CALIPSO:
Advances in CALIOP Aerosol Products

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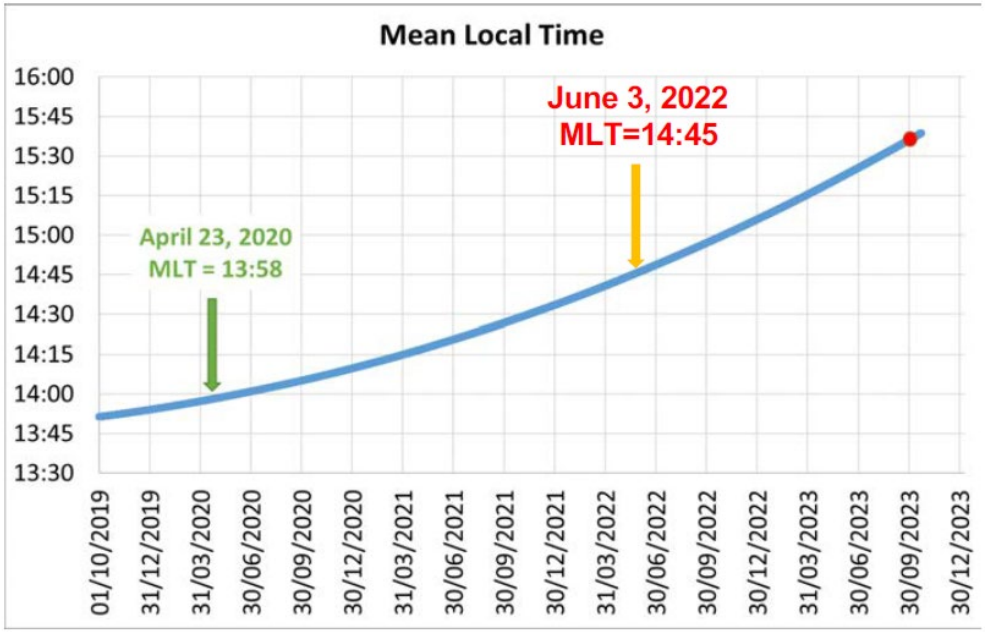
CALIPSO Status

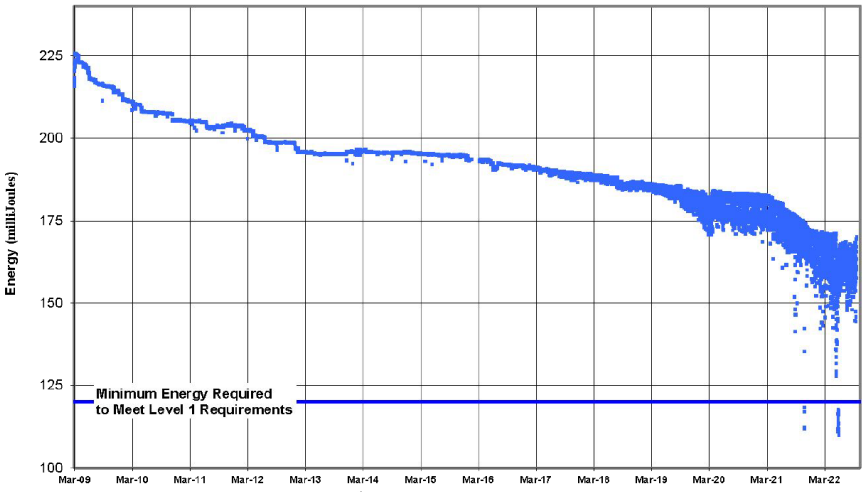
- CALIPSO left the A-train in 2019
- CALIPSO is now drifting to the east and descending ~ 5 m/day
  - Currently at about 15:00 and 680 km
  - Precessed out of the MODIS swath earlier this year



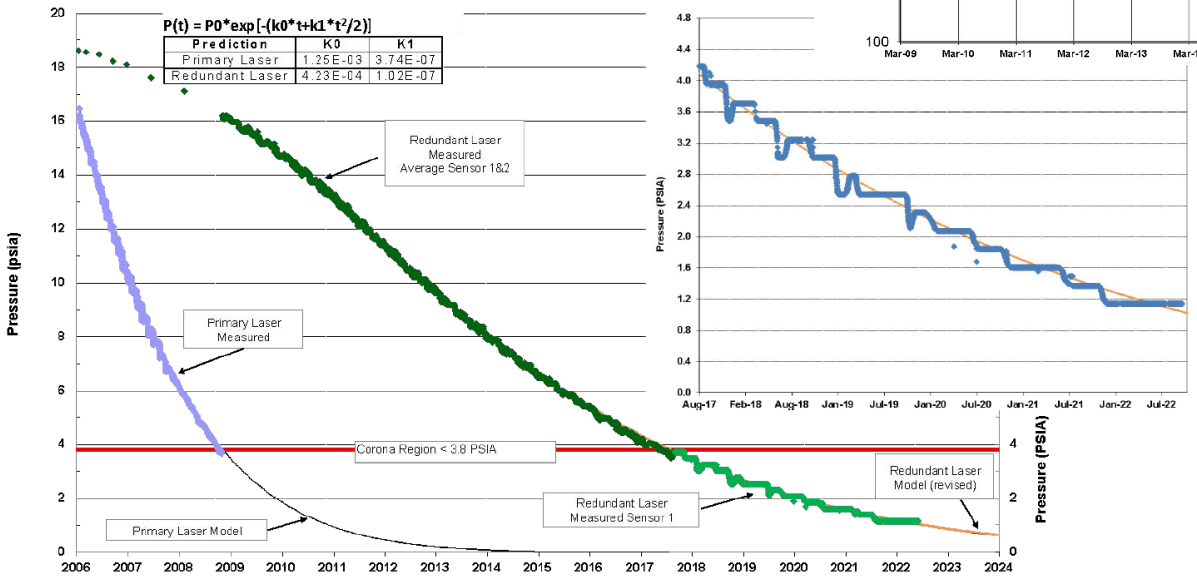
Brief CALIPSO status …
2nd laser now > 8 billion shots!

- Drifting to east
  - out of MODIS swath
- Increasing low energy shots
  - Working on mitigations

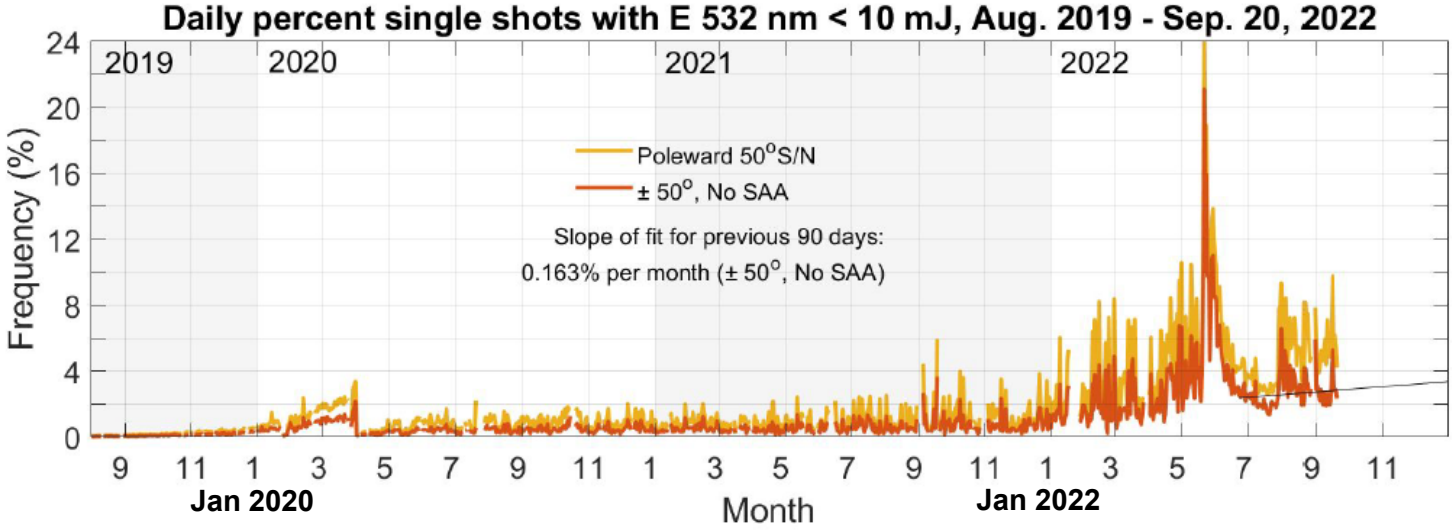
Total laser pulse energy (2009-2022)

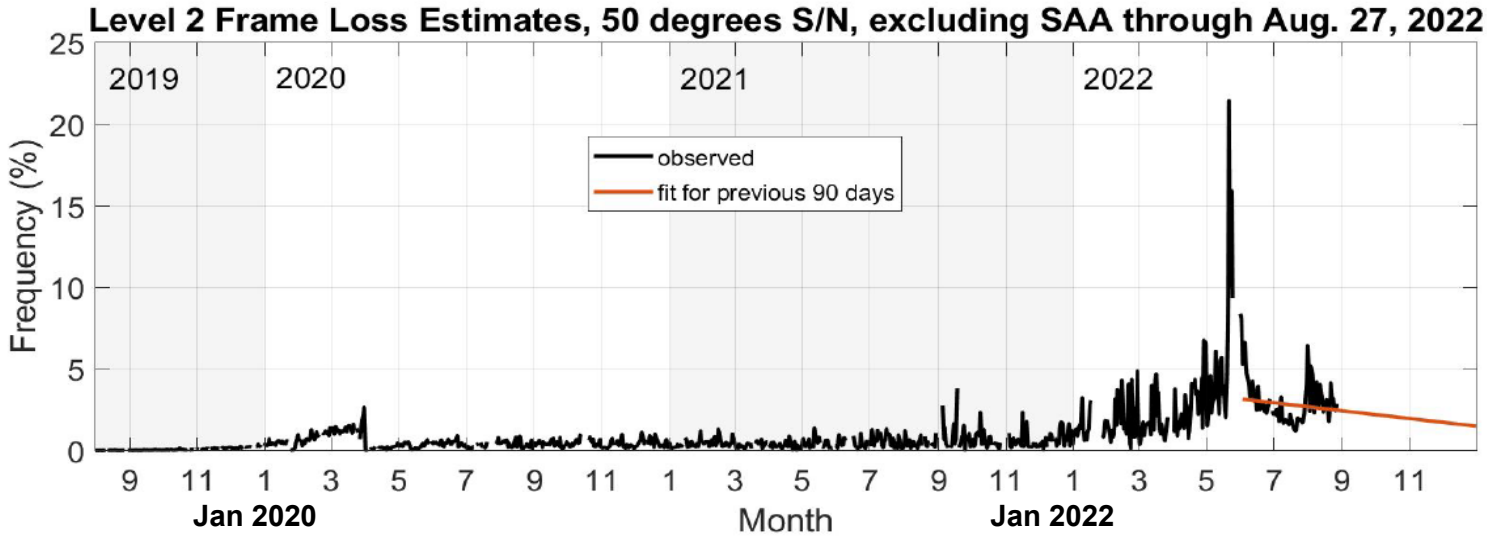


Laser Canister Pressures

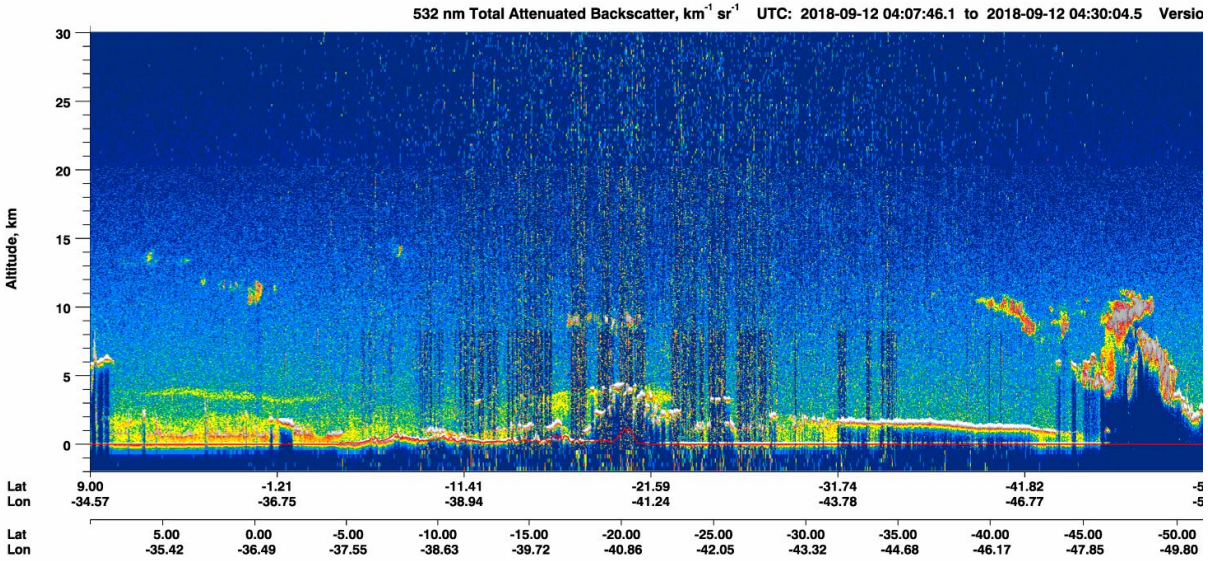


Evolution of Low-Energy Laser Shots

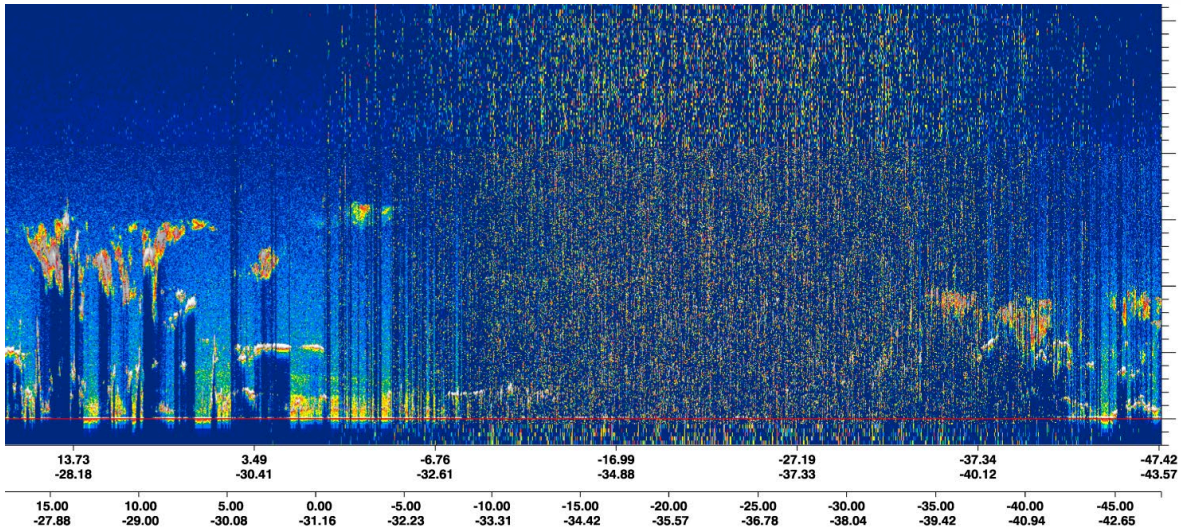




2018-09-12
(V3.4 Expedited)



2022-09-14



Bad news for our friends in Brasil

Data Product Status

- V4.51 Level 1
  - Processing nearly complete
    - ✓ Expect public release before the end of this year
  - For 1064, daytime 532:
    - ✓ Corrected calibration bias due to SAA low energies
  - Improved calibration of 532 nm volume depolarization ratio
    - ✓ smaller (larger) by 1.5 % (4-6%) during daytime (nighttime) relative to V4.2
  - Reminder: expedited L1 V3 is followed by L1 V4.x few months later
  - May introduce some V4.5 improvements into L1 V3 Expedited
- V4.5 Level 2
  - Wrapping up final code now
  - *Anticipate release early next year*
- Level 3 aerosol product will be updated following V4.5 L2

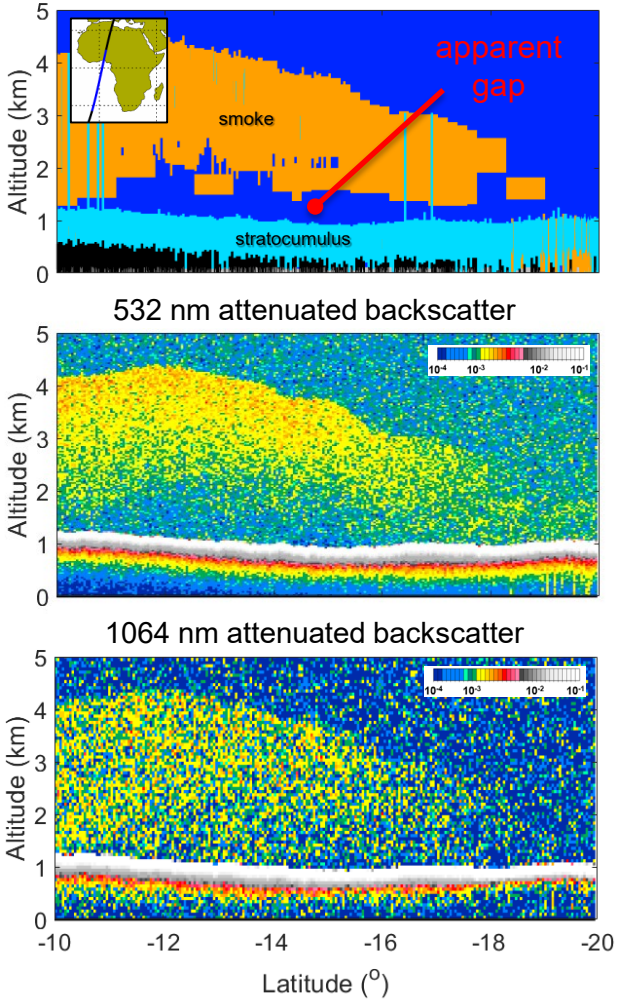
V4.5 L2 Highlights

- Algorithm improvements:
  - Improved smoke bases (southeast Atlantic)
  - Improvements to single-shot cloud clearing (Bug 1507)

- New products:
  - Column optical depth above opaque water clouds (Hu et al 2007)
  - Column optical depth from ocean surface returns (ODCOD)

Level 2: Smoke Base Extension

Version 4.2 Feature Classification

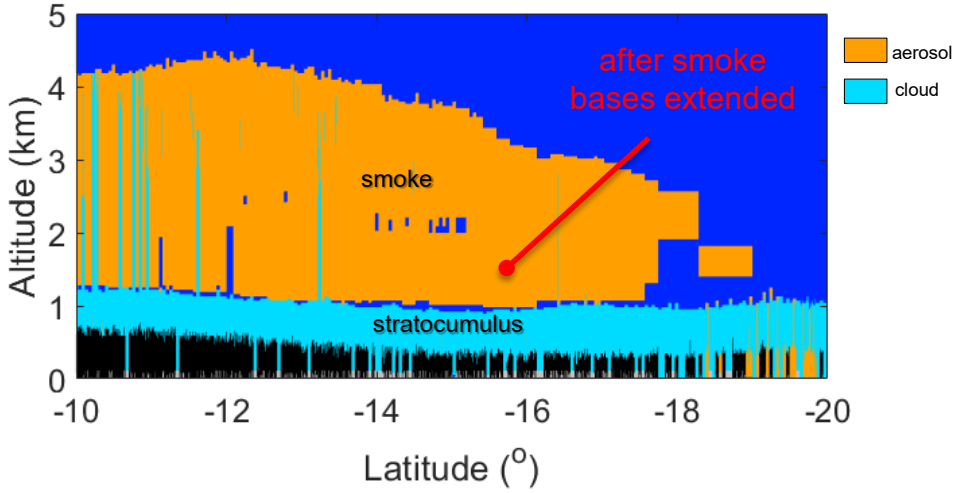


V4.2: Base altitudes of smoke layers over stratocumulus tend to be biased high → AOD is underestimated

In V4.5, retrieval of smoke layer is extended downward to cloud top if there is usable signal within the gap.

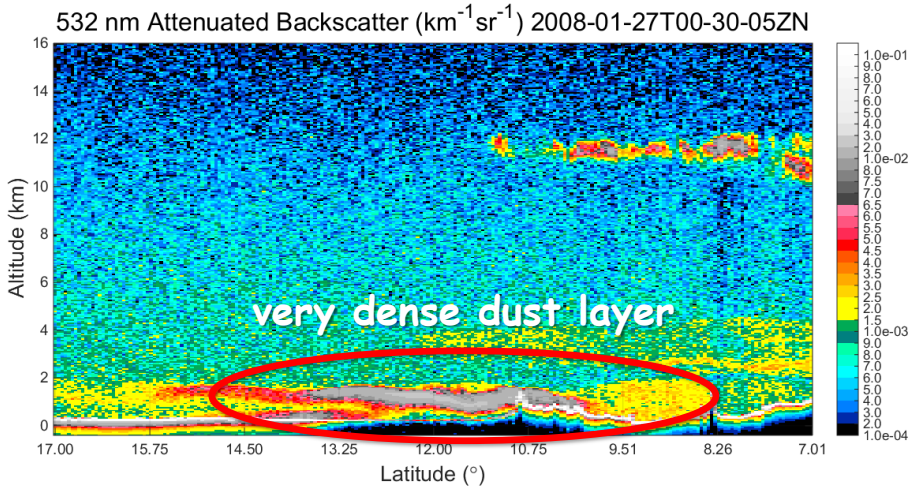
→ Improves smoke optical depths in SE Atlantic

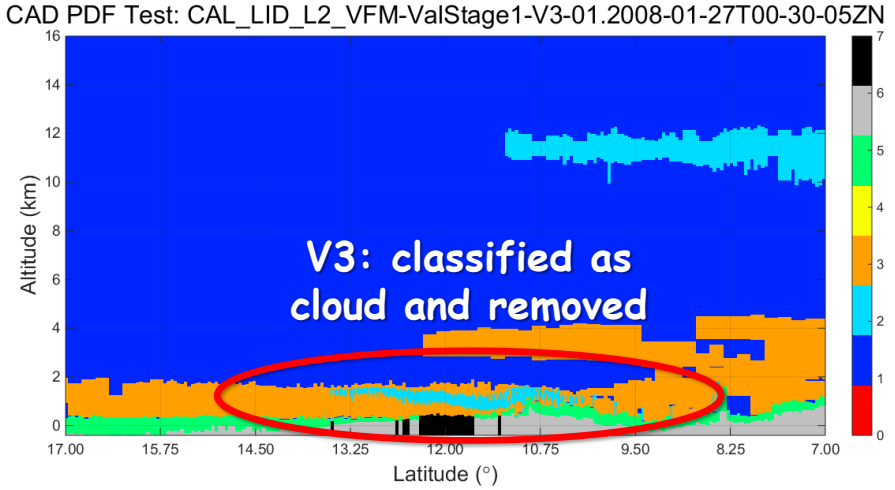
Version 4.5 Feature Classification

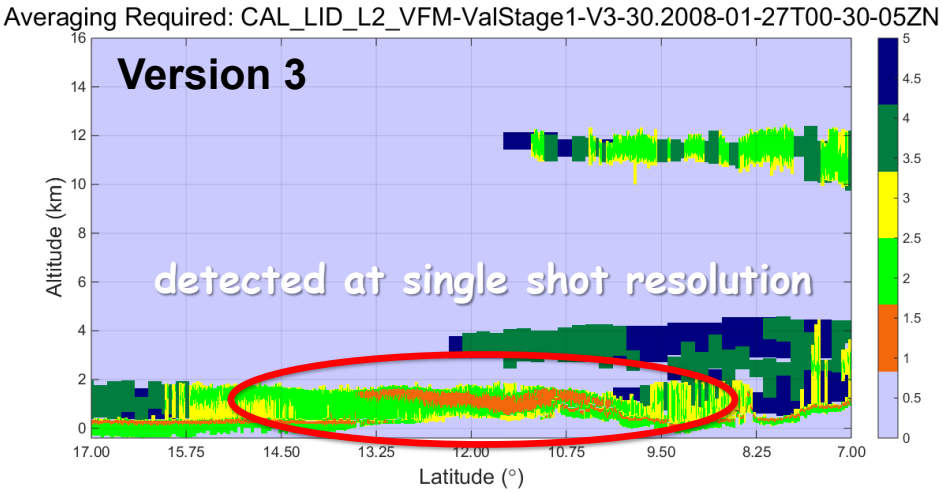


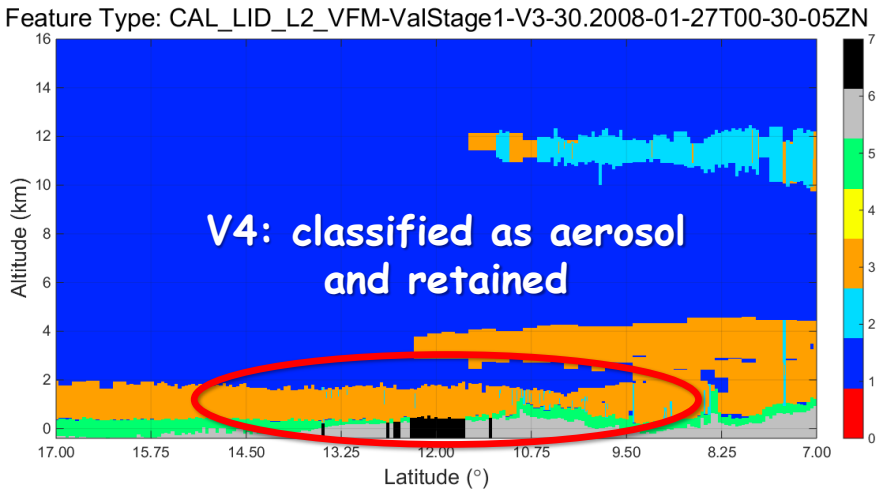
V3: anything detected on single-shots classified as cloud, even dense smoke and dust layers

- V4 applied CAD to single shot profiles for the first time
- Greatly improved retrieval of dense dust, but …



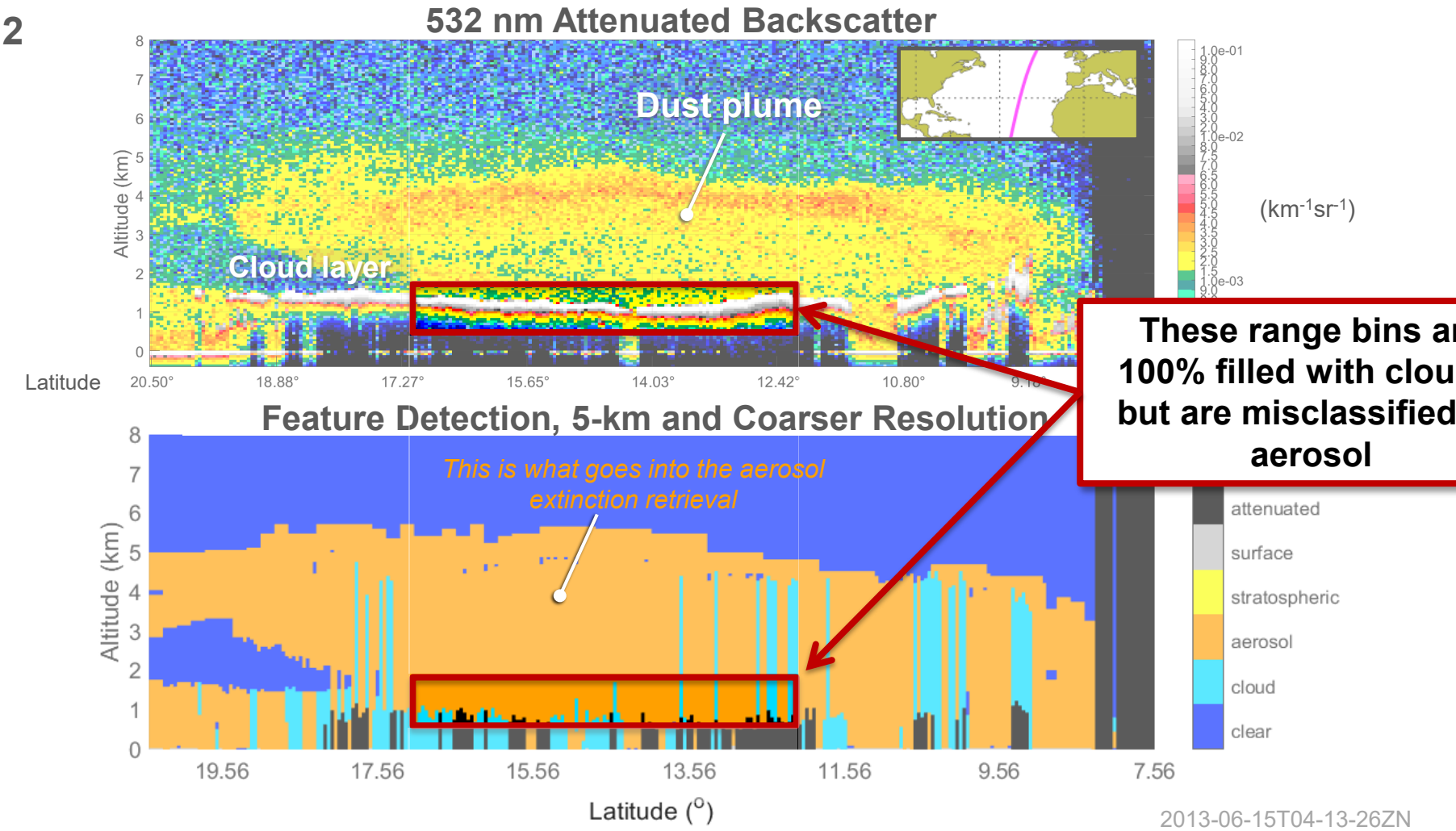






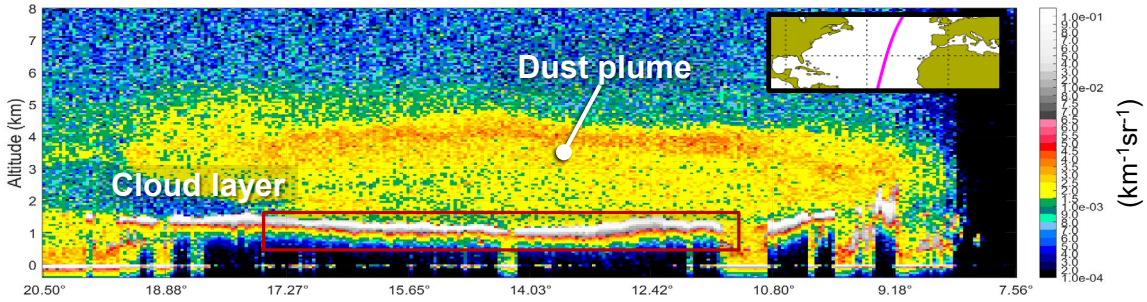
V4.2 Cloud-Clearing Artifacts Example (2)

V4.2



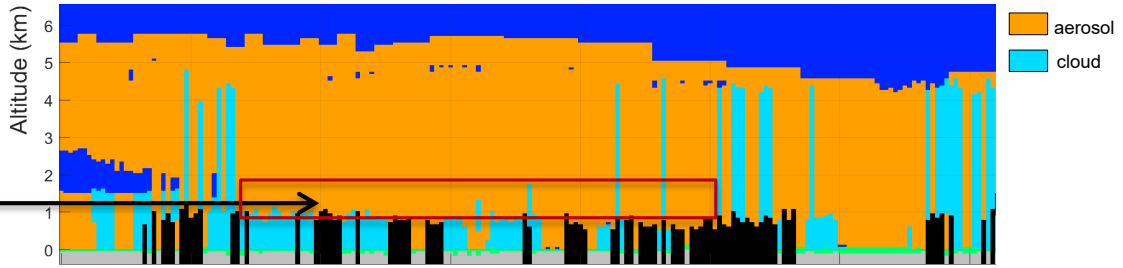
Correction to Single-Shot Cloud-Clearing Artifacts

Clouds detected at single-shot resolution



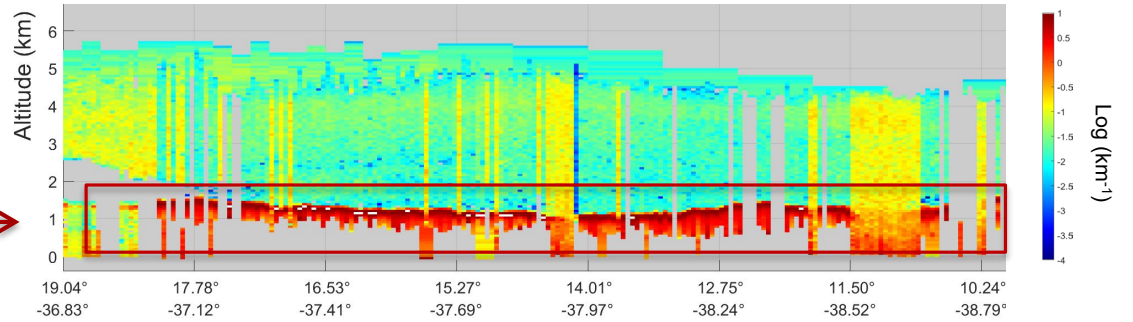
Version 4.2 Feature Classification (5-km resolution)

Cloud deck and overlying dust layer detected as single layer; single-shot clouds not cleared



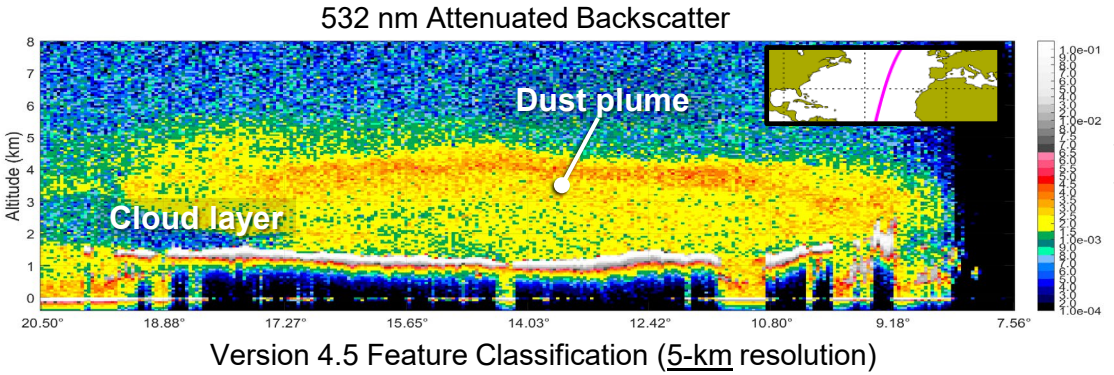
Version 4.2 Aerosol Extinction

Cloud contamination in retrieved aerosol extinction (This error occurs on < 1% of aerosol retrievals)

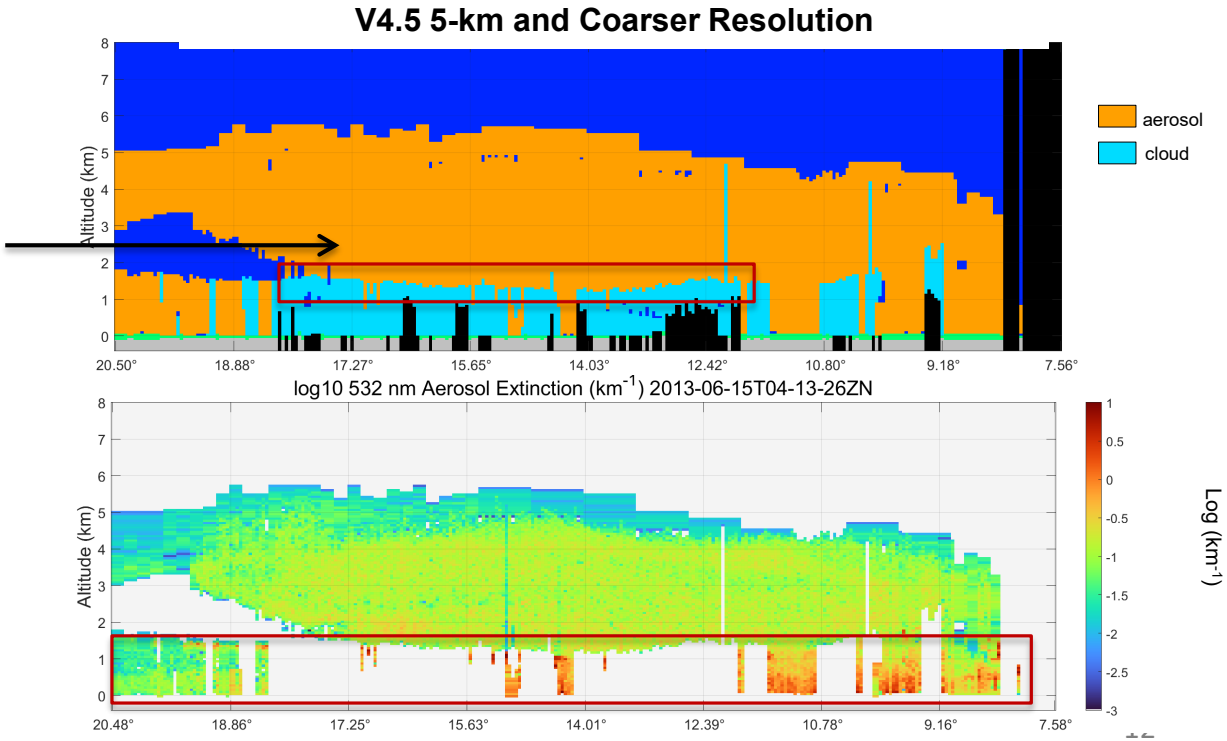


Level 2: Single-Shot Cloud-Clearing Correction

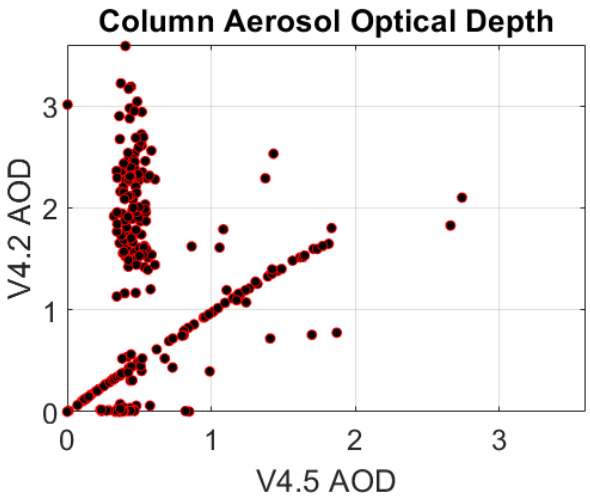
V4.5: algorithm bug is corrected and these situations are properly cloud-cleared



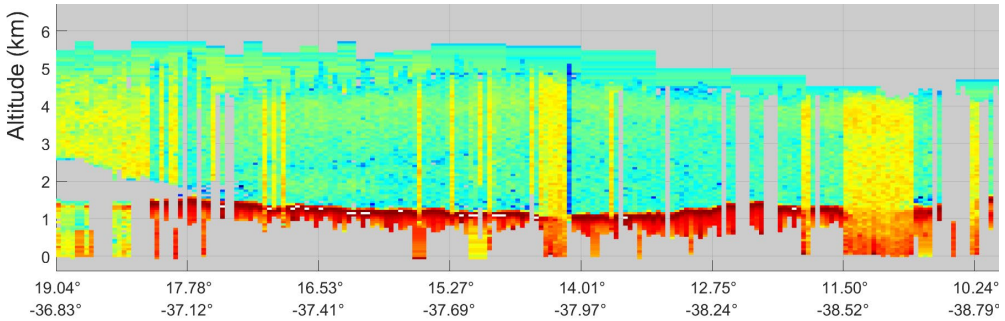
Cloud deck now separated from overlying dust layer



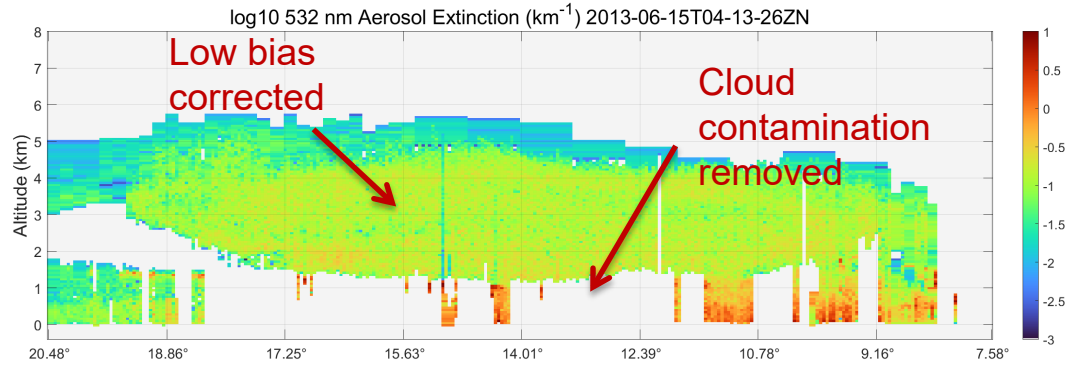
AOD errors of 100-500% in this scene are corrected in V4.5



Version 4.2 Aerosol Extinction

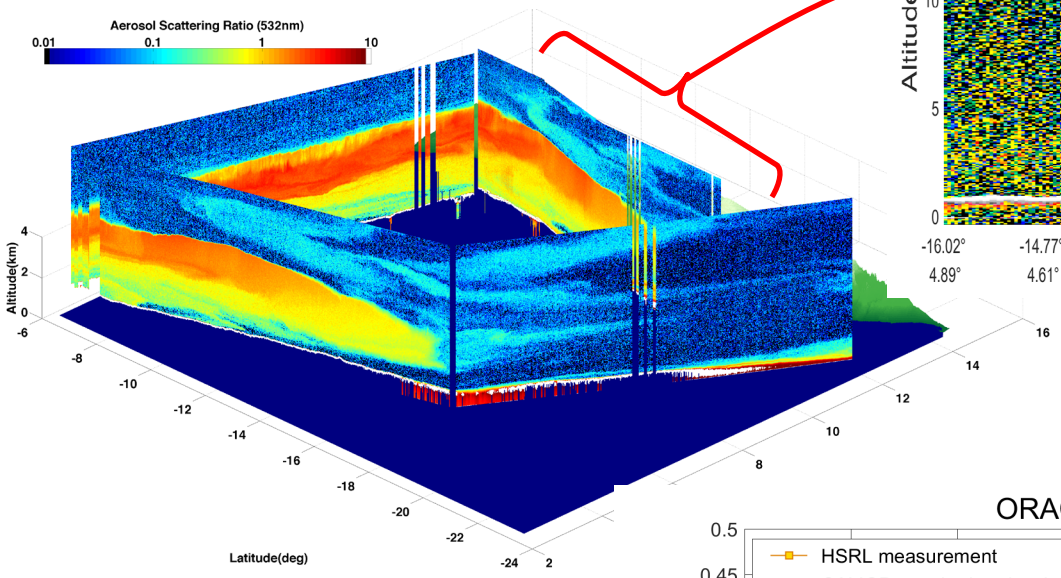


Version 4.5 Aerosol Extinction

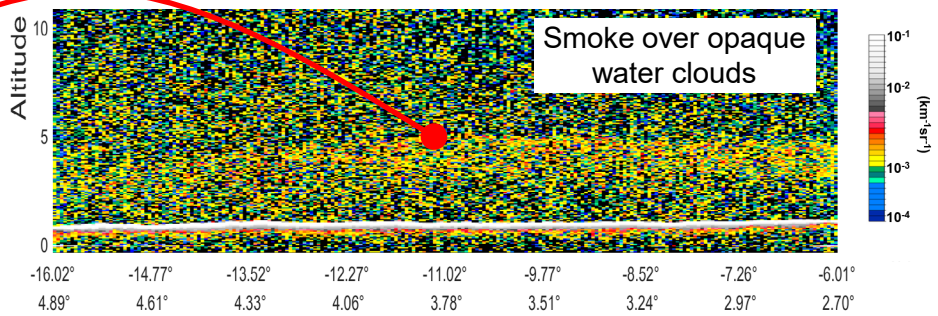


Column OD Above Opaque Water Clouds

HSRL measurements

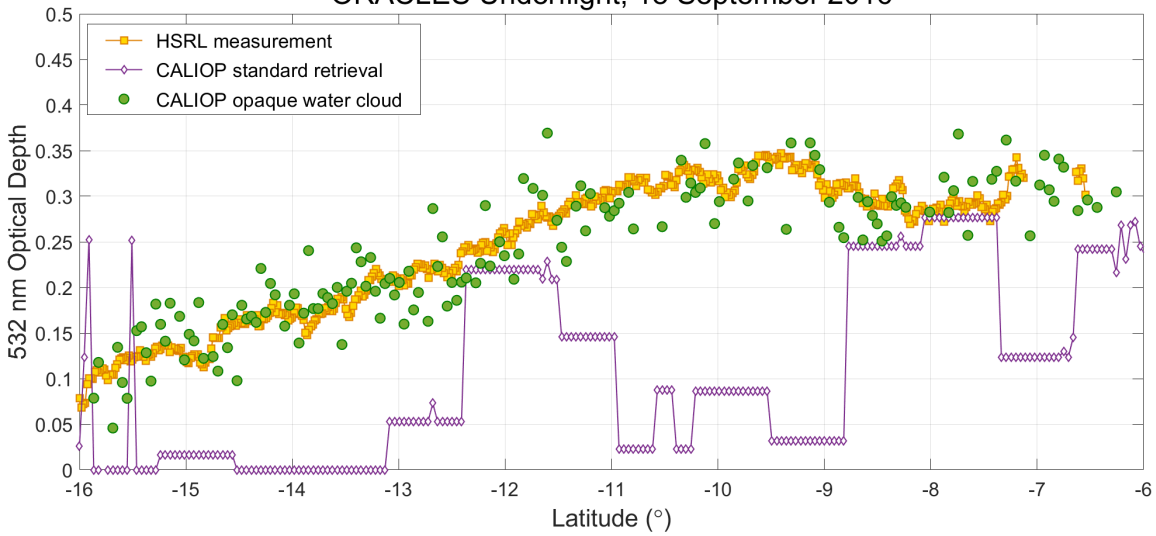


Co-located CALIOP measurements

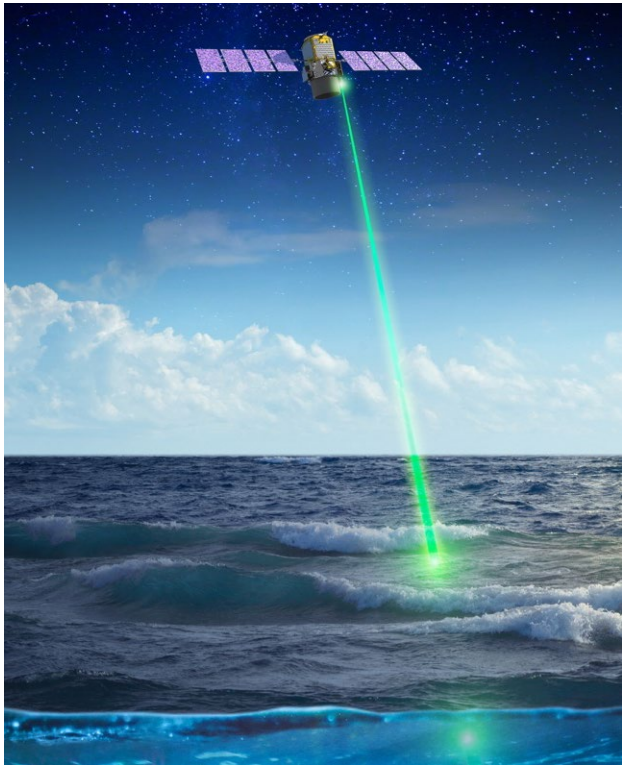


The column OD retrieval method of Hu et al., 2007 (green dots) closely matches the HSRL measurement for this scene.

ORACLES Underflight, 18 September 2016



Column OD from Ocean Surface Return



NASA's Cloud-Aerosol LIdar with Orthogonal Polarization, an instrument aboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation satellite launched in 2006
Credits: NASA/Timothy Marvel

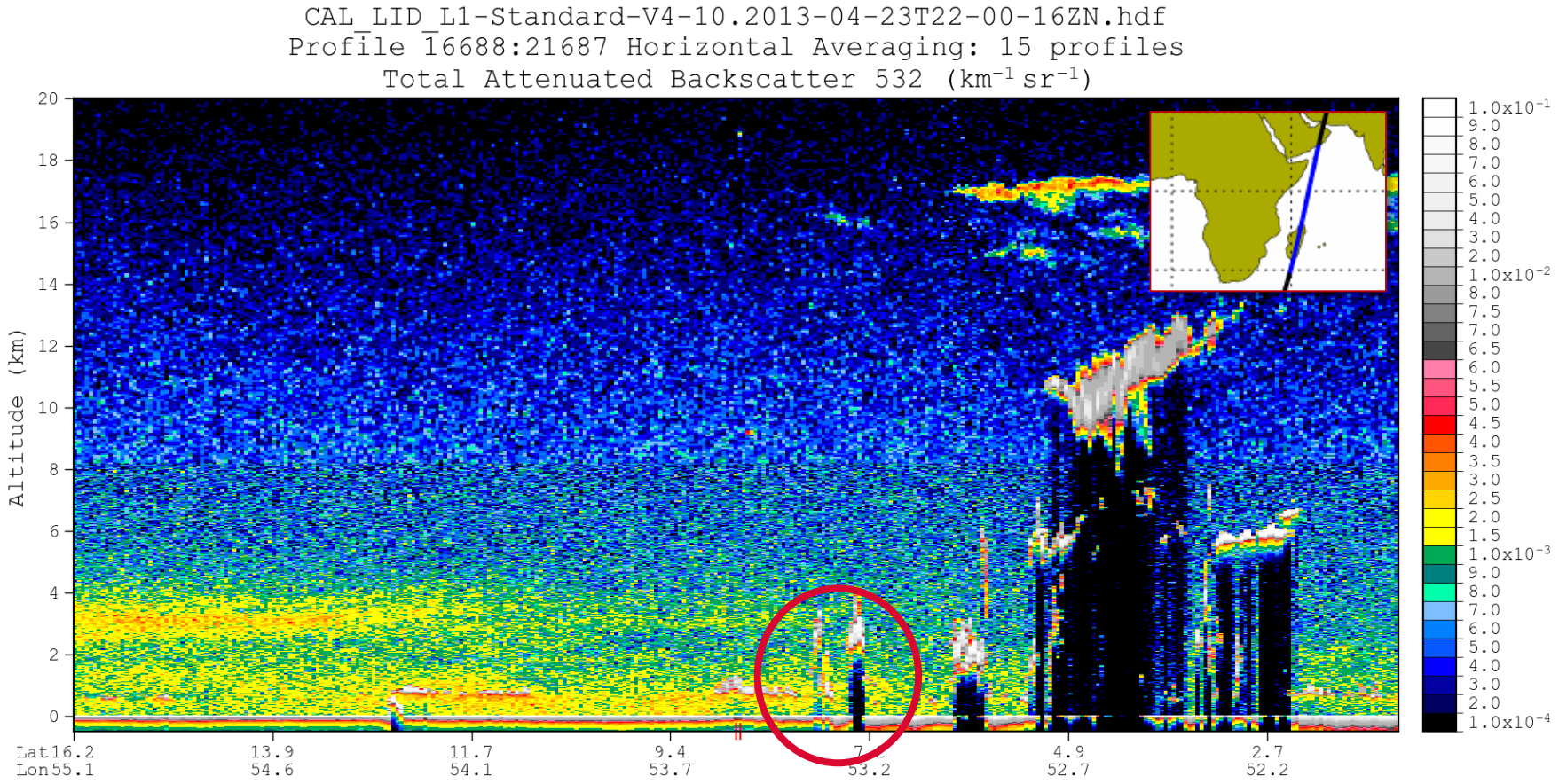
- CALIOP L2 only retrieves extinction within detected layers
  - → low bias in AOD, COD

- Ocean Derived Column Optical Depths (ODCOD)
  - Adaptation of Venkata & Reagan 2016
  - Similar to radar PIA method
  - Retrieves OD without CAD or aerosol typing
  - Must be corrected for multiple scattering effects (if any)

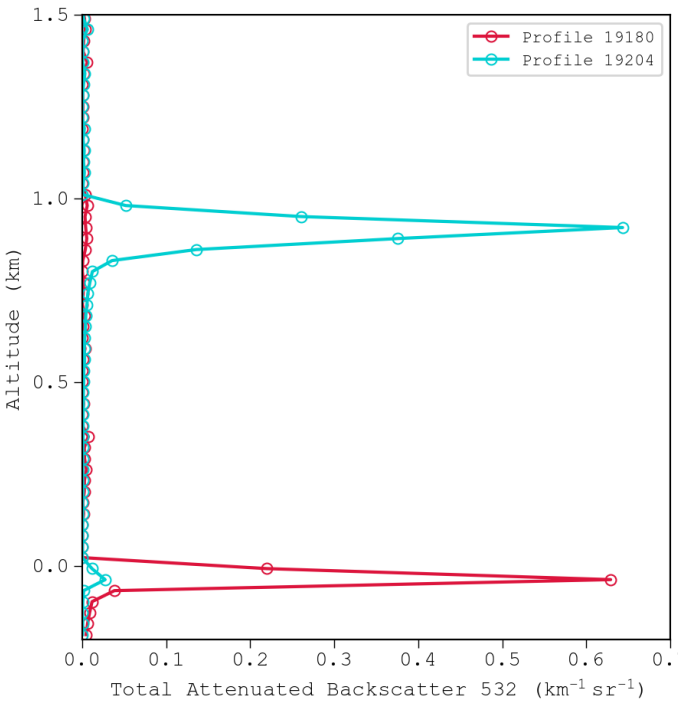
- ODCOD uses the magnitude of CALIPSO's ocean surface return compared to a modeled ideal ocean return to estimate optical depth
- The surface points are fit to a model lidar ocean return
- An accurate wind speed estimate is required to calculate a model surface reflectance
- Surface depolarization is tested to ensure no sea ice or shallow water sea floor is in the return

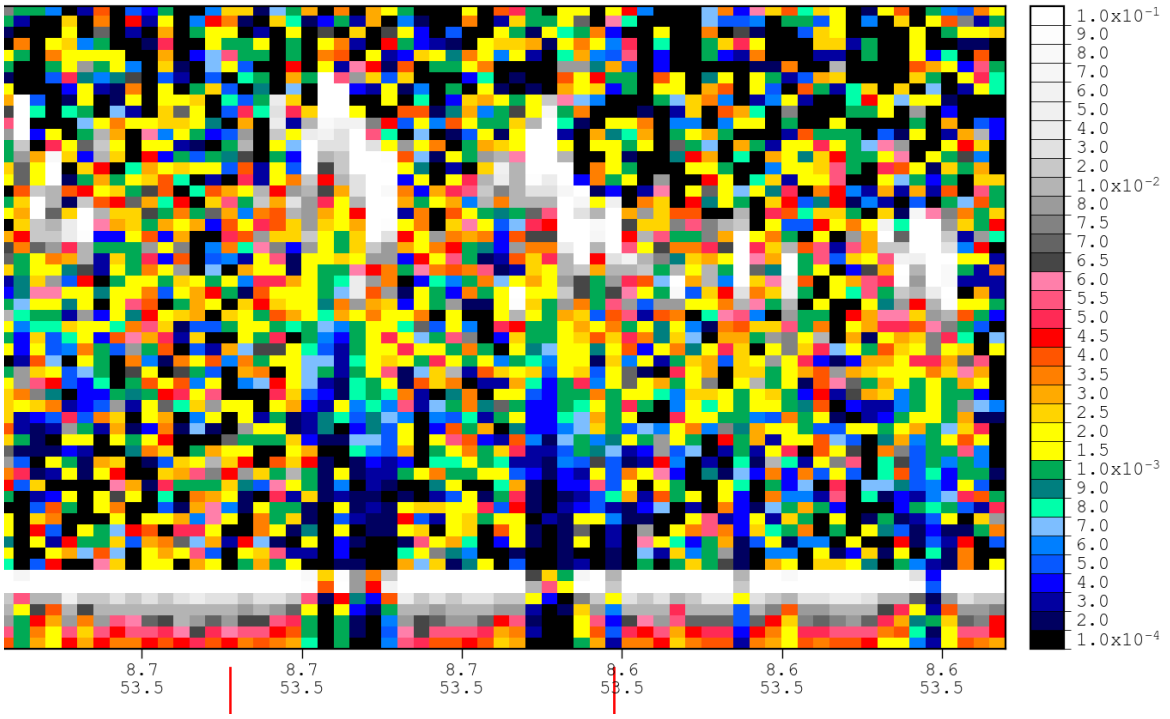
Venkata, S.L., Reagan, J.A., Aerosol Retrievals from CALIPSO Lidar Ocean Surface Returns. Remote Sensing 8(12) 1006 (2016). https://doi.org/10.3390/rs8121006

- In clear skies, backscatter from the ocean surface is very high
- Clouds and aerosols attenuate the signal, reducing the magnitude of the ocean backscatter return.



Clouds and/or aerosols above the surface attenuate the signal, resulting in a notably smaller ocean backscatter return.





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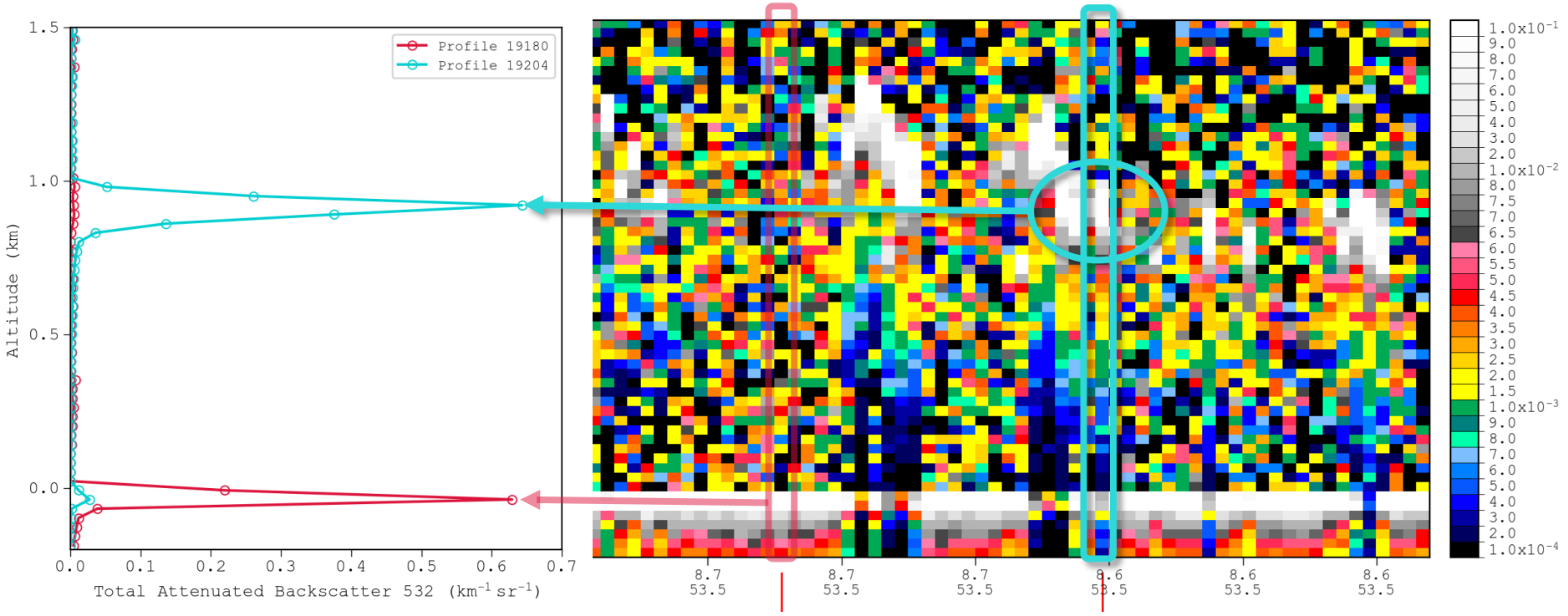


Method

- The magnitude of the ocean surface return pulse (A_c) is a function of the ocean surface retroreflectance (O_{SRR}) and the two-way transmittance of the atmospheric column
- O_{SRR} is a function of whitecap fraction (W), and the wind speed-dependent ocean surface reflectance (R_λ):

$$O_{SRR} = (1 - W)R_\lambda + 0.2W$$

- Two-way particulate transmittance, T^2, is computed from the magnitude of the surface return pulse, corrected for ocean reflectance and molecular absorption

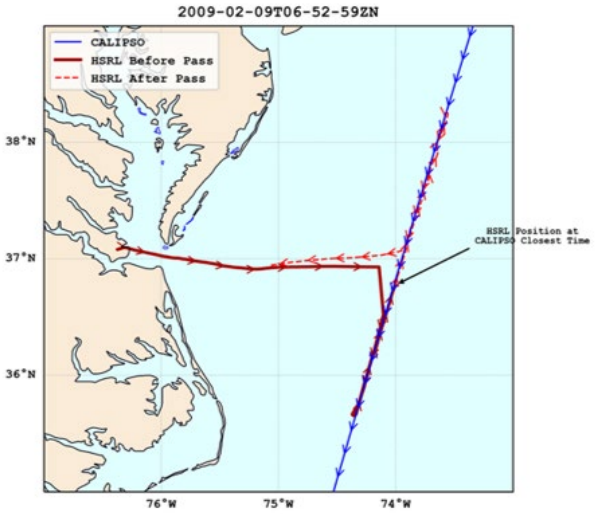
$$T^2 = \frac{2 \cdot A_C}{c \cdot O_{SRR} \cdot T_{mol}^2 \cdot T_{O_3}^2}$$

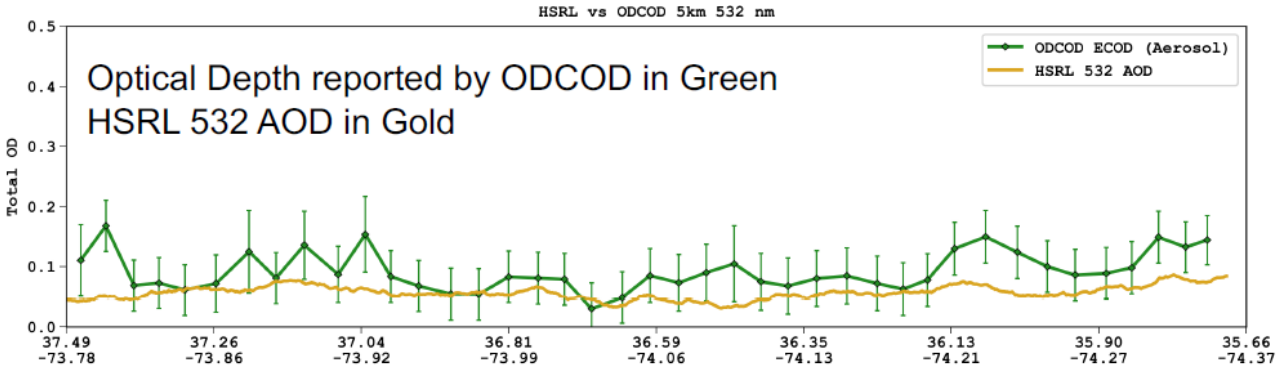
- Column optical depth can then be computed from the two-way transmittance:

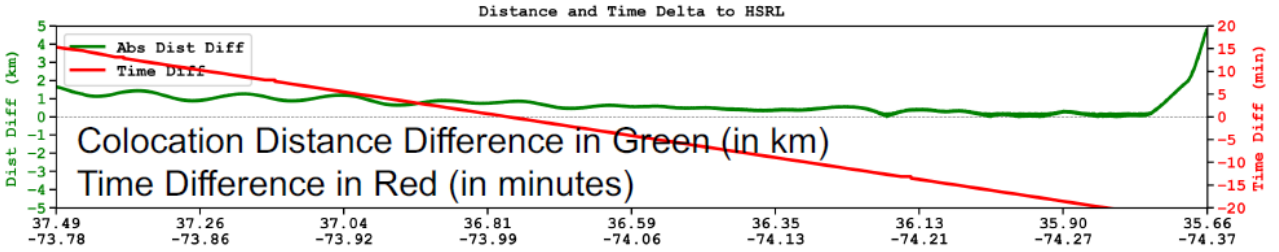
$$\mathrm{OD_{col}} = -\frac{1}{2}\, ln(T^2)$$

ODCOD vs HSRL

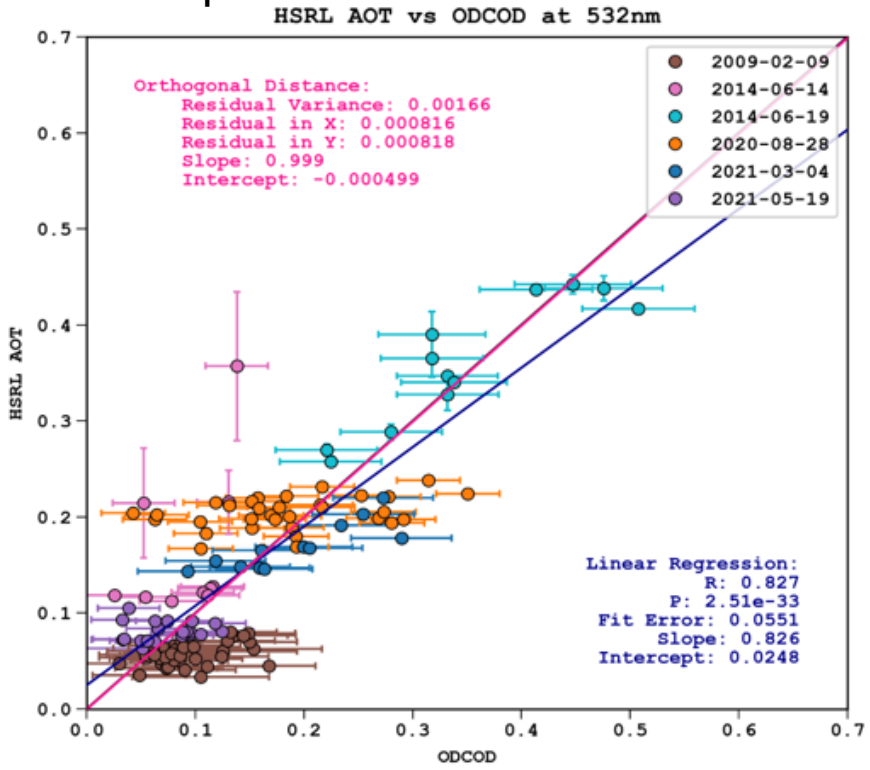
HSRL only measures surface to ~ 8.5 km
so expect $AOD_{ODCOD} > AOD_{HSRL}$







Comparison with co-located HSRL

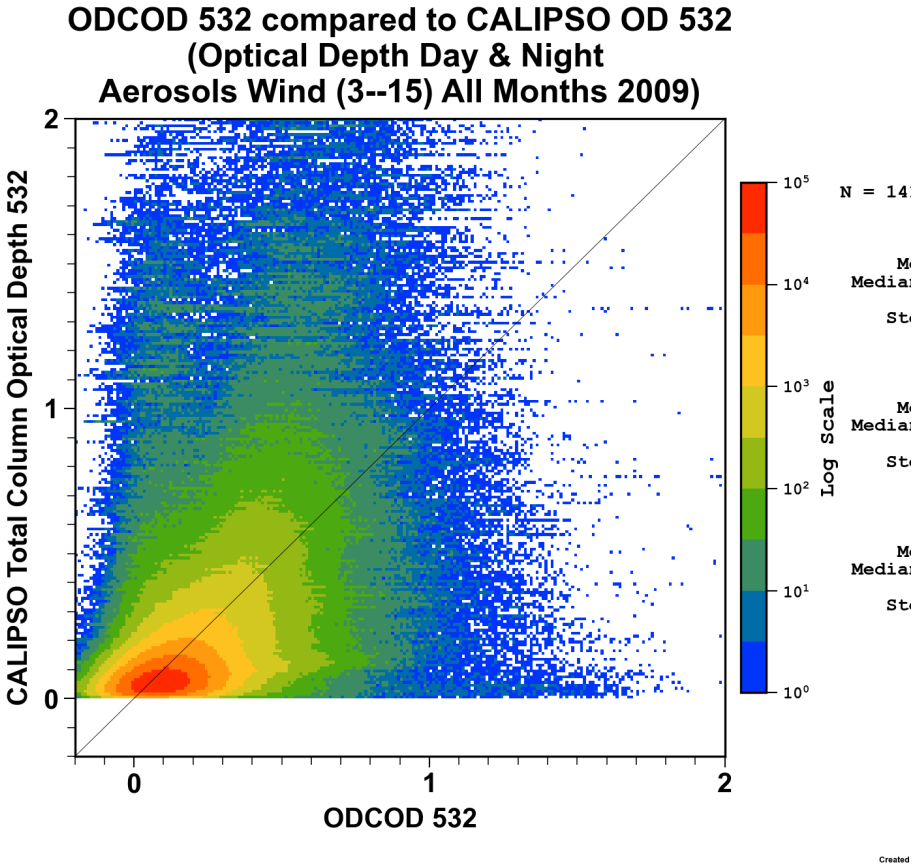


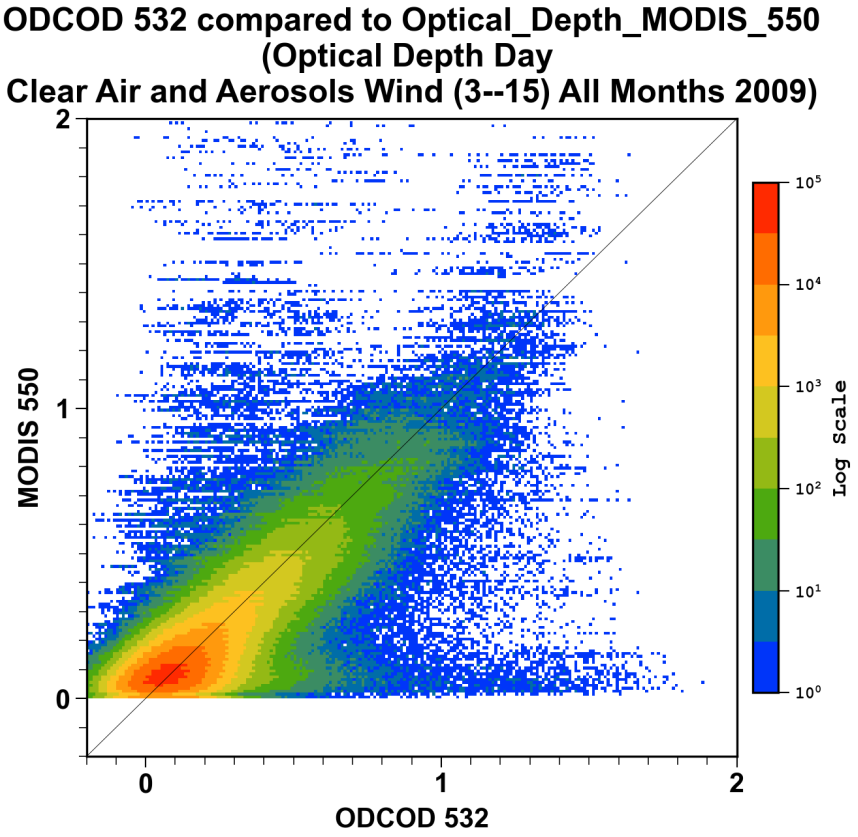
ODCOD-HSRL AOD Difference				
	Median	MAD	Mean	Std. Dev.
Feb 9th 2009	0.029	0.016	0.036	0.028
Jun 14th 2014	-0.049	0.037	-0.066	0.060
Jun 19th 2014	-0.016	0.021	-0.012	0.041
Aug 28th 2020	-0.032	0.041	-0.02	0.069
Mar 4th 2021	0.025	0.028	0.022	0.042
May 19th 2021	-0.010	0.021	-0.008	0.029
All	0.007	0.030	0.001	0.057

HSRL only measures surface to ~ 8.5 km
Climatological background AOD ~ 0.016±0.03 (Kim, et al., 2017)
so expect ODCOD > HSRL

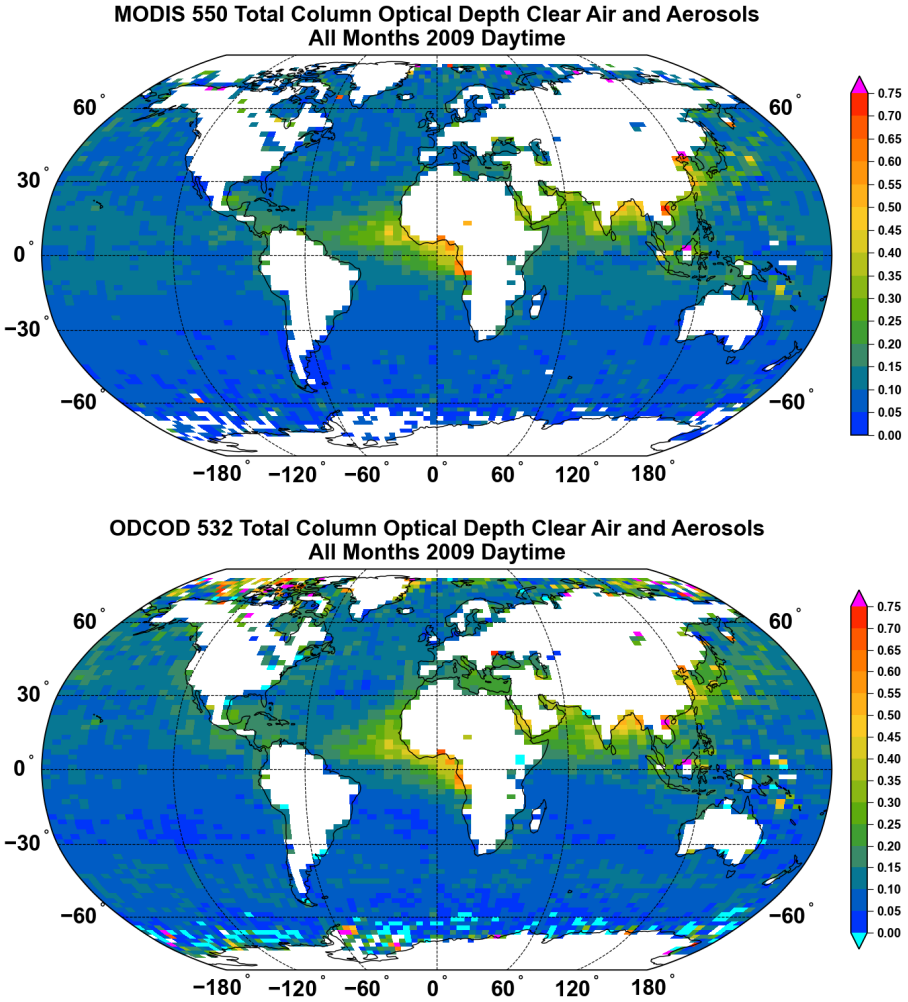
Kim, et al., 2017, JGR, doi:10.1002/ 2016JD025797

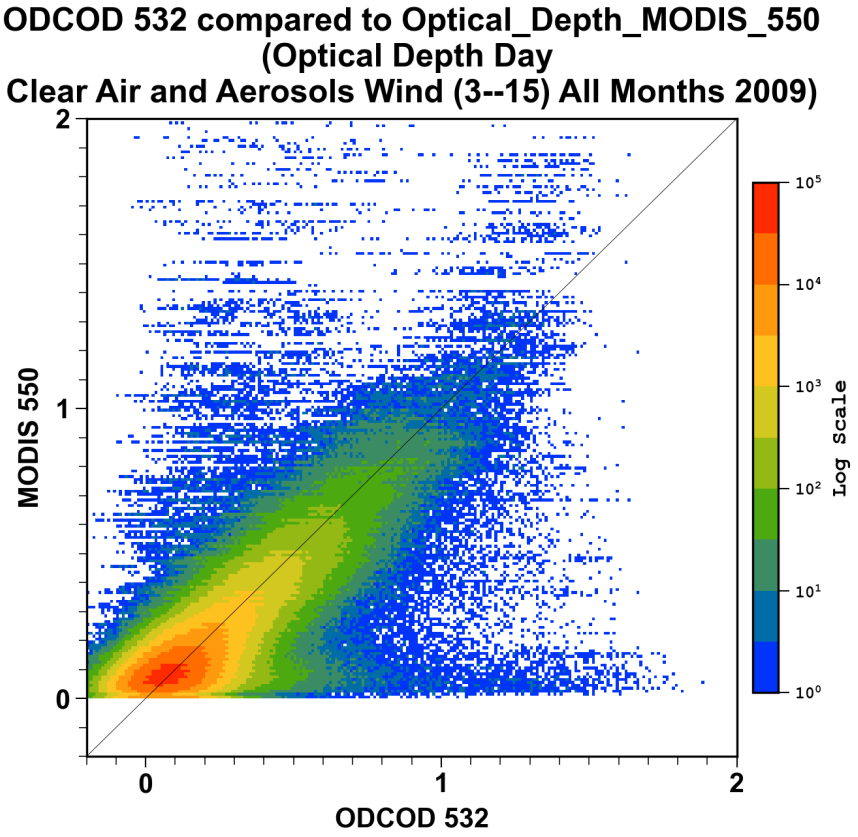
ODCOD


ODCOD 532 compared to CALIPSO OD 532
(Optical Depth Day & Night
Aerosols Wind (3--15) All Months 2009)
CALIPSO Total Column Optical Depth 532
ODCOD 532
Log Scale
N = 14
Created


ODCOD 532 compared to Optical_Depth_MODIS_550
(Optical Depth Day
Clear Air and Aerosols Wind (3--15) All Months 2009)
MODIS 550
ODCOD 532
Log Scale

ODCOD


MODIS 550 Total Column Optical Depth Clear Air and Aerosols
All Months 2009 Daytime
60°
30°
0°
−30°
−60°
−180° −120° −60° 0° 60° 120° 180°
0.75 0.70 0.65 0.60 0.55 0.50 0.45 0.40 0.35 0.30 0.25 0.20 0.15 0.10 0.05 0.00
ODCOD 532 Total Column Optical Depth Clear Air and Aerosols
All Months 2009 Daytime
60°
30°
0°
−30°
−60°
−180° −120° −60° 0° 60° 120° 180°
0.75 0.70 0.65 0.60 0.55 0.50 0.45 0.40 0.35 0.30 0.25 0.20 0.15 0.10 0.05 0.00


ODCOD 532 compared to Optical_Depth_MODIS_550
(Optical Depth Day
Clear Air and Aerosols Wind (3--15) All Months 2009)
MODIS 550
ODCOD 532
0
1
2
Log Scale
10^0
10^1
10^2
10^3
10^4
10^5

Outlook

- Expect end of science mission October 2023
  - Available electrical power decreasing due to increasing solar angle
- 2 years of Phase F funding
  - Reprocess all products using final algorithms (V5)
  - Archive comprehensive documentation
    - ✓ Instrument descriptions
    - ✓ Calibrations
    - ✓ Algorithms, products, and software
    - ✓ Validation results