CATS Version 2 Aerosol Feature Detection and Applications for Data Assimilation

CATS NASA GSFC TEAM

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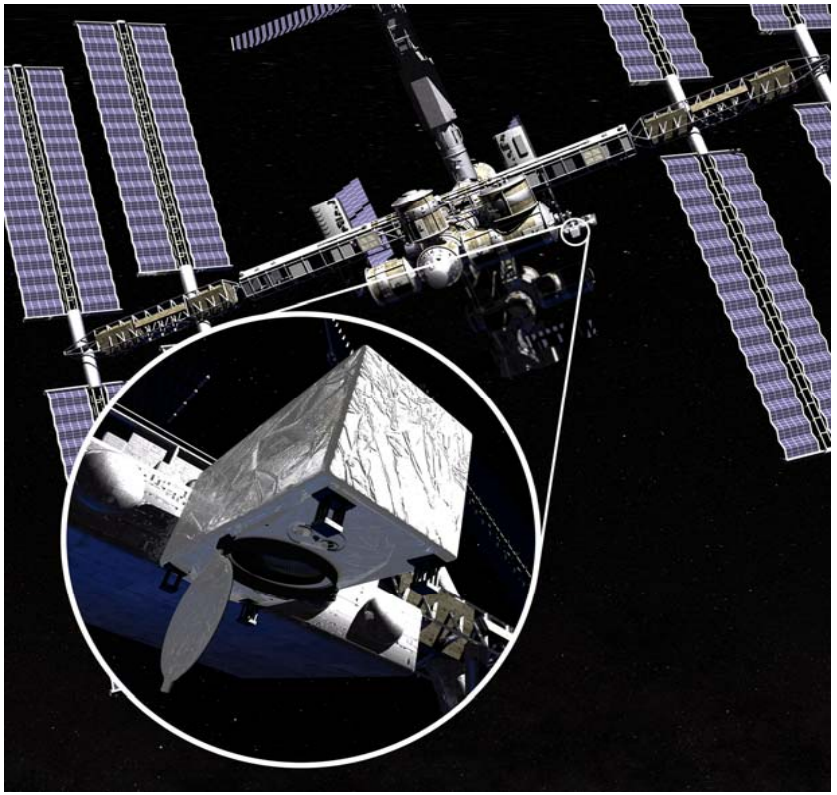
NASA GMAO Collaboration:

Overview

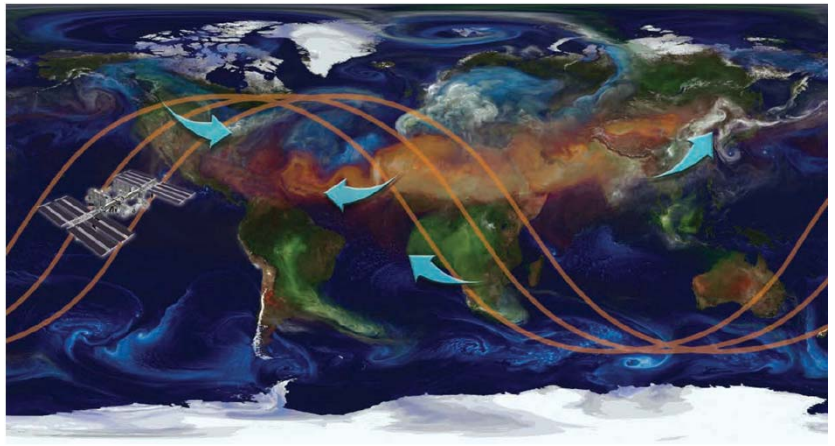
- Part 1:
  - Instrument Status
  - Updates for Upcoming Level 2 Data Release
- Part 2:
  - Assimilating CATS observations in GEOS-5
- Future directions

The CATS Instrument

- The Cloud Aerosol Transport System (CATS) is a high repetition rate lidar built at NASA Goddard Space Flight Center (GSFC) designed for use on the International Space Station (ISS)
  - Intended to operate on – orbit for at least 6 months, up to 3 years (almost there!)
  - The ISS provides a low – cost platform for Earth science capabilities
  - 51° orbit at 405 km
  - Orbit permits the study of diurnal cloud/aerosol variability
  - Installation on the ISS permits near real time data downlinking



CATS installed on the ISS



CATS orbital coverage

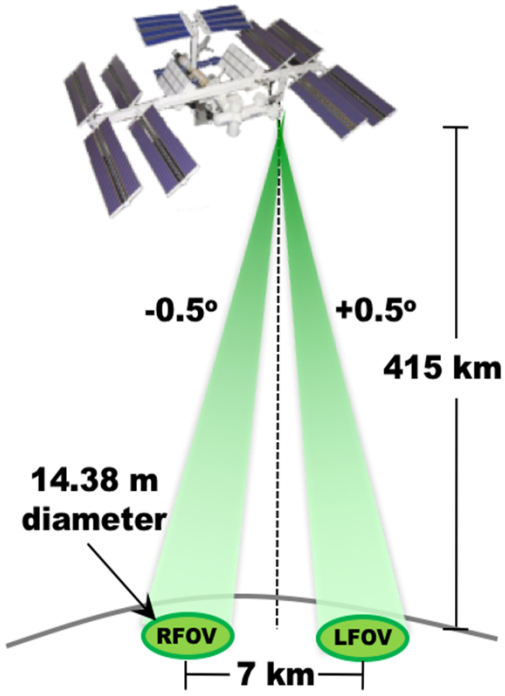
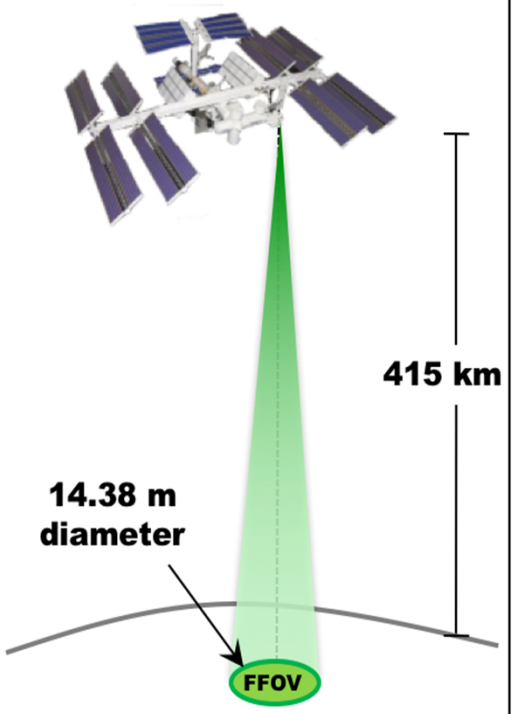
CATS Instrument Status

- Early Issues:
  - Laser 1 failure in March, 2015
  - Seeded laser cannot be stabilized for HSRL retrievals in Mode 2
- Mode 2:
  - Current mode of operation
  - Data has been very reliable:
    - Instrument in good health
    - Signal strength and laser energy are stable
- Currently all version 1 L1B & L2 data quicklooks and data for both modes is available:
  - Online: https://cats.gsfc.nasa.gov
  - NASA Langley Distributed Active Archive Center (DAAC)

TIMELINE:

Jan 10: CATS launched on SpaceX5
Jan 22: Installed on the JEM-EF
Feb 5: "1st light" with laser 1
Feb 10: 1st continuous 24-hr operation
Mar 25: 1st laser 2 operations
Present: near-continuous laser 2 operations

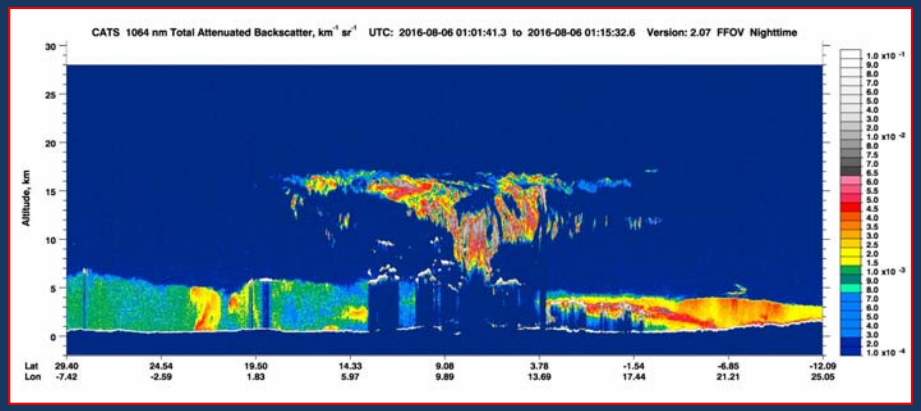
Laser: 177+ billion shots

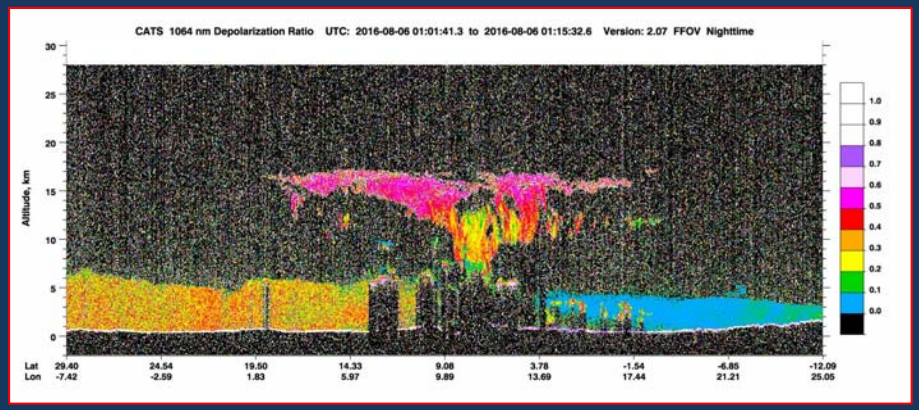
Mode 1: Multi-Beam	Mode 2: Laser 2
Backscatter: 532, 1064 nm Depolarization: 532, 1064 nm L2 Products: 532, 1064 nm	Backscatter: 532, 1064 nm Depolarization: 1064 nm L2 Products: 1064 nm
	
Semi-continuous operation: Feb. 10 – Mar. 21 (2015)	Semi-continuous operation: 25 Mar. 2015 – Present

CATS Data Products

Level 1B (most recent released version 2.07):

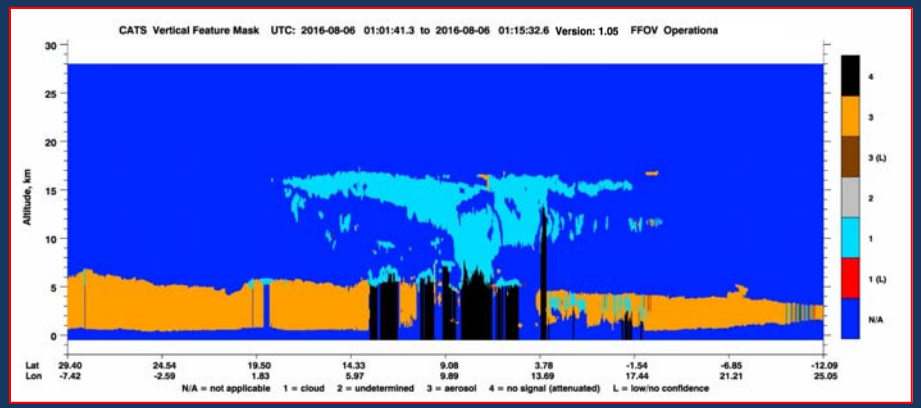
- Attenuated Total Backscatter at 532 and 1064 nm
- Depolarization Ratio at 1064 nm

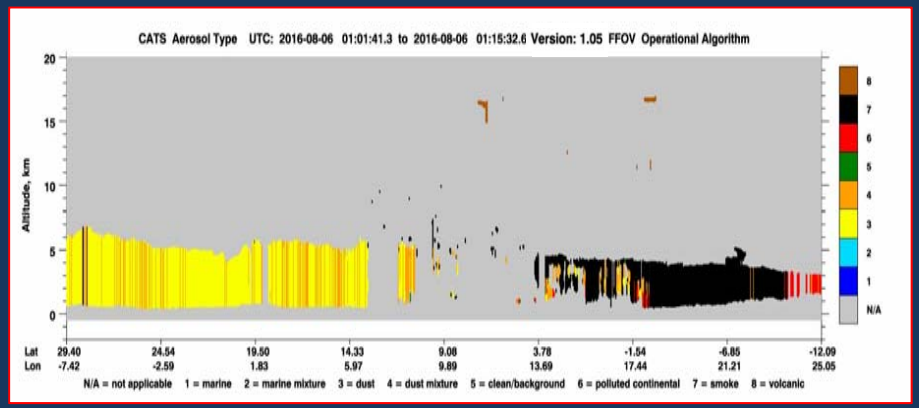




Level 2 (most recent released version 1.05):

- Cloud Aerosol Discrimination and Type
- Cloud and Aerosol Optical Properties (e.g. extinction)

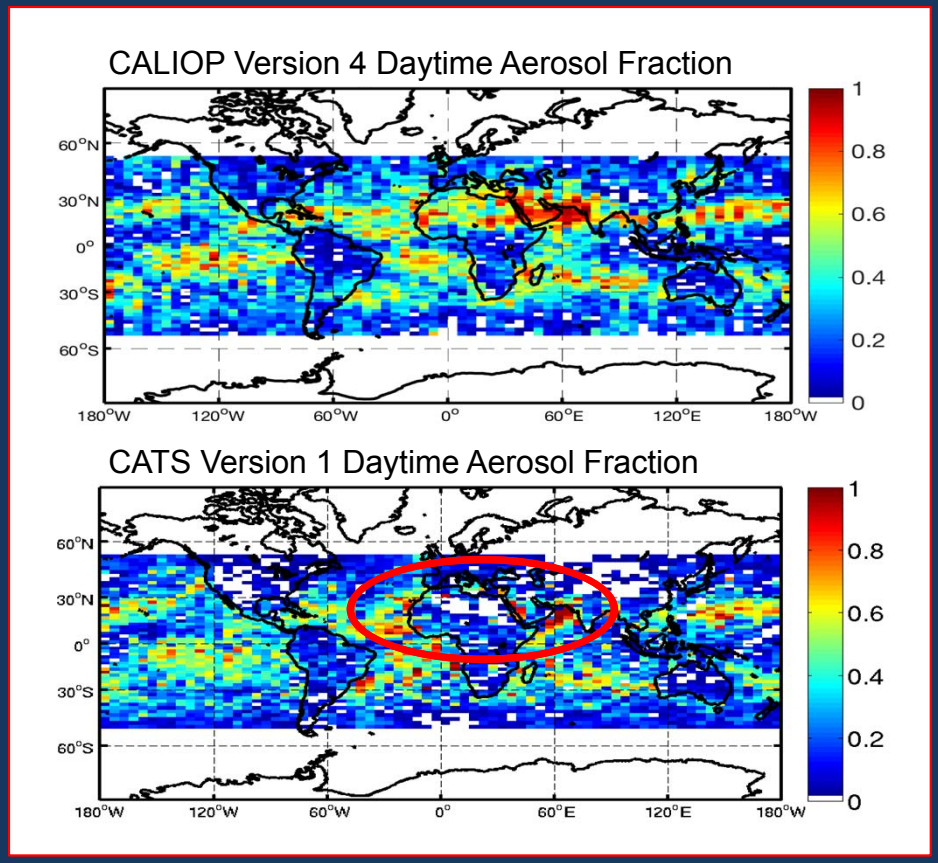




Version 2 Level 2 Aerosol Updates to Aerosol Detection and Typing

Improved Daytime Aerosol Detection

- CATS version 1 level 2 feature detection was performed at 5 km horizontal resolution for both day and night
- Due to lower signal to noise during the day, CATS detected less aerosol layers over land during the daytime



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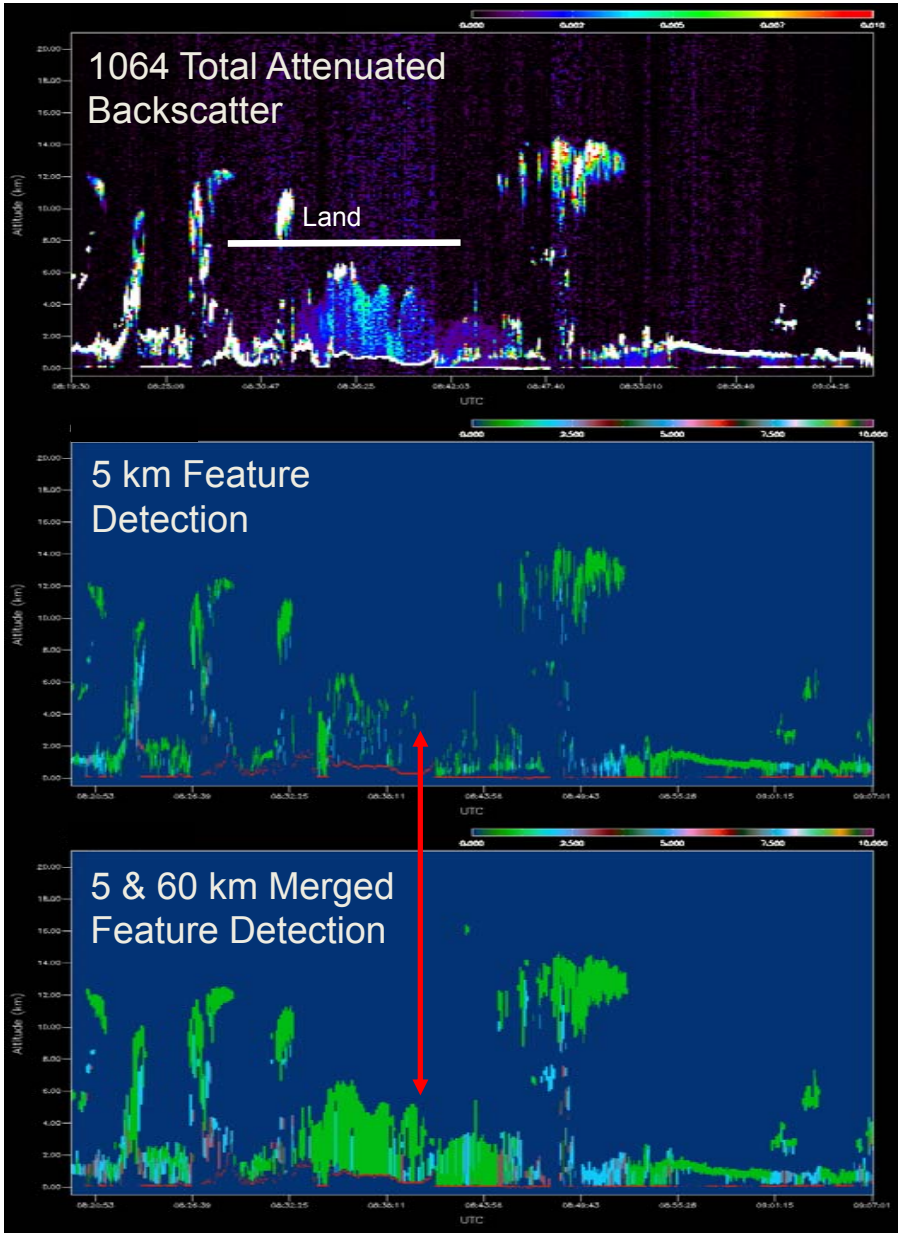

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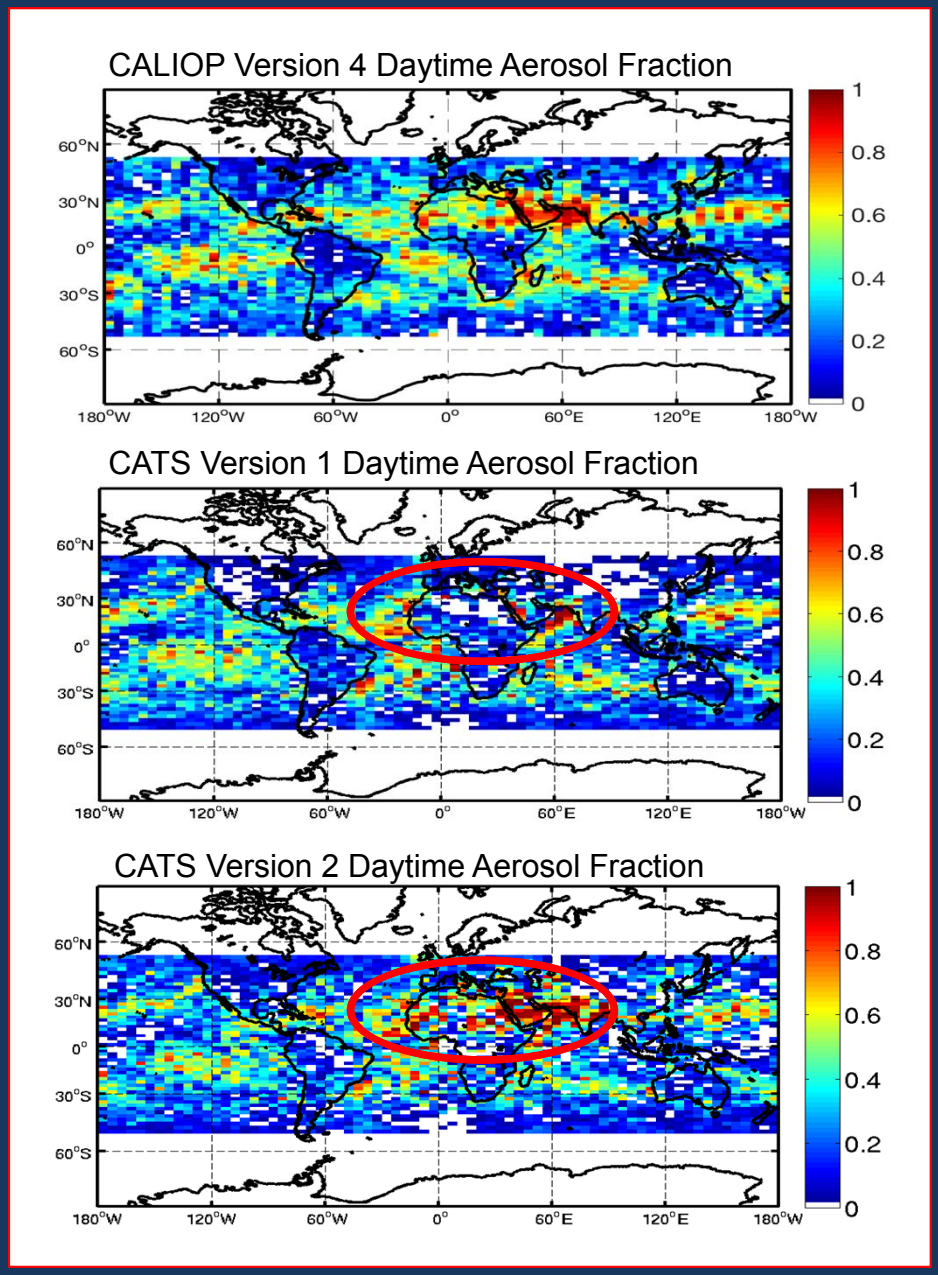
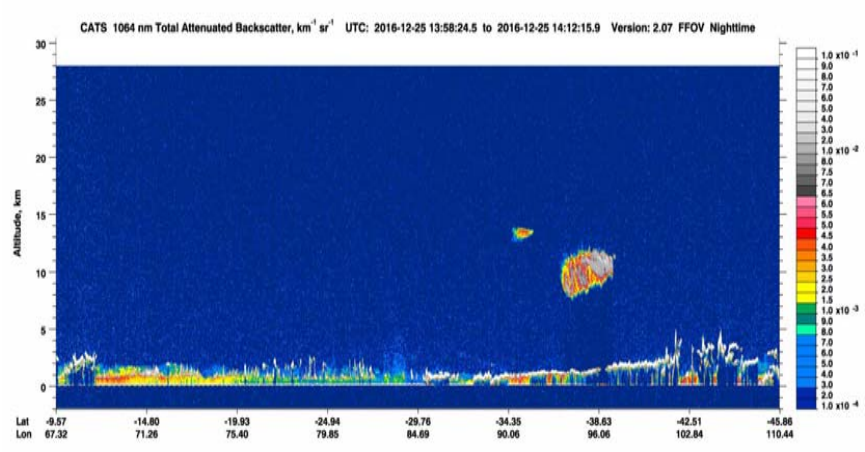
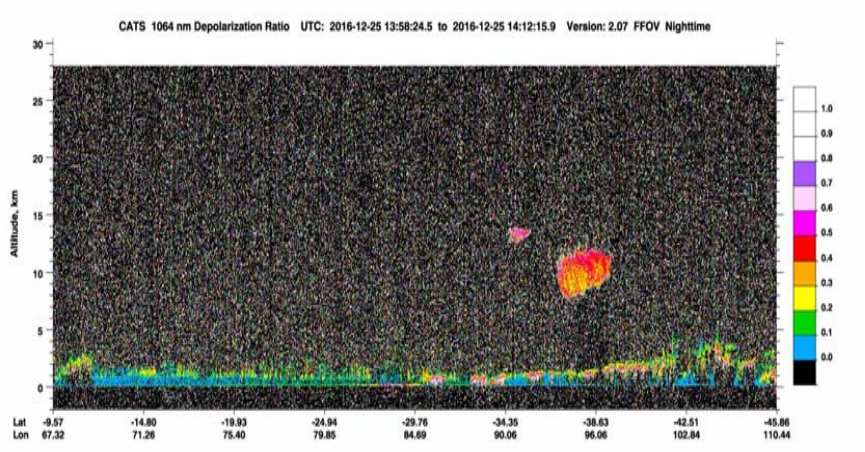
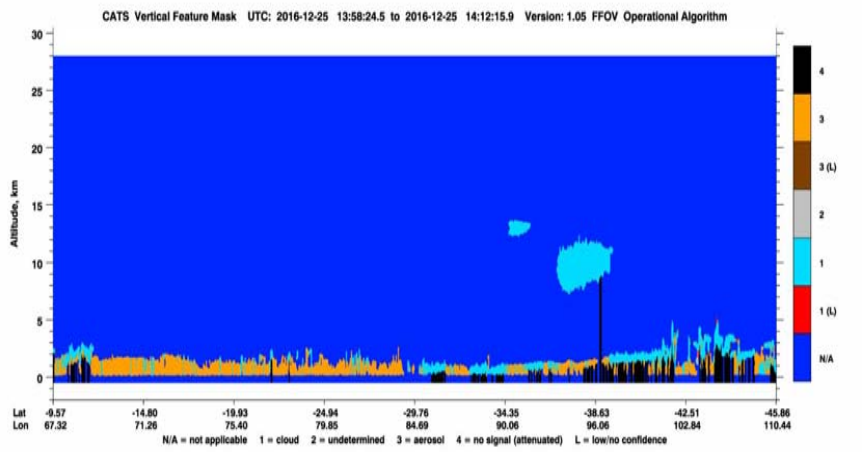
- The new feature detection algorithm significantly increases daytime aerosol detection frequency

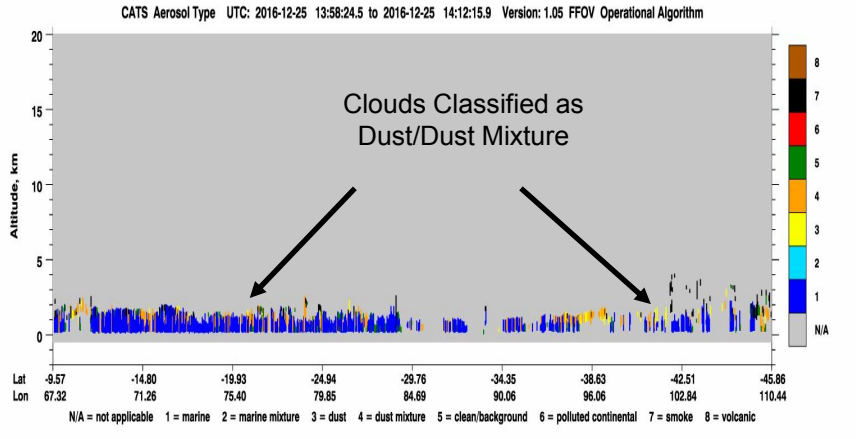


Updated Cloud - Aerosol Discrimination



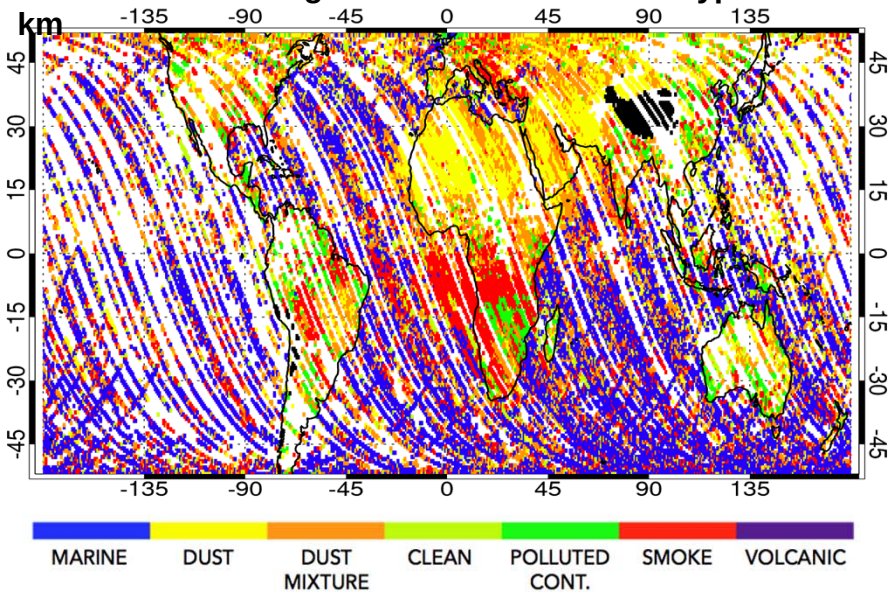




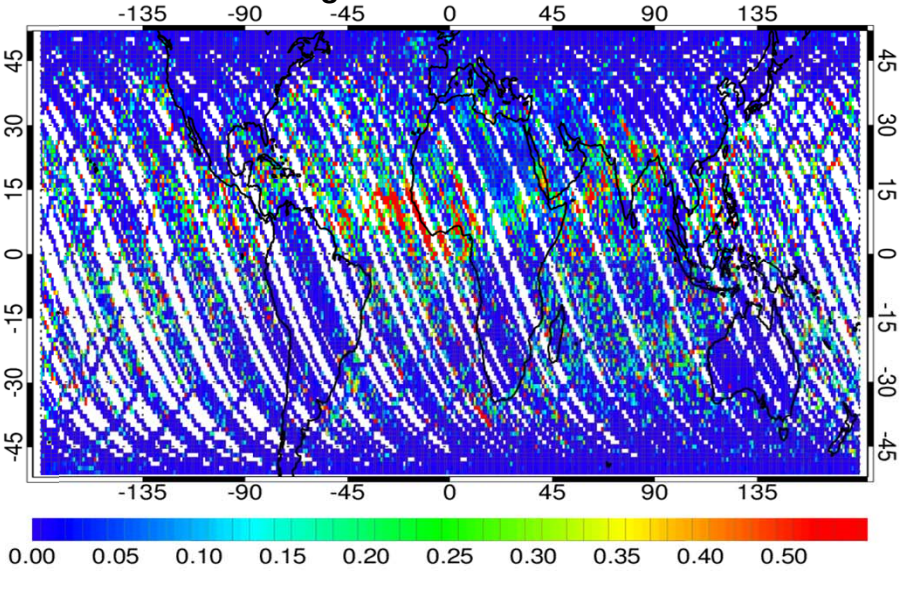


Updated Cloud - Aerosol Discrimination

CATS Version 1 August 2015 Mode Aerosol Type 1 – 2 km



CATS Version 1 August 2015 Dust Mixture AOT



Updated Cloud - Aerosol Discrimination

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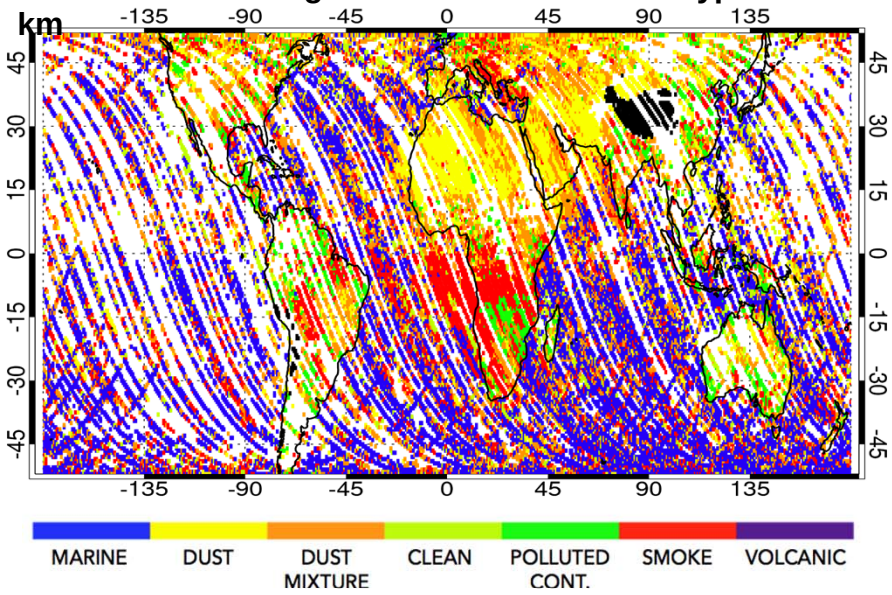

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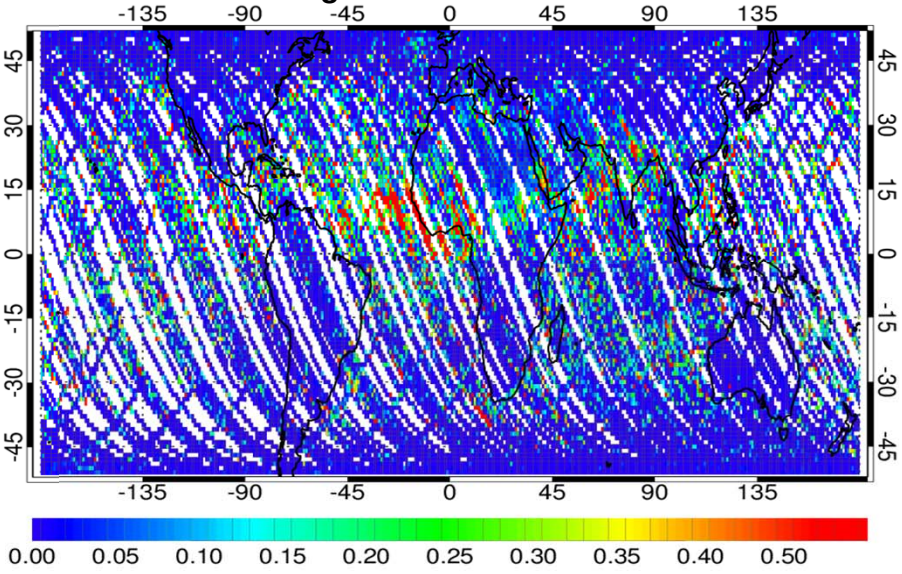
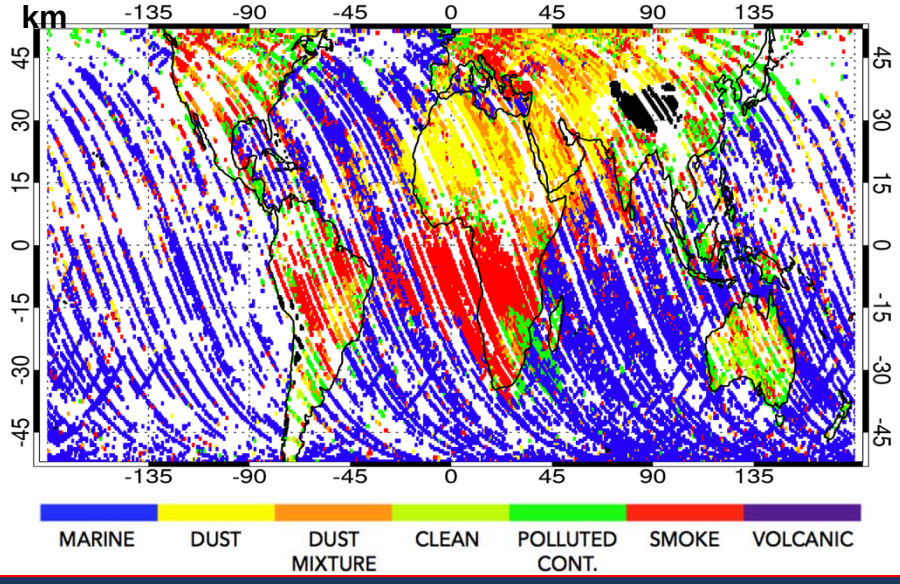


CATS Version 2 August 2015 Mode Aerosol Type 1 – 2 km



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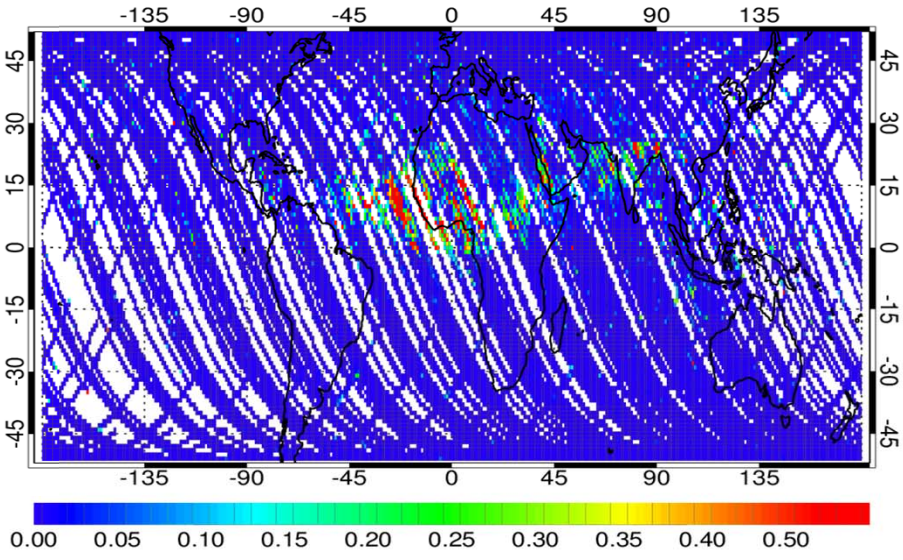


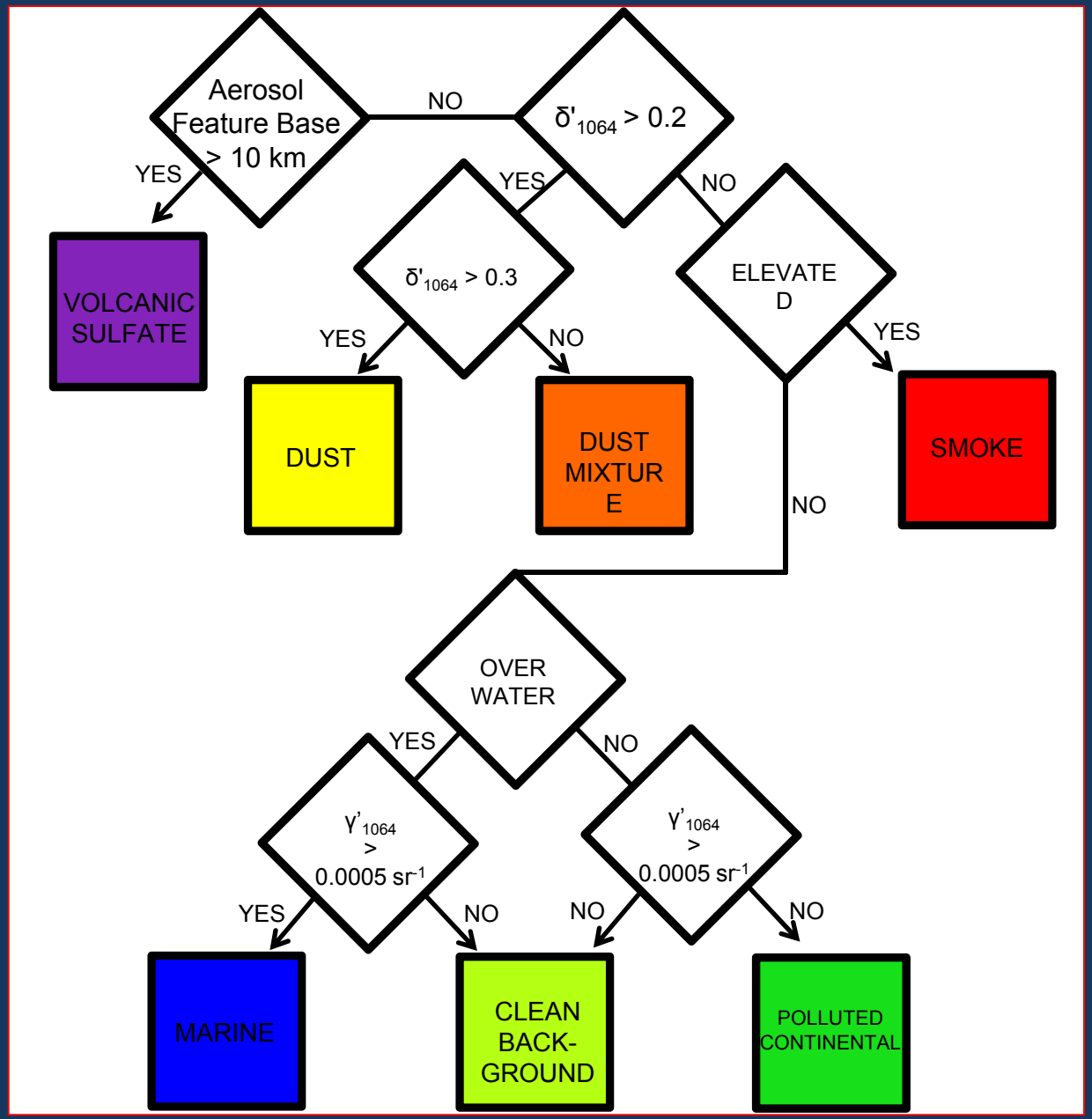
Updated Aerosol Typing Algorithm

CATS Version 1 Mode 2 Aerosol Typing Algorithm

Inputs:

- Feature Integrated Depolarization Ratio at 1064 nm (δ'_{1064}) averaged to 5 km horizontally
- Feature Integrated Total Attenuated Backscatter at 1064 nm (γ'_{1064}) averaged to 5 km horizontally
- Surface Type (for maritime)
- Feature Altitude

* Heritage from CALIOP aerosol typing algorithm



Updated Aerosol Typing Algorithm

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- GEOS-5 Simulated Aerosol

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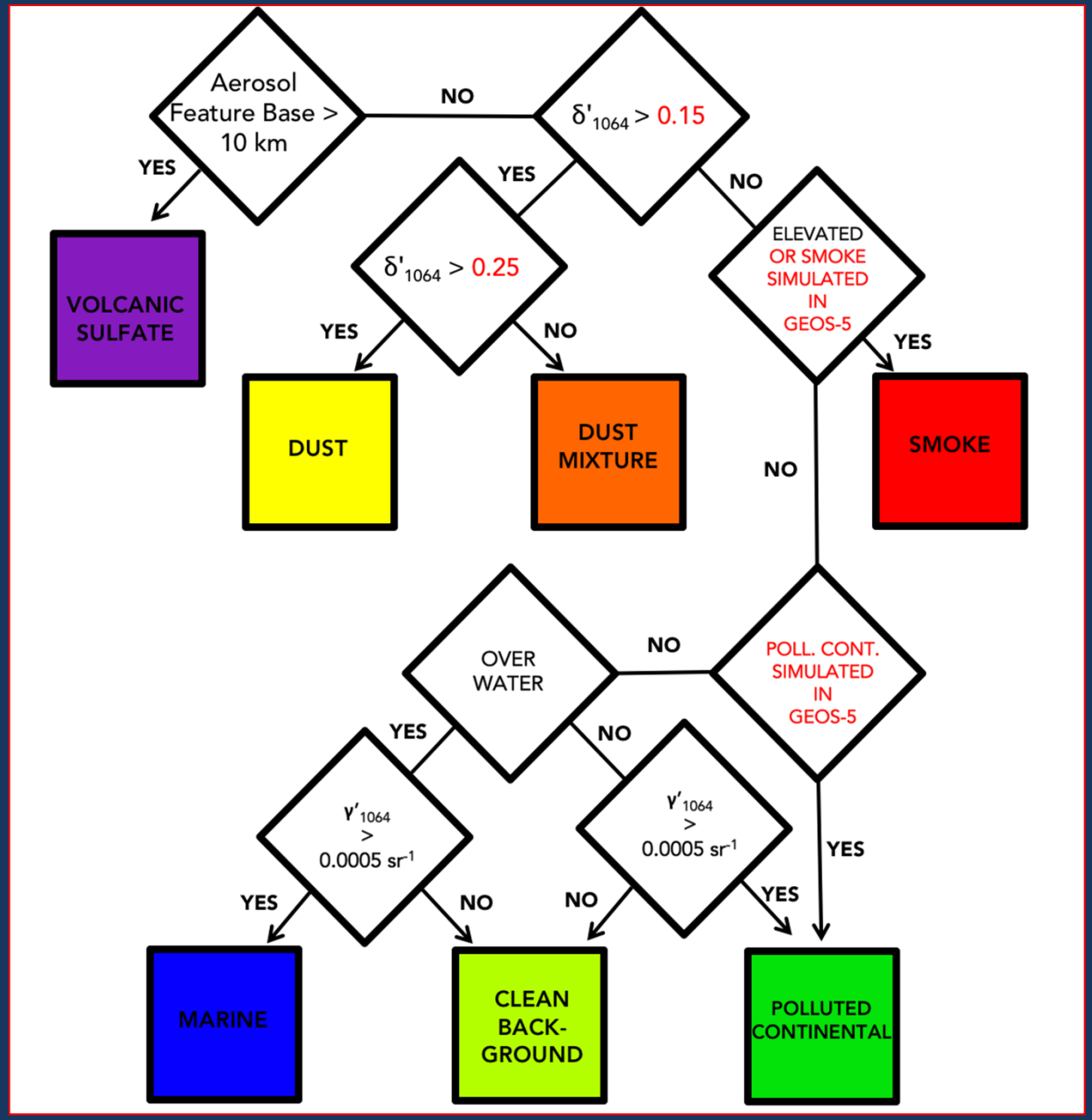

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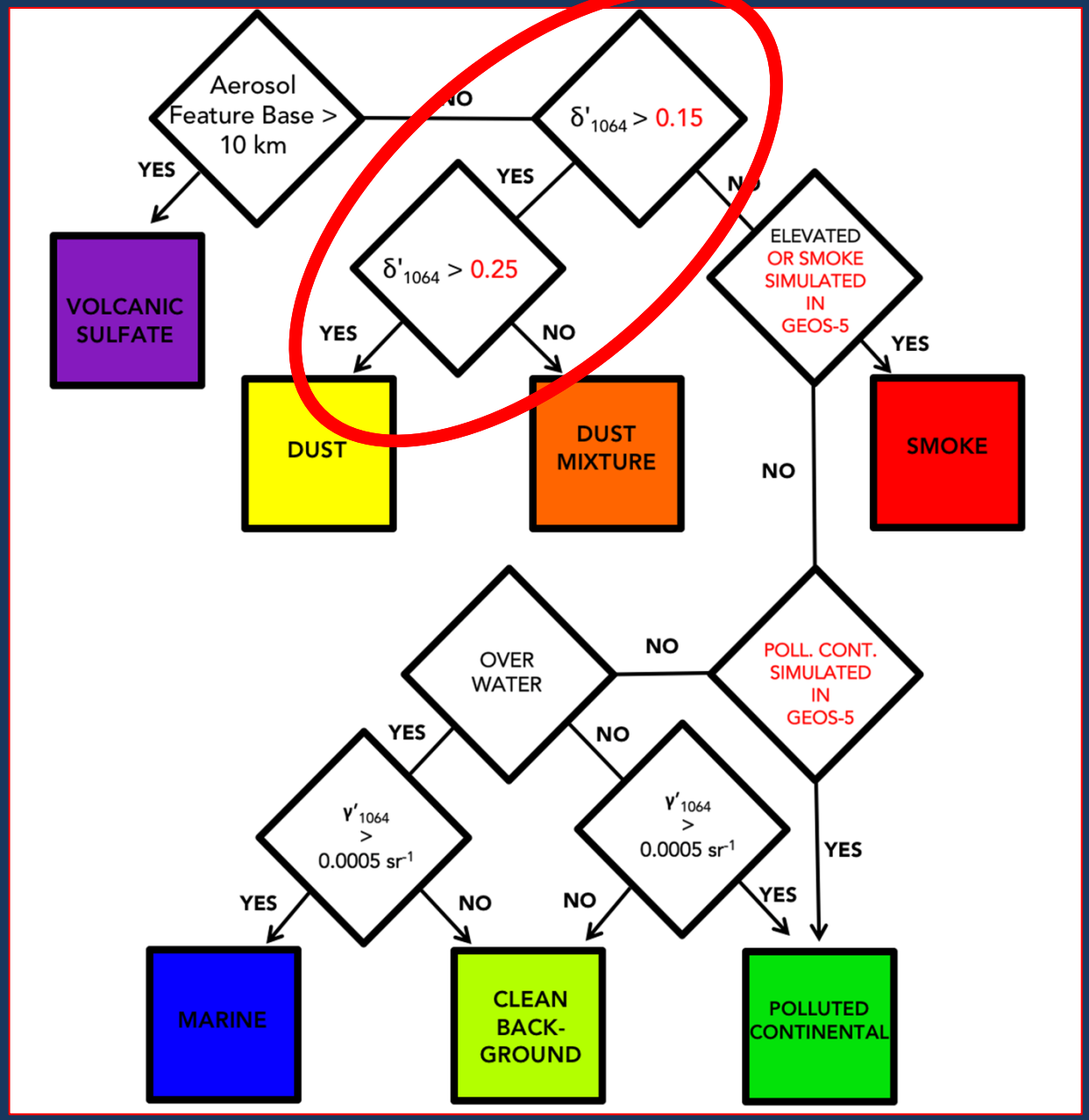
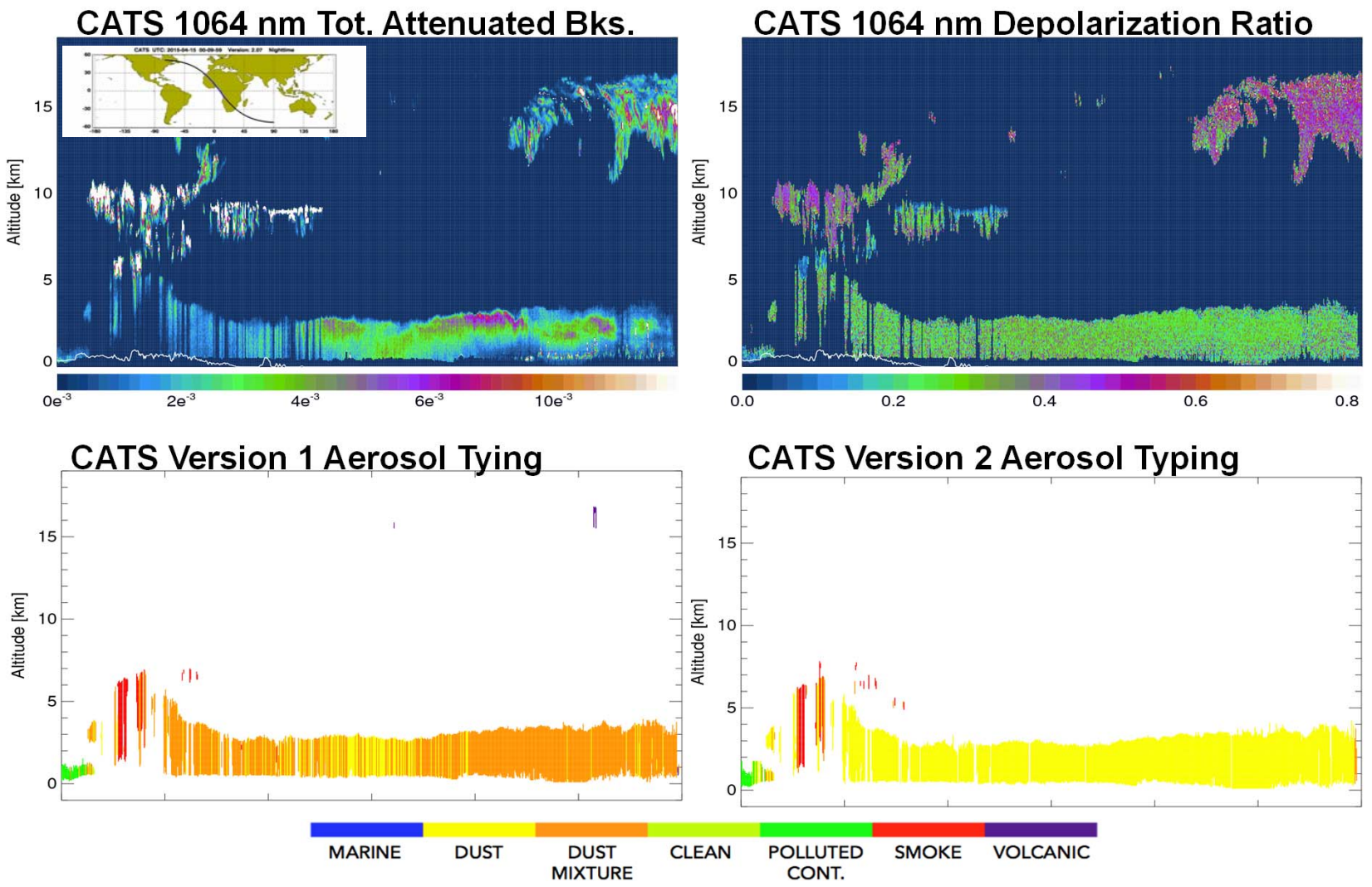


Updated Aerosol Typing: Dust Thresholds & Striping



- Reduction in dust & dust mixture depolarization ratio thresholds based on aerosol type comparisons with CALIPSO over south Asia
- Incorporation of a horizontal persistence test to reduce type “striping” in aerosol layers

Updated Aerosol Typing Algorithm

CATS Version 2 Mode 2 Aerosol Typing Algorithm

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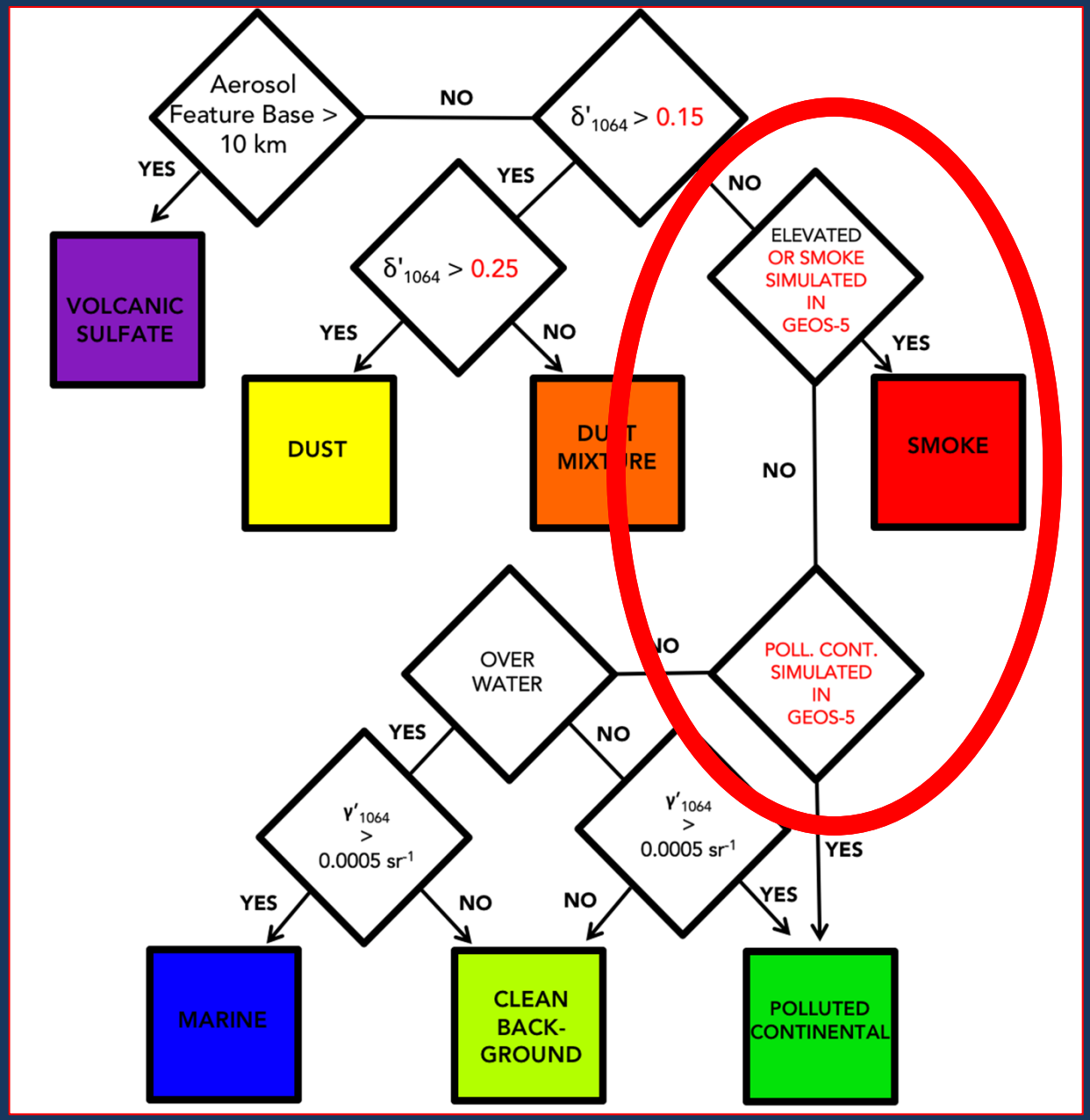
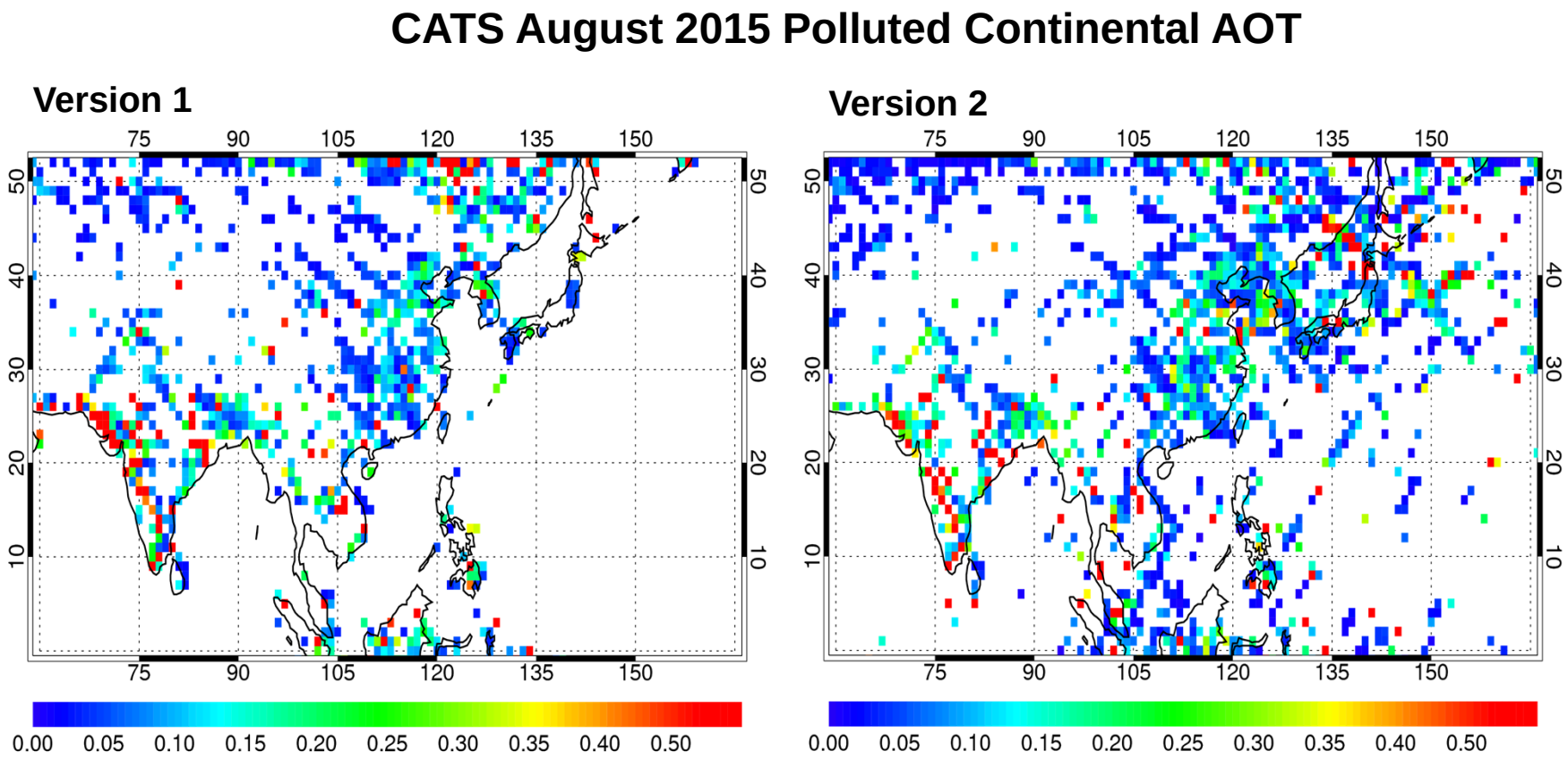


Updated Aerosol Typing: Incorporation of GEOS-5



- Utilization of GEOS-5 simulated aerosols to help identify polluted continental vs. smoke aerosol layers to permit polluted continental classification over water

NRT Applications:
Field Campaign Support:

April – May, 2016

KORUS-AQ

June 2016 - Present

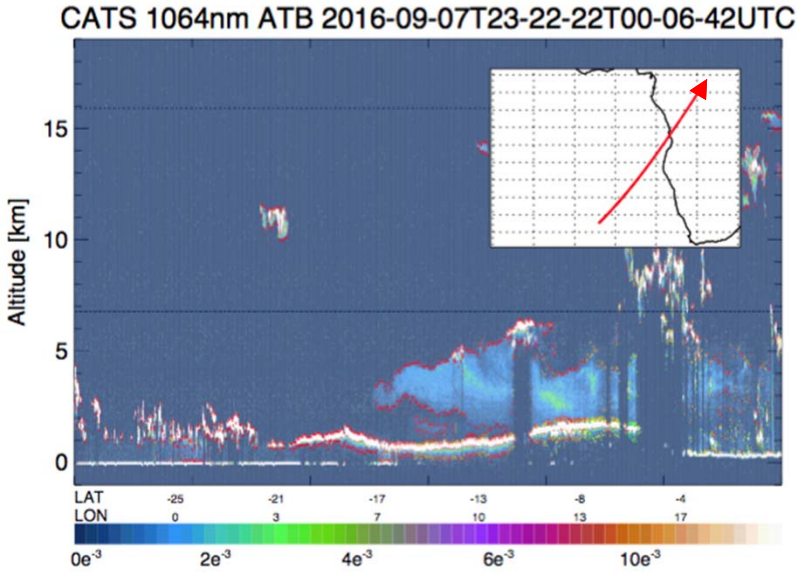
DACCIWA

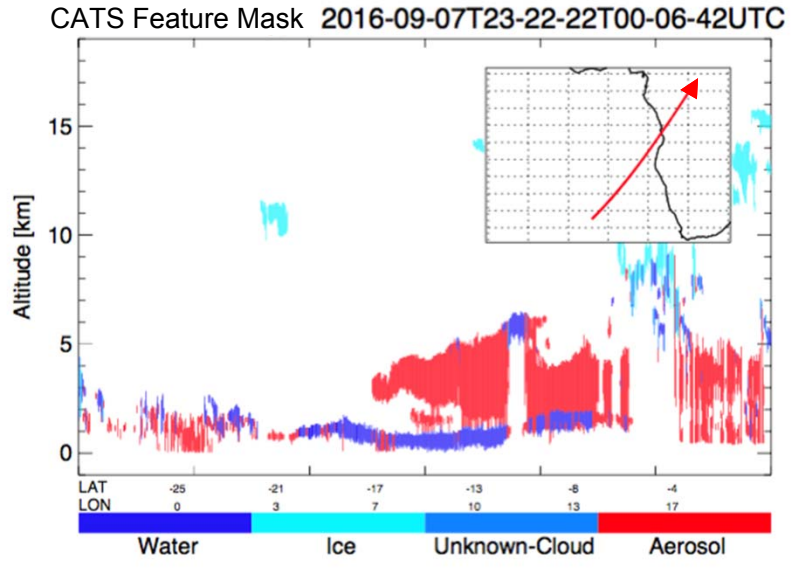
August - October 2016

ORACLES
NASA
EVS-2
P-3
ER-2
WALVIS BAY, NAMIBIA

Also several ground based field experiments

NRT data available within 6 hours of data acquisition





Summary: Part 1

- CATS continues to operate on the ISS, providing high quality observations of attenuated total backscatter and depolarization ratio at 1064 nm.
- CATS NRT data provides a unique opportunity for several applications:
  - Air quality warnings
  - Injection heights for hazardous event forecasting (e.g. volcanoes)
  - Assimilation into operational aerosol transport models

Future Plans:

- Summer 2017 (currently reprocessing):
  - Release an improved version of L1B data (better geolocation and digital elevation map)
  - Release version 2 L2 data:
    - Improved feature detection during daytime
    - Refined cloud – aerosol discrimination
    - Updated aerosol typing
    - Repeat for Mode 1

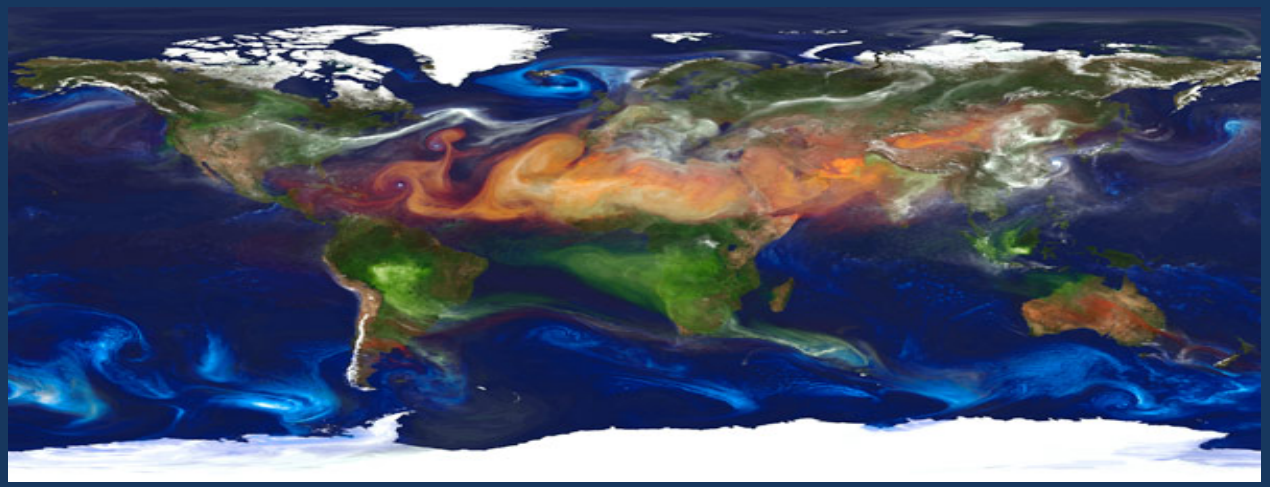
For more information, field campaign support, or help acquiring data, contact:
Ed Nowottnick – edward.p.nowottnick@nasa.gov
John Yorks – john.e.yorks@nasa.gov

Assimilating CATS Observations into GEOS-5

The NASA Goddard Earth Observing System (GEOS – 5) Model

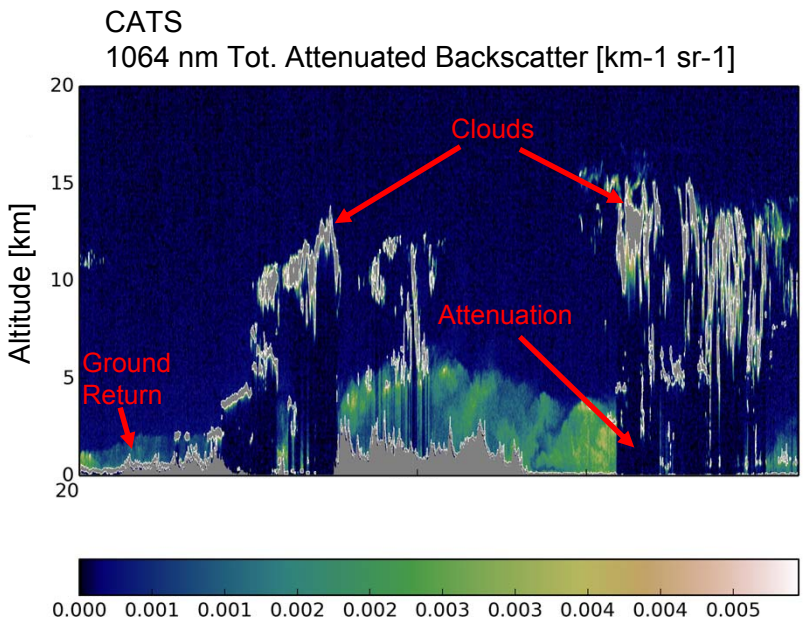
Outputs research forecasts 4x per day (0z, 6z, 12z, 18z):

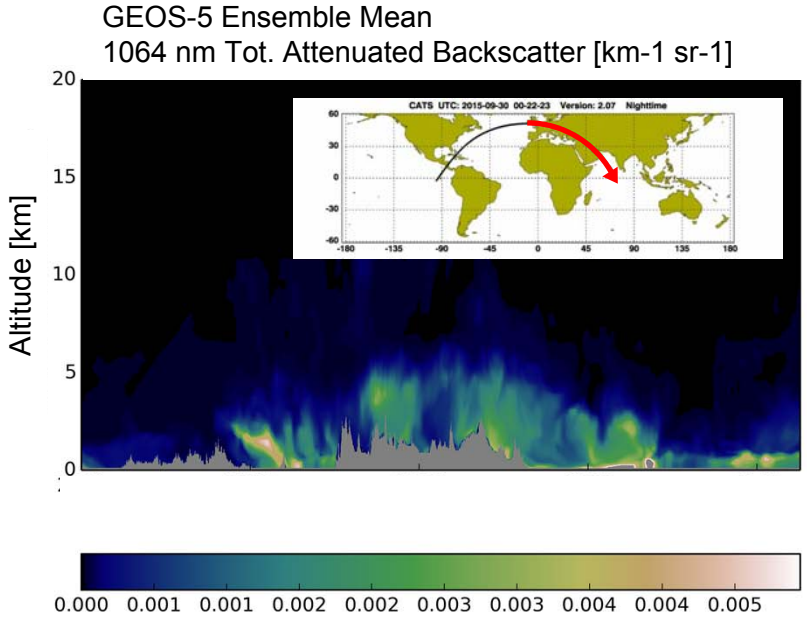
- Ensemble Mean:
  - ~12.5 km horizontal resolution, output at 25 km
  - 72 hybrid-sigma levels in the vertical
- Ensemble Members:
  - 32 members
  - ~50 km horizontal resolution
  - 72 hybrid-sigma levels in the vertical
- Aerosols:
  - Goddard Chemistry, Aerosol, Radiation, and Transport (GOCART) model
  - Dust, Seasalt, Sulfate, Black, and Organic Carbon
  - Aerosol optical properties (e.g. total attenuated backscatter, extinction)
- Assimilates meteorology and aerosol optical thickness (2-D)
  - Currently, observations of aerosol vertical profiles are not assimilated into GEOS-5



Utilizing GEOS-5 ensembles, we are developing a 1-D ensemble approach to assimilate CATS observations of total attenuated backscatter into GEOS-5

1 – D Ensemble Approach:





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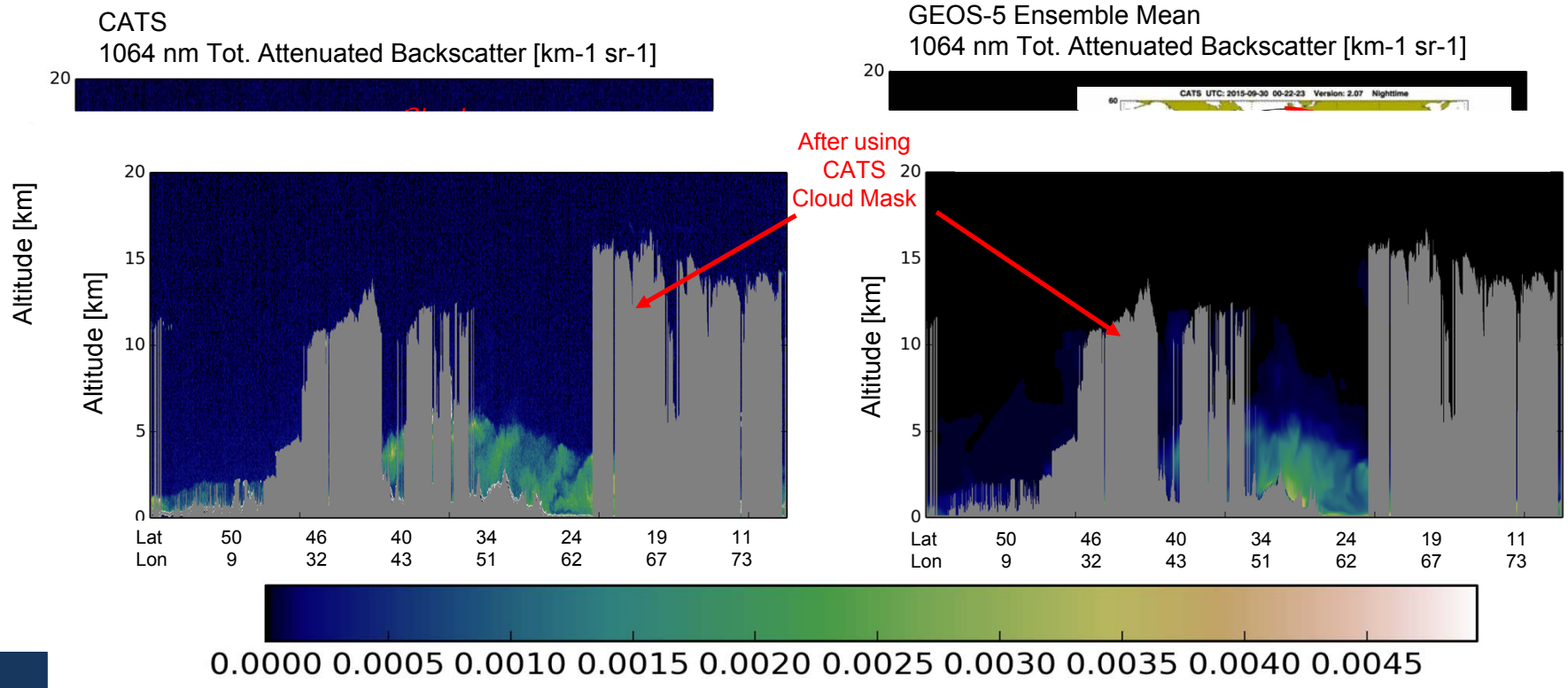

1 – D Ensemble Approach:

$$x_{analysis} = x_{background} + BH^T[HBH^T + R]^{-1} (\gamma_o - Hx_{background})$$

where:

$\mathbf{x}_{background}$ = ensemble mean 1064 nm total attenuated backscatter

$\boldsymbol{\gamma}_o$ = CATS 1064 nm total attenuated backscatter

B = Background error covariance from ensemble perturbations w/vertical localization

R = CATS error covariance

H = Linear operator that regrids GEOS-5 to CATS vertical resolution

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$\boldsymbol{\gamma}_o$ = CATS 1064 nm total attenuated backscatter

B = Background error covariance from ensemble perturbations w/vertical localization

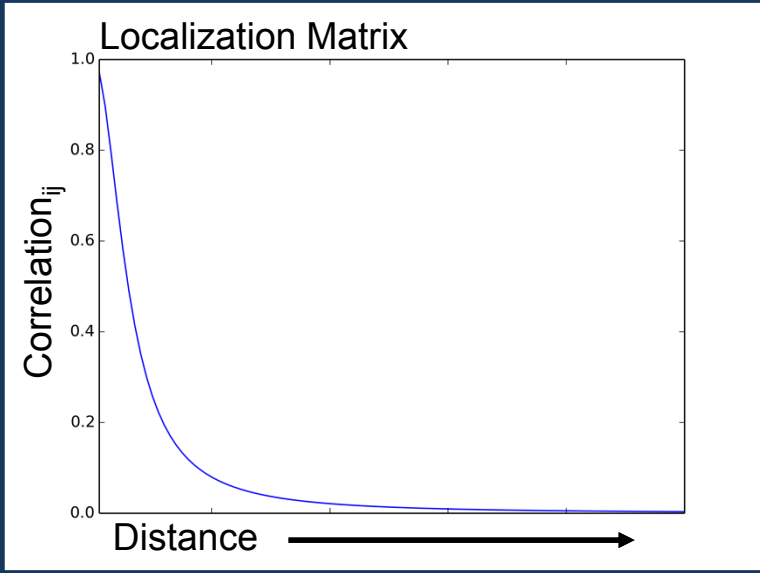
R = CATS error covariance

H = Linear operator that regrids GEOS-5 to CATS vertical resolution

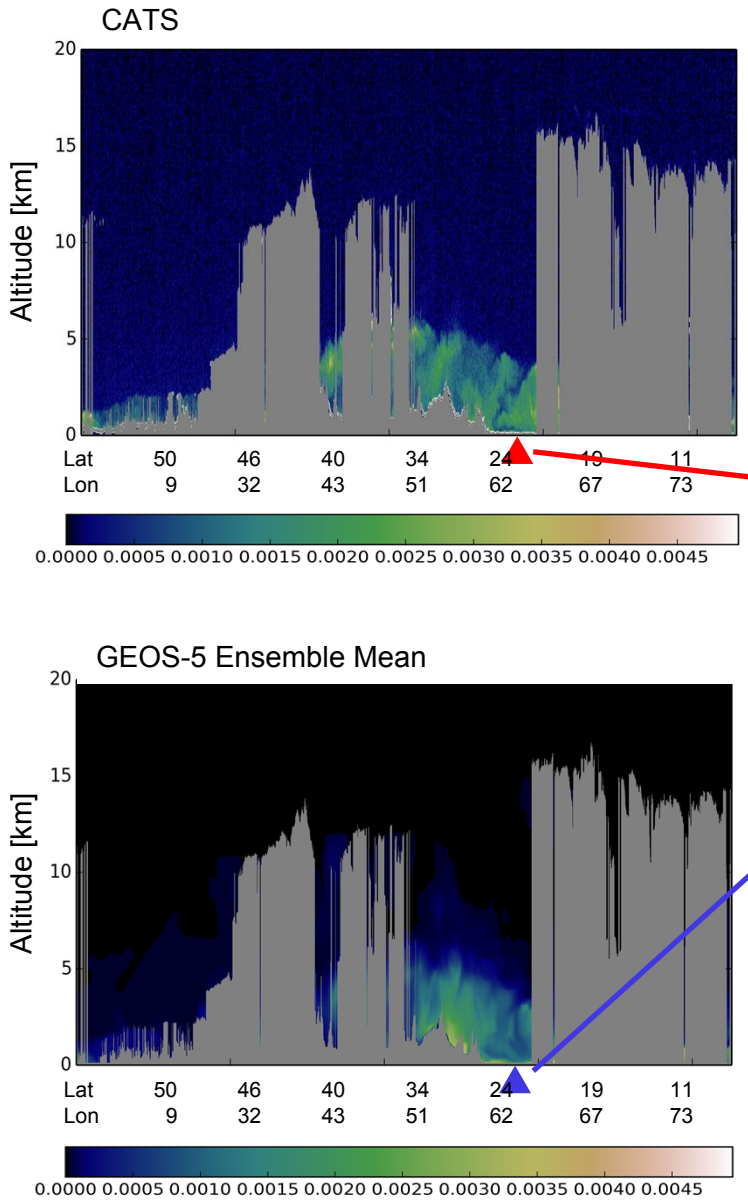
$$B = YY^T \circ C$$

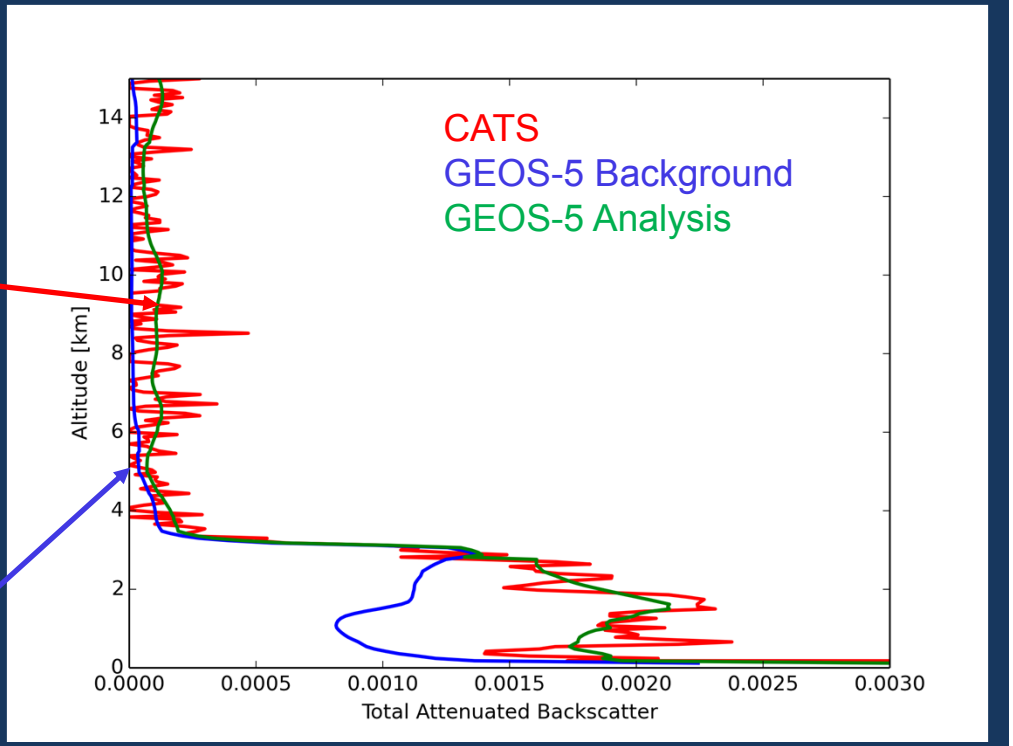
where:

$$Y = [\boldsymbol{\gamma}'(z)_1, \boldsymbol{\gamma}'(z)_2, \ldots, \boldsymbol{\gamma}'(z)_{nens}]$$



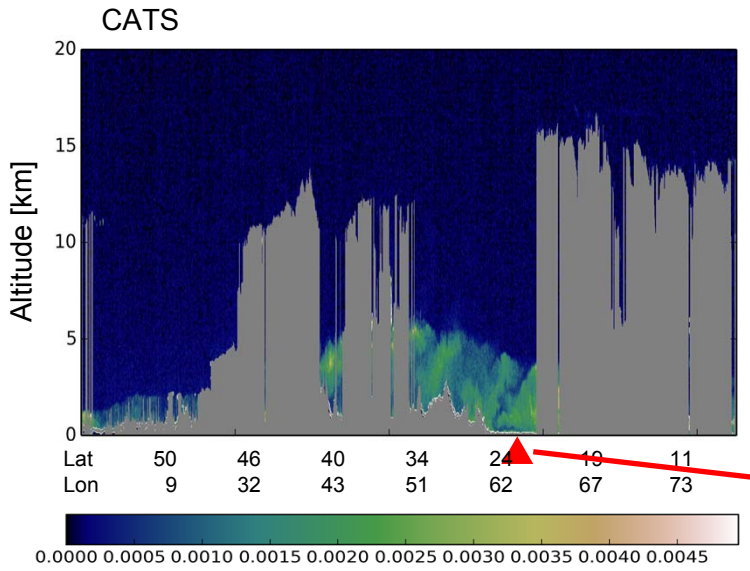
1– D Ensemble Assimilation

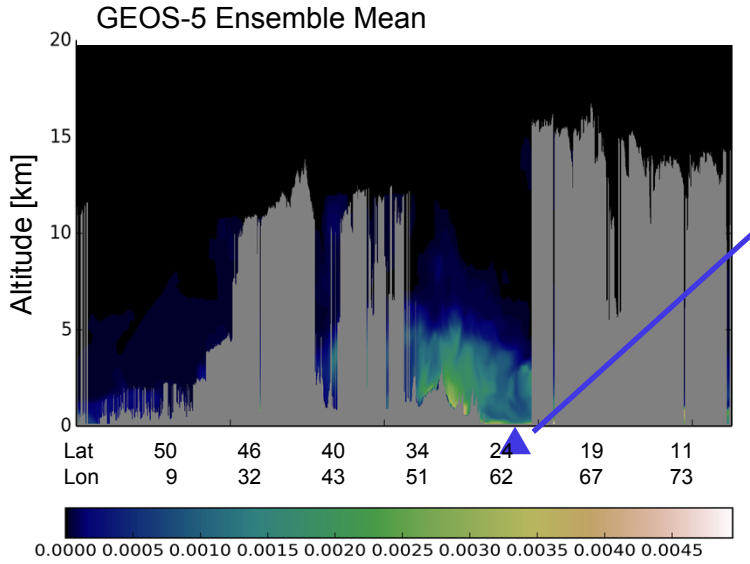


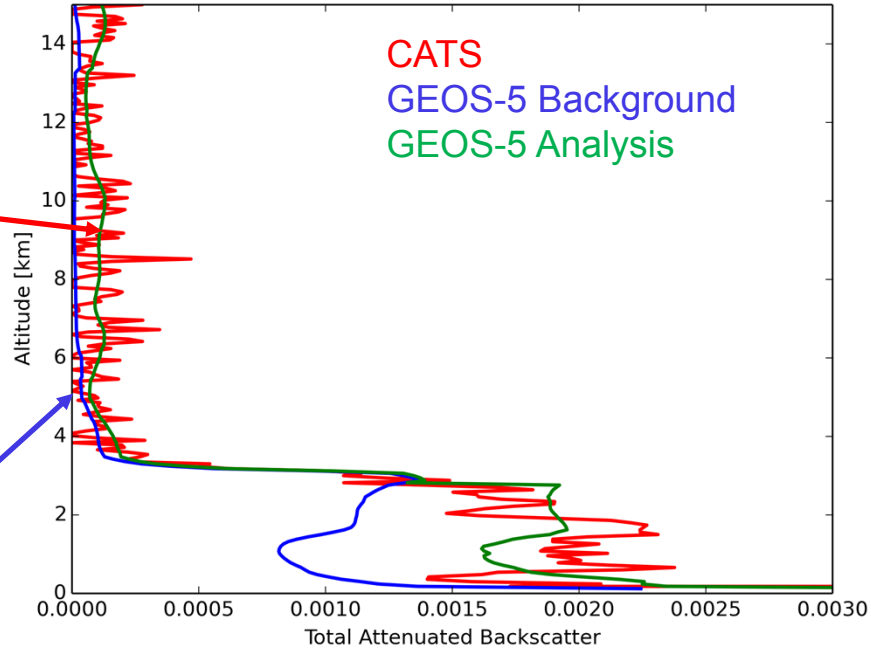


- Here, we perform a 1-D ENS analysis for a single profile, using a uniform vertical length scale of 1 km for vertical localization.
- The analysis draws very closely to the observations, particularly in the planetary boundary layer.

1– D Ensemble Assimilation: Profile with Boundary Layer Localization

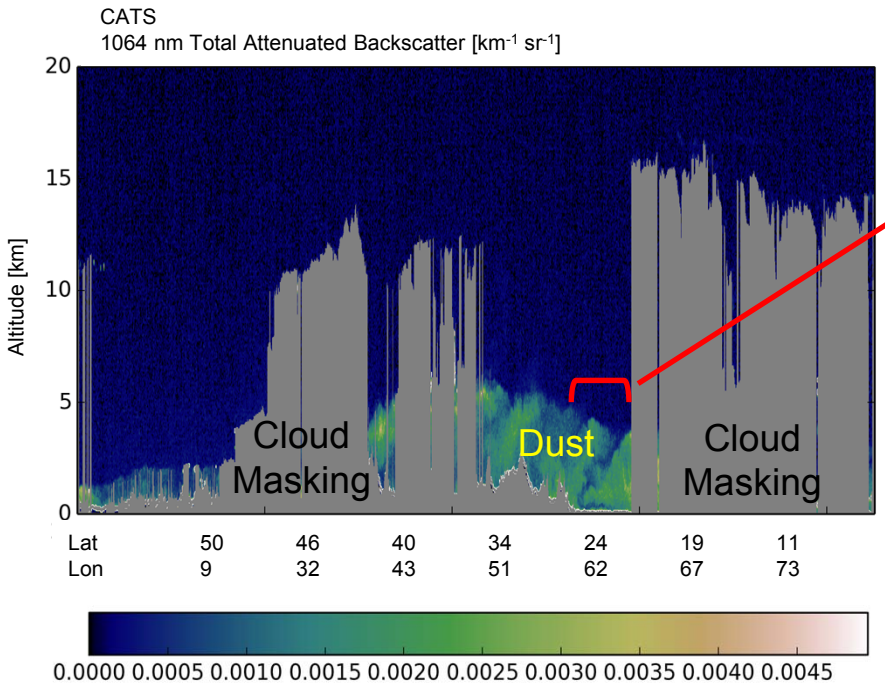




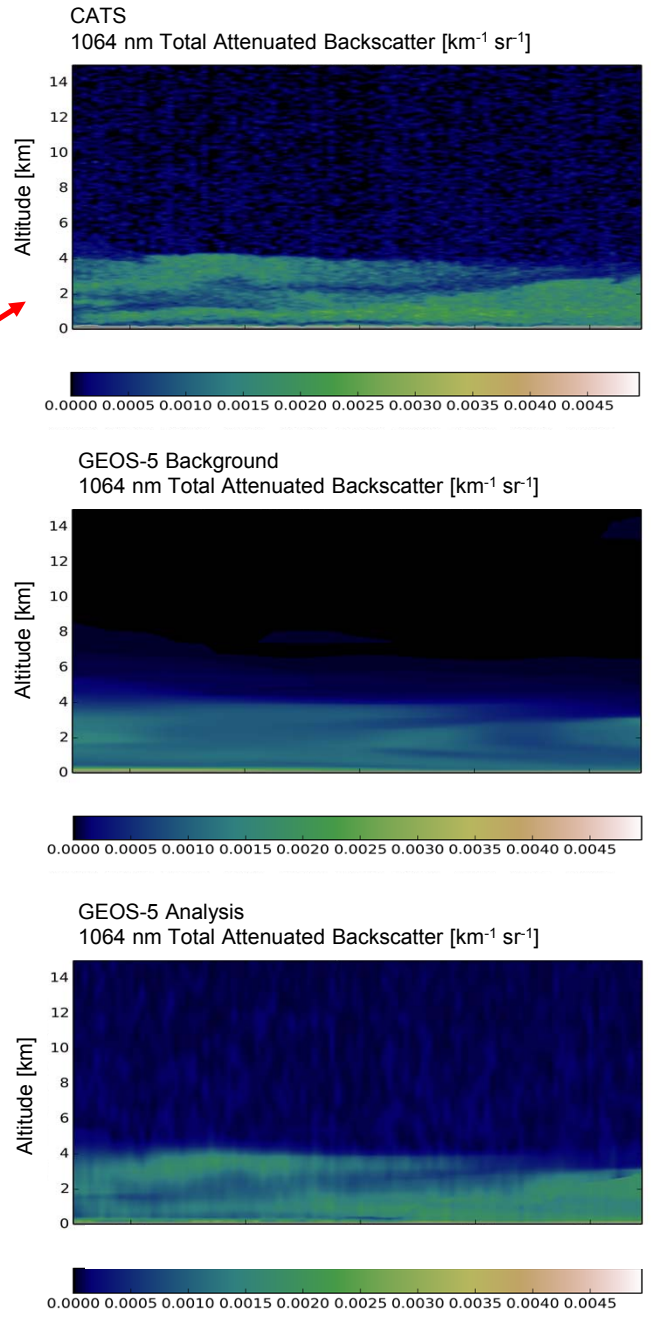


- Next, we explored using different length scales for vertical localization in the planetary boundary layer vs. free troposphere.
- Changing the vertical length scale to 5 km in the PBL:
  - Preserves the transition in γ from the planetary boundary layer to free troposphere, as seen in the background
  - Enhances γ, as seen in observations.

NRT Applications:
1– D Ensemble Assimilation



After performing a series of 1-D ENS assimilations, the detailed structure of the dust layer is enhanced in the GEOS-5 analysis.



1– D Ensemble Assimilation: Considerations for Extinction

Unlike total attenuated backscatter, simulated extinction values are not impacted by attenuation from above and is being considered as our “analysis” variable.

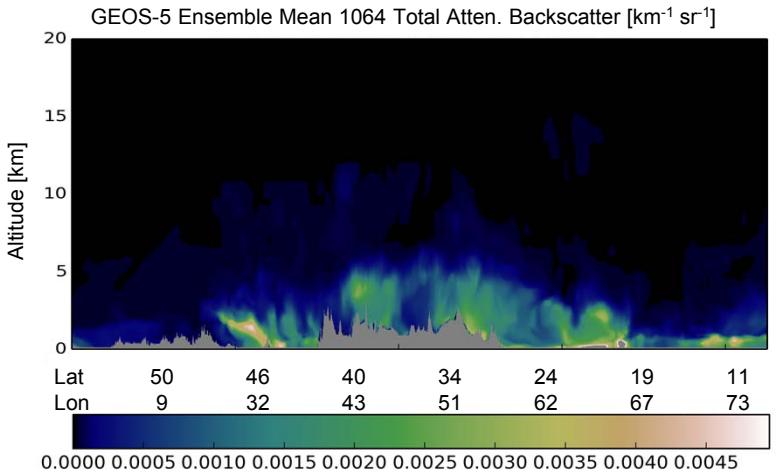
$$x_{analysis} = x_{background} + BH^T[HBH^T + R]^{-1} (\boldsymbol{\gamma}_o - Hx_{background})$$

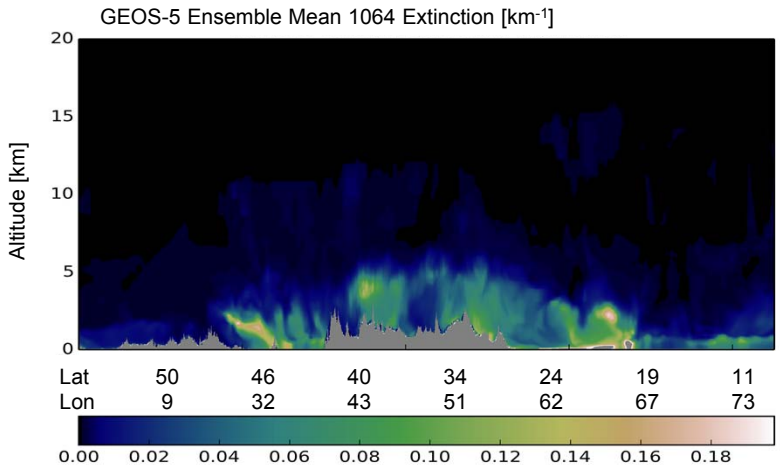
where:

$x_{background}$ = ensemble mean 1064 nm total attenuated backscatter

$\boldsymbol{\gamma}_o$ = CATS 1064 nm total attenuated backscatter

R = CATS error covariance





H = Regrids GEOS-5 to CATS vertical resolution

$B = YY^T \circ C$

where:

Y = Tot. Atten. Bks Perturbations:

$[\boldsymbol{\gamma}'(z)_1, \boldsymbol{\gamma}'(z)_2, \ldots, \boldsymbol{\gamma}'(z)_{nens}]$

H = Regrids GEOS-5 to CATS vertical resolution & linear approximation of $\boldsymbol{\gamma}$ given $\mathbf{x}$

$B = XX^T \circ C$

where:

X = Extinction Perturbations:

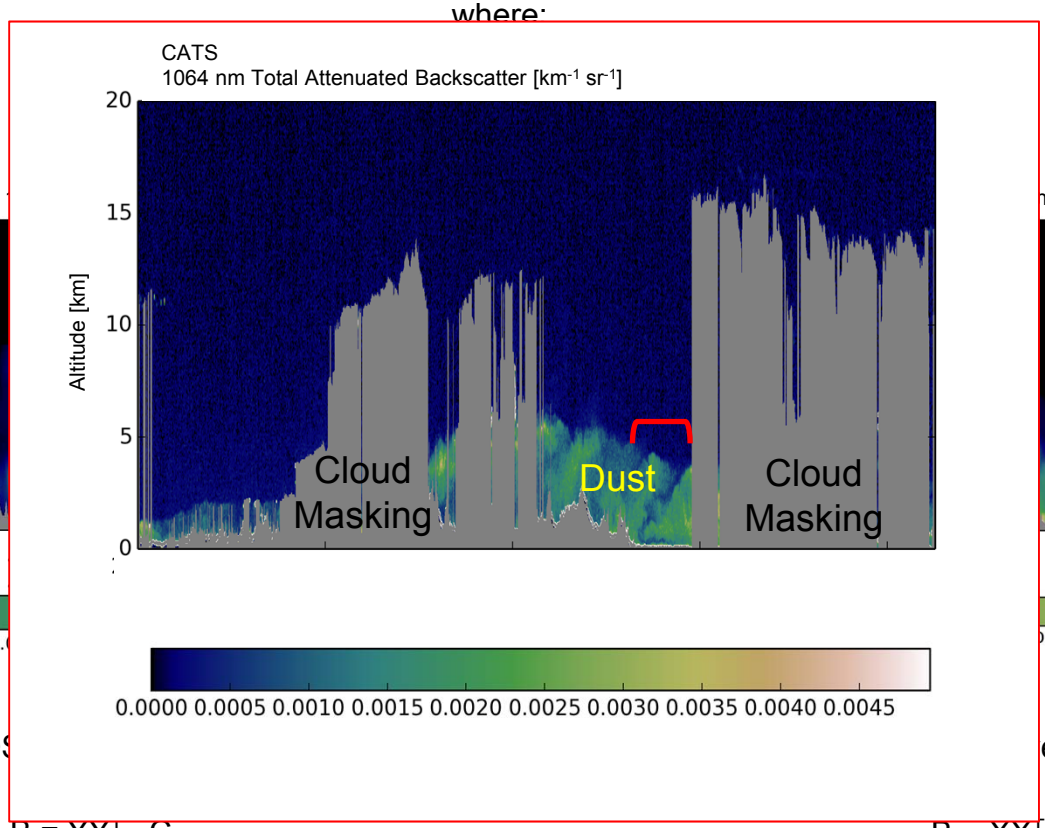
$[x'(z)_1, x'(z)_2, \ldots, x'(z)_{nens}]$

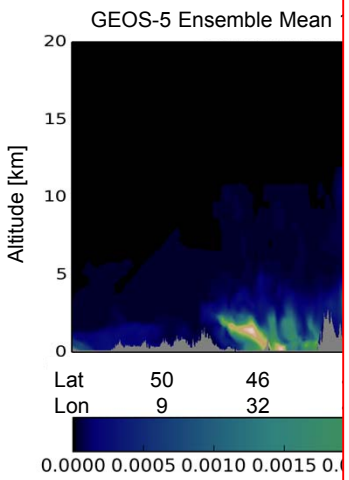
1– D Ensemble Assimilation: Considerations for Extinction

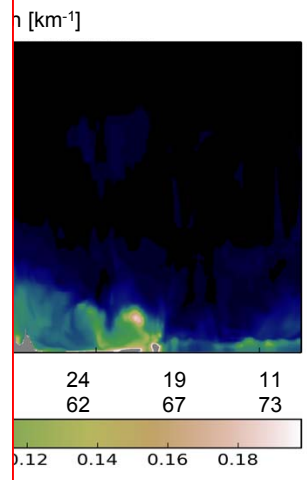
Unlike total attenuated backscatter, simulated extinction values are not impacted by attenuation from above and is being considered as our “analysis” variable.

$$x_{analysis} = x_{background} + BH^T[HBH^T + R]^{-1} (\gamma_o - Hx_{background})$$

where:







H = Regrids GEOS

ertical resolution & linear

γ given **x**

B = $YY^T \circ C$

where:

Y = Tot. Atten. Bks Perturbations:

$[\gamma'(z)_1, \gamma'(z)_2, \ldots, \gamma'(z)_{nens}]$

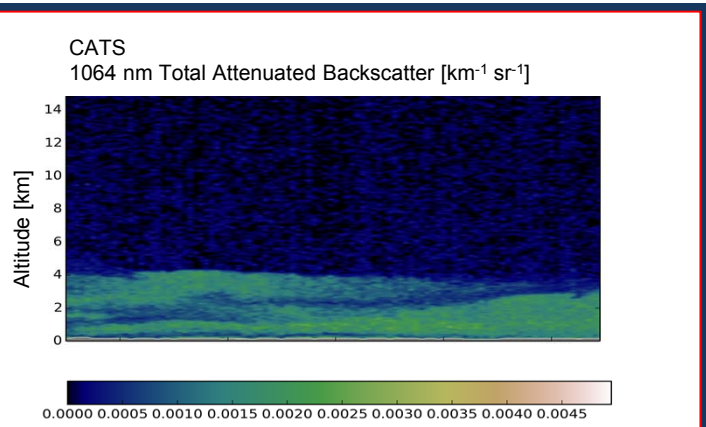
B = $XX^T \circ C$

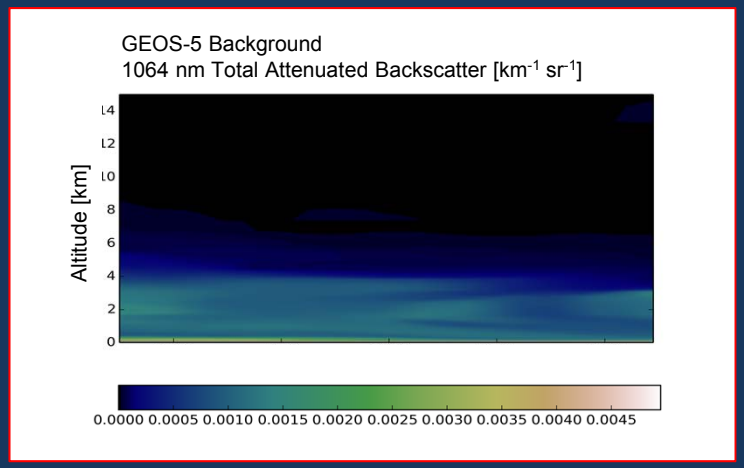
where:

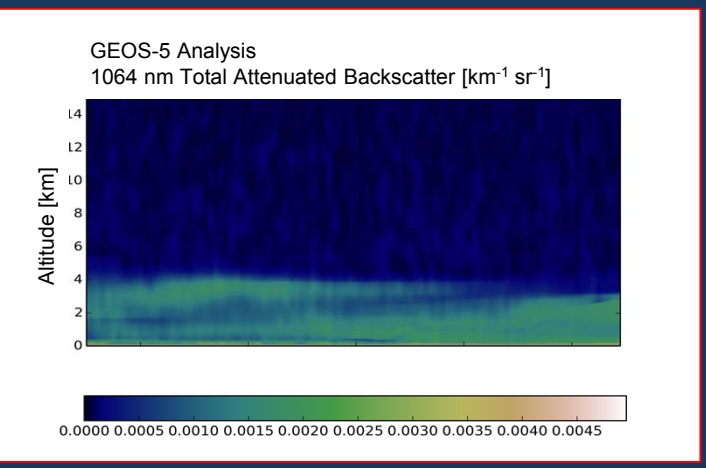
X = Extinction Perturbations:

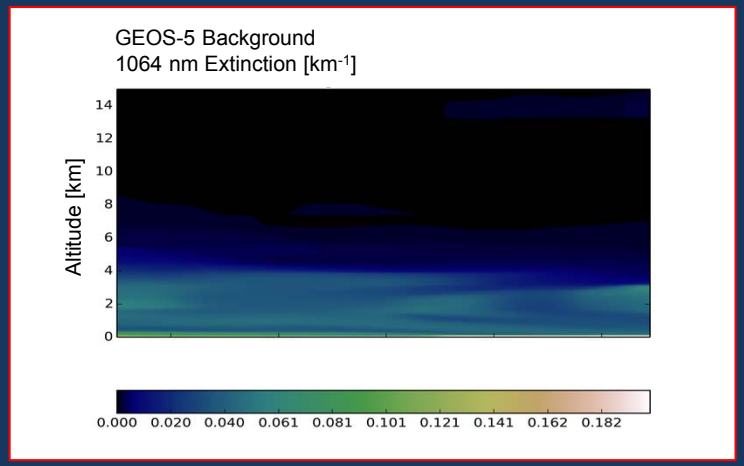
$[x'(z)_1, x'(z)_2, \ldots, x'(z)_{nens}]$

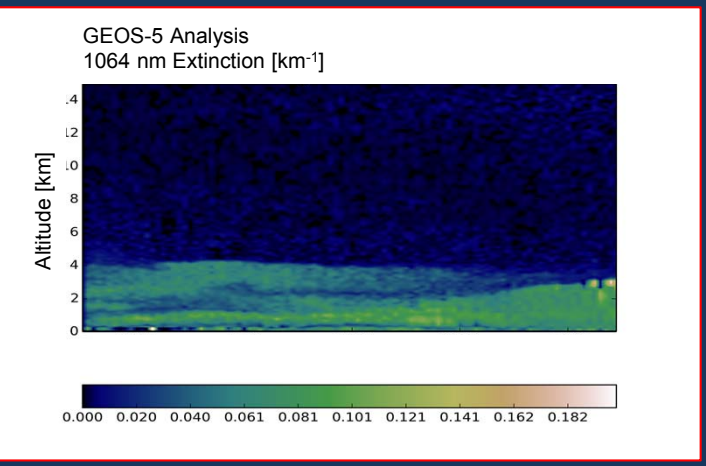
Analysis Performed in Total Attenuated Backscatter vs. Extinction











Summary: Part 2

Using GEOS-5, we are developing a 1– D ENS approach for assimilating CATS near real time observations of total attenuated backscatter at 1064 nm:

- After performing a 1 – ENS assimilation of a cloud – free profile, the GEOS-5 analysis closely followed observed total attenuated backscatter
- Vertical localization length scales were varied for the well – mixed PBL and the free troposphere
- After assimilating a cloud – free segment of a CATS granule, the fine detail of a dust event was obtained in the GEOS-5 analysis for both total attenuated backscatter and extinction

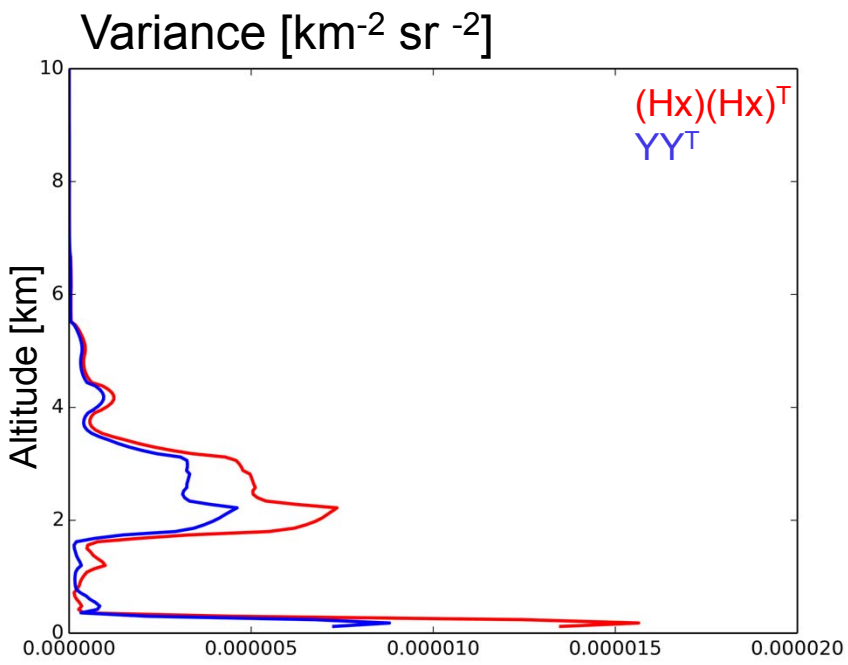
Future Work

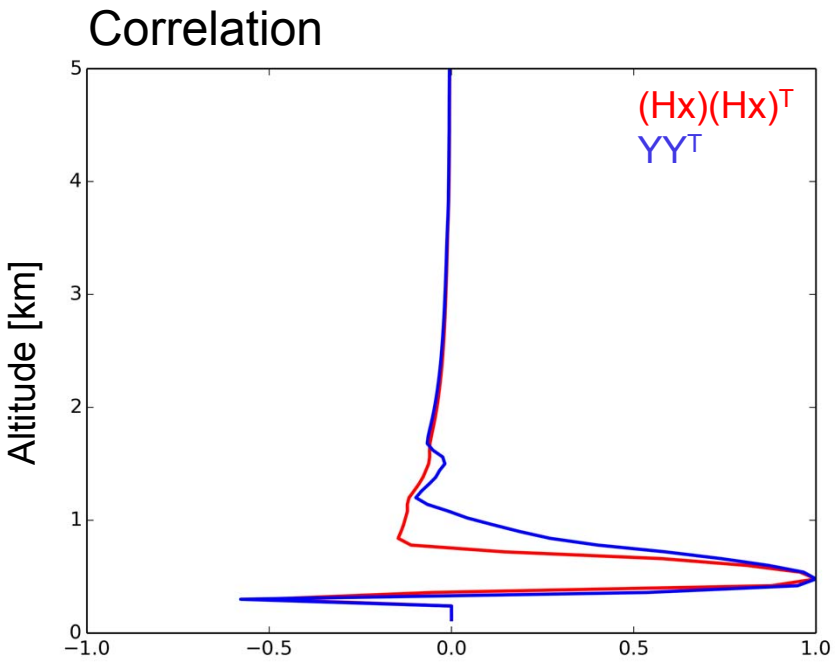
- Explore horizontal localization and test within a cloudy aerosol layer
- Address “noisy” analysis increments in the free troposphere where both CATS and GEOS-5 aerosol loadings are low
- Develop a technique to screen CATS ground return from profiles
- “Dynamic” lidar ratio that will evolve in conjunction with simulated aerosol mixtures

Thanks!

Backups

1– D Ensemble Assimilation: Considerations for Extinction





$YY^T \neq (Hx)(Hx)^T$

1 – D Ensemble Approach:

$$x_{analysis} = x_{background} + BH^T[HBH^T + R]^{-1} (\boldsymbol{\gamma}_o - Hx_{background})$$

where:

$x_{background}$ = ensemble mean 1064 nm total attenuated backscatter

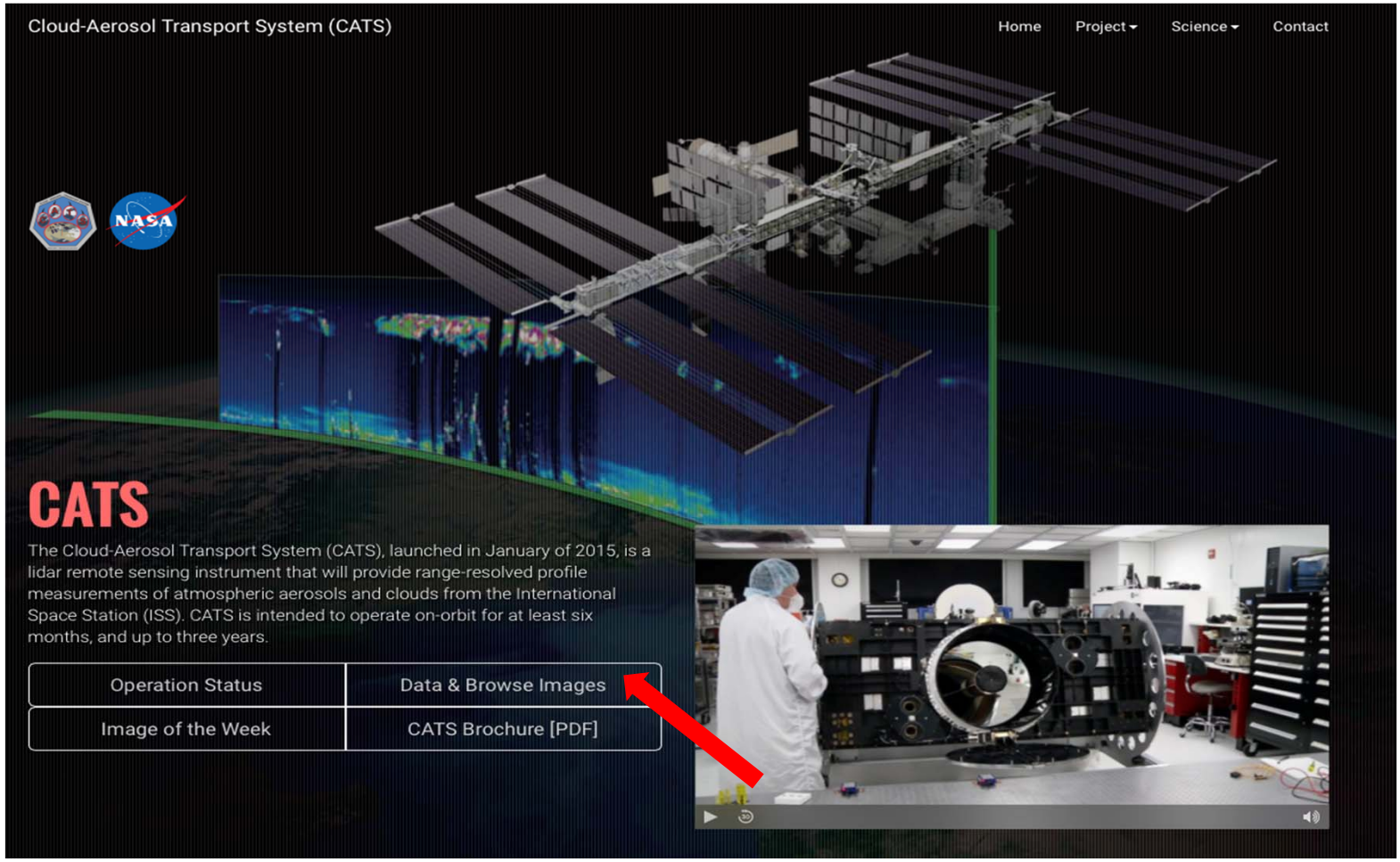
$\boldsymbol{\gamma}_o$ = CATS 1064 nm total attenuated backscatter

B = Background error covariance from ensemble perturbations w/vertical localization

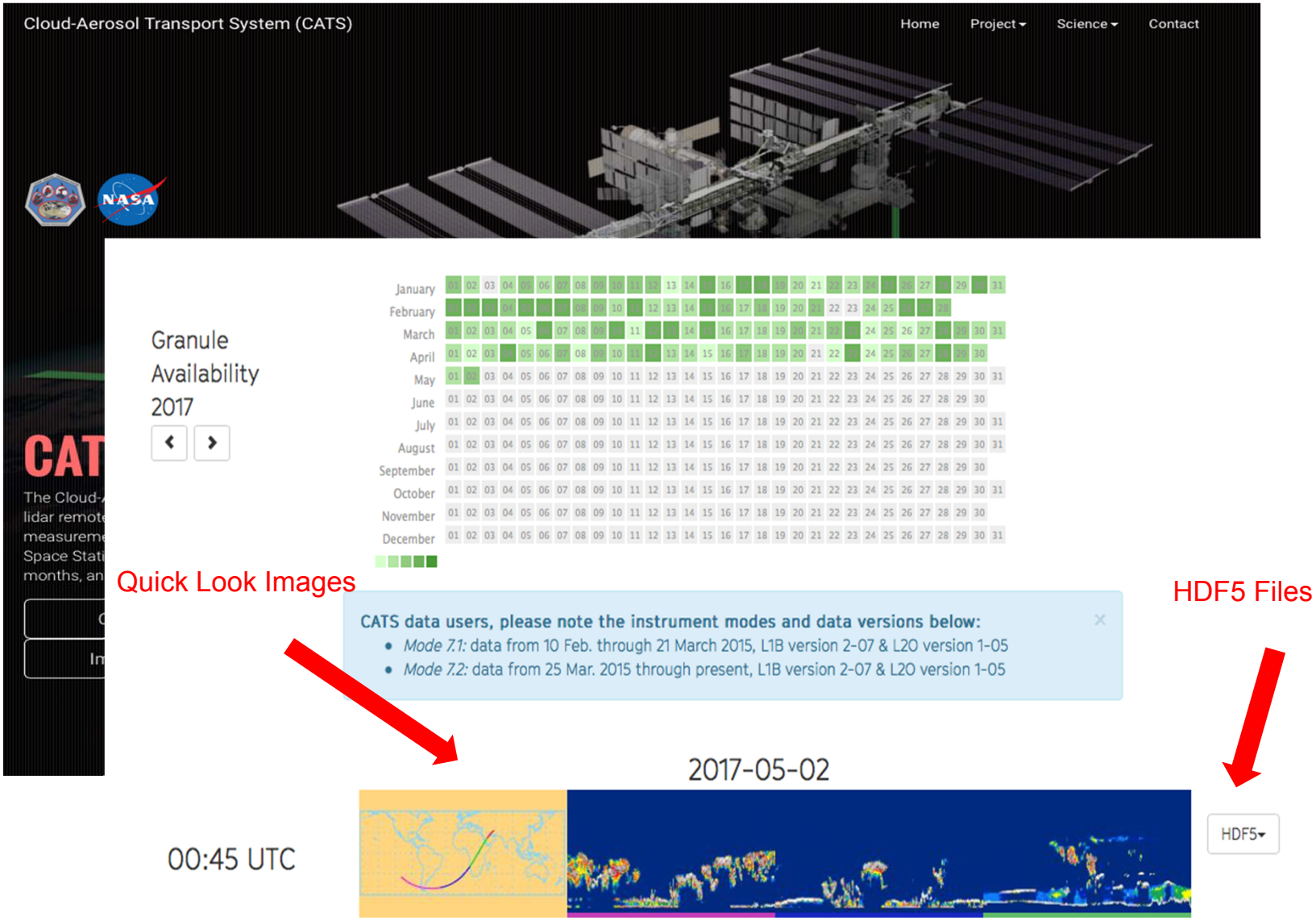
R = CATS error covariance

H = Linear operator that regrids GEOS-5 to CATS vertical resolution

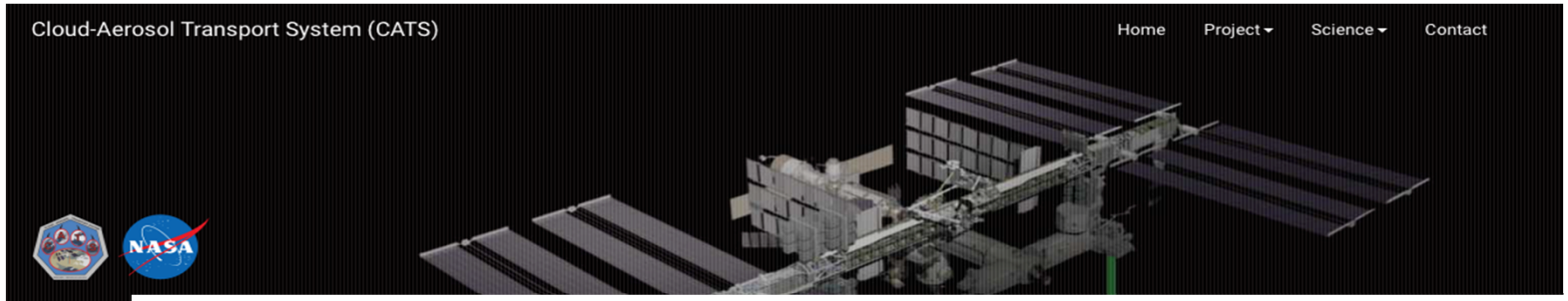
Data Acquisition



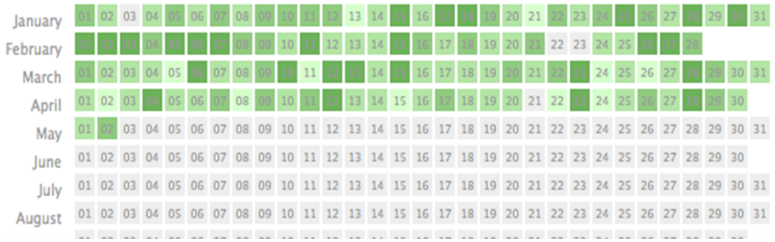
Data Acquisition



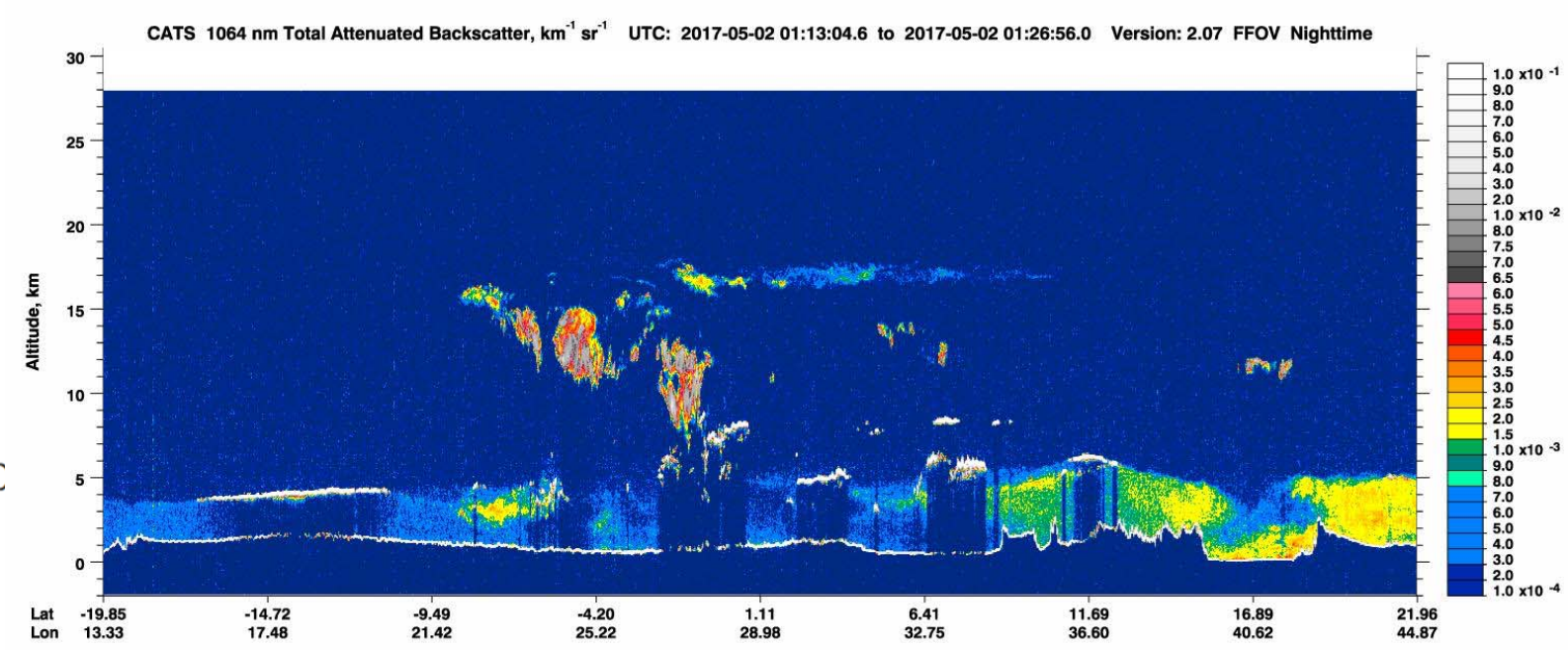
Data Acquisition



Granule Availability 2017



Quick



March 2015 – Present Aerosol Typing [0 – 2 km]