NASA GSFC Elastic Backscatter Lidar Efforts Relevant to EarthCARE Calibration/Validation and Synergistic Data Products

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with contributions from:

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EarthCARE Science and Validation Workshop
November 16, 2023

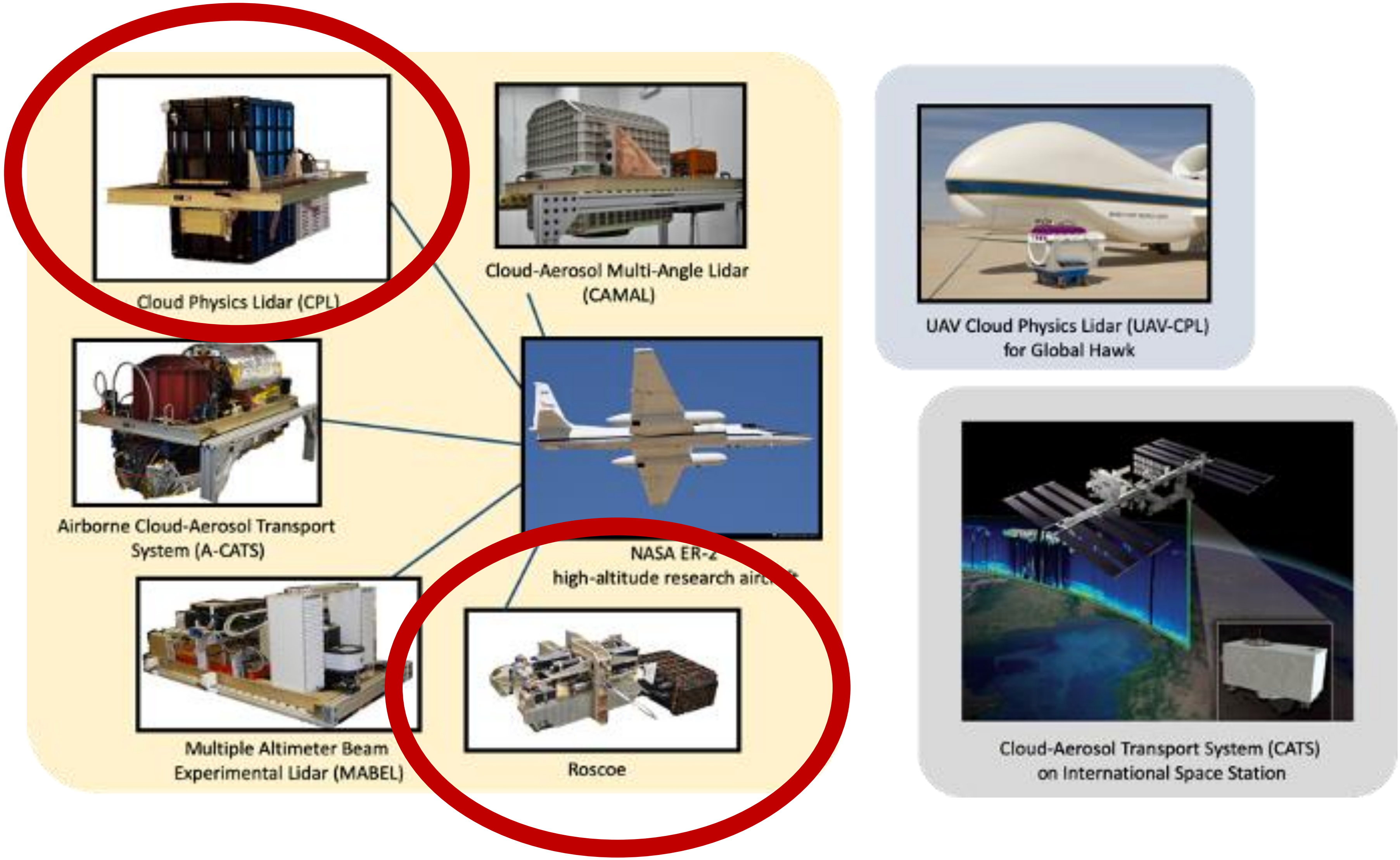
Airborne Lidar Suite at GSFC

Since 1999 multiple autonomous instruments have been built by our lidar group at GSFC photon-counting/high rep-rate designs

Designed primarily for NASA high-altitude aircraft (ER-2, WB-57, Global Hawk) – *now Gulfstreams as well*

Utilize high repetition rate, photon counting technique

Led to the development of the Cloud Aerosol Transport System (CATS) technology demonstration on the ISS(2015-2017) and ALICAT for AOS



CPL Instrument Overview

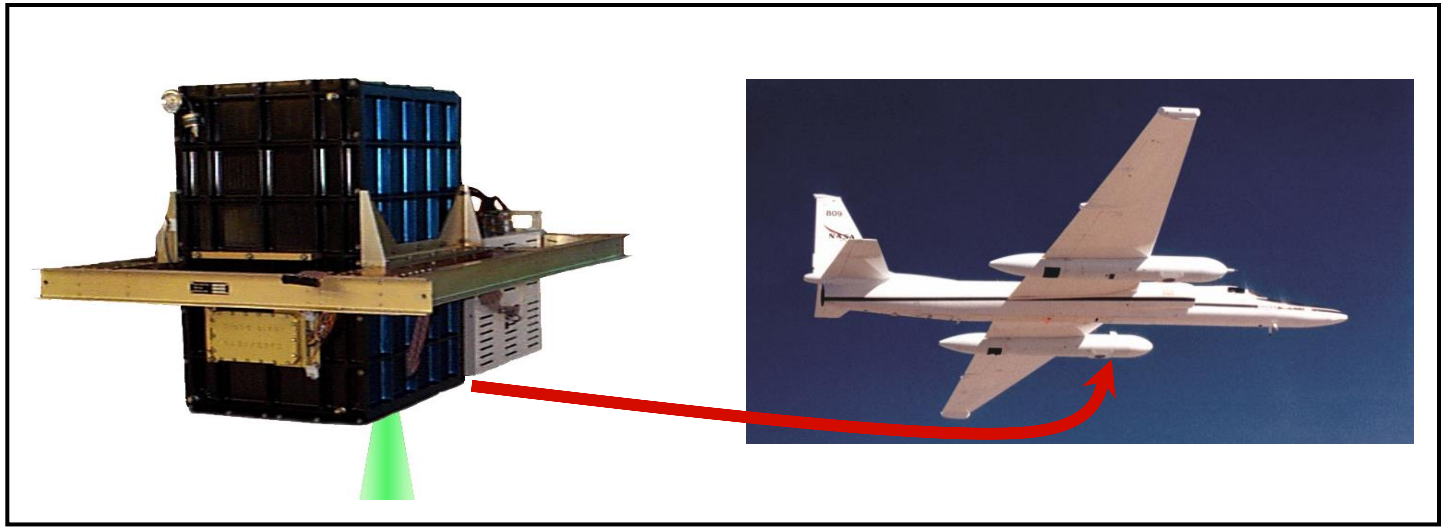
Instrument Characteristics:

- **3 Wavelengths: 1064, 532, and 355 nm**
- **Depolarization using 1064 channel**
- **Fully autonomous**
- **Near nadir pointing**
- **Small FOV minimizes multiple scattering**
- **Resolution: 30 m (vert), 200 m (hor)**

Wavelengths	1064, 532, 355 nm
Laser type	solid state Nd:YVO4
Laser repetition rate	5 kHz
Laser output energy	50 μJ at 1064 nm 25 μJ at 532 nm 50 μJ at 355 nm
Telescope	20 cm diameter
Telescope FOV	100 μradians, full angle

Two duplicate instruments:

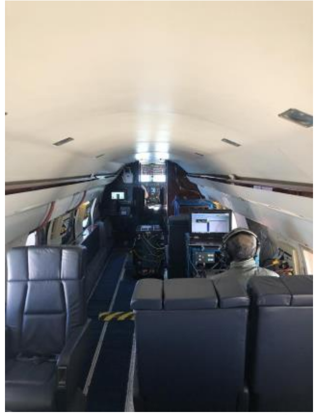
1. **Built for high-altitude aircraft (ER-2)**
   - **Flight altitude of about 20-km**
   - **Measure full troposphere**
2. **Deployed on low-flying aircraft**
   - **Primarily for aerosol/PBL on C-130, Gulfstreams**
   - **Being converted to ER-2 backup**

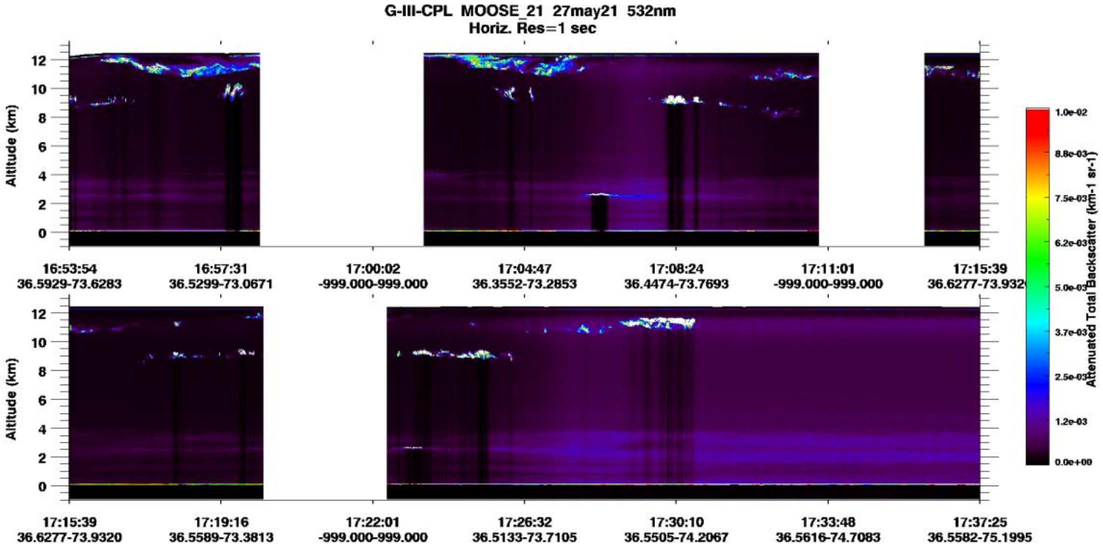


What’s new with CPL?

Integrated on G-III

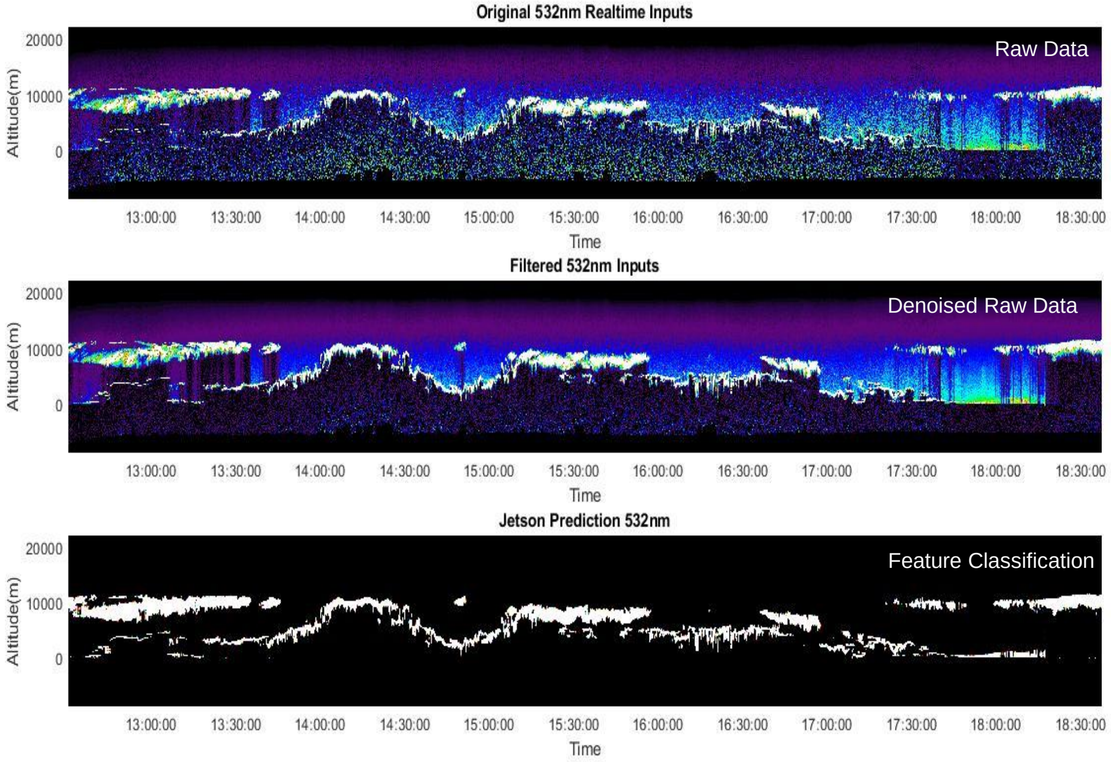
- CPL flew on the NASA G-III (LaRC) in the summer of 2021 as part of the Michigan-Ontario Ozone Source Experiment
- As part of review process, also cleared to fly on the NASA G-V (JSC)





Real-Time Data Products

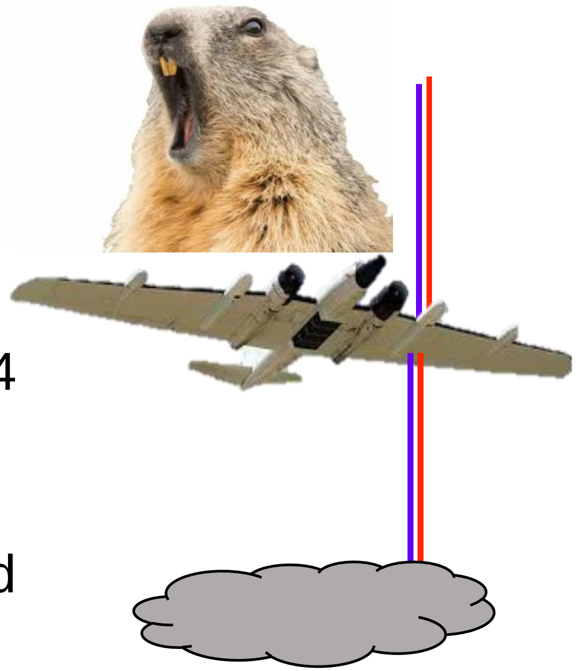
- CPL now employs a Jetson TX-2 GPU that applies signal denoising and convolutional neural network techniques developed on CATS data described in Yorks et al., 2021 for real time data products
- Provides data in real time for flight plan adjustments/coordination

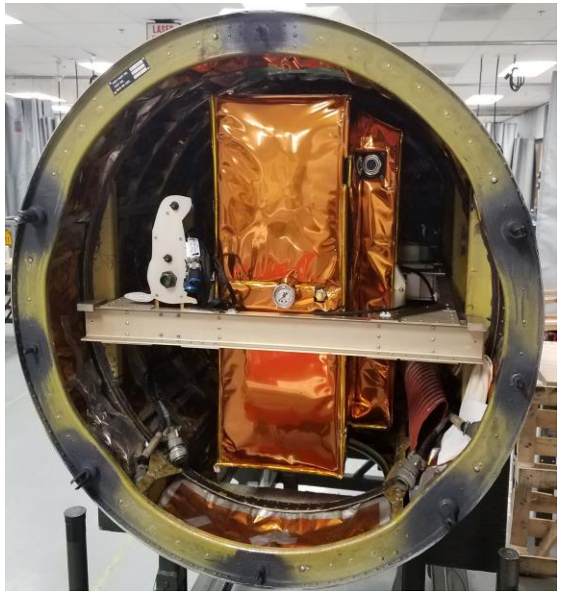


What’s Roscoe?

- Roscoe is a new airborne lidar that has heritage from GSFC’s Cloud Physics Lidar (CPL)

- What’s the difference?
  - **CPL** – Downward looking with attenuated backscatter measurements at 355, 532, and 1064 nm with polarization sensitivity at 1064 nm
  - **Roscoe** – Upward and downward looking attenuated backscatter measurements at 355 and 1064 nm with polarization sensitivity in all wavelengths and directions. Enables UTLS aerosol/cloud measurements while mitigating eye safety concerns (no visible).
- Provides the same data and real-time products as CPL
- The 2021 ACCLIP Test Flights were the first for Roscoe on the WB-57. Engineering flights on the ER-2 were performed pre-pandemic.

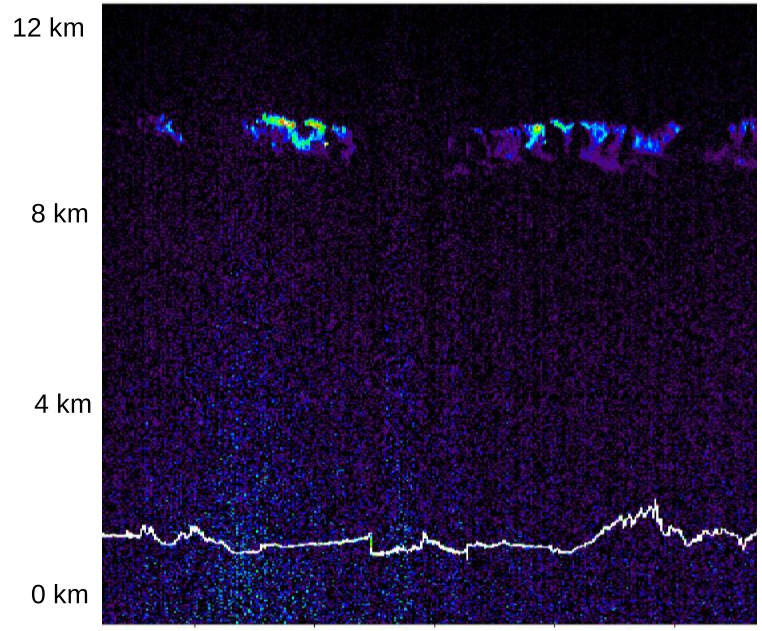


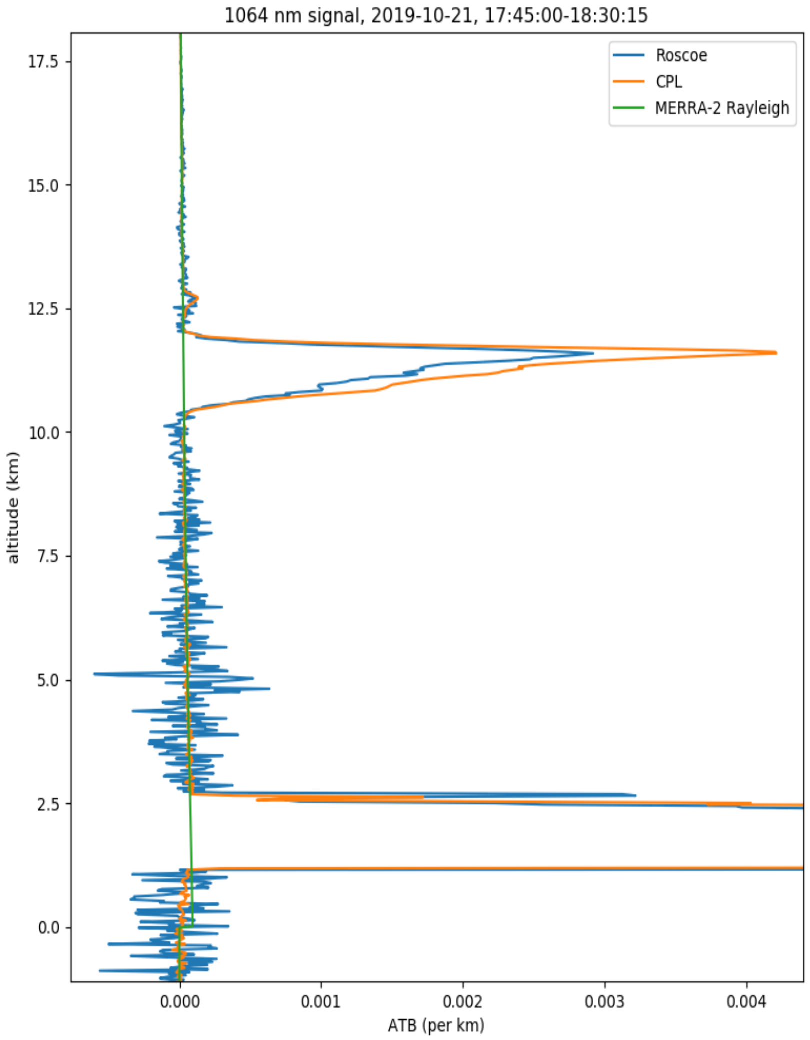


Maiden Test Flights Along with CPL on the ER-2

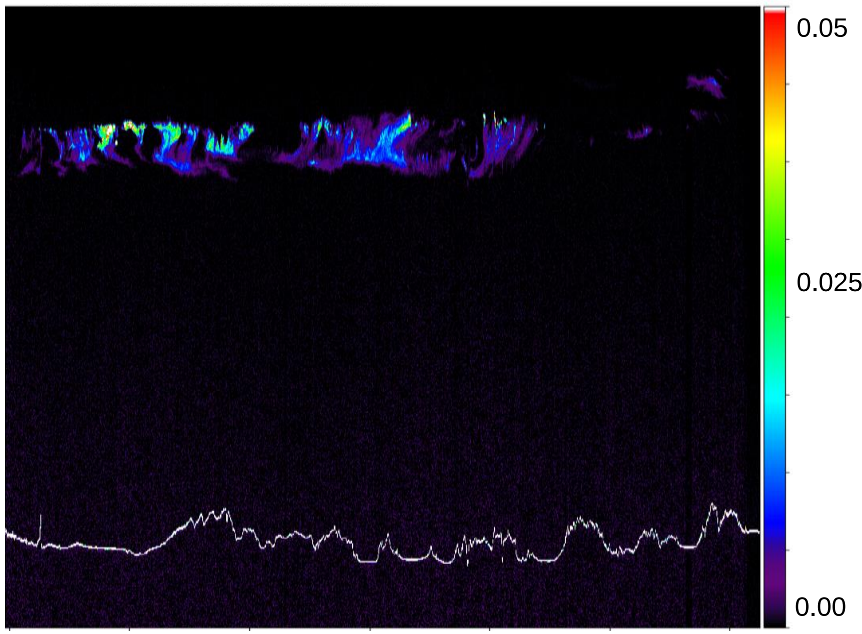
First test flights o

Roscoe 1064 nm [k



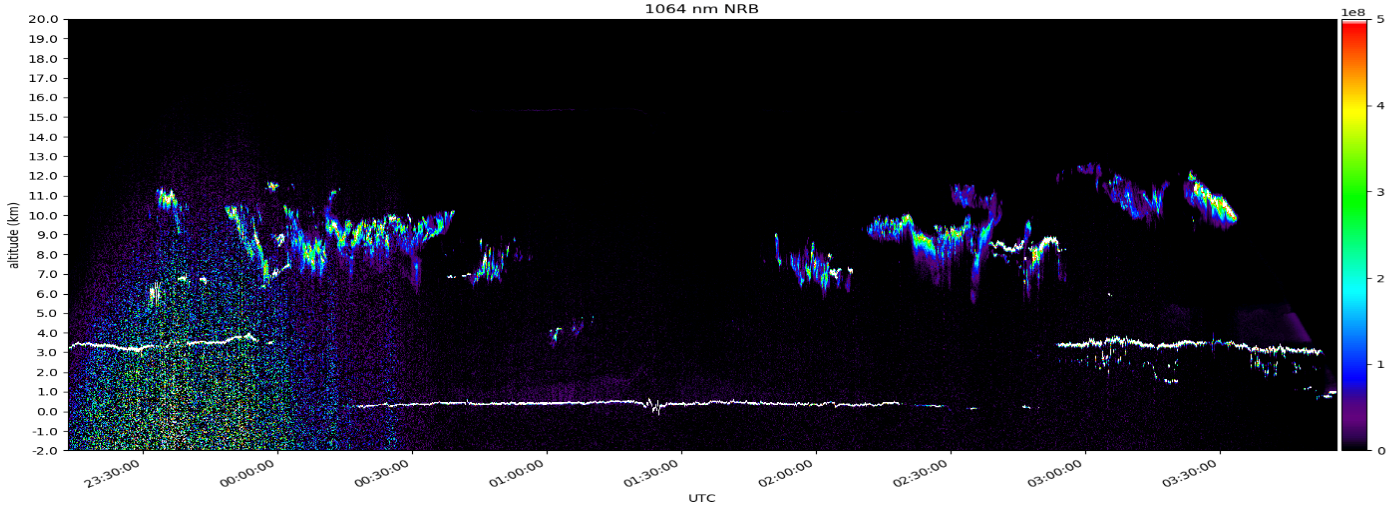


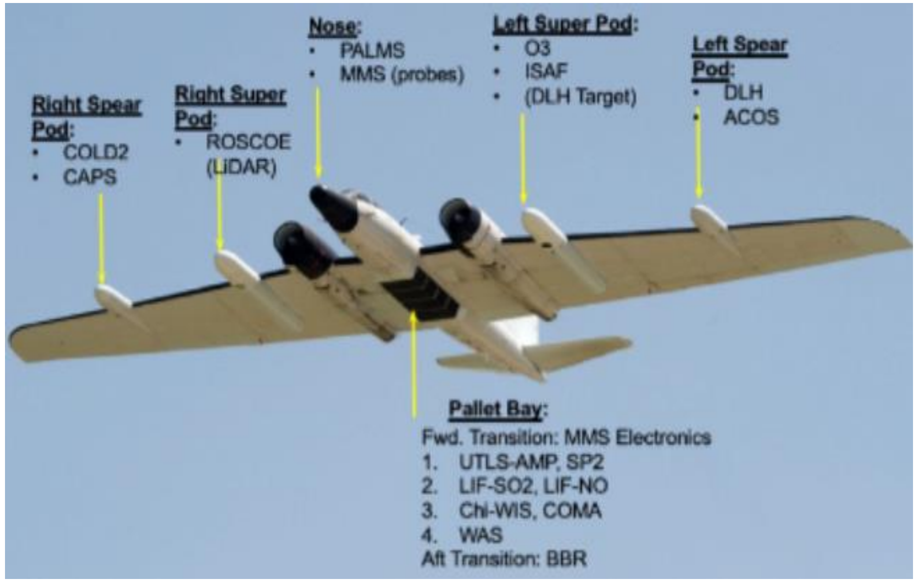
CPL 1064 nm [km^{-1} sr^{-1}]

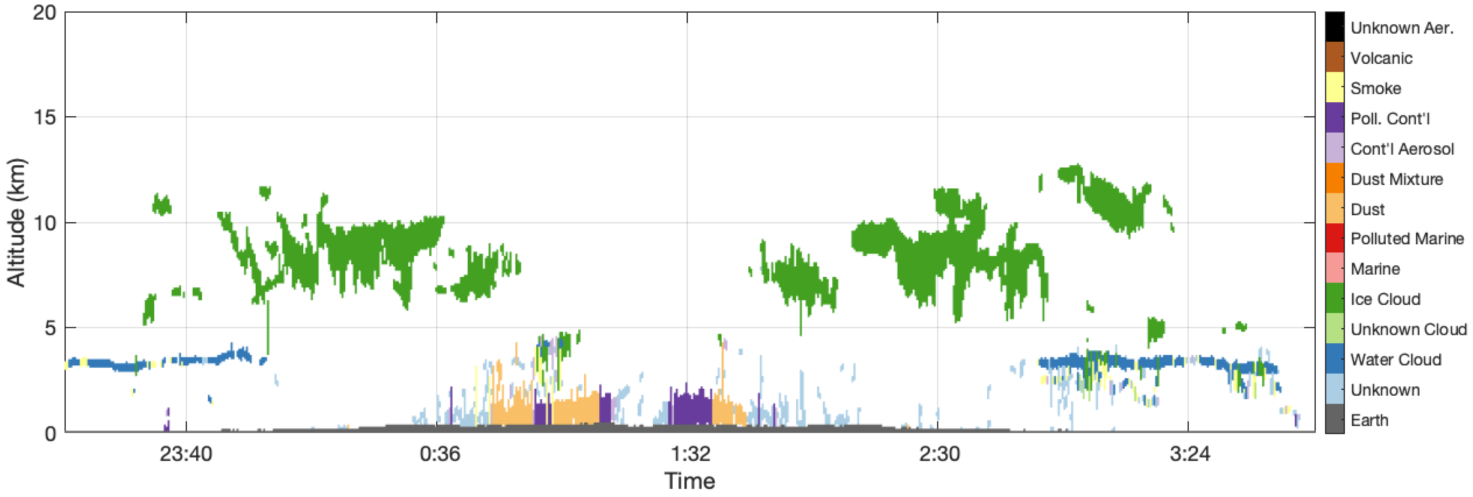


ACCLIP and SABRE Results

- Participated in SABRE test flights (Feb 2022) and ACCLIP Field Campaign (summer 2022)
- Existing CPL processing algorithms working well with Roscoe data
- Still refining the feature typing algorithm but successful first series of campaigns

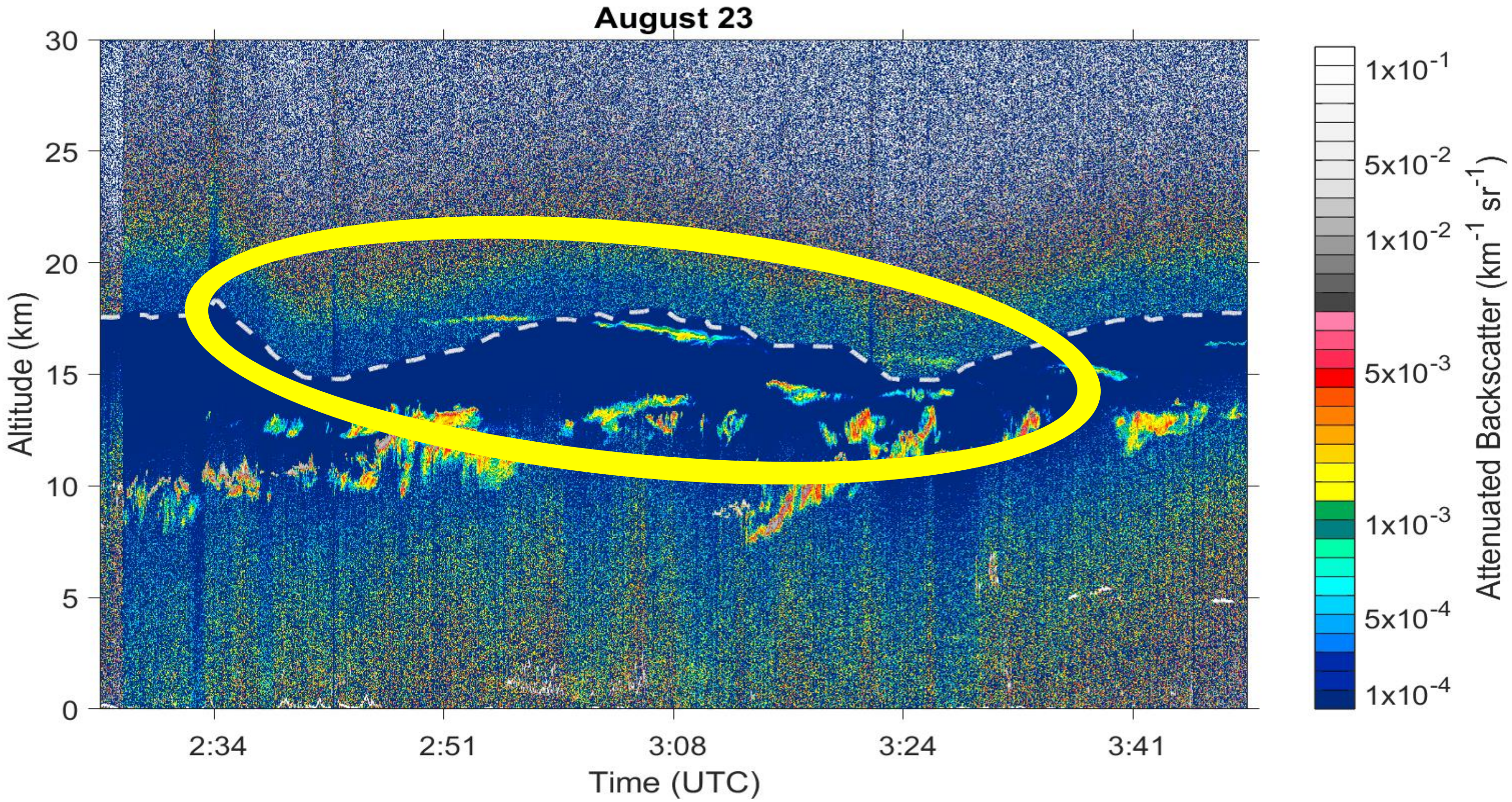




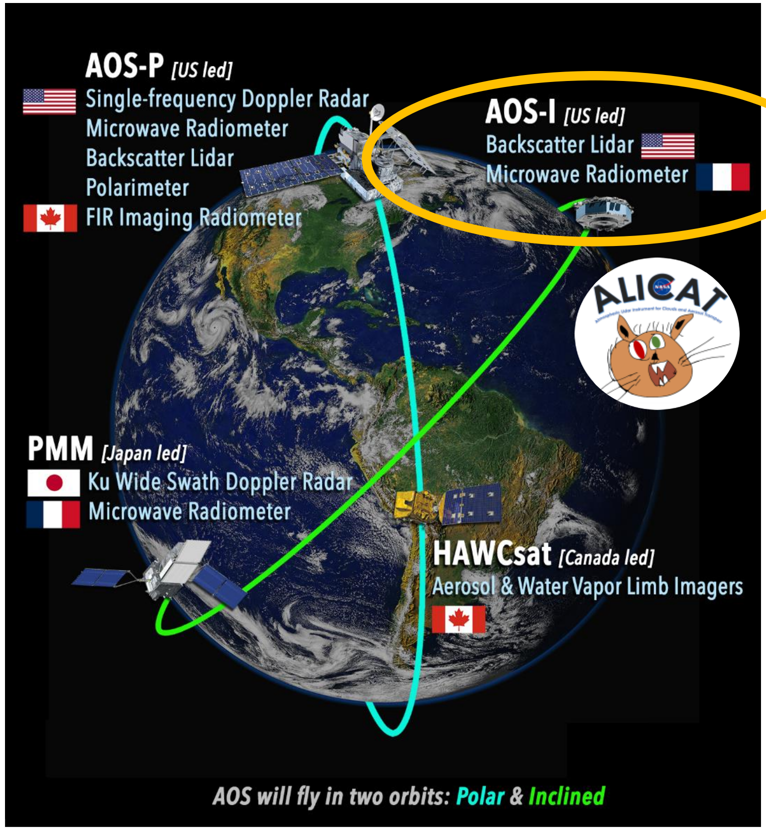


More ACCLIP Results

- Great opportunities to test the upward and downward channels
- Enables lidar measurements on single airborne platform deployments that utilize both remote sensing and *in situ* instruments

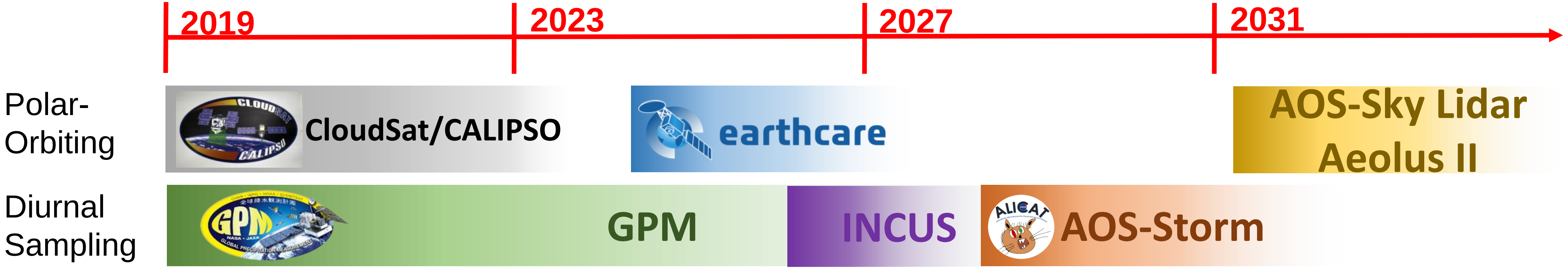


Beyond Airborne Work – ALICAT for AOS



Atmospheric Lidar Instrument for Clouds and Aerosol Transport (ALICAT):

- Provides vertical profiles of total and perpendicular attenuated backscatter at 532 and 1064 nm to identify clouds, aerosols, as well as their phase and type
- Provides a new opportunity for synergistic products in an inclined orbit (e.g. Ku radar+radiometer+lidar products) not possible with CALIPSO or CATS
- Will deliver near-real time (<6 hours) data products to the applications community
- Leverages 20 years of lidar instrument heritage at NASA GSFC, including the Cloud Aerosol Transport System (CATS) that flew on the ISS from 2015-2017 – building and testing it now
- Offers early science delivery for AOS by launching later this decade (2029)



AOS Science Addressed by ALICAT

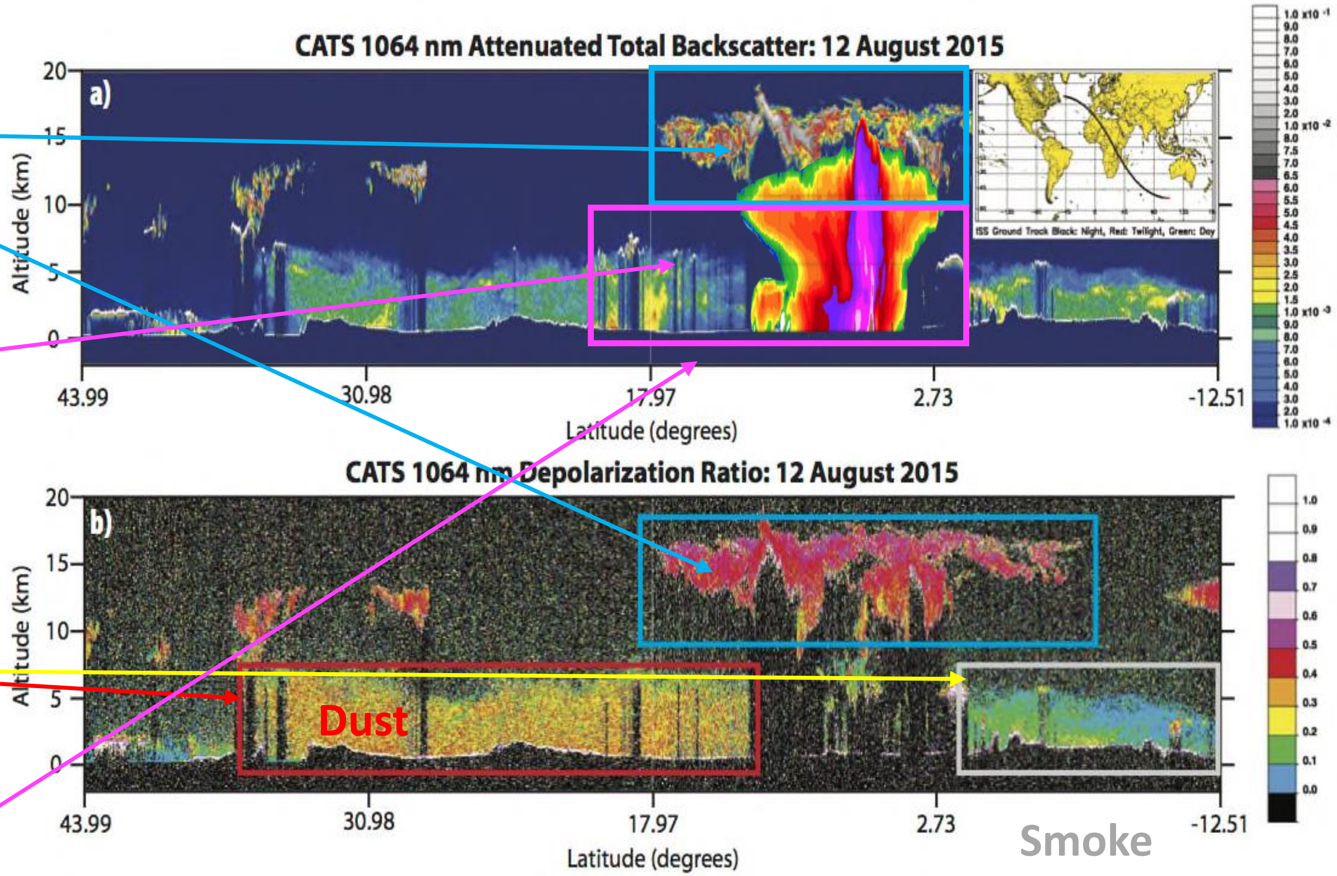
AOS is a process-focused mission with lidars and radars as centerpieces to provide xvertical measurements of aerosols, clouds, and precipitation – ***and their diurnal variability***

Objective 2: High Clouds
Measurements of thin high clouds, especially in the presence of convection

Objective 3: Convective Storms
Detection of environmental aerosols in the presence of convection

Objective 5: Aerosol Attribution/Air-Quality
Measurements of optically thick dust, smoke, and anthropogenic aerosols in source regions above and within the PBL

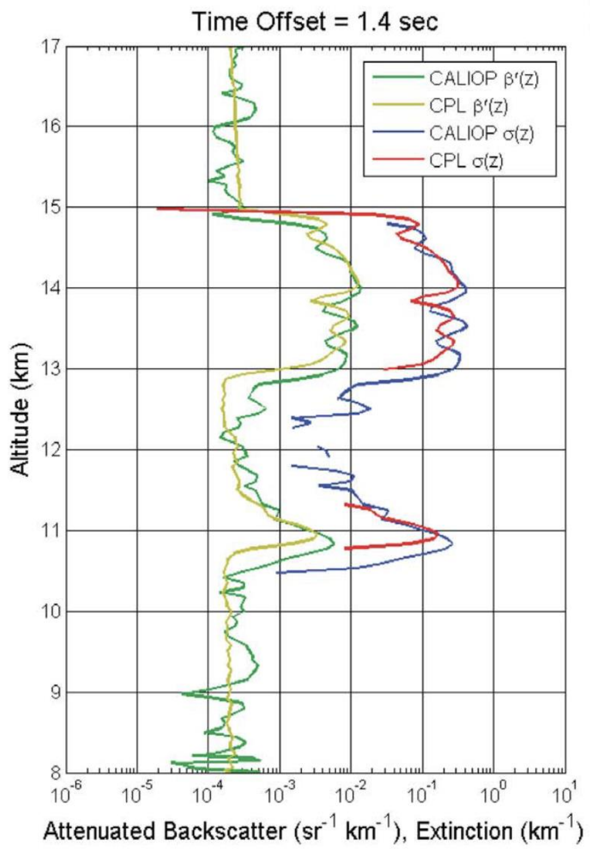
Objective 6: Aerosol Removal & Redistribution
Synergistic observations of aerosols and convective precipitation/vertical motions



ALICAT Science: Cirrus Clouds

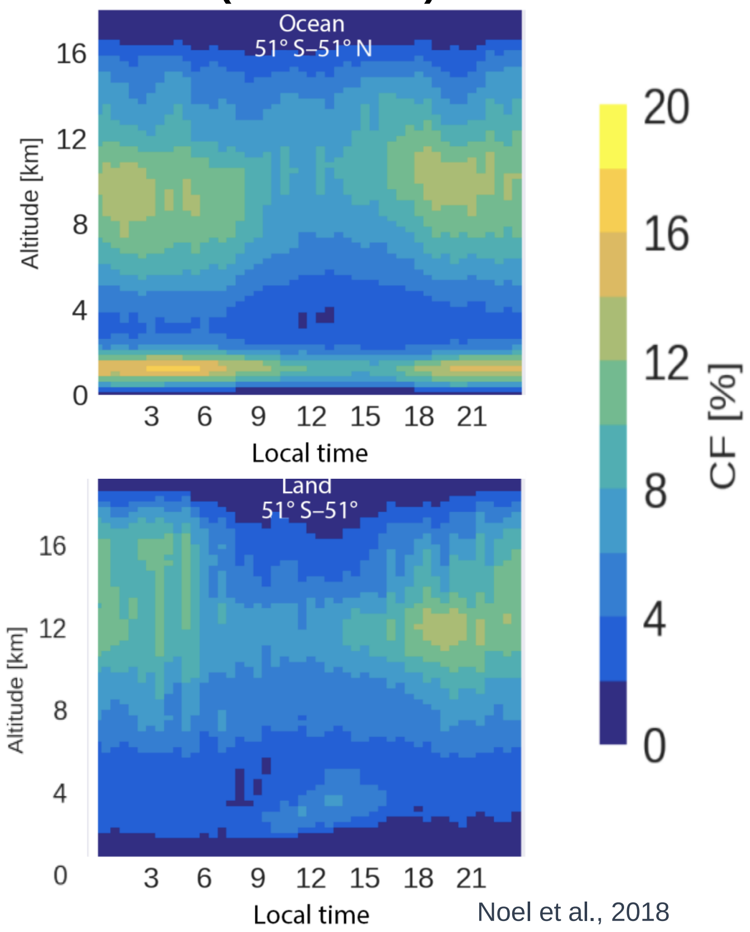
- CALIPSO has provided cloud measurements for 17 years in a sun-sync orbit
- CATS provided diurnal measurements of clouds with a single wavelength, but was a tech demo without science requirements
- ALICAT offers ***improved SNR*** compared to CATS and an opportunity to provide CALIPSO quality measurements with an added ***time dimension*** in an affordable package
- AOS-Storm matches ALICAT with microwave radiometers and a Ku radar for diurnal sampling of convective processes

CALIPSO Cirrus Validation of Cloud Measurements using Airborne CPL



Hlavka et al., 2012

Diurnal Cycle of Clouds Observed by CATS Tech Demo (2015-2017)

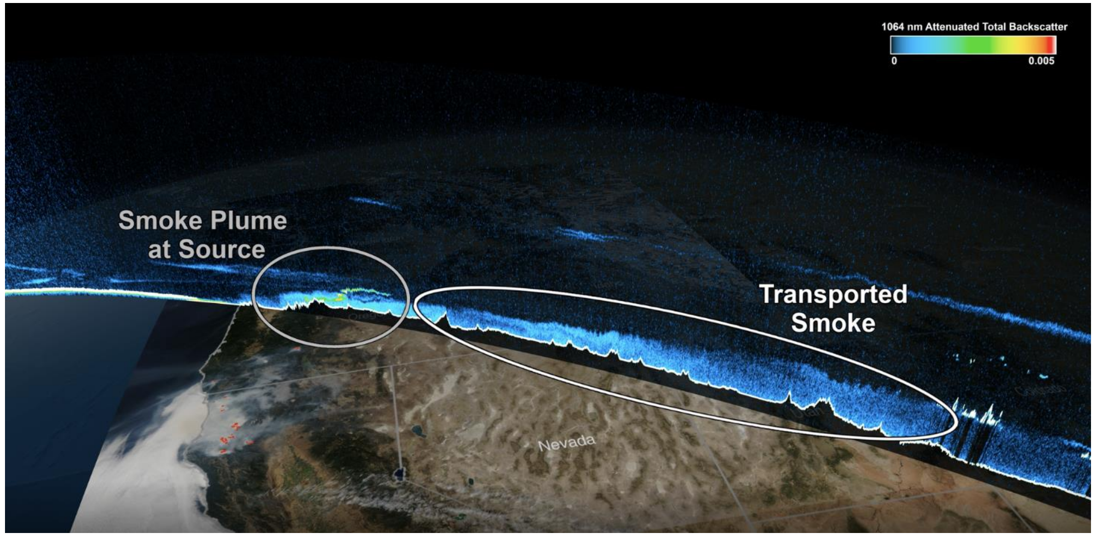


Noel et al., 2018

ALICAT Science: Aerosols

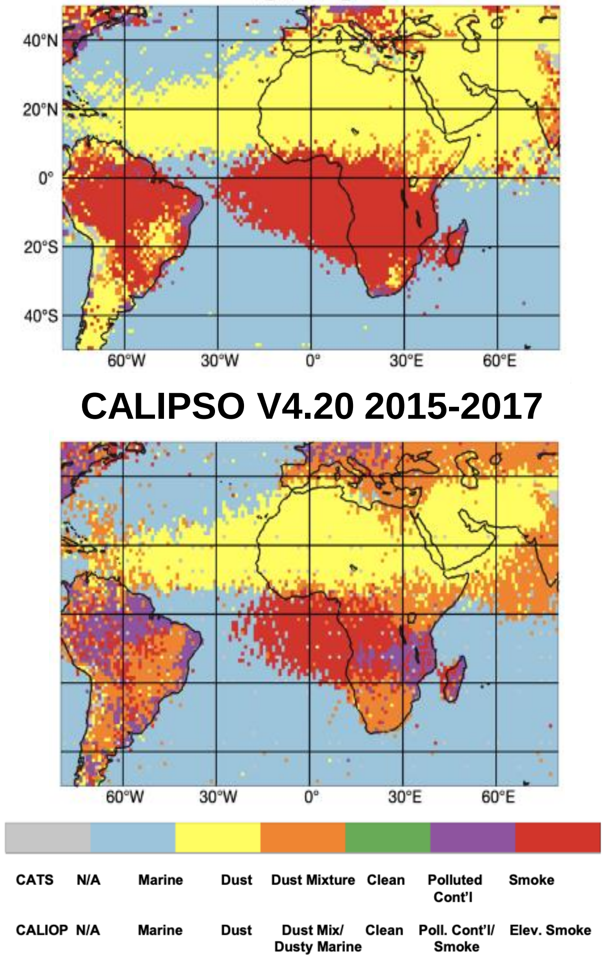
- Dust and smoke aerosols exhibit diurnal cycles that typically correspond to enhanced burning during daytime hours*
- Smoke interacts with the evolution of the planetary boundary layer and has implications for the diurnal cycle of convection** - important for smoke transport forecasting in current models***

Smoke from Oregon: Implications for Transport and Air Quality Observed by CATS

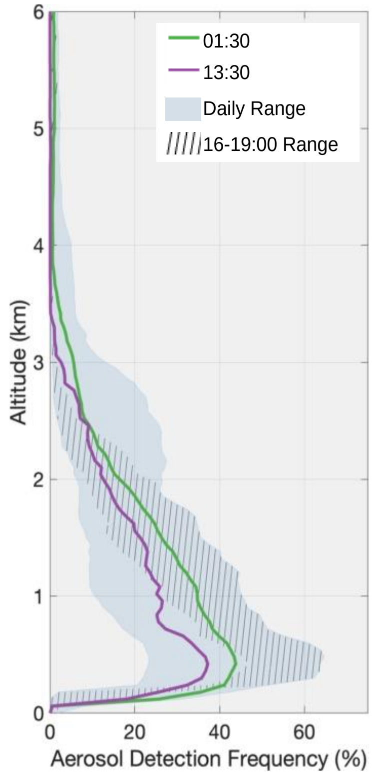


CATS V3 2015-2017

CALIPSO V4.20 2015-2017



Diurnal Variability of Smoke Aerosols Observed by CATS over Borneo



* Hyer et al., 2013
** Zhang and Zuidema, 2019; Hodzik and Duvell, 2017
*** Ye et al., 2021

Opportunities for Future Collaboration

Airborne:

- Planned NASA ER-2 mission using CPL in the fall 2024 out of Palmdale, California – underpasses of EarthCARE?
- UTLS aerosol detection validation using Roscoe
- Future NASA EVS-4 opportunities (TBD) or joint field campaign activities (e.g. CPEX-AW; CPEX-CV)

Spaceborne:

- Leverage aerosol typing from ATLID and any planned validation efforts to help inform lidar ratio selection for ALICAT – more robust than simple algorithms that rely on ancillary information despite differences in wavelength

Thanks!

Contact:

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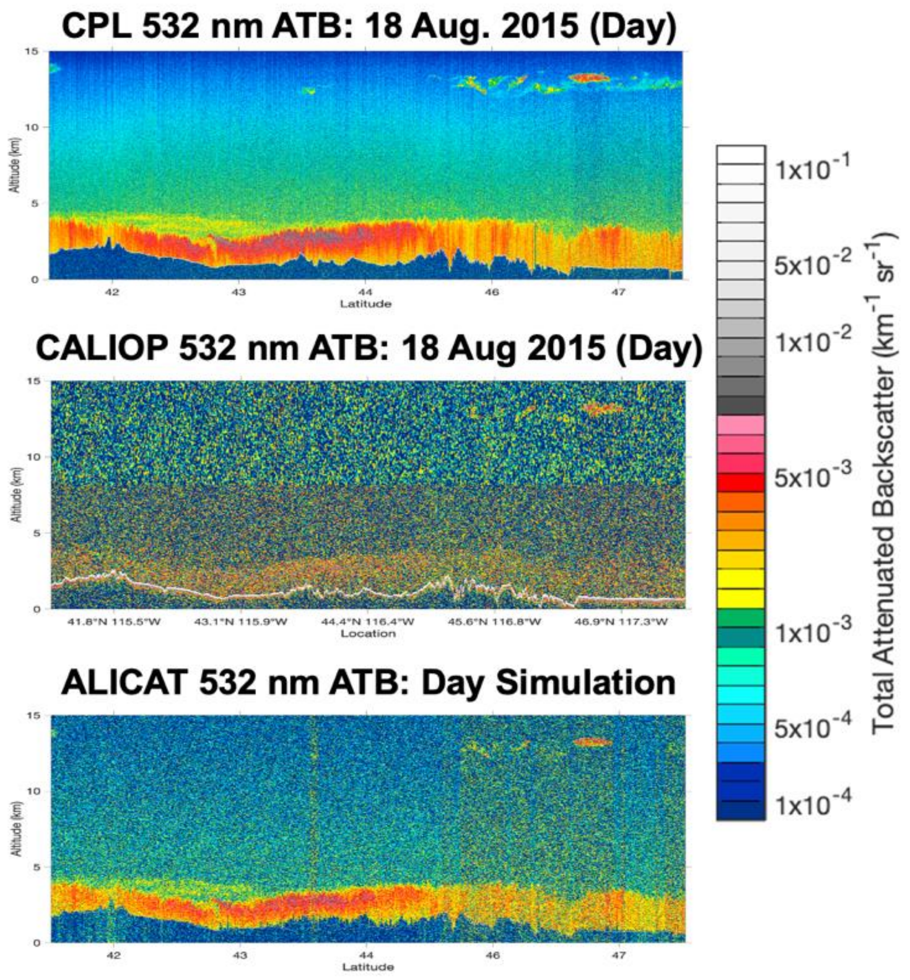
Backup

ALICAT Daytime Performance

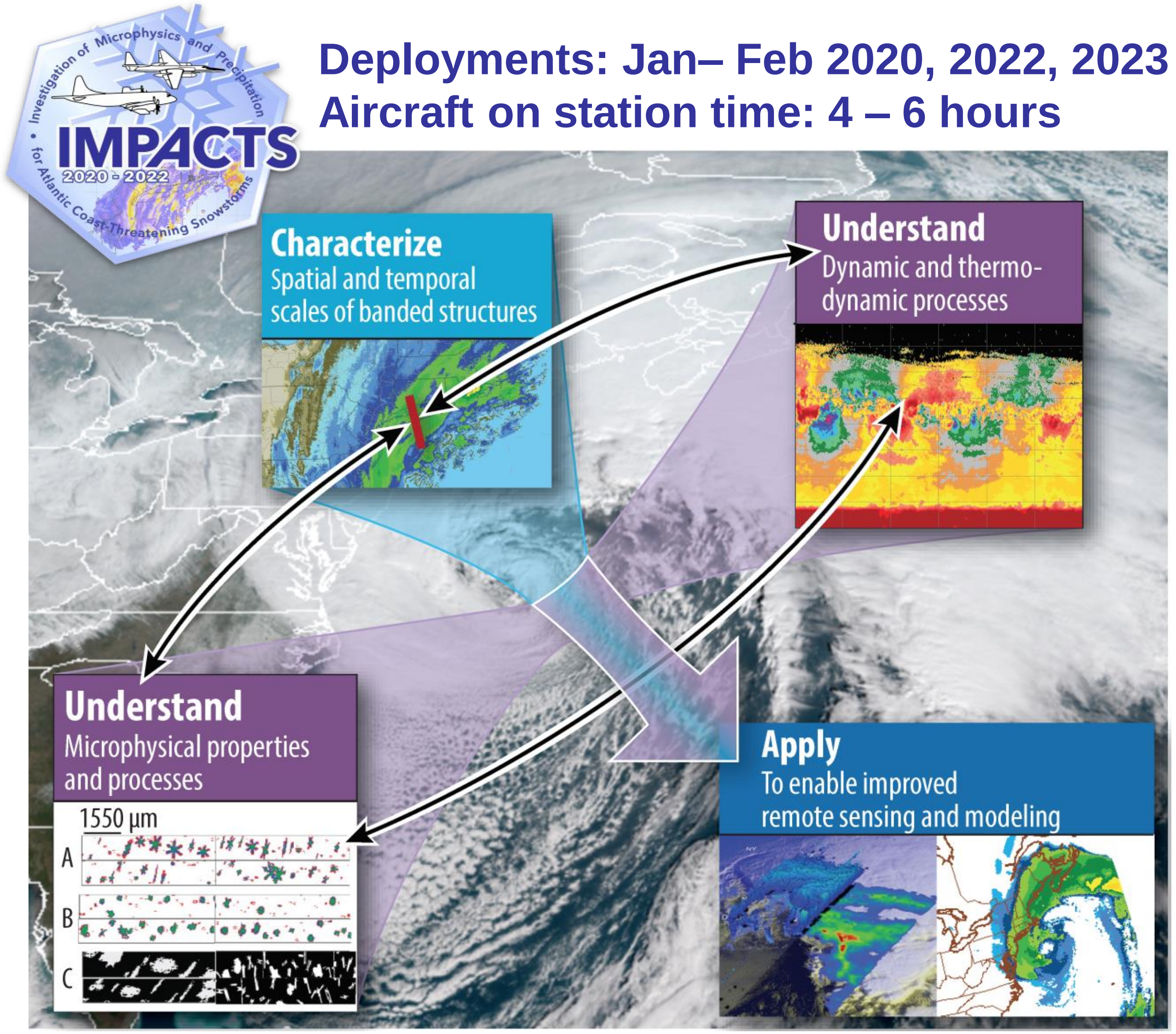
ALICAT daytime 532 nm ATB (bottom) will have improved SNR compared to CATS and CALIOP (middle)

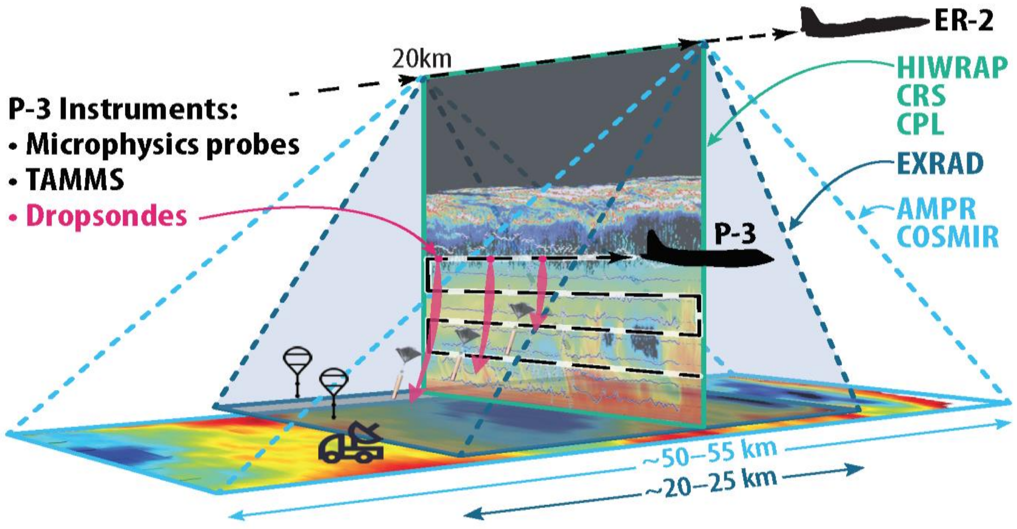


CPL data from the NASA ER-2 aircraft (top panel) and CALIOP (middle panel) during a validation flight on 18 August 2015 over the western US. ALICAT ATB (bottom) simulated for day using the airborne lidar data as input.

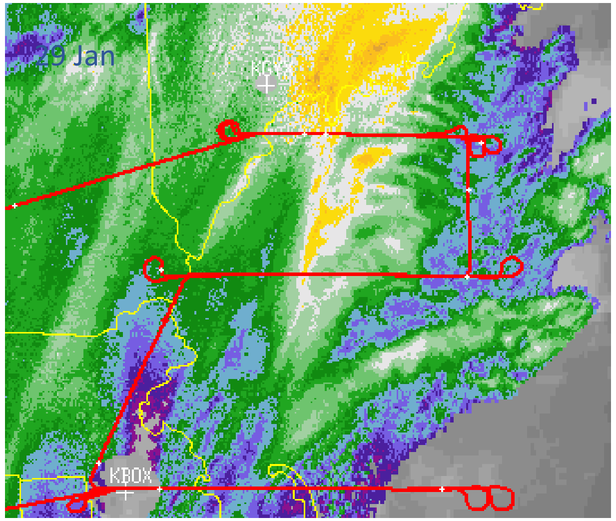
IMPACTS EVS-3 Field Deployment (2020-2023)

Deployments: Jan– Feb 2020, 2022, 2023
Aircraft on station time: 4 – 6 hours





Conducted 33 flights and over 150+ hours (21 coordinated flights) in 2020-2023 during strong winter storms, weaker storms, and clippers.



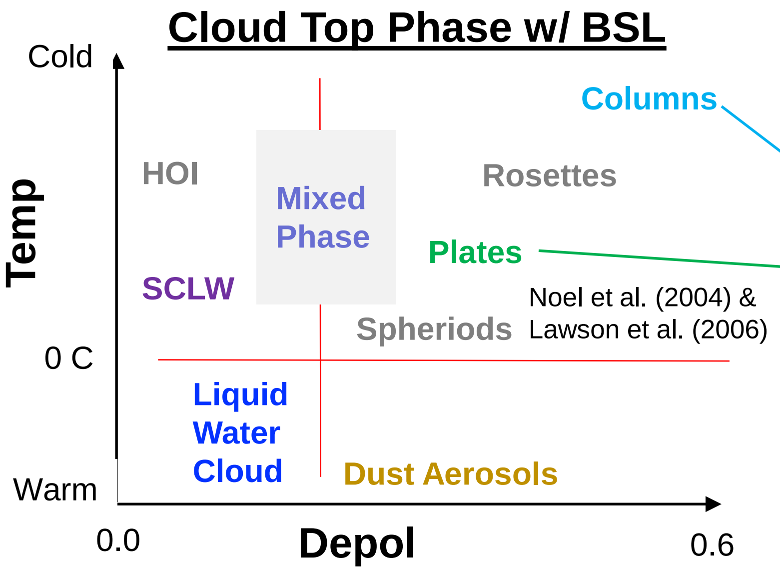
Cloud Phase & Habit Type using CPL during IMPACTS

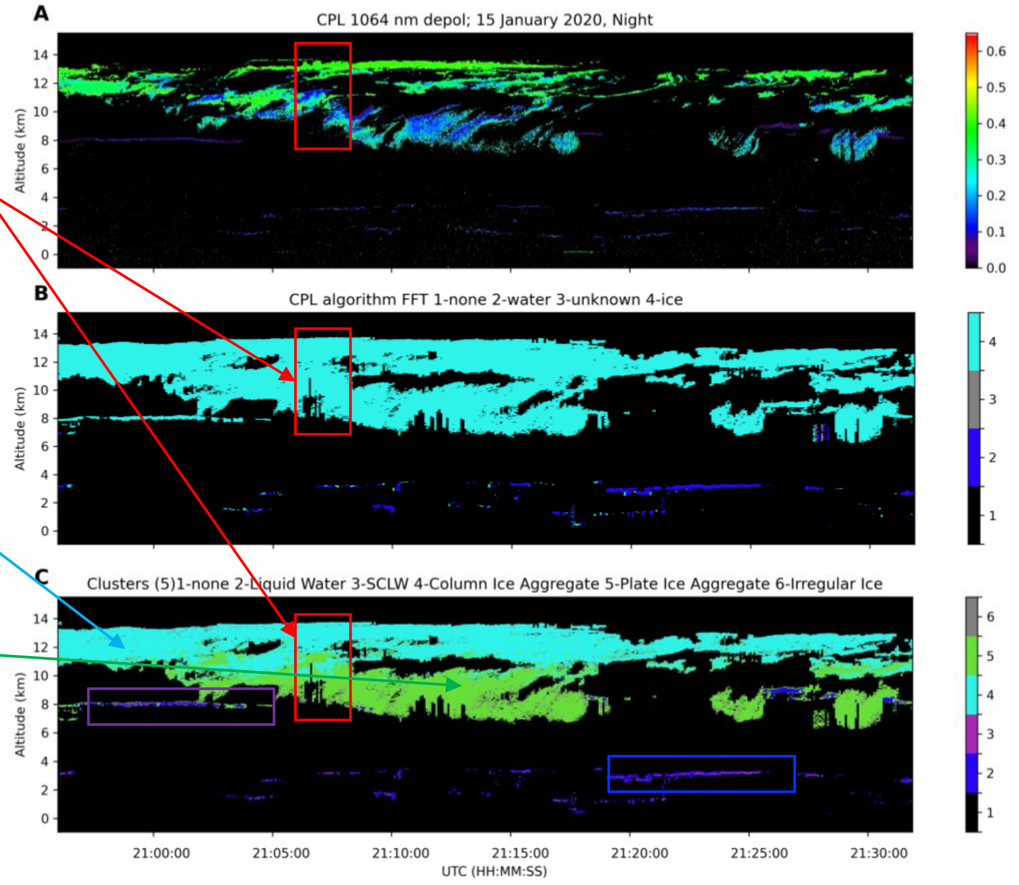
Hierarchical clustering technique to enable finer cloud particle phase/type classifications with improved vertical resolution and create a training dataset for a CNN model

Uses BSL depol. ratio, temperature, and altitude of each bin

- **5 clusters of potential particle phases/types: column aggregates, plate aggregates, irregular/other ice, SCLW, warm liquid water (C, right)**
- **Particle phases/types are assigned based on literature and/or collocated in situ data from P-3 aircraft during IMPACTS field campaign flights.**

Current cloud phase algorithms classify phase on a cloud "layer" basis for each profile
- **This does NOT capture the vertical variability within a cloud**
- **Clustering technique DOES capture this vertical variability**





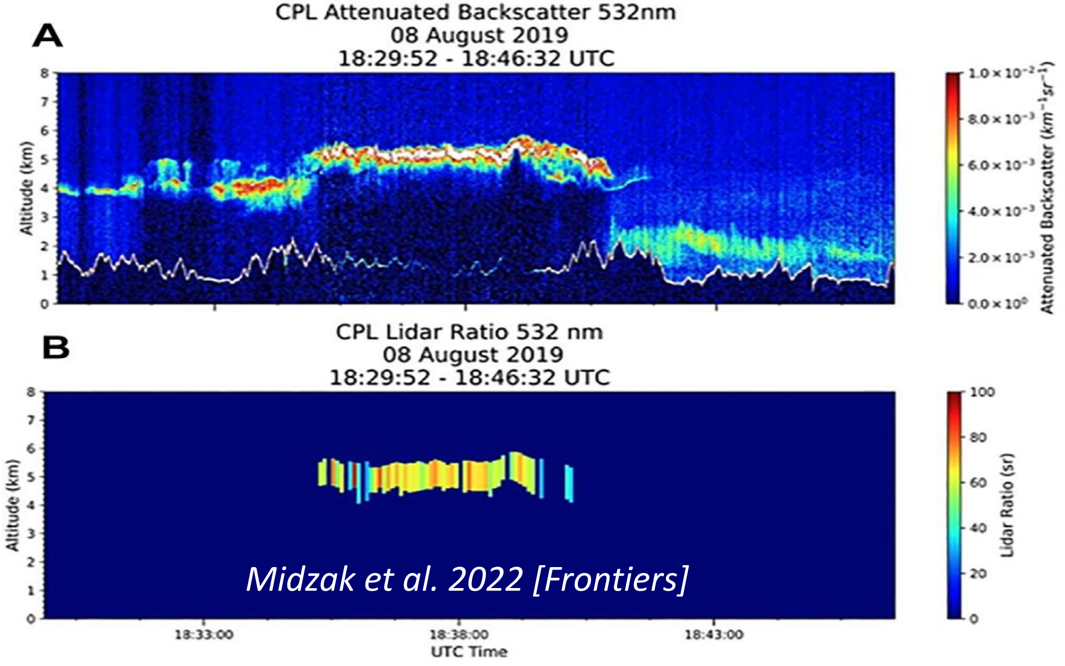
Ongoing work at NASA GSFC (Joe Finlon)

Improved Constrained Retrievals of Extinction

Signal Loss Method for Aerosol Layers

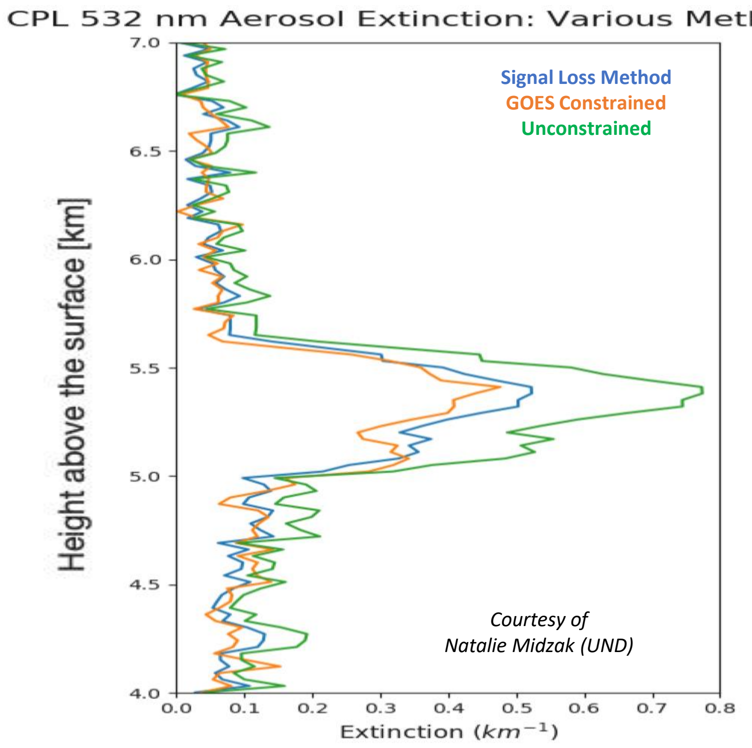
- Technique is traditionally restricted to clouds
  - Results in an iterative, best-fit solution to measured two-way transmittance loss of signal through a transparent layer
- Integrated attenuated total backscatter is compared to the estimated integrated molecular signal in the clear air zone to calculate layer transmission

Williams Flats Fire



Constraints from Geostationary AOD

- Uses the AOD from a passive aerosol sensor (i.e., MODIS, VIIRS, ABI, etc.) to retrieve a layer-average lidar ratio and thus more accurate extinction profile.
- Midzak et al. (2022) shows errors <25%



CPL overpass of Williams Flats Fire on 08 August was collocated with GOES-R

AOD values from both sensors compare well

- GOES: 0.59±0.09
- CPL constrained: 0.59±0.66
- CPL unconstrained: 0.81±0.62