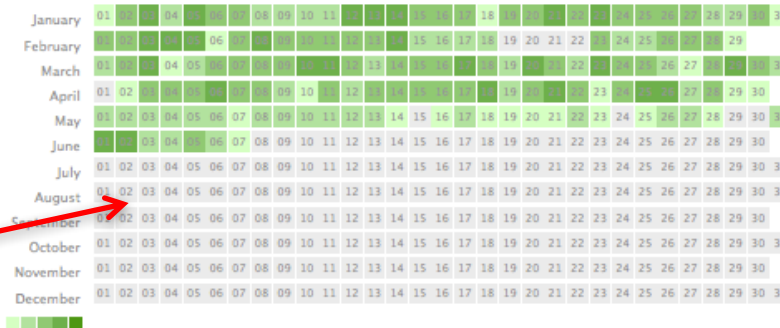

CATS Dust Detection Frequency: March 2015 – March 2016

CATS Data Availability
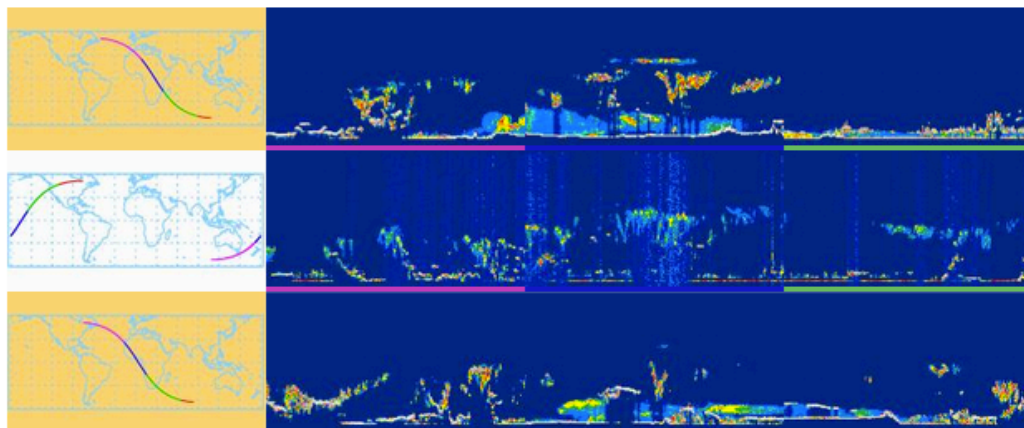
ISS | **Earth Science**

For NRT data contact me: john.e.yorks@nasa.gov
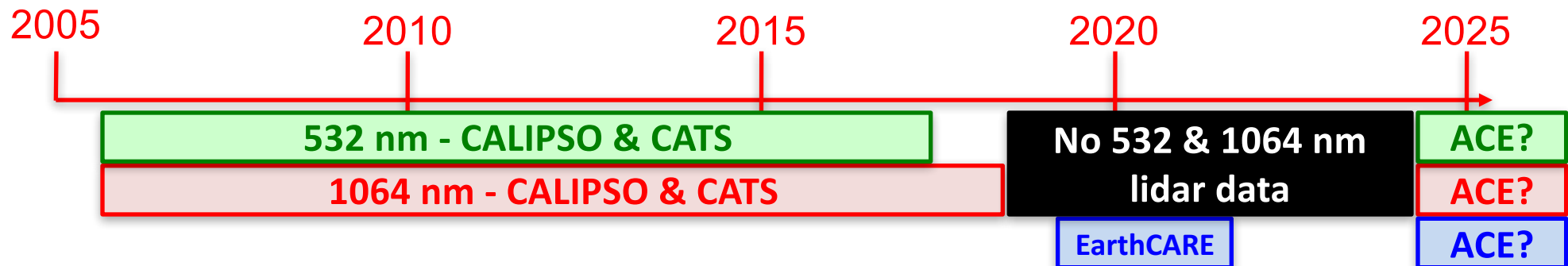
- **CATS is a pathfinder for:**
  - Quick turn-around, low-cost Class D payloads (build-to-cost/schedule)
  - NASA-developed science payloads for ISS

- **CATS has demonstrated new technologies in space:**
  - Multiple beams separated by 7 km at surface (1.5 months of data)
  - First space-based measurements of depolarization at 1064 nm (& 2 wavelengths)

- **CATS data can be utilized for many aerosol modeling applications:**
  - Assimilation into operational aerosol transport models
  - Injection heights for forecasting volcanic plume transport and wildfire plumes
  - Aerosol Above Cloud – Detection of clouds embedded in aerosols at 1064 nm
  - Fills in spatial/temporal gaps between CALIPSO for aerosol transport

- **Special thanks to:**
  - ISS Program (HEOMD) for funding the instrument
  - NASA SMD for funding algorithms/data products (joint w/ LaRC)

- ## Unsolicited proposal at NASA HQ for CATS Follow On (CATS-FO):
  - Simple backscatter lidar with backscatter and depolarization at 532 & 1064 nm
  - Fully redundant instrument design proposed for 3+ year mission lifetime
  - Same low cost, quick turnaround approach as CATS
  - Ability to point +/- 20° off-nadir to target hazardous events (fires, volcanoes)
  - Continue/improve NRT data delivery (< 3 hrs) for aerosol forecasting assimilation
  - 2019 launch would provide continuity in lidar climate record after CATS & CALIPSO

| 2005 | 2010 | 2015 | 2020 | 2025 |

532 nm - CALIPSO & CATS	No 532 & 1064 nm lidar data	ACE?
1064 nm - CALIPSO & CATS		ACE?
	EarthCARE	ACE?

- ## ICAP has provided a letter of support:
  - Encourage you or your agency management to express your desire for such data to Dr. Michael Freilich (NASA HQ) ASAP!

Backups

- **CPL data from ER-2 validation flights show good agreement in 1064 nm backscatter, depolarization ratio, extinction coefficient**
  - Data used to improve 532 nm PGR and calibration
- **Statistical comparisons underway to detect more subtle biases in L2 products**

CATS 1064 nm Attenuated Total Backscatter: 22 February 2015
Right FOV, Resolution: 60 m (vertical), 350 m (horizontal)
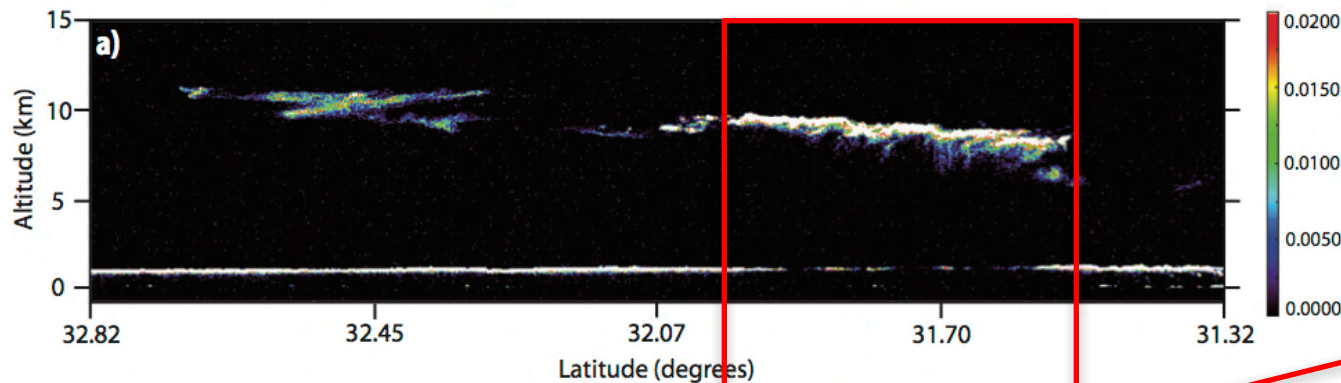
CPL 1064 nm Attenuated Total Backscatter: 22 February 2015
Nadir, Resolution: 30 m (vertical), 200 m (horizontal)

CATS and CPL Comparison: 22 Feb. 2015
1064 nm Attenuated Total Backscatter

CATS ATB RFOV
CATS ATB LFOV
CPL ATB
Latitude: 32.2 - 31.5