Validation of EarthCARE ATLID Level-1b Profile Products Using Airborne Lidar Observations from NASA's HSRL-2 and HALO Lidars

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5 flights of 355-nm measurements from the **HSRL-2** instrument (Multiwavelength HSRL) flown on ER-2 Aircraft (PACE-PAX): HSRL-2 PI John Hair

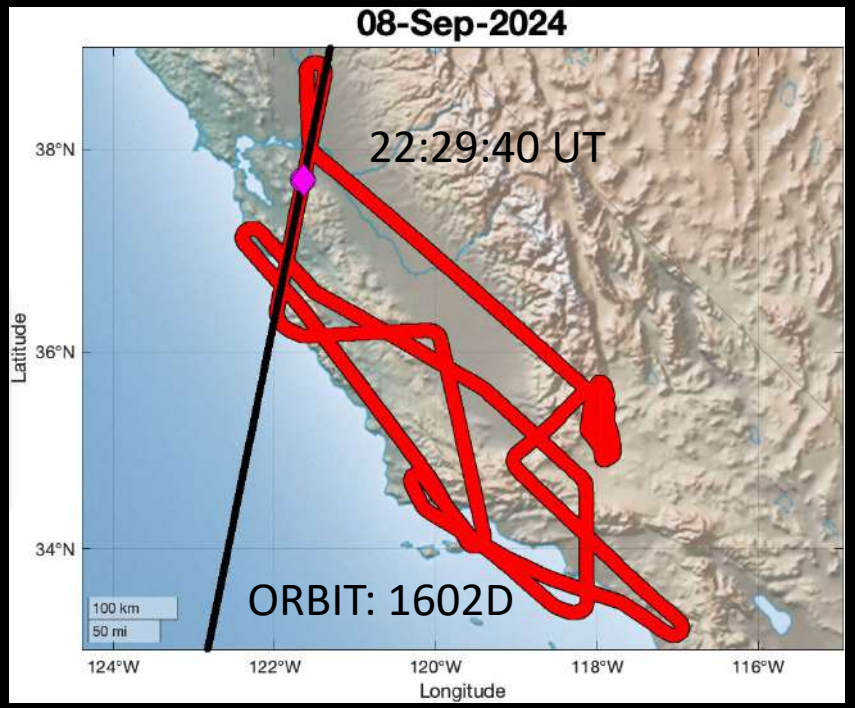
3 flights of 532-nm measurements from the **HALO** instrument (HSRL/H20 DIAL) flown on GIII Aircraft (ARCSIX, WH^{2}YMSIE/APEX): measurements converted to 355nm: HALO PI Amin Nehrir

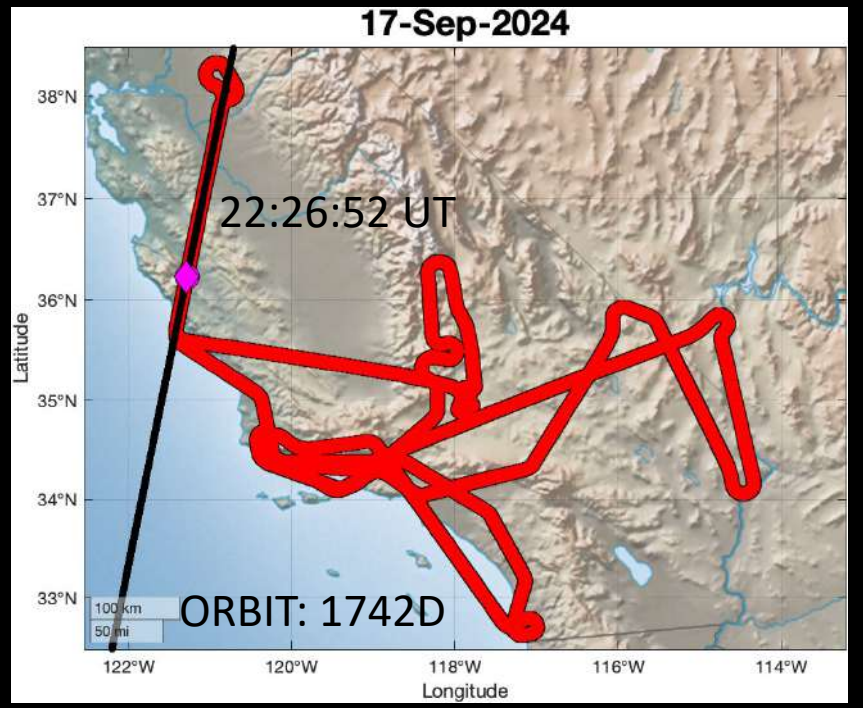
Data are still PRELIMINARY for HSRL-2/HALO

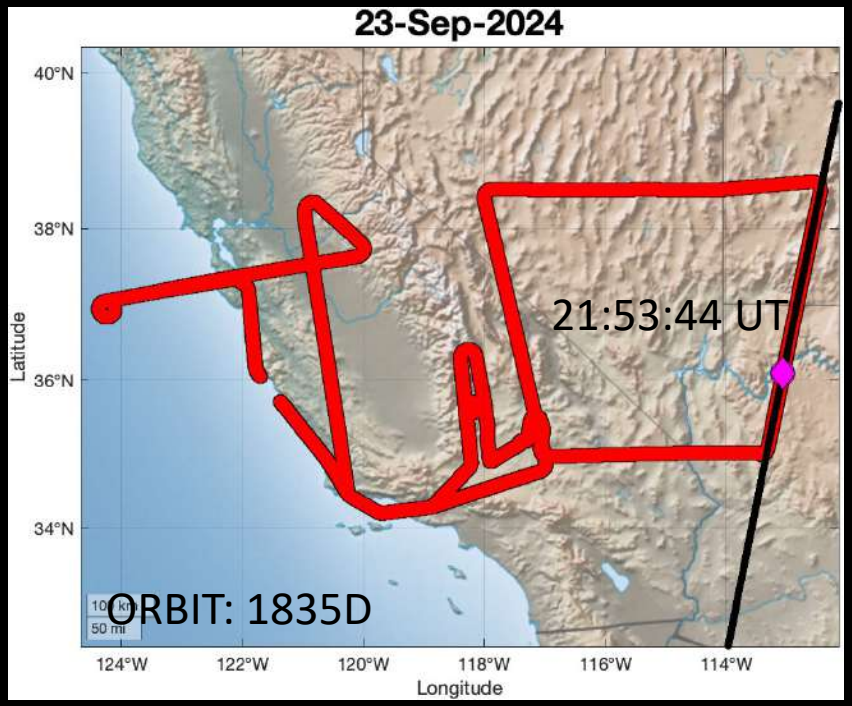
Summary: the accuracy of the ATLID data is truly impressive!

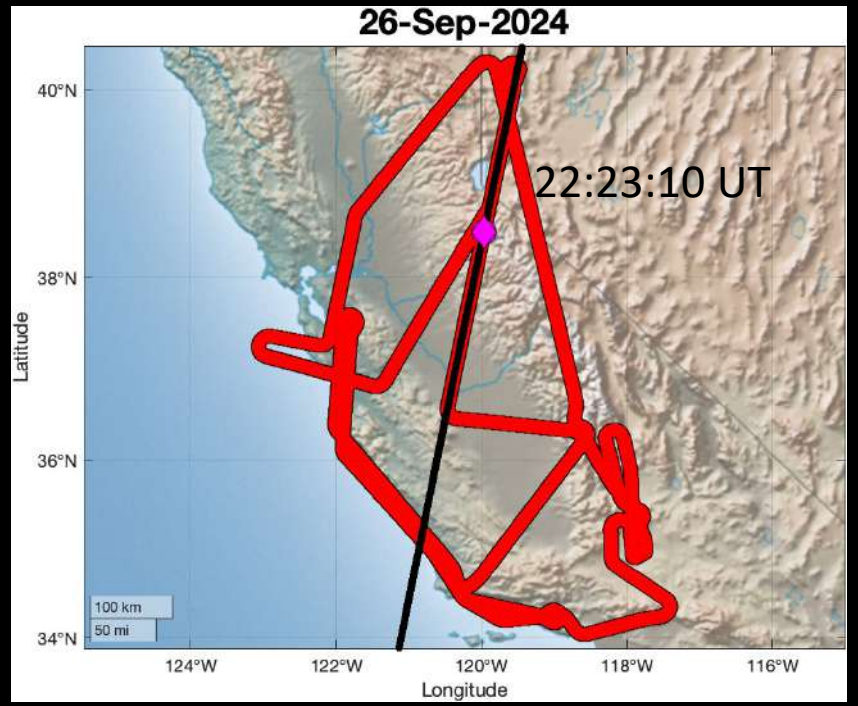
PACE-PAX flights on the ER-2

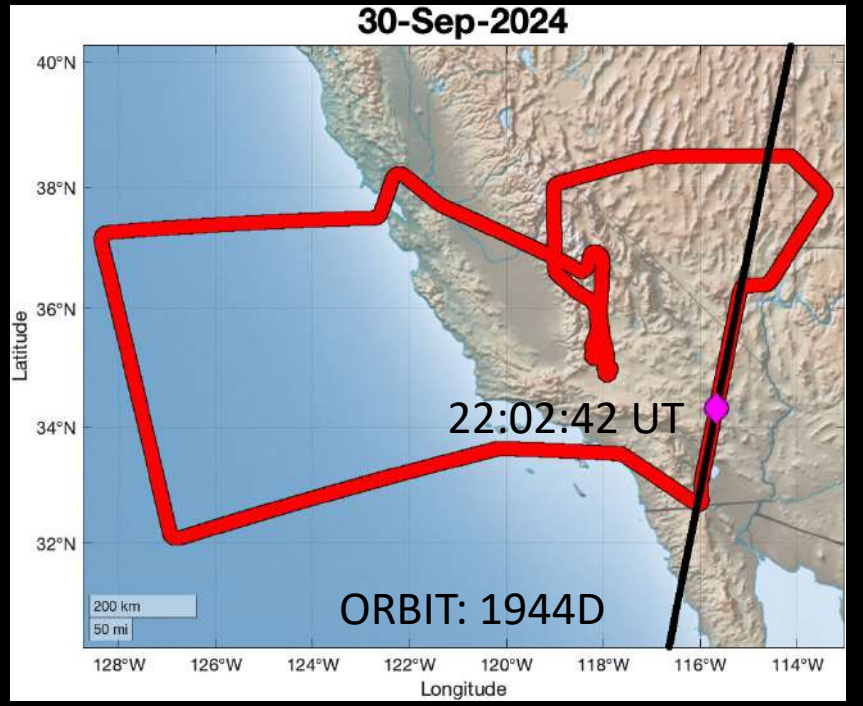
20 km nominal altitude
Spatial coordination within 1km
All flights during day





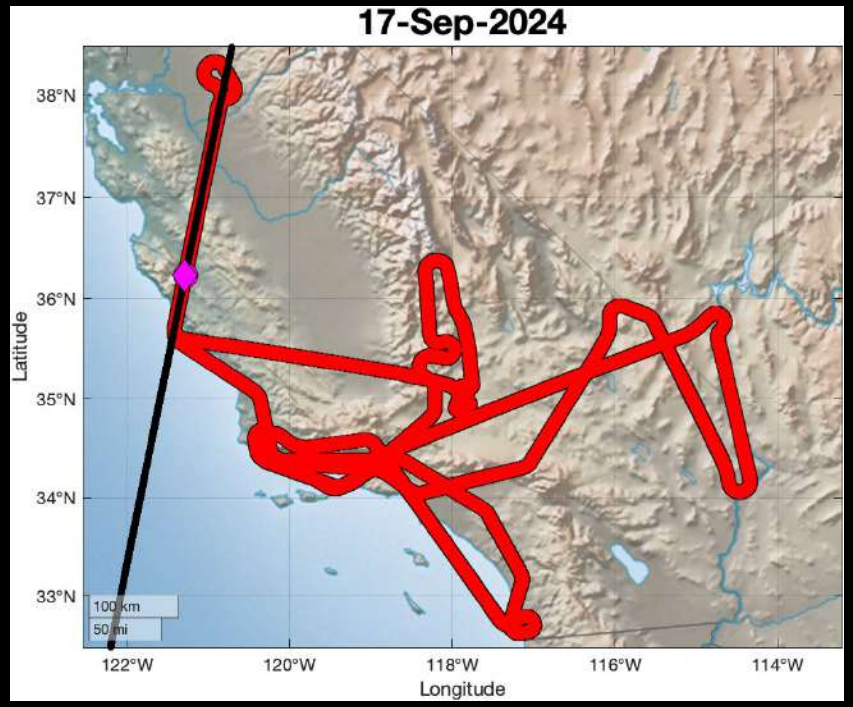






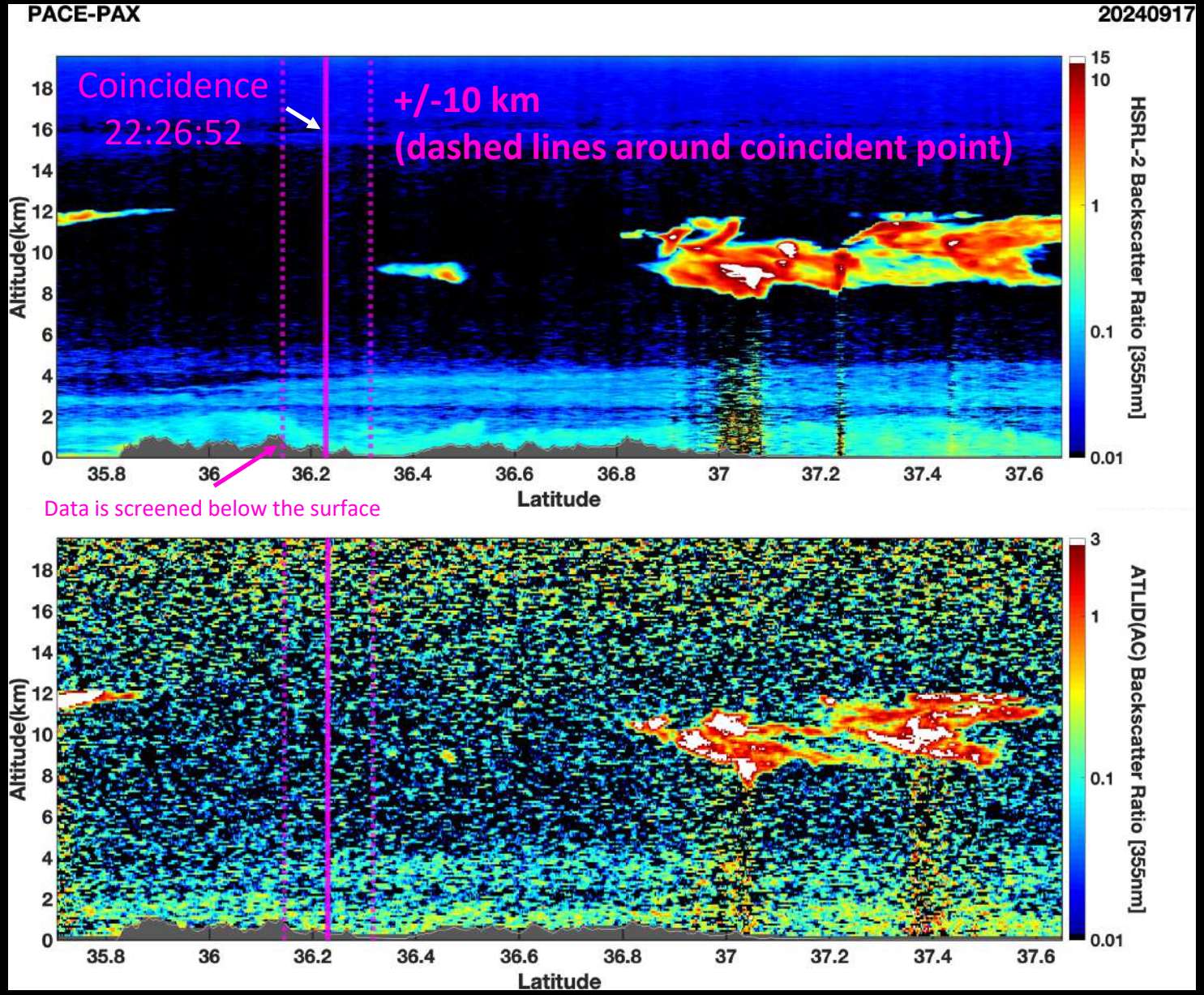
Coordination Summary (355nm) (17 Sep 2024)

Solid Magenta: Coincident Time of Overpass
Dashed Magenta: 10km on each side of overpass time

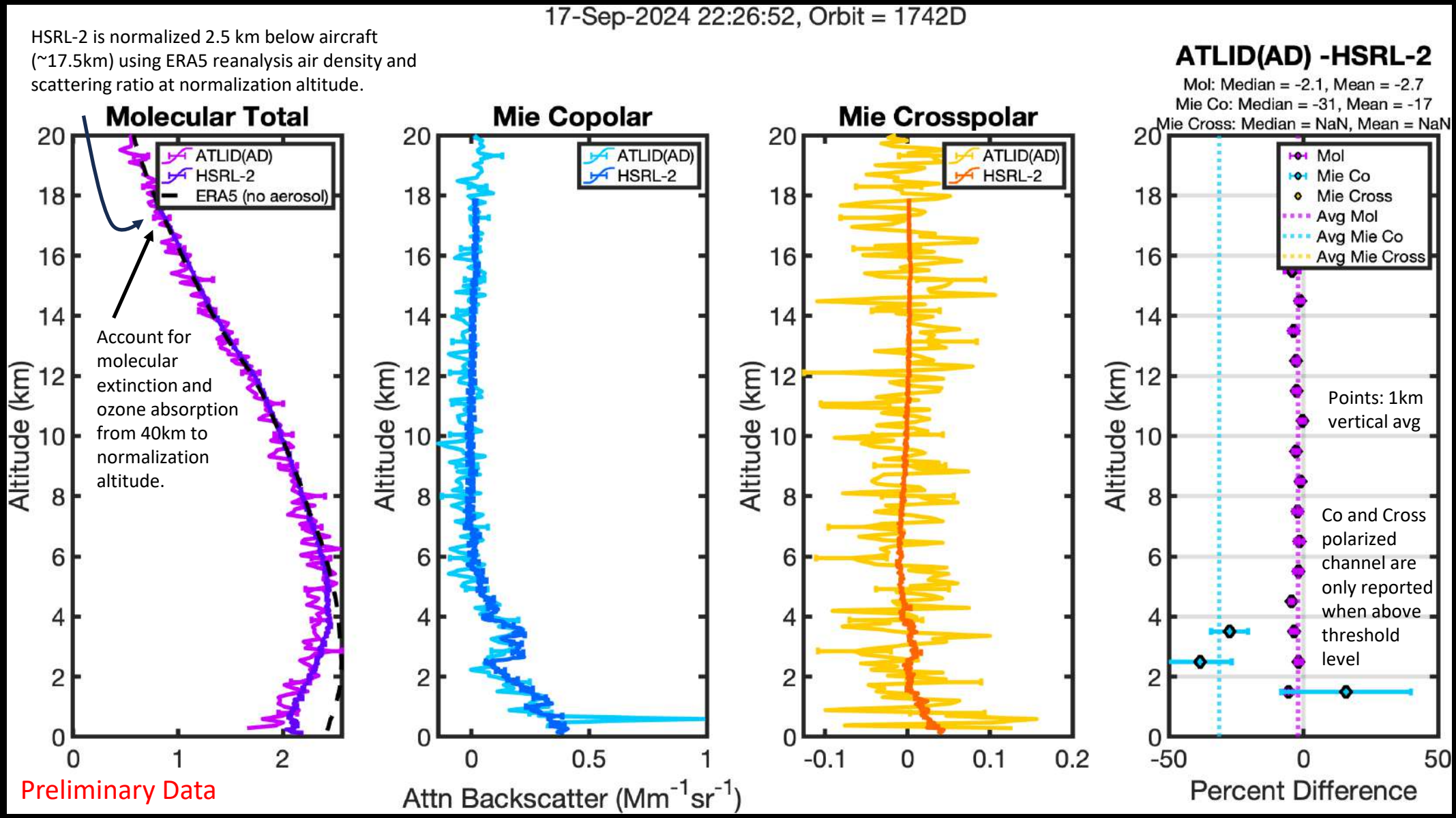


ER-2 Flight track – red
ATLID Ground Track - Black

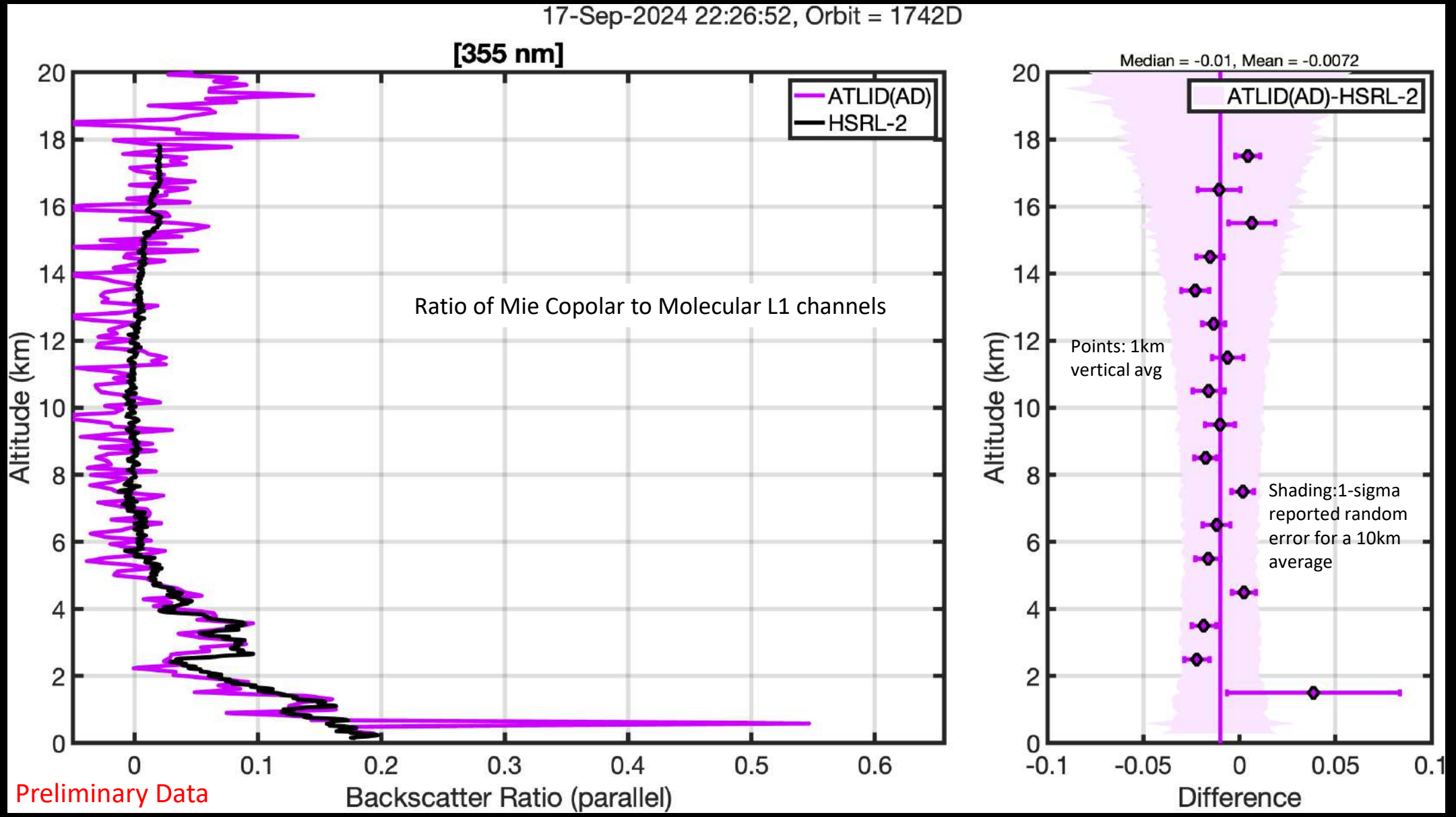
Preliminary Data



Level 1 Signals: Attenuated Molecular, Mie, Cross

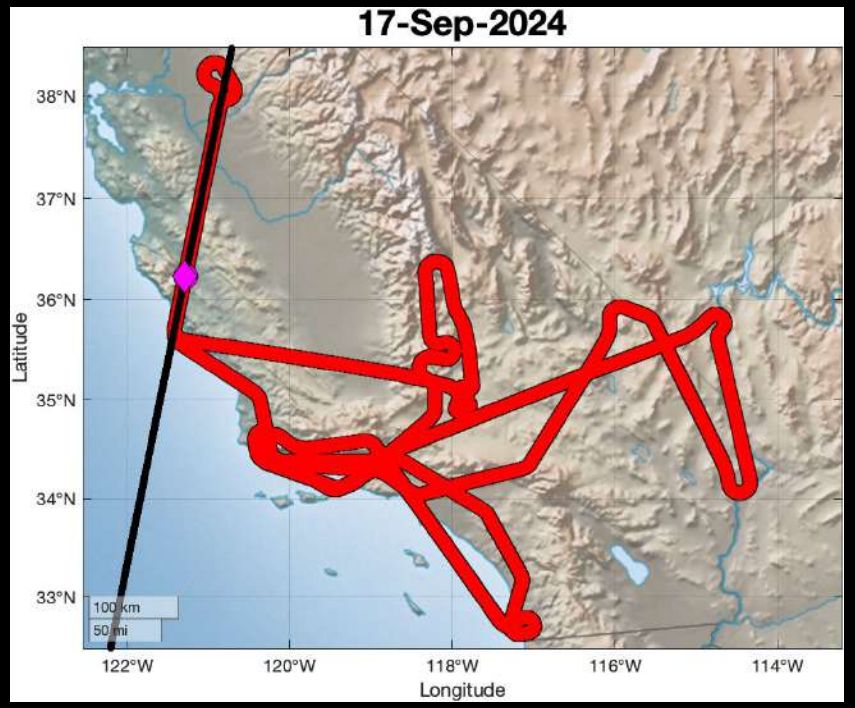


Scattering Ratio (parallel aerosol-to-molecular)



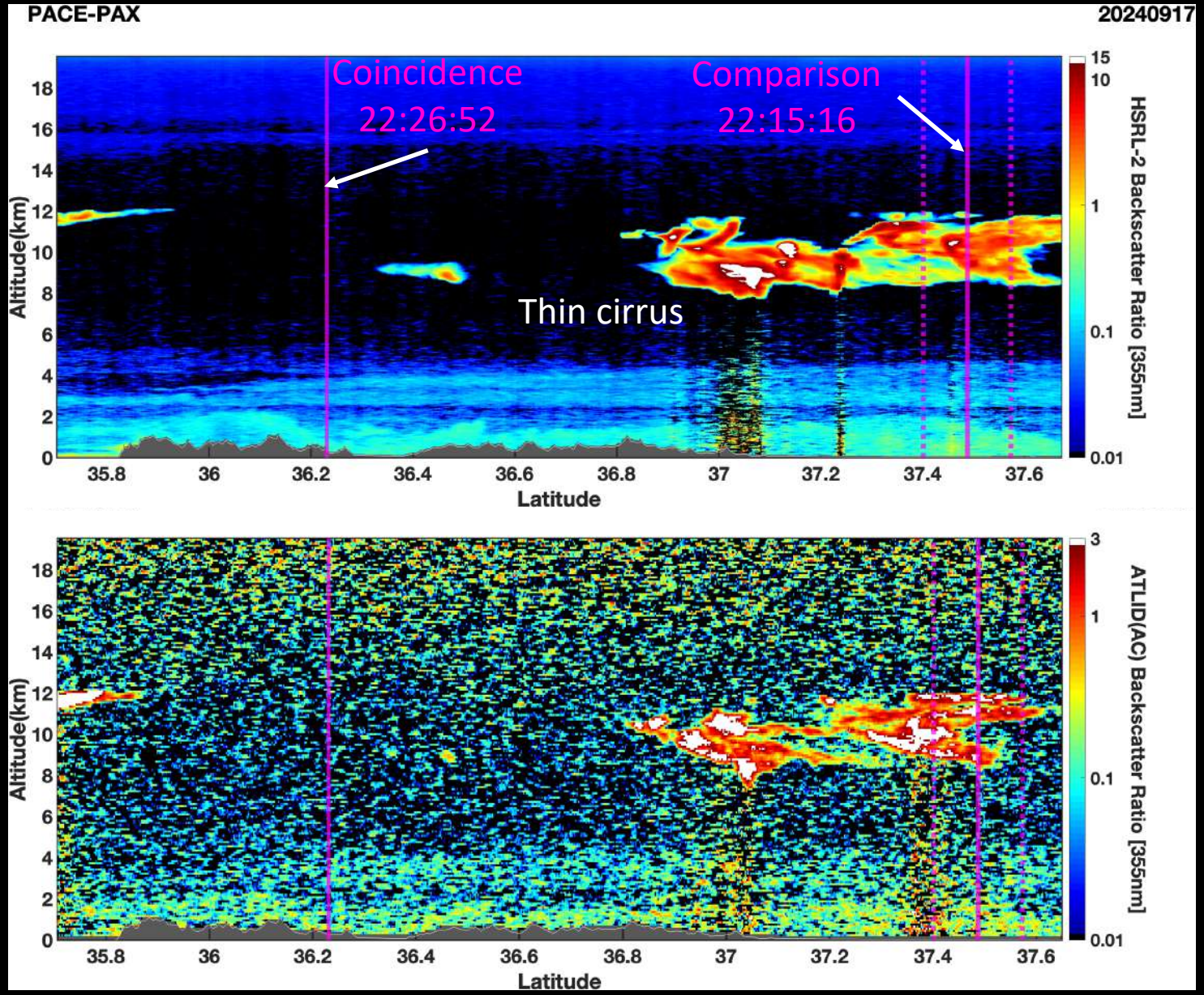
Coordination Summary (355nm) (17 Sep 2024)

Flight Track – Southern California



ER-2 Flight track – red
ATLID Ground Track - Black

Preliminary Data



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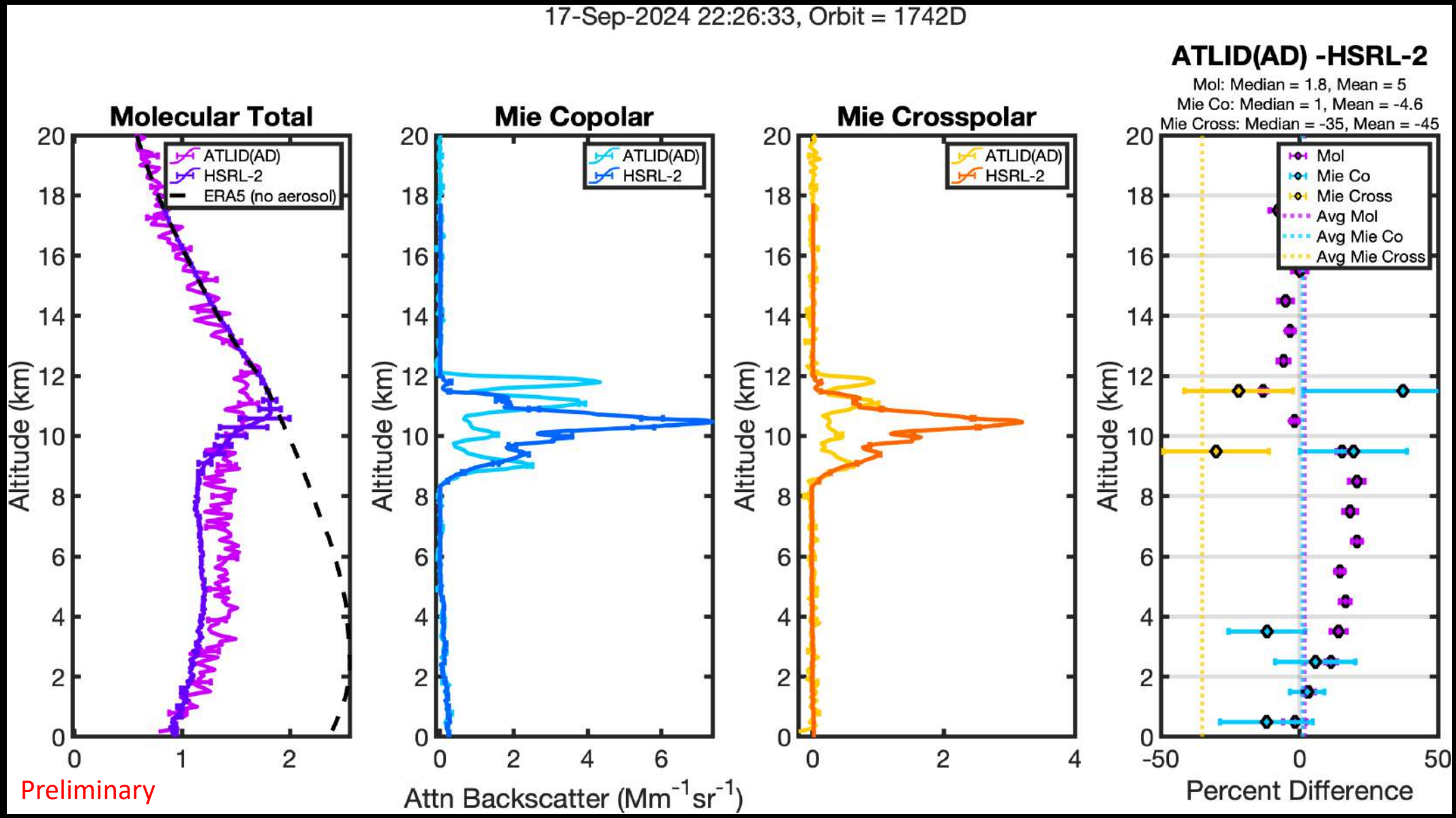
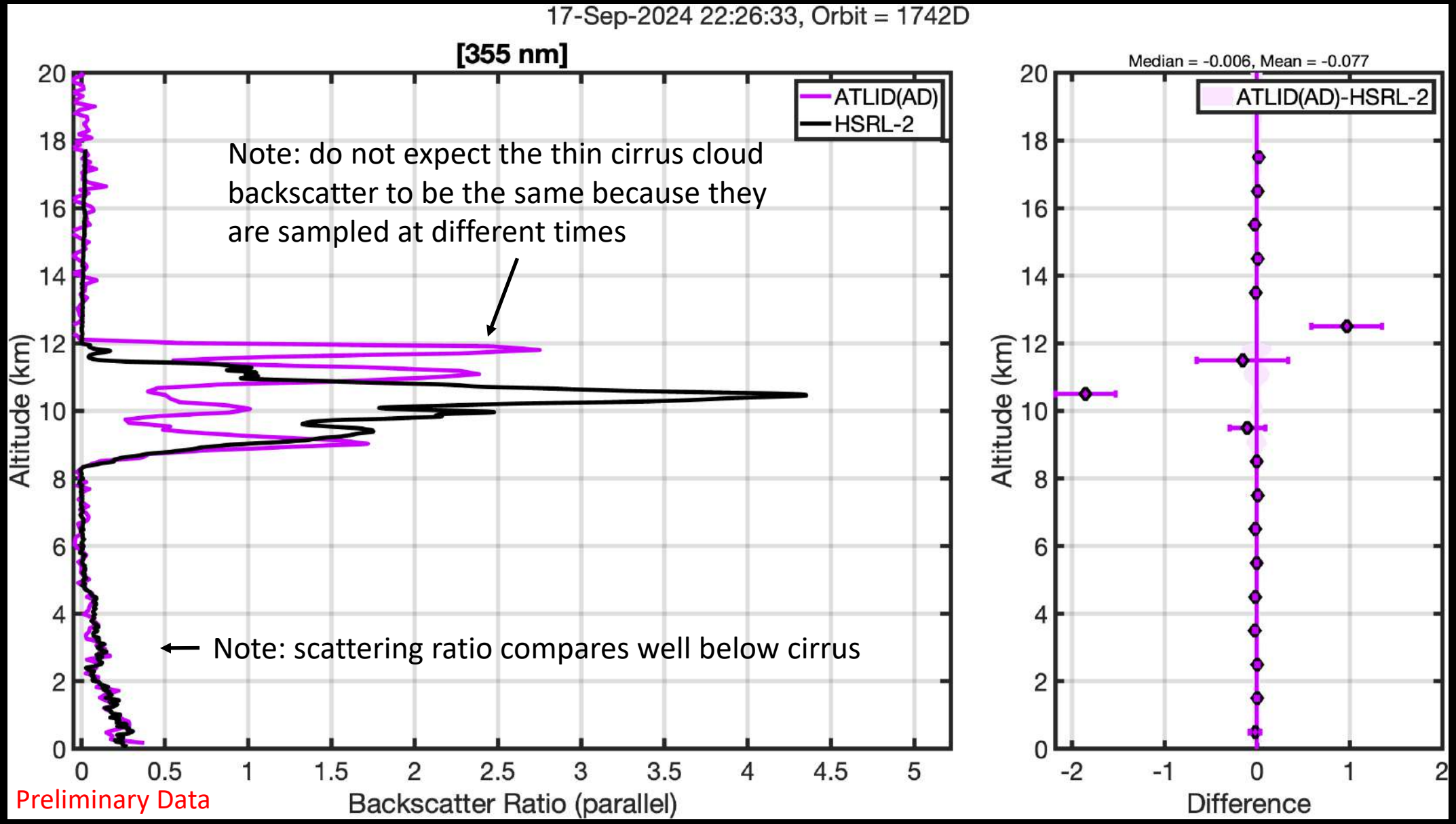
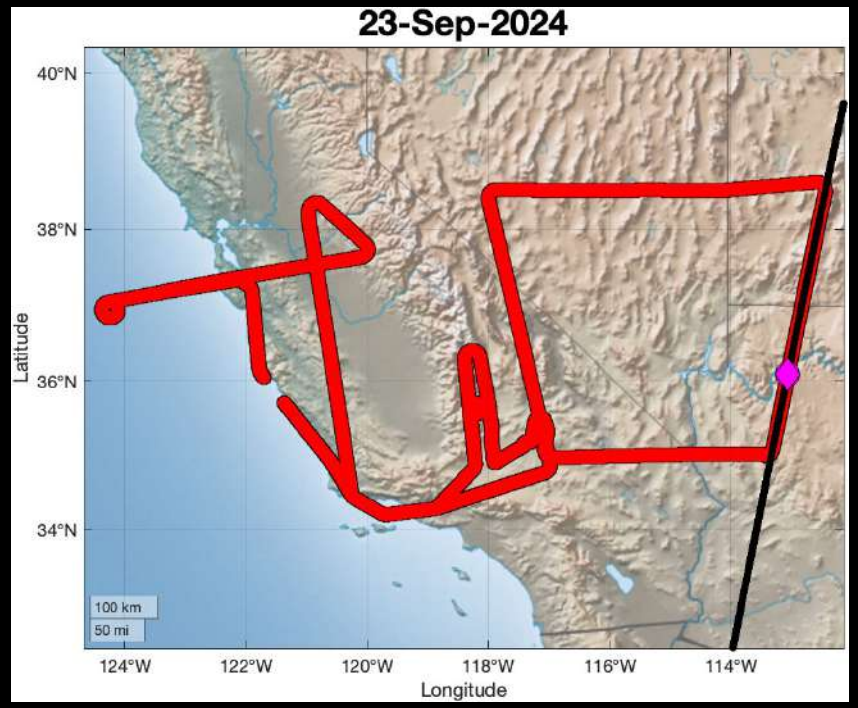


Scattering Ratio (parallel aerosol-to-molecular)



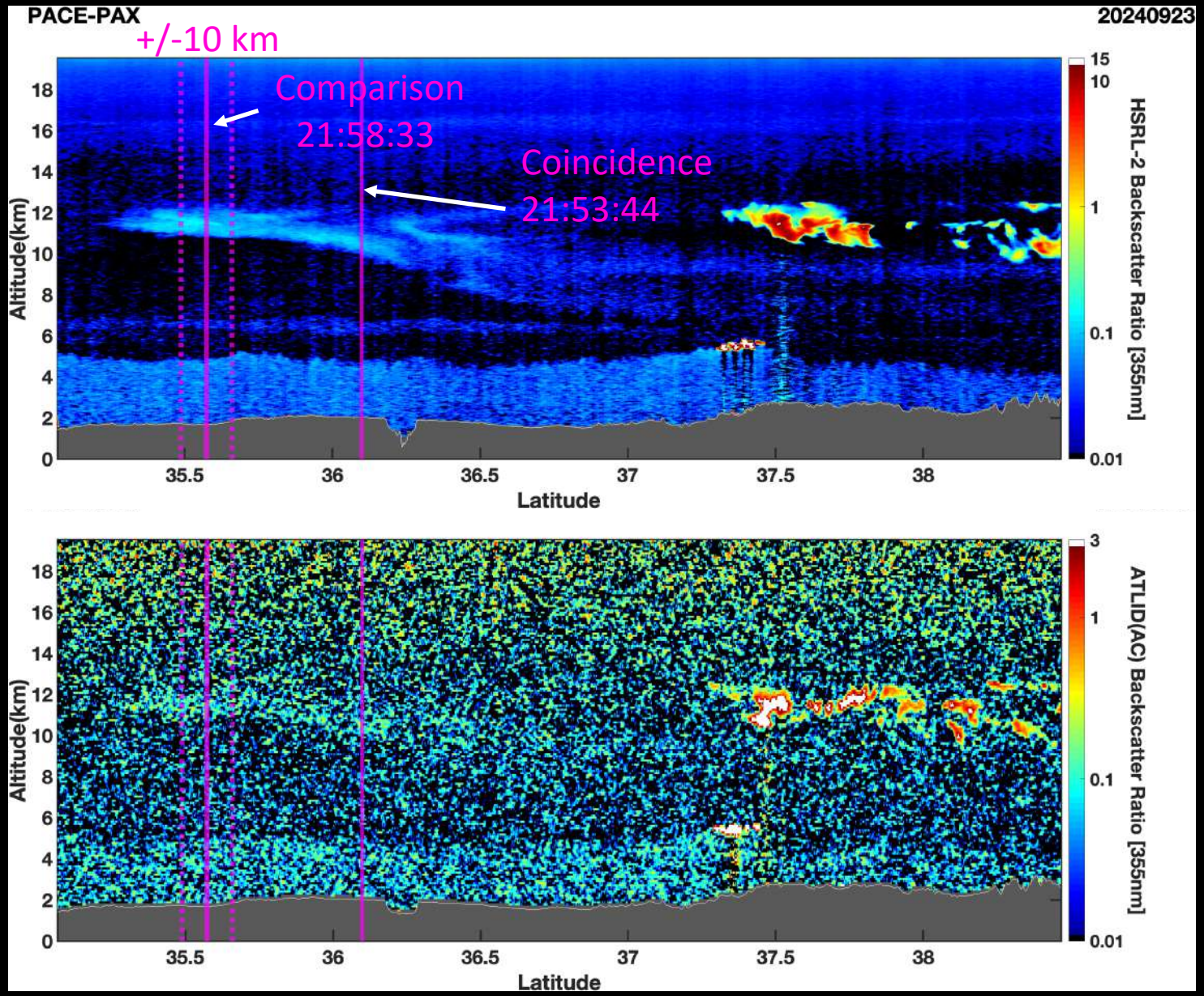
Coordination Summary (355nm) (23 Sep 2024)

Flight Track – Southern California

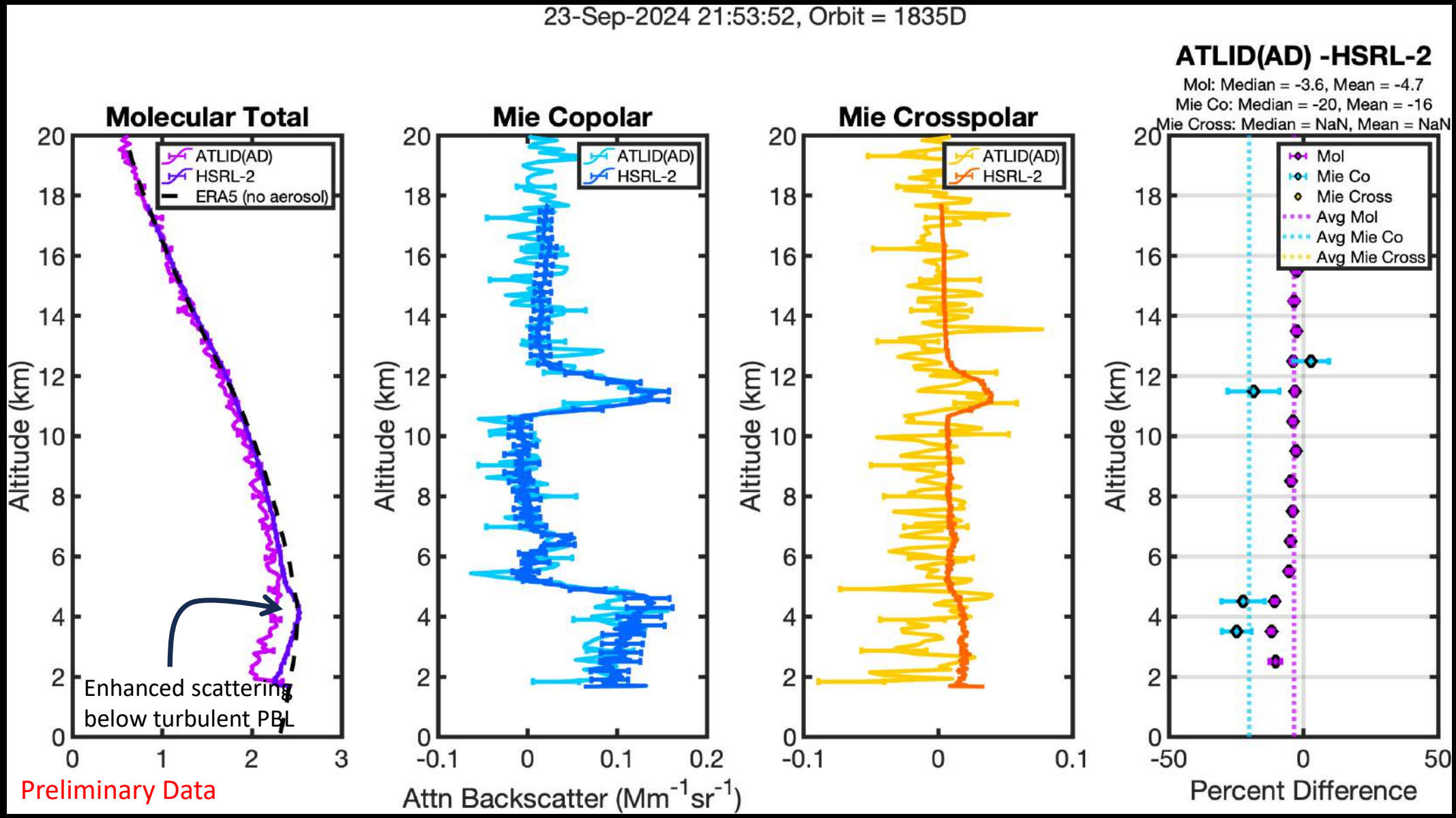


ER-2 Flight track – red
ATLID Ground Track - Black

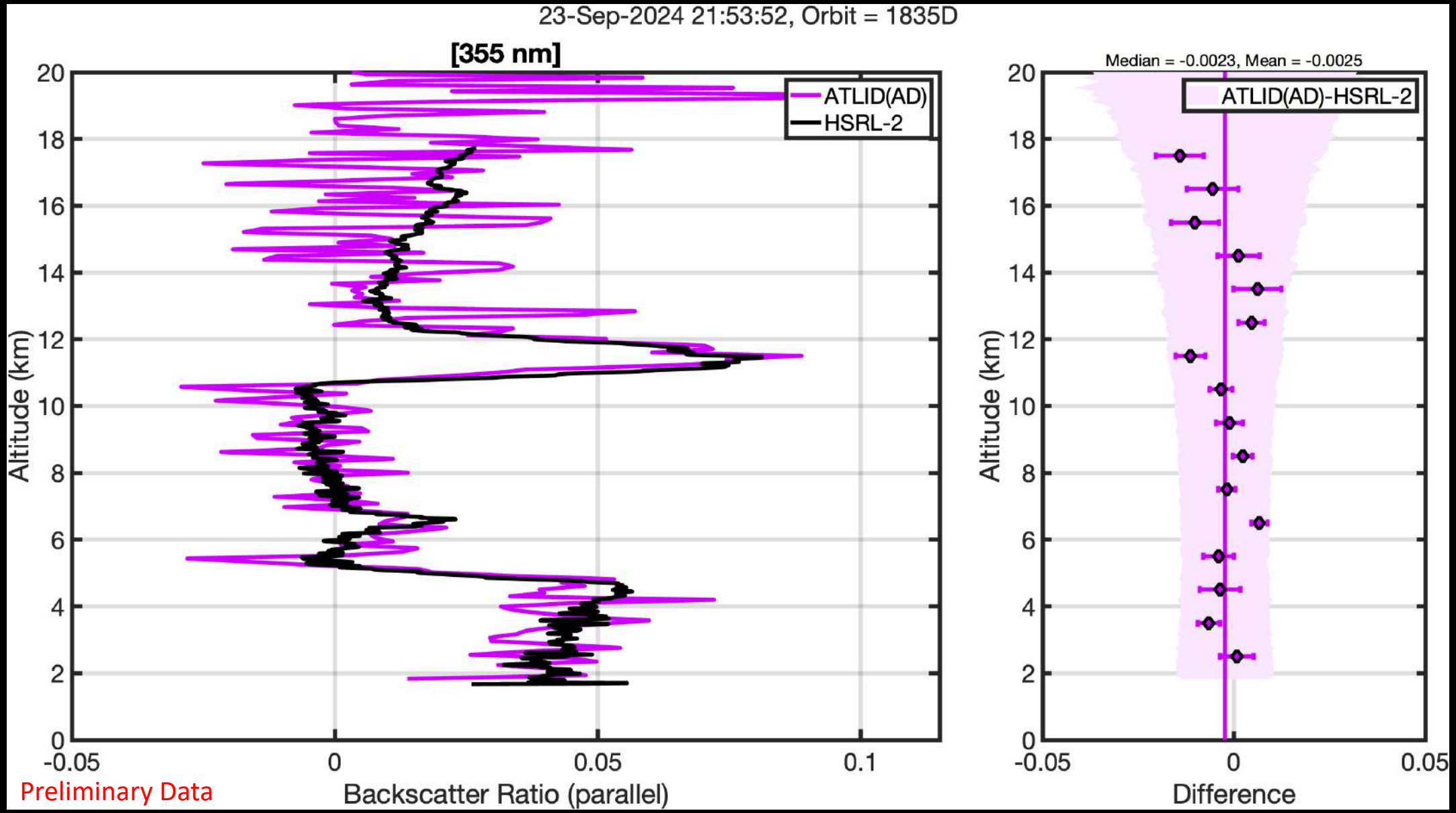
Preliminary Data



Level 1 Signals: Molecular, Mie, Cross



Scattering Ratio (parallel aerosol-to-molecular)

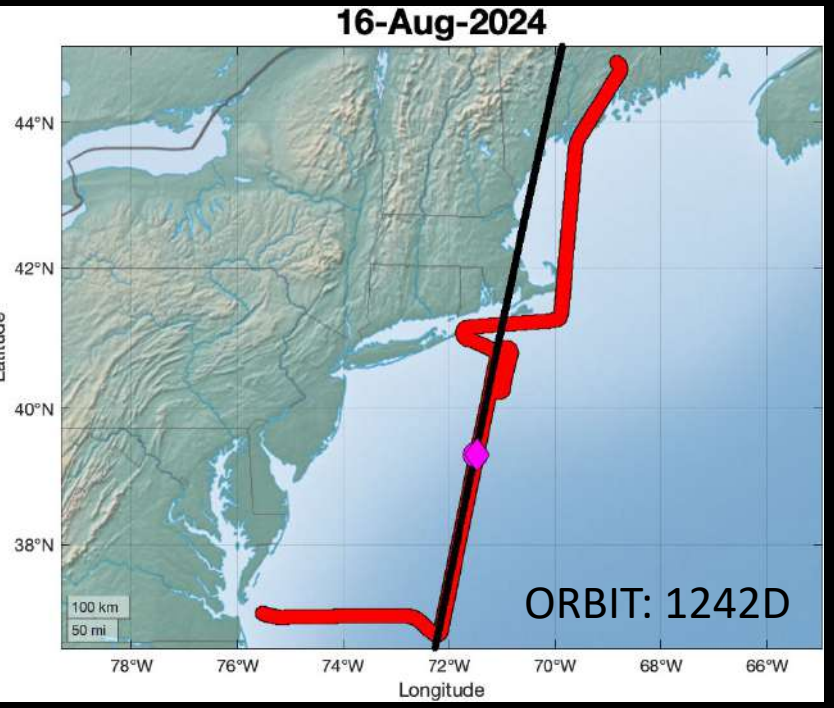


ARCSIX, WH^{2}YMISE/APEX EarthCARE underflights

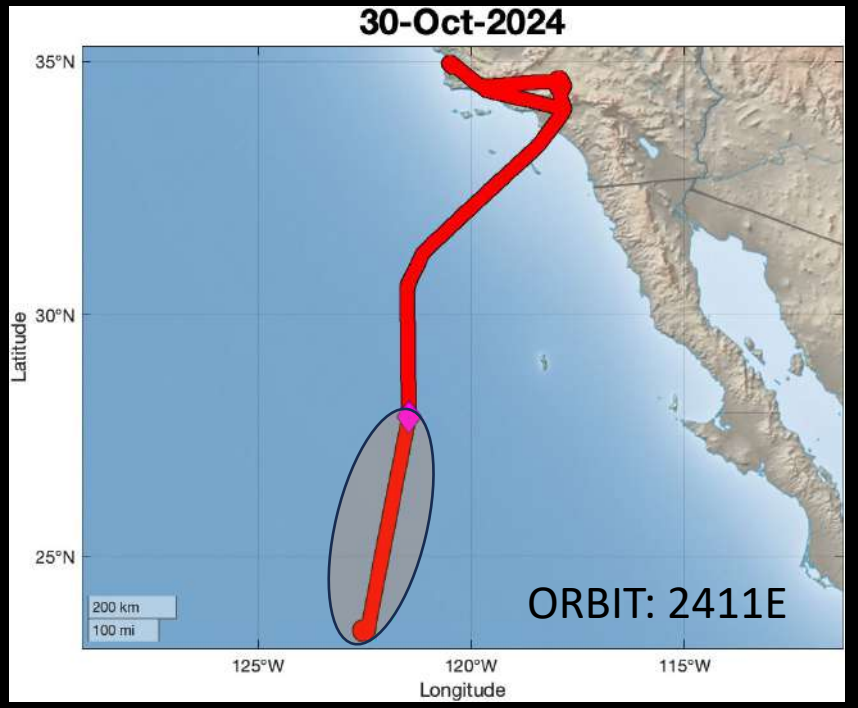
Nominal spatial coordination: <1km
Orbits were all daytime: descending

Note: 30 October 2024 does not have ATLID data (maneuver?). This flight was an out and back flight along the satellite ground track.

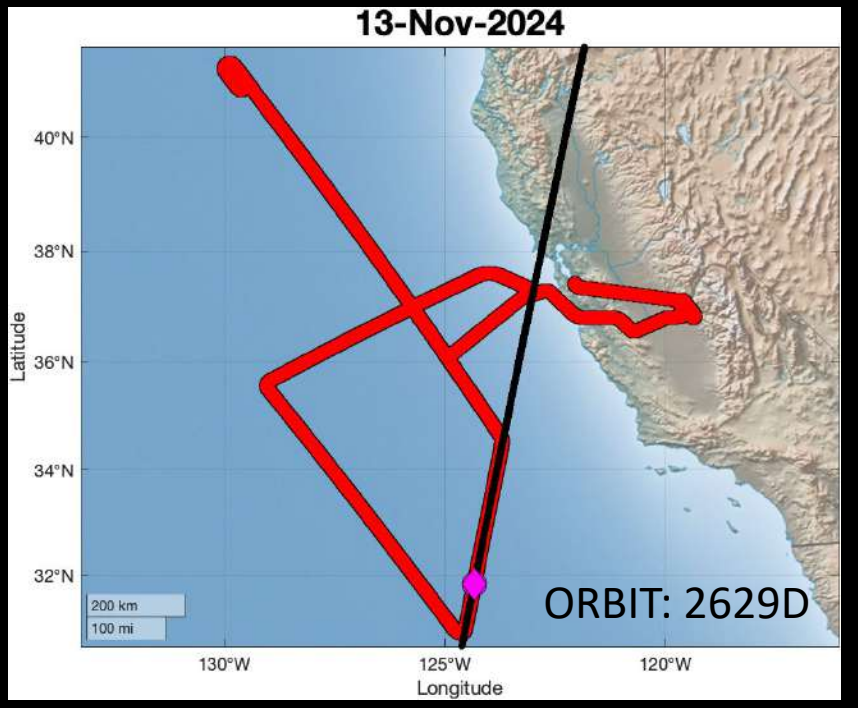
US North-East Coast (ARCSIX)



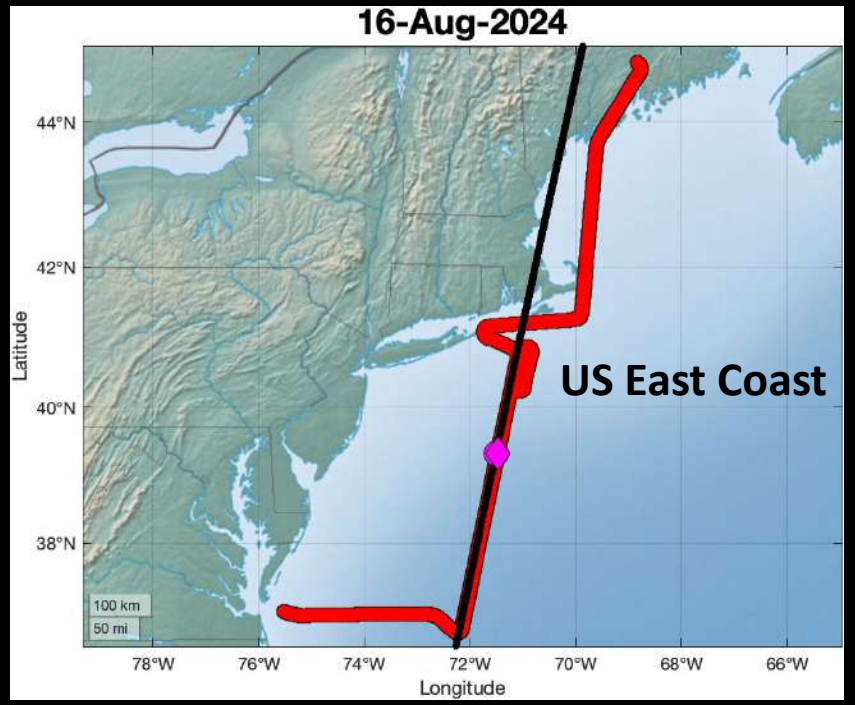
US West Coast/California/Baja



US West Coast/California

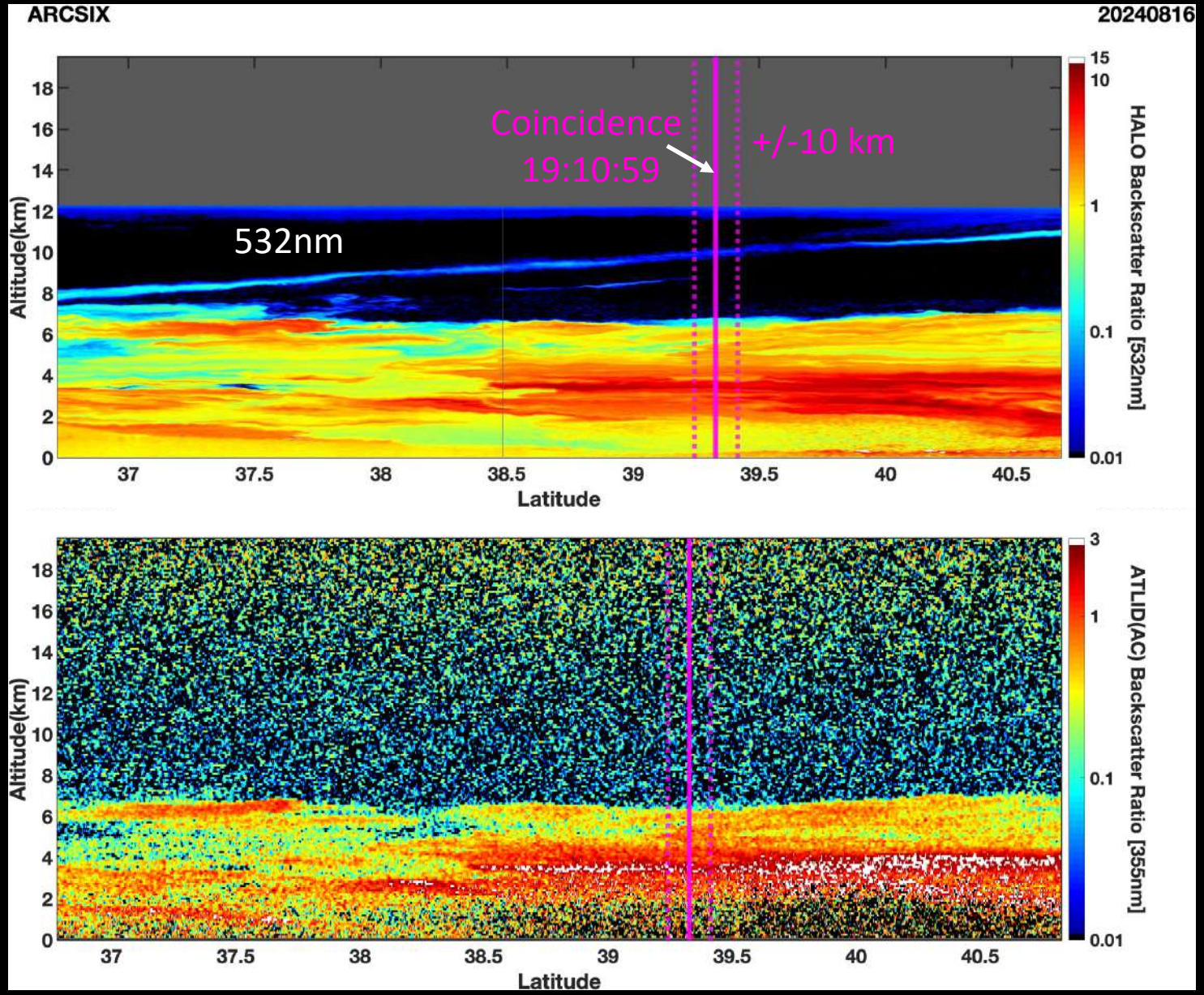


HALO 532-nm measurements converted to 355 nm

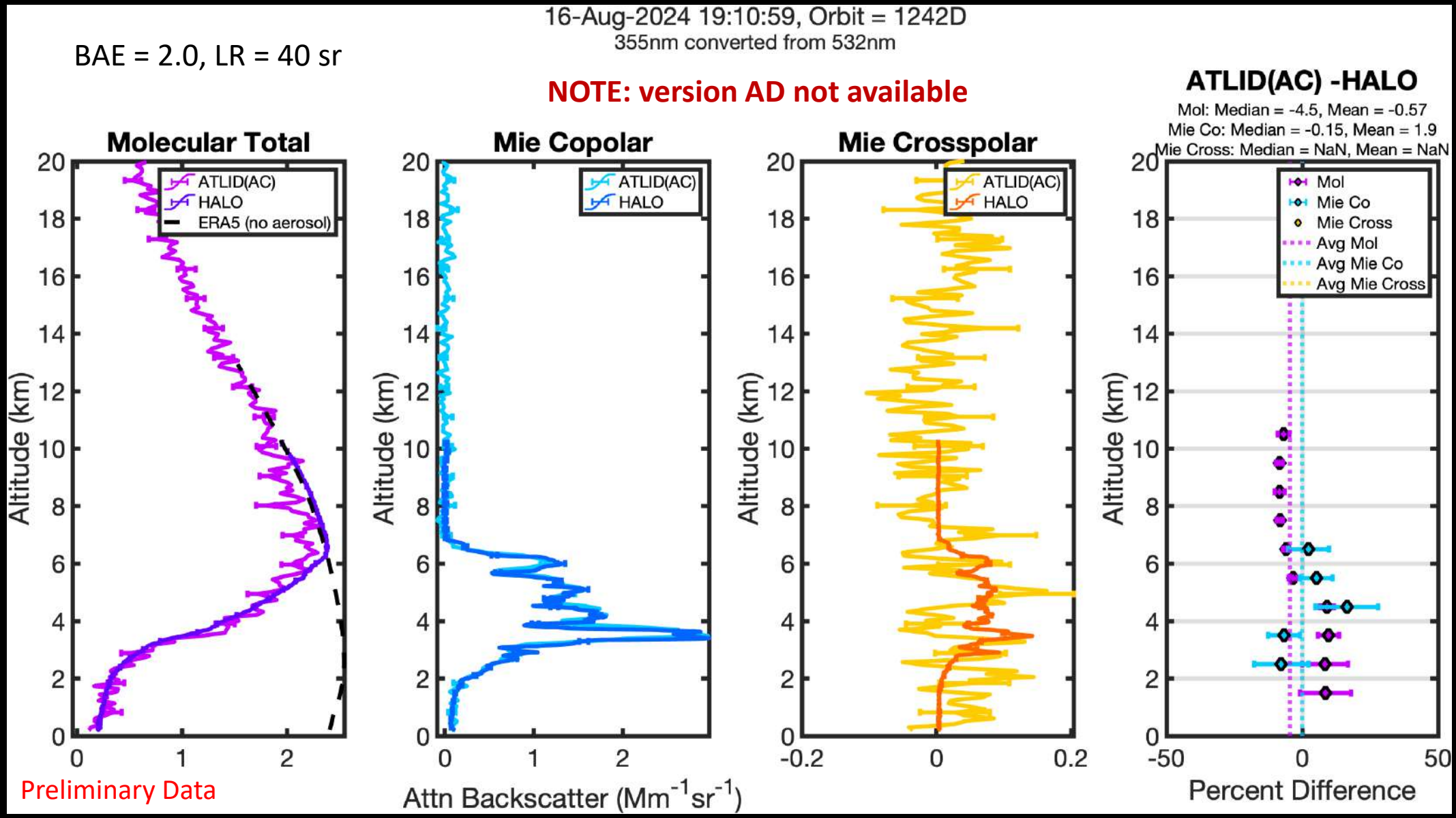


GIII Flight track – red
ATLID Ground Track - Black

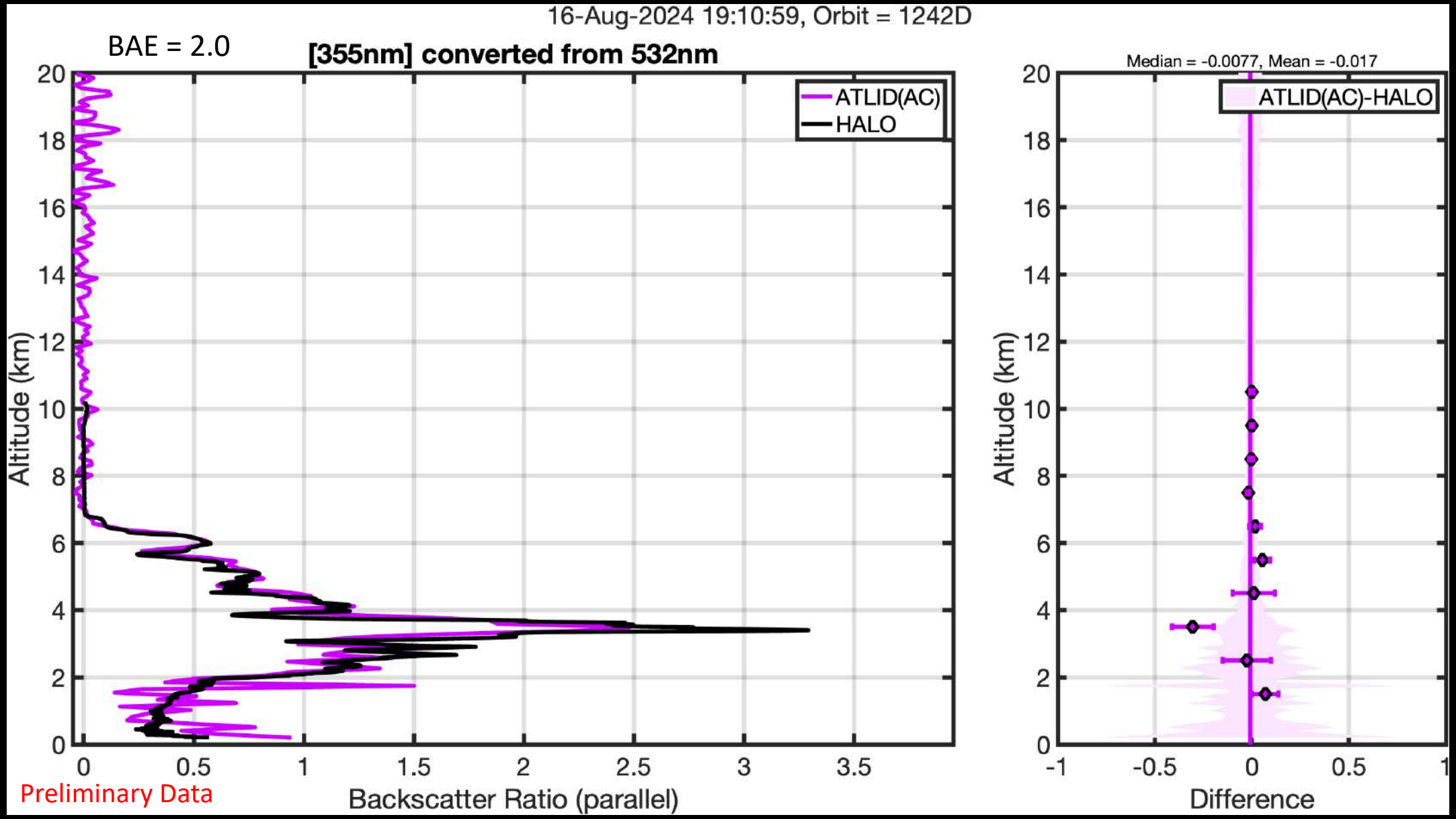
Preliminary Data



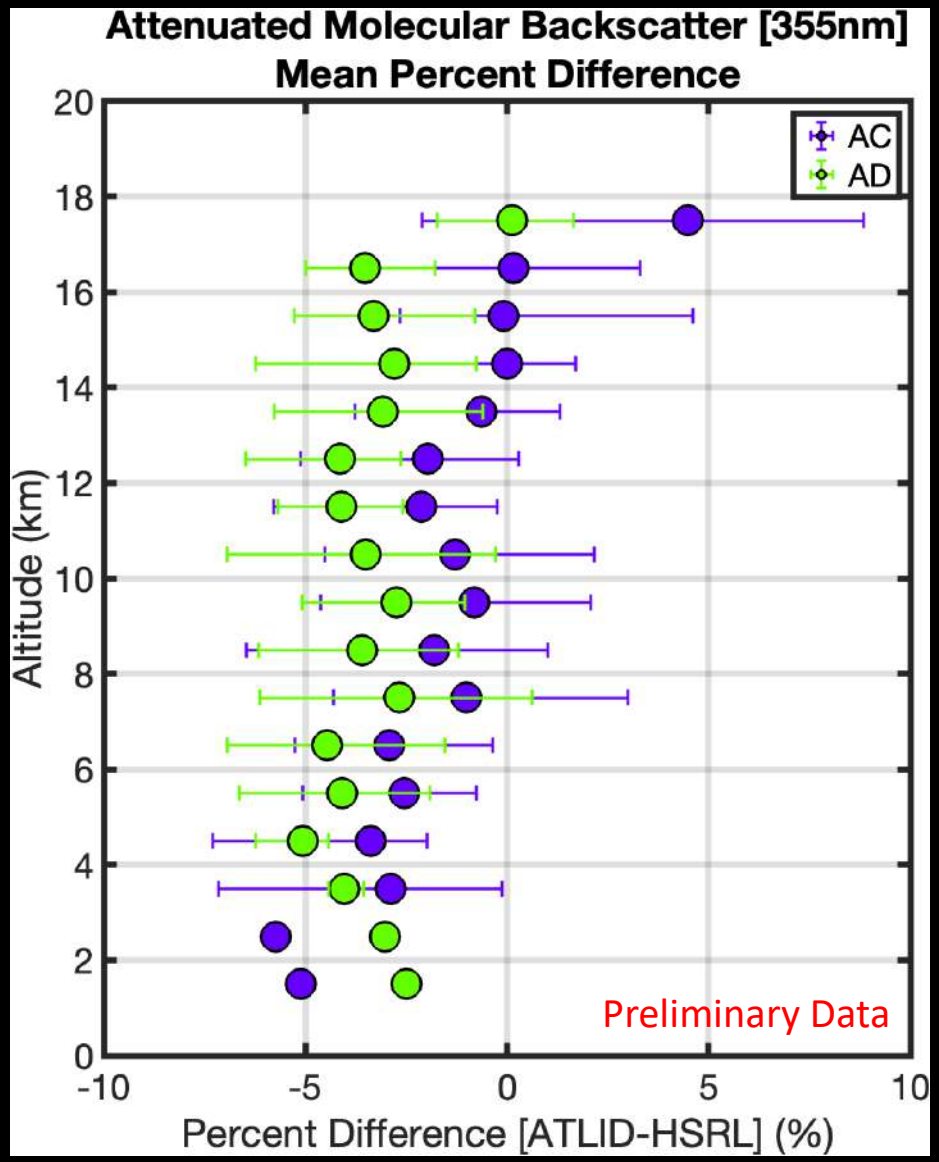
Level 1 Signals: Molecular, Mie, Cross



Scattering Ratio (parallel aerosol-to-molecular)



HSRL-2 Comparison (AC & AD) molecular scattering



Attenuated Molecular Backscatter Percent Differences (bars are min/max values) based on 'clear regions' from HSRL-2 normalization region and lower.

- 1-km vertical and 20-km horizontal average differences differ by < +/- 5%
- Airborne data provides independent measurements to assess the changes in the processing algorithm. Here version AC v. AD (first public release data)
- Notice the percent difference is more constant with altitude in version AD compared to version AC, and spread over the 6 flights is significantly less.
- Airborne data will continue to provide validation in future release of processing versions.

Nighttime Bermuda Lidar Underflights of EarthCARE - NightBLUE

Rationale:

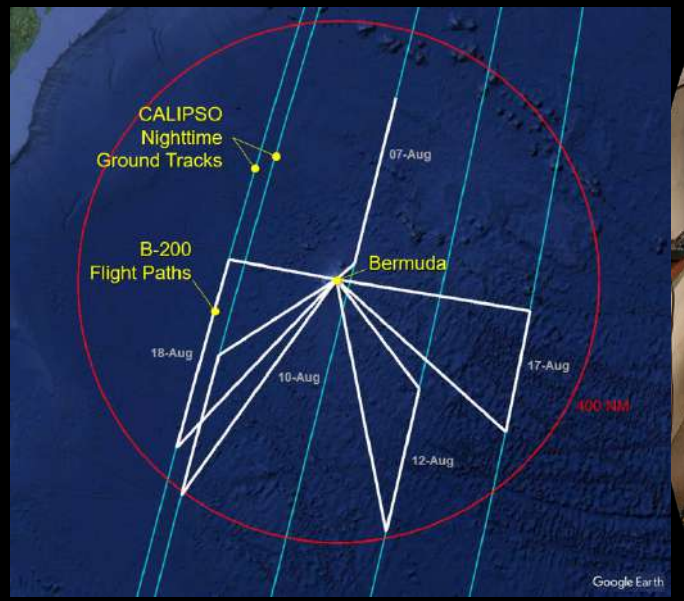
- Nighttime validation is currently a high priority of the ATLID algorithm team
- Eliminates complications from solar background noise in assessing basic aspects of instrument and algorithm performance

Approach: Similar to CALIPSO nighttime validation flights from Bermuda conducted in 2022

- Deploy NASA's HSRL-2 on the G-III (13km)
- Base in Bermuda - September 2025, 3 weeks
- Conduct 10+ underflights along EarthCARE's ATLID ground track at night (~2:30 AM local time)
- Coordinate targets (aerosols, warm clouds, cirrus clouds) with ATLID algorithm team

NASA LaRC Gulfstream III

Example: CALIPSO Night Validation Flights 2022



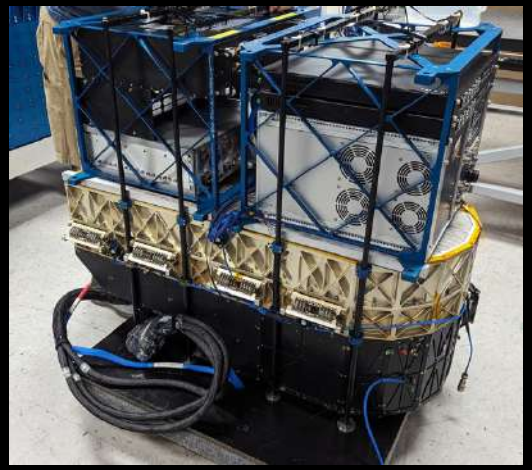
High Spectral Resolution Lidar
HSRL-2 355nm & 532nm

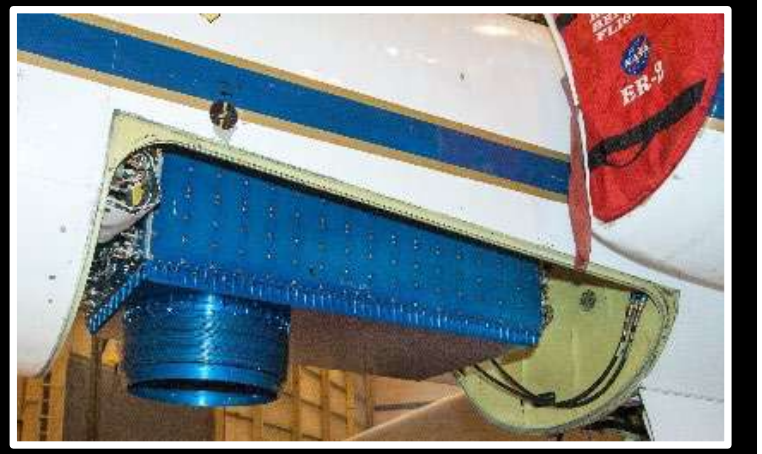
Instrument Team: HSRL-2 on ER-2 for PACE-PAX

HSRL-2 Team Members

Sharon Burton
Brian Collister
Tony Cook
Marta Fenn
Rich Ferrare
John Hair*
David Harper
Chris Hostetler
Madison Hetlage
Amin Nehrir
Tony Notari
Amy Jo Scarino
Taylor Shingler

HSRL measurements at 355 and 532 nm





Nominal flight altitude – 20 km

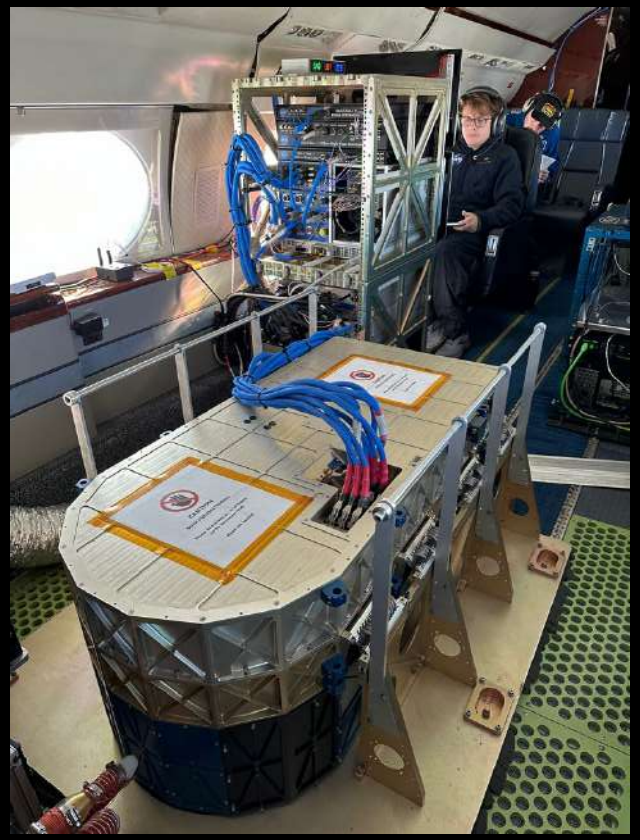
Instrument Team: High-Altitude Lidar Observatory (HALO) on G-III for ARCSIX, WH^{2}YMSIE, APEX

HALO Team Members

Rory Barton-Grimley
James Collins
Brian Collister
Ewan Crosbie
Rich Ferrare
John Hair
David Harper
Madison Hetlage
Joe Lee
Amin Nehrir *
Tony Notari
Taylor Shingler
Ashwin Yerasi

HSRL measurements at 532 nm and Water Vapor

HALO instrument and rack



HALO + AVIRIS-NG (ARCSIX)

HALO + AWP(WH^{2}YMSIE/APEX)

Summary

- ATLID's Level 1B molecular and Mie channels are impressively accurate!
  - e.g., the 355nm attenuated molecular backscatter is within 5% of the HSRL-2 measurement in the 'clean' troposphere.
- Conclusion based on 7 flights with NASA LaRC HSRL-2 and HALO instruments.
  - HSRL-2 measurements are at 355 nm, HALO at 532 nm
  - 5 HSRL-2 flights deployed from the ER-2 at 20 km, providing full troposphere comparison
  - We have implemented at least one method to convert 532nm data to 355nm for L1B comparisons
- ATLID cross polarized channel shows lower values than HSRL.
  - Comparison hampered by low depolarization ratios in the scenes; need better cases
- Next steps: additional flights in September 2025 (nighttime calibration)

Thanks for your attention!

Comments on Method of Comparisons

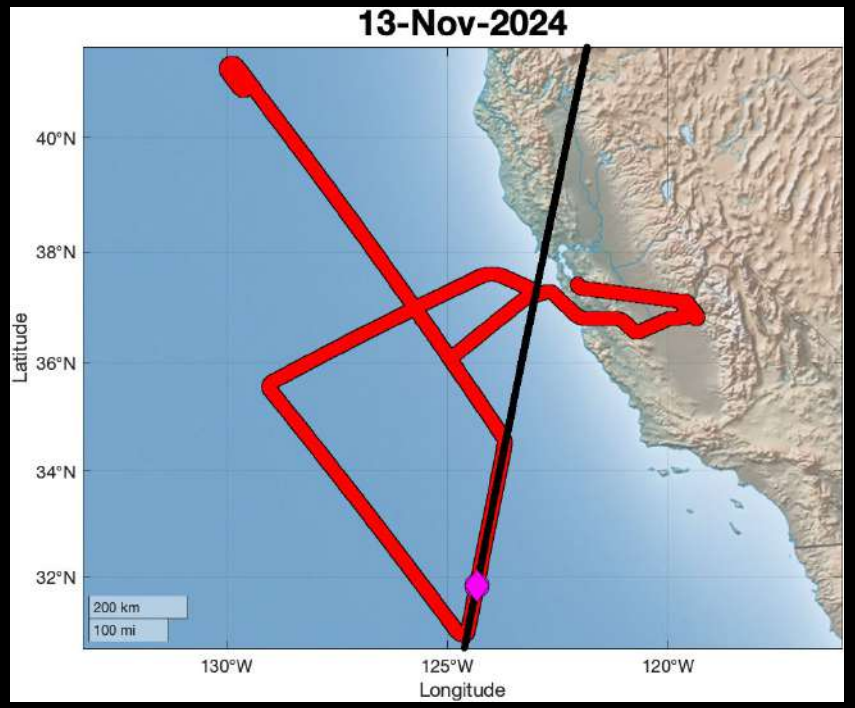
- Independent analogs of level 1B ATLID data products (355nm)
  - Attenuated (2-way) Total Molecular Backscatter ($m^{-1}\,sr^{-1}$)
  - Attenuated Parallel Particulate (Mie) Backscatter ($m^{-1}\,sr^{-1}$)
  - Attenuated Cross Polar Mie Backscatter ($m^{-1}\,sr^{-1}$)
- HSRL-2 calibration requirements which are determined during flight
  - Optical and electrical gain ratio (~1-2%)
  - Interferometer filter coefficients (i.e. cross talk)
    - Atmospheric temperature profiles are NOT required (transmission through HSRL-2 interferometer is insensitive to temperature by design)
    - Mie transmission and reflection coefficients (i.e. contrast ratio) determined from clouds and surface
  - ERA5 reanalysis (air density) at normalization (17-18km) and total scattering ratio from HSRL-2 is used to determine absolute lidar calibration needed to calculate attenuated products
- HSRL-2 attenuation down to calibration point
  - Attenuation from molecular extinction and ozone absorption determined from ERA5
  - Attenuation from particulate extinction (i.e. stratospheric aerosols) are not included
- Turbulence effects (enhanced backscatter) can impact HSRL-2 attenuated backscatter. It appears that ATLID does not observe this effect.
- Preliminary Data: still expect refinements of filter coefficients and gain ratios for HSRL-2

Comments on Converting 532nm to 355nm for HALO data

1. Assign vertically constant particulate (Mie) backscatter color ratio or backscatter Angstrom coefficient (BAE) – can use knowledge on aerosol type (i.e. smoke and marine)
2. Assign vertically constant 355nm lidar ratio - can use knowledge of aerosol type
3. Calculate unattenuated particulate backscatter coefficient at 532nm
4. Calculate 355nm particulate (Mie) backscatter coefficient using color ratio
5. Calculate 355nm particulate extinction from 355nm backscatter and 355nm lidar ratio
6. Scale 355nm backscatter coefficient with ratio of 2-way attenuation to calculate the attenuated particulate backscatter
7. Currently, cross polarization channel color ratio assumed to be same
8. Still need to evaluate biases from input parameters– smoke example above is sensitive choice of inputs.

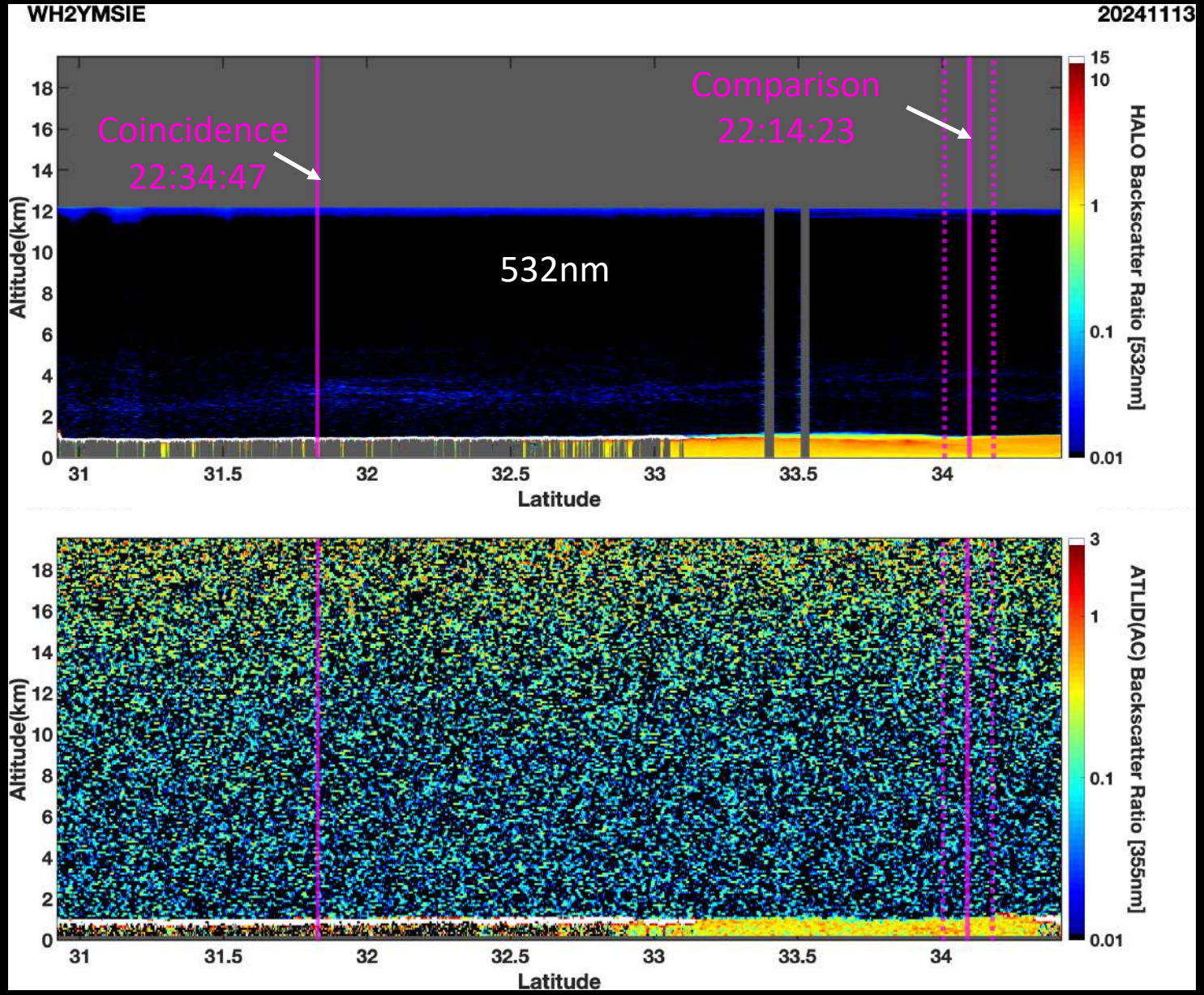
Coordination Summary (355nm converted from 532nm) (13 November 2024)

Flight Track – Southern California



GIII flight track– red
ATLID Ground Track - Black

Preliminary Data



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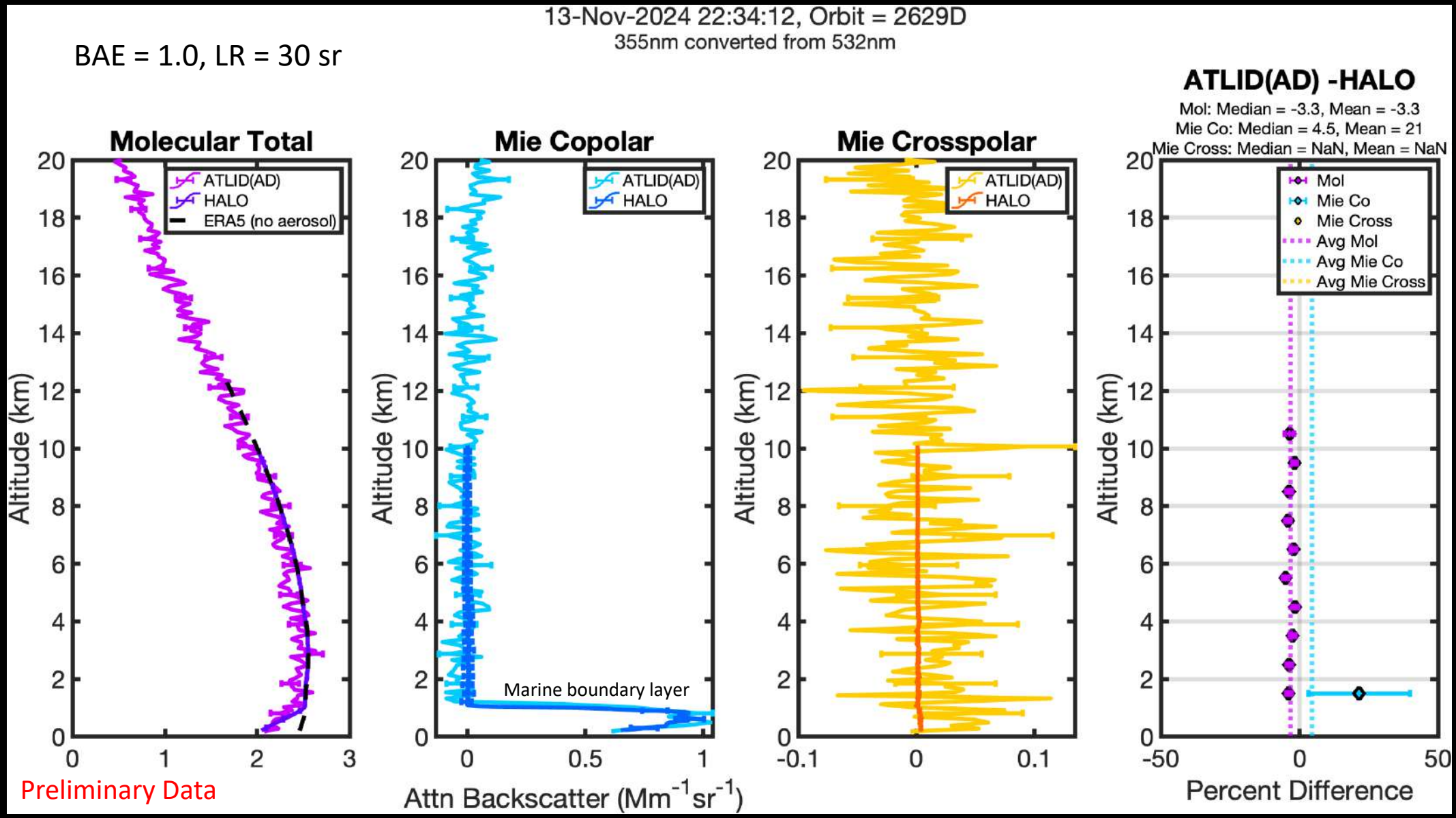

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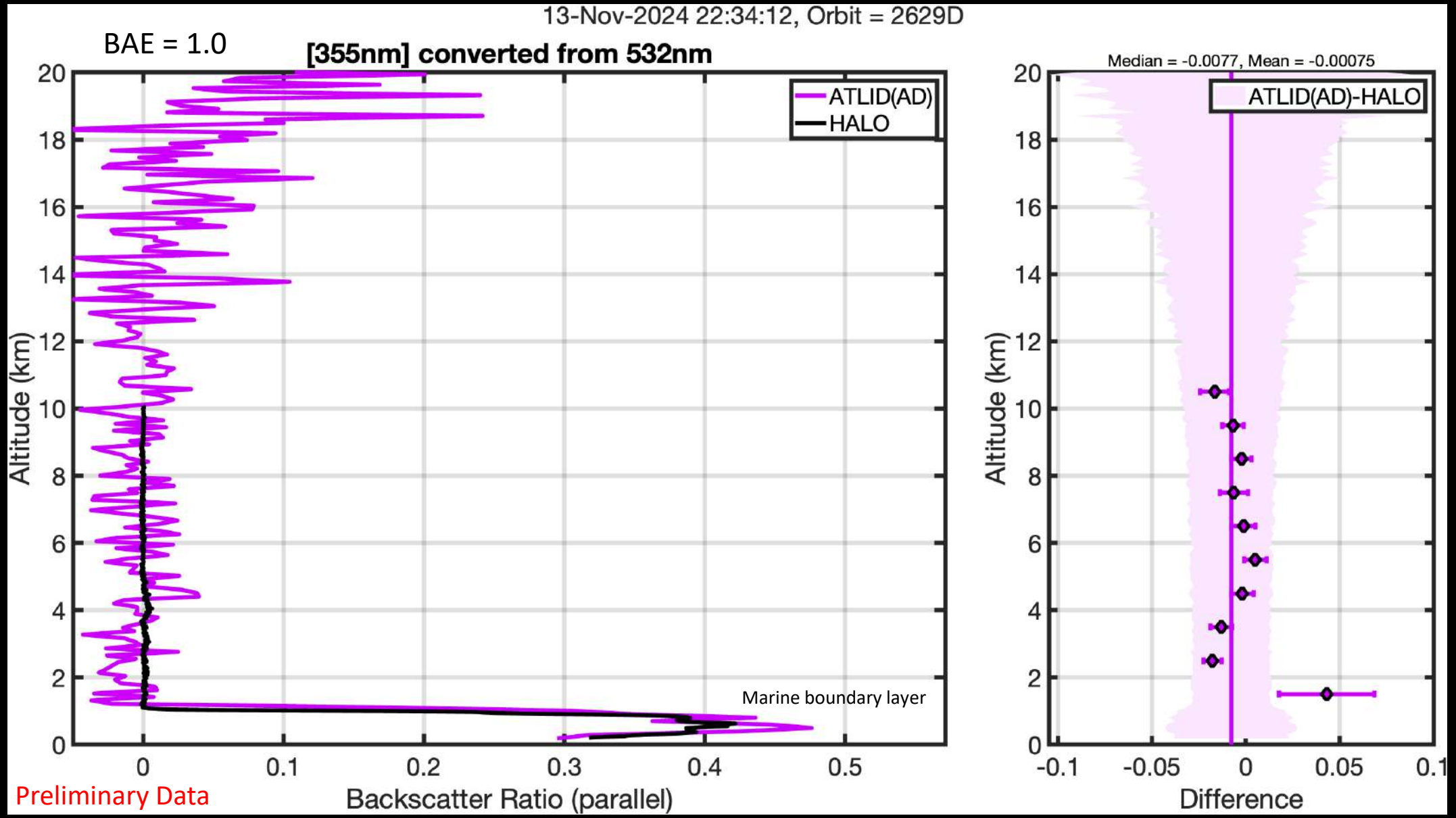
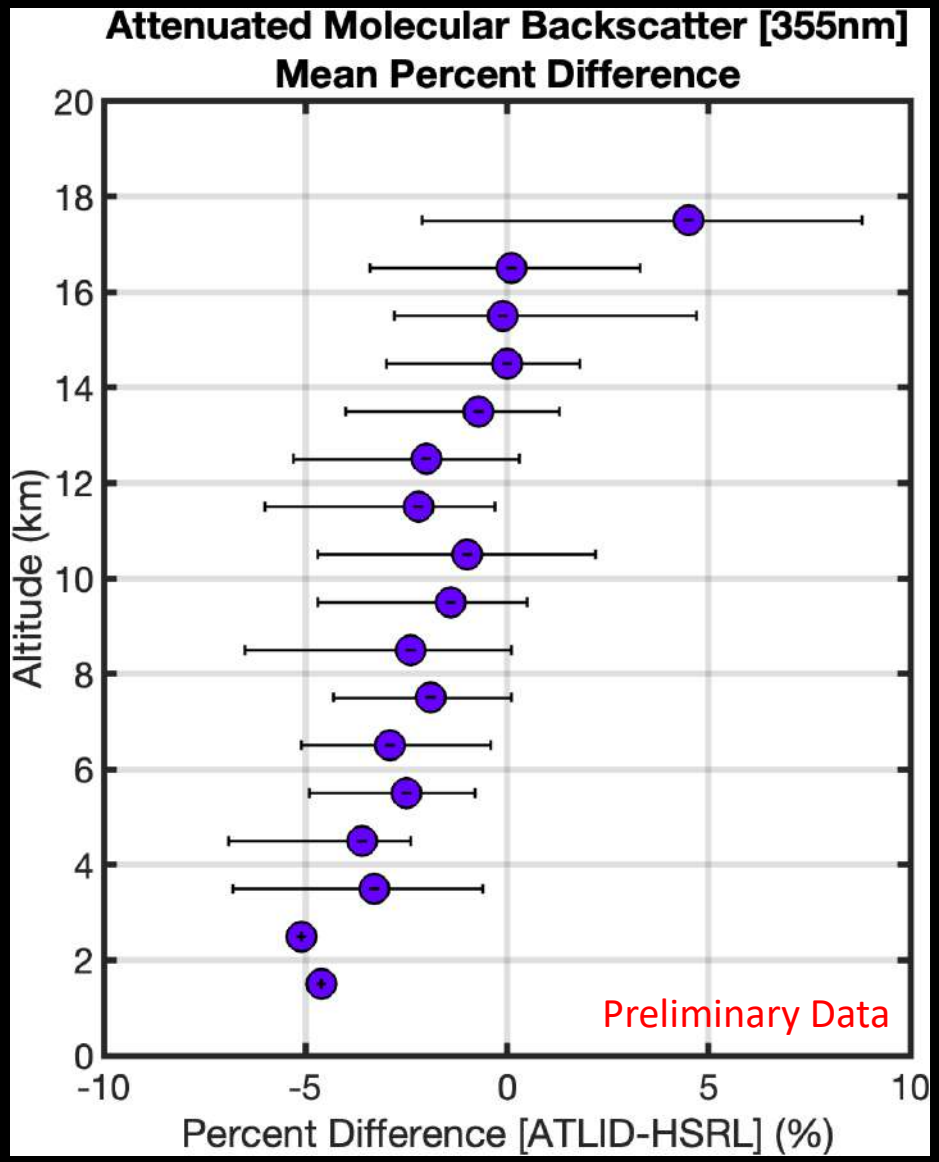


HSRL-2 Initial Comparison (AC) molecular scattering



Attenuated Molecular Backscatter Percent Differences (bars are min/max values) based on 'clear regions' from HSRL-2 normalization region and lower. Note, clear regions are where there is low scattering from aerosol and no clouds.

- 1-km vertical and 20-km horizontal average differences differ by < +/- 5%
- Comparisons of ATLID and HSRL-2 show on average no offset from 13-16km and has 4-5% difference (ATLID lower than HSRL-2) near the surface.
- Recall that these are independent measurement and HSRL-2 does not require temperature profiles for filter coefficients.
- The values here do show a small trend (5%). Potential reason for the trend might be related to the filter cross talk corrections. (see next slide to compare to ver. AD)