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Achieving consistency in global cloud dataset retrieved from ALADIN/Aeolus and CALIOP/CALIPSO spaceborne lidars

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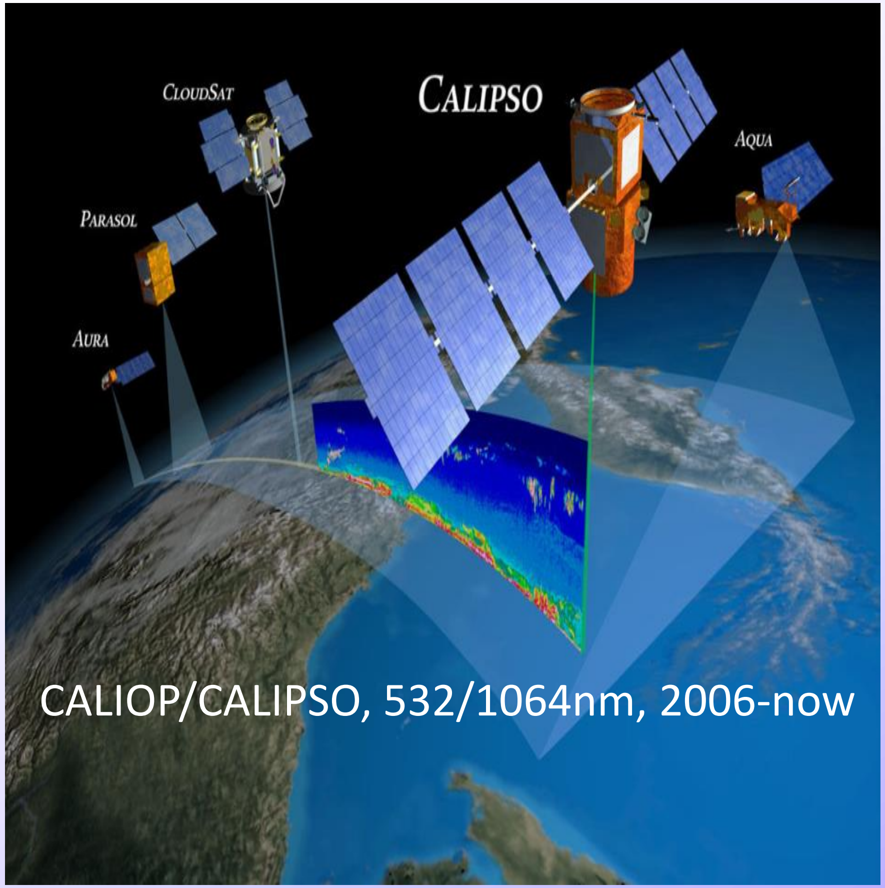
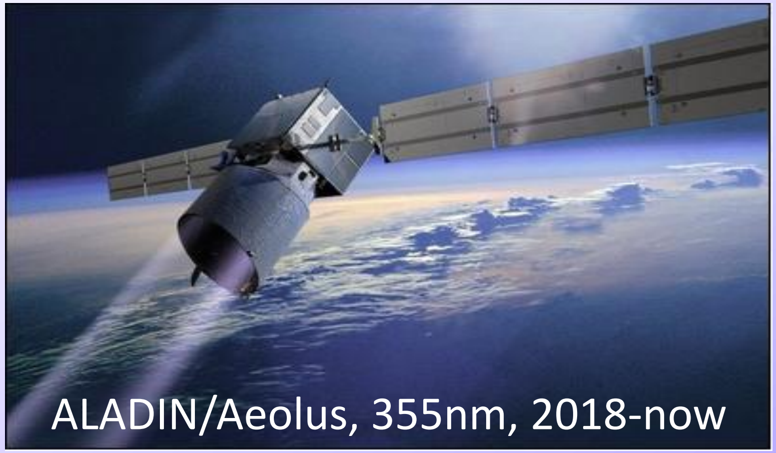
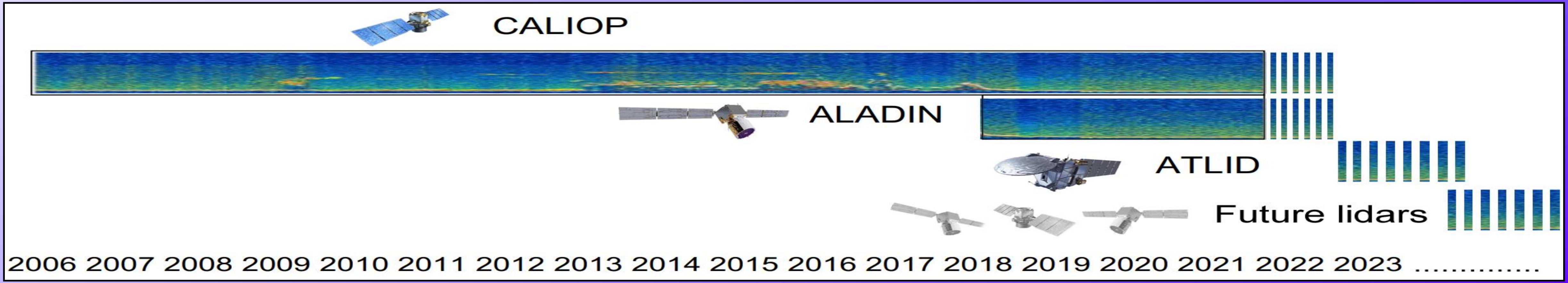
Continuous cloud record from space-borne lidars





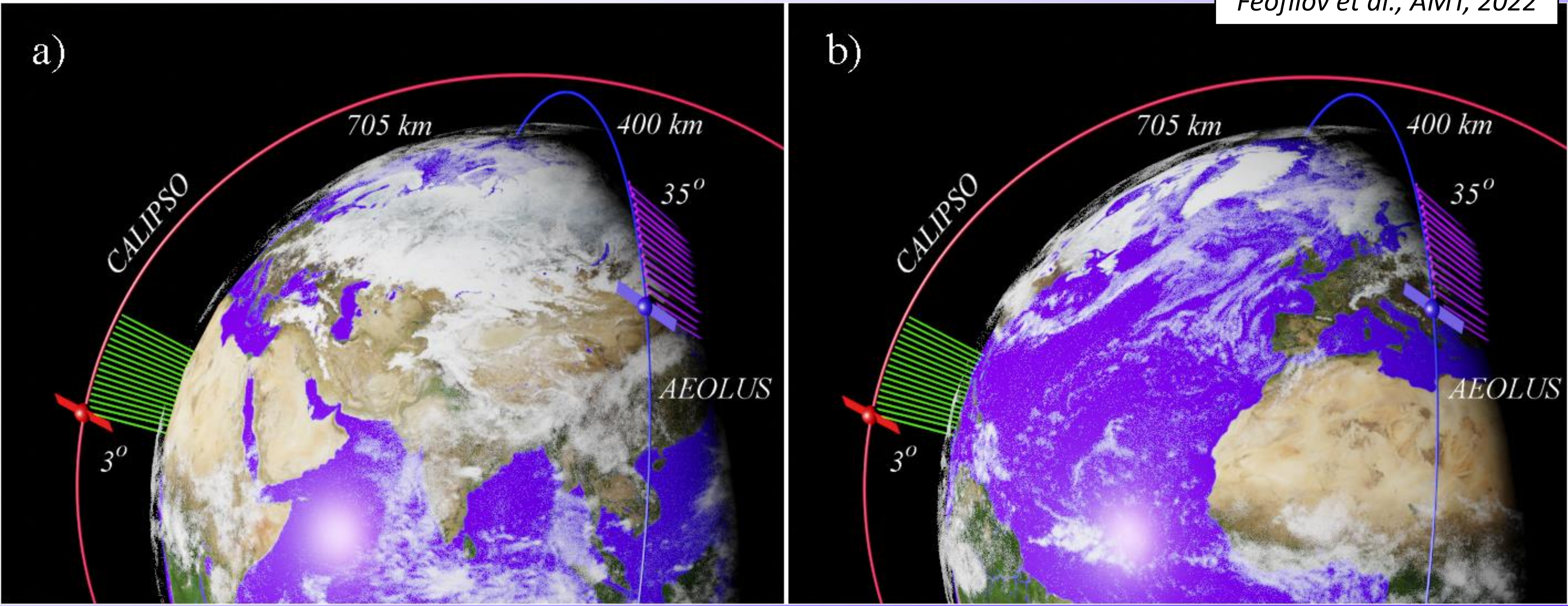
- General principle is the same: polar orbit, 15 tracks per day, sounding radiation is sent downwards, the backscattered signal is sampled and interpreted.

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



Differences between CALIPSO and AEOLUS

Feofilov et al., AMT, 2022



Observation geometry and orbits of ALADIN/Aeolus and CALIOP/CALIPSO space borne lidars. ALADIN observes the atmosphere at dawn-dusk, whereas CALIOP passes the equator at 01:30 and 13:30 local solar time. The difference between (a) and (b) panels is in the position of Earth and the time: in (b), AEOLUS overflies the same area (centered over Africa) as was observed by CALIOP ~4.5 h earlier (in (a)).

Step # 1 – compensating for wavelength difference and defining a CALIOP-like cloud

Compensating for wavelength difference

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

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

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

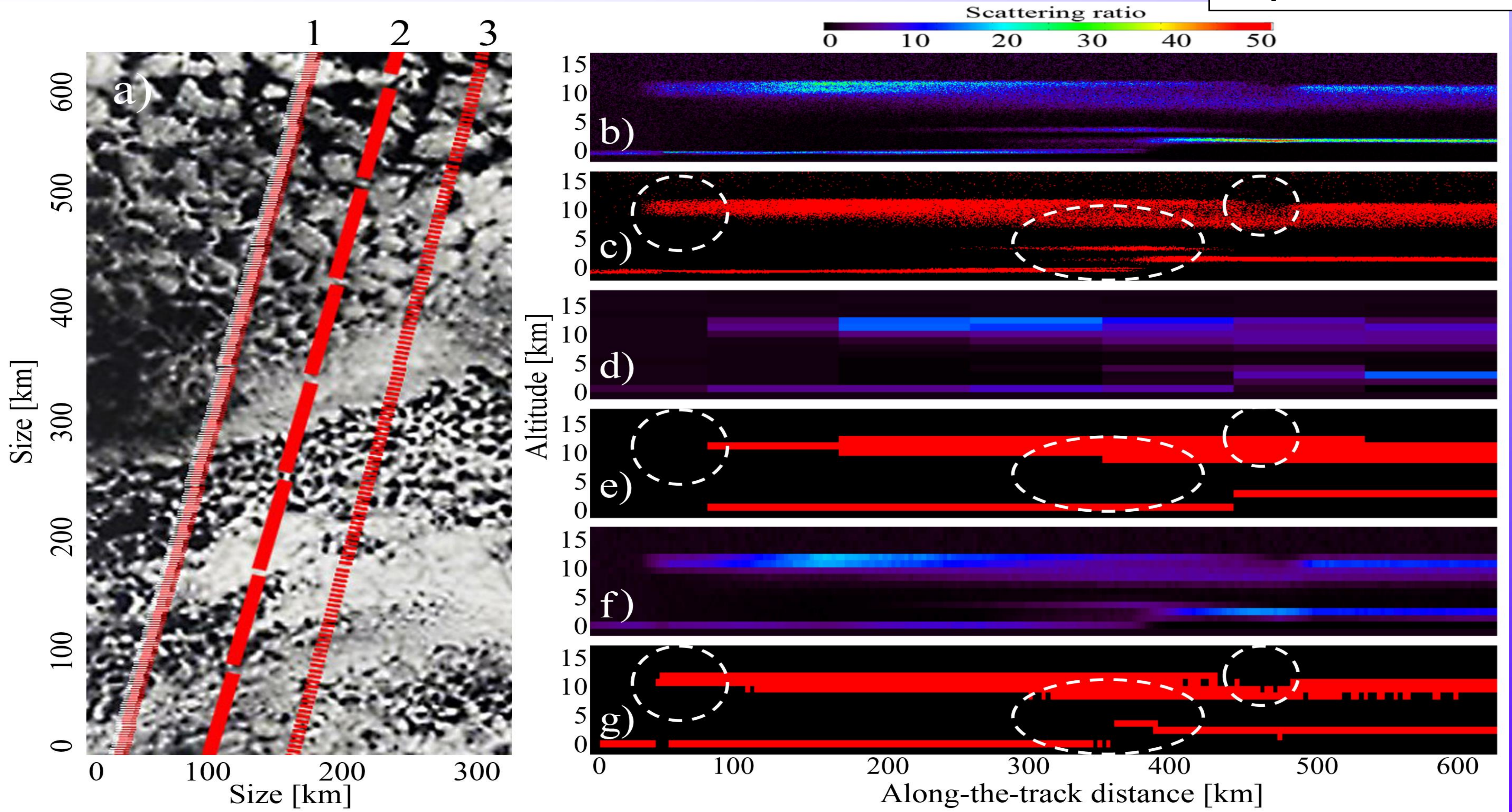
Threshold is applied to “native” and converted SR values

Feofilov et al., 2022

Step # 2 – compensating for averaging effects

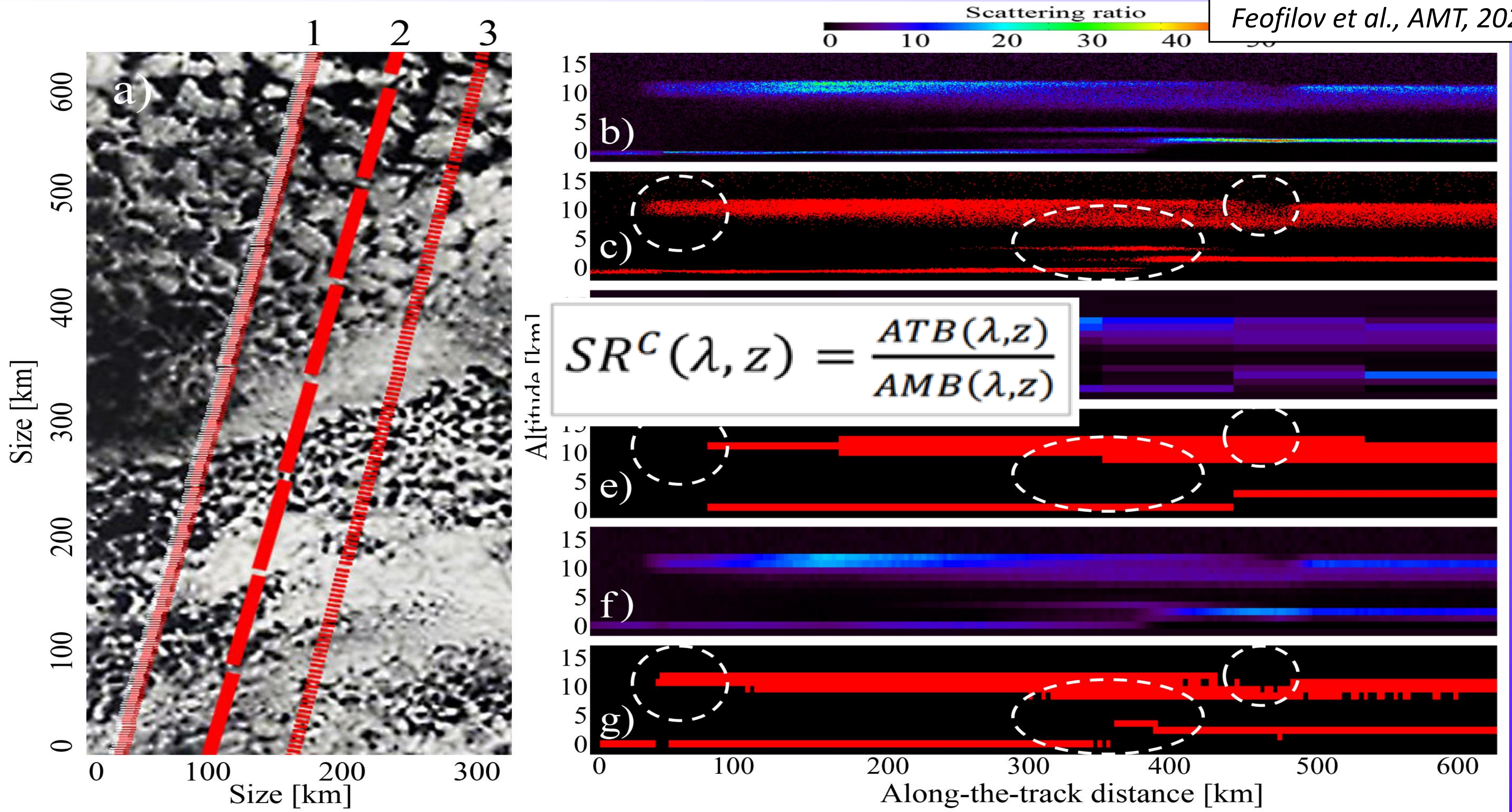
Differences associated with averaging

Feofilov et al., AMT, 2022



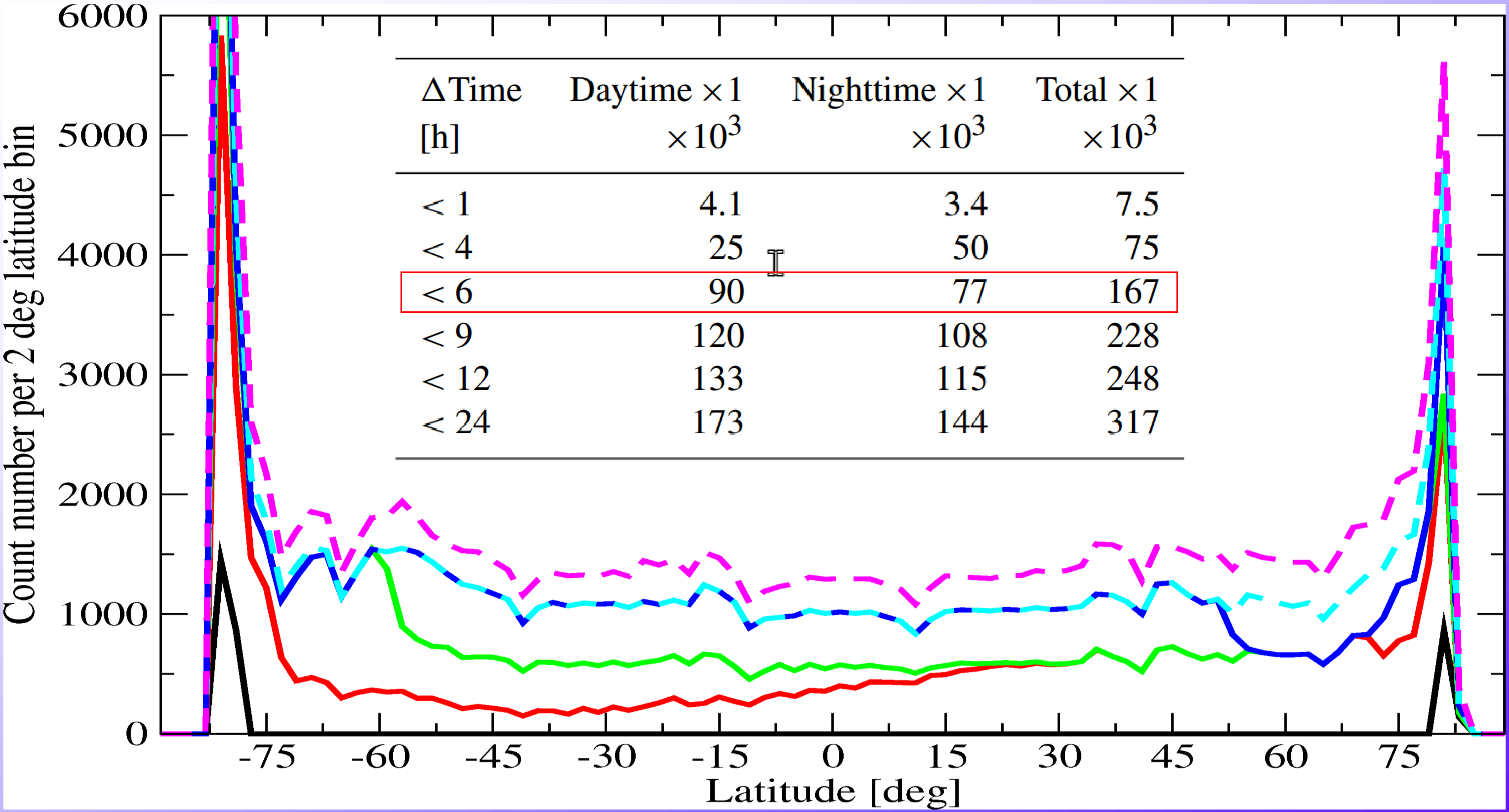
Degrading CALIOP requires recalculation of SR

Feofilov et al., AMT, 2022



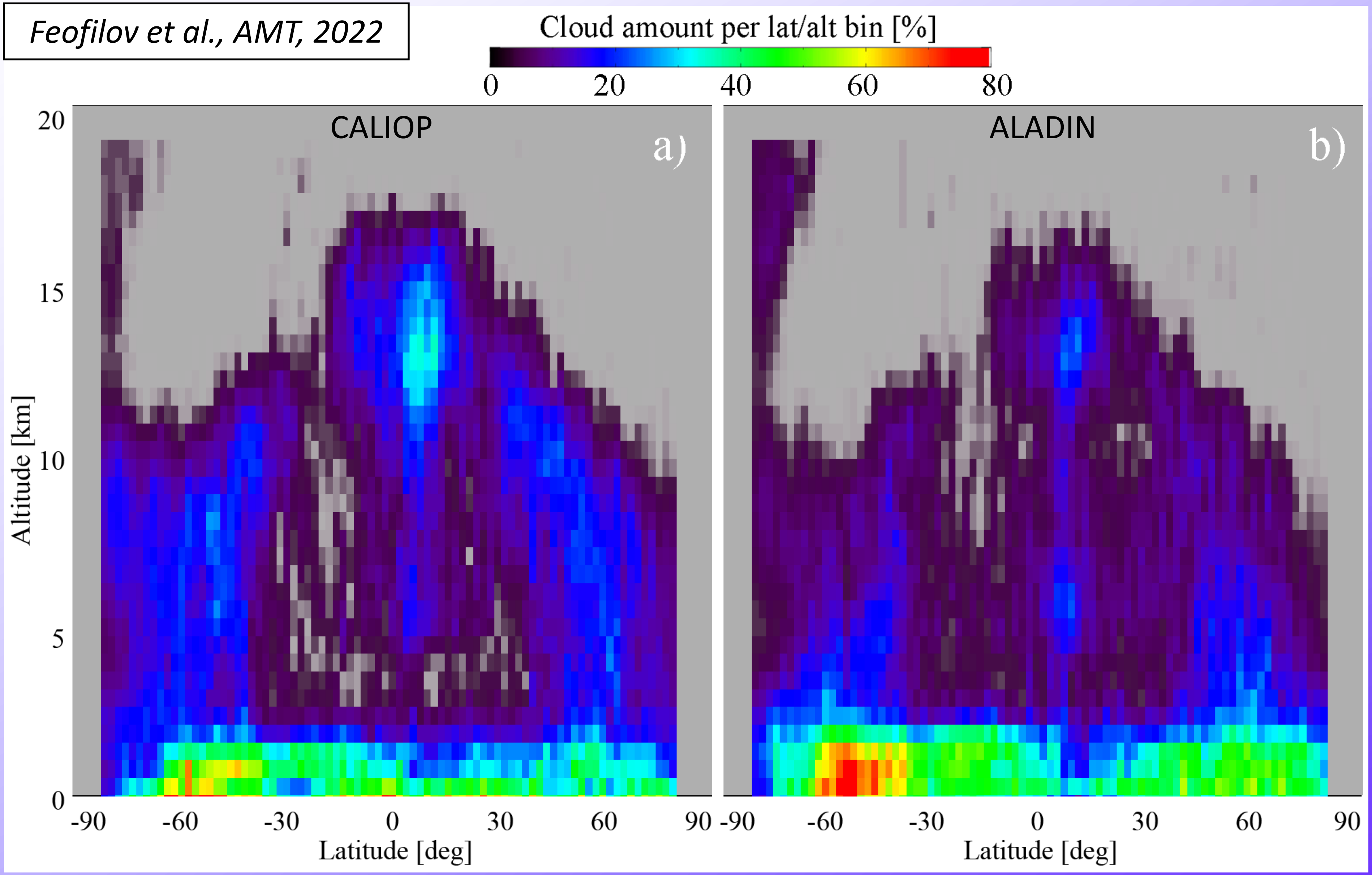
$$SR^{C}(\lambda, z) = \frac{ATB(\lambda,z)}{AMB(\lambda,z)}$$

Colocated dataset used in the study



ΔTime [h]	Daytime $\times 1 \times 10^3$	Nighttime $\times 1 \times 10^3$	Total $\times 1 \times 10^3$
< 1	4.1	3.4	7.5
< 4	25	50	75
< 6	90	77	167
< 9	120	108	228
< 12	133	115	248
< 24	173	144	317

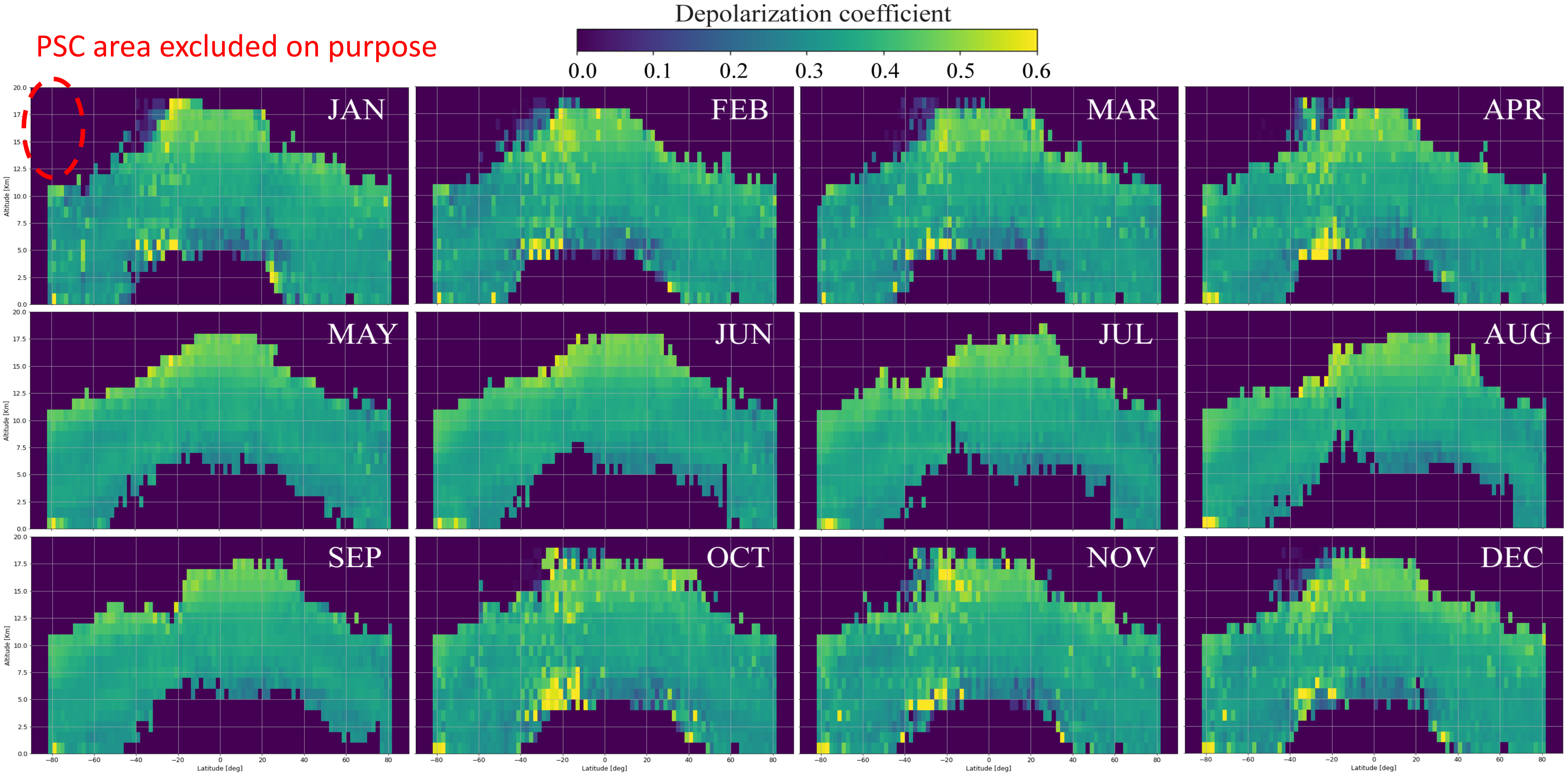
Cloud amount from CALIOP and ALADIN, only λ and resolution



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

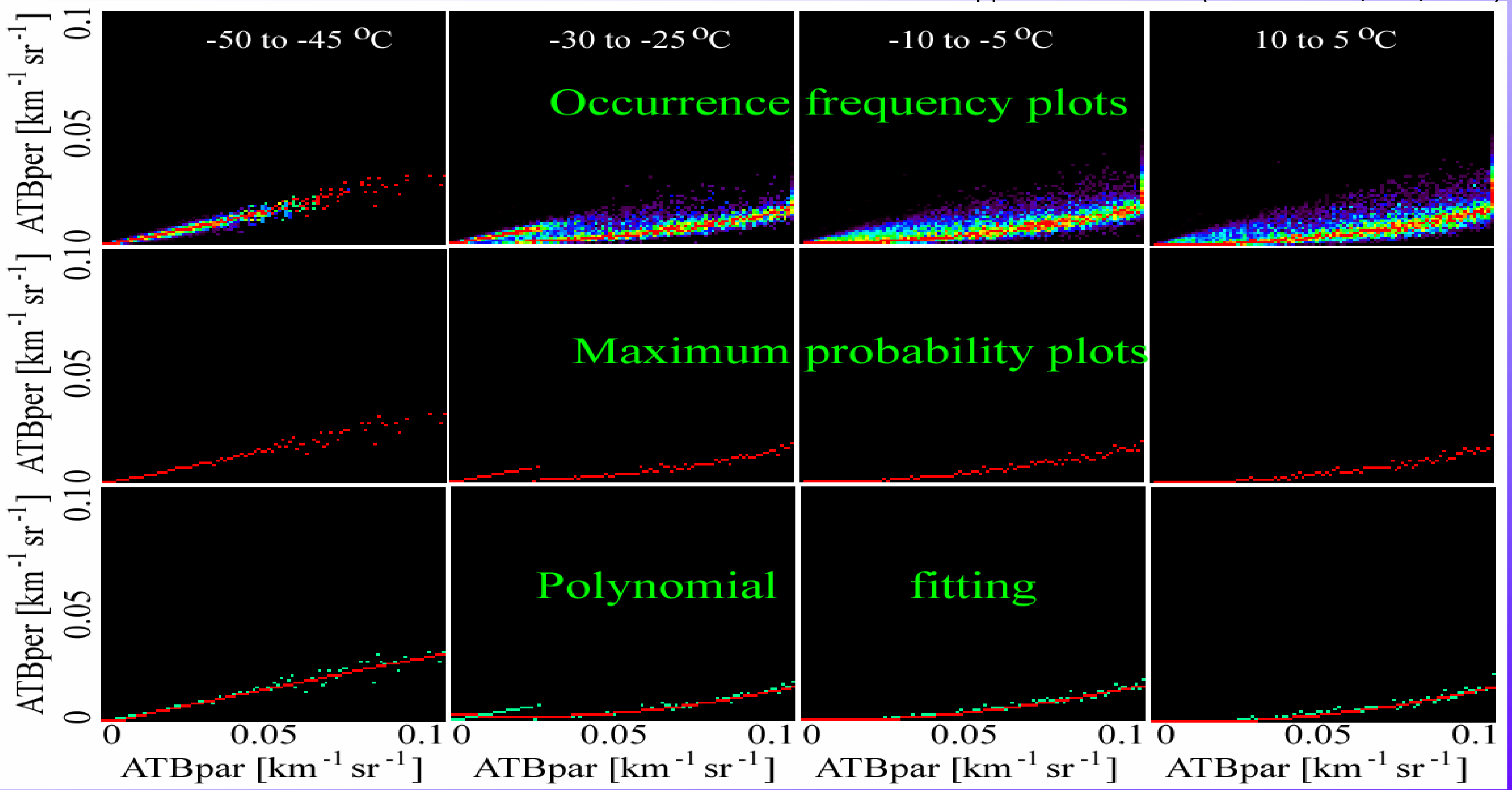
Step # 3 – compensating for missing perpendicular component

Accounting for depolarisation effects – climatology δ(month, lat, Z)



Parameterizing the ATB$_\perp$ vs T and ATB$_\parallel$

Approach similar to (Cesana et al., JGR, 2013)



Layer-by-layer fixing the extinction and backscatter coefficients

$$\alpha_{part}(z_i) = \alpha_{part}^{source}(z_i)\frac{1+\delta(z_i)}{\vartheta(z_i)} \; ; \qquad \beta_{part}(z_i) = \beta_{part}^{source}(z_i)\frac{1+\delta(z_i)}{\vartheta(z_i)}$$

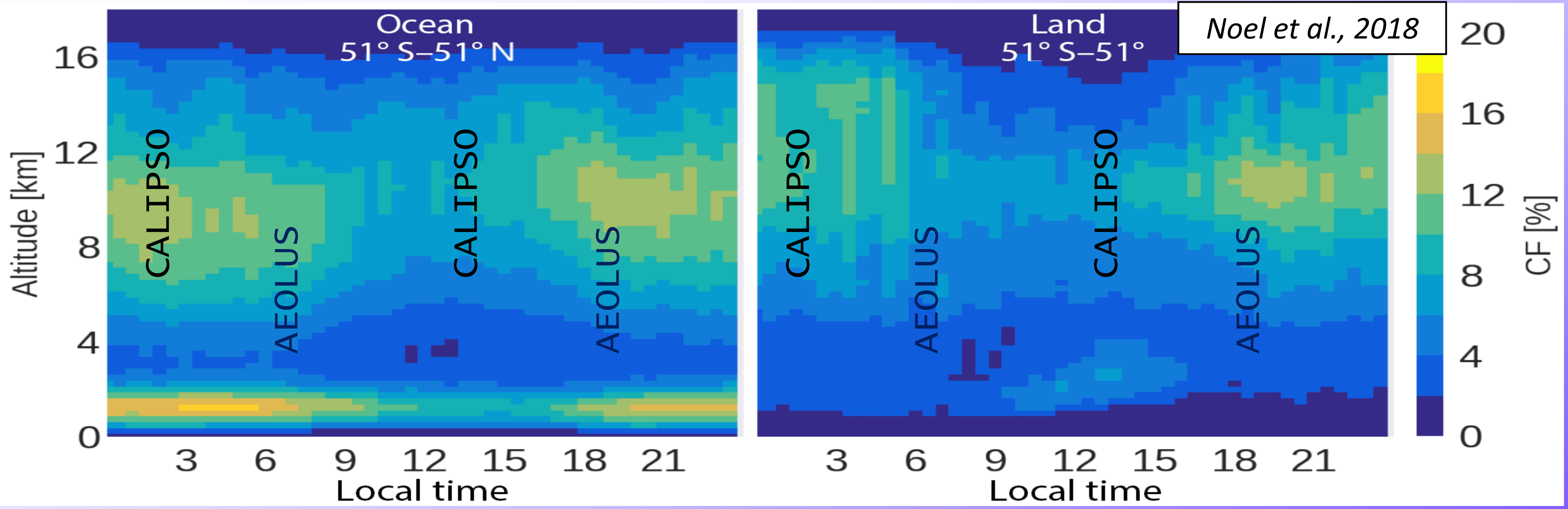
$$\delta(z_i) = \frac{ATB_{\perp}(z_i)}{ATB_{\parallel}(z_i)} \qquad \vartheta(z_i) = \prod_{TOA}^{i} \exp(-2 \times \Delta z_i \times \alpha_{part}(z_i) \times \delta(z_i))$$

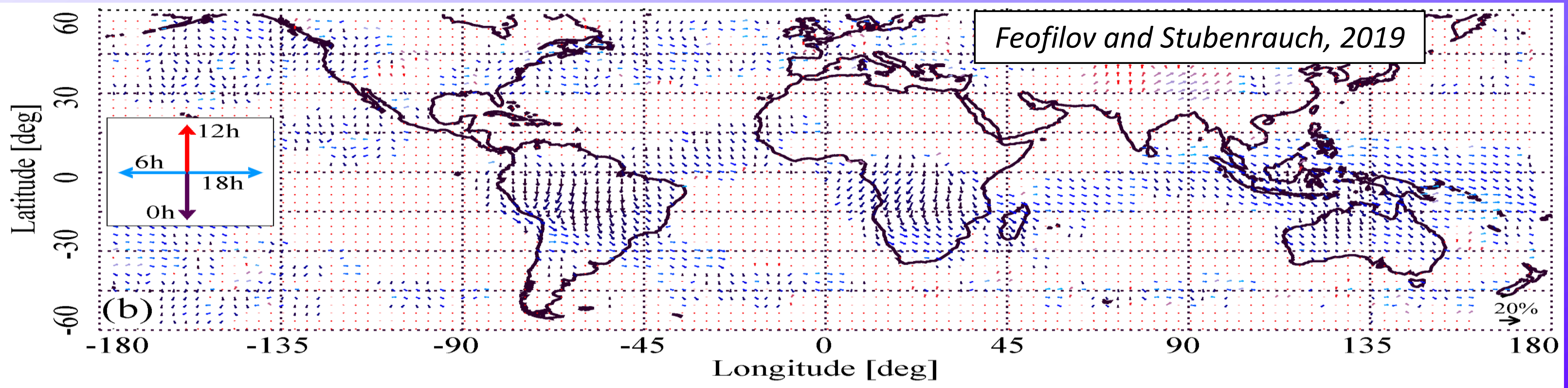
where $\alpha_{part}(z_i)$ is a corrected extinction, $\alpha_{part}^{source}(z_i)$ is a source extinction, $\beta_{part}(z_i)$ is a corrected backscatter, $\beta_{part}^{source}(z_i)$ is a source backscatter, $\delta(z_i)$ is a depolarization coefficient, $\vartheta(z_i)$ is a cumulative attenuation coefficient.

Once the backscatter and extinction coefficients are fixed, they can be transferred to aforementioned wavelength conversion procedure.

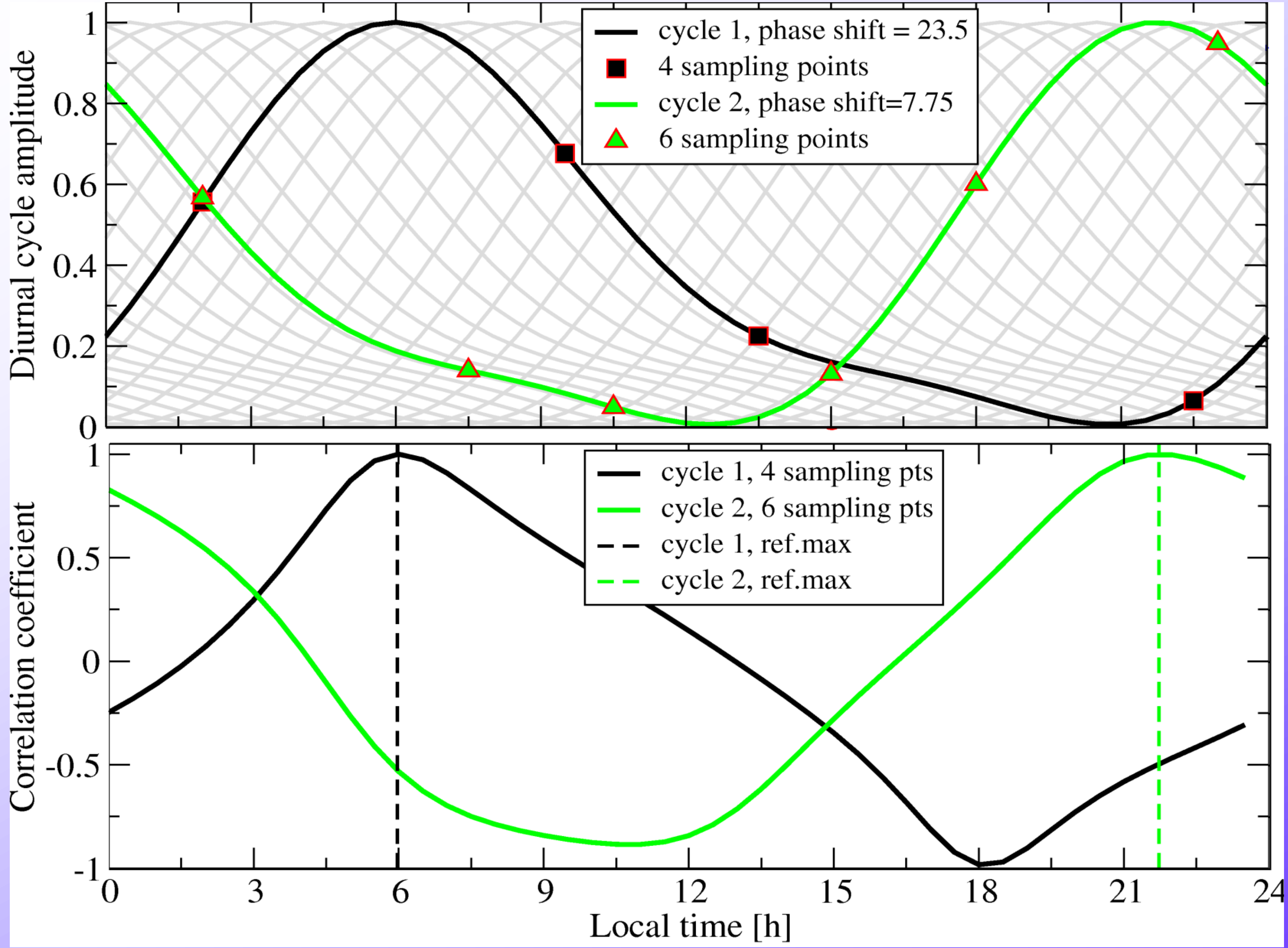
Step # 4 – compensating for diurnal cycle

Accounting for the diurnal cycle effects in clouds





Diurnal cycle retrieval approach for any (lat,lon,height) bin



Feofilov and Stubenrauch, 2019

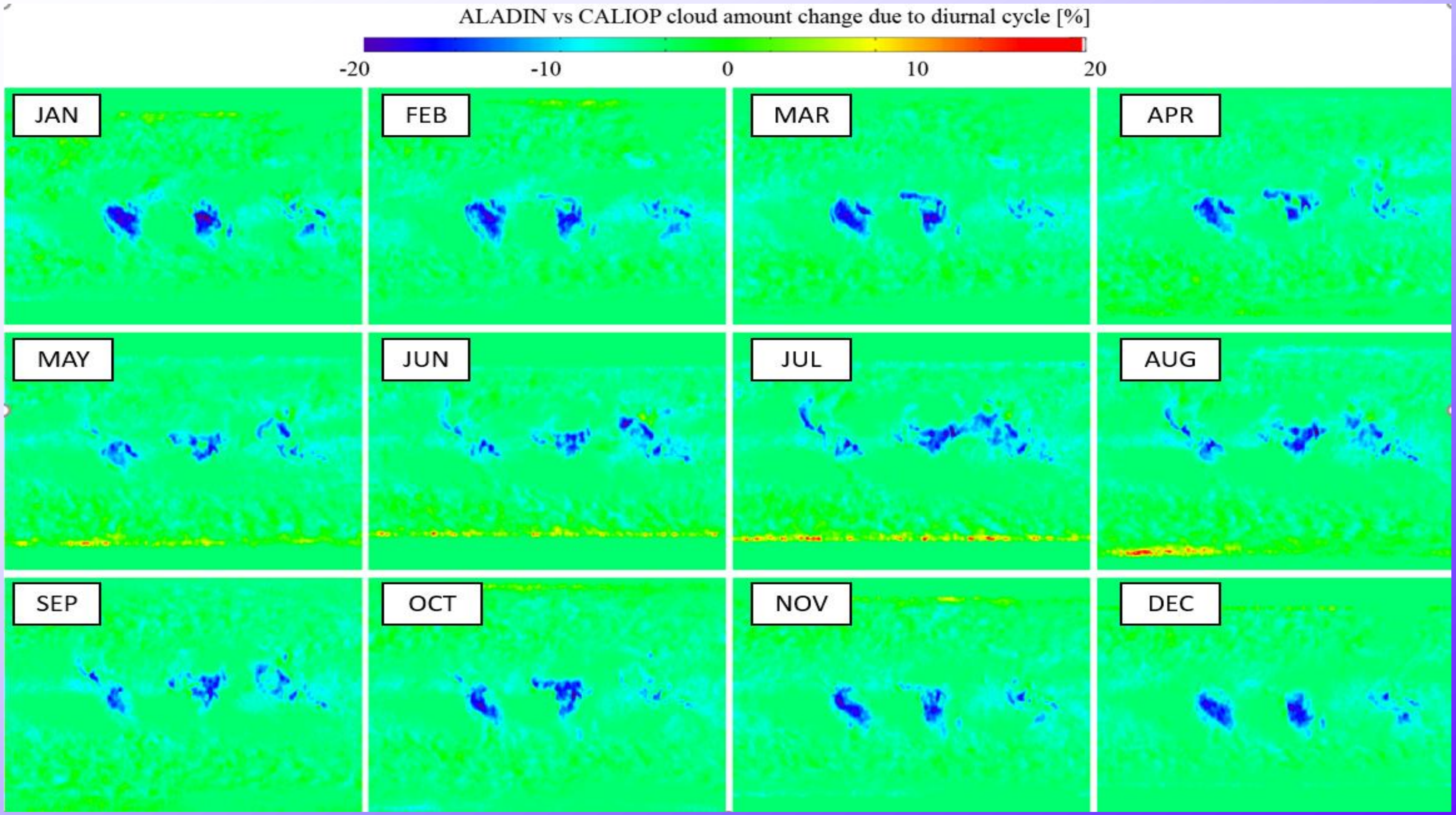
$$A(t) = A_{24} \cdot \sin\left(\frac{2\pi}{24}t + \varphi_{24}\right) + A_{12} \cdot \sin\left(\frac{2\pi}{12}t + \varphi_{24} + \Delta\varphi\right)$$
$$= A_{24} \cdot \left[\sin\left(\frac{2\pi}{24}t + \varphi_{24}\right) + 0.28 \cdot \sin\left(\frac{2\pi}{12}t + \varphi_{24} + \Delta\varphi\right)\right]$$

The “standard shape” comes from *(Cairns, 1995)*

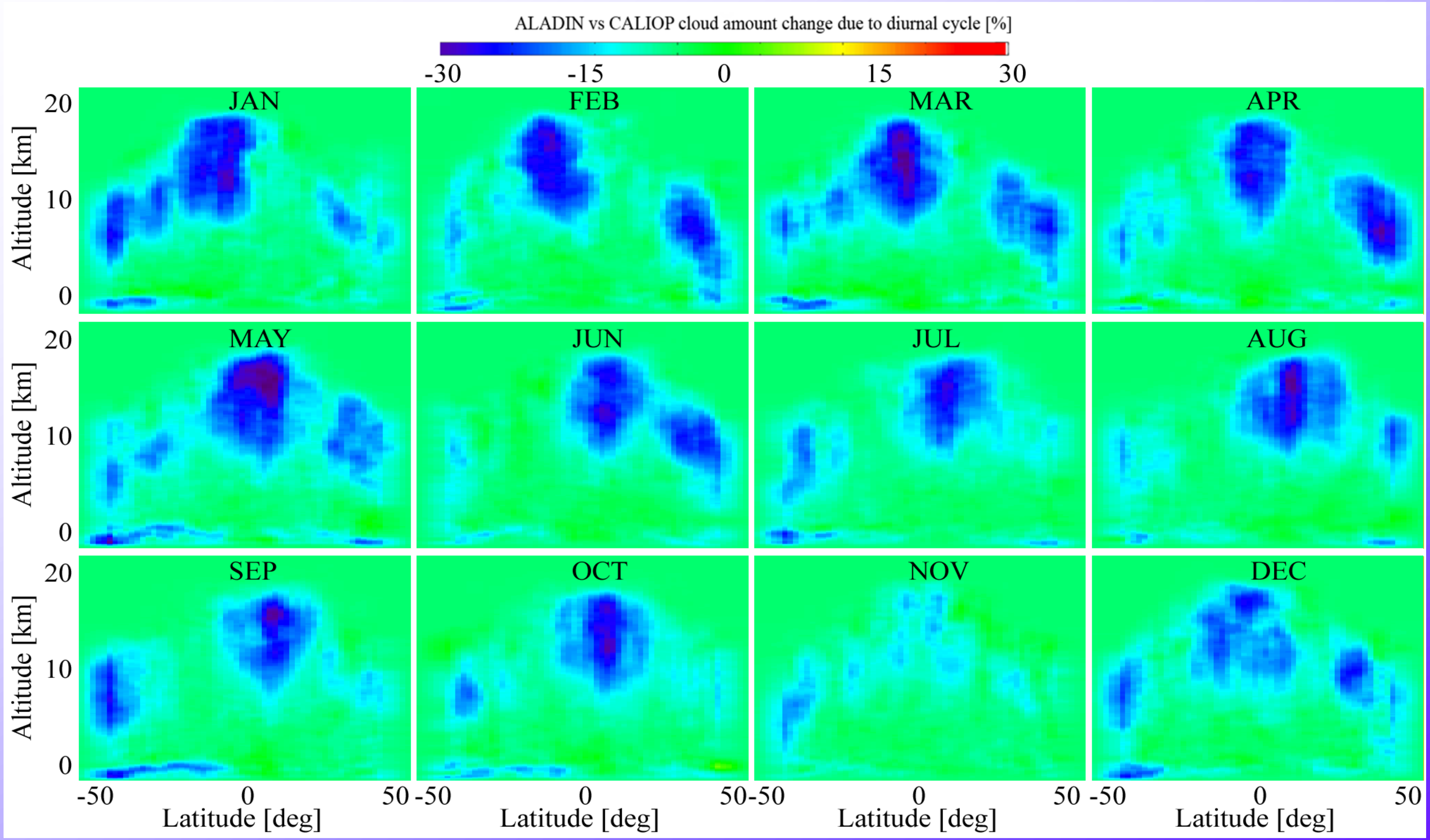
The methodology has been applied to high clouds from AIRS/IASI data (Feofilov and Stubenrauch, 2019) and to vertically resolved CATS data (Noel et al., 2018)

Two 1º×1º gridded datasets (A_{24} and ϕ_{24}) are available for download

Diurnal cycle correction for high clouds from AIRS/IASI

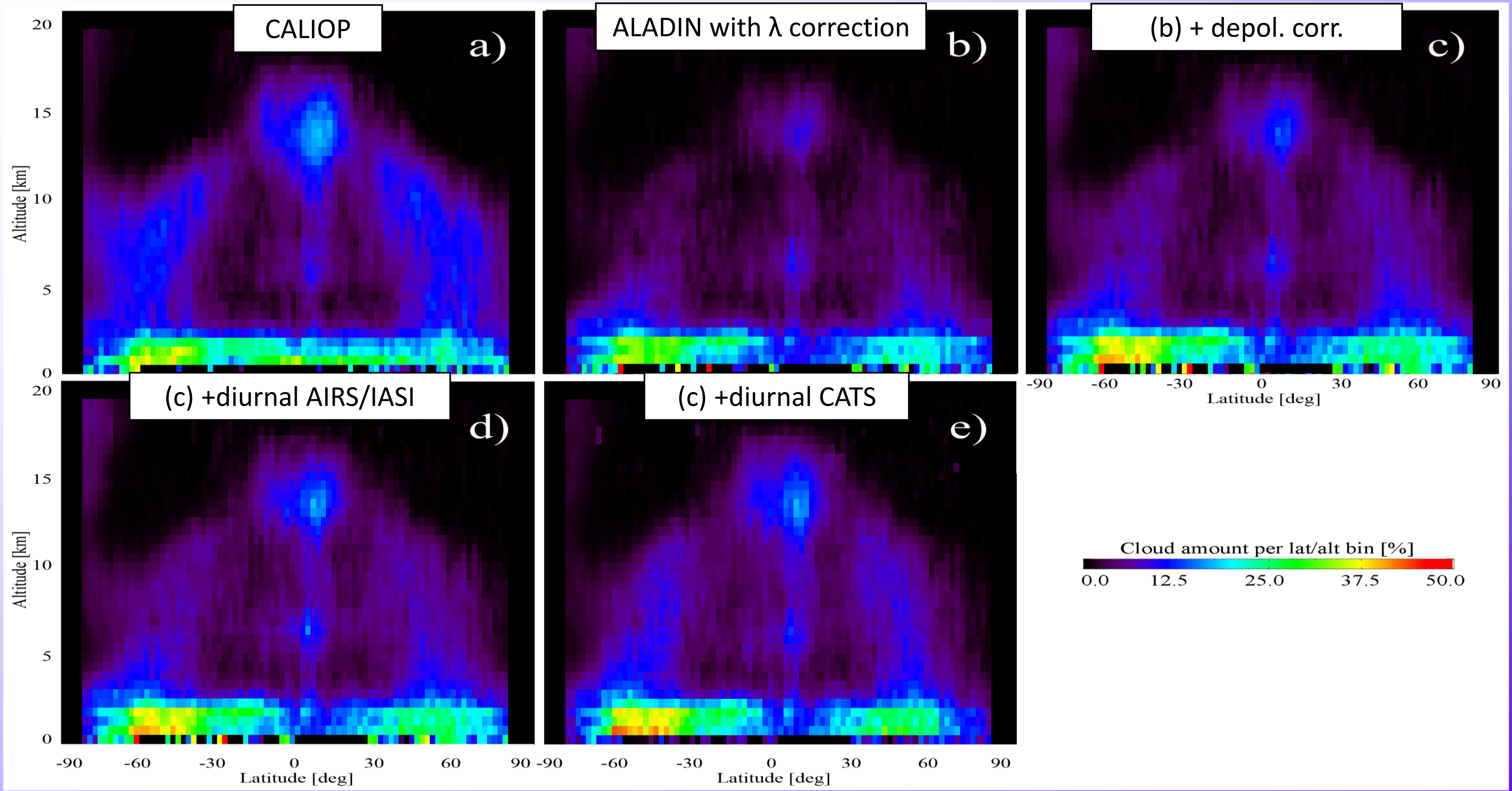


Height-resolved diurnal cycle correction from CATS

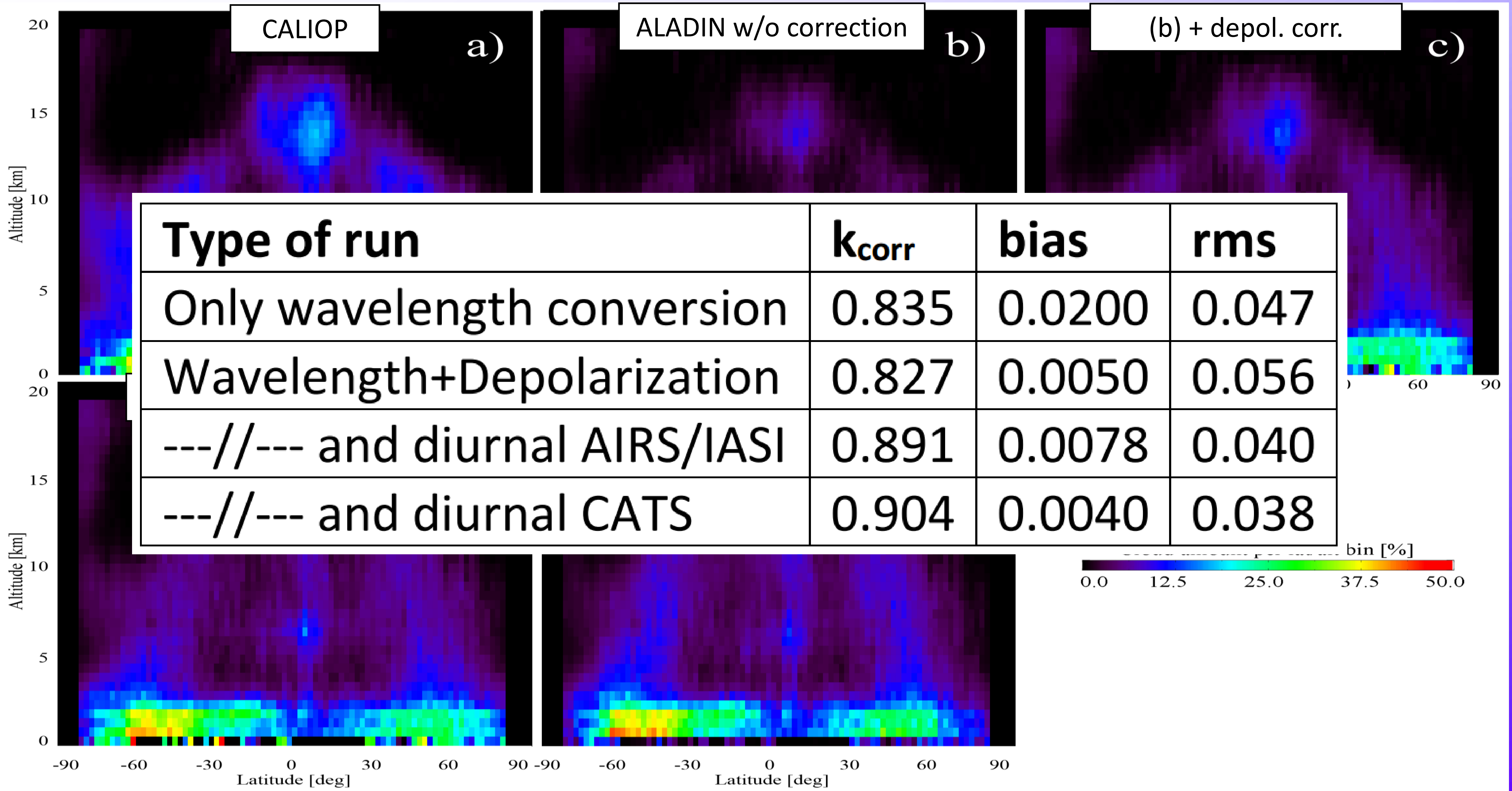


Step #1 + Step #2 + Step #3 + Step #4
yield Aeolus cloud product

Depolarization- and diurnal cycle- corrected cloud amounts



Depolarization- and diurnal cycle- corrected cloud amounts



Type of run	k_{corr}	bias	rms
Only wavelength conversion	0.835	0.0200	0.047
Wavelength+Depolarization	0.827	0.0050	0.056
---//--- and diurnal AIRS/IASI	0.891	0.0078	0.040
---//--- and diurnal CATS	0.904	0.0040	0.038

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 instrumental difference, the diurnal cycle, and averaging effects.

- Compensating for depolarization effects **significantly** improves the agreement in high clouds between ALADIN and CALIOP → depolarization channel **highly advised** for AEOLUS 2

- Compensating for depolarization effects performed layer per layer brings the existing extinction and backscatter coefficients closer to reality.

- Compensating for diurnal cycle effects using AIRS/IASI or CATS further improves the agreement between CALIOP and ALADIN. For high clouds over land, the cloud fraction correction is up to 20%.

- Aeolus cloud retrieval is on the way for the whole period of observations, data will be delivered to ESA.