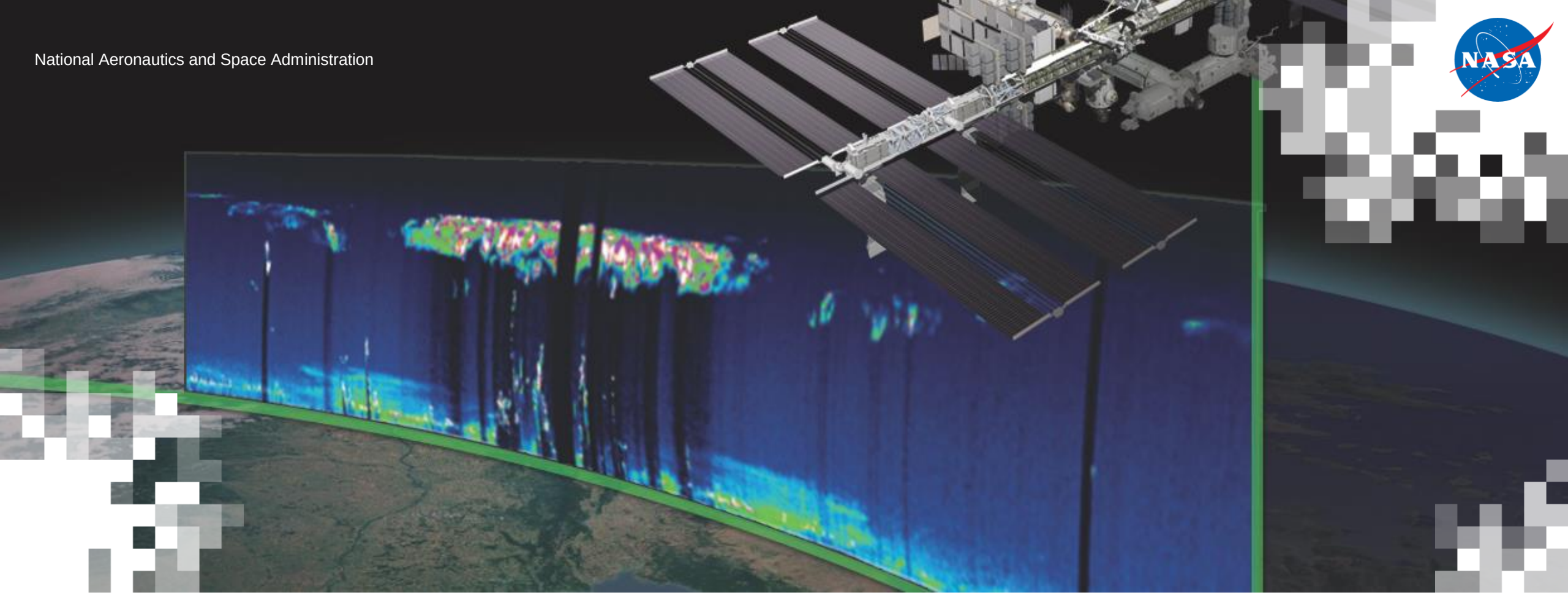
National Aeronautics and Space Administration



Lidar Profiling Satellite Observations for Air Quality Applications

Part 2: Observations to Feature Type – Theory and Real World Examples

Ed Nowottnick (NASA Goddard Space Flight Center)

June 11, 2025

Training Outline

Part 1

Introduction to LiDAR Measurements and Missions

June 4, 2025

10 AM/2PM ET

Part 2

Observations to Feature Type – Theory and Real World Examples

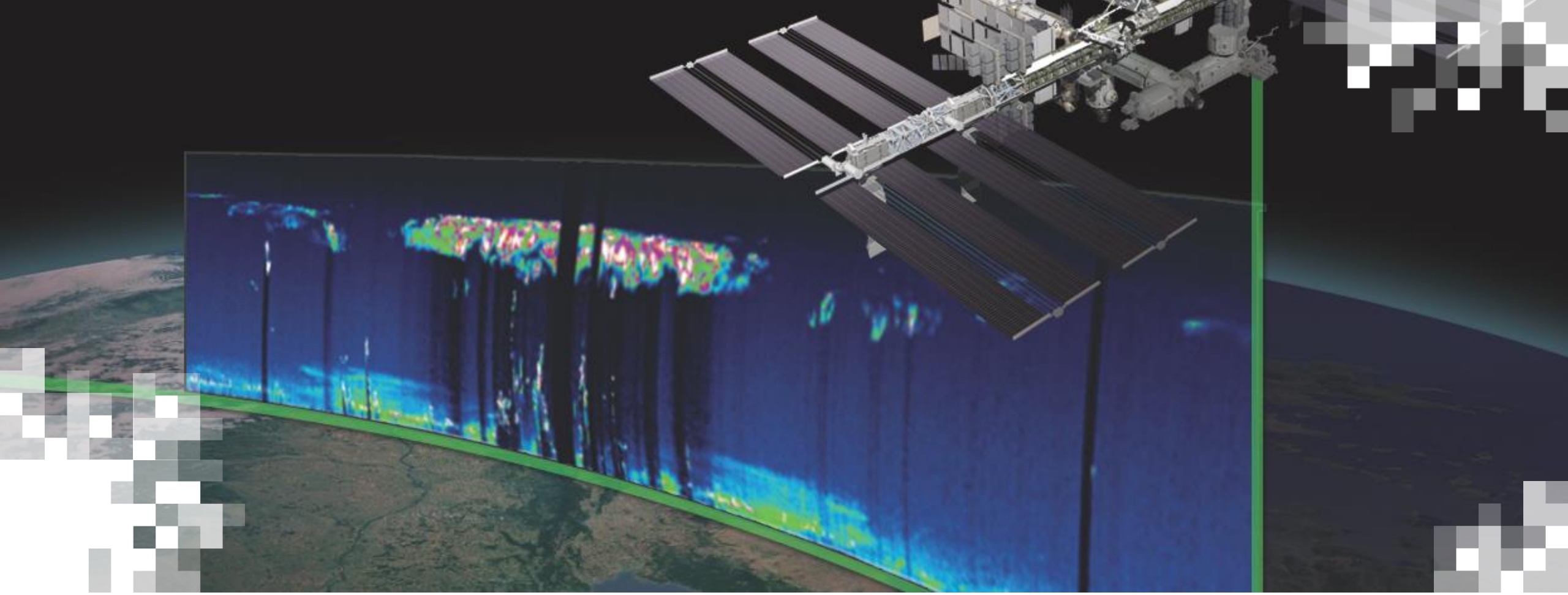
June 11, 2025

10 AM/2PM ET

Homework

Opens June 11 – Due June 25 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend both live sessions and complete the homework assignment(s) before the given due date.



Part 2

Observations to Feature Type – Theory and Real World Examples

Part 2 – Trainer

Ed Nowottnick

Research Physical Scientists

NASA GSFC

Training Objectives Covered in Part 1

1. ***Identify past and currently available lidar missions and their characteristics*** ✓
2. ***Recognize the capabilities of lidar active remote sensing in measuring vertical profiles of aerosols and clouds for informing air quality applications*** ✓
3. Interpret information within lidar curtains to discern cloud phase, aerosol type, and aerosol plume altitude for a given scene
4. ***Recognize the strengths and limitations of lidar observations*** ✓
5. Find lidar images and data for a particular time period and location using NASA Earthdata and mission websites

Spaceborne Lidars for Today's Training:

- Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) and Cloud-Aerosol Transport System (CATS)
- Both atmospheric backscatter lidars with similar data products

Training Objectives Covered in Part 2

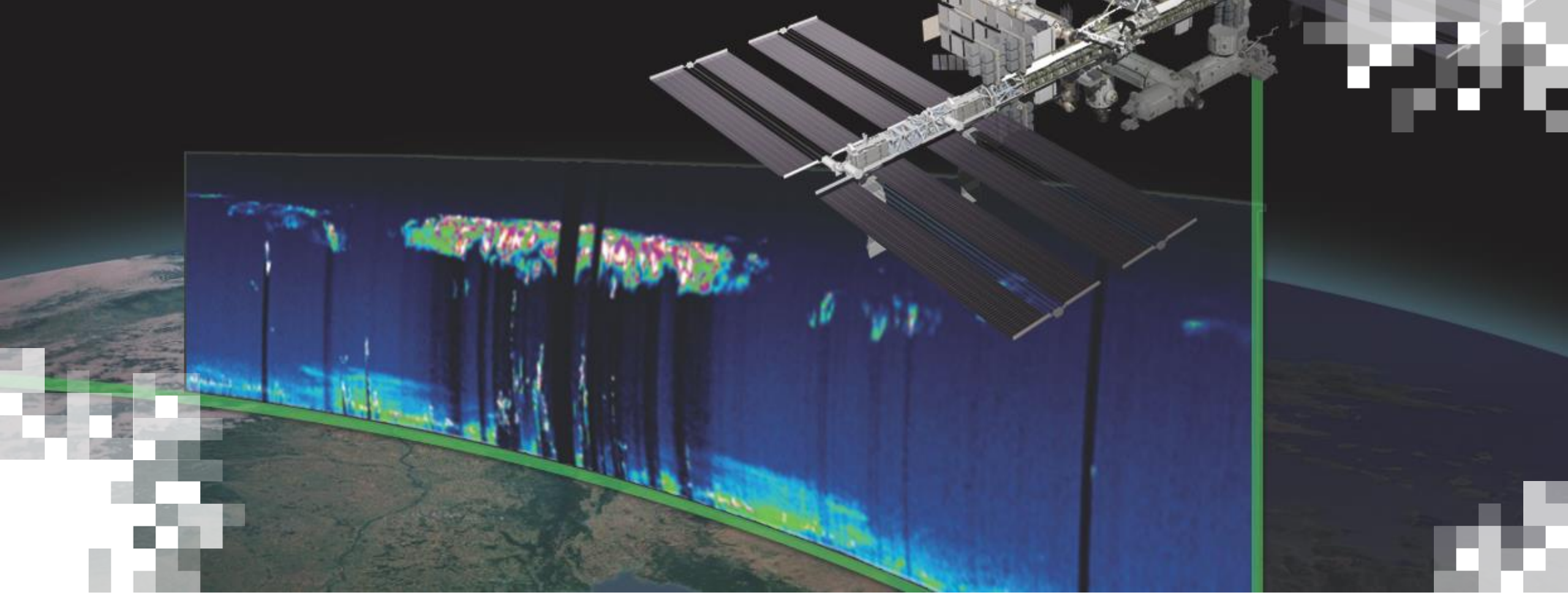
1. Identify past and currently available lidar missions and their characteristics
2. Recognize the capabilities of lidar active remote sensing in measuring vertical profiles of aerosols and clouds for informing air quality applications
3. **Interpret information within lidar curtains to discern cloud phase, aerosol type, and aerosol plume altitude for a given scene**
4. Recognize the strengths and limitations of lidar observations
5. **Find lidar images and data for a particular time period and location using NASA Earthdata and mission websites**

Spaceborne Lidars for Today's Training:

- Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) and Cloud-Aerosol Transport System (CATS)
- Both atmospheric backscatter lidars with similar data products

How to Ask Questions

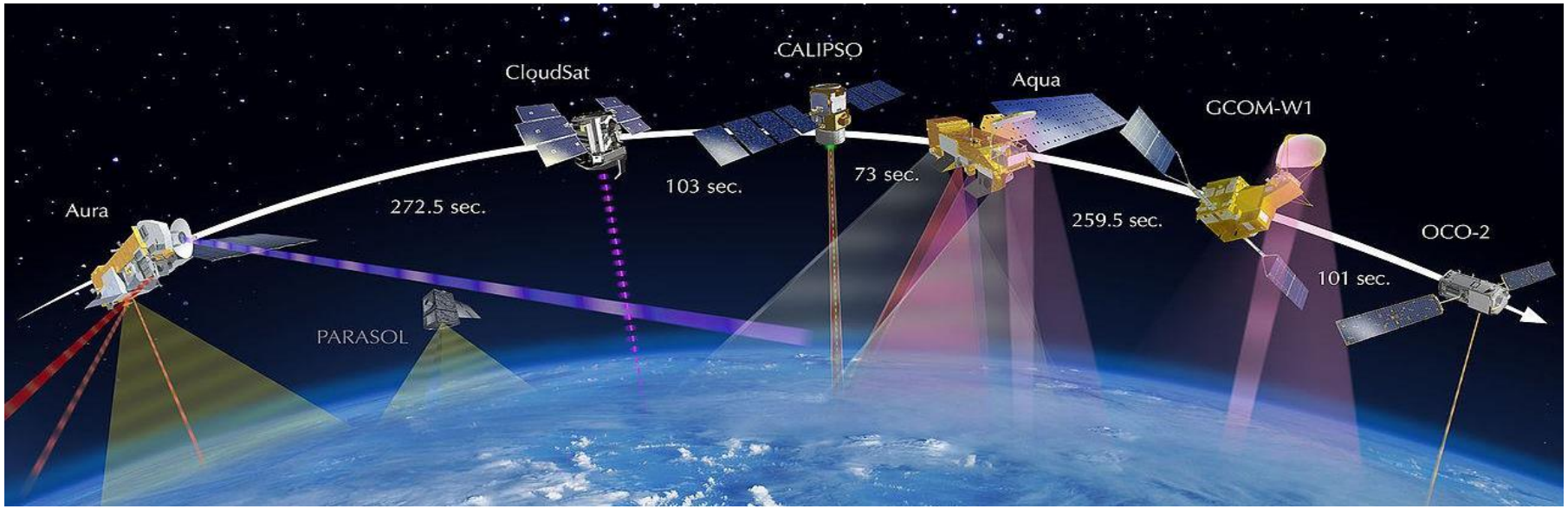
- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

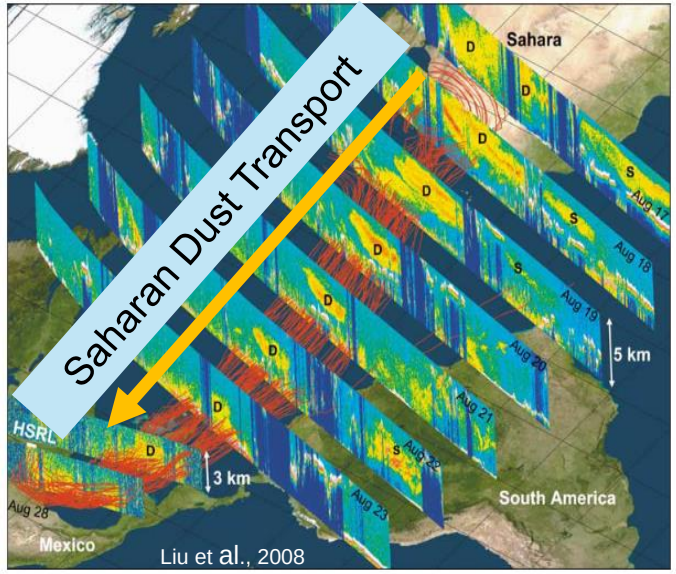


Part 1 Review

CALIPSO Refresher

- In 2006, NASA and CNES launched CALIPSO the NASA A-train as a dedicated polar-orbiting lidar to measure the vertical distribution of aerosols and clouds at both 532 and 1064 nm.
- Helped validate cloud lifetimes and aerosol transport in global models
- Ceased operations in 2023
- Provided unprecedented opportunity to track the vertical distribution of aerosols and clouds globally



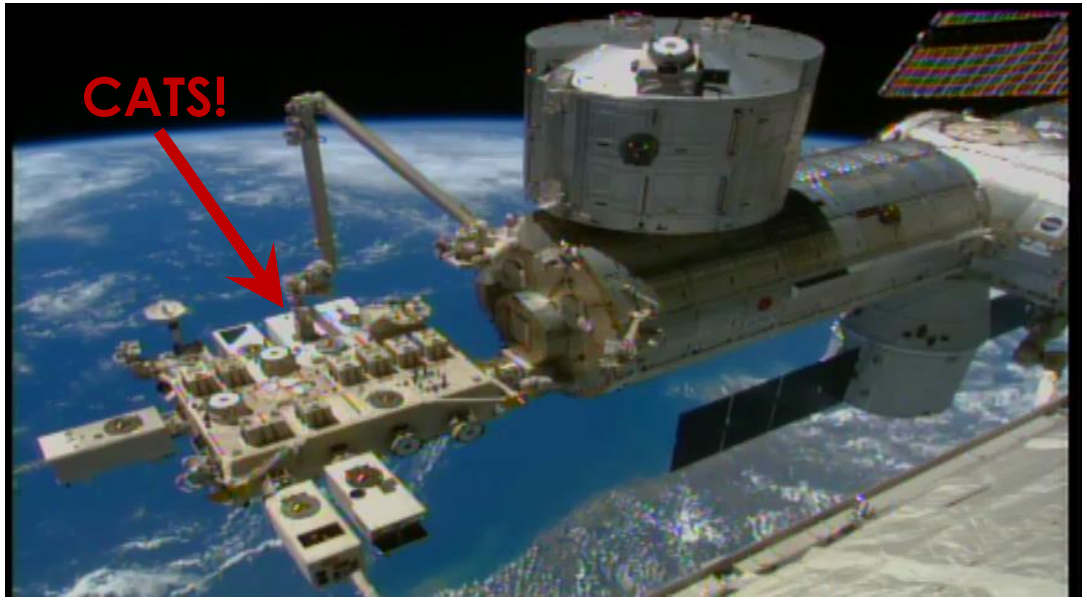


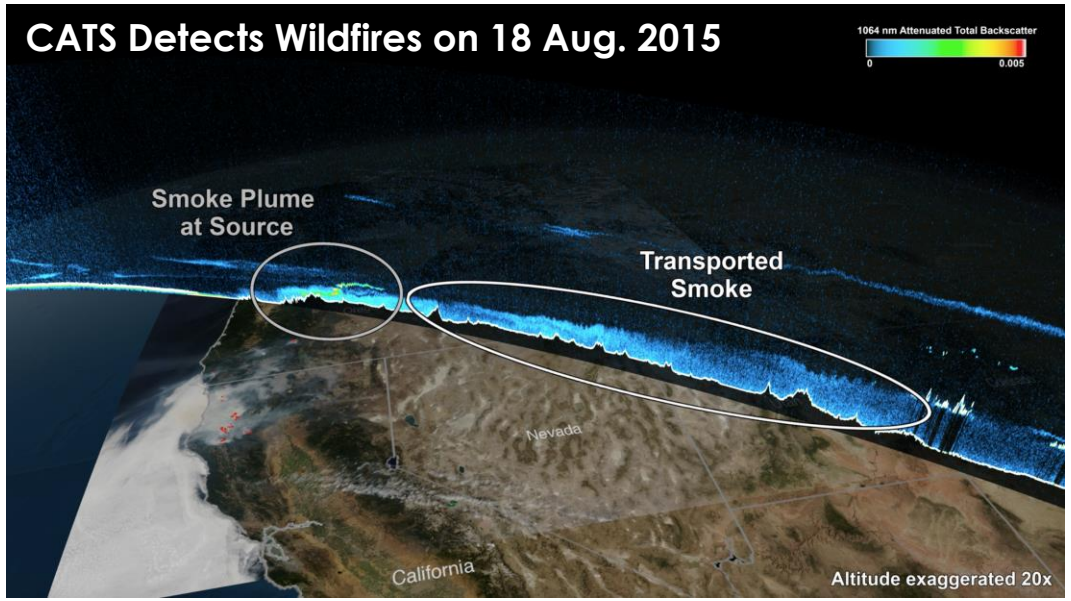
CATS Refresher

The **C**loud-**A**erosol **T**ransport **S**ystem (CATS) was designed as a tech demo (6-month lifetime) utilizing the **I**nternational **S**pace **S**tation (ISS) low inclination orbit as an affordable Earth Science platform to:

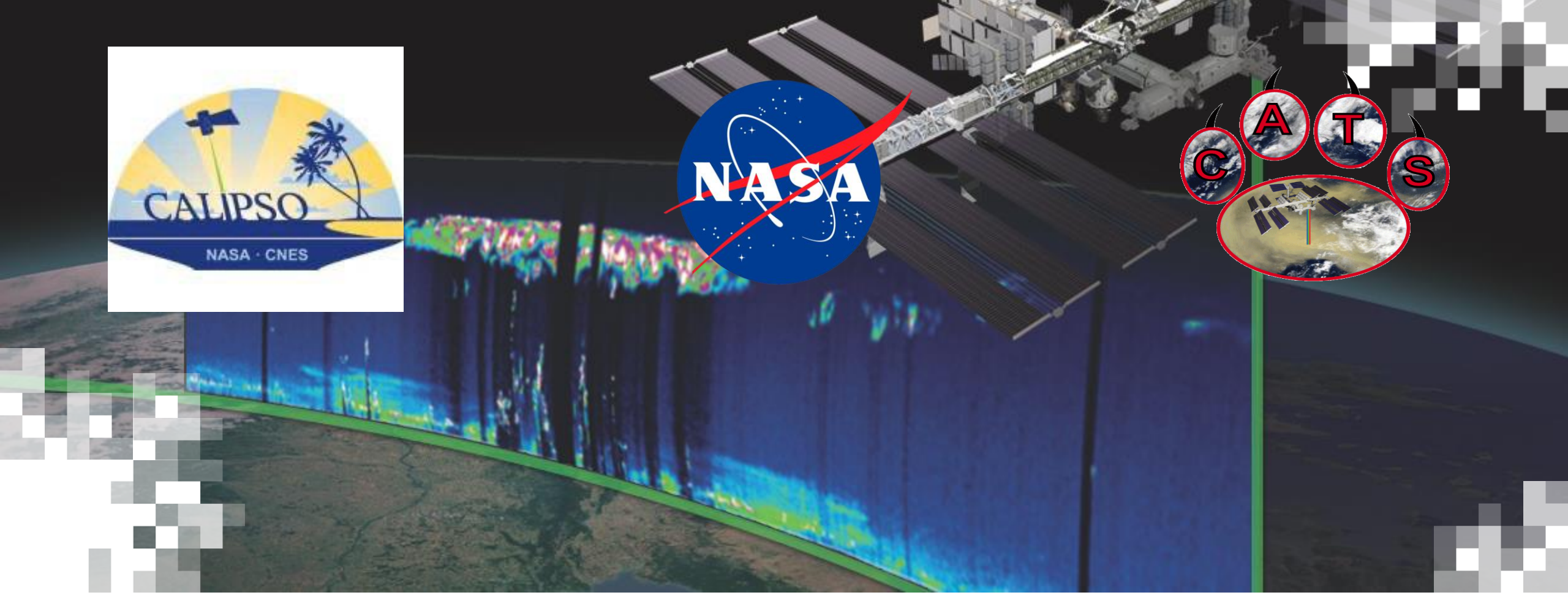
- Complement CALIPSO data record with diurnally varying cloud/aerosol vertical profiles
- Monitor dynamic events such as wildfires and volcanic eruptions
- Was the first spaceborne lidar to provide data products in near real-time (within 6 hours)
- Primarily operated at 1064 nm but with some 532 nm measurements as well

CATS operated on the ISS for 33 months and fired 200+ billion laser shots.



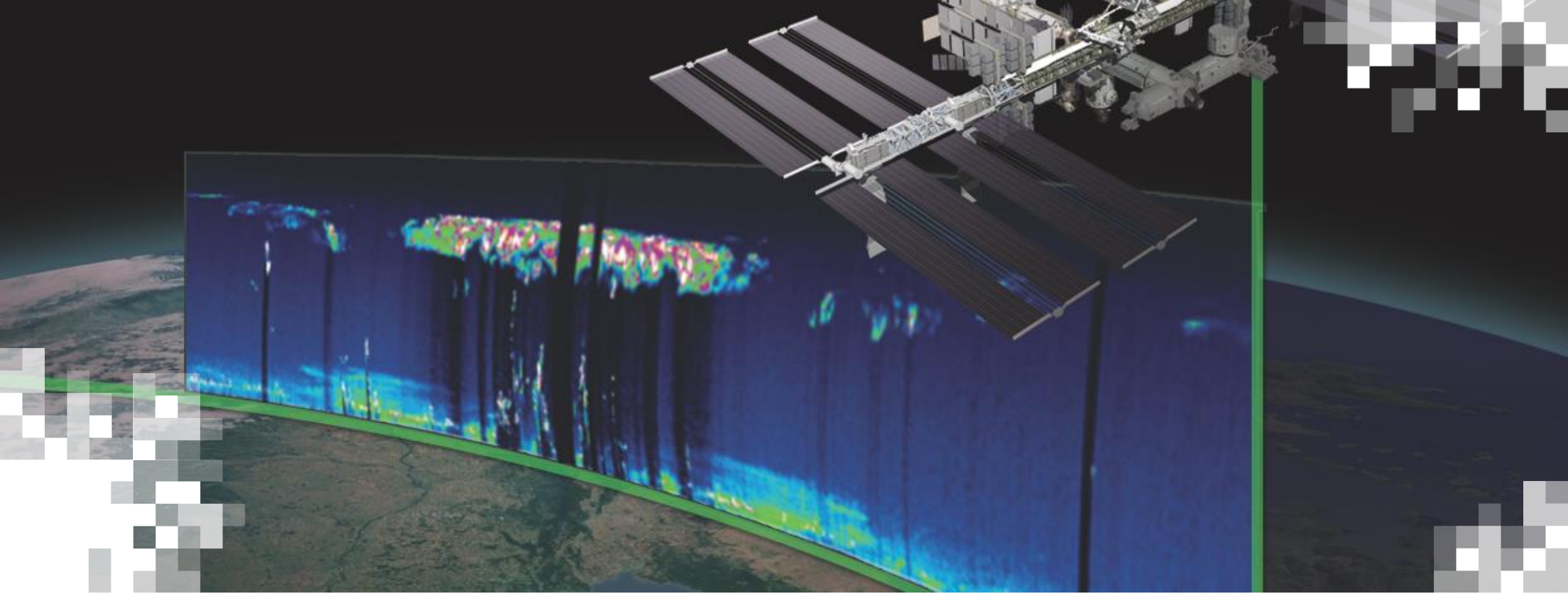


https://cats.gsfc.nasa.gov/



Learning Check 1

What are two differences between CALIPSO and CATS?



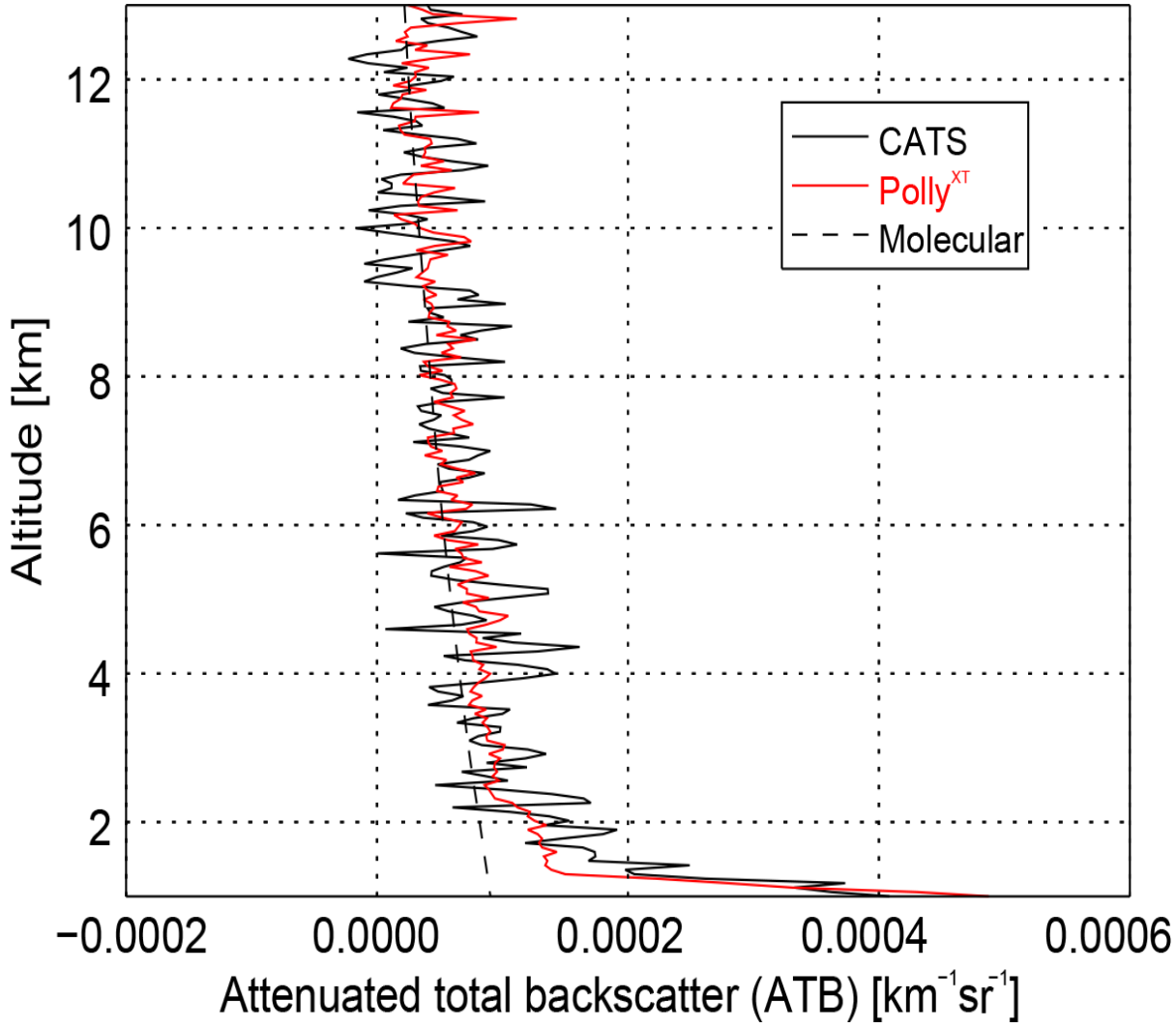
Observations to Feature Type: Theory

We measured photons, what's next? Calibrate the signal.

For backscatter lidars, the return signal is normalized to the Rayleigh profile in the upper atmosphere to compute the calibration constant (C).

Calibrating a backscatter lidar requires normalizing to Molecular profile and depends on several things:

1. Signal-to-noise ratio (SNR) in the calibration region (need molecular signal)
2. Estimates of the molecular backscatter profile
3. Aerosol loading in the calibration region



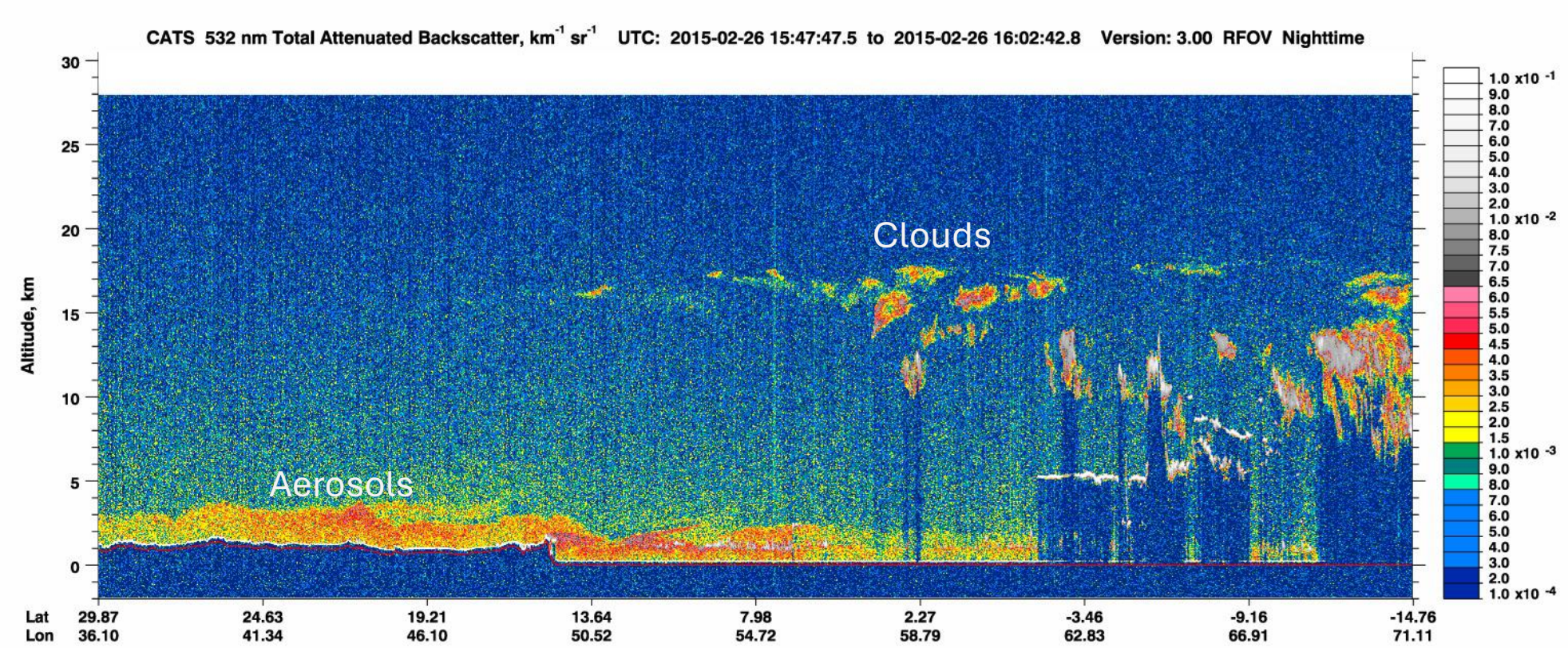
Level-1 Product: Total Attenuated Backscatter at 532 nm

This product is known as Total Attenuated Backscatter (TAB):

- "Attenuated" because it includes signal attenuation
- "Total" because it includes both molecular and particulate contributions

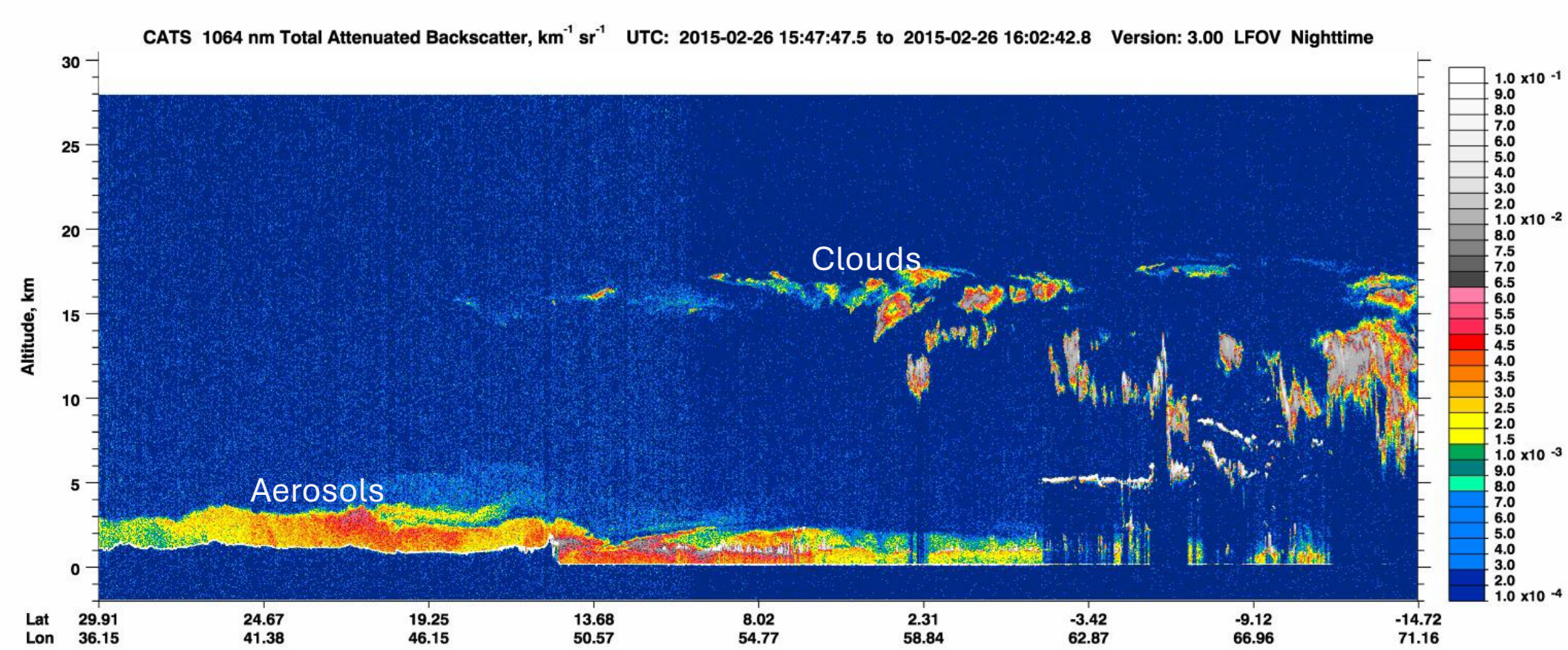
TAB is used as main Level-1 data product

- Used to compute additional level-2 products, including optical properties



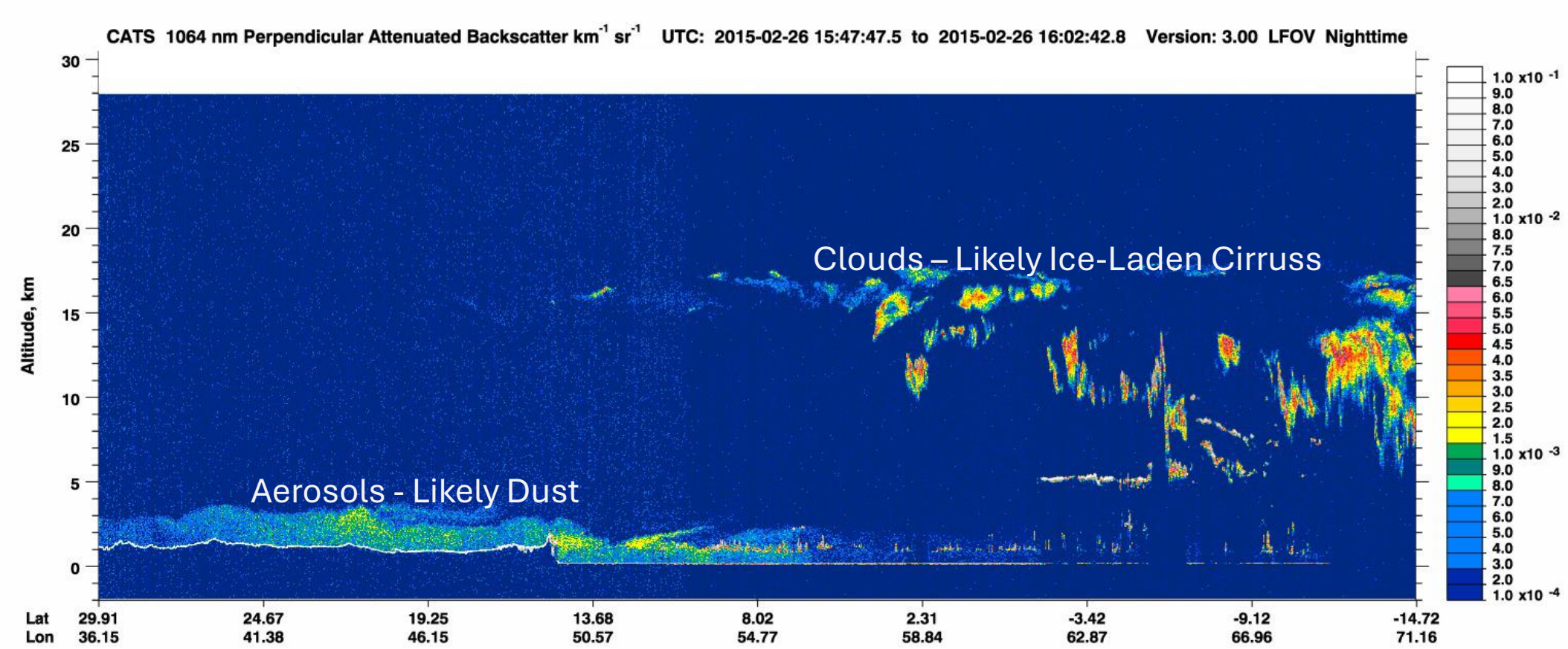
Level-1 Product: Total Attenuated Backscatter at 1064 nm

- Spaceborne lidar systems are often multi-wavelength within the ultra-violet and near-infrared.
- Exploiting the wavelength dependence of the returned signal provides information on particle (cloud, aerosol) size.



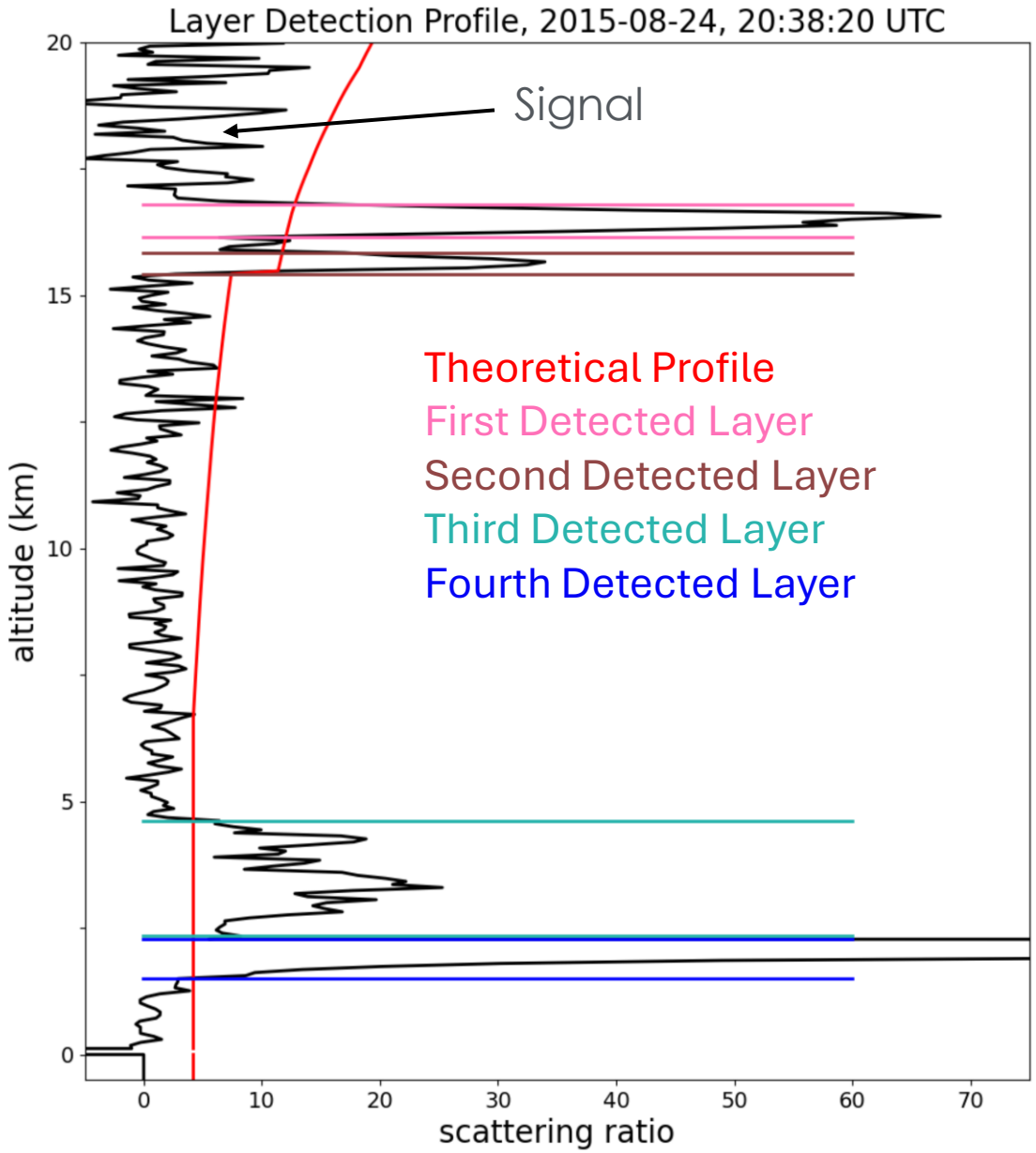
Level-1 Product: Perpendicular Attenuated Backscatter

- Lidar systems transmit polarized light.
- Particles in the atmosphere can preferentially orient the returned light parallel and perpendicular to the transmitted light.
- Perpendicular returns are a signature of non-spherical particles and are smaller than the total signal.
- Non-spherical particles are indicative of ice clouds and dust



Level-2: Feature Detection

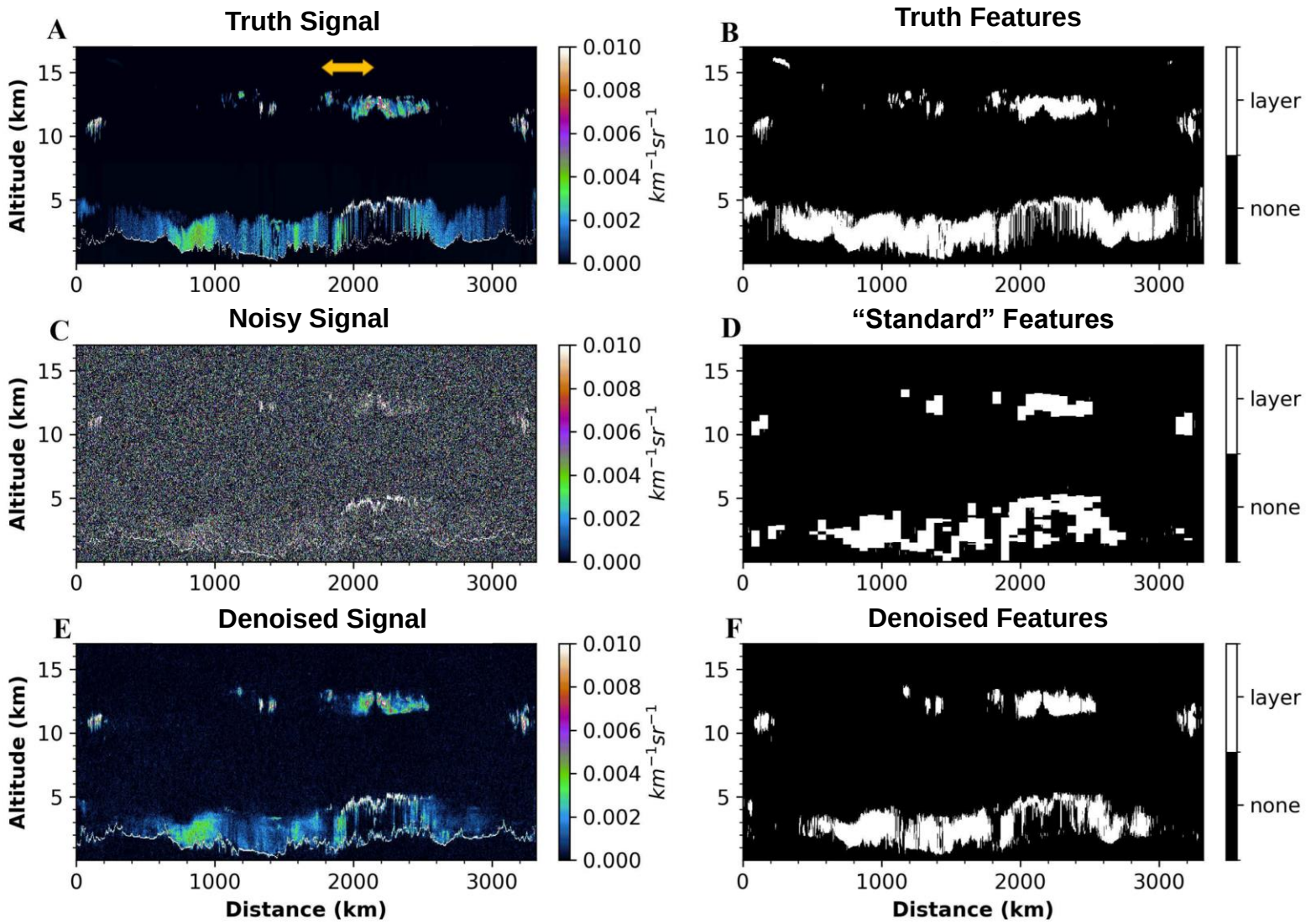
- To detect atmospheric features (or layers) (i.e., aerosols and clouds), algorithms search for deviations from the theoretical molecular(Rayleigh) signal.
- Using this approach, numerous atmospheric features may be detected within the column.
- For fainter, tenuous features, horizontal averaging is often used to boost signal-to-noise ratio.



Machine Learning for De-Noising Noisy Daytime Lidar Data

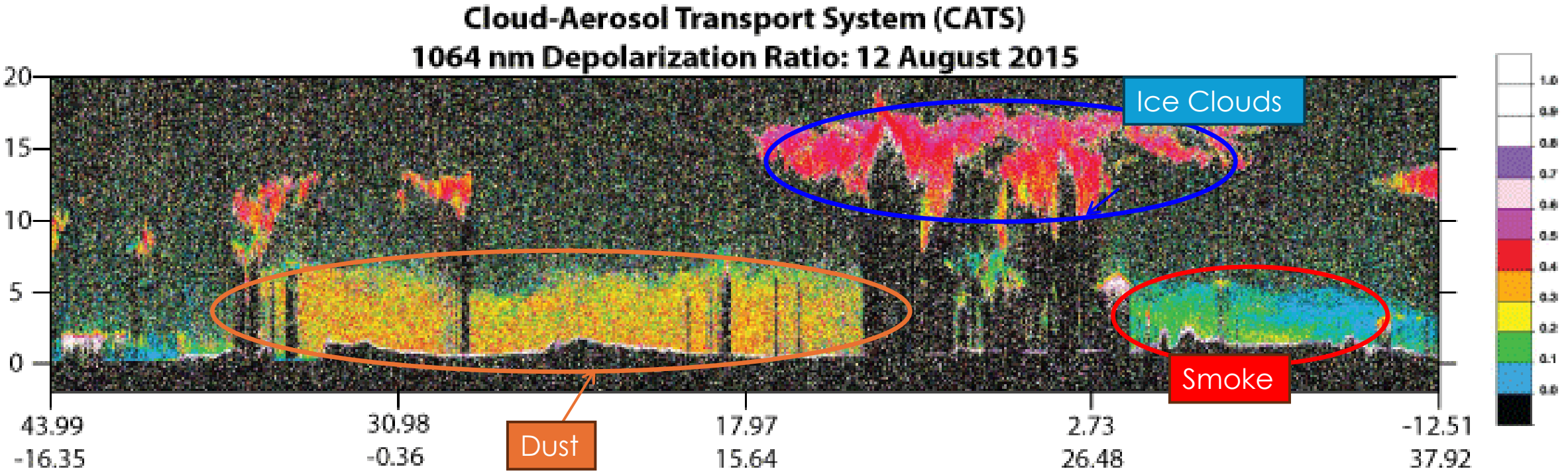
- Recently, Selmer et al., [2024] demonstrated the utility of signal denoising using autoencoders during daytime viewing conditions, when lidar SNR is plagued by solar background.

- ***This technique enables feature detection at raw data product resolution.***



Depolarization Ratio

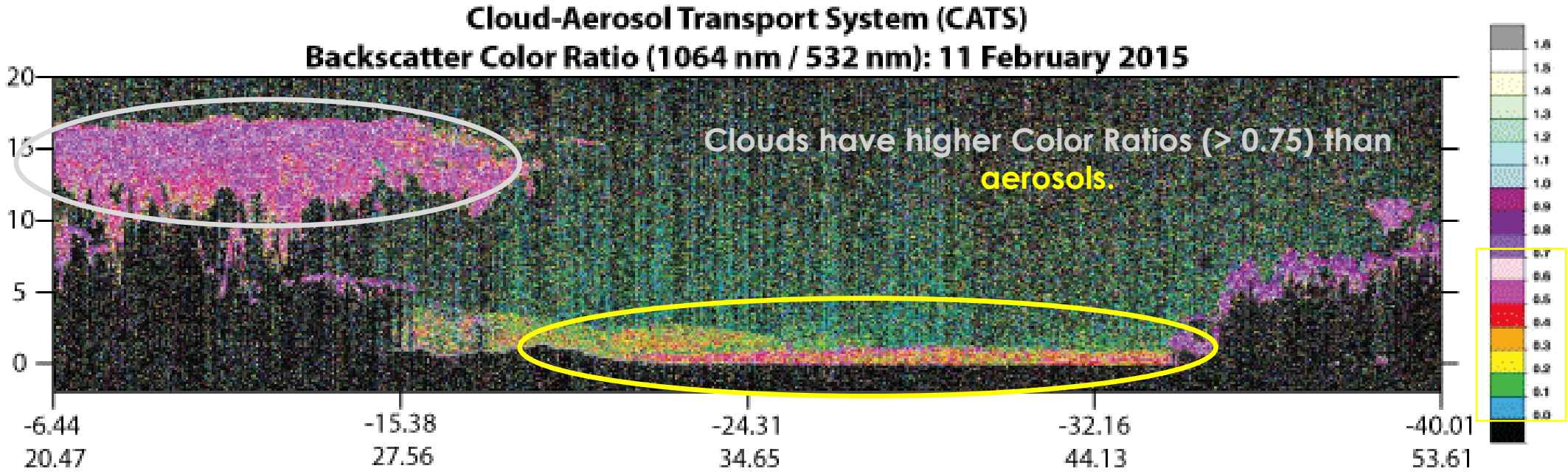
- Non-spherical particles cause signal depolarization and a perpendicular return.
- Spherical particles (water droplets) do not appreciably depolarize the signal.
- Features have substantially different degrees of depolarization. Thus, the ratio of perpendicular to parallel polarized signal can be used to identify these features.



Color Ratio

Provides information on spectral dependence of scattering properties of an atmospheric layer (particle size)

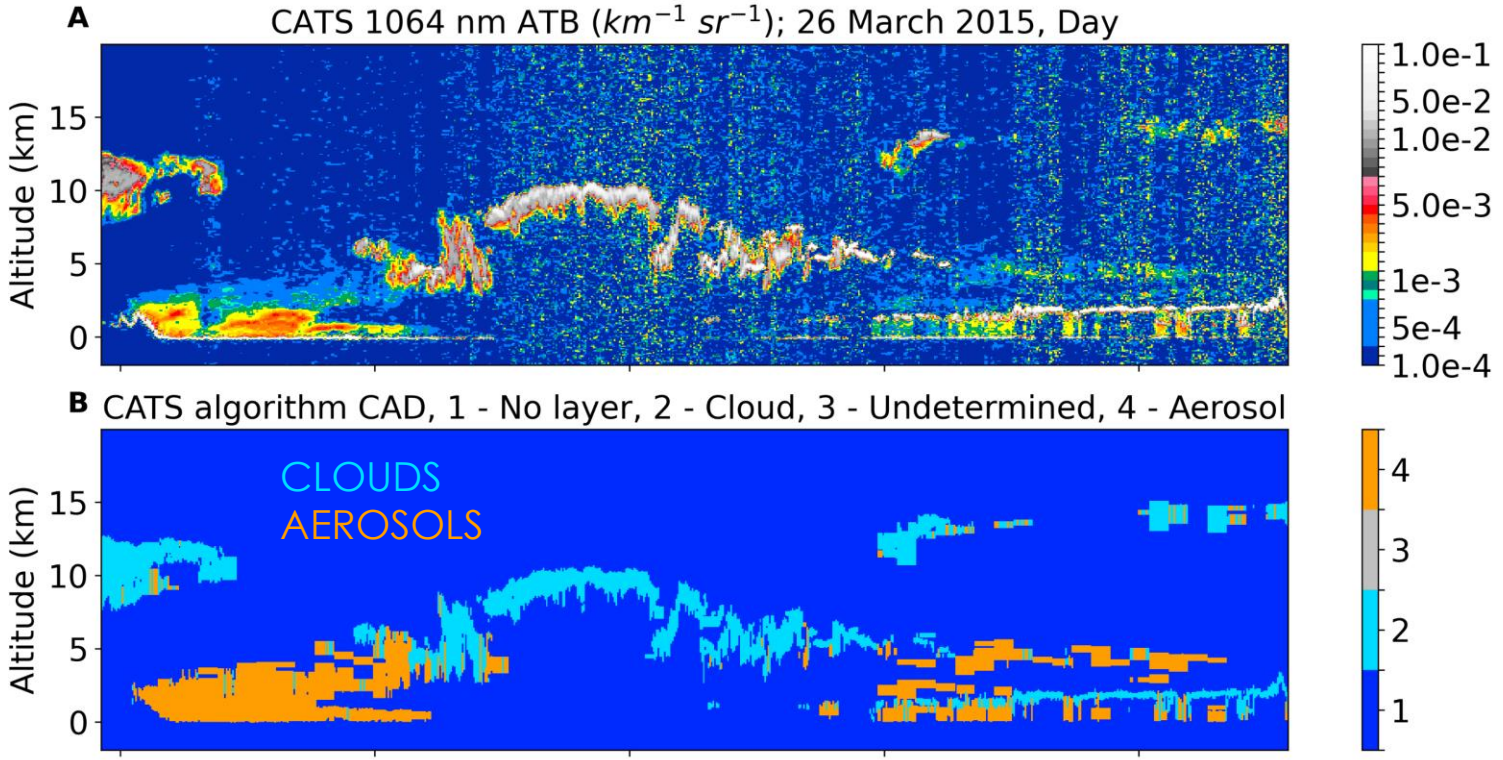
- Clouds: Cirrus: 0.60 to 1.0 - Water Clouds: 0.80 to 1.40
- Aerosols: 0.0 to 0.60
- Color ratio is the ratio of the signal at both wavelengths integrated over the feature.



Color Ratio = 1064 nm Backscatter / 532 nm Backscatter

Level-2: Cloud–Aerosol Discrimination

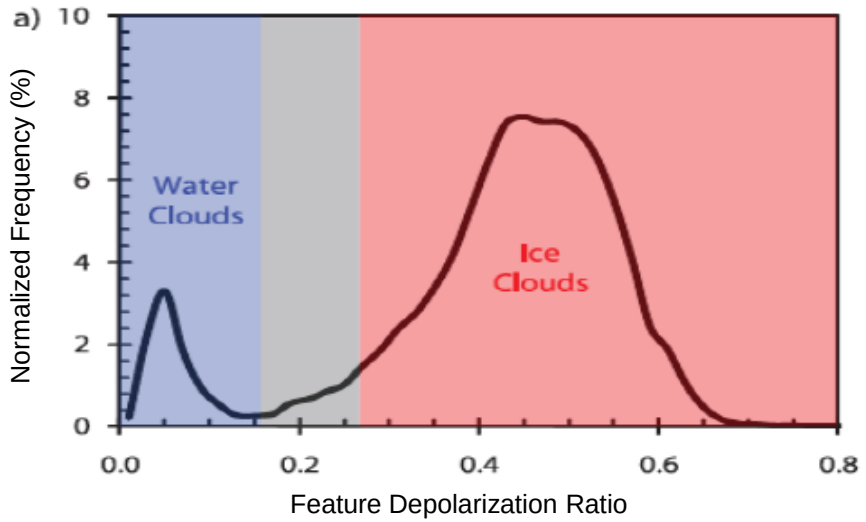
- Following feature detection, information (primarily color ratio) is used to first discriminate clouds from aerosols.
- Reminder:
  - Clouds have color ratios ~0.6 – 1.4
  - Aerosols have color ratios ~0 – 0.6

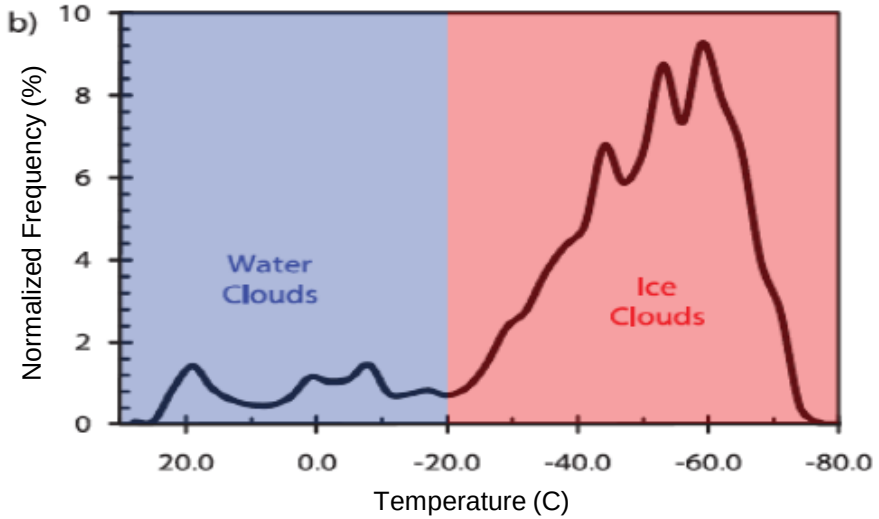


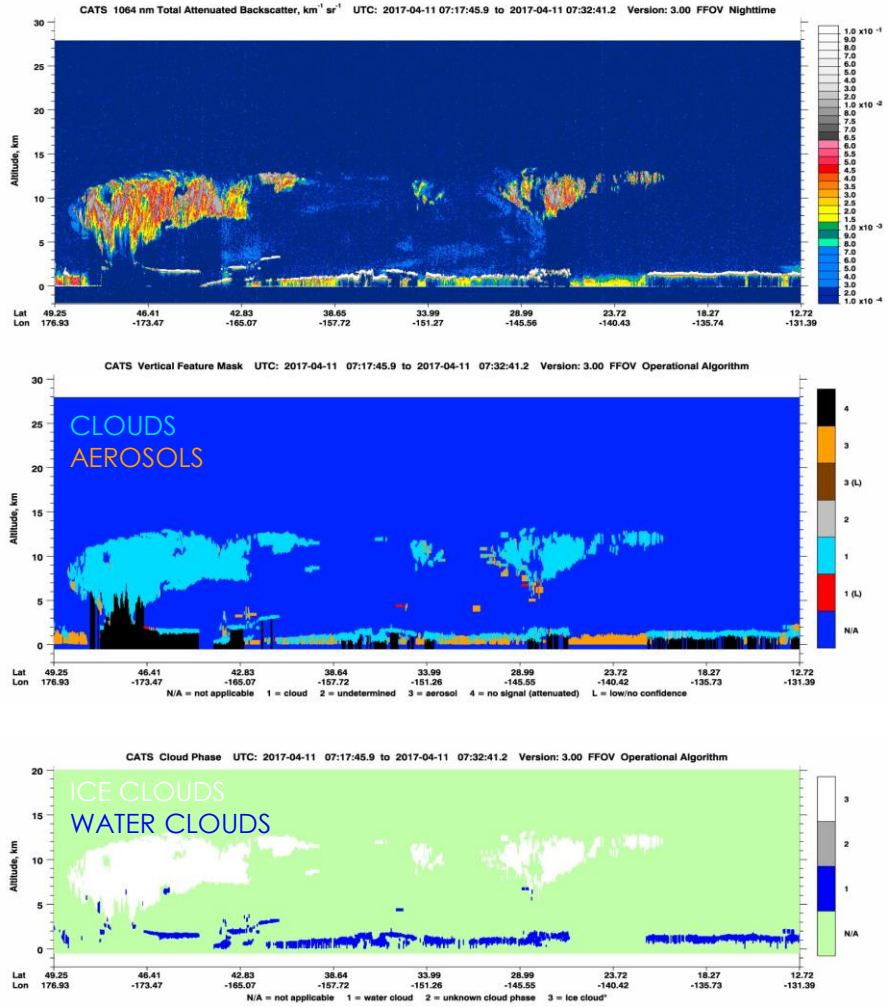
Yorks et al., 2020

Level-2: Cloud Phase

- Using depolarization ratio and temperature, clouds are classified as ice or water.



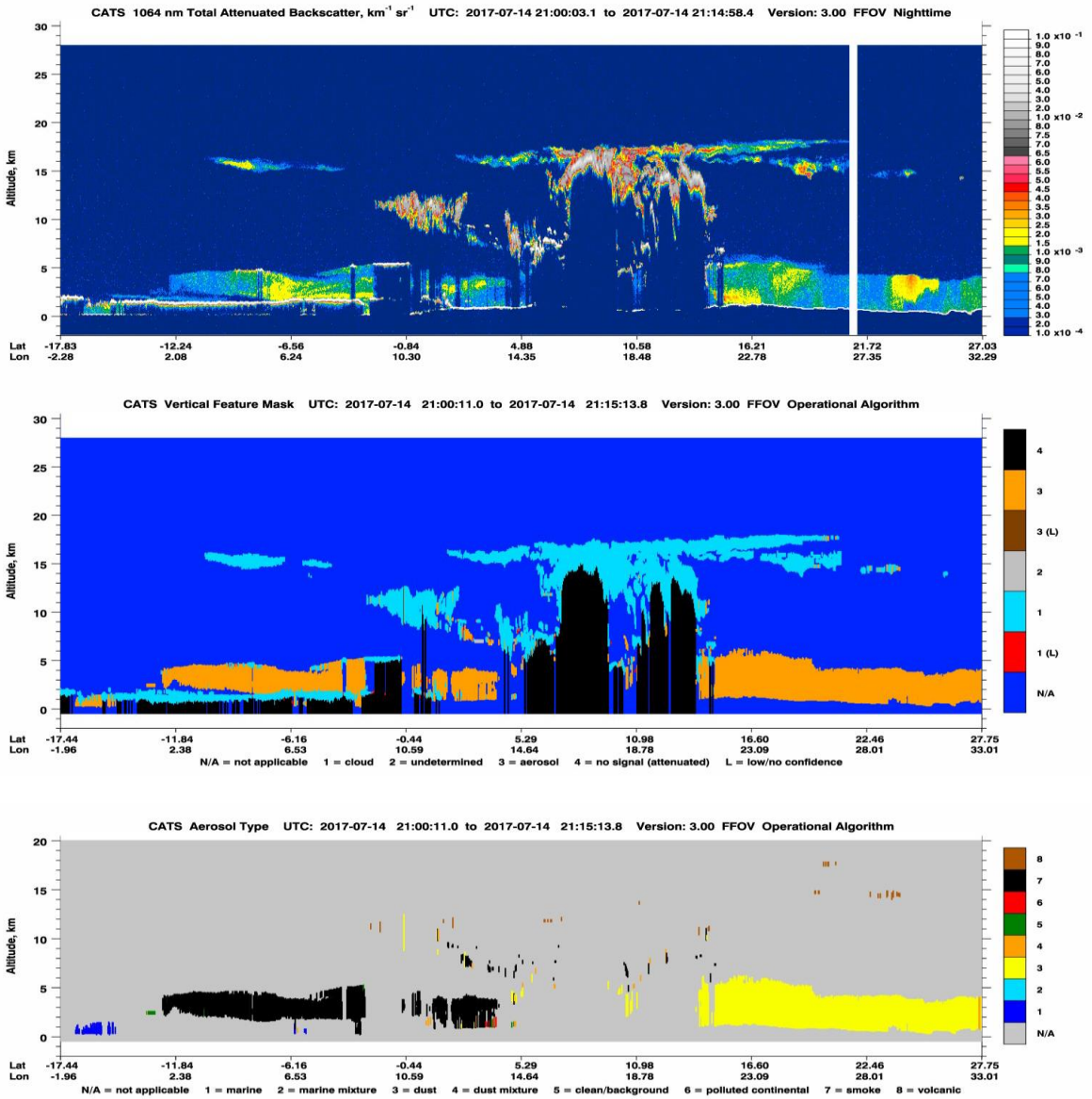




Level-2: Aerosol Type

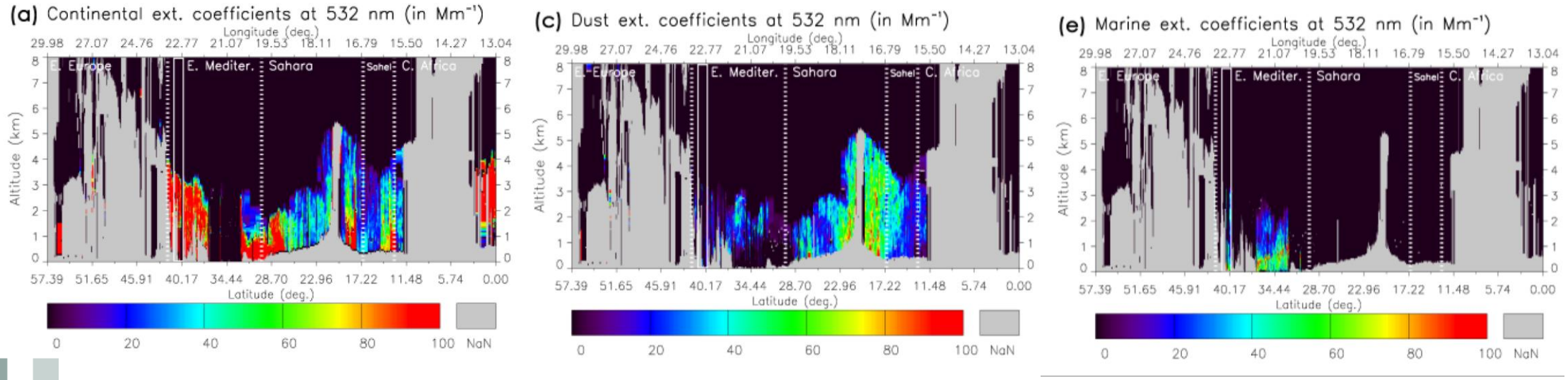
After a feature is classified as aerosol, the following information may be used to assign an aerosol type:

- Feature Depolarization Ratio
- Feature Thickness
- Underlying Surface Type
- Feature Elevation
- Model Information

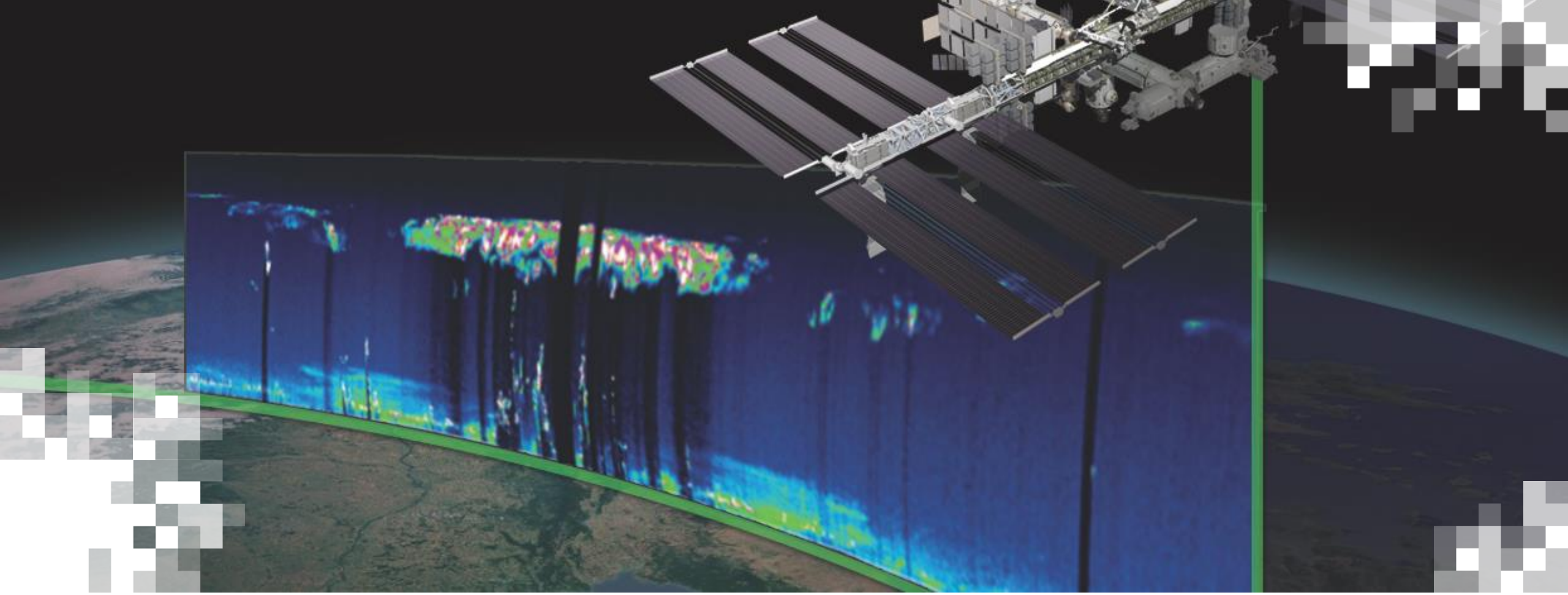


Optical Property Retrievals

- To retrieve optical properties, such as extinction, elastic backscatter lidar systems typically require assuming an extinction-to-backscatter ratio – known as lidar ratio.
- One of the primary purposes of classifying cloud phase and aerosol type is to assign a corresponding lidar ratio for optical property retrievals.
- Aerosol lidar ratios typically range from 10–80 Steradians (Sr), while cloud lidar ratios typically range from 10–30 Sr.
- The higher the lidar ratio, the more absorbing the particulate.
- HSRL lidars do not need to assume a lidar ratio and enable direct retrievals of optical properties.



Georgoulias et al., 2020

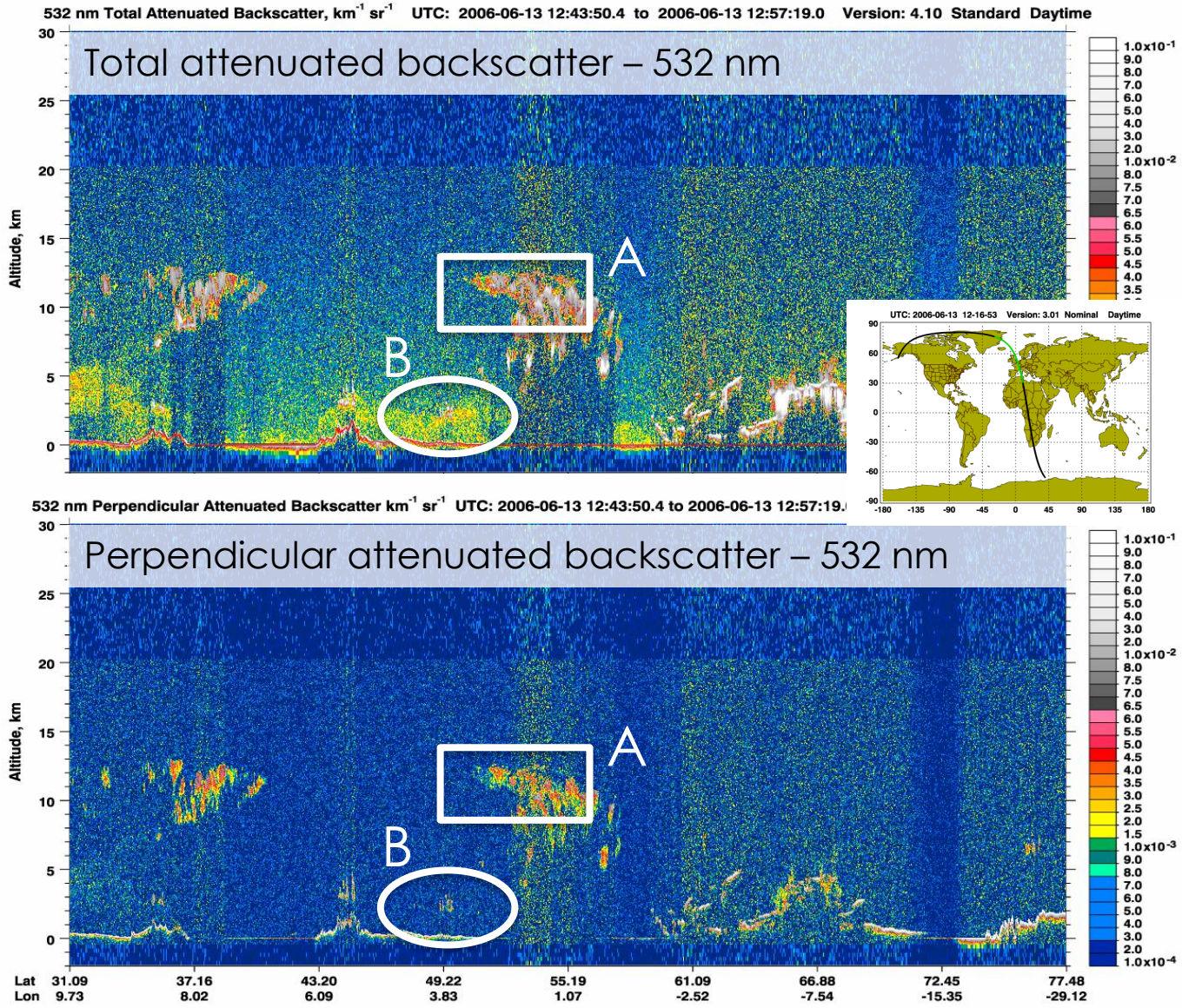


Observations to Feature Type: Real World Example

CALIPSO Case Study: Level-1 to Level-2 Products

Level 1 Products

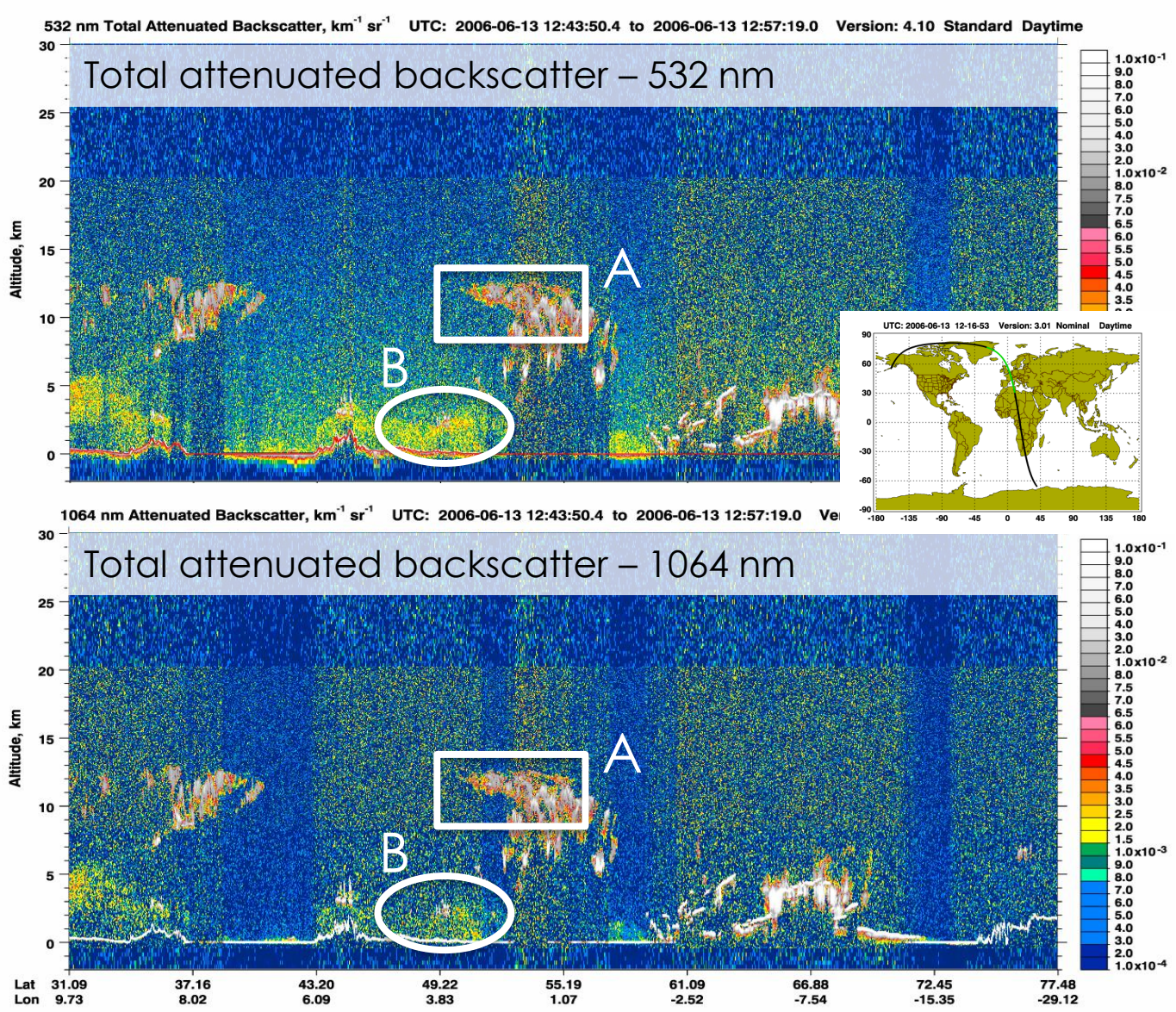
- Measurements of signal depolarization allow the discrimination of spherical and non-spherical cloud and aerosol particles (Winker et al. 2007)
- If enhanced signal in both images then non-spherical particles (Region A)
- If enhanced signal in total backscatter image but little or no enhancement in the perpendicular image, then spherical particles (Region B)



CALIPSO Case Study: Level-1 to Level-2 Products

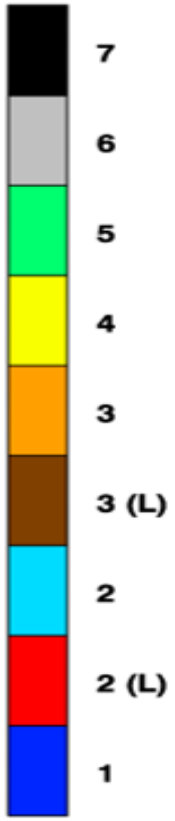
Level 1 Products

- Two-wavelength signals provide qualitative information on particle size and aid in discrimination of cloud and aerosol and the identification of aerosol type (Winker et al. 2007)
- If same intensity in both channels, coarse, larger particles
- If signal more intense in the 532 channel: fine, smaller particles
- Region A: coarse non spherical
  - cirrus cloud?
- Region B: fine spherical
  - urban pollution?



CALIPSO Case Study: Level-1 to Level-2 Products

Level 2 Products



Totally Attenuated

Subsurface

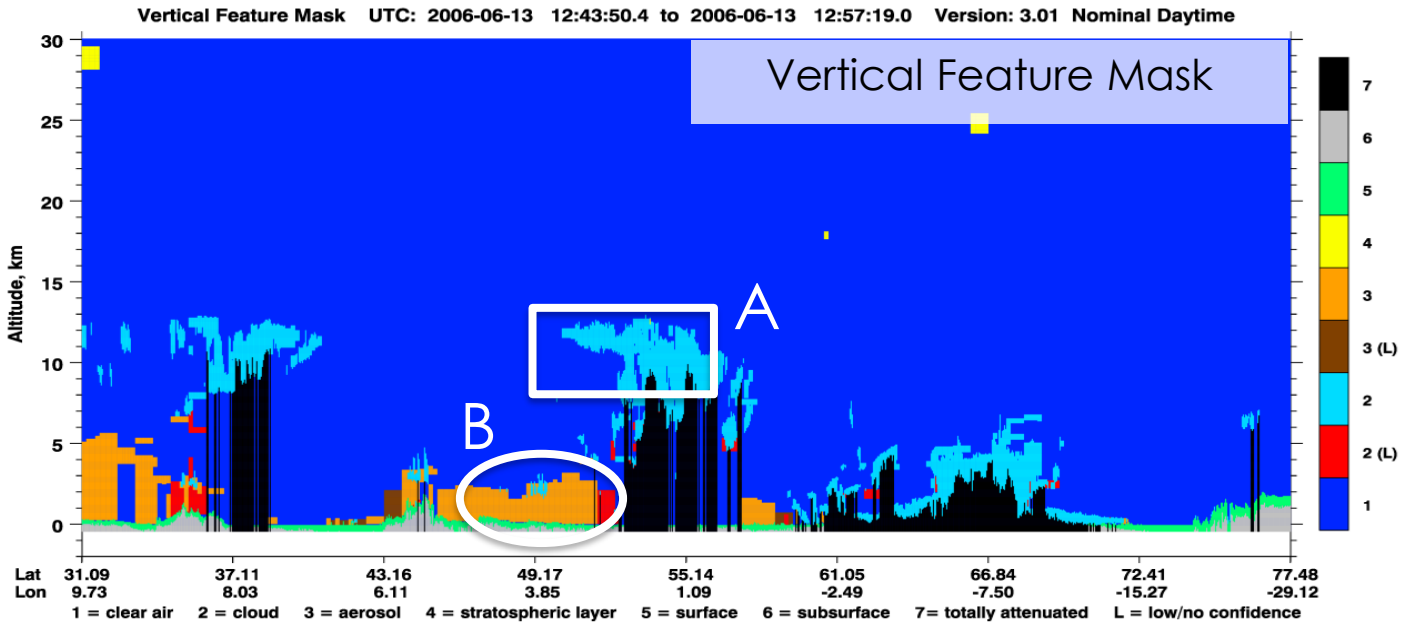
Surface

Stratospheric layer

Aerosol

Cloud

Clear air



Feature mask indicates Region A is cloud and Region B is aerosol

CALIPSO Case Study: Level-1 to Level-2 Products

Level 2 Products

Smoke

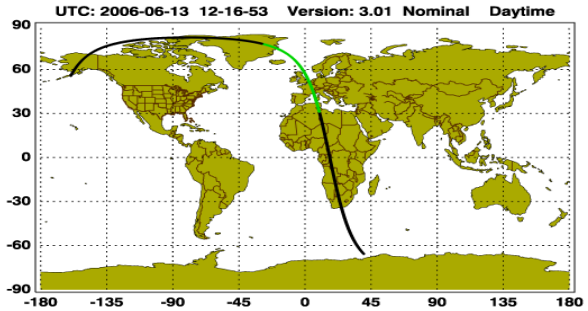
Polluted Dust

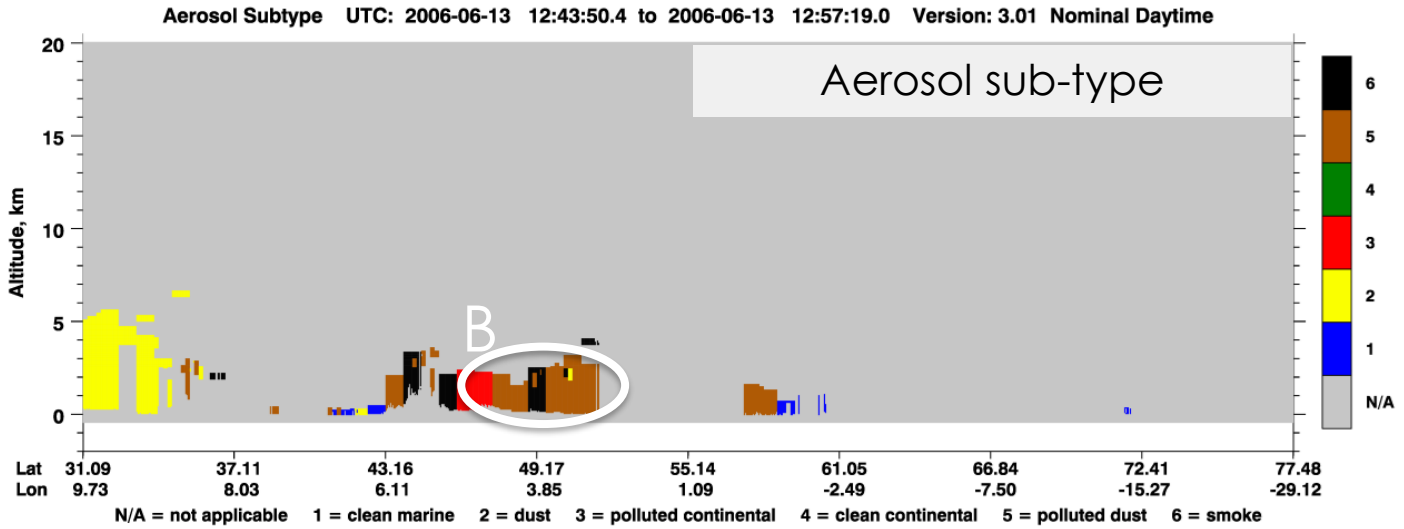
Clean Continental

Polluted Continental

Dust

Clean Marine

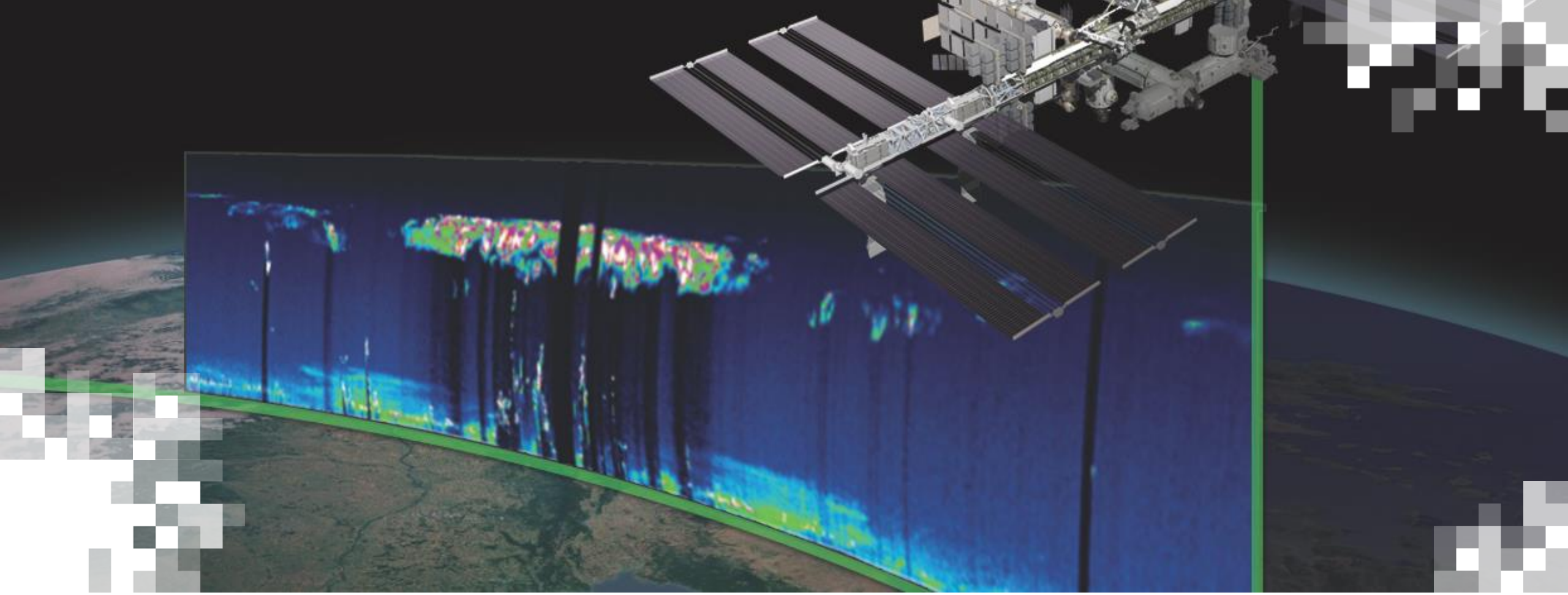




Aerosol sub-type indicates polluted dust or smoke

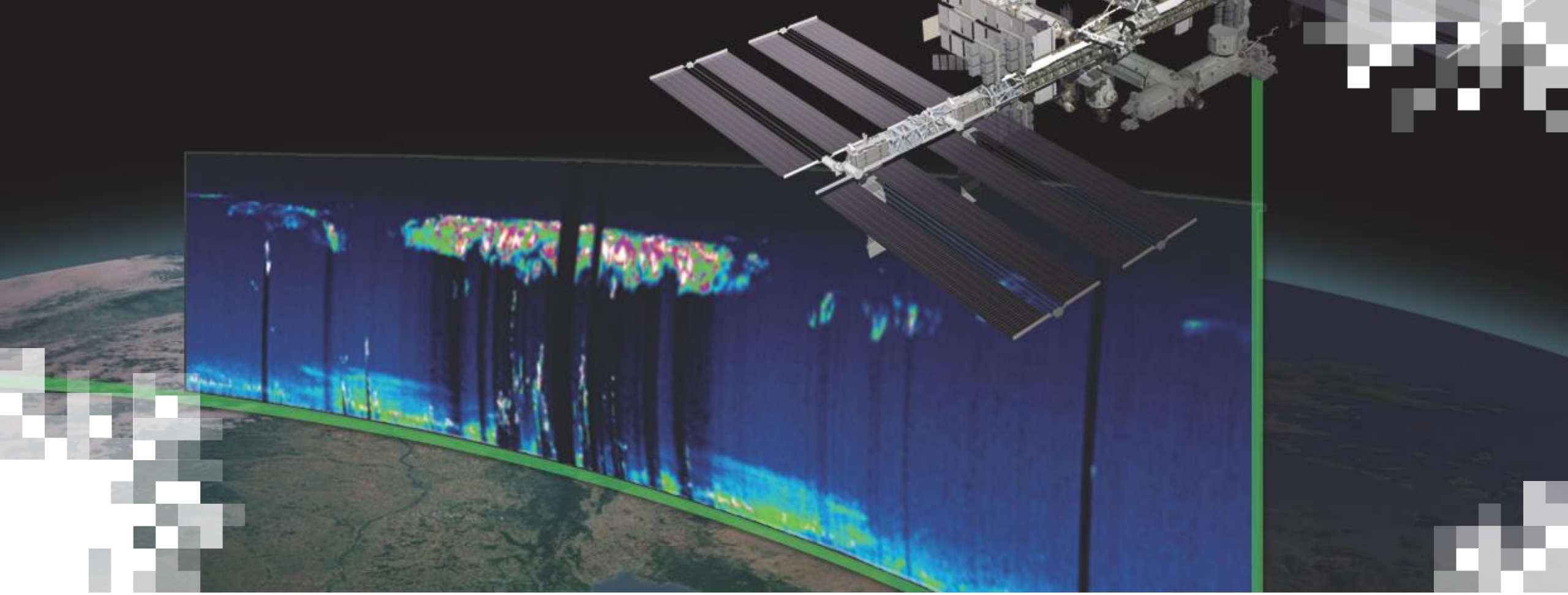
Level 1 analysis indicates fine, non-spherical particles

Potentially Secondary Organic Aerosol (SOA)?

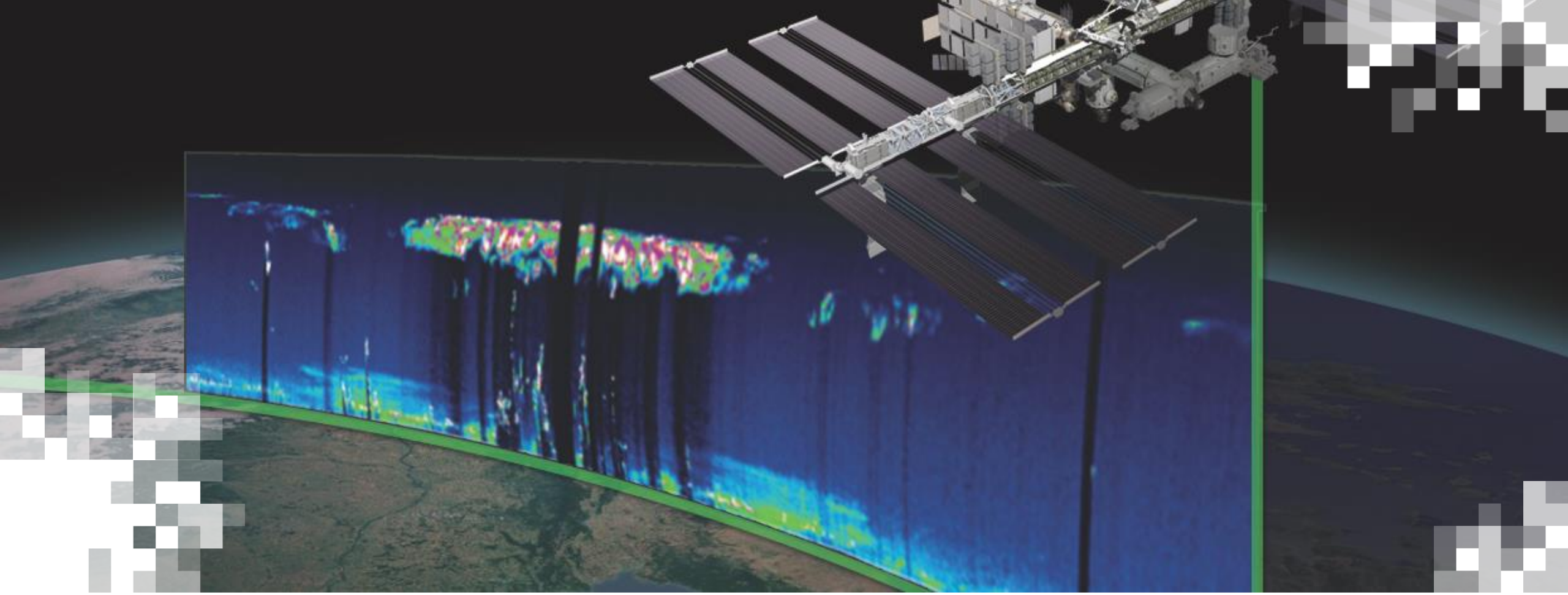


Real World Example

Starting with an event, find and interpret lidar curtain



Did CALIPSO fly over my event of interest?
NASA Worldview



Find Lidar curtains

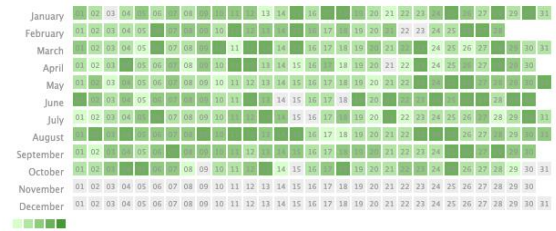
Spaceborne Lidar Quick-Looks: Great for Case Studies

CATS

http://cats.gsfc.nasa.gov/data/browse

Data Availability Calendar

Granule Availability 2017



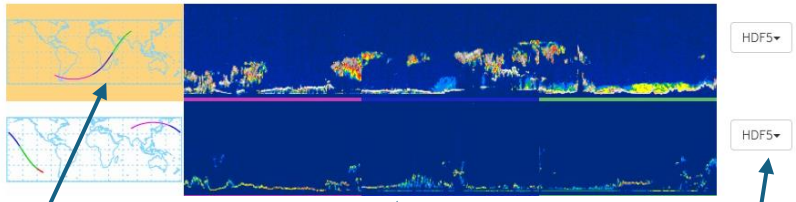
CATS data users, please note the instrument modes and latest data versions below:
- *Mode 7.1:* data from 10 Feb. through 21 March 2015, L1B version 3.00 & L2O version 3.00
- *Mode 7.2:* data from 25 Mar. 2015 through 29 Oct. 2017, L1B version 3.00 & L2O version 3.00

For more information on these data products, please see the latest documentation.

2017-10-29

00:26 UTC

01:10 UTC



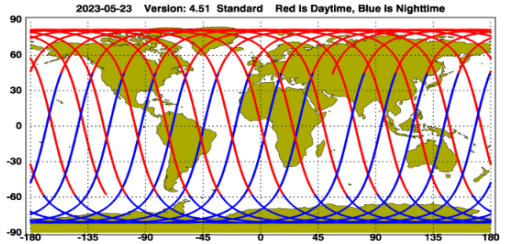
Night (Orange) Day (White)

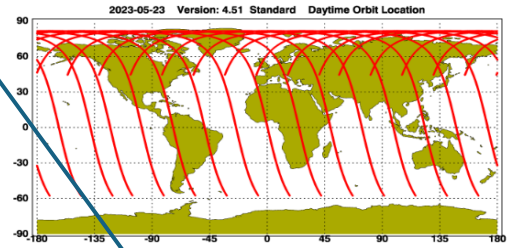
Click to View Quick-Look

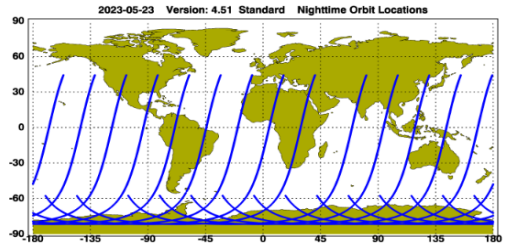
Link to Download Individual Files for Case

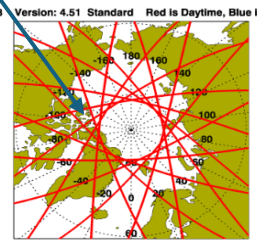
CALIPSO

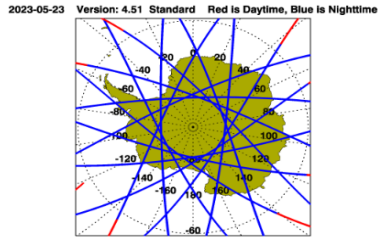
https://www-calipso.larc.nasa.gov/products/lidar/browse_images/

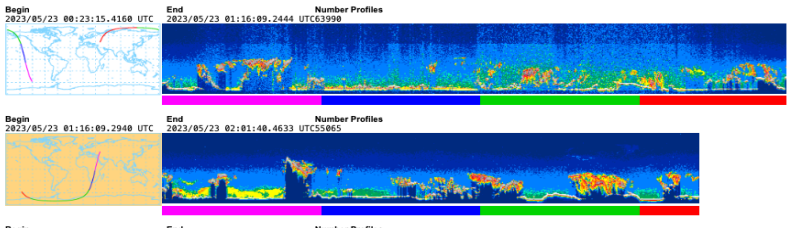












Spaceborne Lidar Data Access

For accessing and downloading large volumes of CALIPSO and CATS data, use the NASA Atmospheric Science Data Center (ASDC).

CALIPSO: https://asdc.larc.nasa.gov/project/CALIPSO

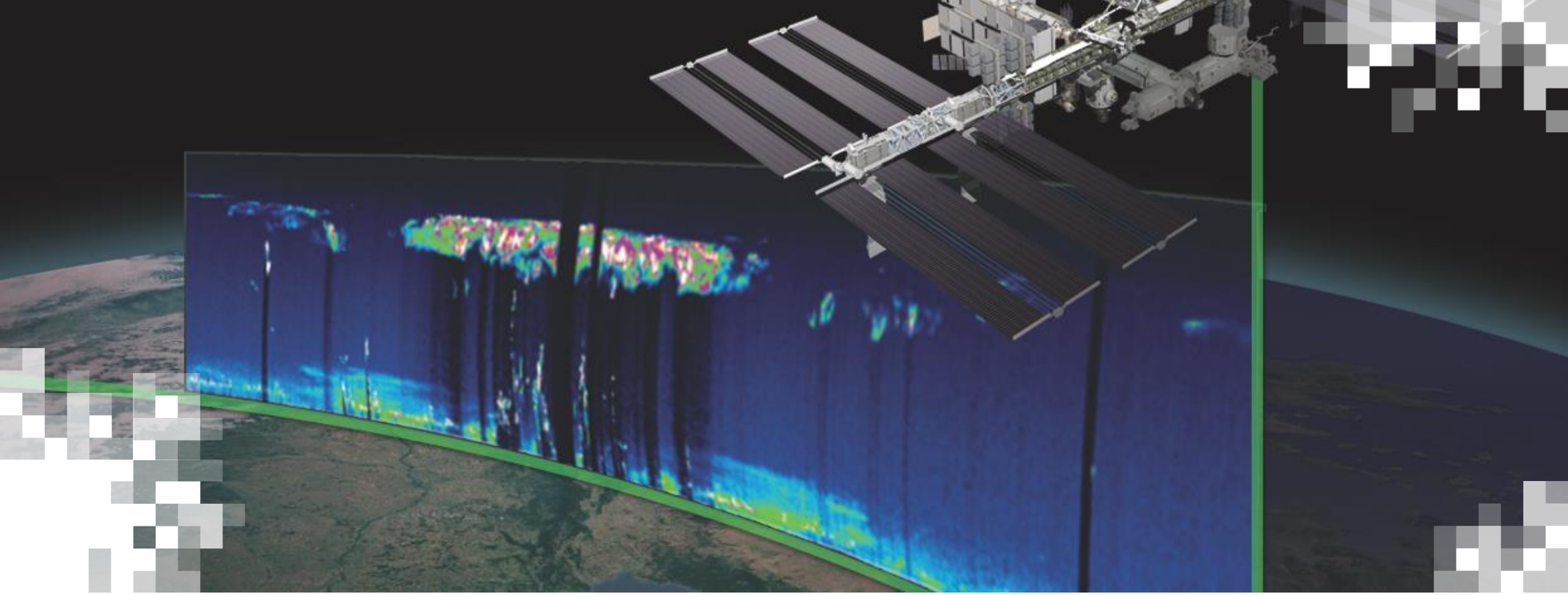
Level 3 | Level 2 | **Level 1B** | Level 0

Collection	Disciplines	Spatial	Temporal
CAL_IIR_L1-Prov-V1-13_V1-13 CALIPSO Imaging Infrared Radiometer Level 1B Radiance data, Provisional V1-13	Aerosols, Clouds, Radiation Budget	Spatial Coverage: (S: -90, N: 90), (W: -180, E: 180)	Temporal Coverage: 1993-01-01 - 1993-01-01, 2020-10-01 - Present
CAL_IIR_L1-Standard-V2-00_V2-00 CALIPSO Imaging Infrared Radiometer Level 1B Radiance data, Standard V2-00	Aerosols, Clouds, Radiation Budget	Spatial Coverage: (S: -90, N: 90), (W: -180, E: 180) Horizontal Resolution Range: 1 km - < 10 km or approximately .01 degree - < .09 degree	Temporal Coverage: 2006-06-12 - Present Temporal Resolution Range: 1 second - < 1 minute Temporal Resolution: 8.15 seconds
CAL_IIR_L1-Standard-V2-01_V2-01 CALIPSO Imaging Infrared Radiometer (IIR) Level 1B Radiance, Standard V2-01	Aerosols, Clouds, Radiation Budget	Spatial Coverage: (S: -90, N: 90), (W: -180, E: 180)	Temporal Coverage: 1993-01-01 - 1993-01-01, 2020-10-01 - Present
CAL_LID_L1-Standard-V4-10_V4-10 CALIPSO Lidar Level 1B profile data, V4-10	Aerosols, Clouds, Radiation Budget	Spatial Coverage: (S: -90, N: 90), (W: -180, E: 180)	Temporal Coverage: 2006-06-12 - 2021-09-06
CAL_LID_L1-Standard-V4-11_V4-11 CALIPSO Lidar Level 1B profile data, V4-11	Aerosols, Clouds, Radiation Budget	Spatial Coverage: (S: -90, N: 90), (W: -180, E: 180)	Temporal Coverage: 2020-07-01 - 2022-01-19
CAL_LID_L1-Standard-V4-51_V4-51 CALIPSO Lidar Level 1B profile data, V4-51	Aerosols, Clouds, Radiation Budget	Spatial Coverage: (S: -90, N: 90), (W: -180, E: 180)	Temporal Coverage: 2006-06-12 - 2023-06-30
CAL_LID_L15-Standard-V1-00_V1-00 CALIPSO Lidar Level 1.5 Profile, V1-00	Aerosols	Spatial Coverage: (S: -90, N: 90), (W: -180, E: 180)	Temporal Coverage: 2006-06-12 - 2020-08-01
CAL_LID_L15-Standard-V1-01_V1-01 CALIPSO Lidar Level 1.5 Profile, V1-01	Aerosols	Spatial Coverage: (S: -90, N: 90), (W: -180, E: 180)	Temporal Coverage: 2020-07-01 - 2022-01-19

CATS: https://asdc.larc.nasa.gov/project/CATS-ISS

Level 2 | **Level 1B**

Collection	Disciplines	Spatial	Temporal
CATS-ISS_L1B_D-M7.1-V3-00_V3-00 CATS-ISS Level 1B Day Mode 7.1 Version 3-00	Aerosols, Clouds	Spatial Coverage: (S: -52, N: 52), (W: -180, E: 180)	Temporal Coverage: 2015-02-10 - 2015-03-21 Temporal Resolution: .051 second
CATS-ISS_L1B_D-M7.2-V3-00_V3-00 CATS-ISS Level 1B Day Mode 7.2 Version 3-00	Aerosols, Clouds	Spatial Coverage: (S: -52, N: 52), (W: -180, E: 180)	Temporal Coverage: 2015-03-25 - 2017-10-29 Temporal Resolution: .051 second
CATS-ISS_L1B_N-M7.1-V3-00_V3-00 CATS-ISS Level 1B Night Mode 7.1 Version 3-00	Aerosols, Clouds	Spatial Coverage: (S: -52, N: 52), (W: -180, E: 180)	Temporal Coverage: 2015-02-10 - 2015-03-21 Temporal Resolution: .051 second
CATS-ISS_L1B_N-M7.2-V3-00_V3-00 CATS-ISS Level 1B Night Mode 7.2 Version 3-00	Aerosols, Clouds	Spatial Coverage: (S: -65, N: 52), (W: -180, E: 180)	Temporal Coverage: 2015-03-25 - 2017-10-29 Temporal Resolution: .051 second



Training Summary

Training Summary

Thank you for attending Part 2 of LiDAR Profiling Satellite Observations for Air Quality Applications!

Topics Covered Today:

1. Interpret information within lidar curtains to discern cloud phase, aerosol type, and aerosol plume altitude for a given scene ✓
    - Understand:
        - How different wavelengths are used to discern clouds from aerosols
        - The utility of depolarization ratio for information about particle shape

2. Find lidar images and data for a particular time period and location using NASA Earthdata and mission websites ✓
    - Know:
        - Where to go to see if CALIPSO or CATS passed over a target of interest
        - How to find CALIPSO and CATS Level 1 and Level 2 quick look imagery

Resources

- Useful websites:
  - CALIPSO: https://www-calipso.larc.nasa.gov/
  - CATS: https://cats.gsfc.nasa.gov/
  - ICESat-2: https://icesat-2.gsfc.nasa.gov/
  - EarthCARE: https://earth.esa.int/eogateway/missions/earthcare
- References from this presentation:

  - Pauly, R.M., Yorks, J.E., Hlavka, D.L., McGill, M.J., Amiridis, V., Palm, S.P., Rodier, S.D., Vaughan, M.A., Selmer, P.A., Kupchock, A.W. and Baars, H., 2019. Cloud-Aerosol Transport System (CATS) 1064 nm calibration and validation. Atmospheric measurement techniques, 12(11), pp.6241-6258.
  - Selmer, P., Yorks, J.E., Nowottnick, E.P., Cresanti, A. and Christian, K.E., 2024. A Deep Learning Lidar Denoising Approach for Improving Atmospheric Feature Detection. Remote Sensing, 16(15), p.2735.
  - Nowottnick, E.P., Christian, K.E., Yorks, J.E., McGill, M.J., Midzak, N., Selmer, P.A., Lu, Z., Wang, J. and Salinas, S.V., 2022. Aerosol detection from the cloud–aerosol transport system on the international space station: Algorithm overview and implications for diurnal sampling. Atmosphere, 13(9), p.1439.
  - Georgoulias, A.K., Marinou, E., Tsekeri, A., Proestakis, E., Akritidis, D., Alexandri, G., Zanis, P., Balis, D., Marenco, F., Tesche, M. and Amiridis, V., 2020. A first case study of CCN concentrations from spaceborne lidar observations. Remote Sensing, 12(10), p.1557.
  - Winker, D.M., Vaughan, M.A., Omar, A., Hu, Y., Powell, K.A., Liu, Z., Hunt, W.H. and Young, S.A., 2009. Overview of the CALIPSO mission and CALIOP data processing algorithms. *Journal of Atmospheric and Oceanic Technology*, *26*(11), pp.2310-2323.

- Other useful references:

  - Yorks, J.E., McGill, M.J., Palm, S.P., Hlavka, D.L., Selmer, P.A., Nowottnick, E.P., Vaughan, M.A., Rodier, S.D. and Hart, W.D., 2016. An overview of the CATS level 1 processing algorithms and data products. *Geophysical Research Letters*, *43*(9), pp.4632-4639.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on June 11, 2025
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - Due by June 25, 2025

- **Certificate of Completion:**
  - Attend both live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

Trainers:

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  - edward.p.nowottnick@nasa.gov

- ARSET Website
- ARSET YouTube

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Thank You!