CATS Version 2 Aerosol Feature Detection and Applications for Data Assimilation

CATS NASA GSFC TEAM

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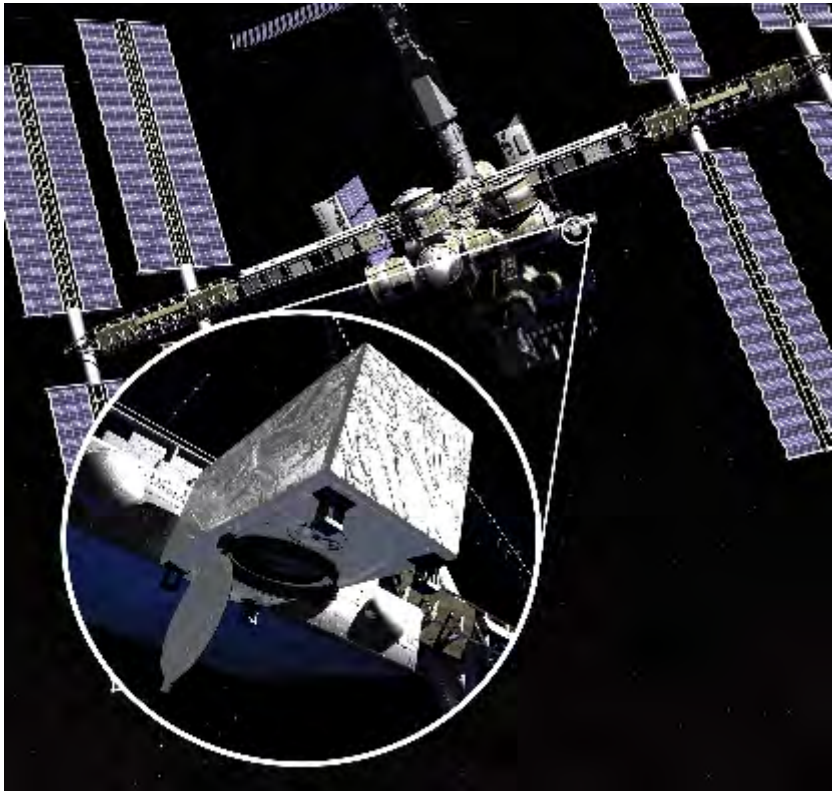
NASA GMAO Collaboration:

Overview

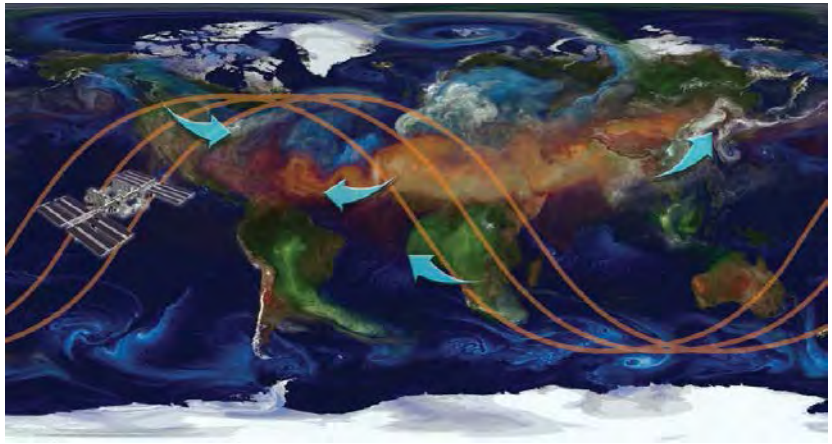
- Part 1:
  - Instrument Status
  - Updates for Upcoming Level 2 Data Release
- Part 2:
  - Assimilating CATS observations in GEOS-5
- Future directions

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

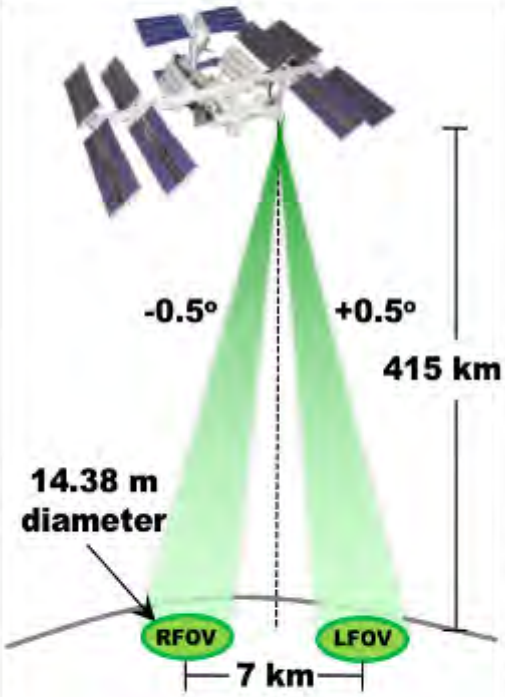
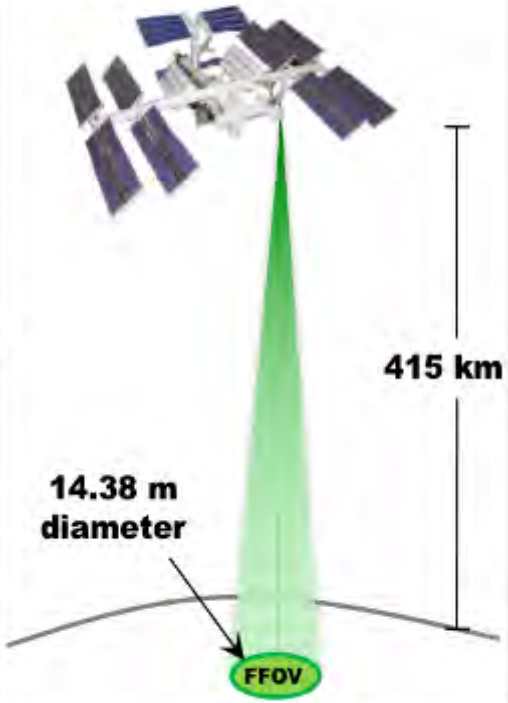
CATS Instrument Status

- 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

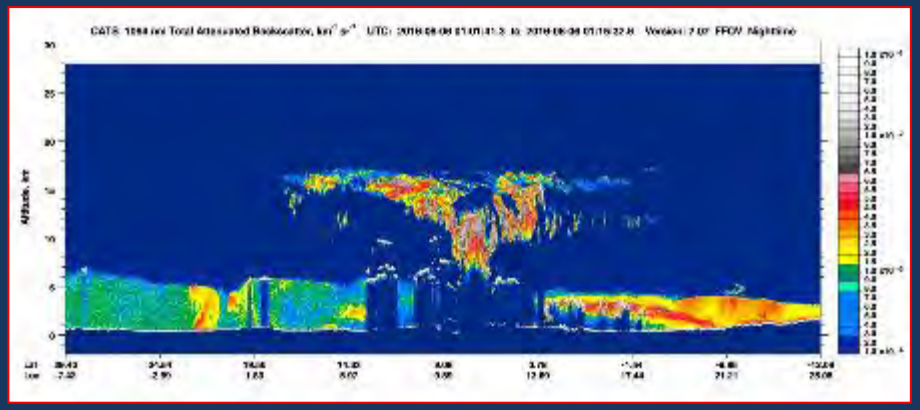
Laser: 177+ billion shots

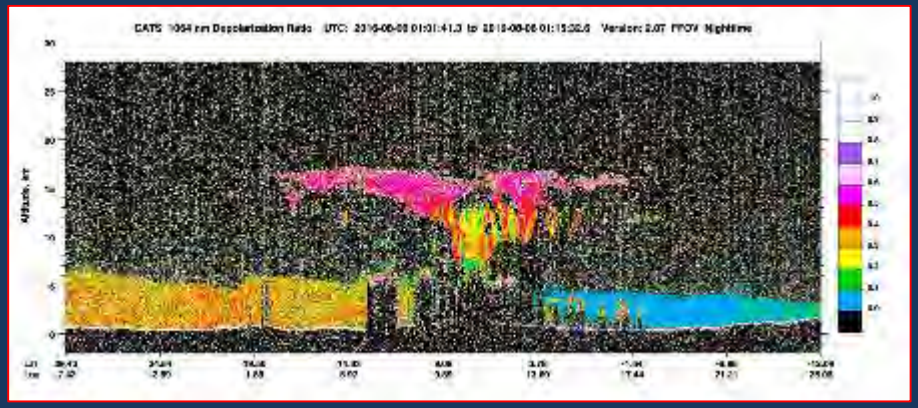
Mode 1: Multi-Beam	Mode 2: Laser 2
Backscatter: 532, 1064 nm Depolarization: 532, 1064 nm L2 Products: 532, 1064 nm	Backscatter: 532, 1064 nm Depolarization: 1064 nm L2 Products: 1064 nm
	
Semi-continuous operation: Feb. 10 – Mar. 21 (2015)	Semi-continuous operation: 25 Mar. 2015 – Present

CATS Data Products

Level 1B (most recent released version 2.07):

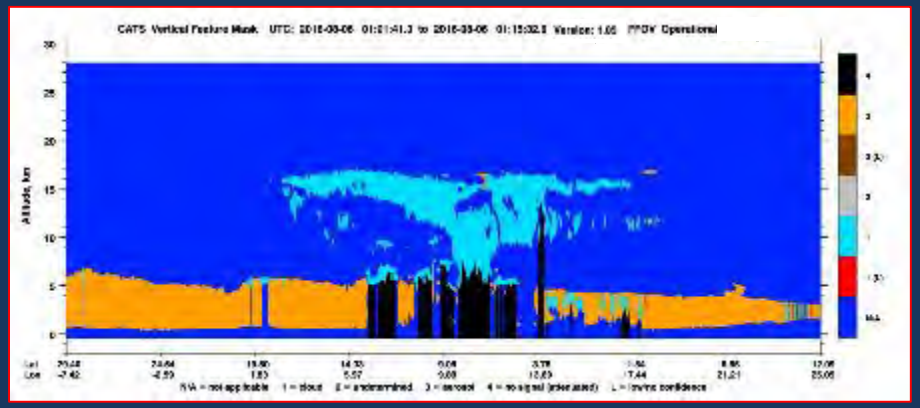
- Attenuated Total Backscatter at 532 and 1064 nm
- Depolarization Ratio at 1064 nm

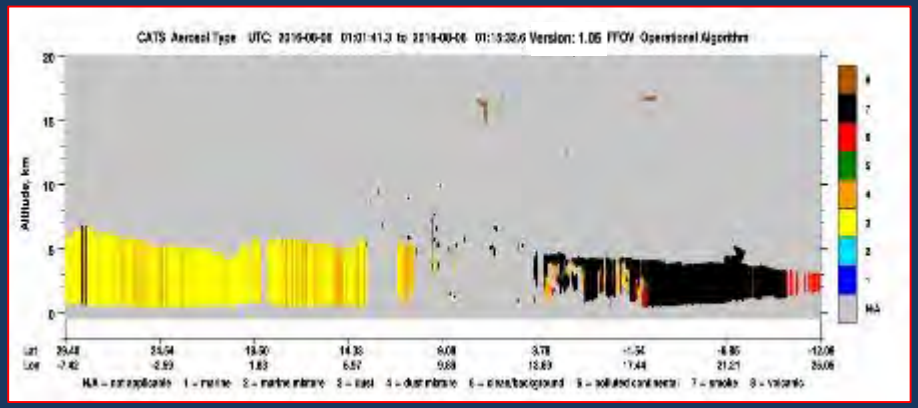




Level 2 (most recent released version 1.05):

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

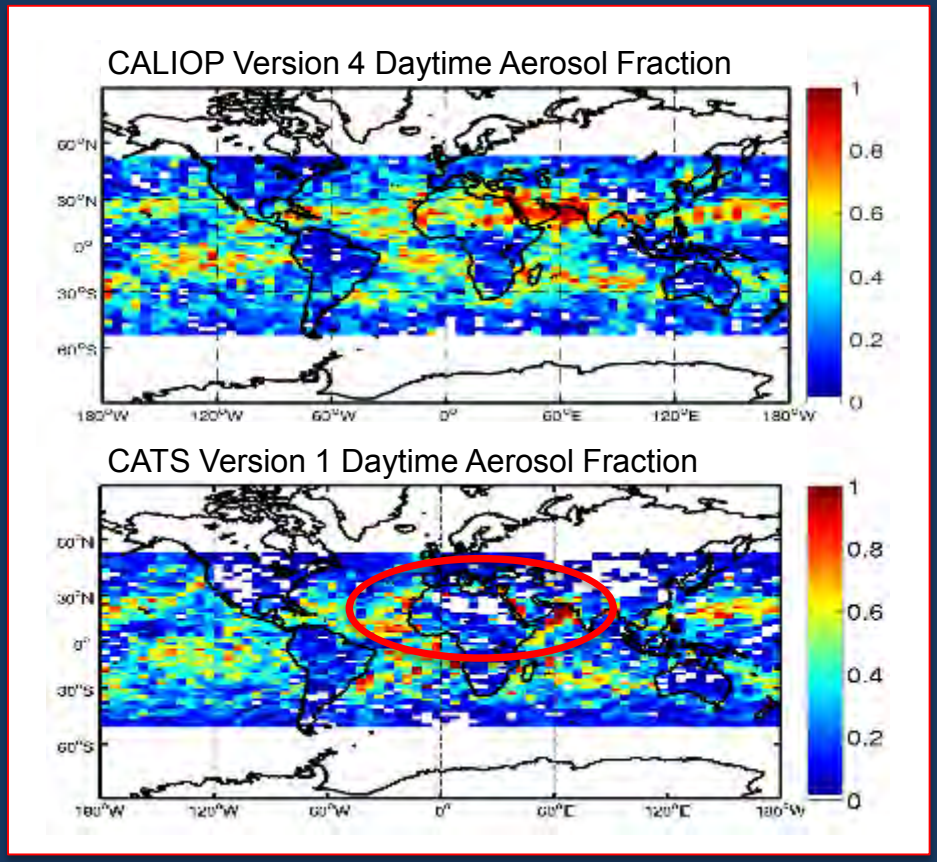




Version 2 Level 2 Aerosol Updates to Aerosol Detection and Typing

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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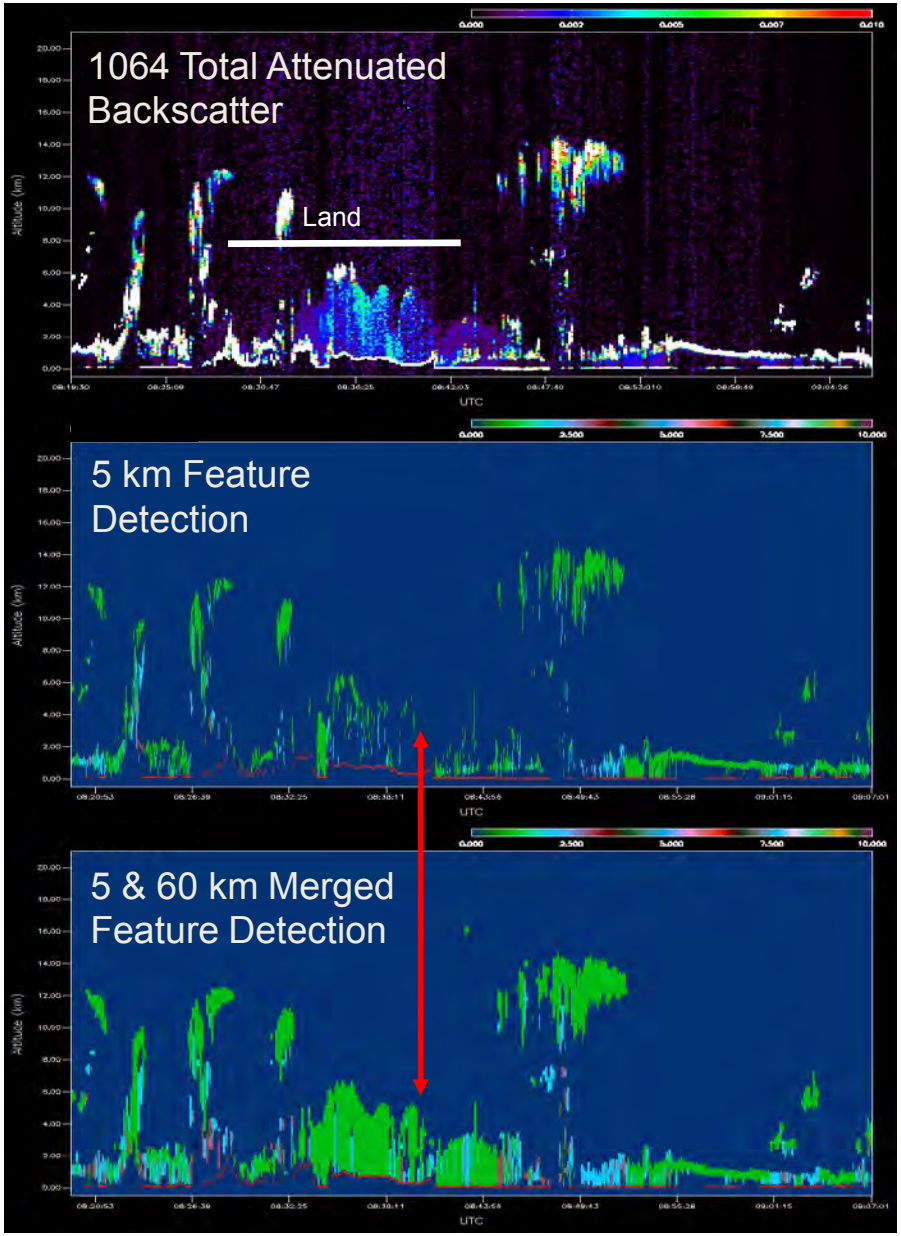
- The new version 2 level 2 feature detection algorithm uses both 5 and 60 km horizontal resolution during day and night and reports a “merged” product at 5 km



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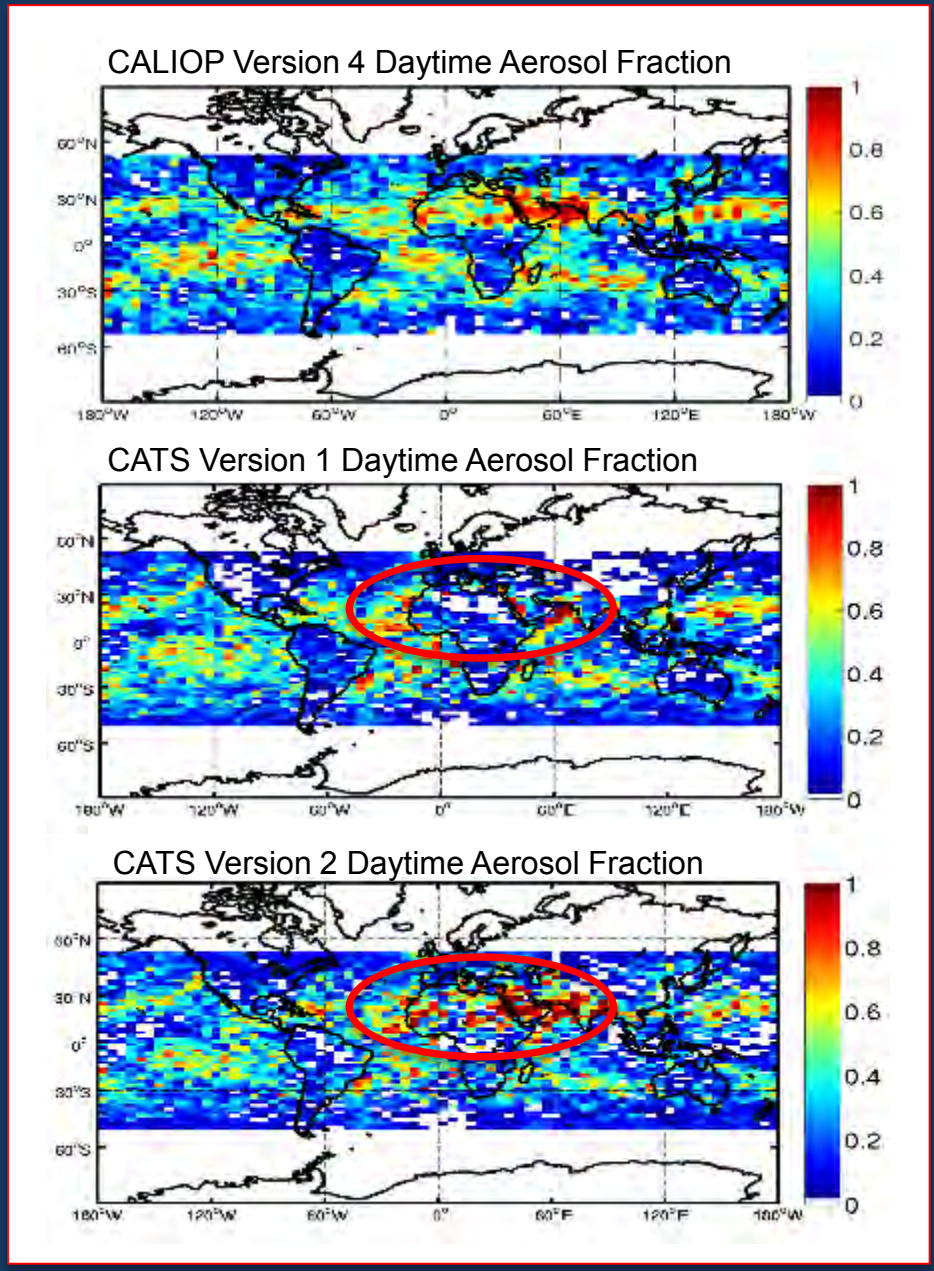
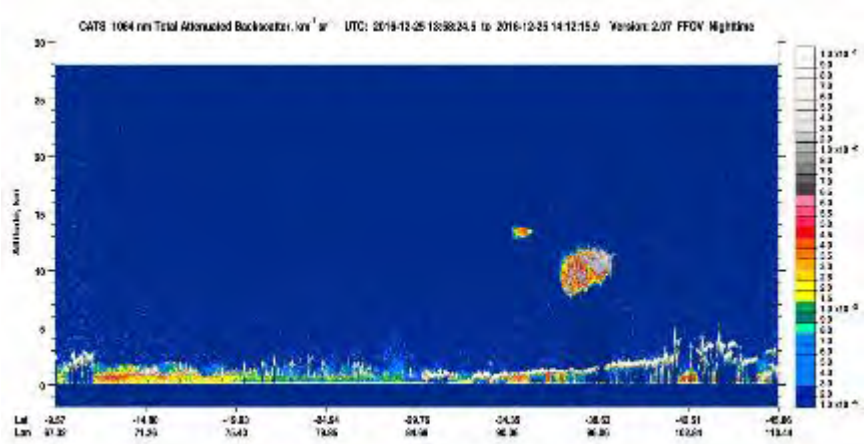
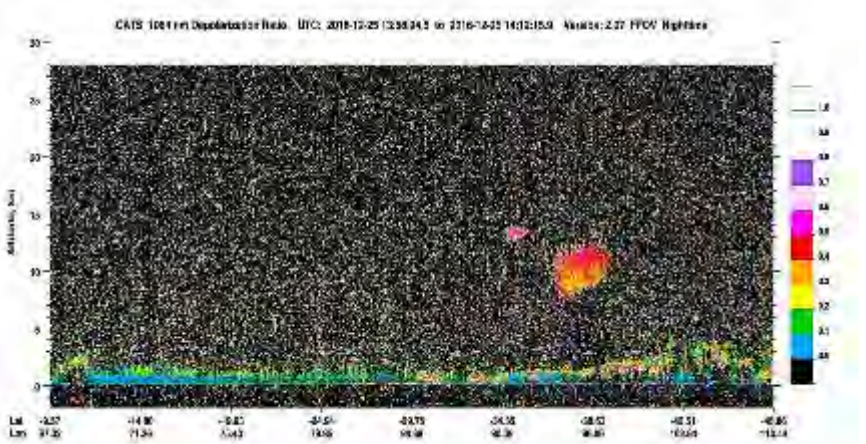
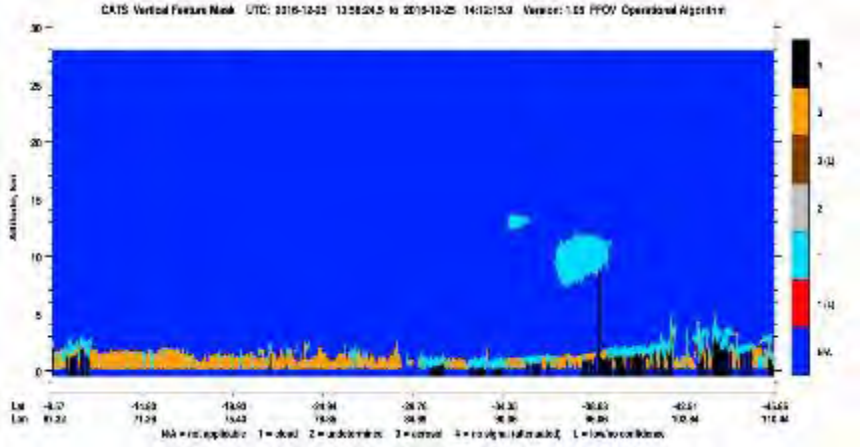
- The new version 2 level 2 feature detection algorithm uses both 5 and 60 km horizontal resolution during day and night and reports a “merged” product at 5 km
- The new feature detection algorithm significantly increases daytime aerosol detection frequency

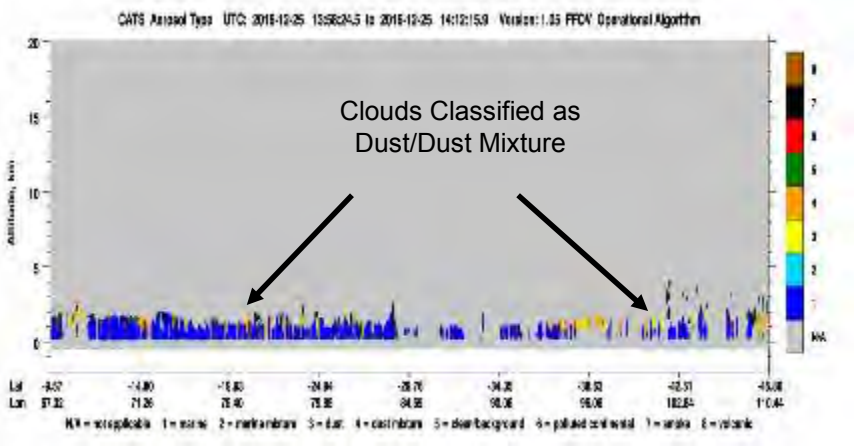


Updated Cloud - Aerosol Discrimination



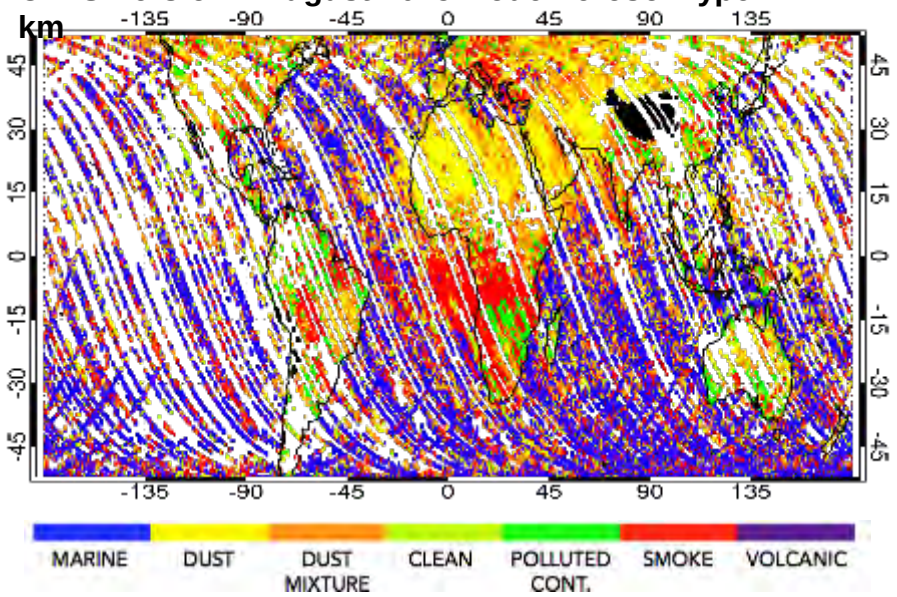




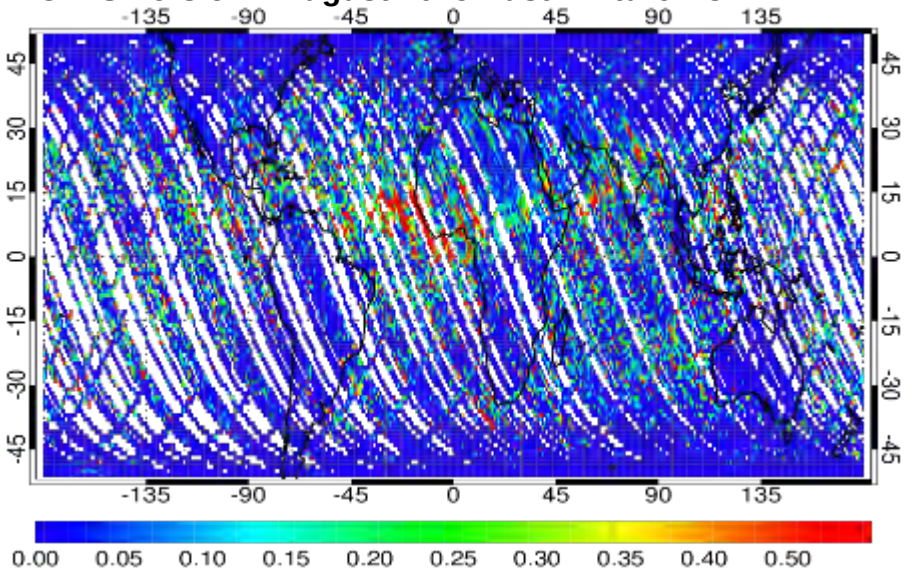


Updated Cloud - Aerosol Discrimination

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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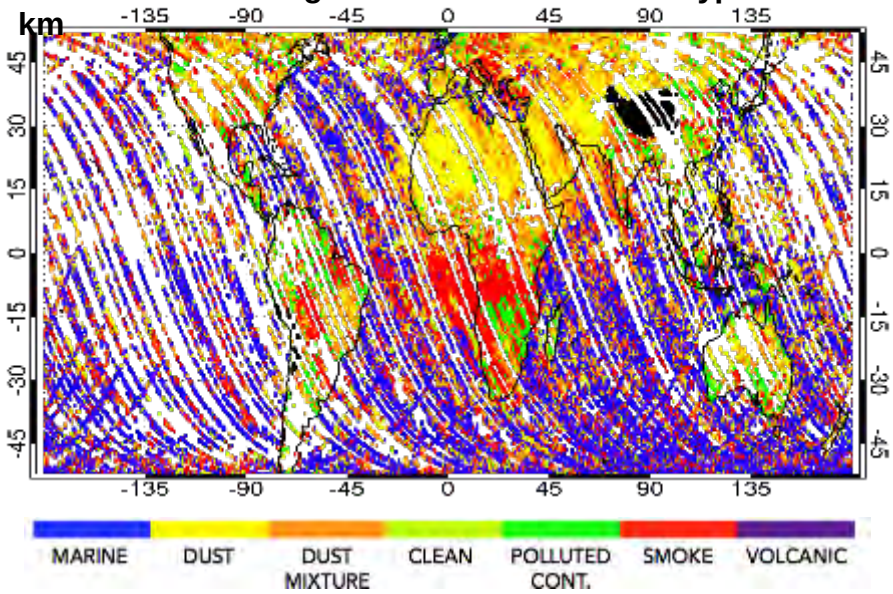

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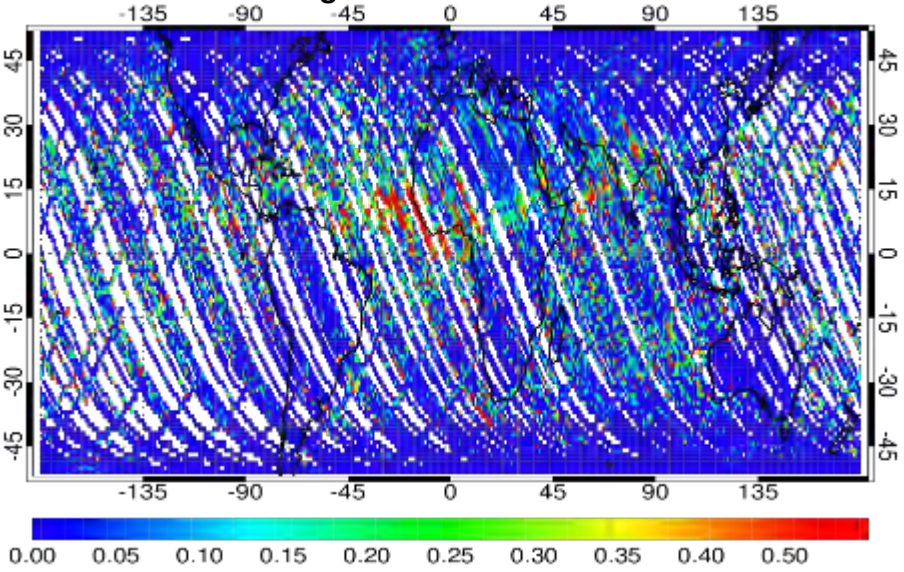
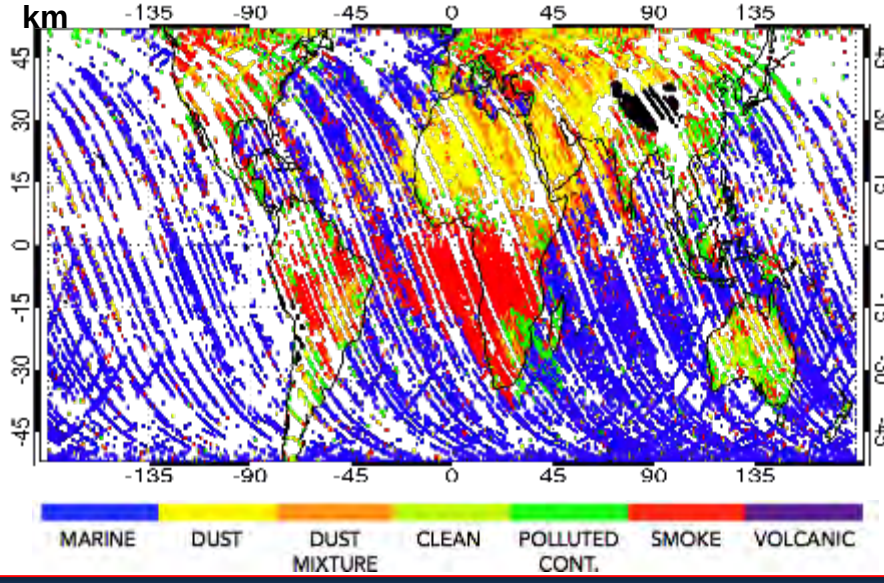
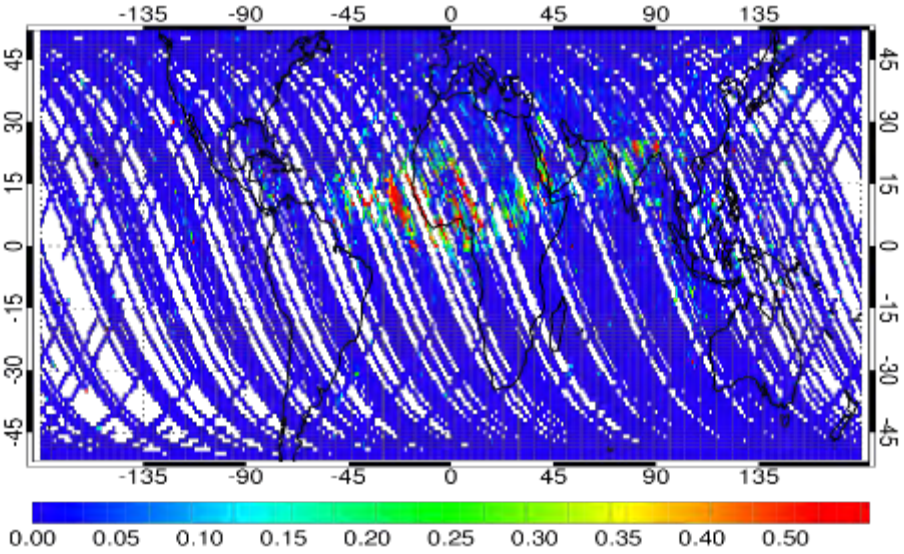


CATS Version 2 August 2015 Mode Aerosol Type 1 – 2 km



CATS Version 2 August 2015 Dust Mixture AOT



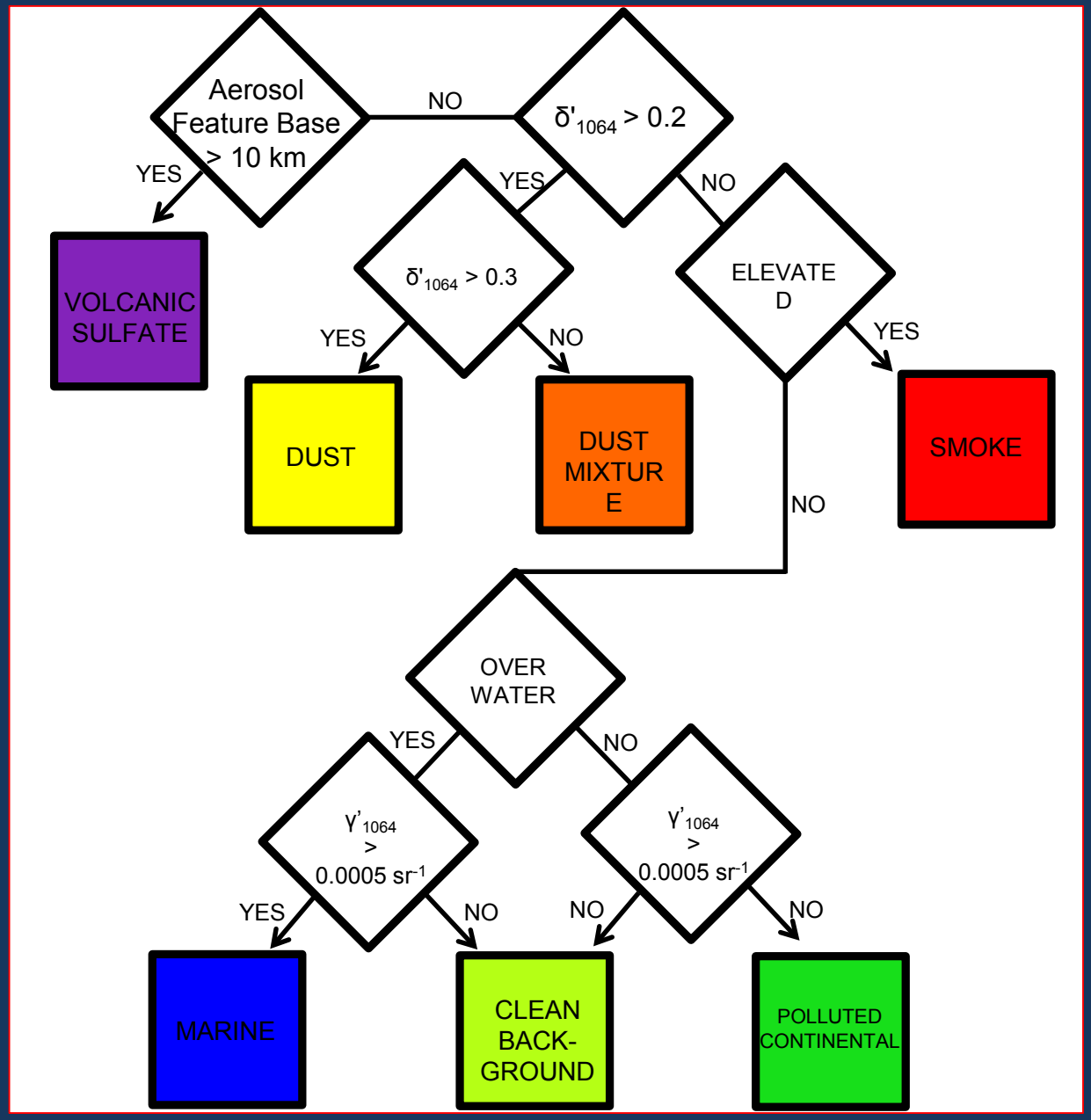
Updated Aerosol Typing Algorithm

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

CATS Version 2 Mode 2 Aerosol Typing Algorithm

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

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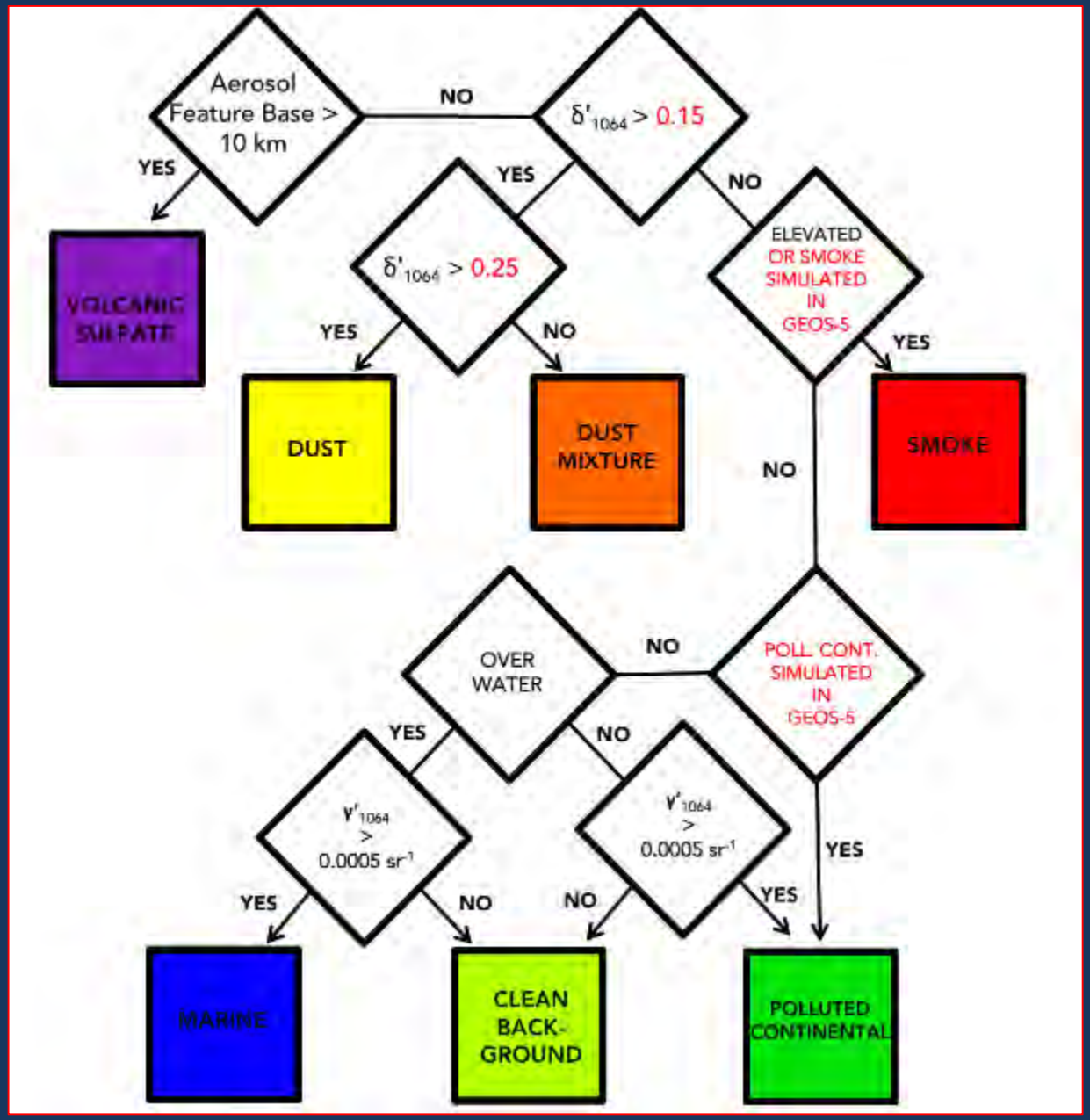

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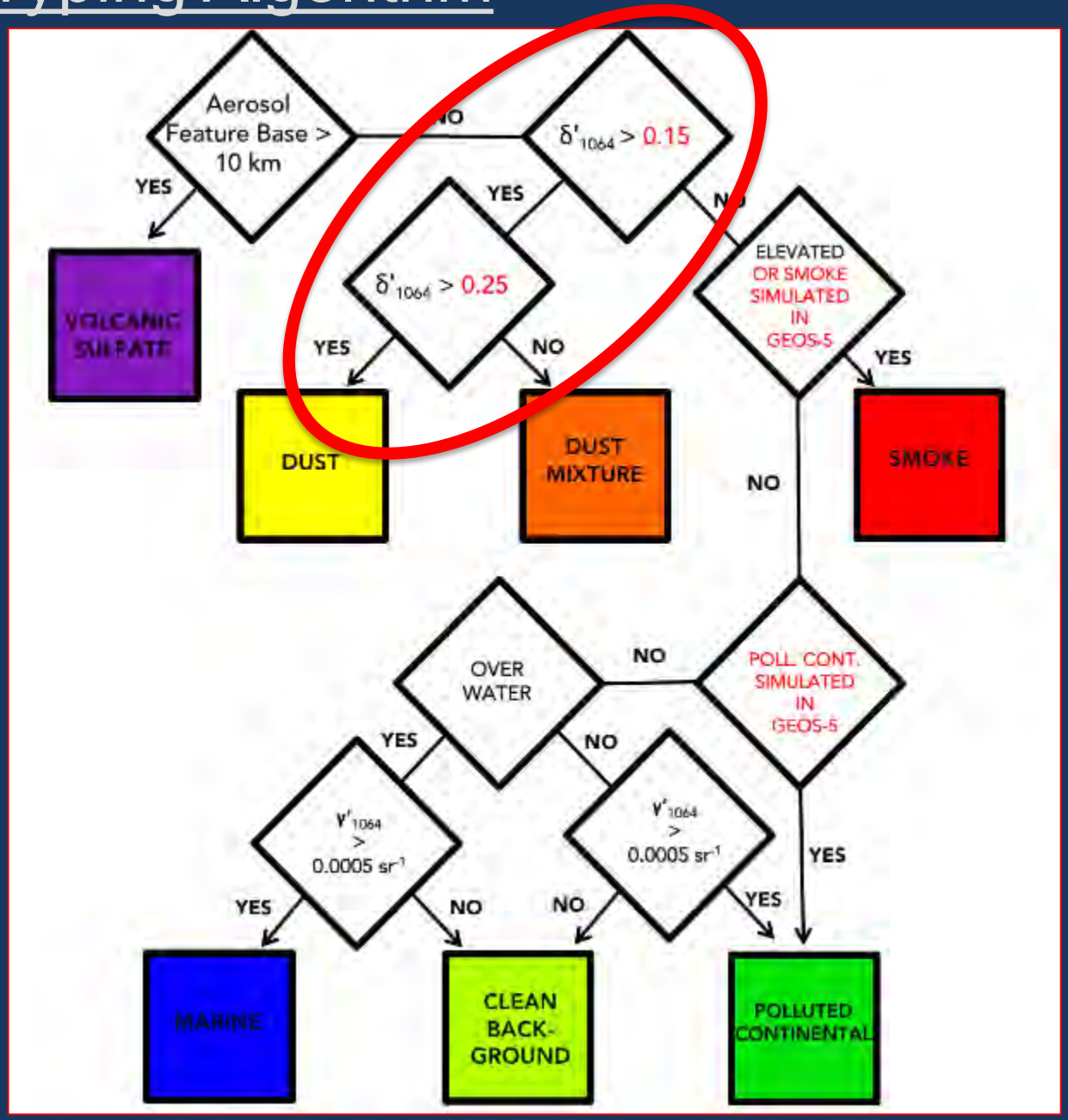
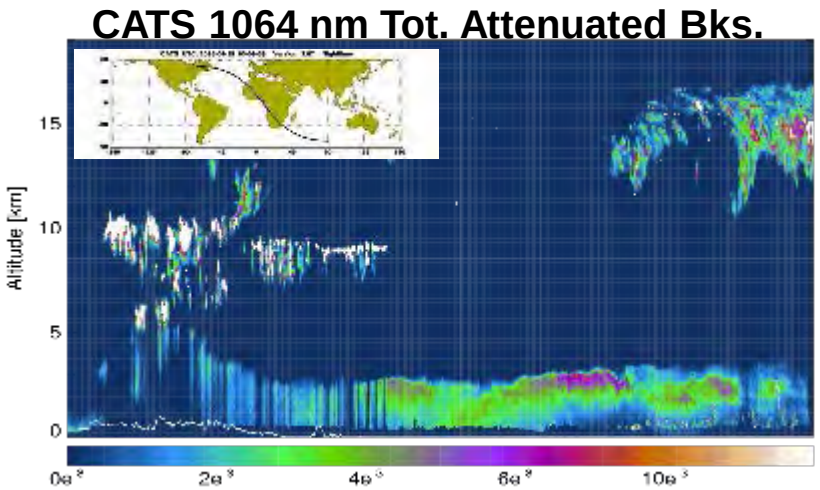
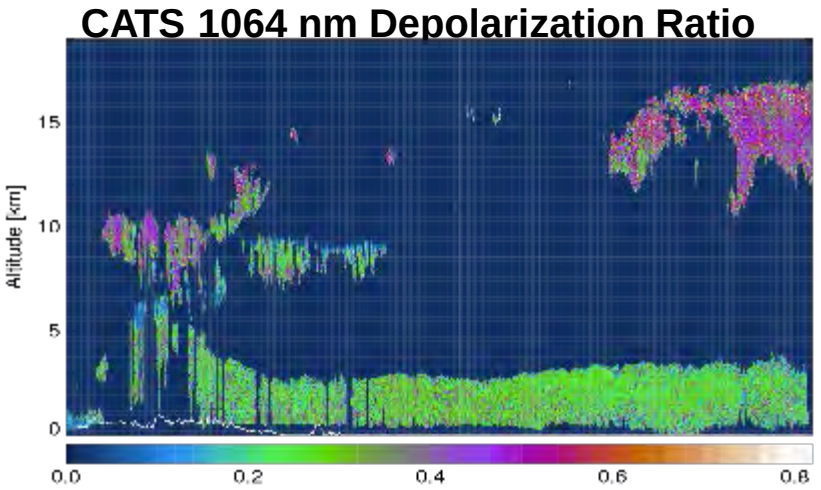
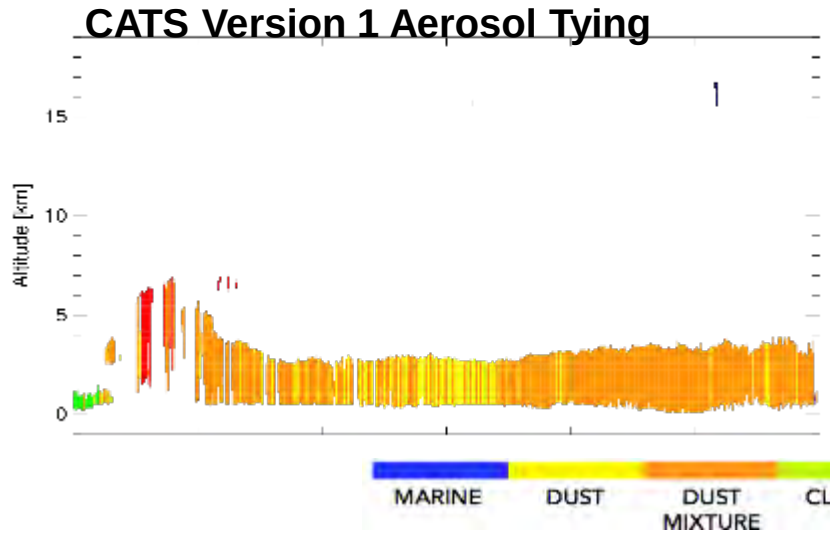
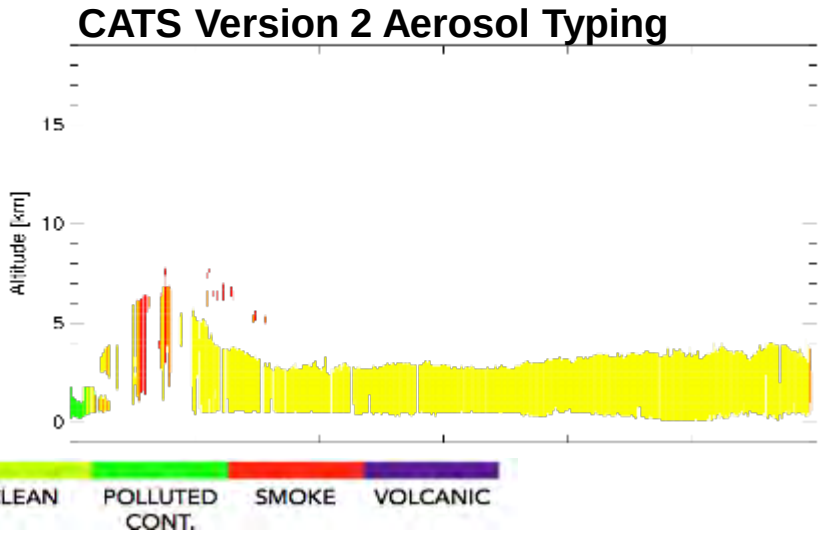


Updated Aerosol Typing: Dust Thresholds & Striping









- 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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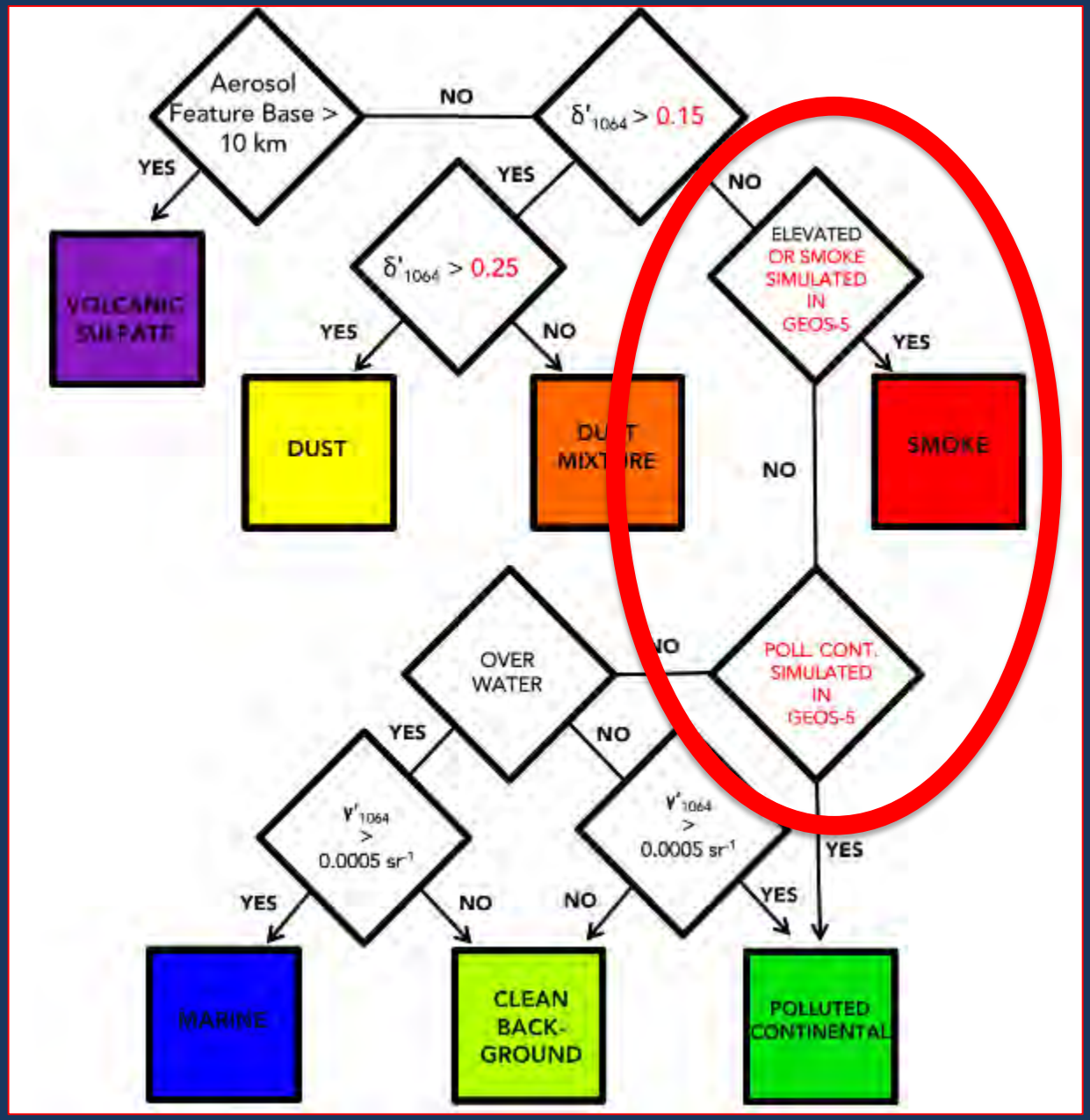
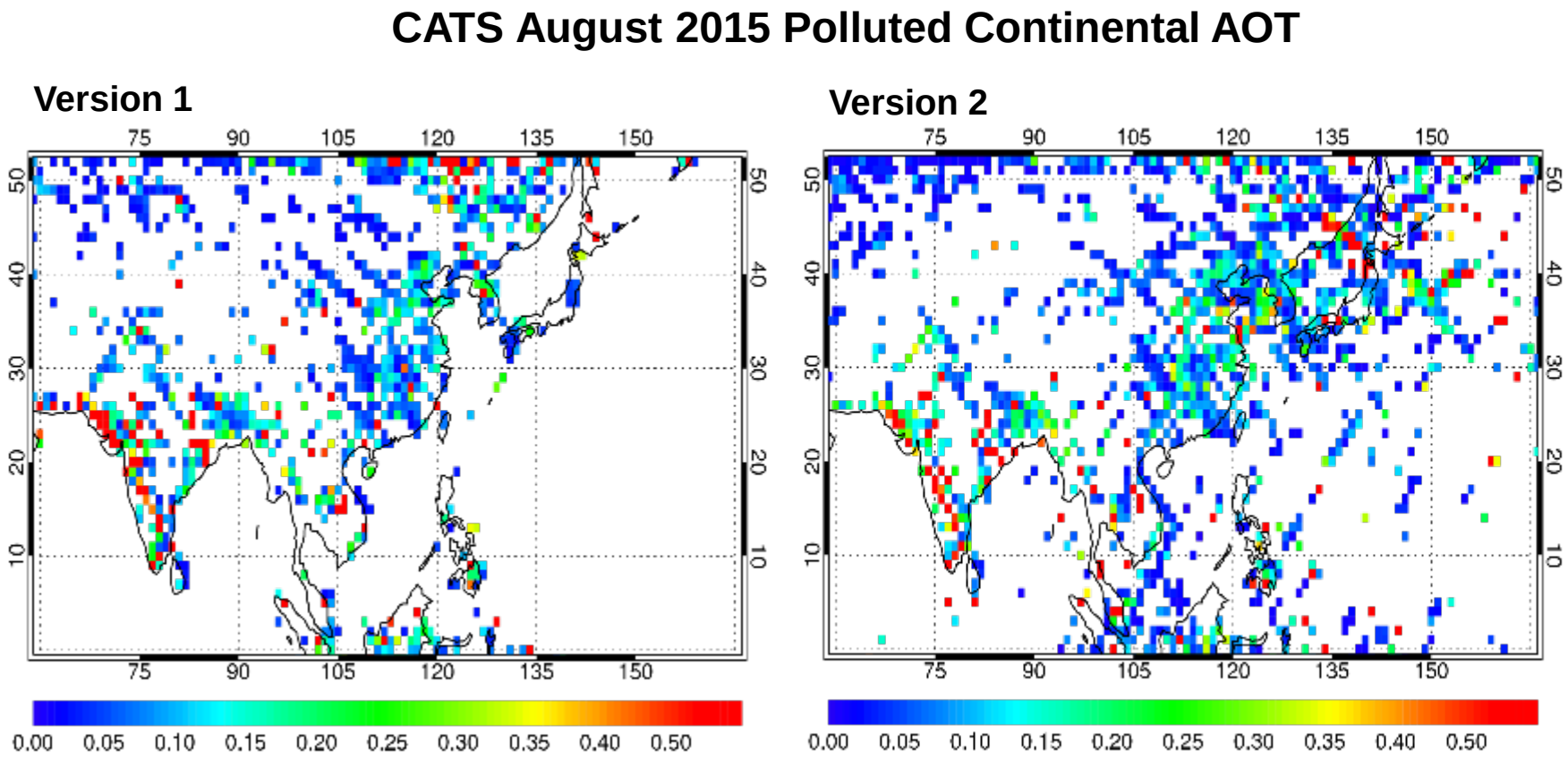


Updated Aerosol Typing: Incorporation of GEOS-5



- 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

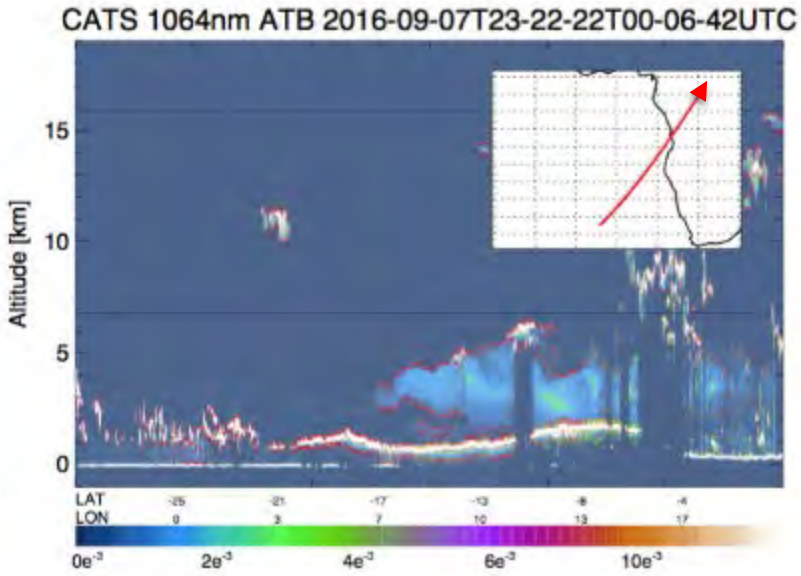
DACCIWA

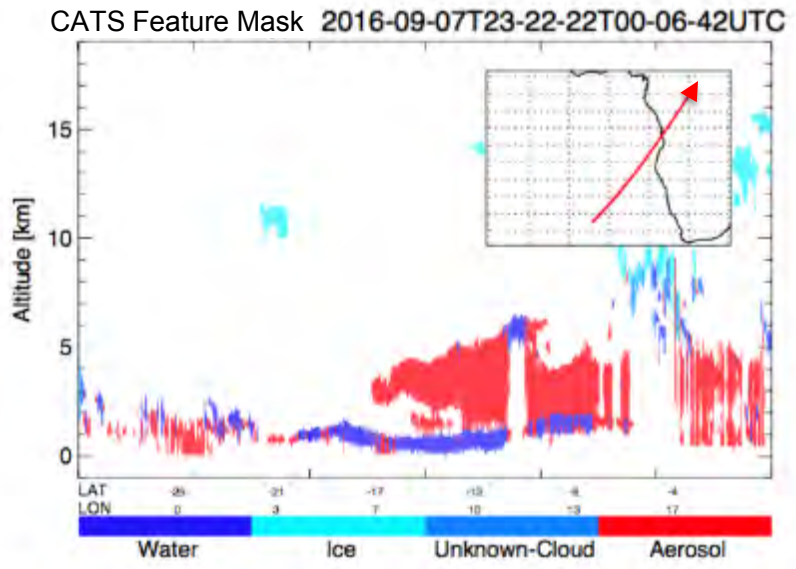
August - October 2016

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

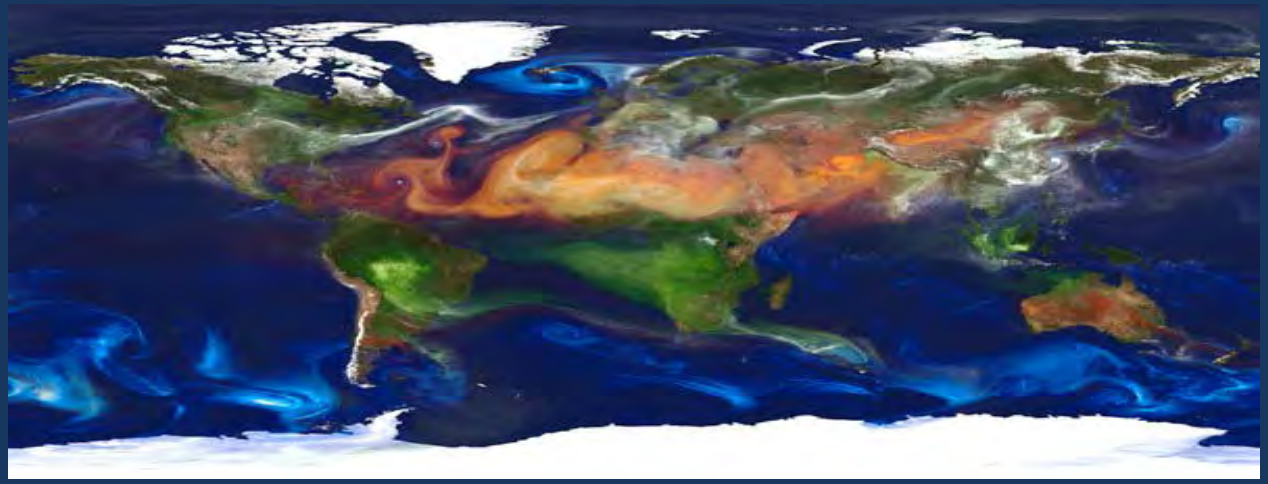
For more information, field campaign support, or help acquiring data, contact:
Ed Nowottnick – edward.p.nowottnick@nasa.gov
John Yorks – john.e.yorks@nasa.gov

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):

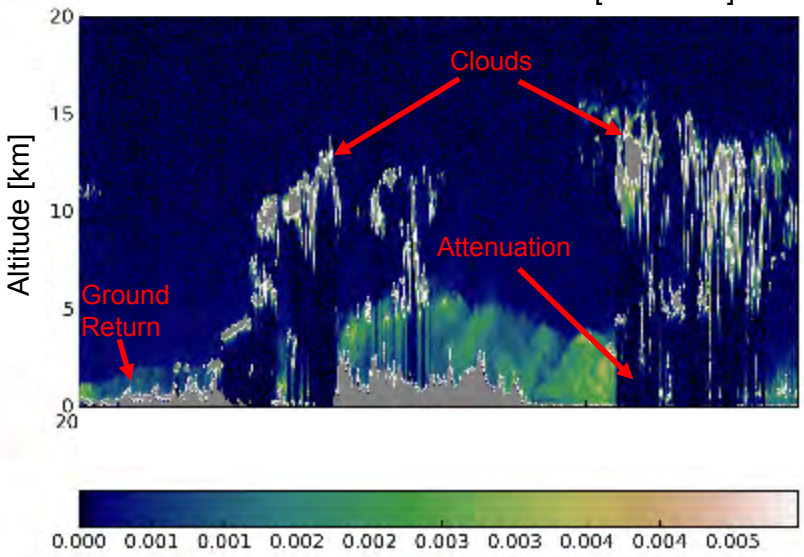
- Ensemble Mean:
  - ~12.5 km horizontal resolution, output at 25 km
  - 72 hybrid-sigma levels in the vertical
- Ensemble Members:
  - 32 members
  - ~50 km horizontal resolution
  - 72 hybrid-sigma levels in the vertical
- Aerosols:
  - Goddard Chemistry, Aerosol, Radiation, and Transport (GOCART) 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



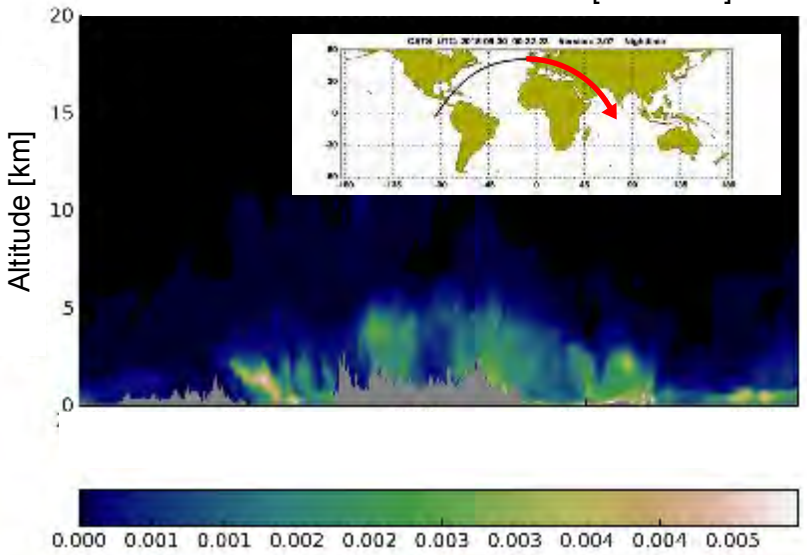
Utilizing GEOS-5 ensembles, we are developing a 1-D ensemble approach to assimilate CATS observations of total attenuated backscatter into GEOS-5

1 – D Ensemble Approach:

CATS
1064 nm Tot. Attenuated Backscatter [km-1 sr-1]



GEOS-5 Ensemble Mean
1064 nm Tot. Attenuated Backscatter [km-1 sr-1]



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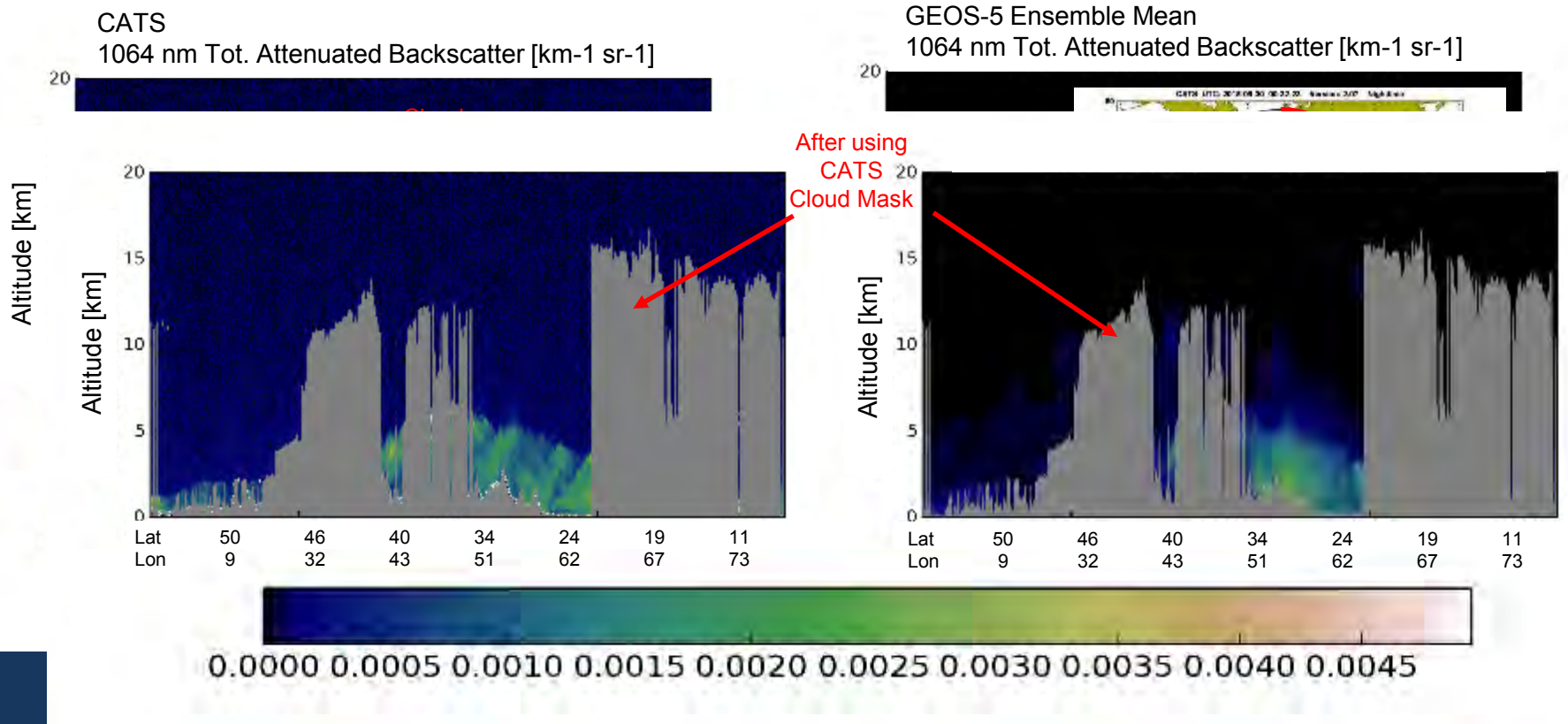

1 – D Ensemble Approach:

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

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

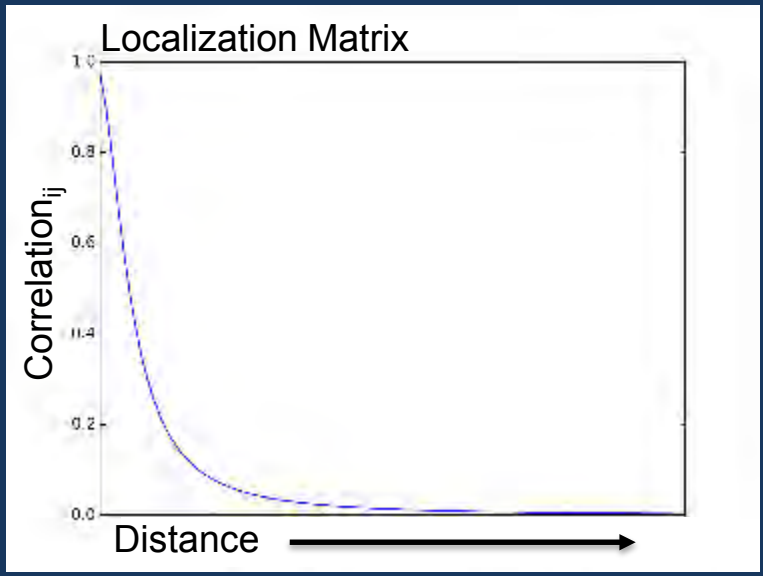
R = CATS error covariance

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

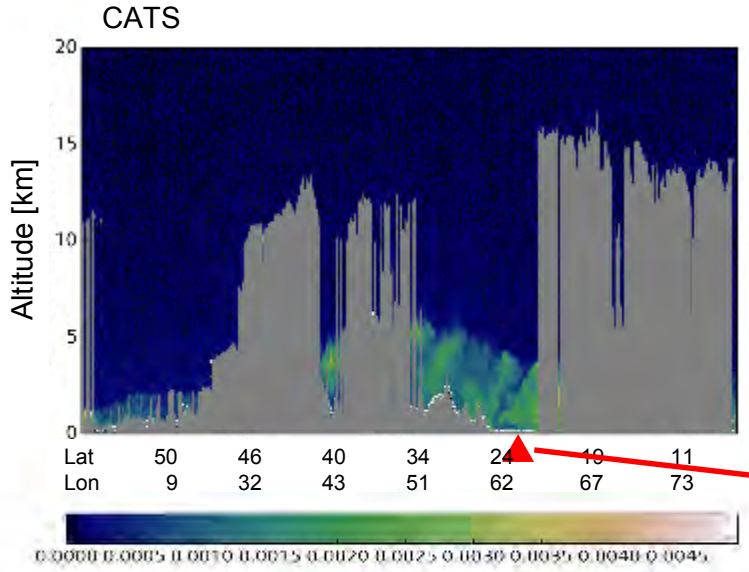
$$B = YY^T \circ C$$

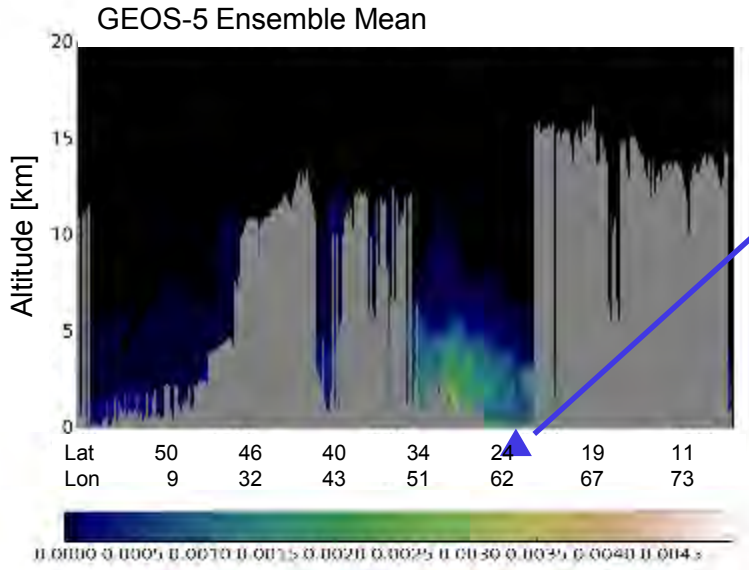
where:

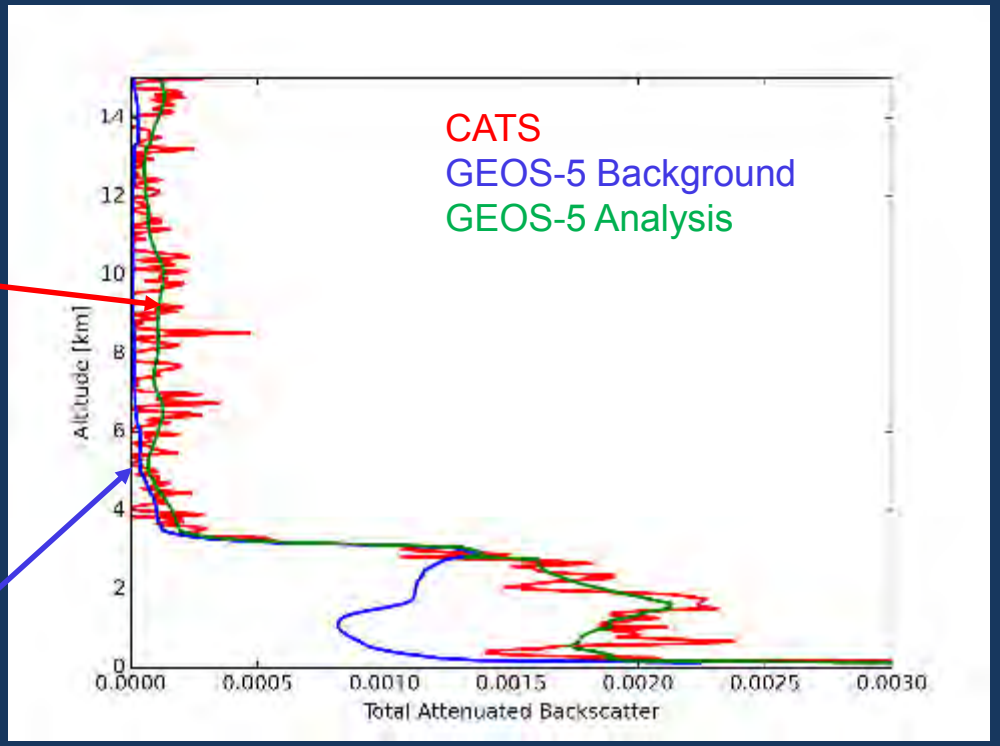
$$Y = [\boldsymbol{\gamma}'(z)_1, \boldsymbol{\gamma}'(z)_2, \ldots, \boldsymbol{\gamma}'(z)_{nens}]$$



1– D Ensemble Assimilation

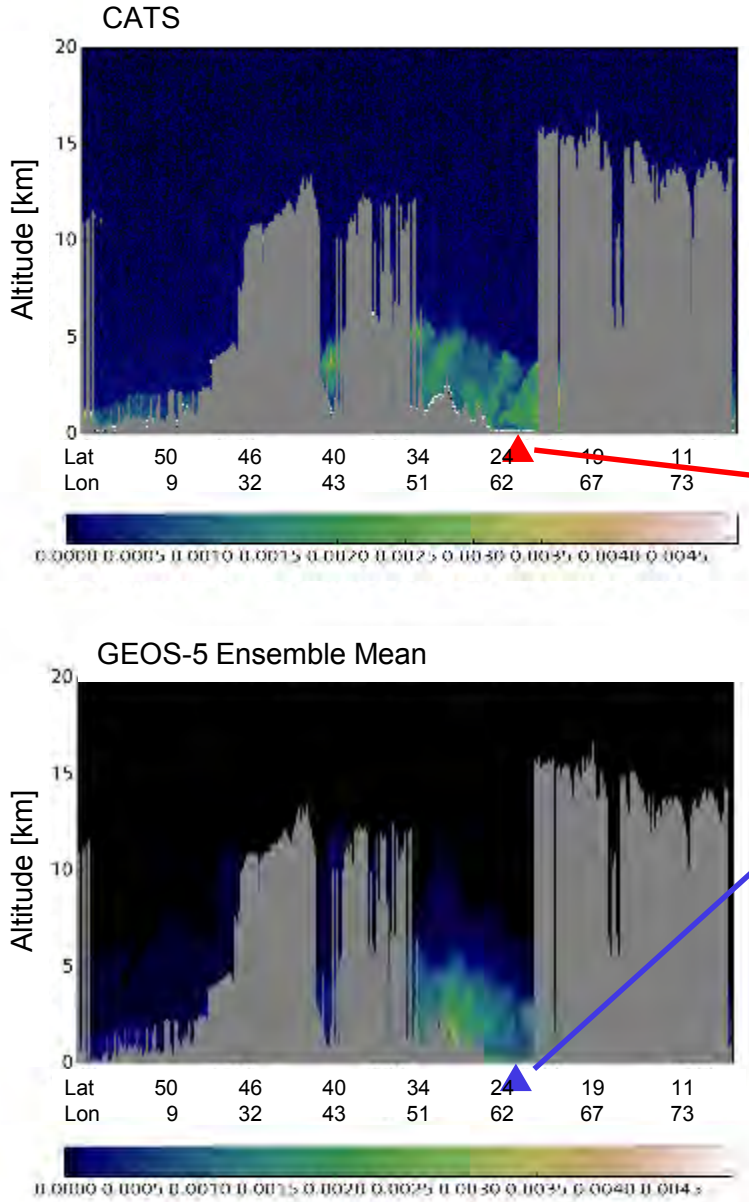


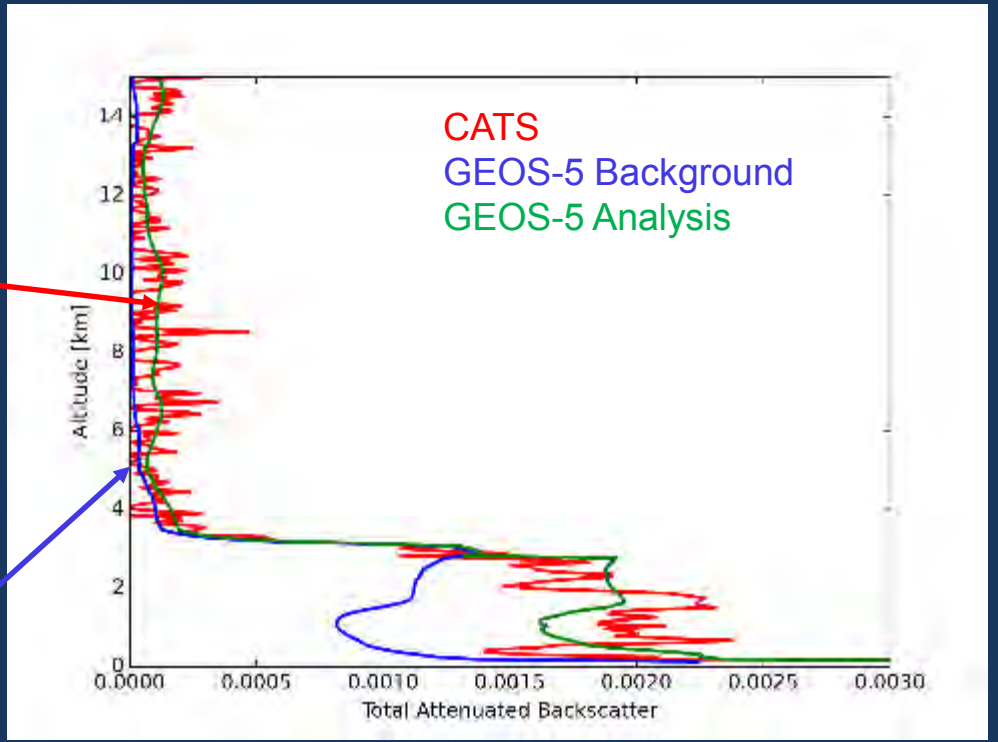




- Here, we perform a 1-D ENS analysis for a single profile, using a uniform vertical length scale of 1 km for vertical localization.
- The analysis draws very closely to the observations, particularly in the planetary boundary layer.

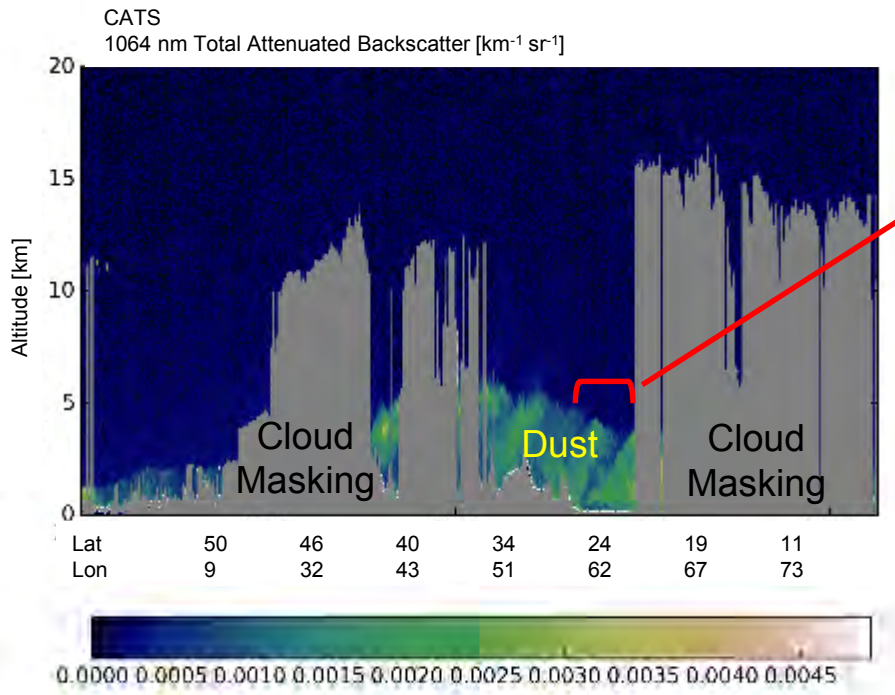
1– D Ensemble Assimilation: Profile with Boundary Layer Localization



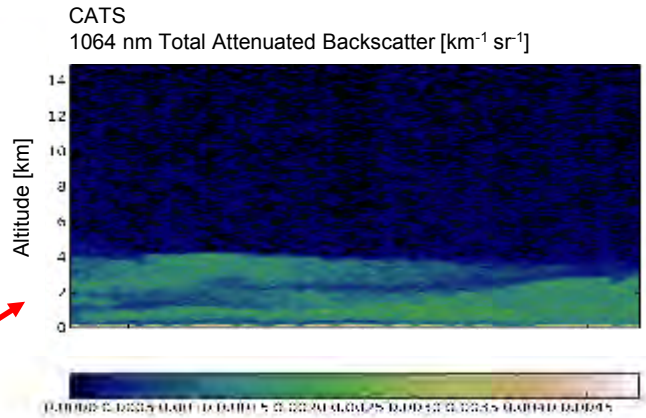


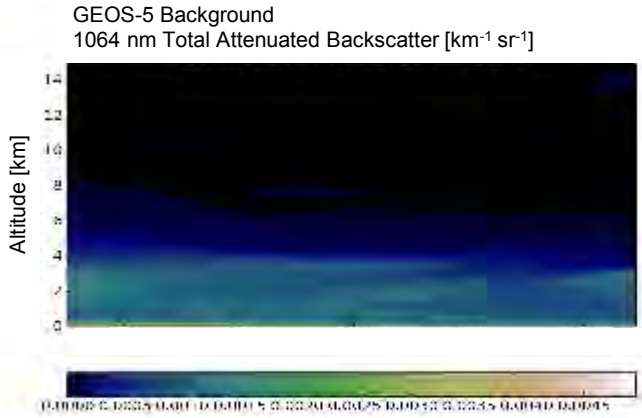
- Next, we explored using different length scales for vertical localization in the planetary boundary layer vs. free troposphere.
- Changing the vertical length scale to 5 km in the PBL:
  - Preserves the transition in γ from the planetary boundary layer to free troposphere, as seen in the background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

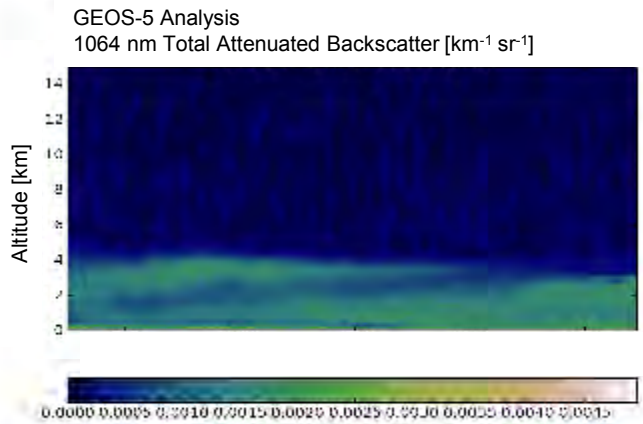
NRT Applications:
1– D Ensemble Assimilation



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.

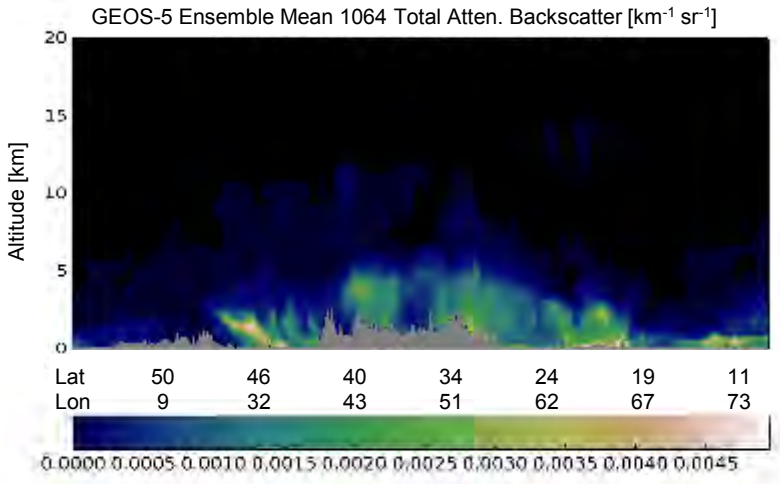
$$x_{analysis} = x_{background} + BH^T[HBH^T + R]^{-1} (\gamma_o - Hx_{background})$$

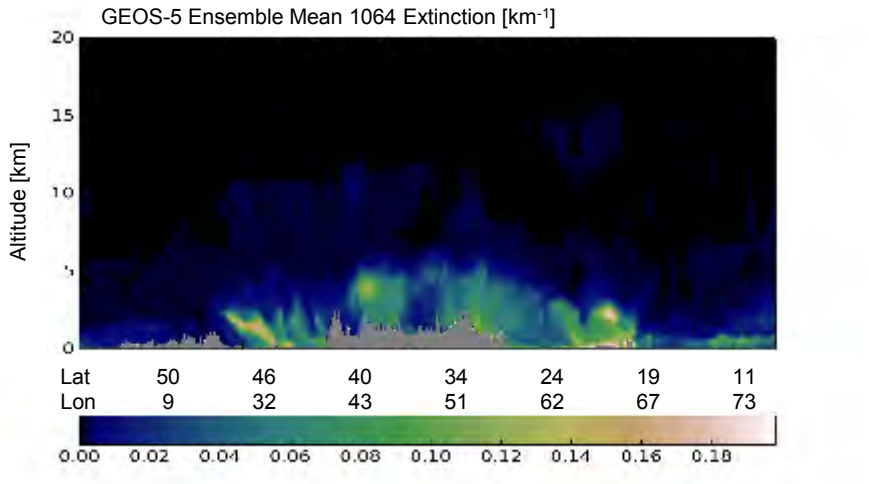
where:

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

γ_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:

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

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

$B = XX^T \circ C$

where:

X = Extinction Perturbations:

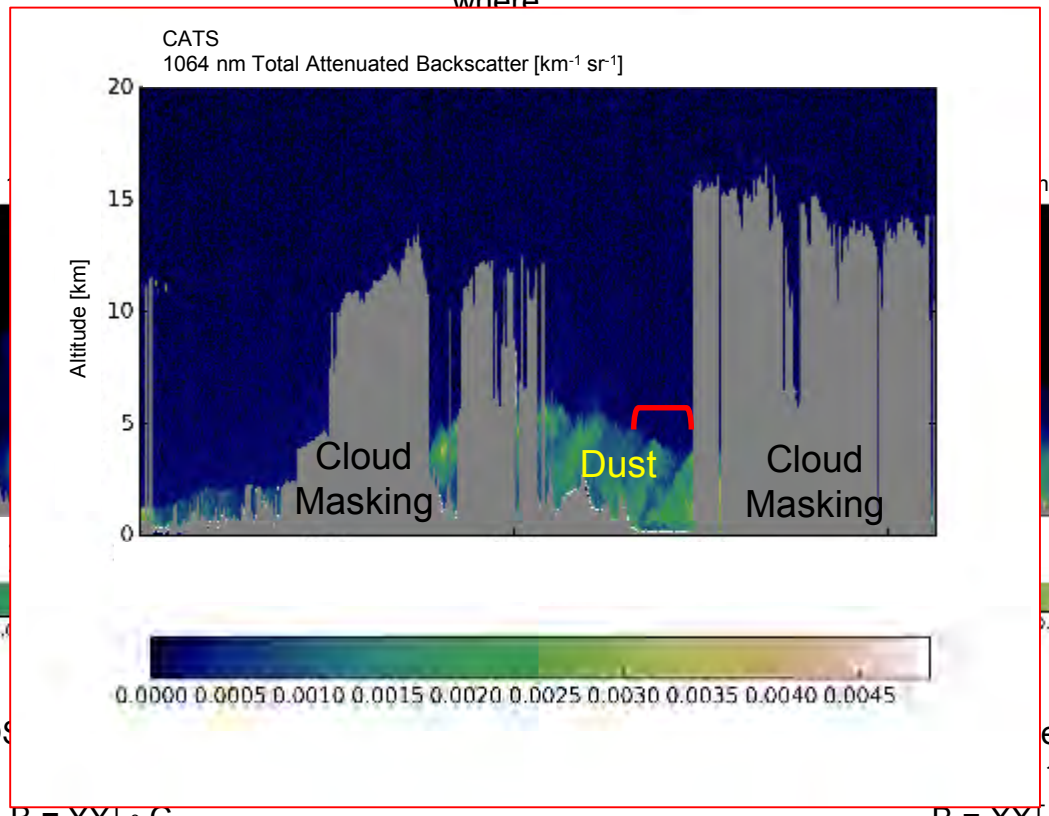
$[x'(z)_1, x'(z)_2, \ldots, x'(z)_{nens}]$

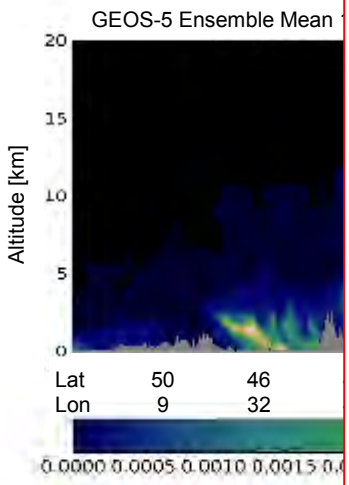
1– D Ensemble Assimilation: Considerations for Extinction

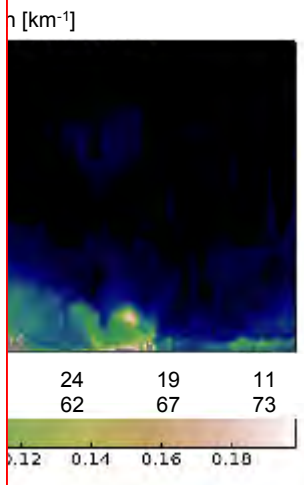
Unlike total attenuated backscatter, simulated extinction values are not impacted by attenuation from above and is being considered as our "analysis" variable.

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

where:







H = Regrids GEOS

ertical resolution & linear

γ given **x**

$B = YY^T \circ C$

where:

Y = Tot. Atten. Bks Perturbations:

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

$B = XX^T \circ C$

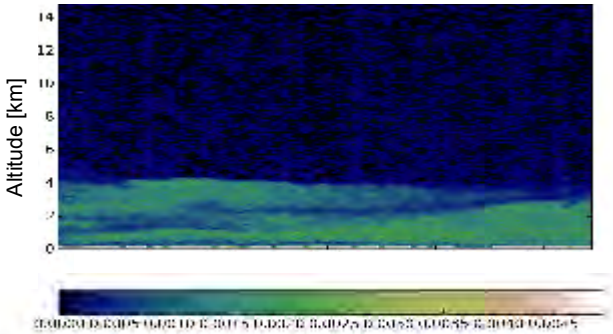
where:

X = Extinction Perturbations:

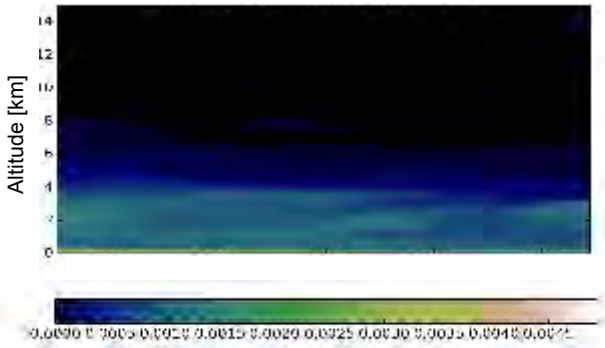
$[x'(z)_1, x'(z)_2, \ldots, x'(z)_{nens}]$

Analysis Performed in Total Attenuated Backscatter vs. Extinction

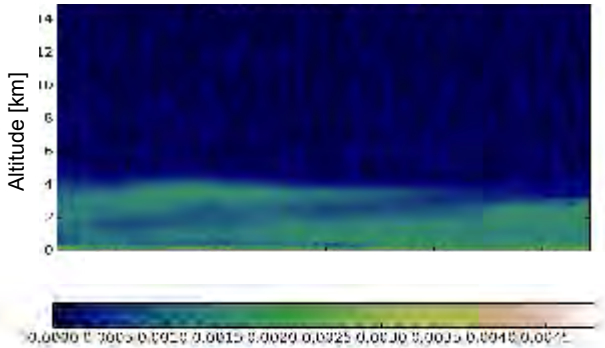
CATS
1064 nm Total Attenuated Backscatter [km^{-1} sr^{-1}]



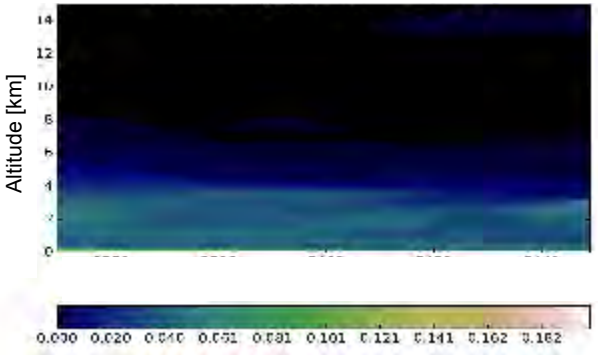
GEOS-5 Background
1064 nm Total Attenuated Backscatter [km^{-1} sr^{-1}]



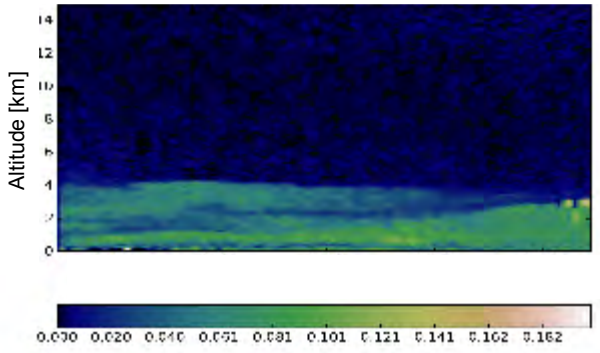
GEOS-5 Analysis
1064 nm Total Attenuated Backscatter [km^{-1} sr^{-1}]



GEOS-5 Background
1064 nm Extinction [km^{-1}]



GEOS-5 Analysis
1064 nm Extinction [km^{-1}]



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

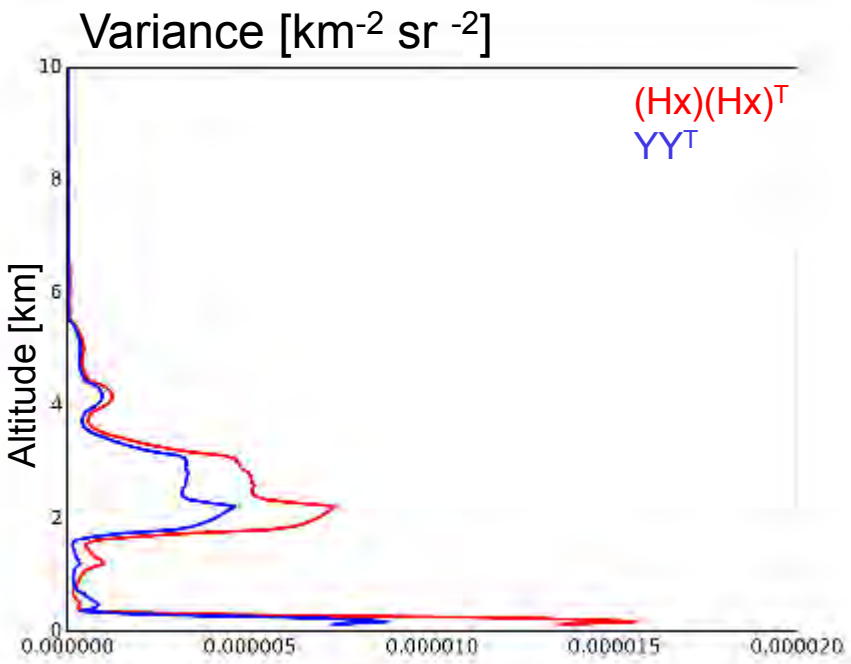
Future Work

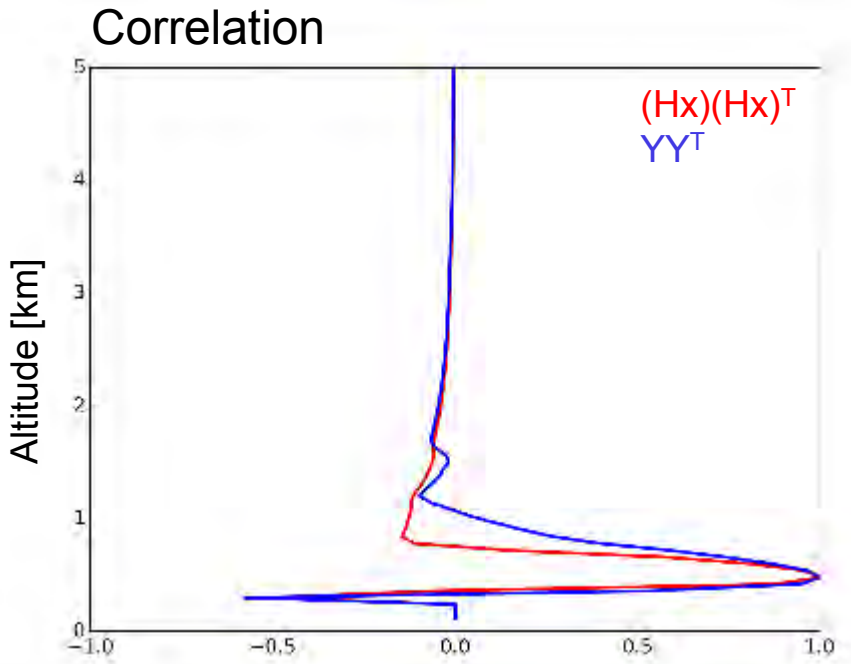
- Explore horizontal localization and test within a cloudy aerosol layer
- Address “noisy” analysis increments in the free troposphere where both CATS and GEOS-5 aerosol loadings are low
- Develop a technique to screen CATS ground return from profiles
- “Dynamic” lidar ratio that will evolve in conjunction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

Granule Availability 2017

January
February
March
April
May
June
July
August
September
October
November
December

Quick Look Images

HDF5 Files

CATS data users, please note the instrument modes and data versions below:

- *Mode 7.1:* data from 10 Feb. through 21 March 2015, L1B version 2-07 & L2O version 1-05
- *Mode 7.2:* data from 25 Mar. 2015 through present, L1B version 2-07 & L2O version 1-05

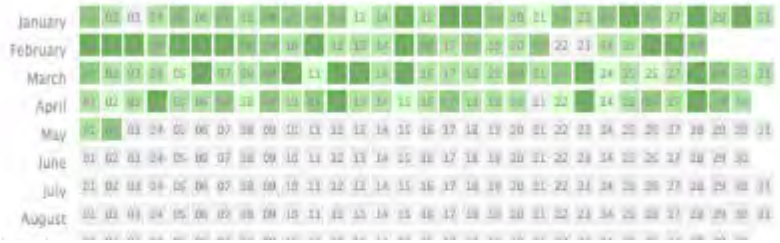
2017-05-02

00:45 UTC

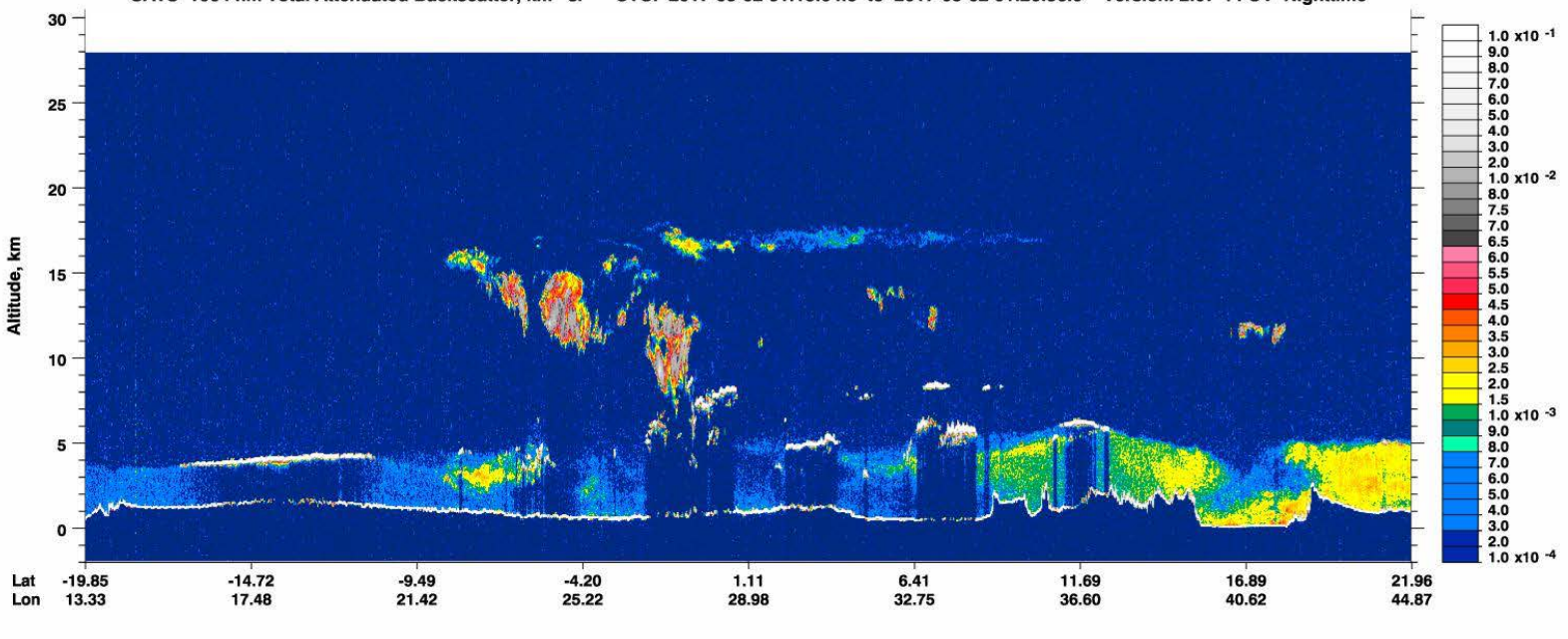
HDF5

Data Acquisition

Granule Availability 2017



Quick



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