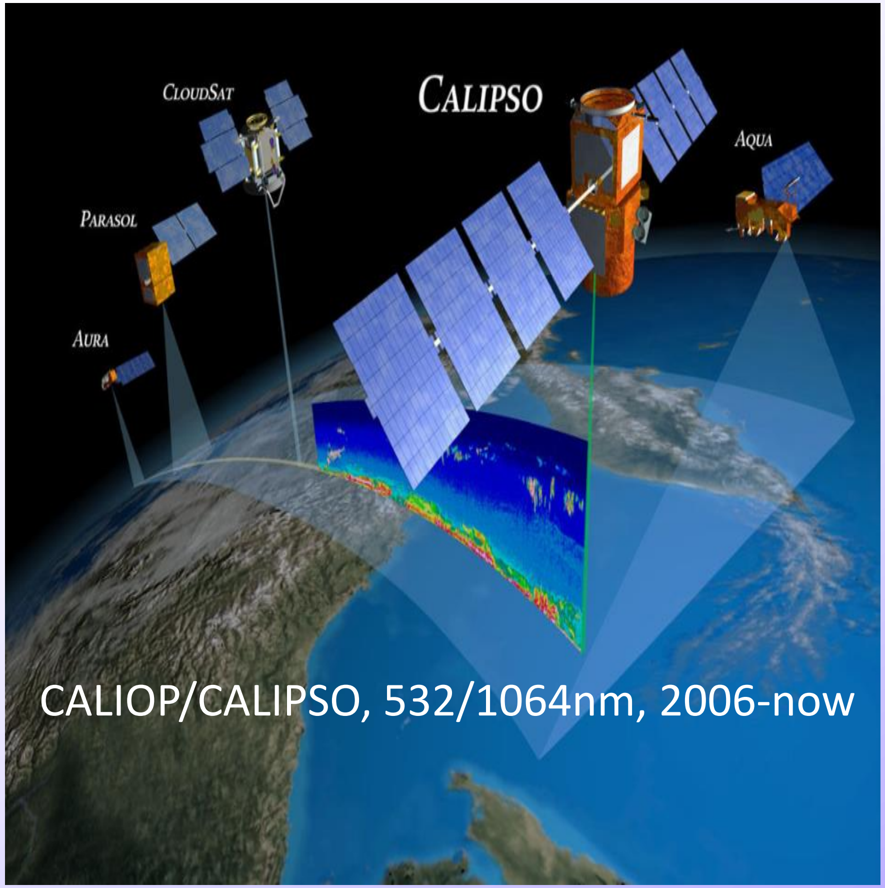
Merging lidar observations into a climate record of cloud profile

Artem Feofilov[1], Helene Chepfer[1],
Vincent Noel[2], and Marjolaine Chiriaco[3]

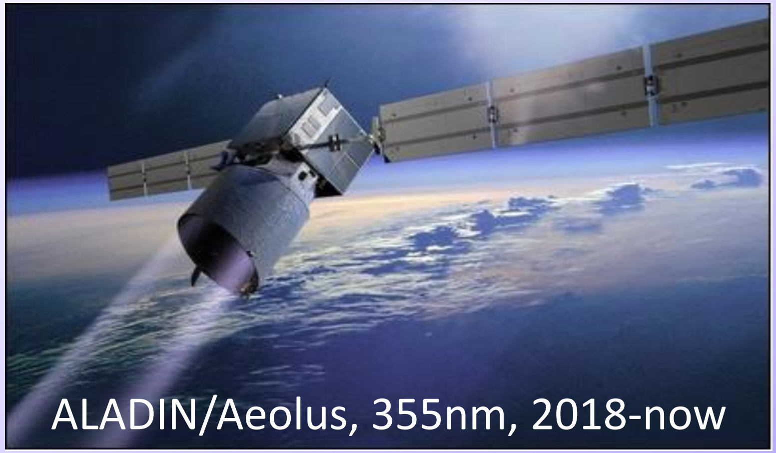
1 – LMD / Sorbonne Université / IPSL / Ecole Polytechnique
2 - Laboratoire d'Aérologie; 3 - LATMOS / OVSQ

EUMETSAT, 23.09.2022, Brussels, Belgium

Continuous cloud record from space-borne lidars



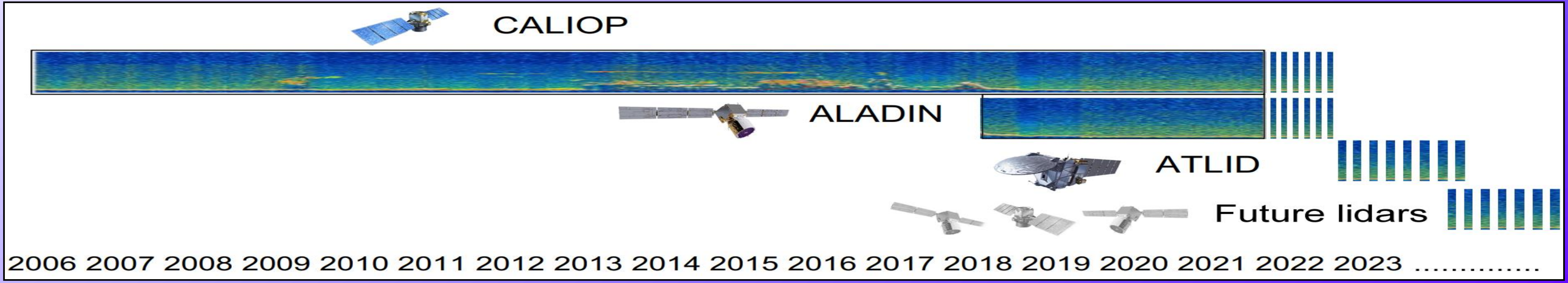
CALIOP/CALIPSO, 532/1064nm, 2006-now


ALADIN/Aeolus, 355nm, 2018-now

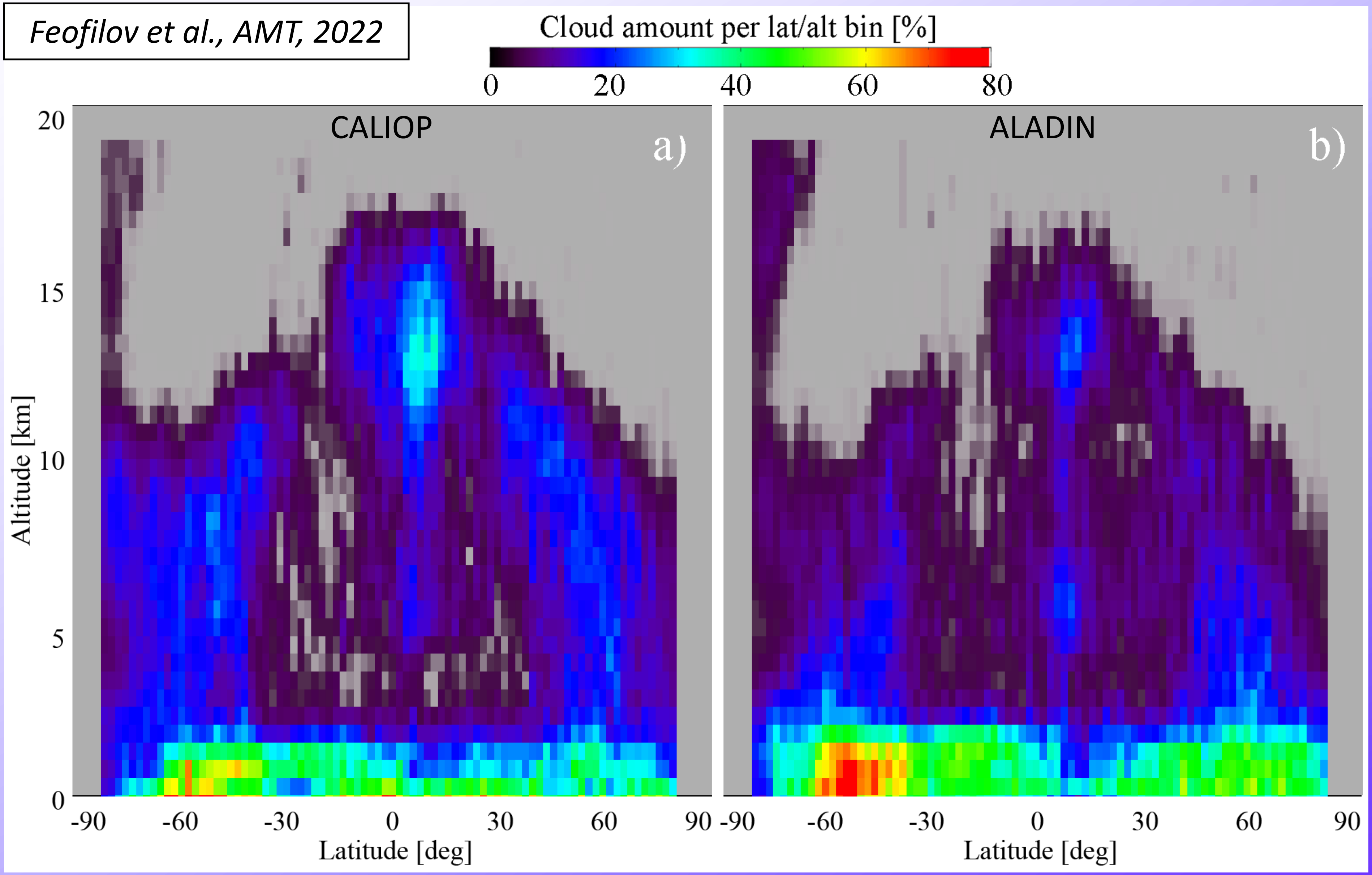

ATLID/EarthCare, 355nm, 2023 (?)

• 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.

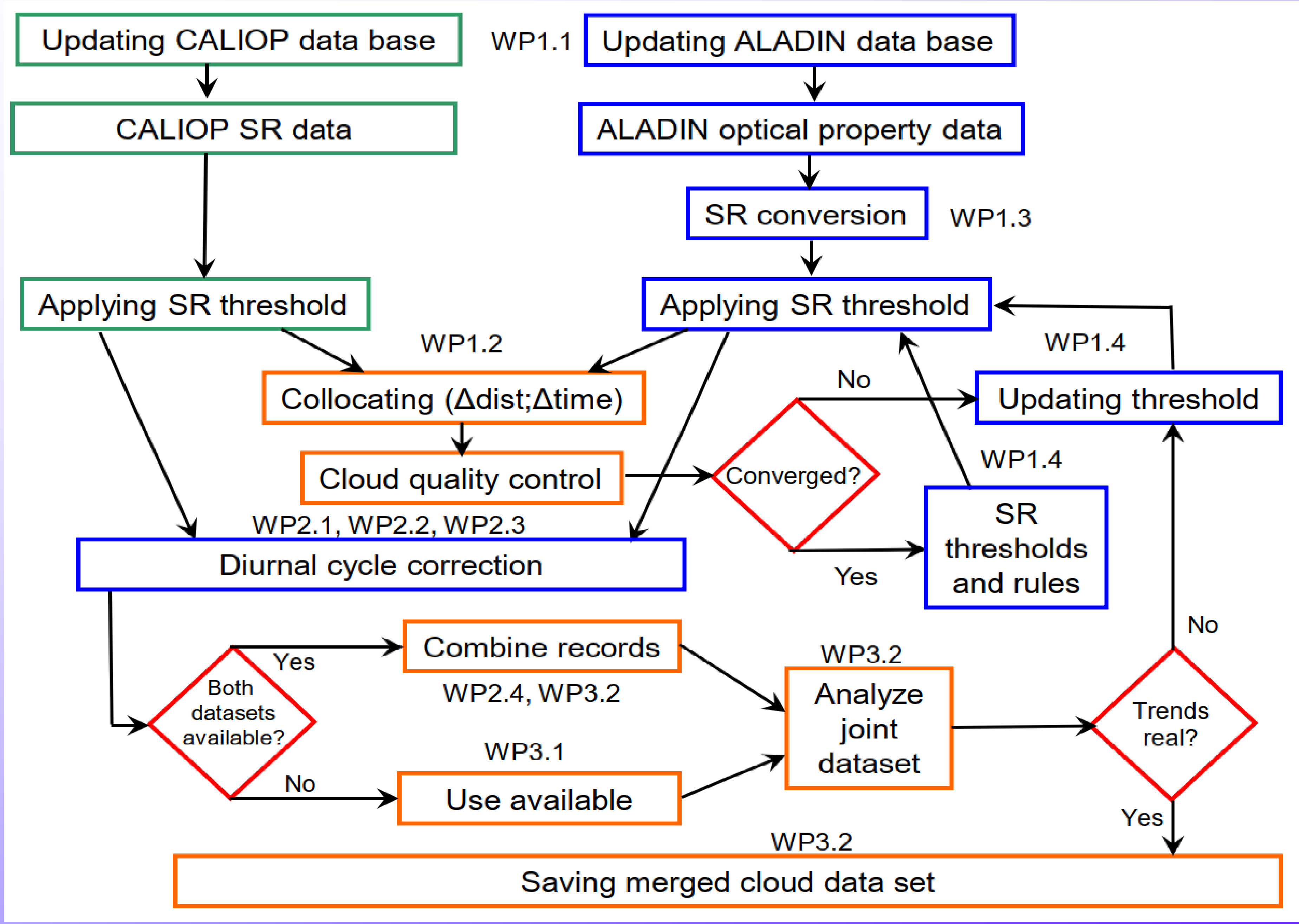


Cloud amount estimated from CALIOP and ALADIN

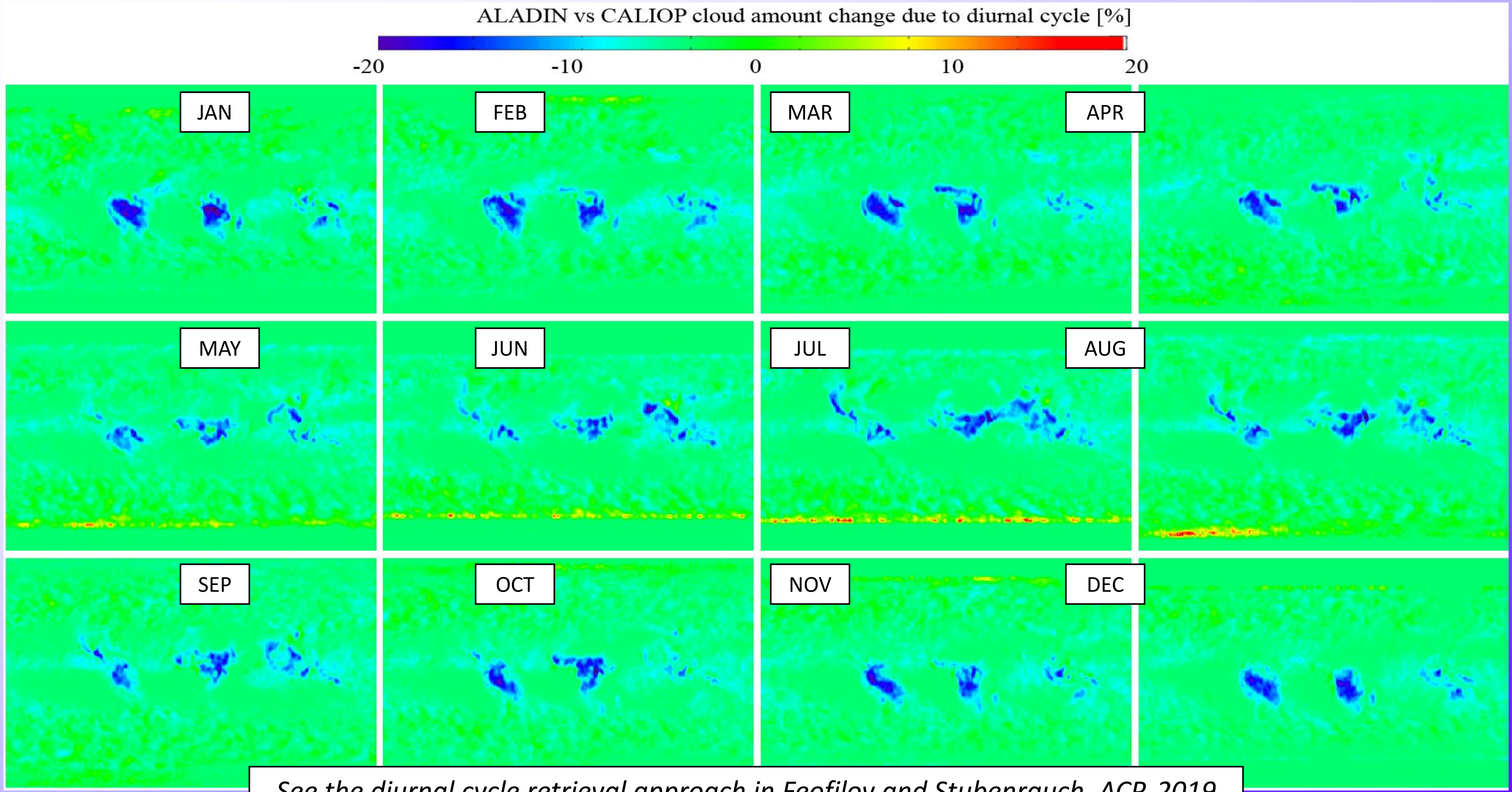


The same cloud detection threshold SR>5 applied to SR profiles
at the same vertical and horizontal resolutions (Chepfer et al. 2013)

Cloud product merging approach (ESA project)

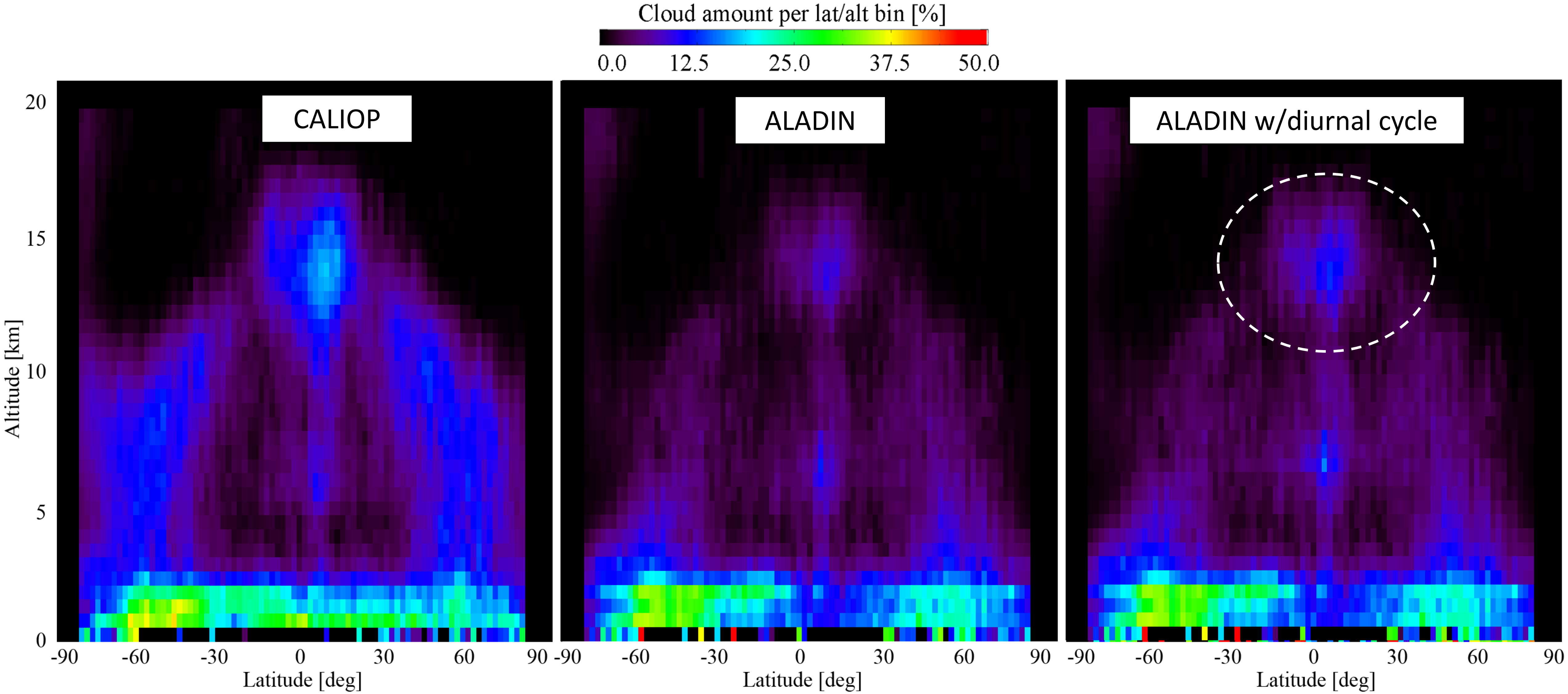


Diurnal cycle amplitude correction for 06:00 vs 01:30 LST



See the diurnal cycle retrieval approach in Feofilov and Stubenrauch, ACP, 2019

Diurnal cycle corrected cloud amounts

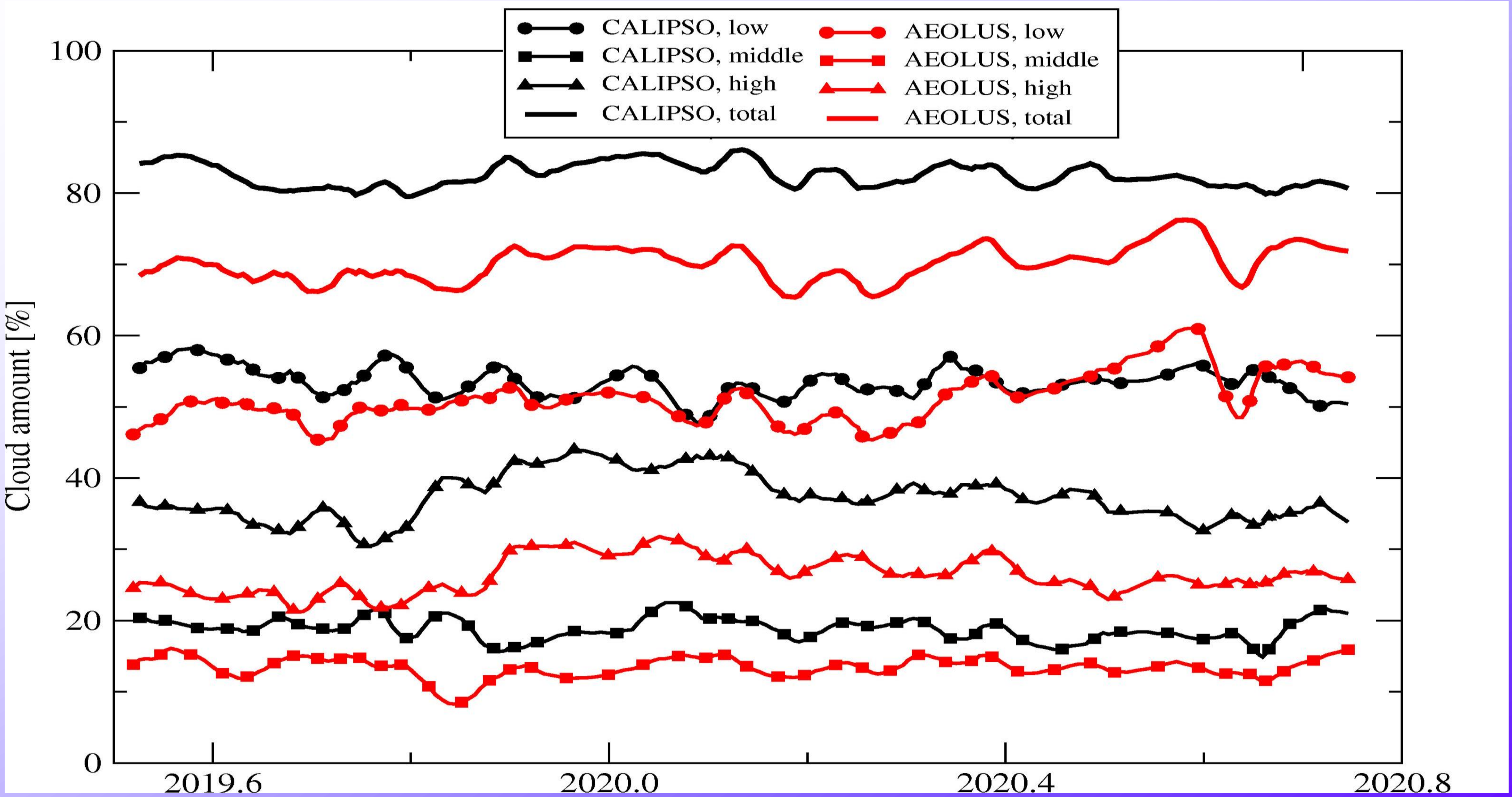


Mean diff = 0.4

Main improvement in tropical area over land

Mean diff = 0.34

Diurnal cycle corrected cloud amounts in the tropics



Accounting for depolarisation effects

ADM-AEOLUS Science Report, 2008

Flamant et al., 2021

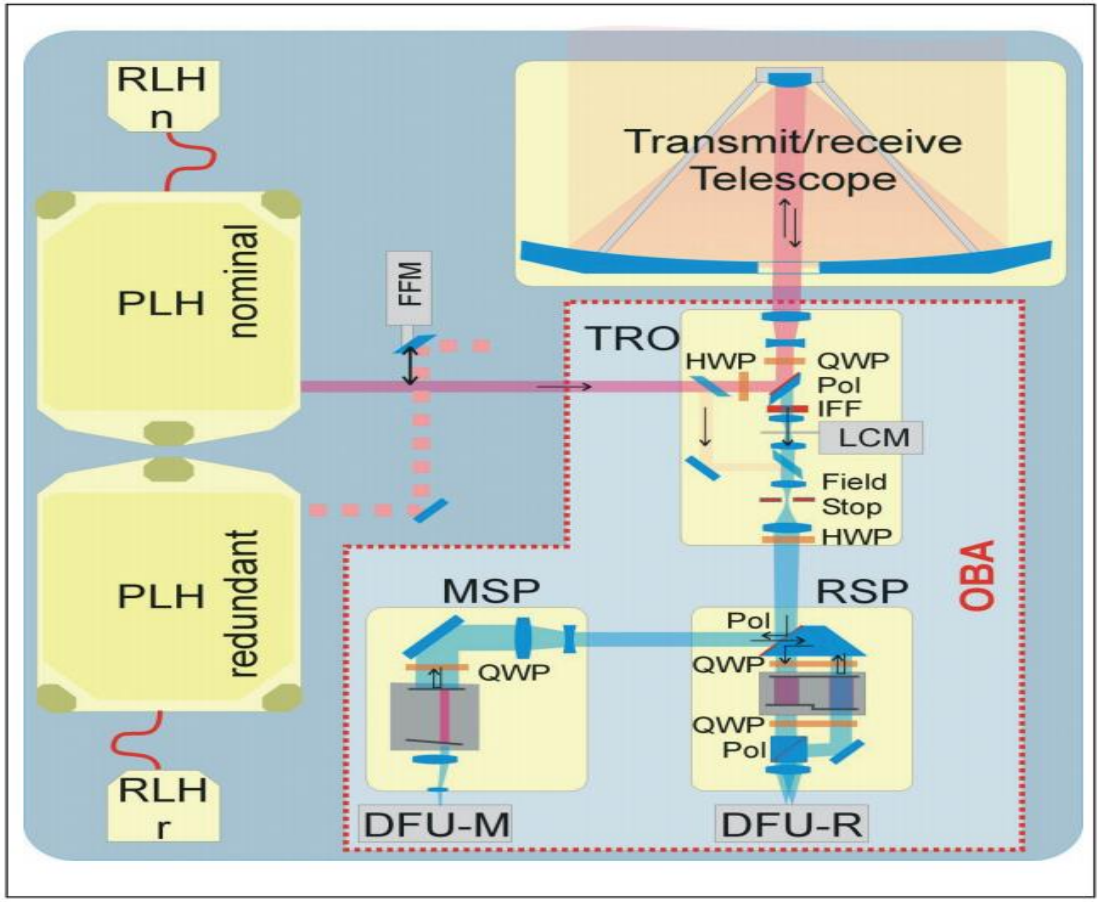


Fig. 4.13. Optical architecture of ALADIN. PLH: Power Laser Head, RLH: Reference Laser Head, FFM: Flip-Flop Mirror, LCM: Laser Chopper Mechanism, TRO: Transmit/Receive Optics, RSP: Rayleigh Spectrometer, DFU: Detection Front-end Unit, QWP: Quarter-Wave Plate, HWP: Half-Wave Plate, Pol: Polariser, IFF: Interference Filter.

3 Known limitations

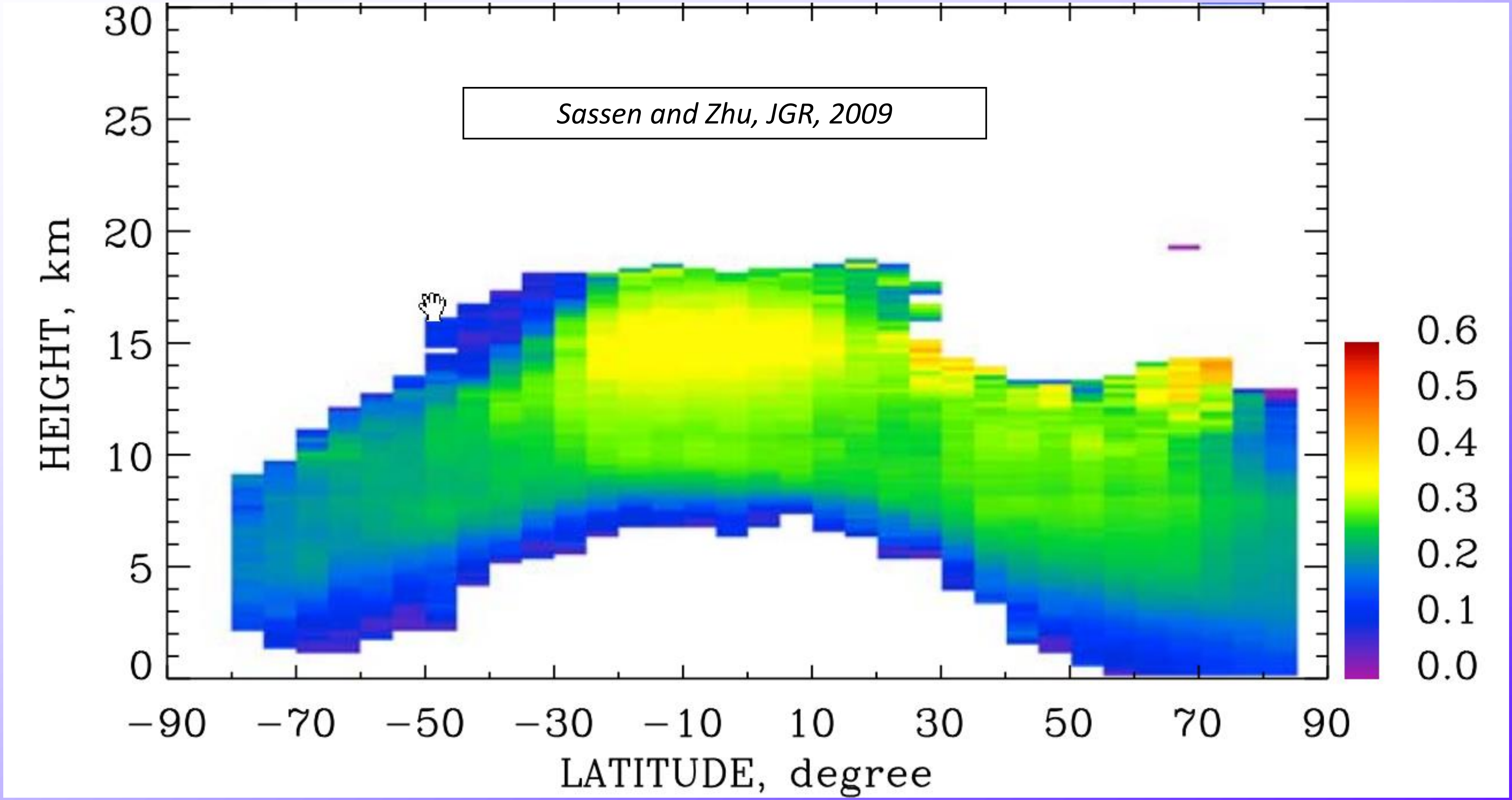
3.1 Instrument limitations

ALADIN was designed primarily for wind determination. The fraction of light sent through the Fizeau interferometer of the Mie channel is smaller than for the Rayleigh channel. The Mie SNR is then lower than the Rayleigh SNR and limits the precision of signals calculated through the cross-talk correction.

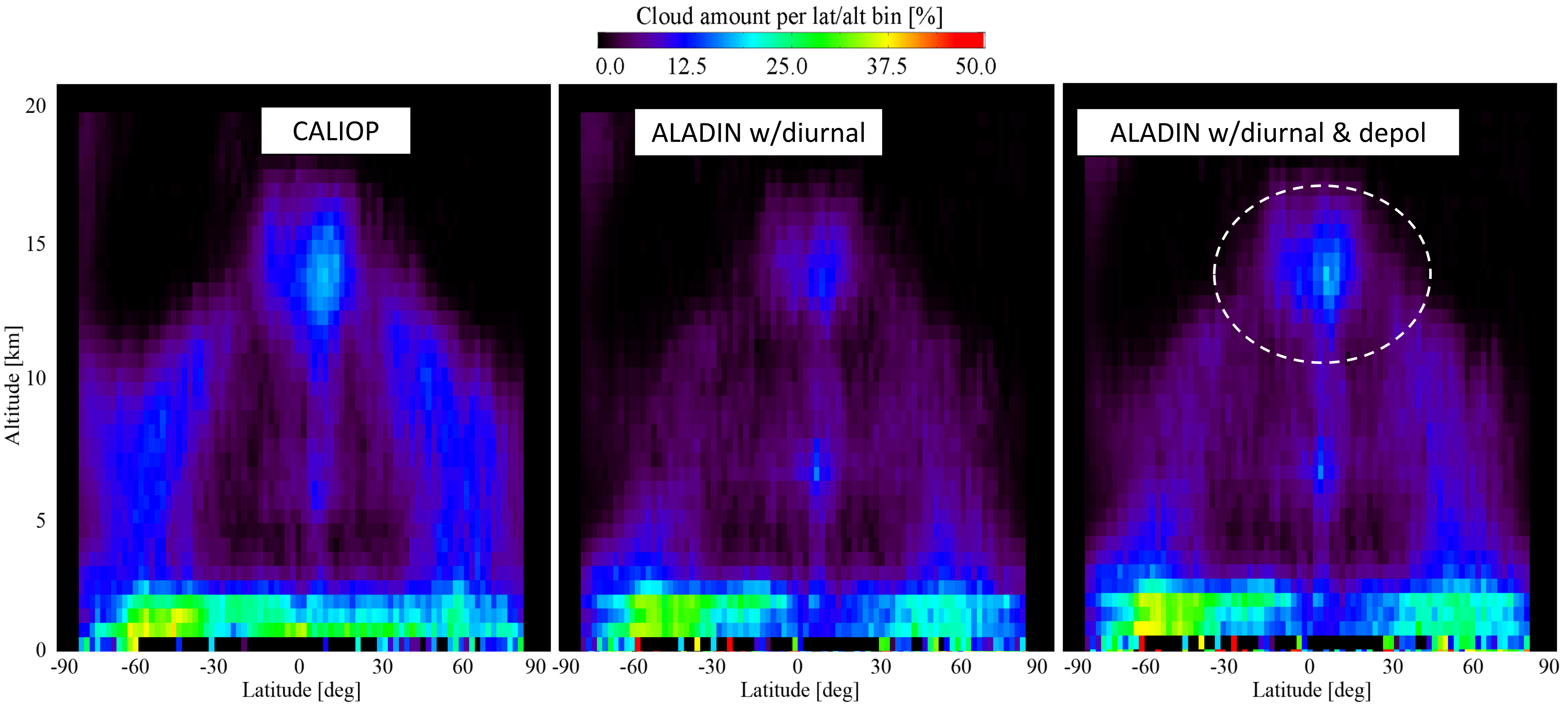
Designed as a wind lidar, ALADIN was not initially aimed at observing aerosol optical properties in detail. Under these requirements, it was not fitted with the ability to measure depolarization. The UV laser beam is linearly polarized at the laser output. It goes through a quarter-wave plate (see Fig. 4.13 in ESA, 2008) before being routed towards the telescope and is thus transmitted towards the atmosphere with a circular polarization. On the way back, backscattered light goes again through the quarter-wave plate. The circularly polarized light that was transmitted might come back elliptically polarized in the case it was backscattered by depolarizing targets. After going through the quarter-wave plate, it becomes a mix of linearly polarized light, either along the same

https://doi.org/10.5194/amt-14-7851-2021

Accounting for depolarisation effects – what to expect



Diurnal cycle- and depolarization-corrected cloud amounts

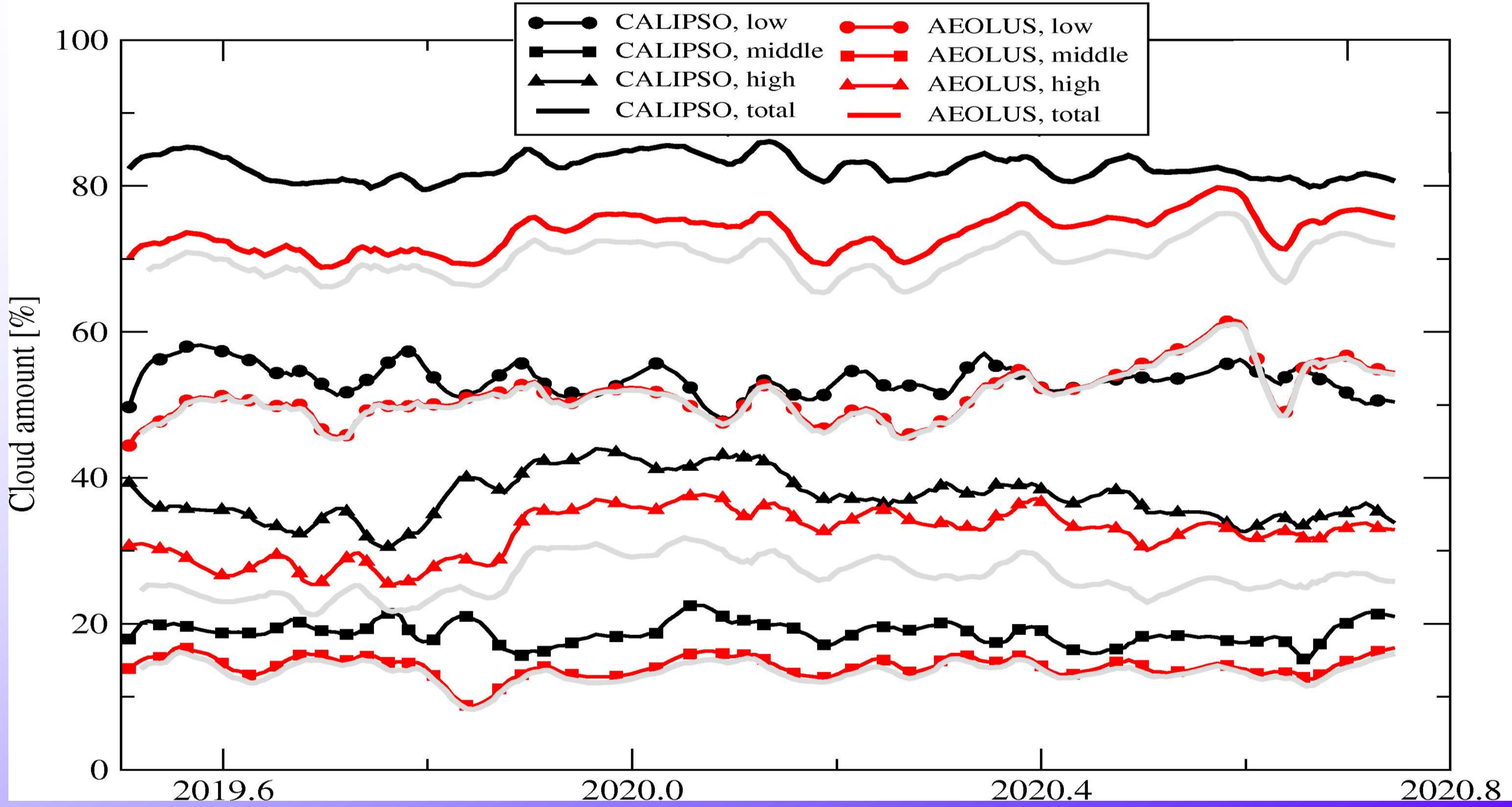


Mean diff=0.34

Main improvement in high clouds !

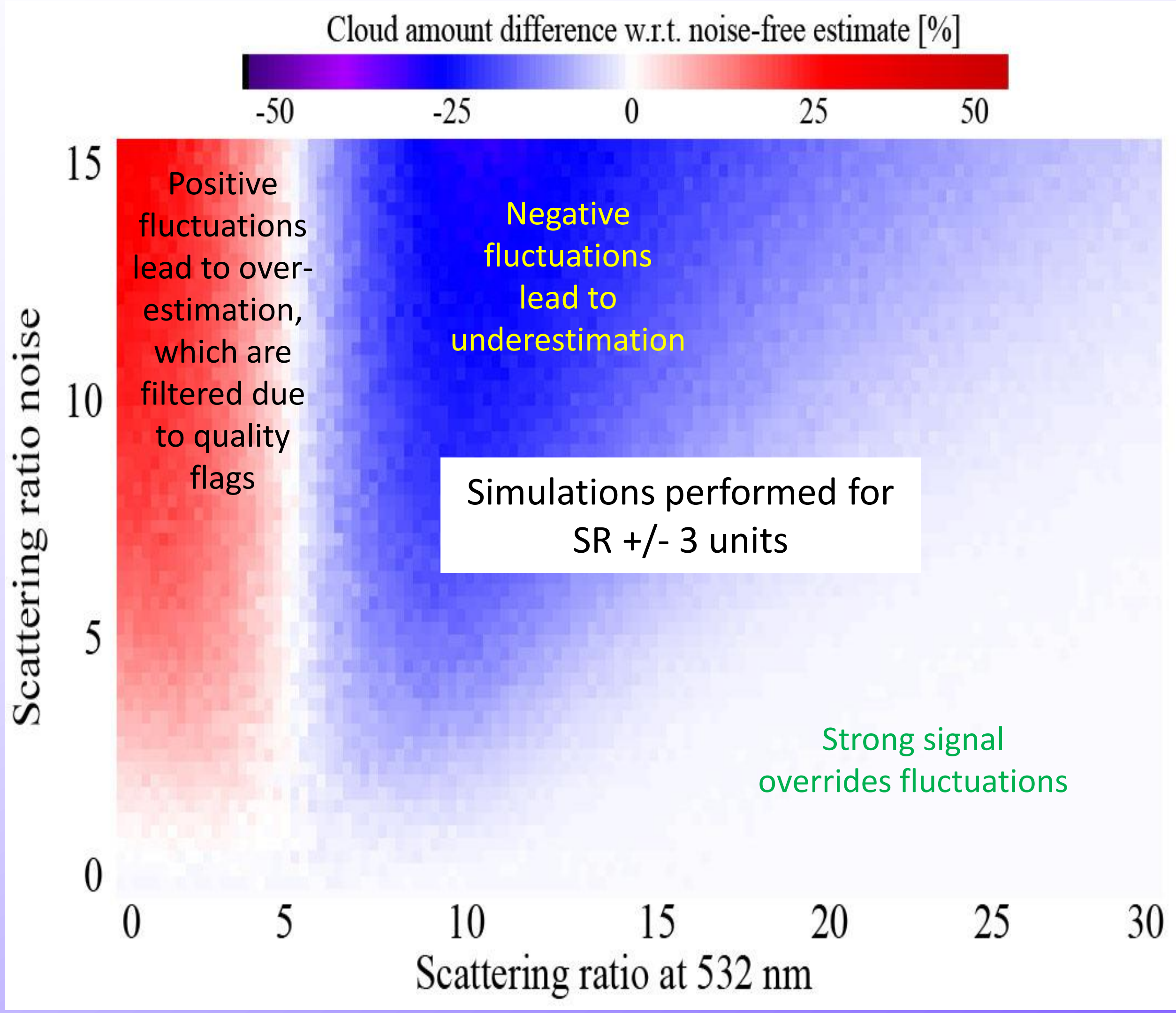
Mean diff = 0.1

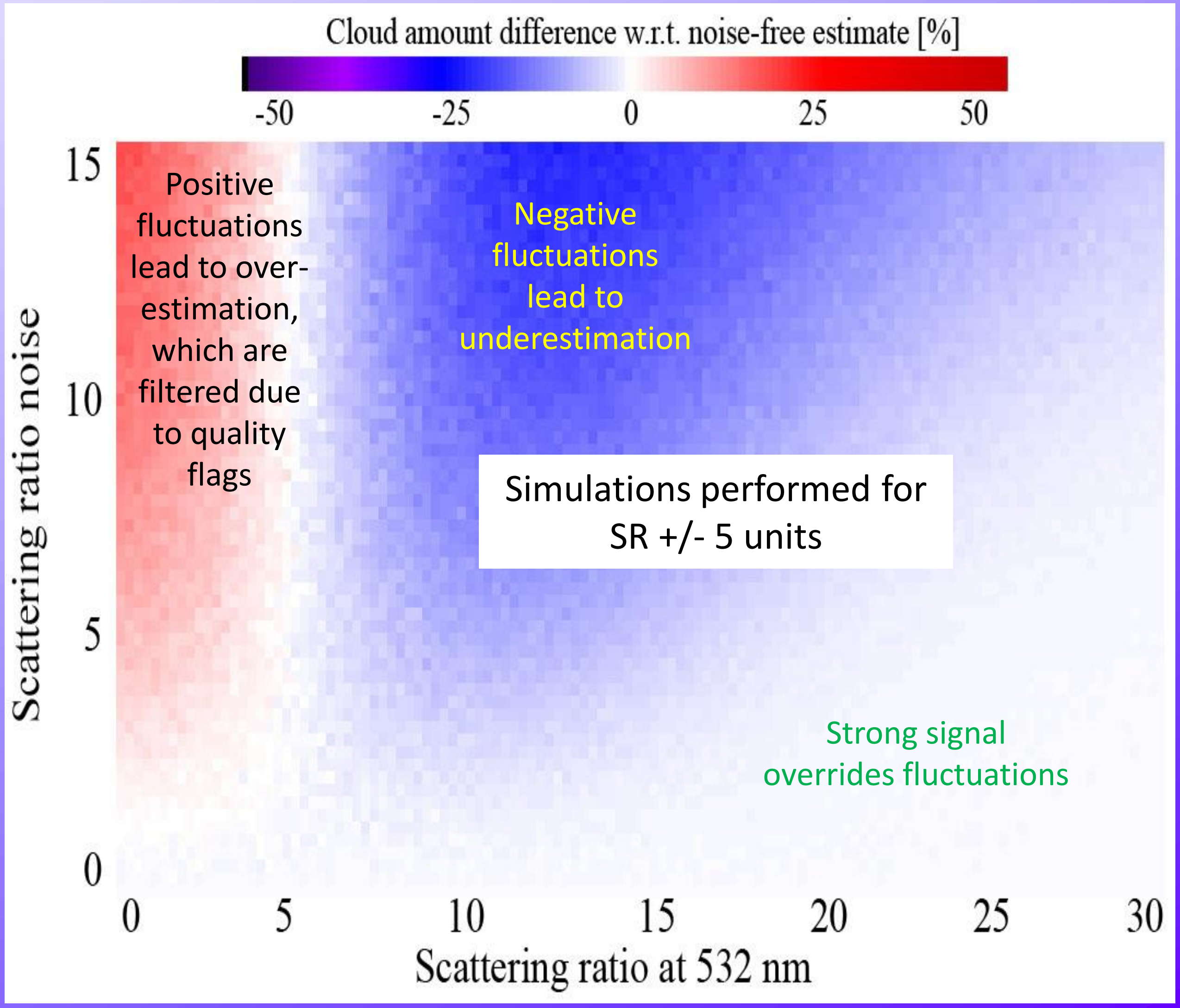
Diurnal cycle- and depolarization-corrected cloud amounts in the tropics



Accounting for detection bias caused by noise

- Each atmospheric object varies along the satellite's track (Gaussian distribution)
- Measured backscattered signal passes through a number of conversion stages (Poissonian noise)
- Applying the threshold to their superposition might skew the mean value





Compensating for depolarized radiance in absence of CALIPSO?

ALADIN L2A algorithm retrieves particle backscatter and extinction at 355nm, whereas we want to compare the clouds estimated from scattering ratio at 532nm

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

Scattering ratio definition

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

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 absence of particles

$$\beta_{mol}(\lambda, z) = (d\sigma/d\Omega)_\lambda \times N(z);\; \alpha_{mol}(\lambda, z) = \frac{4\pi}{1.5}\beta_{mol}(\lambda, z)$$

$$(d\sigma/d\Omega)_\lambda = \frac{\sigma(\lambda,z)}{4\pi} \times \frac{3}{4}(1 + cos^2(\pi))$$

$$\sigma(\lambda, z) = \frac{24\pi^3(n_s^2(\lambda)-1)^2(6+3\rho(\lambda))}{\lambda^4 N_s^2(n_s^2(\lambda)+2)^2(6-7\rho(\lambda))}$$

Calculating molecular backscatter and extinction coefficients

$$\alpha_{part}(355\text{nm}, z) \approx \alpha_{part}(532\text{nm}, z) \qquad \beta_{part}(355\text{nm}, z) \approx \beta_{part}(532\text{nm}, z)$$

x 1/(1-depol_ratio) estimated from what?

$$SR(532nm, z) > 5$$

Threshold is applied to “native” and converted SR values

Feofilov et al., 2022

Take home messages

- To detect long-term trends in cloud radiative effects and feedbacks, one needs to merge cloud records from several lidars.

- The merging procedure should take into account the diurnal cycle, wavelength differences, observation geometry and averaging effects.

- Compensating for diurnal cycle effects using AIRS/IASI improves the agreement between CALIOP and ALADIN over land where the difference in cloud amount is up to 20%.

- Compensating for depolarization effects **significantly** improves the agreement in high clouds

- The remaining difference might be explained by cloud detection bias caused by noise – to be studied starting from L1 signals → error propagation → SR noise → compensation coefficient.

- For the future - compensation for depolarized radiance in the absence of CALIOP will require ancillary data