EarthCARE's Atmospheric Lidar (ATLID-version AC) L1B Comparisons from NASA's PACE-PAX, ARCSIX, WH^2YMSIE, and APEX Aircraft Campaigns

Johnathan Hair, Amin Nehrir – NASA Langley Research Center

1. Comparisons at 355nm with HSRL-2 instrument (Multiwavelength HSRL) flown on ER-2 Aircraft (PACE-PAX)
2. Comparisons at 355nm converted from 532nm HALO instrument (HSRL/H20 DIAL) flown on GIII Aircraft (ARCSIX, WH^2YMSIE/APEX)

Data are still PRELIMINARY for HSRL-2/HALO

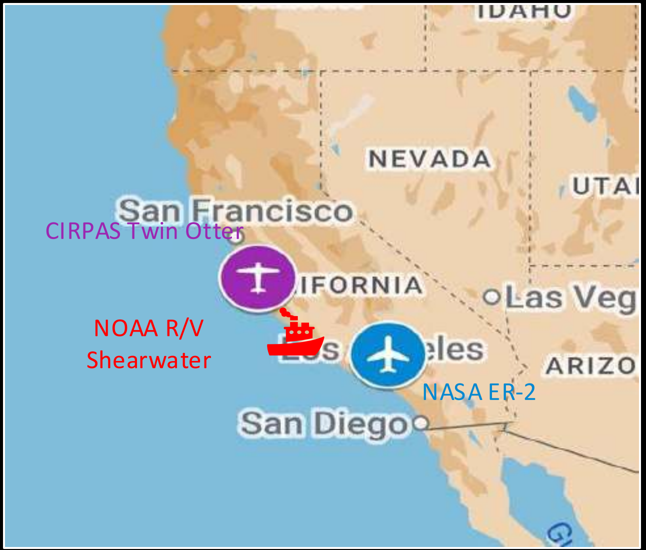
Final Data for HSRL-2 (HALO) due before March 2025 (Feb 2025)

Summary: comparisons are impressive, especially at this early stage!

PACE Postlaunch Airborne eXperiment (PACE-PAX)

PACE-PAX

Objective: validate new ocean, atmosphere and land surface products from NASA's PACE observatory

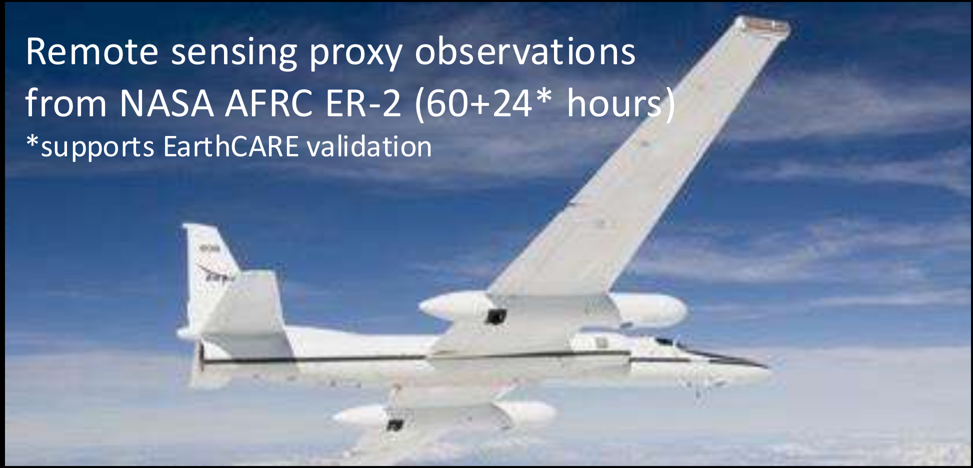


Campaign Leads

Kirk Knobelspiesse, Brian Cairns, Ivona Cetinić

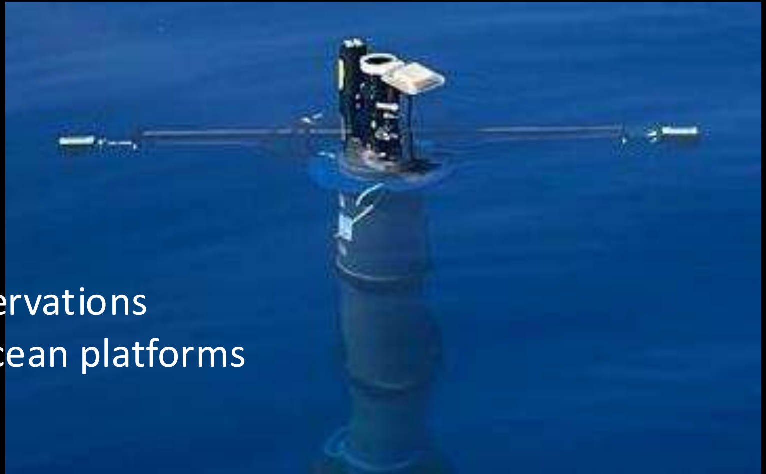
pace.oceansciences.org/campaigns.htm

In situ sampling with CIRPAS Twin Otter (60 hours, based in Marina, CA)



Remote sensing proxy observations from NASA AFRC ER-2 (60+24* hours)

*supports EarthCARE validation



Coordinated observations over surface sites & ocean platforms

Day trips from Santa Barbara, NOAA R/V Shearwater

Objectives of PACE-PAX

- Objective: **The Plankton, Aerosol, Cloud, ocean Ecosystem Postlaunch Airborne eXperiment (PACE-PAX)** took place in September 2024, to gather data for the validation of the recently launched PACE mission.
- Secondary Objective: Additional flight hours (24) augmented underflights of the EarthCARE satellite along the ATLID ground track This was supported through NASA's Research and Analysis Program (Dr. Jack Kaye).

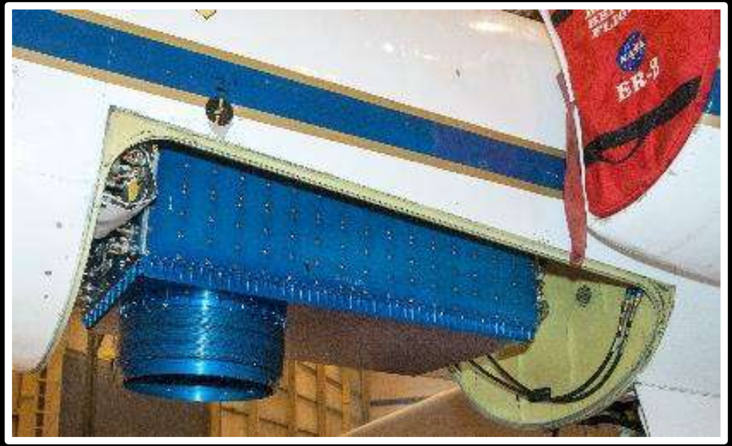
- Link to White Paper (open access) and preliminary data (password protected):
  - https://www-air.larc.nasa.gov/missions/pacepax/
- Final data due March 2025 (6 months from end of campaign)

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

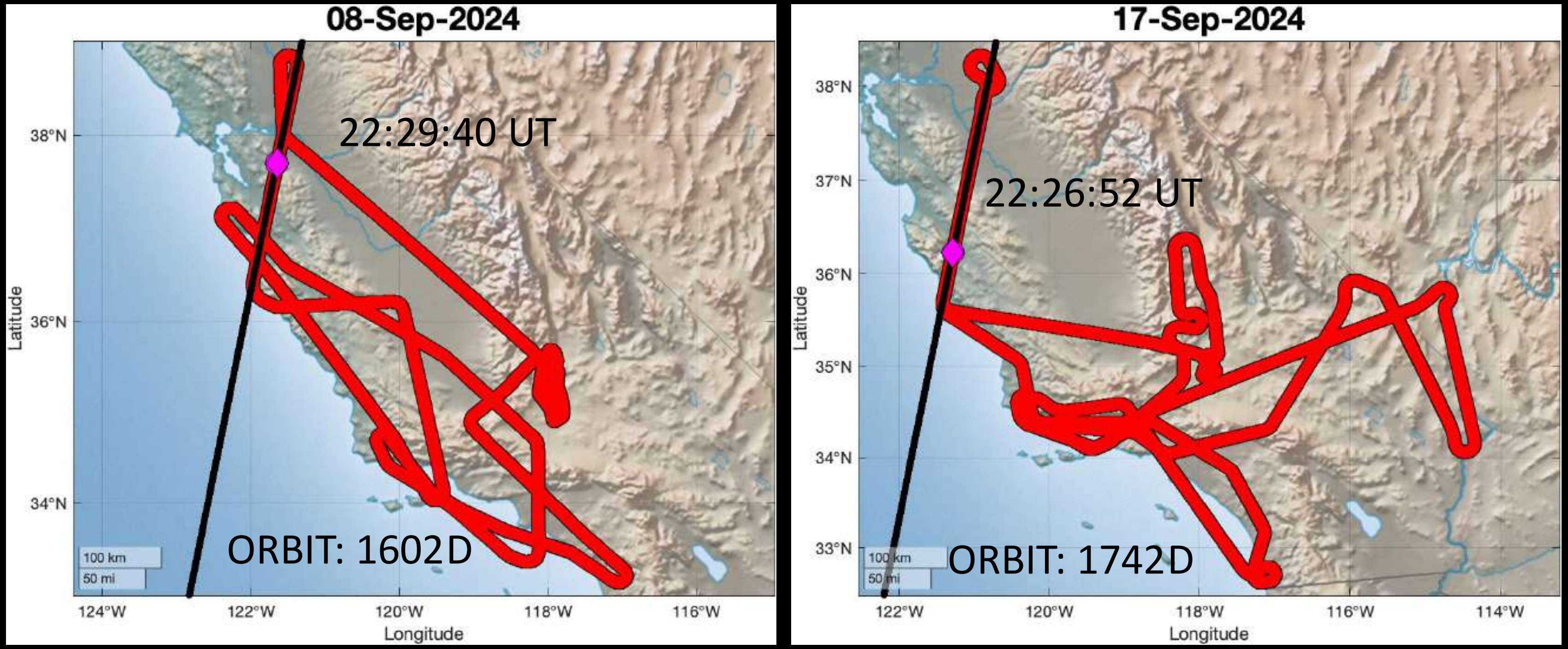
HSRL measurements at 355 and 532 nm

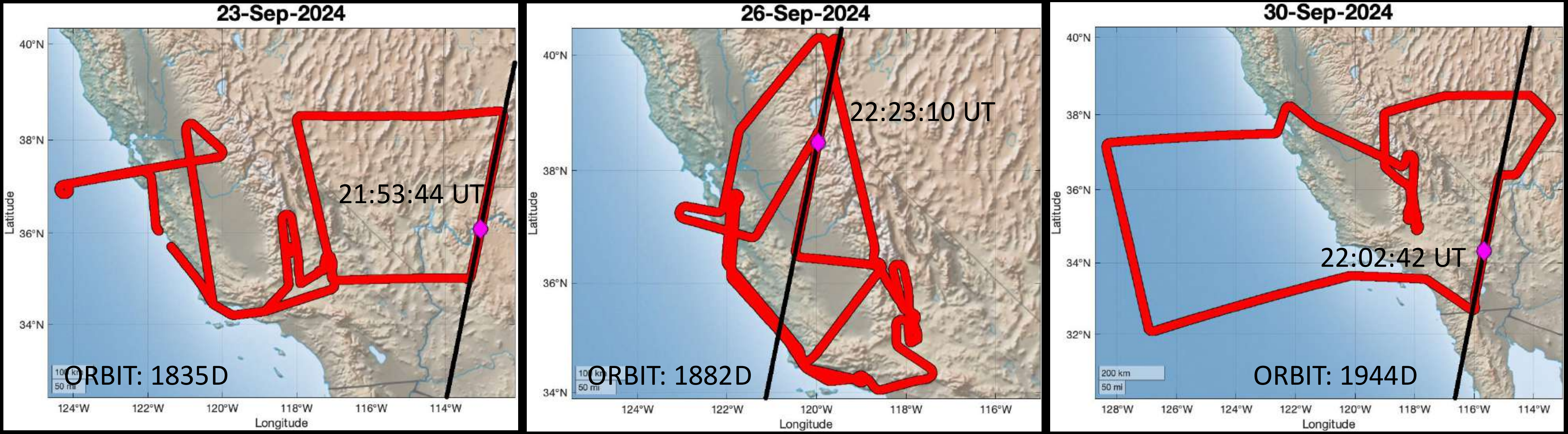


Nominal flight altitude – 20 km

PACE-PAX flights along ATLID ground track

Spatial coordination within 1km
Orbits were all daytime: descending and “D” frame

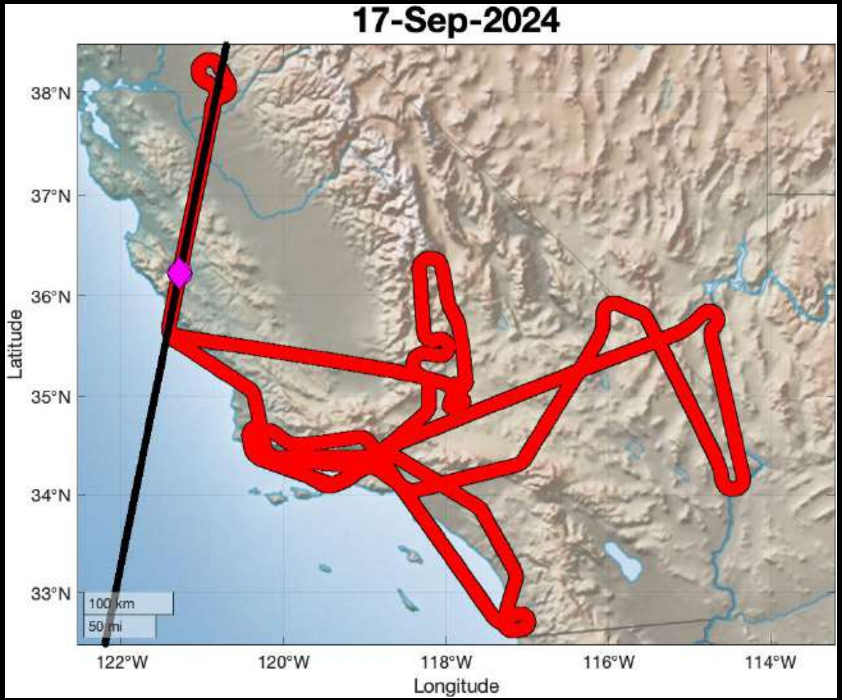




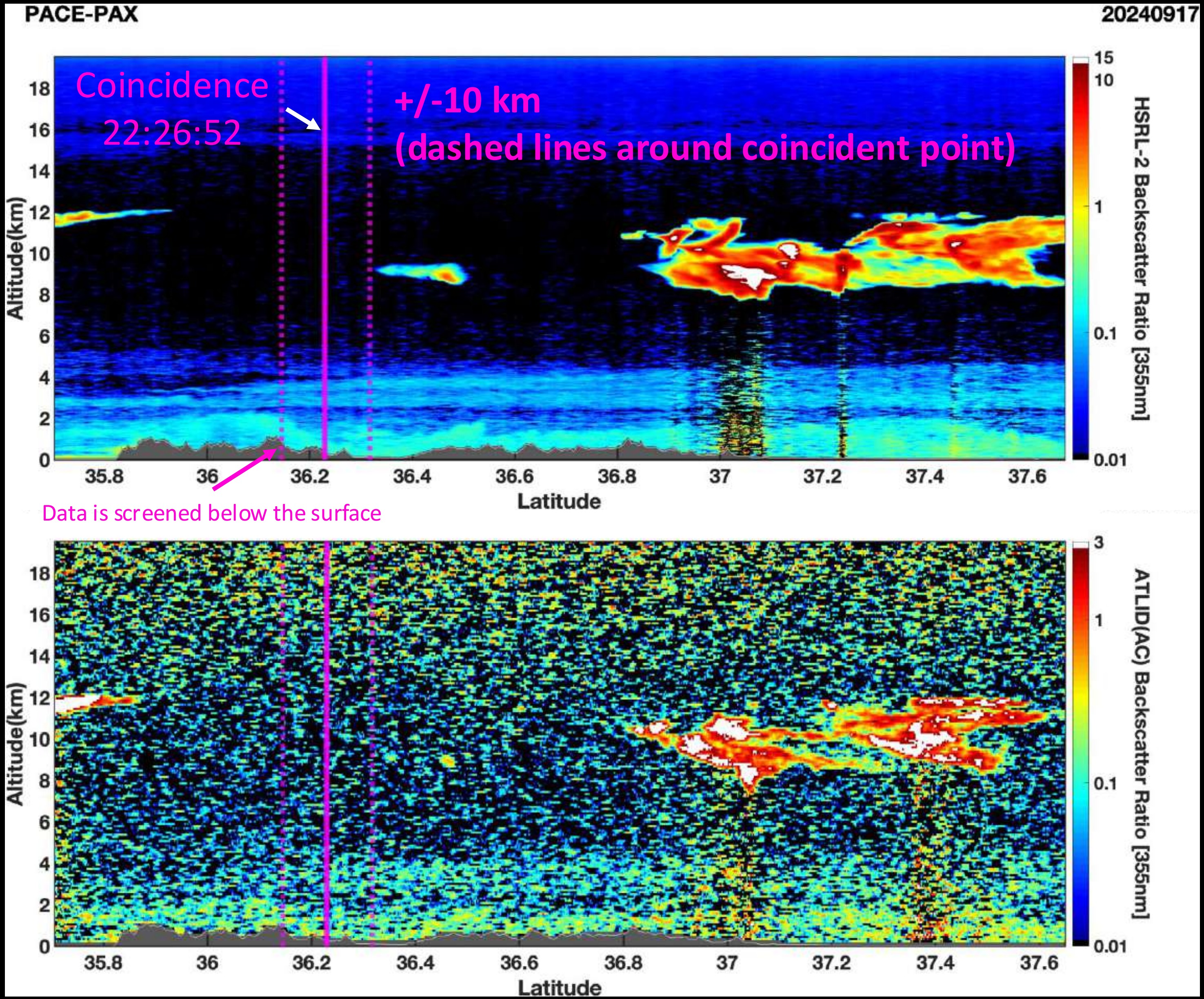
Coordination Summary (355nm) (17 Sep 2024)

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

Flight Track – Southern California

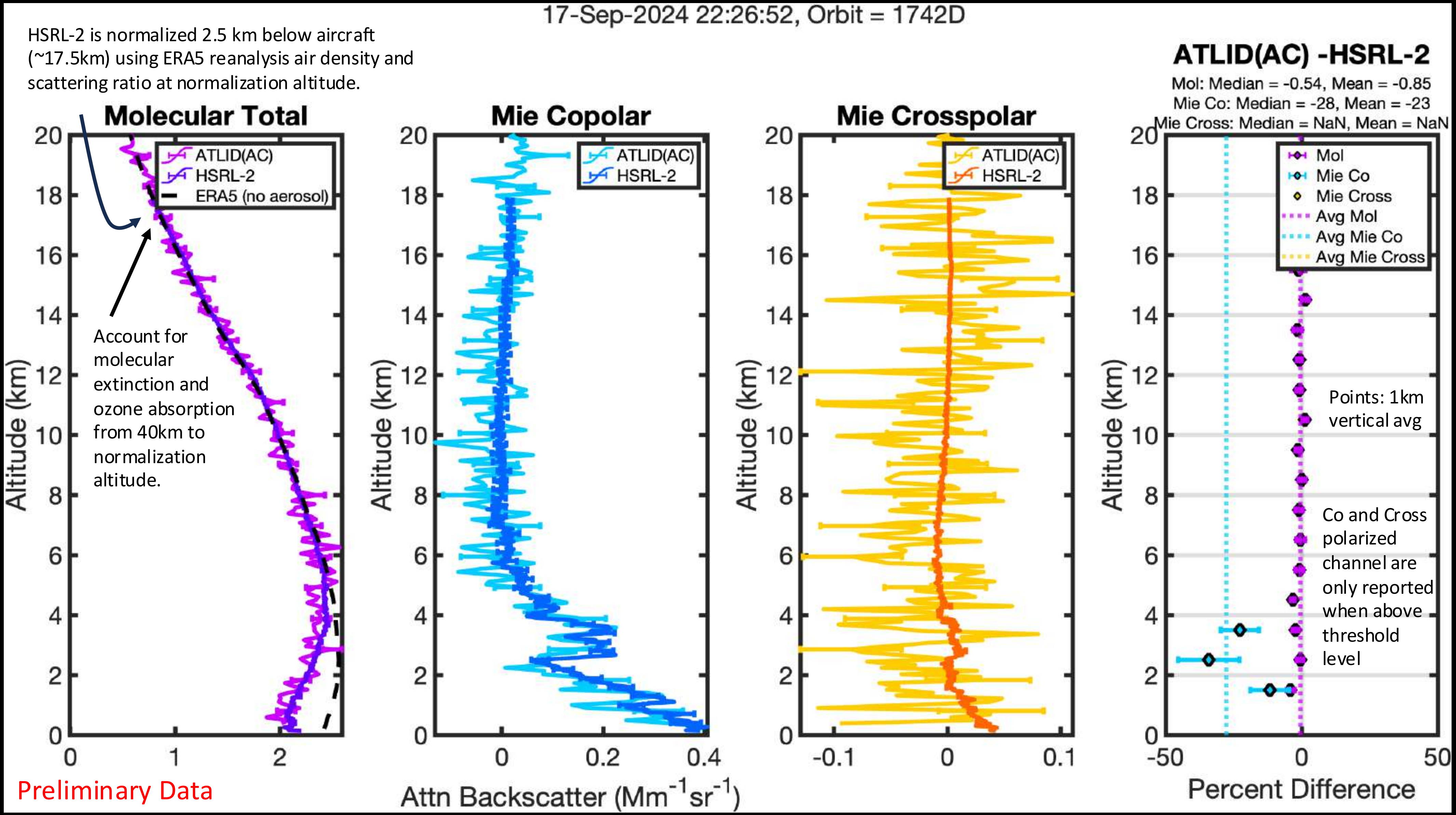


ER-2 Flight track – red
ATLID Ground Track - Black

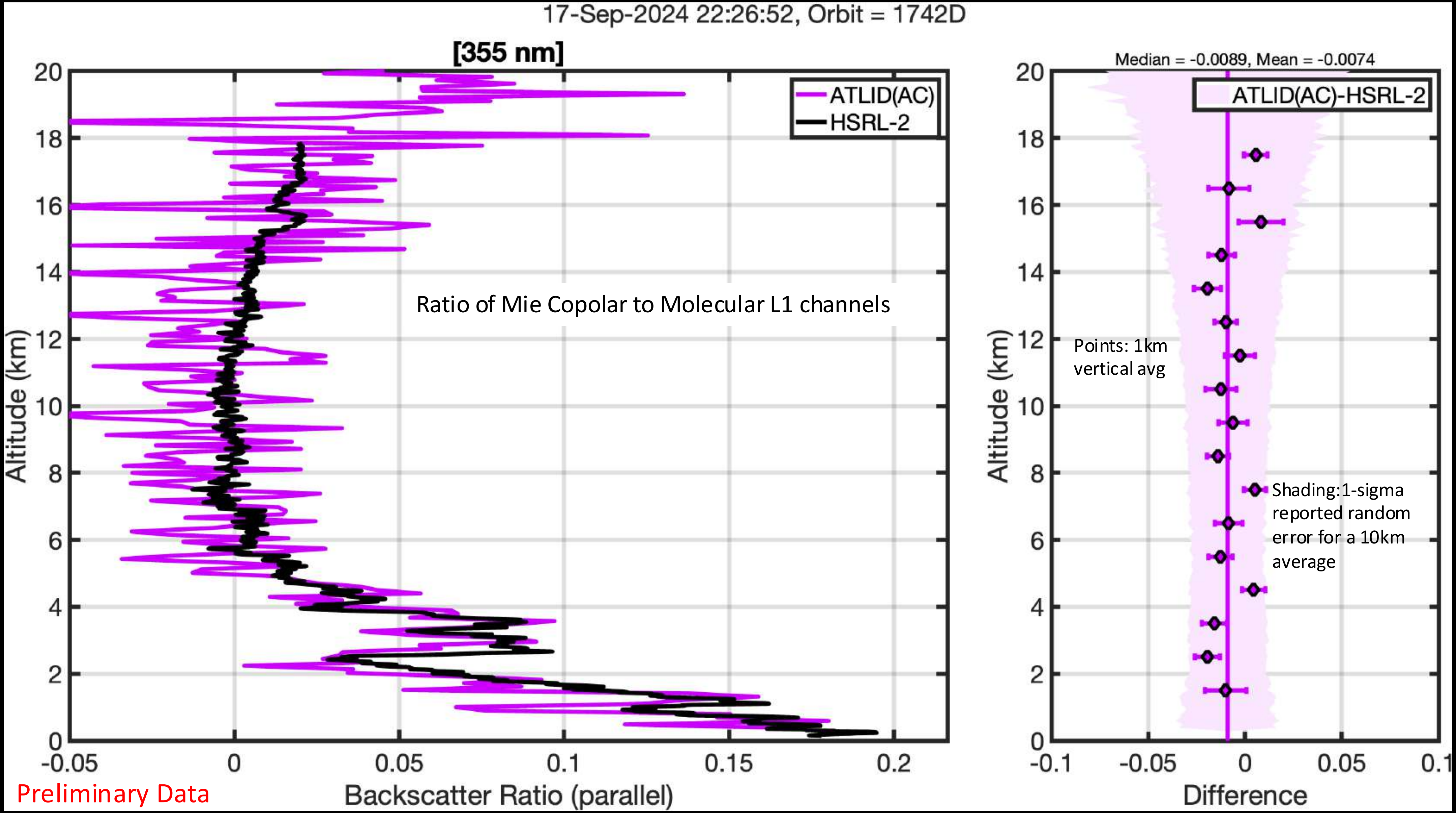


Preliminary Data

Level 1 Signals: Attenuated Molecular, Mie, Cross



Scattering Ratio (parallel aerosol-to-molecular)

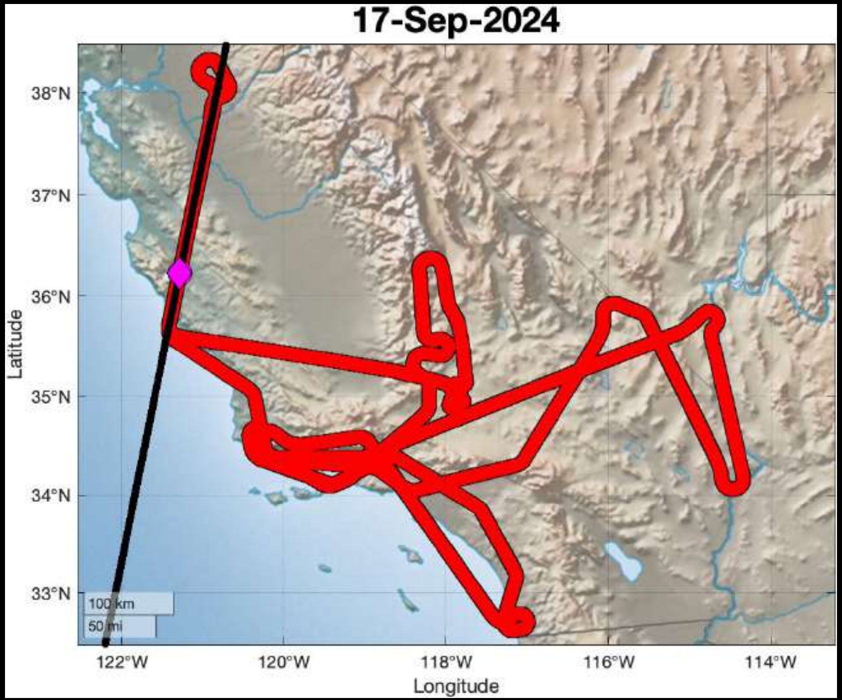


Comments on Method of Comparisons

- 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

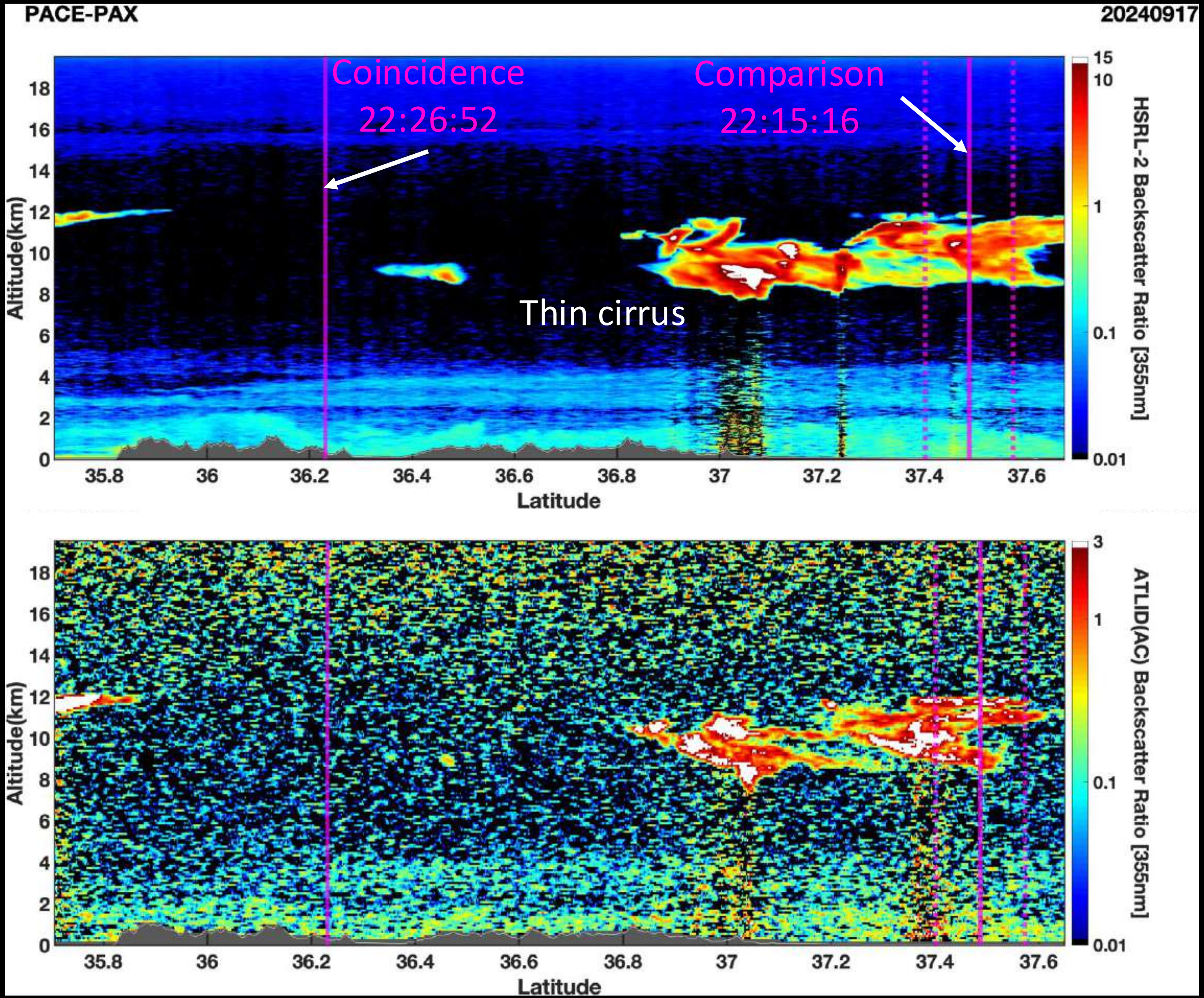
Coordination Summary (355nm) (17 Sep 2024)

Flight Track – Southern California

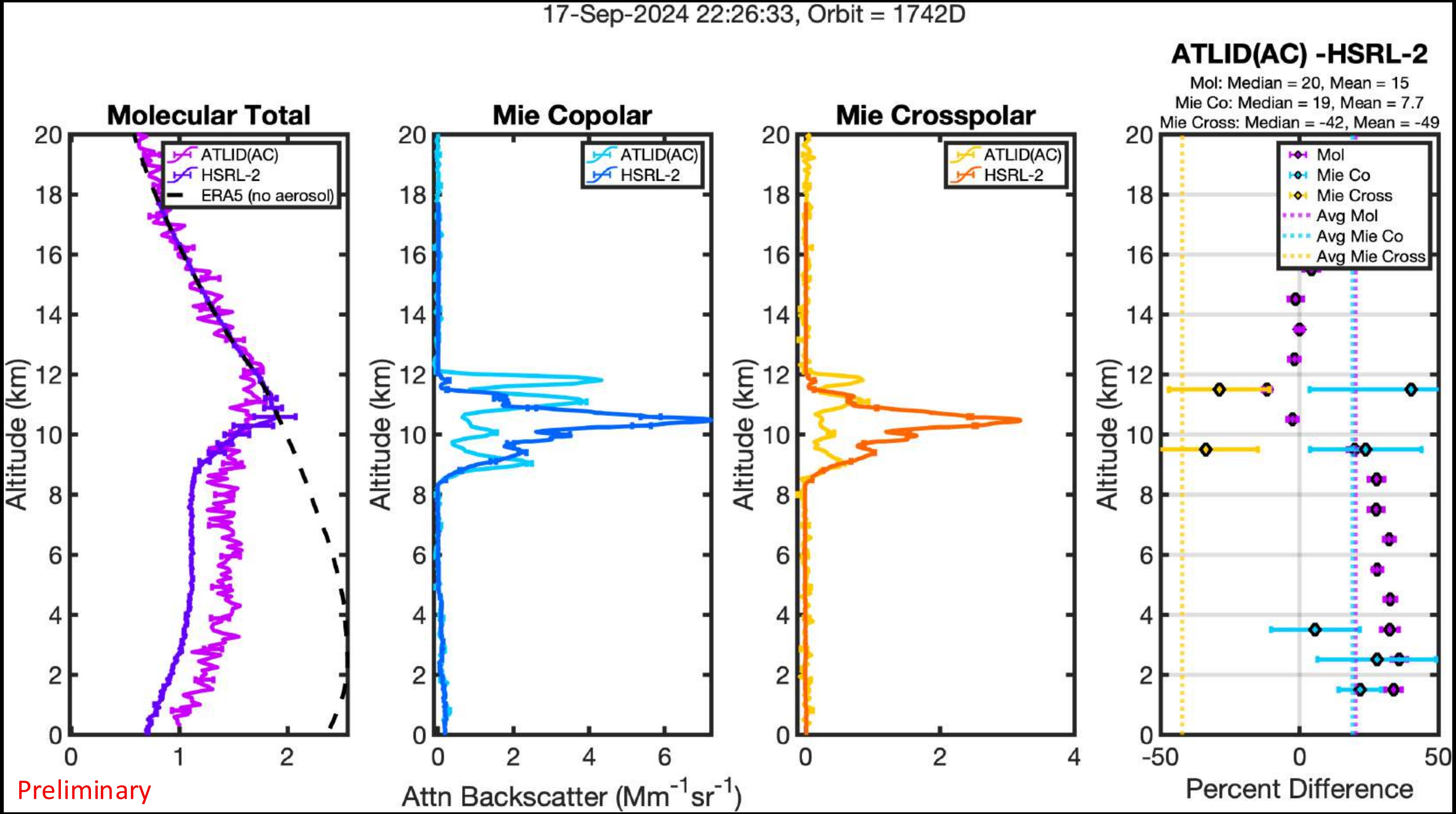


ER-2 Flight track – red
ATLID Ground Track - Black

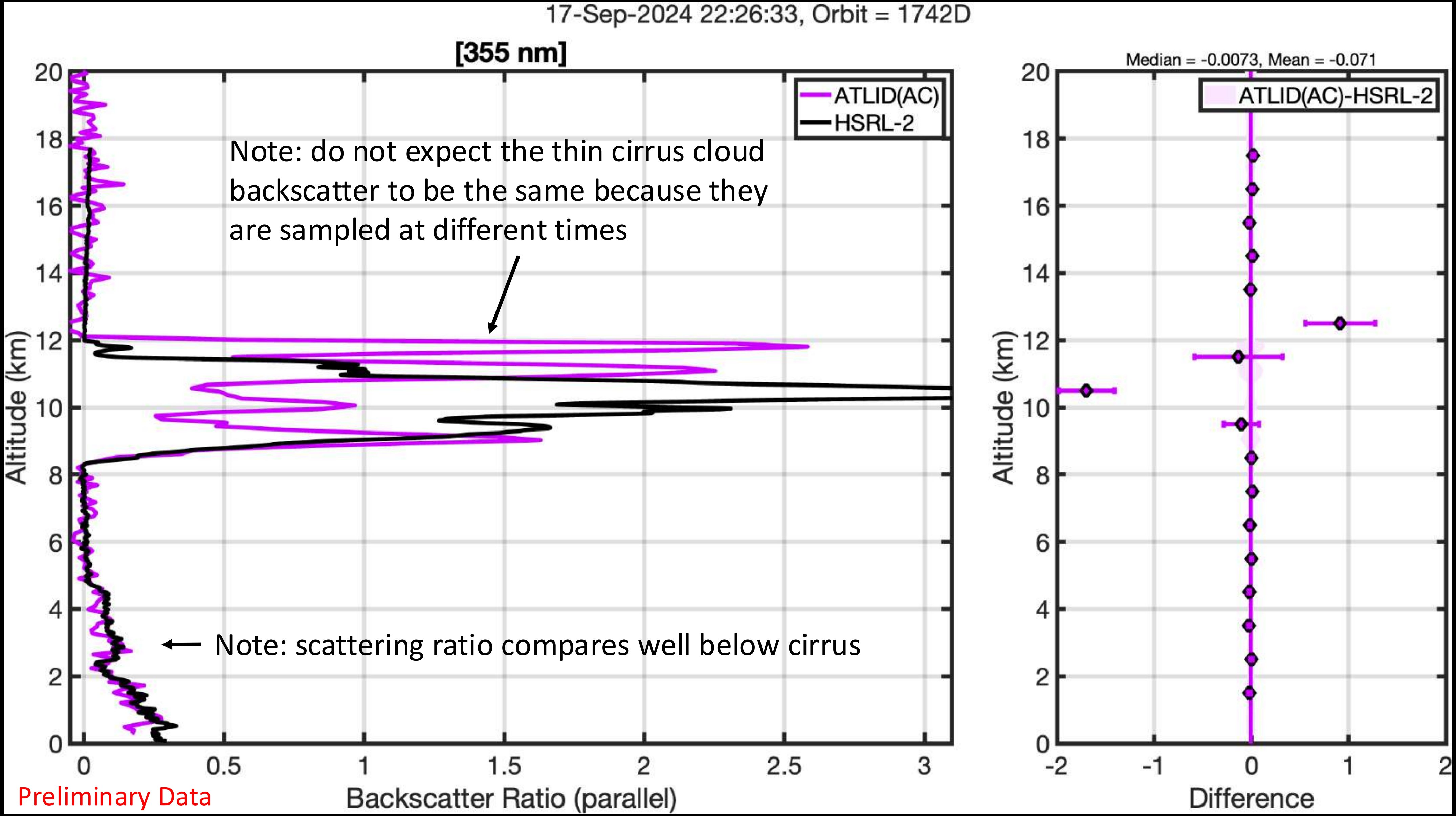
Preliminary Data



Level 1 Signals: Molecular, Mie, Cross



Scattering Ratio (parallel aerosol-to-molecular)

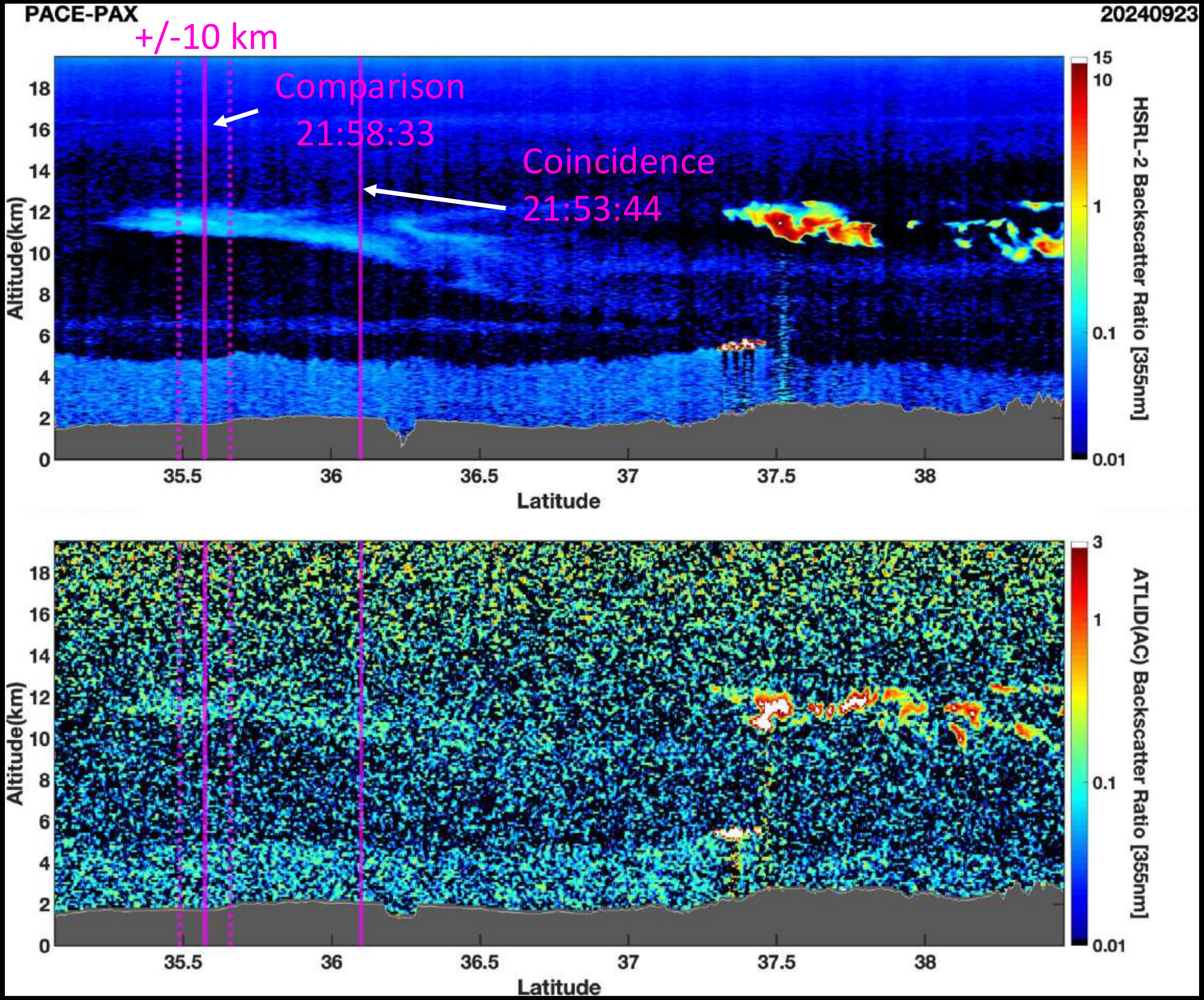


Coordination Summary (355nm) (23 Sep 2024)

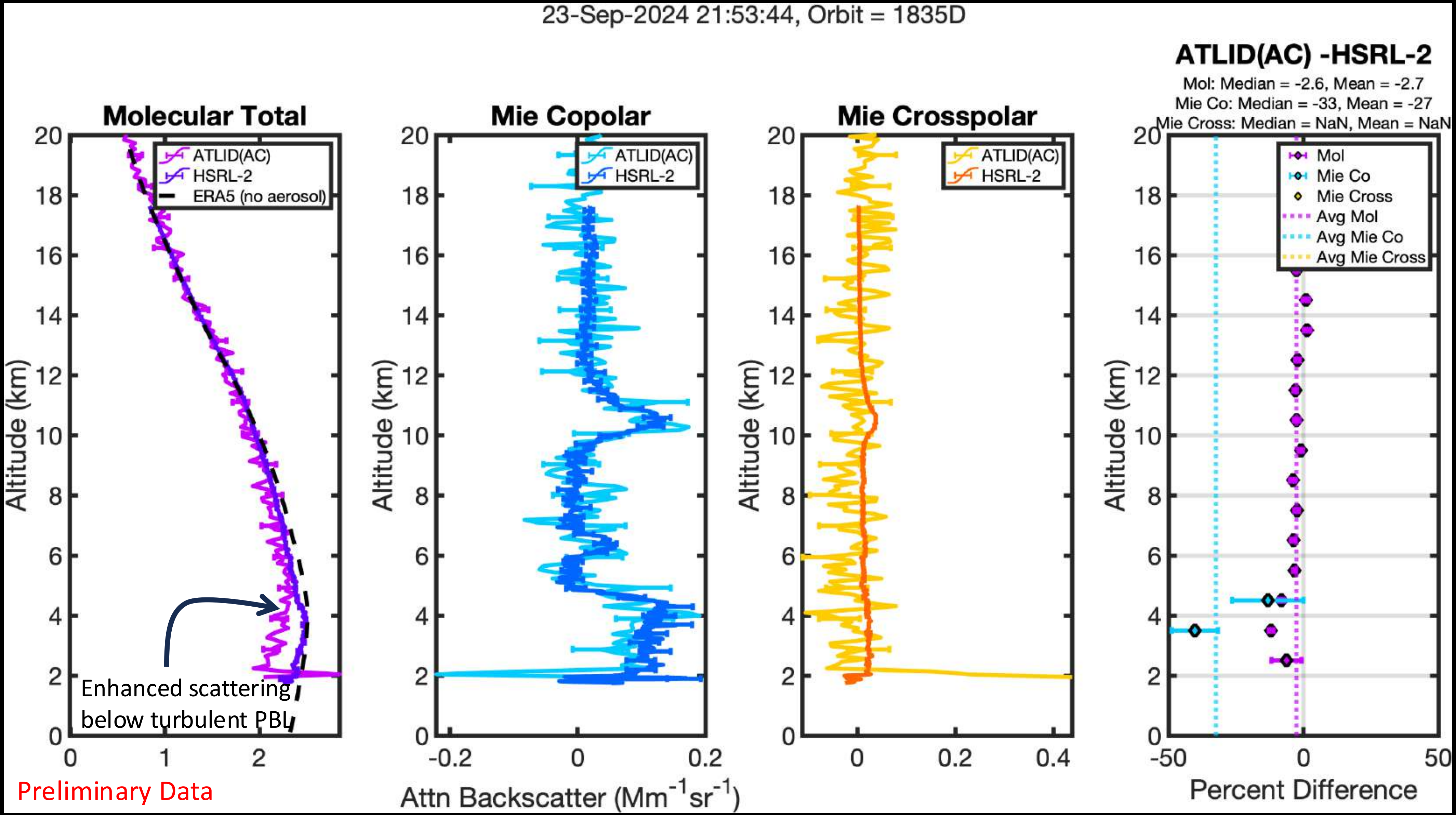
Flight Track – Southern California

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

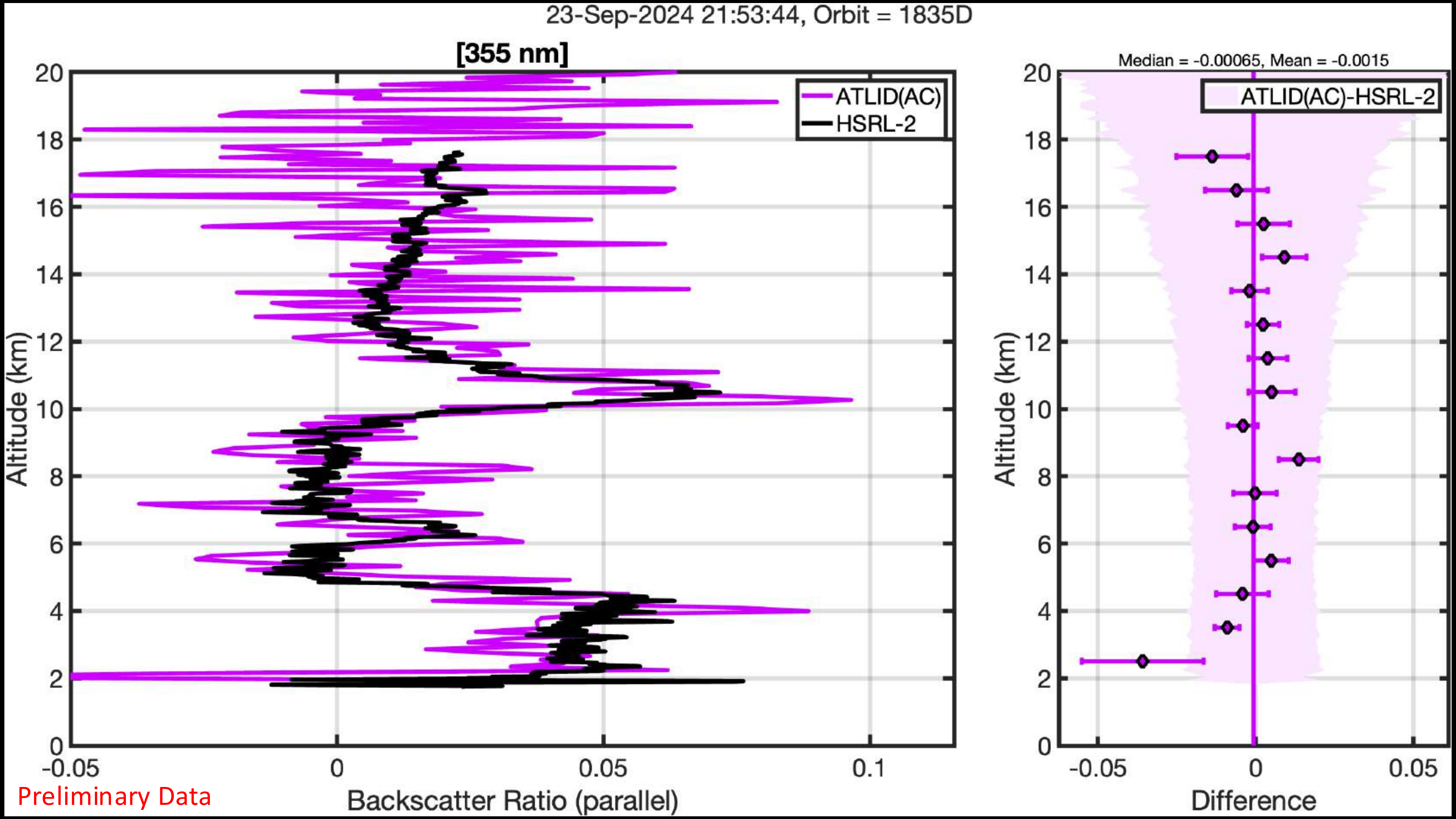
Preliminary Data



Level 1 Signals: Molecular, Mie, Cross



Scattering Ratio (parallel aerosol-to-molecular)



Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment(ARCSIX)

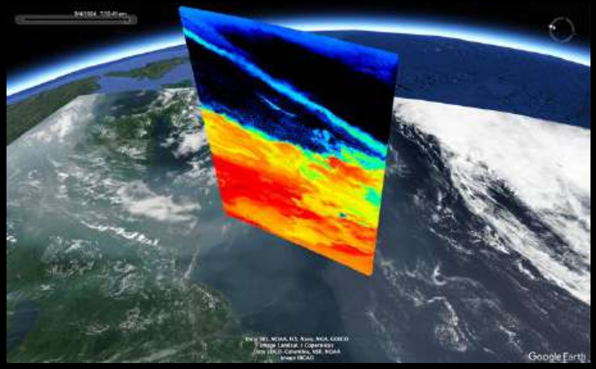
https://www-air.larc.nasa.gov/missions/arcsix/index.html

Campaign Leads

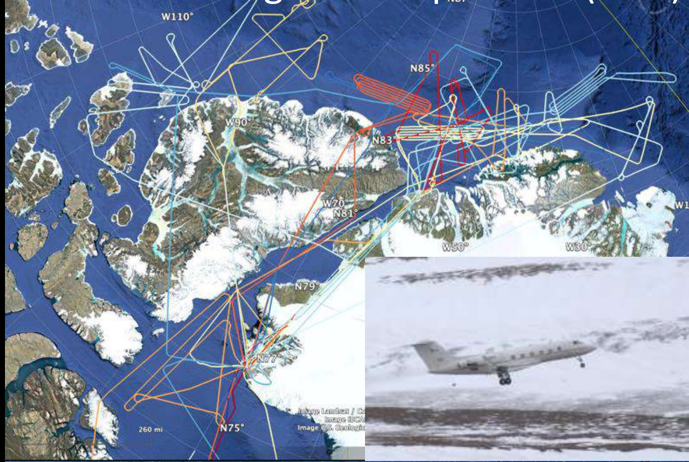
Sebsatian Schmidt, Patrick Taylor

Objective: quantify the contributions of surface properties, clouds, aerosol particles, and precipitation to the Arctic summer surface radiation budget and sea ice melt during the early melt season

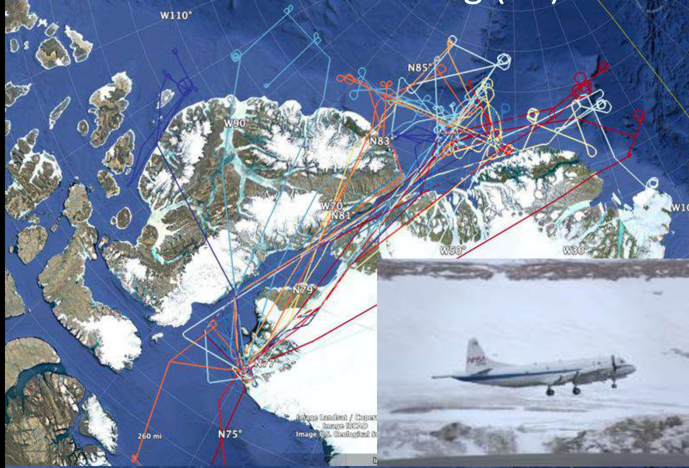
Secondary Objective: calibration , validation, and interpretation of satellite retrievals of clouds, aerosols, and surface properties



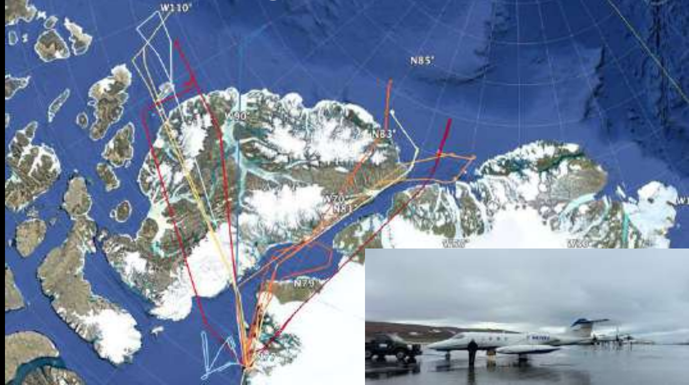
Remote Sensing and Dropsondes (G-III)



In-situ and remote sensing (P3)



Remote Sensing and In-Situ (LearJet)

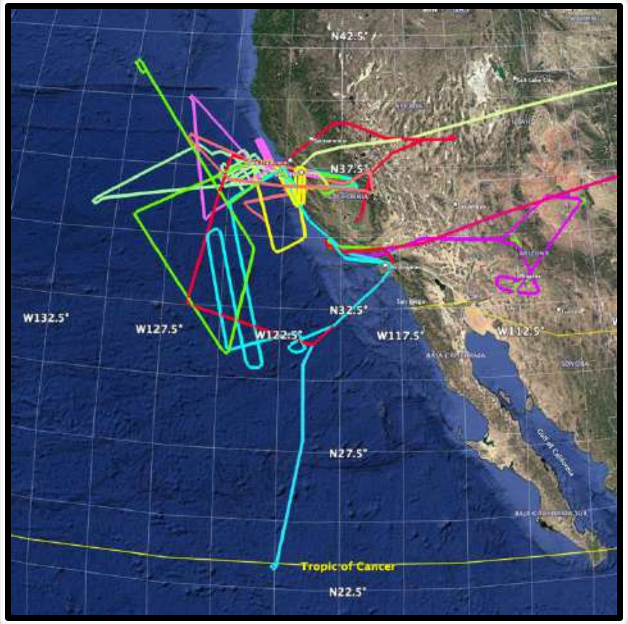


Westcoast & Heartland Hyperspectral Microwave Sensor Intensive Experiment (WH^{2}YMSIE)
&
Active Passive PBL Profiling EXperiment (APEX)

https://www-air.larc.nasa.gov/missions/whymsie/index.html

Campaign Leads

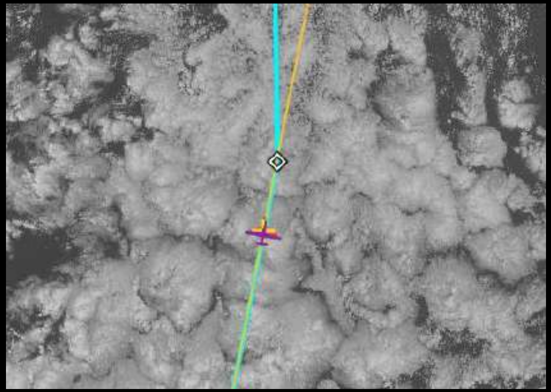
Antonia Gambacorta and Amin Nehrir



Objectives: 1) Evaluation and validation of emerging passive microwave sounding technology. 2) Benchmark dataset for active (DIAL) / passive (infrared and microwave sounders) retrievals of temperature and moisture. 3) Calibration, validation, and interpretation of satellite retrievals of thermodynamics and aerosols/clouds

Active/Passive Remote Sensing (ER-2)

DIAL/HSRL, Doppler Lidar, Dropsondes (G-III)



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
- <u>Amin Nehrir</u> *
- Tony Notari
- Taylor Shingler
- Ashwin Yerasi

HSRL measurements at 532 nm and Water Vapor

HALO instrument and rack

HALO + AVIRIS-NG (ARCSIX)

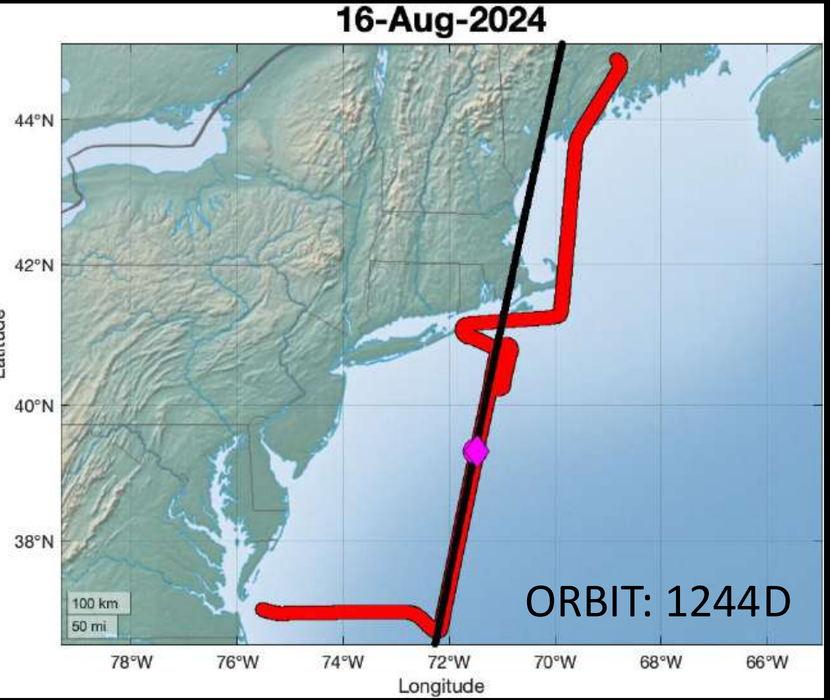
HALO + AWP(WH^{2}YMSIE/APEX)

ARCSIX, WH²YMISE/APEX flights along ATLID ground track

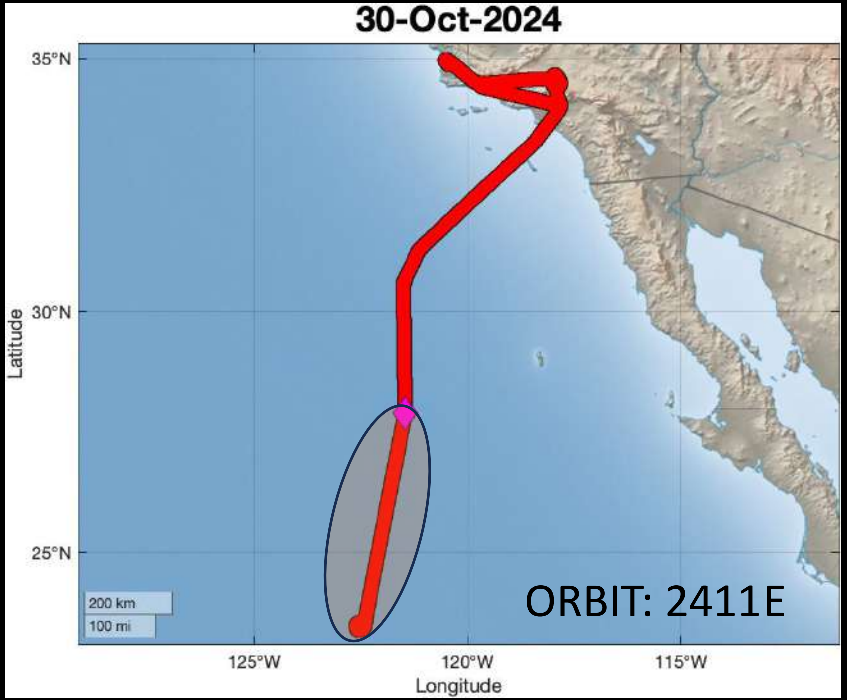
Nominal spatial coordination: <1km
Orbits were all daytime: descending

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

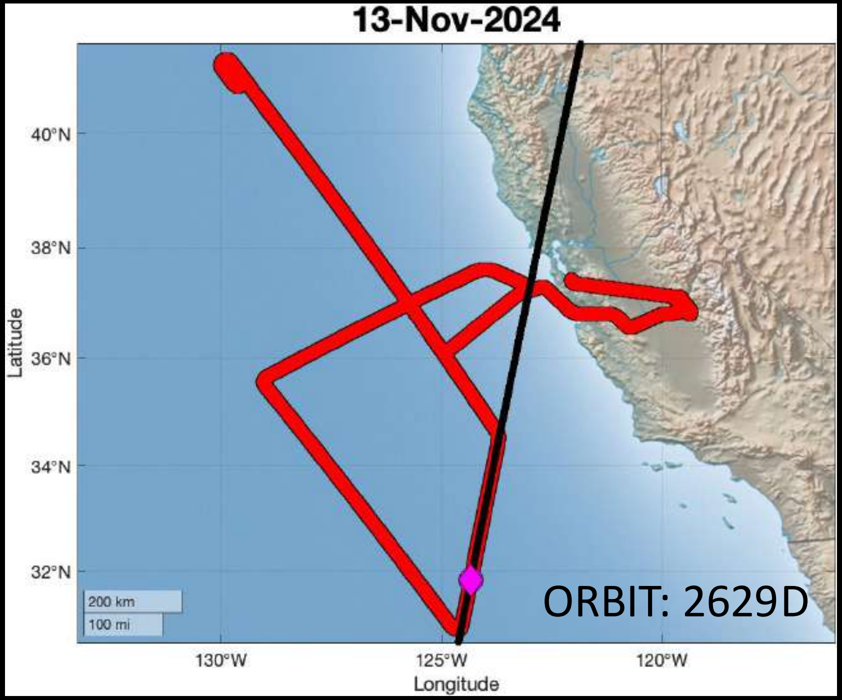
US North-East Coast (ARCSIX)



US West Coast/California/Baja



US West Coast/California

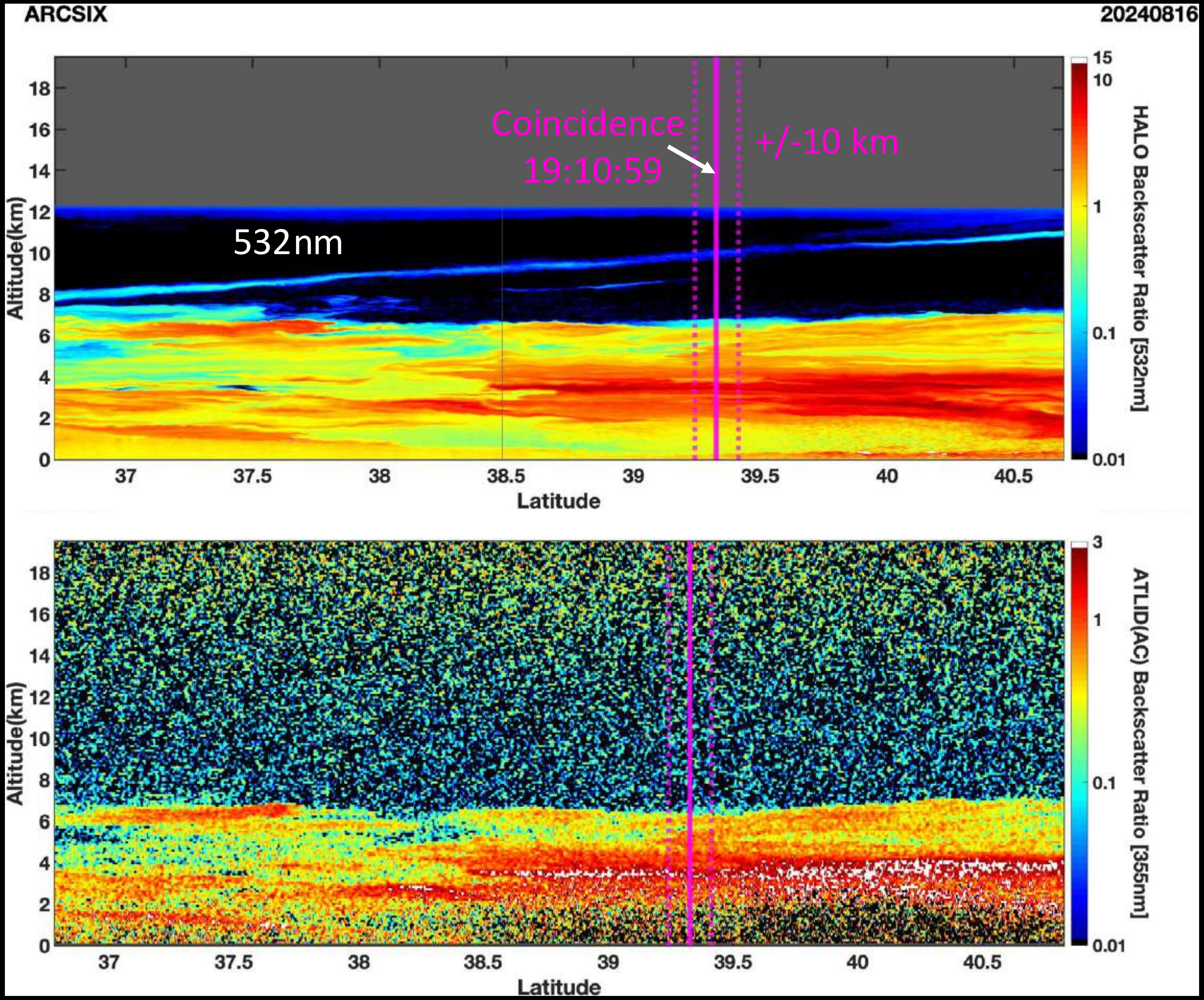


Coordination Summary (355nm converted from 532nm) (16 August 2024)

Flight Track – US East Coast

GIII Flight track – red
ATLID Ground Track - Black

Preliminary Data

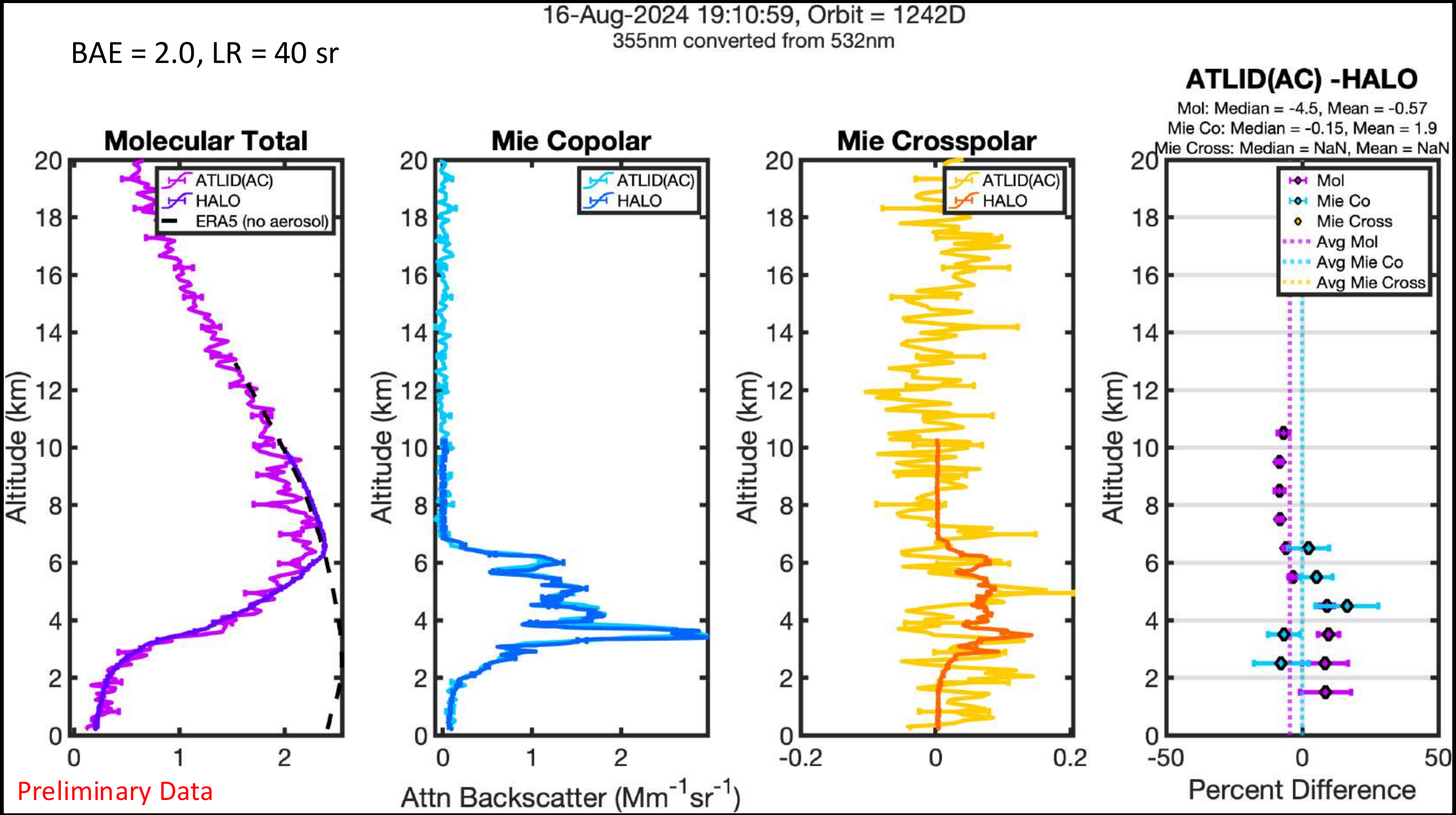


Comments on Converting 532nm to 355nm for HALO data

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.

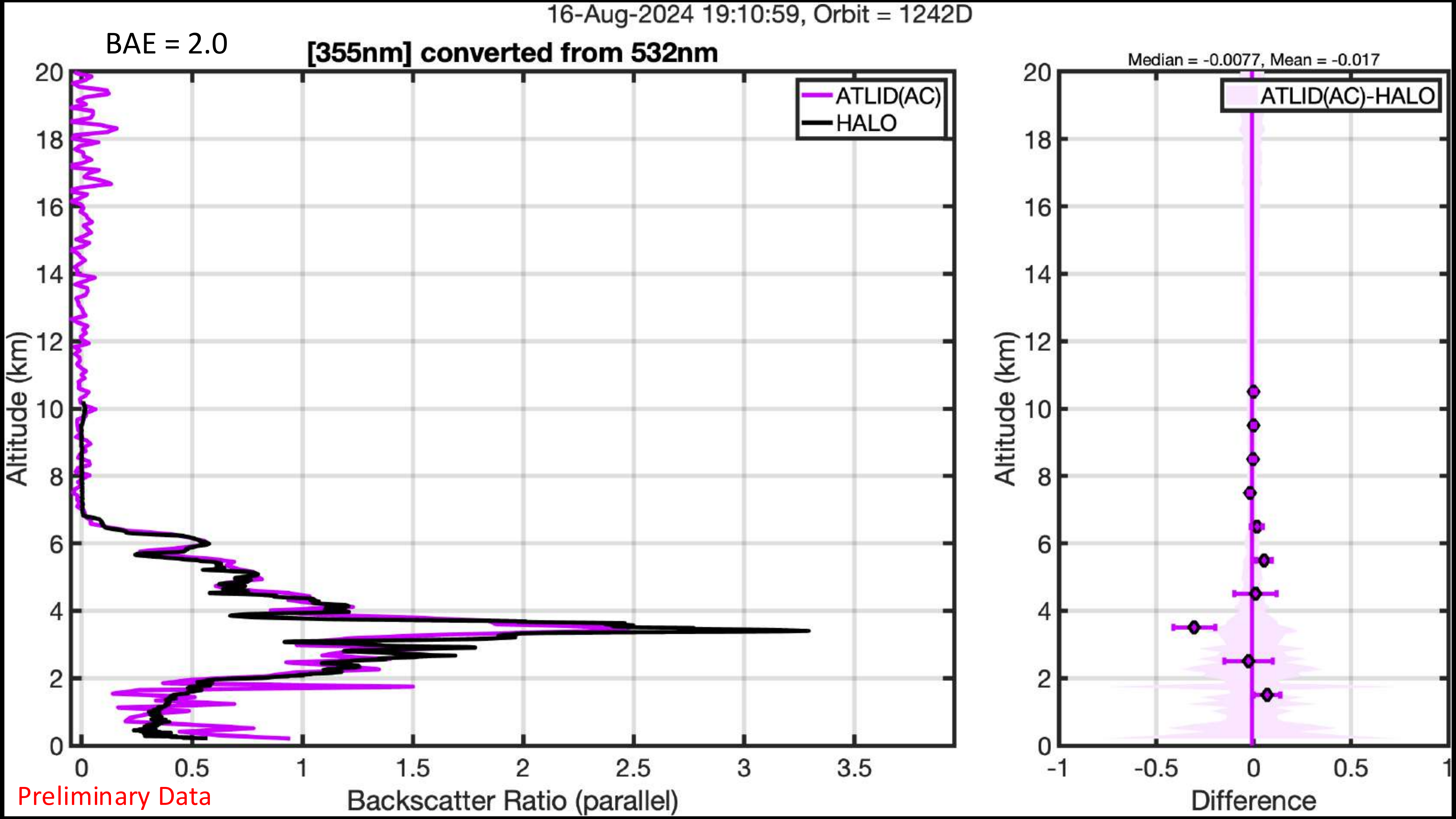
Level 1 Signals: Molecular, Mie, Cross

BAE = 2.0, LR = 40 sr



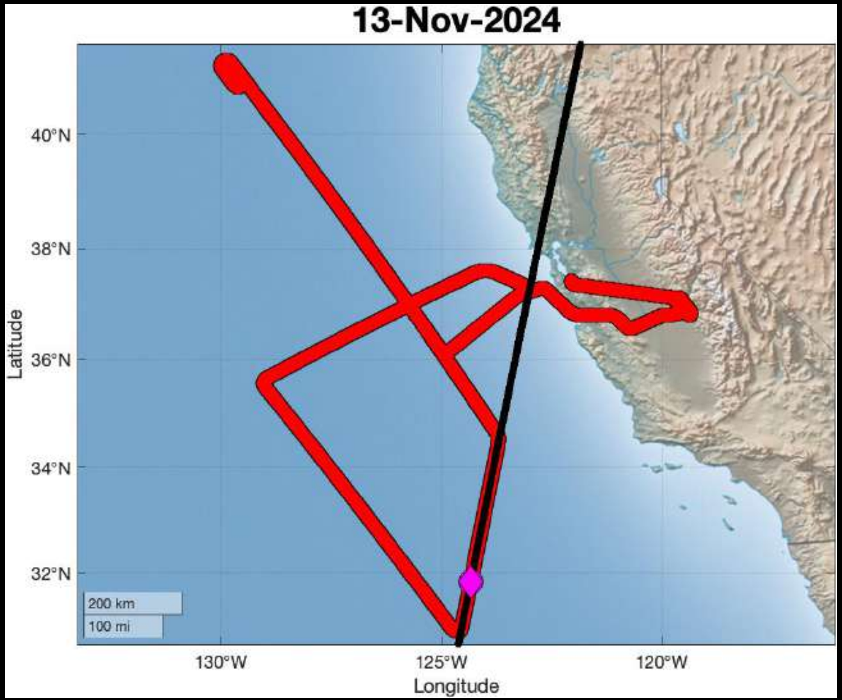
Preliminary Data

Scattering Ratio (parallel aerosol-to-molecular)



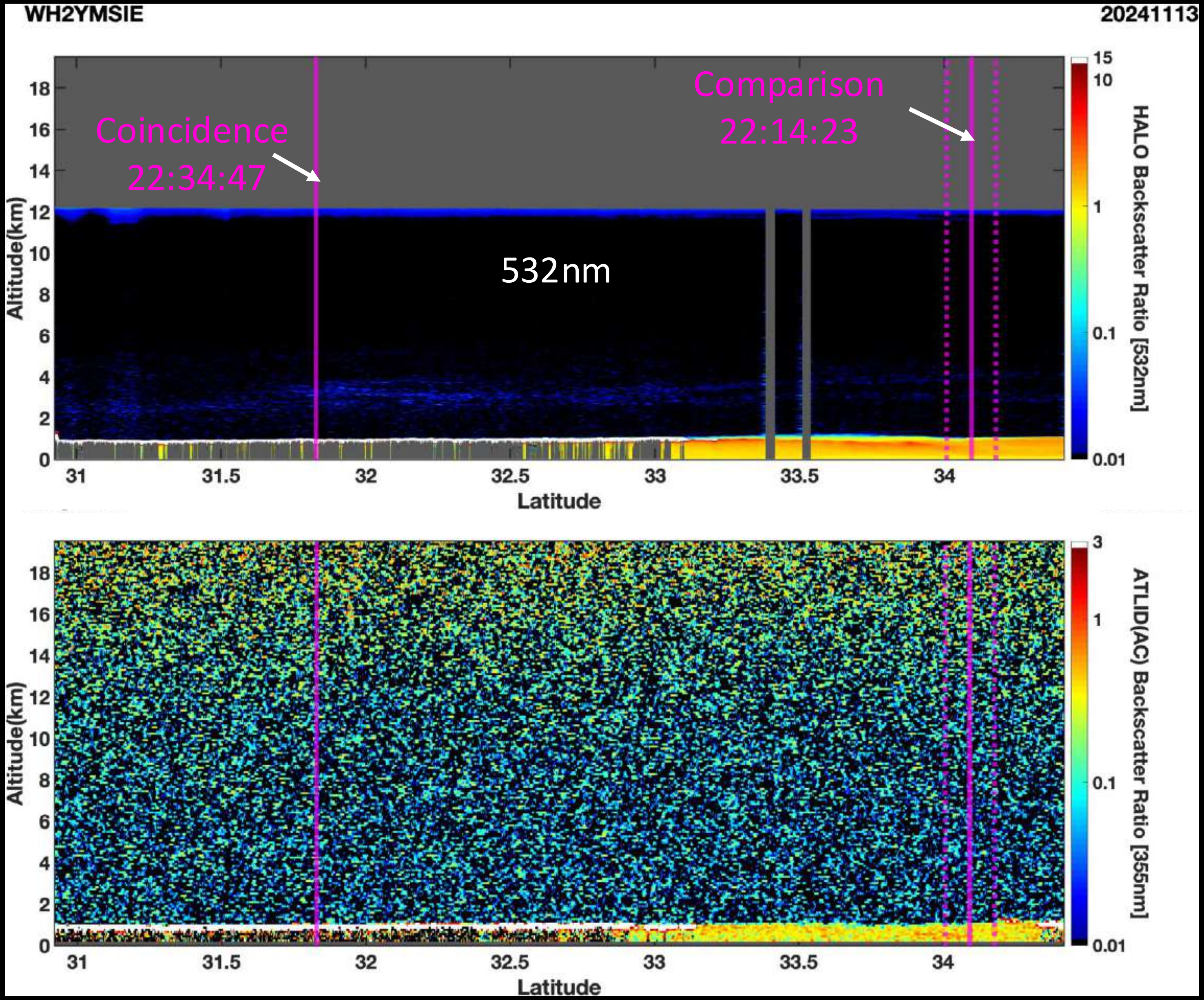
Coordination Summary (355nm converted from 532nm) (13 November 2024)

Flight Track – Southern California

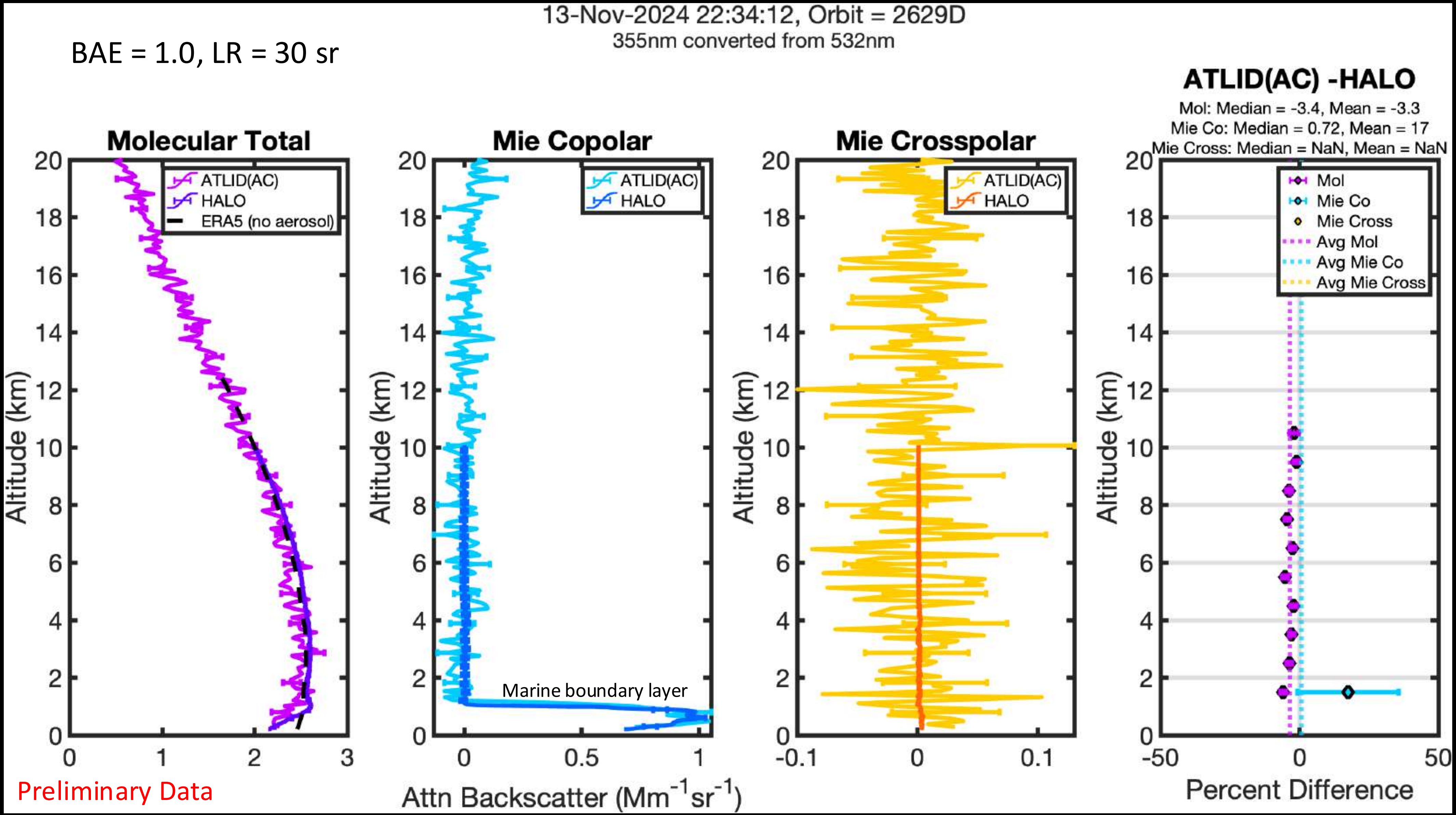


GIII flight track– red
ATLID Ground Track - Black

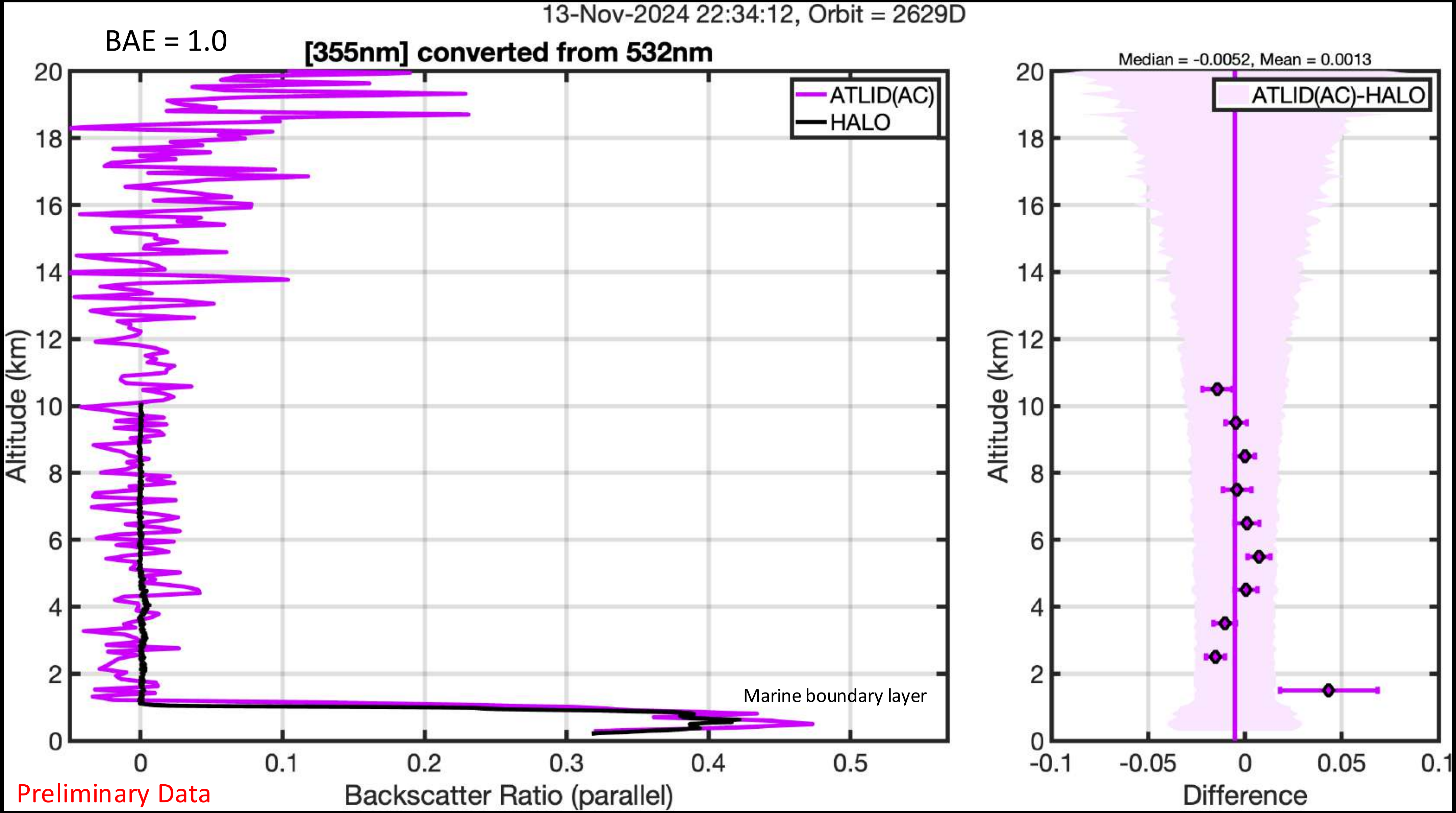
Preliminary Data



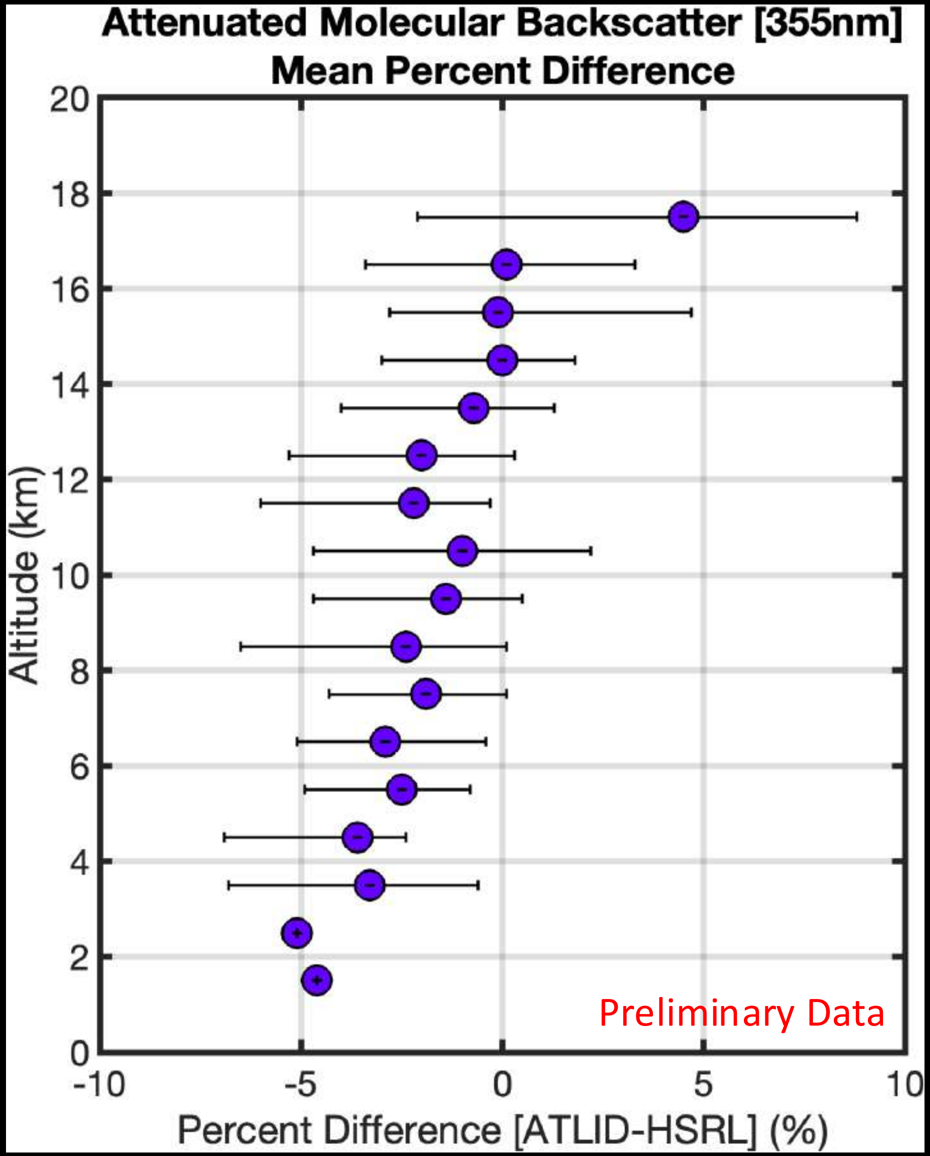
Level 1 Signals: Molecular, Mie, Cross



Scattering Ratio (parallel aerosol-to-molecular)



HSRL-2 Initial Comparison - ‘Clean Tropospheric Cases’



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%
- 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.

Nighttime Bermuda Lidar Underflights of EarthCARE - NightBLUE

Objective: Collect nighttime 355-nm HSRL measurements to assess the performance EarthCARE's Atmospheric Lidar (ATLID) L1B profiles and L2 aerosol and cloud data products.

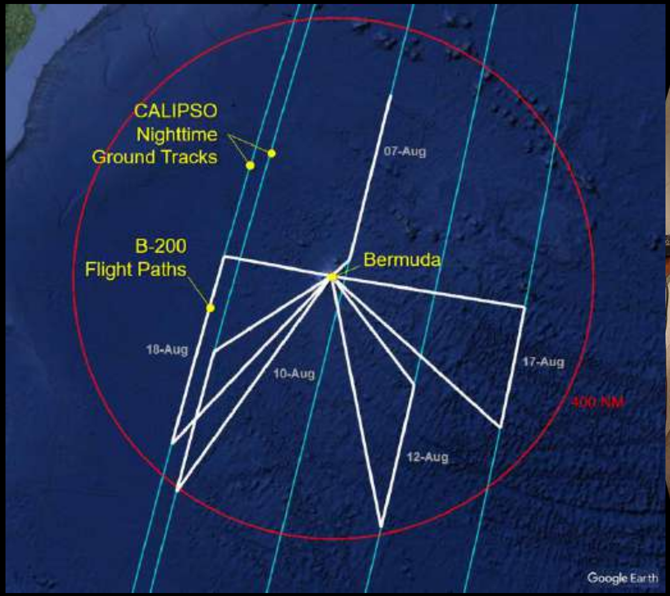
Rationale: Nighttime validation is currently a high priority of the ATLID algorithm team. Lack of solar background noise makes nighttime observations optimal for investigating basic aspects of instrument performance and algorithm approaches.

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



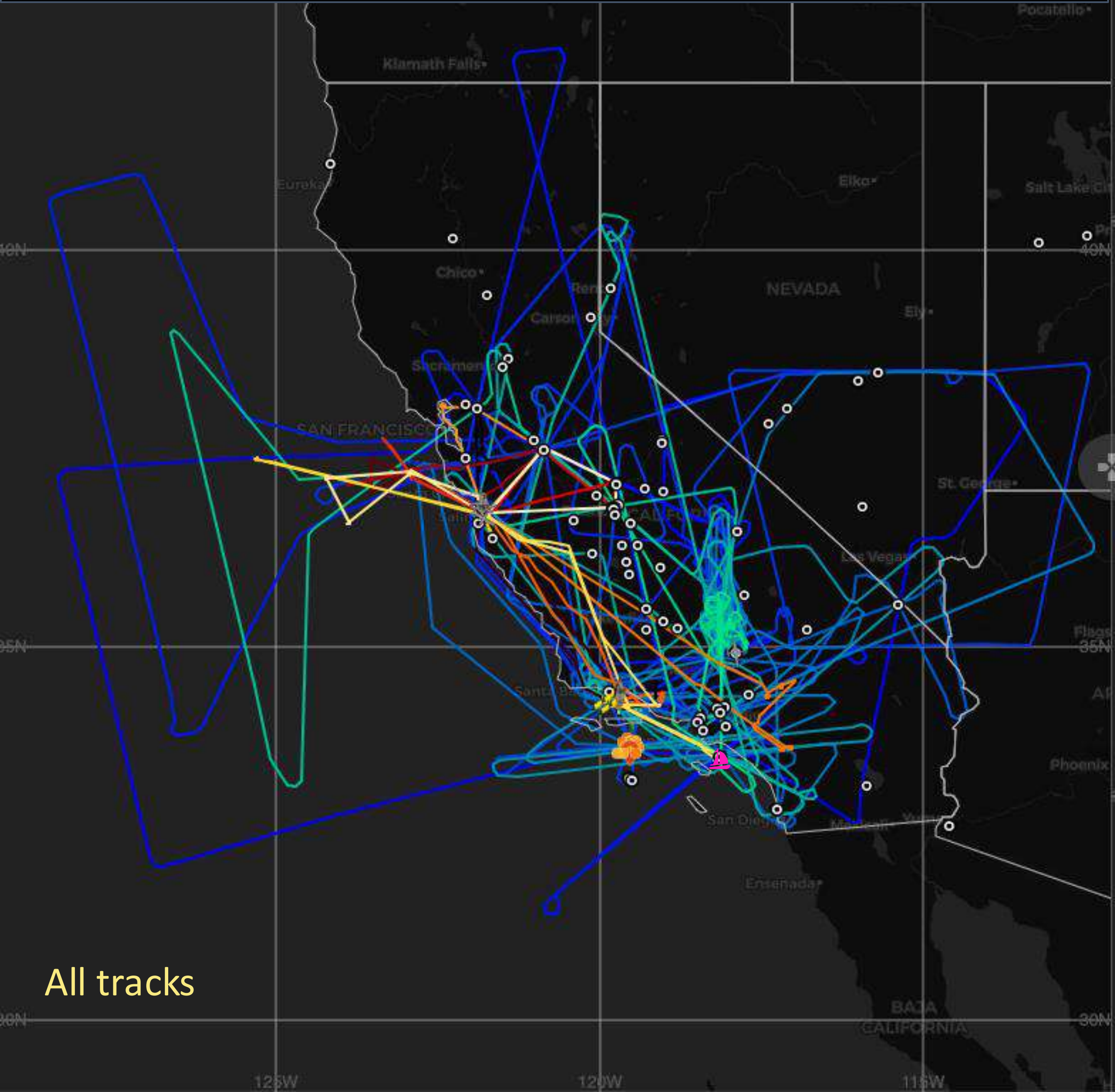
High Spectral Resolution Lidar HSRL-2 <u>355nm</u> & 532nm

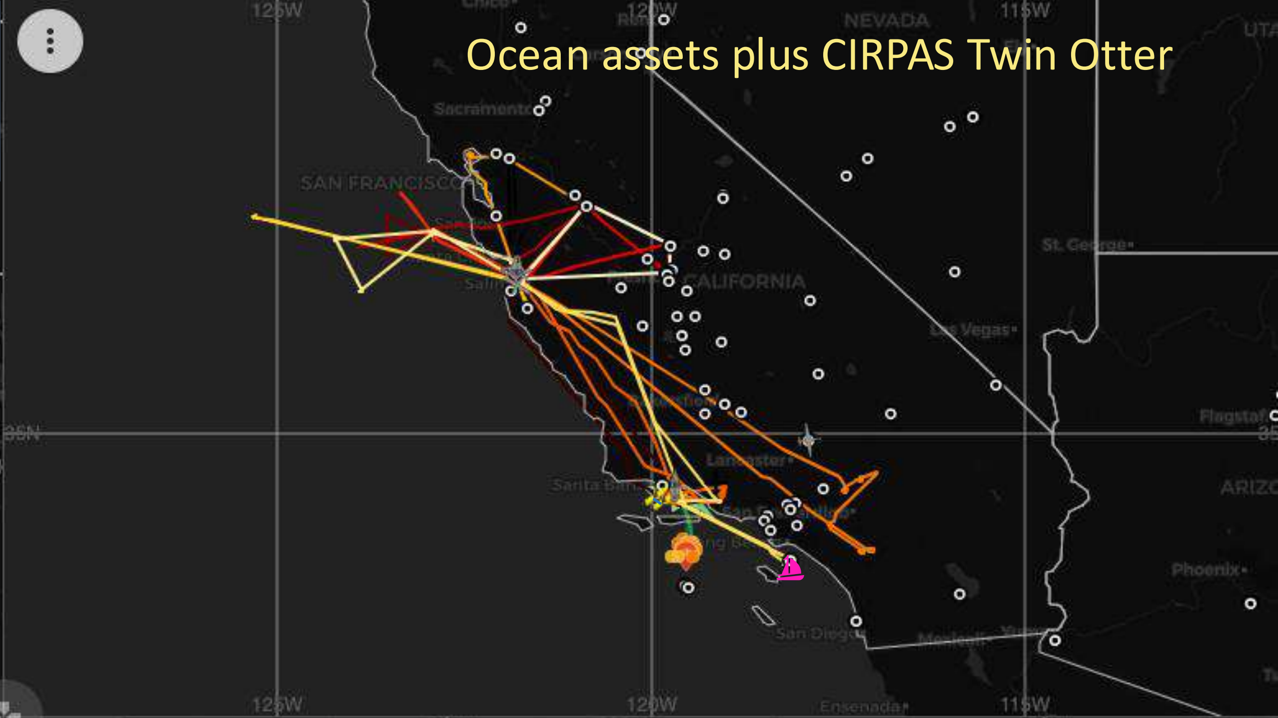
Summary

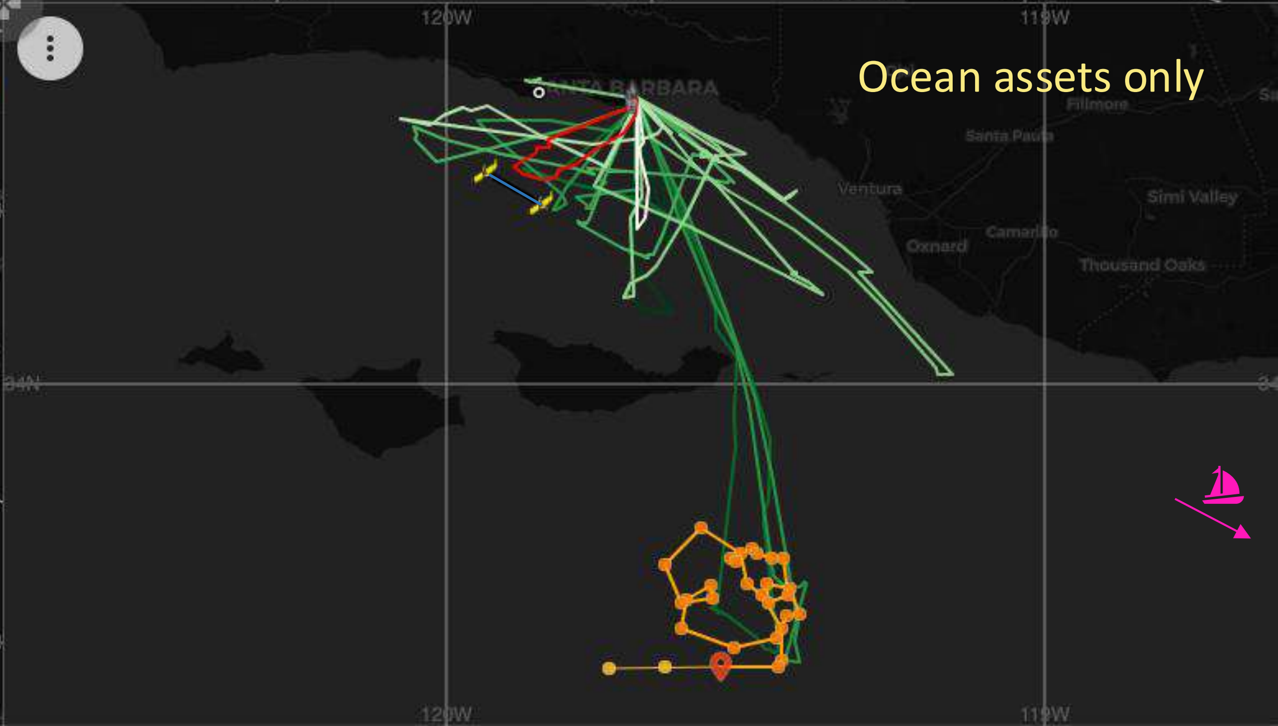
- ATLID's Level 1B molecular and Mie channels are impressively accurate!
  - e.g., the 355nm attenuated molecular backscatter is within 5% of the HSRL-2 measurement in the 'clean' troposphere.
- Conclusion based on 7 flights with NASA LaRC HSRL-2 and HALO instruments.
  - HSRL-2 measurements are at 355 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
  - ATLID Level 1 algorithm team is using HSRL-2 comparisons for algorithm modifications.
- Next steps: additional flights in September 2025 (nighttime calibration)

PACE-PAX aircraft/ship tracks

Blue/green: NASA ER-2
Purple: U. Delaware Gliders
Grey: R/V Rachel Carson
Greens: R/V Shearwater
Magenta: R/V Blissfully
Red/orange: CIRPAS Twin Otter
Orange: HyperNAV floats
Circles: AERONET







PACE-PAX

PACE-Postlaunch Airborne eXperiment

September 3-30th, 2024, Lancaster, Santa Barbara, Marina, California
Kirk.Knobelspiesse@nasa.gov, Brian.Cairns@nasa.gov, Ivona.Cetinic@nasa.gov

EarthCARE validation assessment

Operations ID	Date	ER-2 flight segment	Twin Otter flight segments	PACE overpass time	EarthCARE overpass time	EarthCARE orbit number	Coordinated observation location	Coordination observation conditions	Comments
RF0908	9/8/24	22:18 – 22:40	22:06-22:23 (up) 22:23-22:43 (down)		22:39	1602	ER-2: Monterey Bay, Northern California and Central Valley; Twin Otter: CEOBS site	Marine stratocumulus clouds over bay, low AOD over land. CEOBS site cloud free	CEOBS is Navy Postgraduate School site with scanning radar, lidar, microwave radiometer, AERONET and more.
RF0917	9/17/24	21:41 – 21:58 22:12 – 22:33		20:14	22:47	1742	Out and back along line from coastal central California over Central Valley to Modesto	Moderate aerosol loads (most likely smoke) under intermittent cirrus clouds	Out and back along EarthCARE track, end of line 15 min prior to EarthCARE overpass.
RF0919	9/19/24		21:50-22:00 (over cloud) 22:10-22:30 (no cloud)	19:45, 21:23	22:15	1773	Twin Otter spirals near Camarillo, CA	Partly cloudy; first spiral down to cloud top, then repositioned for second spiral in cloud free conditions	~~Planned ER-2 flight scrubbed due to aircraft~~ problem. Note Twin Otter spiral times TBC
RF0923	9/23/24	21:34 – 22:05	-	20:25	21:53	1835	Arizona, including Grand Canyon	Some clouds in northern portion, otherwise no cloud with low aerosol load	
~~**RF0924**~~	~~9/24/24~~		~~-~~	~~20:59~~	~~22:33~~	~~1851~~	~~Offshore Northern California~~	~~Low marine stratocumulus cloud top~~	**Cloud top was too low for viable Twin Otter Spiral**, cloud profiles in the general vicinity but direct coordination not possible
RF0926	9/26/24	22:09 – 22:40	-	20:31	22:22	1882	California Central Valley and Sierra Nevada mountains, Nevada near Reno	Cloud free, low aerosol load	Note additional ground instrumentation in Reno at the Desert Research Institute
RF0930	9/30/24	21:48– 22:20		21:09	22:02	1944	South-East California from Mexico border to west of Las Vegas	Elevated aerosols identified as 'dusty mix'	

Bridge fire in San Gabriel mountains, September 10, 2024. Photo by NASA ER-2 pilot Kirt Stallings