Building a Long-Term Cloud Record from Spaceborne Lidars: Bridging CALIOP to ATLID

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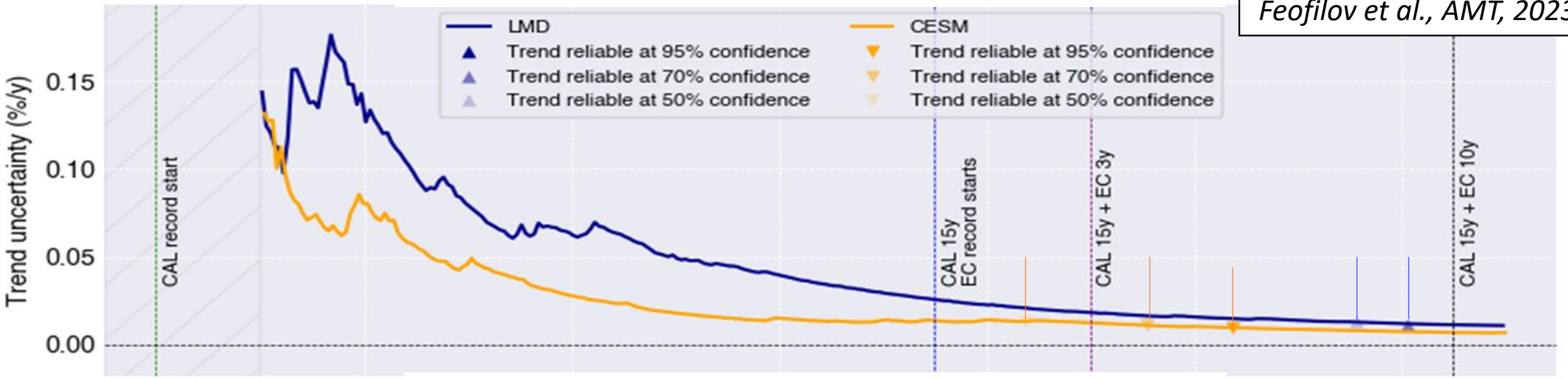
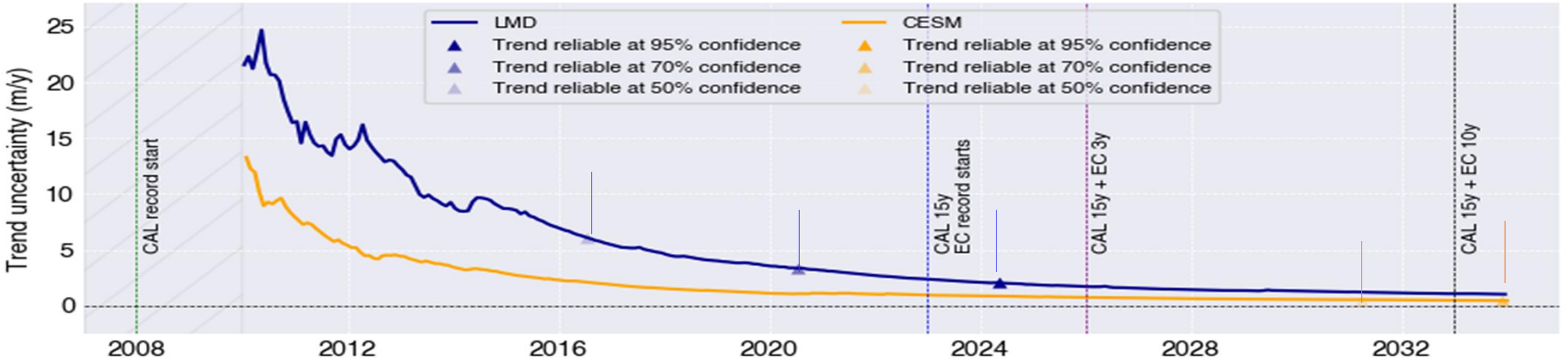
Motivation - how long will it take to detect a trend in clouds using lidars?

Chepfer et al., JGR, 2018
Feofilov et al., AMT, 2023

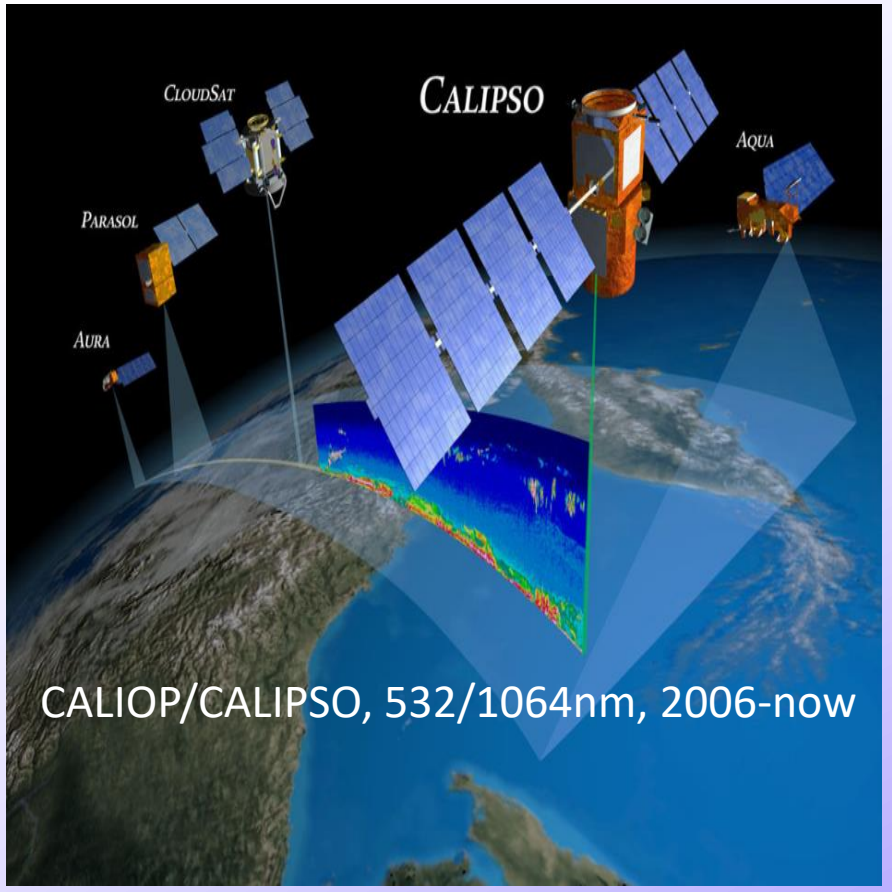
Opaque cloud cover trend uncertainty – tropics, all clouds

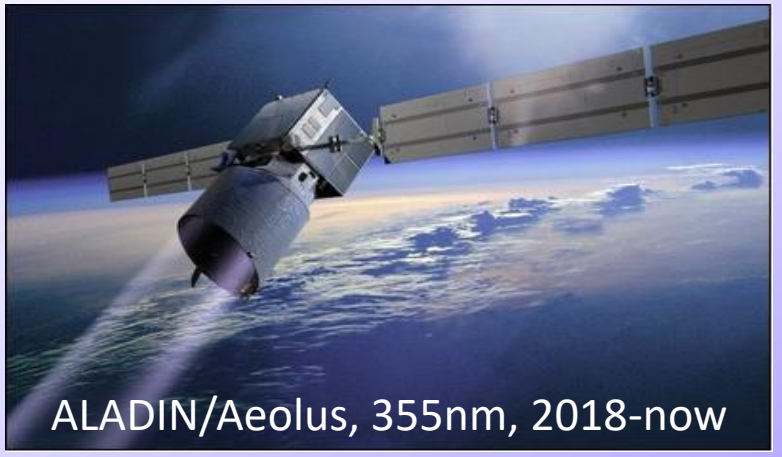


Opaque cloud height trend uncertainty – tropics, all clouds



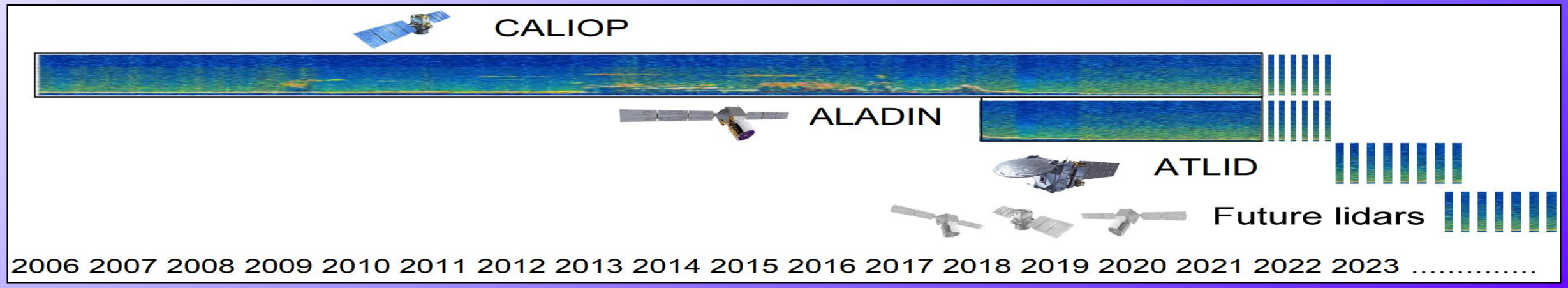
Continuous cloud record from space-borne lidars





- General principle is the same: polar orbit, 15 tracks per day, sounding radiation is sent downwards, the backscattered signal is sampled and interpreted.

- Differences between lidars: wavelength, observation geometry and time, HSRL capability, averaging distance, vertical resolution, noise.



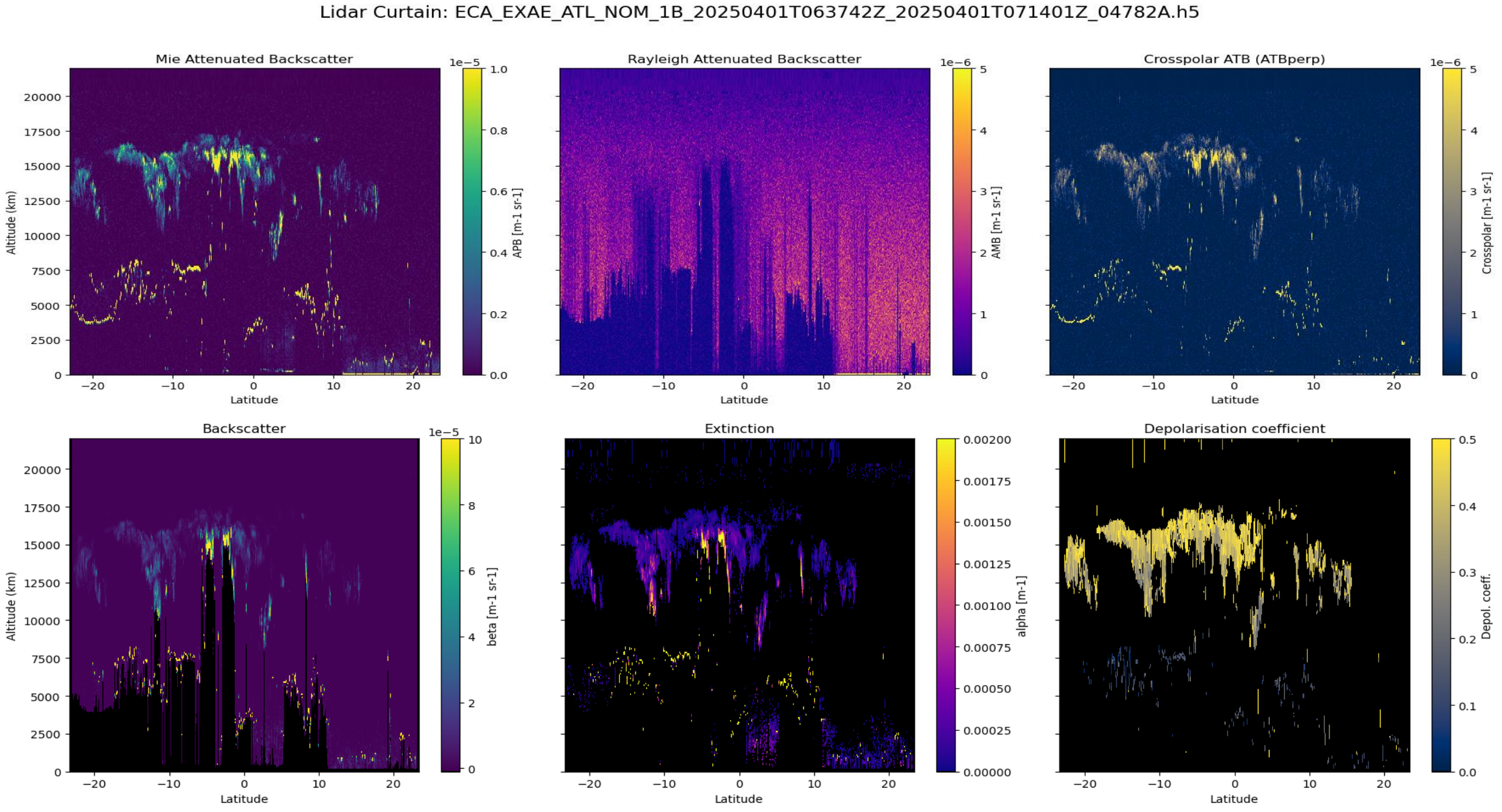
Differences and similarities of space-borne lidars

Parameter	Symbol	CALIOP	ALADIN	ATLID
Altitude, [km]	Z	688[#]	320	393
Orbital inclination, [deg]	I	98.05	97.0	97.050
Equator overpass time [LST hours]		01:30/13:30	06:00/18:00	02:00/14:00
Wavelength, [nm]	λ	532/1064	355	355
Off-nadir viewing angle [deg]		3	35	2
Cross-polar radiance detection		YES	NO	YES
Pulse Repetition Frequency, [Hz]	PRF	20	50 (2)[*]	51 (25.5)[*]
Horizontal distance between profiles, [m]	Δx	333	140 (3000)	285
Finest Vertical resolution (troposphere), [m]	Δz	30	250→1000	100
Telescope diameter, [m]	d_{tel}	1.0	1.5	0.6
Telescope Field of view, [μrad]	φ	130	19	64
Energy/pulse, [mJ]	E_{pulse}	110	100	35 (70)[*]
Footprint, [m]	d_{fp}	90	6	29
Laser beam divergence [μrad]	θ	100	12	45
Solar filter bandwidth, [nm]	Δλ	0.04/0.475	1.0/(0.067)	0.71 (0.35)[**]
Solar filter transmission	ξ_{filter}	0.85	0.8	0.87
Total optical system transmission	ξ_{rec}	0.67/0.68	0.6	0.62
Detector type		PMT/APD	ACCD	CCD
Detector efficiency	γ	0.11/0.4	0.8	0.79mol/0.75part

ATLID's performance, L1 and L2, low daytime noise

L1, Measured

L2, Retrieved



Cloud definition through scattering ratio at 532nm

$$ATB(\lambda,z) = (\beta_{mol}(\lambda,z) + \beta_{part}(\lambda,z)) \times e^{-2\int_{z_{sat}}^{z}(\alpha_{mol}(\lambda,z\prime)+\eta\alpha_{part}(\lambda,z\prime))dz\prime}$$

Lidar equation

$$AMB(\lambda,z) = \beta_{mol}(\lambda,z) \times e^{-2\int_{z_{sat}}^{z}\alpha_{mol}(\lambda,z\prime)\,dz\prime}$$

Attenuated molecular backscatter in the absence of particles

$$SR\ (\lambda,z) = \frac{ATB(\lambda,z)}{AMB(\lambda,z)}$$

Scattering ratio

$SR(532nm,z) > 5$

ATB(532nm,z) – AMB(532nm,z)>2.5x10^{-6} m^{-1} sr^{-1}

If both conditions are met for a given layer, then we have a cloud

Chepfer et al., JAOT, 2013

Compensation for wavelength difference: $\alpha_{part}(355nm)\sim=\alpha_{part}(532nm)$, $\beta_{part}(355nm)\sim=\beta_{part}(532nm)$

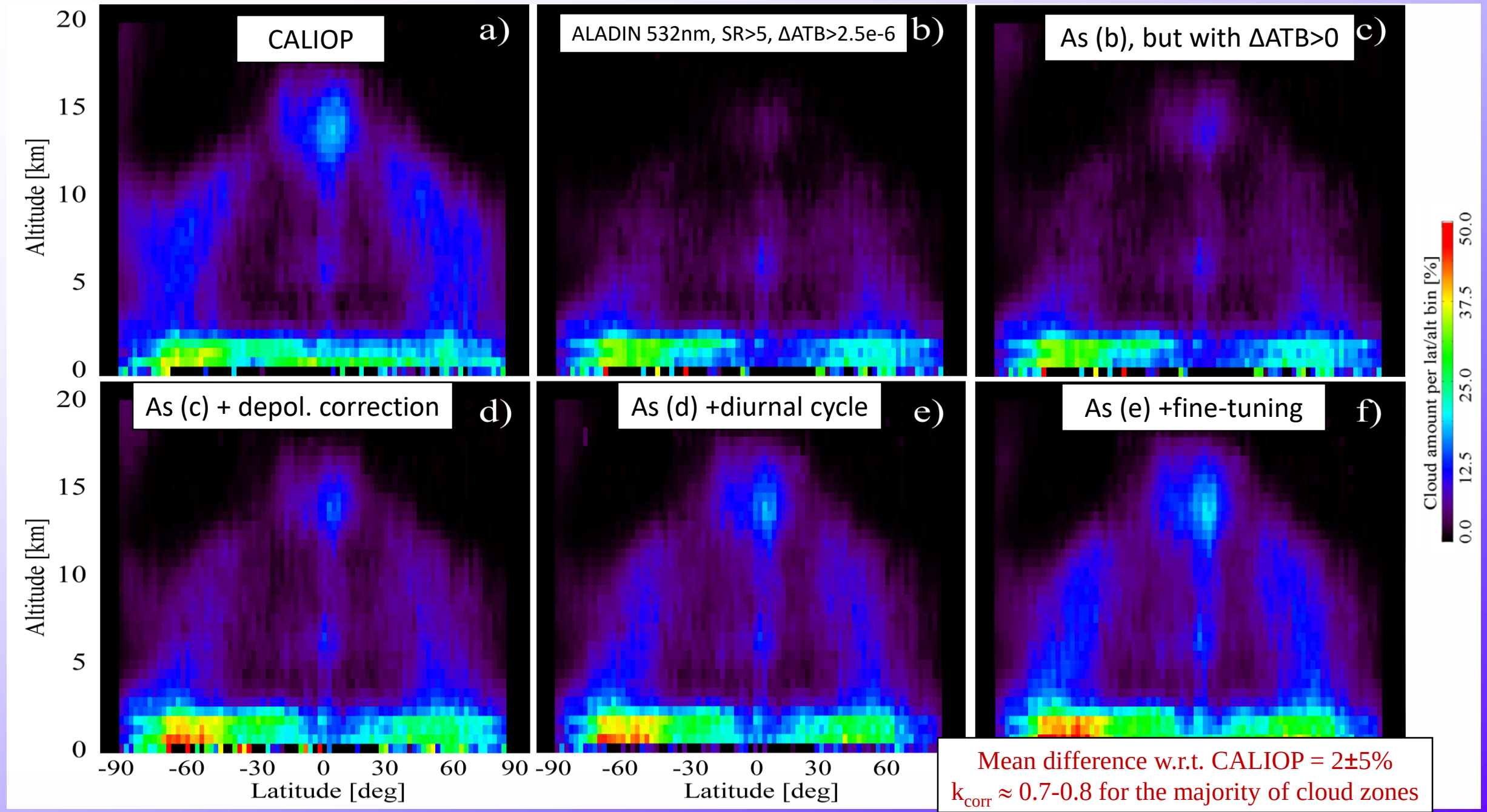
Recalculated SR

$$\mathrm{SR}'(532\,\mathrm{nm},z) = \frac{\left(\beta_{\mathrm{mol}}(532,z)+\beta_{\mathrm{part}}(355,z)\right)\times e^{-2\int_{z_{\mathrm{sat}}}^{z}\left(\alpha_{\mathrm{mol}}(532,z')+\eta_{355}\alpha_{\mathrm{part}}(355,z')\right)\mathrm{d}z'}}{\beta_{\mathrm{mol}}(532,z)\times e^{-2\int_{z_{\mathrm{sat}}}^{z}\alpha_{\mathrm{mol}}(532,z')\,\mathrm{d}z'}}.$$

Feofilov et al., AMT, 2023

Past experience: making Aeolus clouds consistent with CALIPSO

Feofilov et al., SAT, 2024

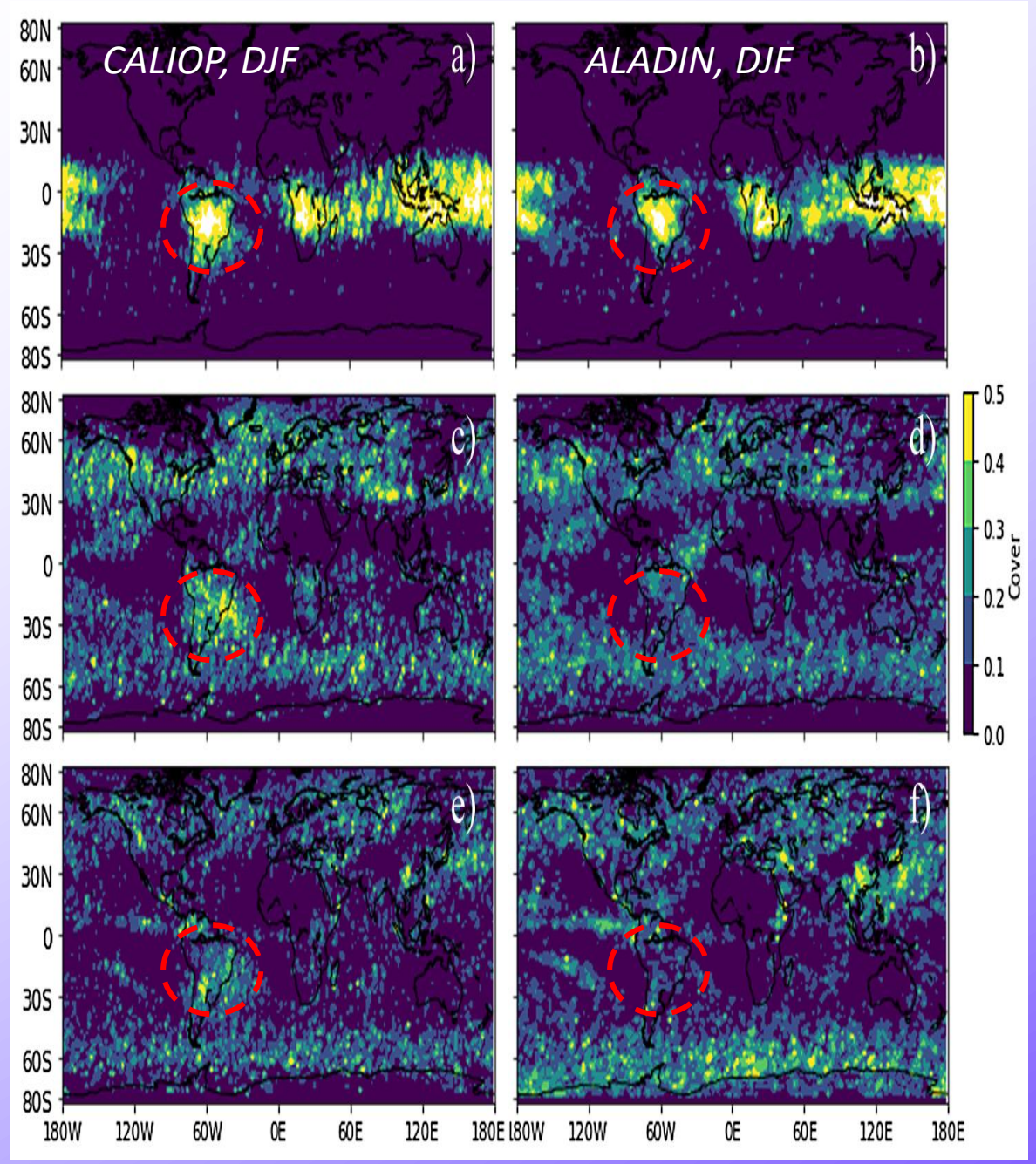


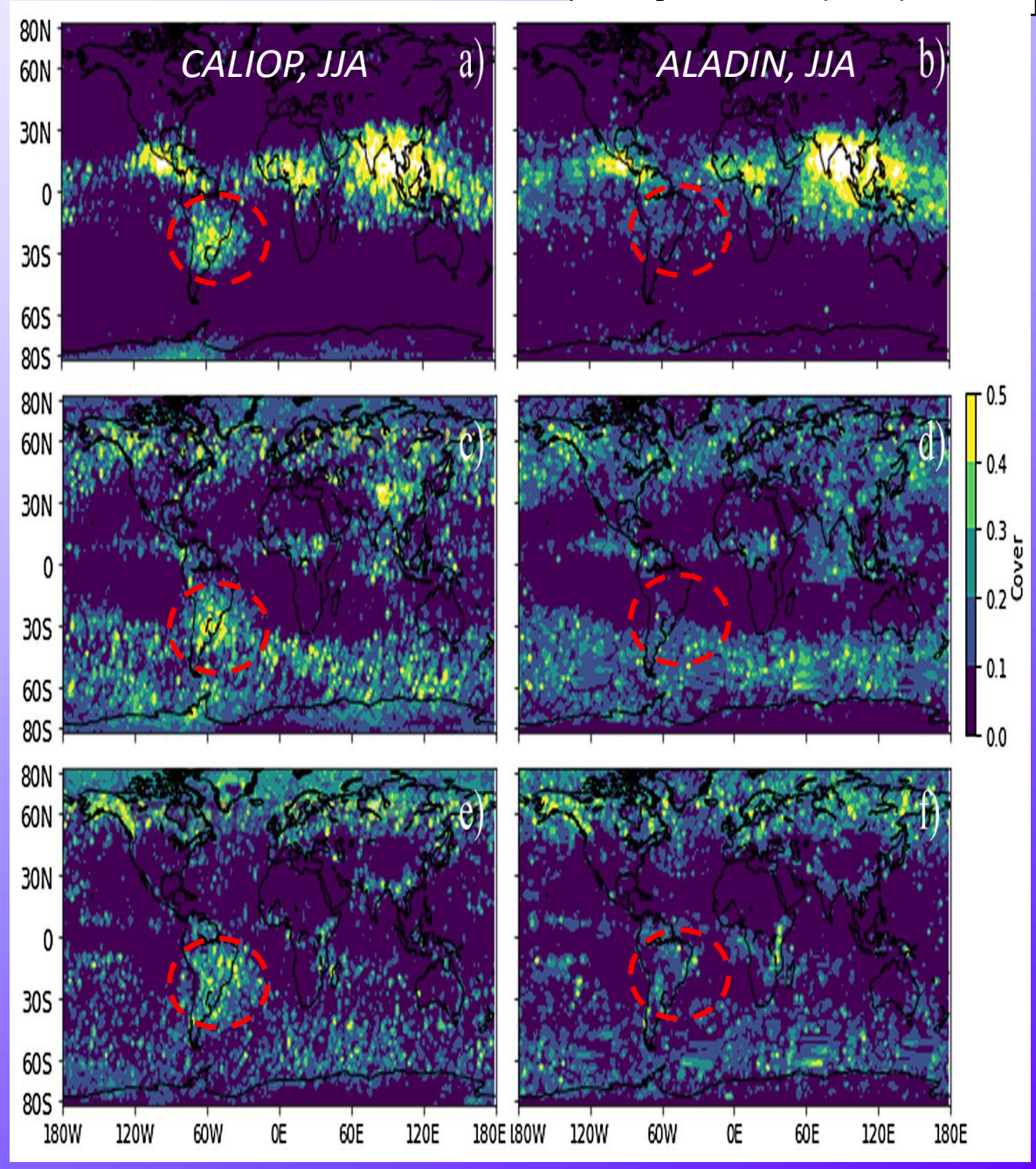
Mean difference w.r.t. CALIOP = 2±5%

$k_{corr} \approx 0.7\text{-}0.8$ for the majority of cloud zones

Past experience: Height-stratified cloud fractions for winter and summer

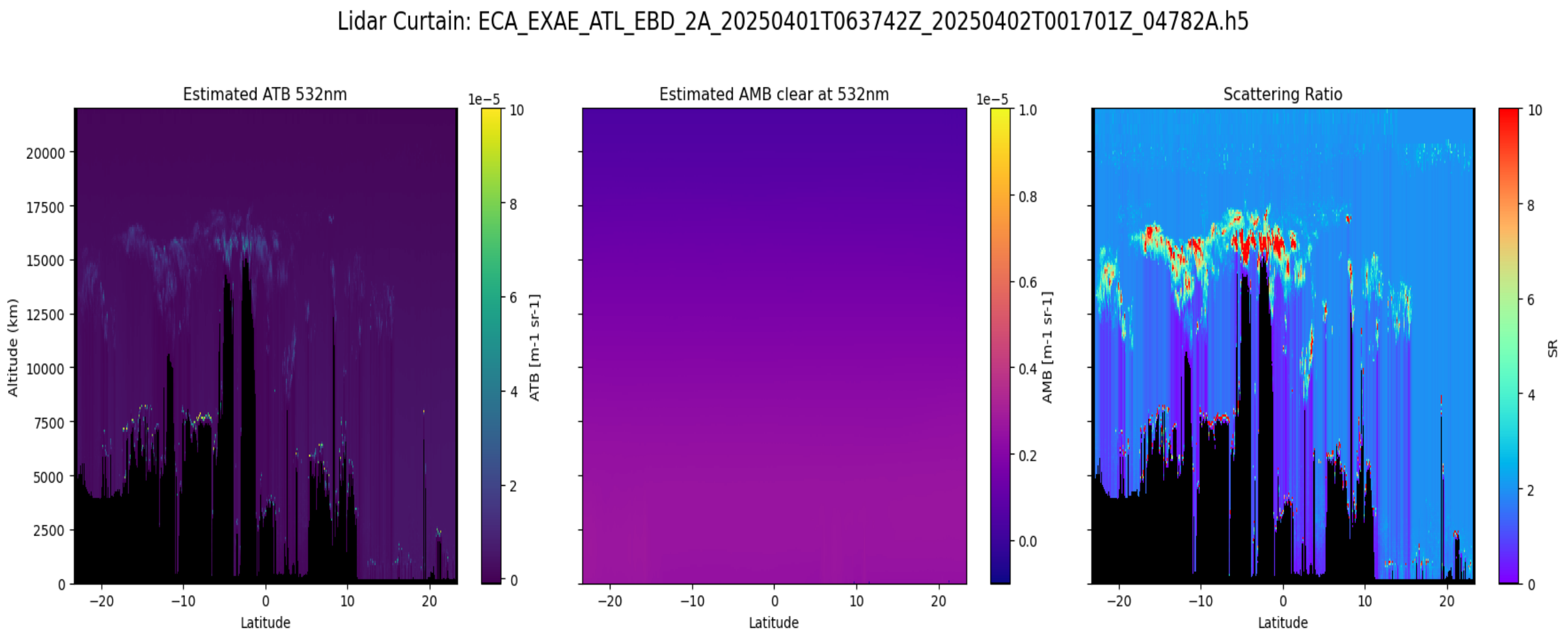
Feofilov et al., SAT, 2024





Converting ATLID measurements to CALIOP-like ones and estimating cloud occurrence

ATLID's L2 data converted to 532nm : ATB_{532}, $AMBclear_{532}$, and SR_{532}



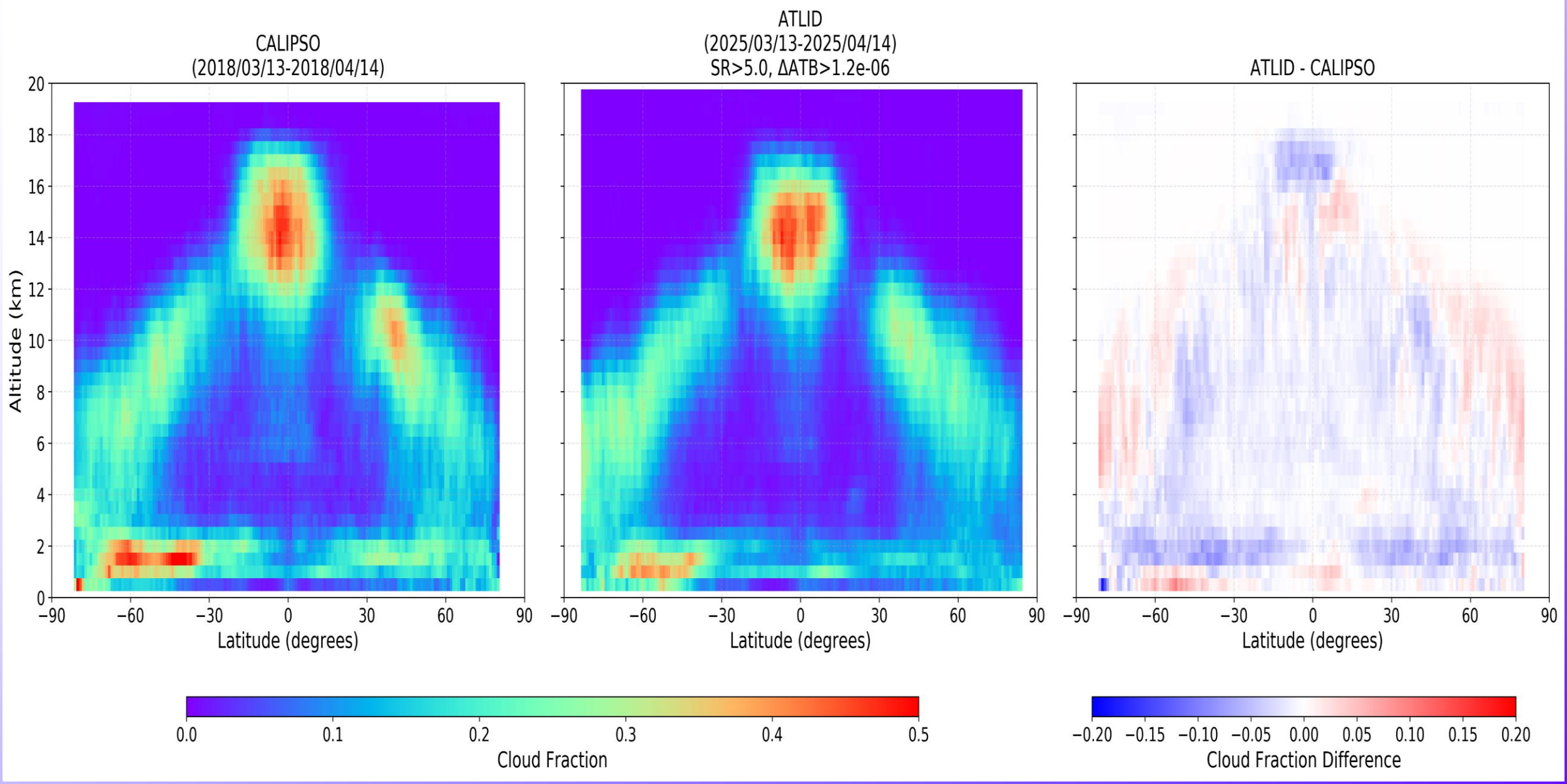
Noise is small and is defined by the backscatter coefficient's noise

Noise-free (theoretical calculation)

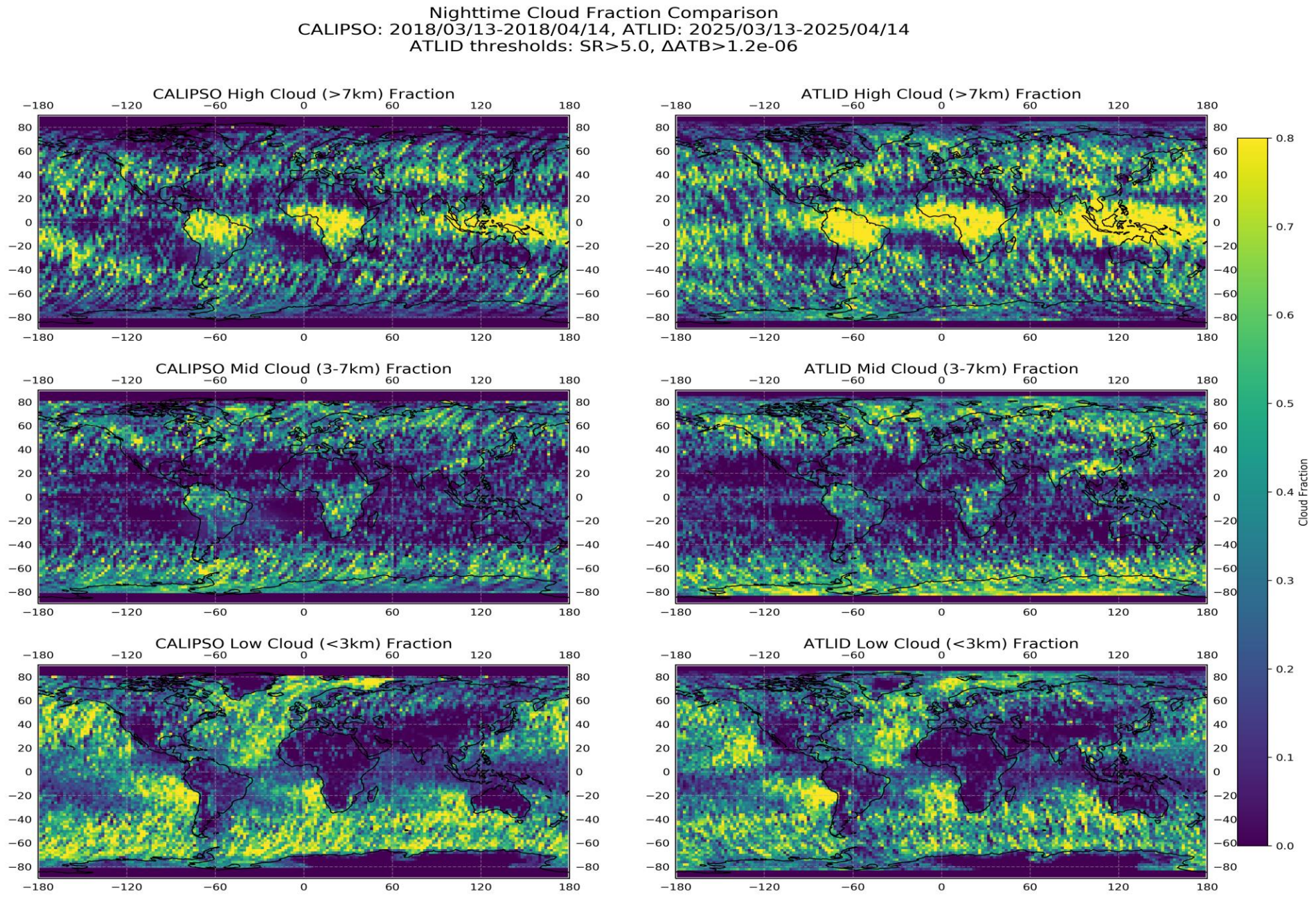
SR is less noisy than APB/AMB

Feofilov et al., AMT, 2023

The first comparison - zonal mean, latitude/altitude cloud fraction

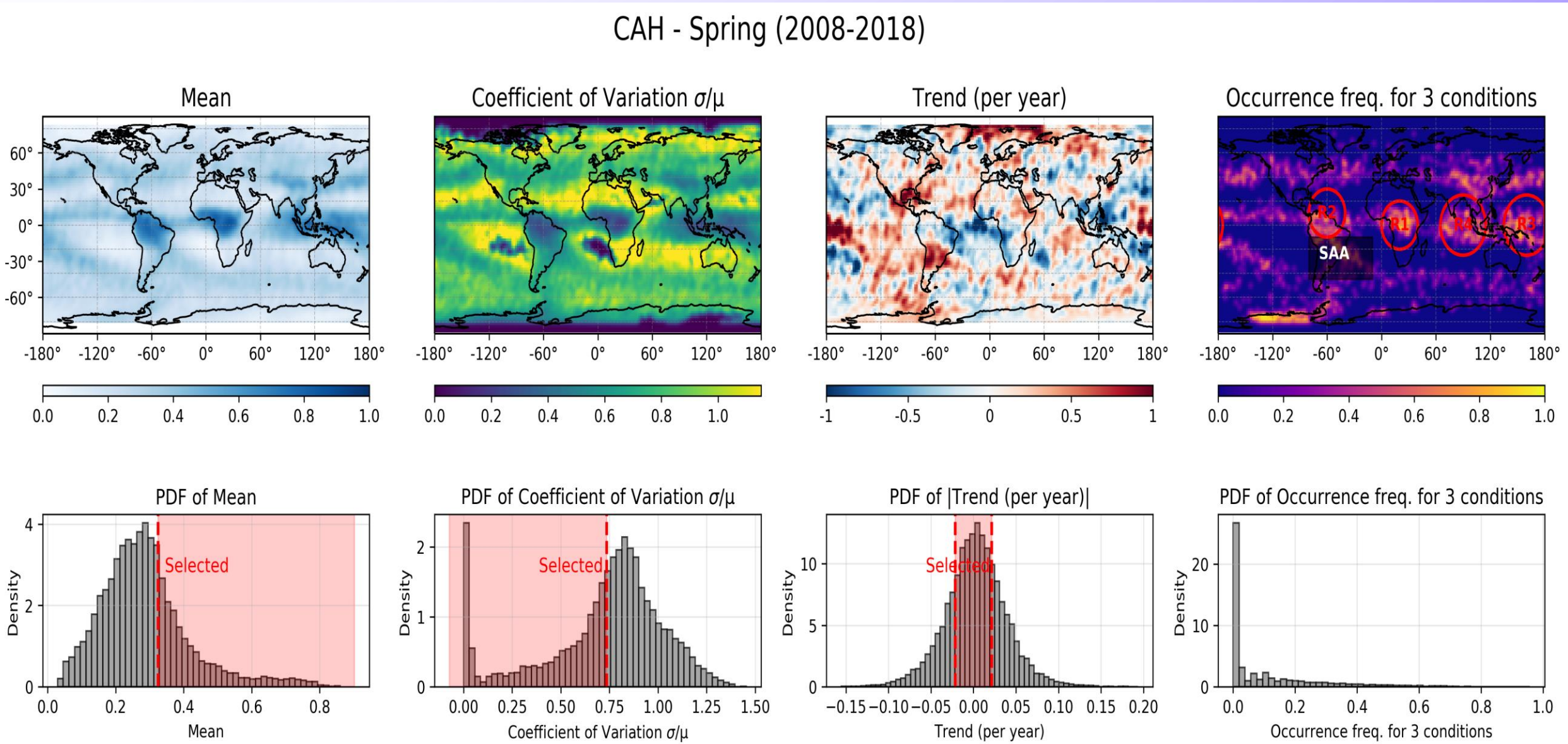


Geographical distribution of high/mid/low clouds

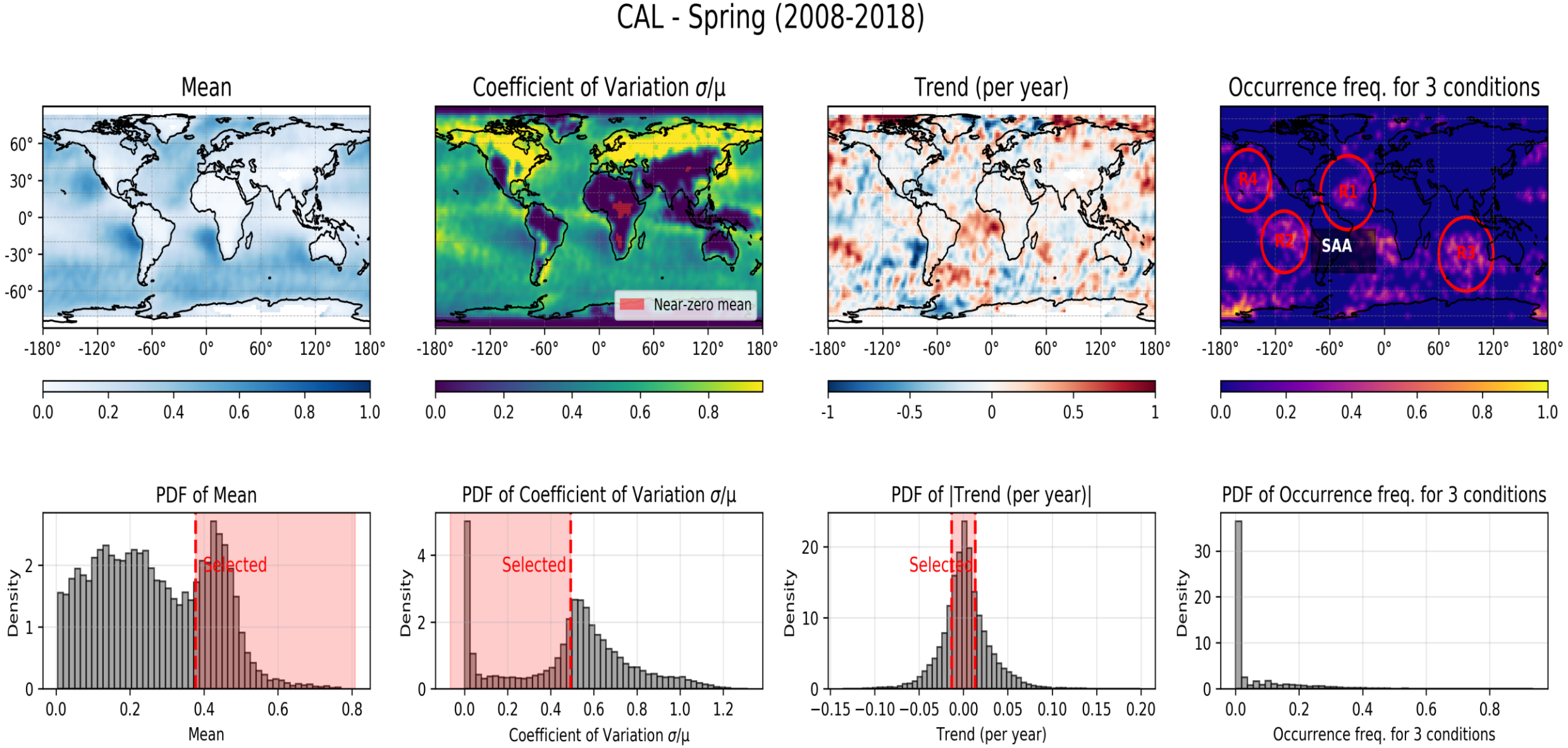


Future steps

Merging ATLID with CALIPSO: 2024-2025 vs 2007-2023**
Choosing the reference zones for high-level clouds (P<440hPa)



Merging ATLID with CALIPSO: 2024-2025 vs 2007-2023**
Choosing the reference zones for low-level clouds (P>680hPa)



Take home messages

- To detect long-term trends in cloud radiative effects and feedbacks, one needs to merge cloud records from several lidars (20+ years for 95% confidence)
- ATLID alone demonstrates excellent sensitivity to clouds and aerosols and low daytime noise, but its clouds are not directly comparable to those of CALIPSO.
- Merging method adapted from ALADIN/Aeolus vs CALIOP/CALIPSO study, which yielded –2%±5% consistency between the mean cloud fields
- The first comparisons are encouraging, but more statistics is needed (a continuous baseline starting from the beginning of the mission)
- Future plans: adding more data, adjusting the detection thresholds, adding IceSat2 lidar for cross-calibration, publishing the joint cloud dataset.