Aerosol Layer Height by Polar and Geostationary passive satellites: Lessons learned, limitations and improvements

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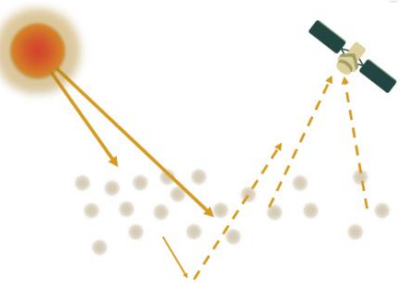
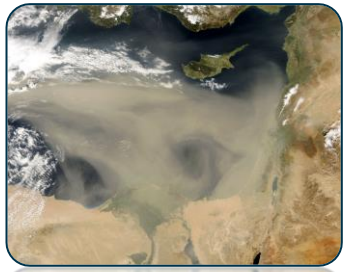
Why is the height of the aerosol layer important?

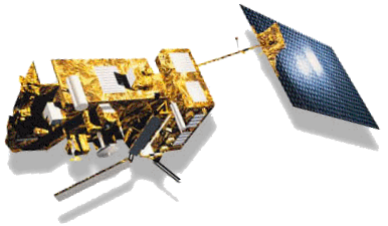
- Knowledge of the ALH, is essential for understanding the impact of aerosols on the climate system
- Important in the framework of aviation safety, transported dust, smoke and ash aerosols over large distances
- Can provide accurate values to the modelling communities and improve air quality forecasting.





Satellite aerosol layer height products in this work

GOME-2/MetOp



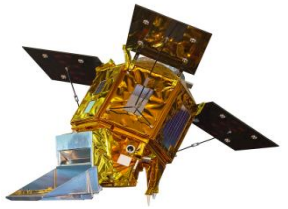
Since 2006

MetOp-A, -B, -C
Daily global coverage
Cross. Time ~09:30LT
Swath ~ 1920 km
Spatial res. (40x80km)

Absorbing Aerosol Height (AAH)

- The AAH algorithm based on FRESCO+ retrieves cloud fraction (CF), cloud Height (CH), scene albedo (SA) and scene height (SH) from simulated 02-A band reflectance spectra
- Absorbing Aerosol Index (AAI) identifies scenes
- The algorithm determines whether CH/SH should be reported as AAH

TROPOMI/S5P



Since 2017

Daily global coverage
Cross. Time~13:30LT
Swath ~2600 km
Spatial res. (5.5 x 3.5km)

Aerosol Layer Height (ALH)

- Based on absorption in the Oxygen O2-A band
- Aerosols are assumed to be distributed in a single layer
- ALH algorithm applies a forward model and employs a NN scheme for speedy processor performance

GEMS

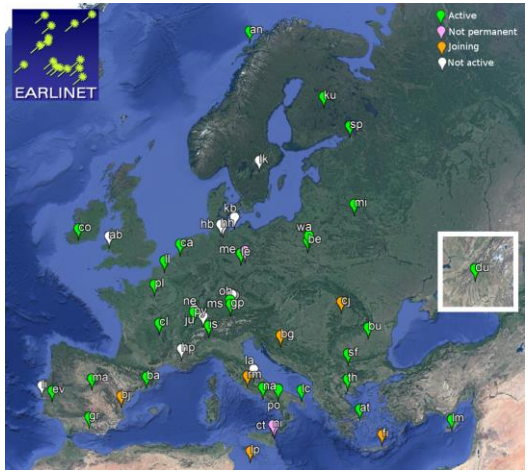
Since 2020

Geostationary
Coverage: 5°S - 45°N, 75°E - 145°E
Swath ~5000km
Temporal res. 8-10/day
Spatial res. (3.5 x 8 km2)

Aerosol Layer Height (ALH)

- Based on the AER-AOD algorithm
- OEM-Spectral fitting 354, 388, 412, 443, 477, 490 nm

Aerosol layer height from ground-based measurements

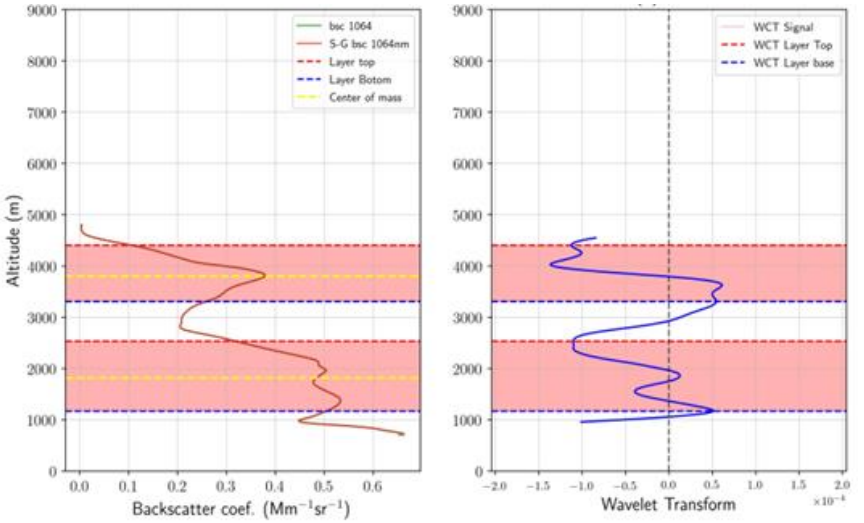


How can we estimate layering information from the lidar measurements

Wavelet Covariance Transform (WCT)

Apply $h\left(\frac{z-b}{a}\right) = \begin{cases} +1 \text{ for } b - \frac{a}{2} \le z \le b \\ -1 \text{ for } b \le z \le b + \frac{a}{2} \\ 0 \text{ elsewhere} \end{cases}$ to the signal

The choice of **a** (spatial extend or dilation) and **b** (centered location or vertical translation) affect the **number of detected layers** and thus their geometric characteristics (layer top height, layer bottom height)



Aerosol Effective Height (Center of mass)

$$ALH_{bsc} = \frac{\int_{z_{i=1}}^{z=n} z_i \cdot \beta_{aer,i}(z)\,dz}{\int_{z_{i=1}}^{z=n} \beta_{aer,i}(z)\,dz}$$

Can be applied to the **whole profile** or to **individual layers**

Problem:
How is this affected by the incomplete overlap of a lidar system

Quality assured lidar data

- Lidar measurements from **the ACTRIS-EARLINET database**
- Data processed with the Single Calculus Chain.
- Volume Backscatter coefficient at 1064nm or 532nm
- Only Level-2 aerosol optical products are included.

Limitation: There might be aerosol layers beyond the vertical range of the archived lidar measurements

Aerosol layer height from ground based measurements

Uncertainties and issues when estimating layering information from the lidar measurements

Investigation of **Overlap height** impact on the weighted lidar ALH determination

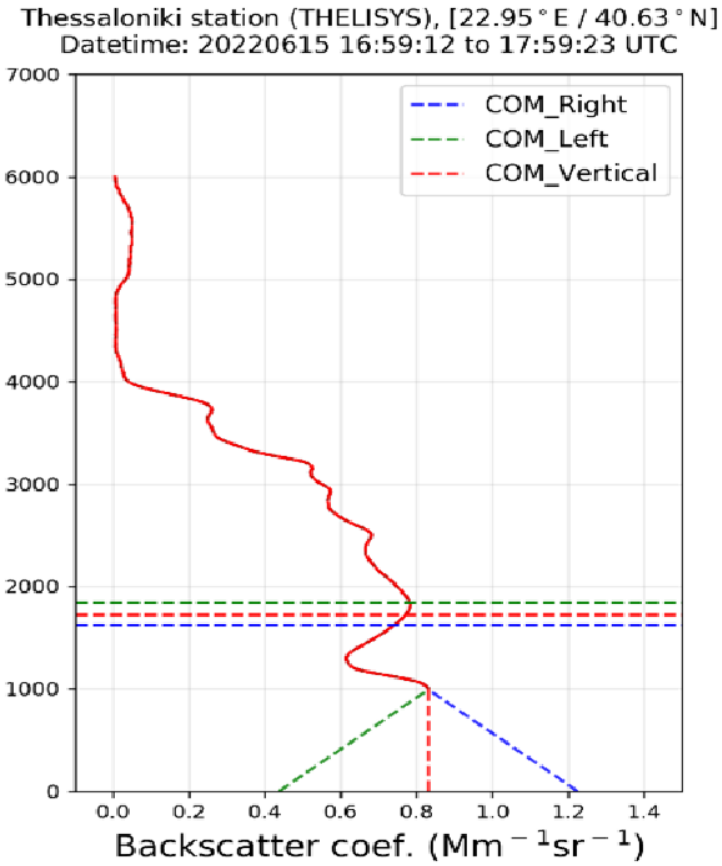
The uncertainty due to the overlap in determining the ALH is of the order of **100 - 400m**, depending on the technical characteristics of each lidar system

Investigation of **Lidar Ratio** impact on the weighted lidar ALH determination

The results show that in both cases the effect of the different lidar ratio values on the weighted height calculation (ALH_{bsc}) is small, lower than **40m**.

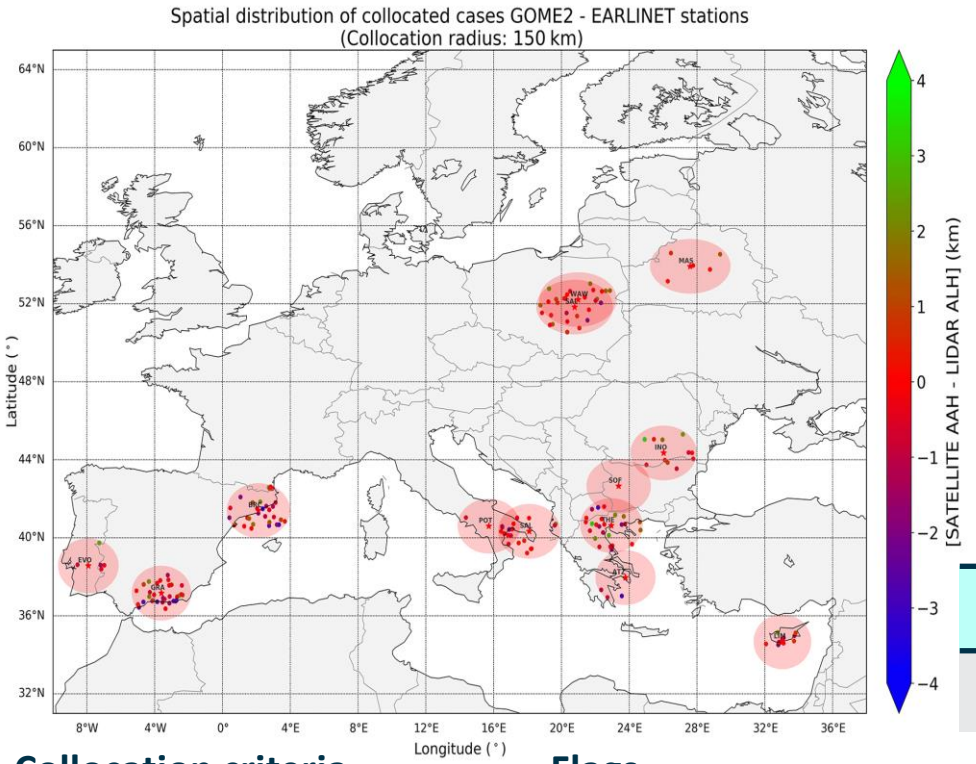
How the errors of the EARLINET measurements affect the the weighted lidar ALH determination

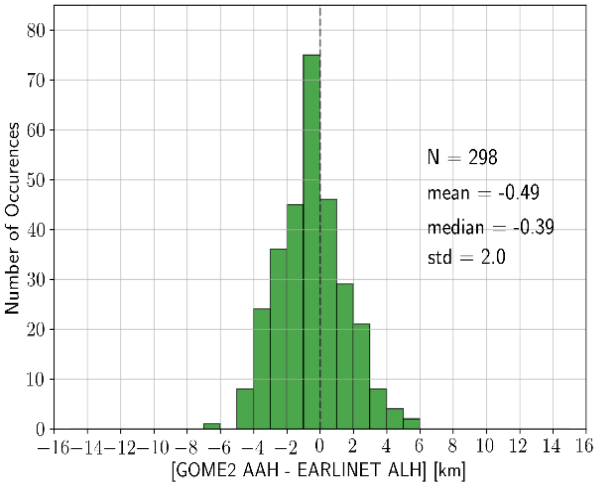
The effect of the error in the retrieval of the backscatter coefficient on the estimation of the ALH_{bsc} ranges between **10 - 60 m**.

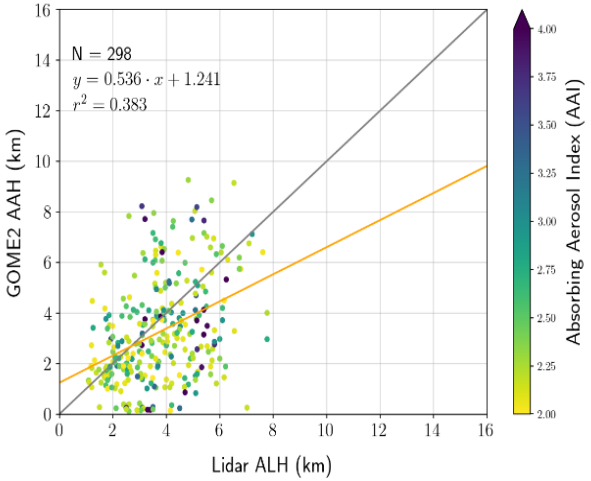


Validation of GOME-2 AAH

13 EARLINET stations







We compare the top boundary of the upper most aerosol layer with GOME-2 AAH

Collocation criteria

Spatial (Δx): **150km**
Temporal (Δt): **4-h interval**

Flags

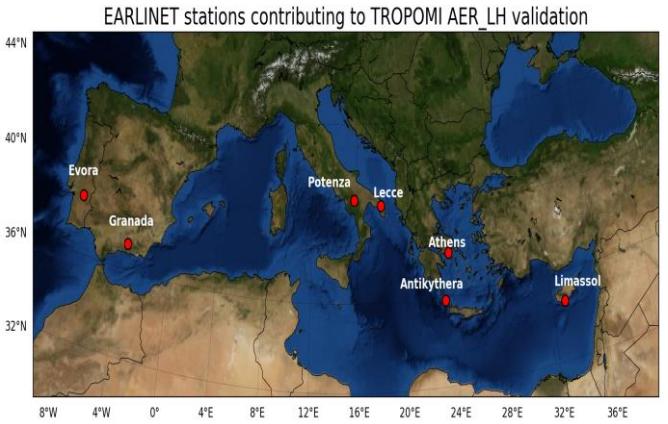
Use AAI >2
Flag sun glint

Metric	
Number of collocated cases	298
Mean difference	**-0.49 km**
Standard deviation	**2.01 km**
Min/Max of the differences	-6.7/5.2 km
Correlation/ Slope / Y-inter.	0.39 / 0.53 / 1.24

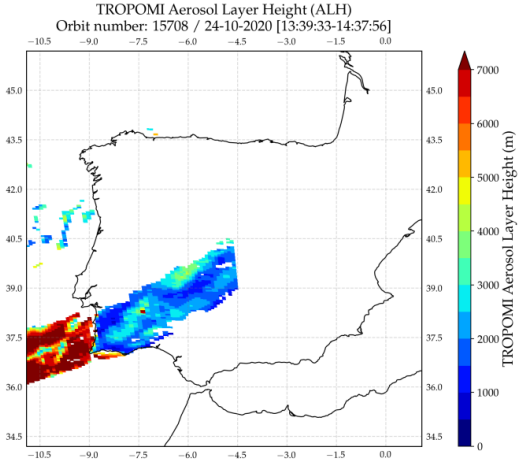
Michailidis et al, ACP, 2021

EUMETSAT AC SAF ATMOSPHERIC COMPOSITION MONITORING

Validation of TROPOMI ALH 1/2

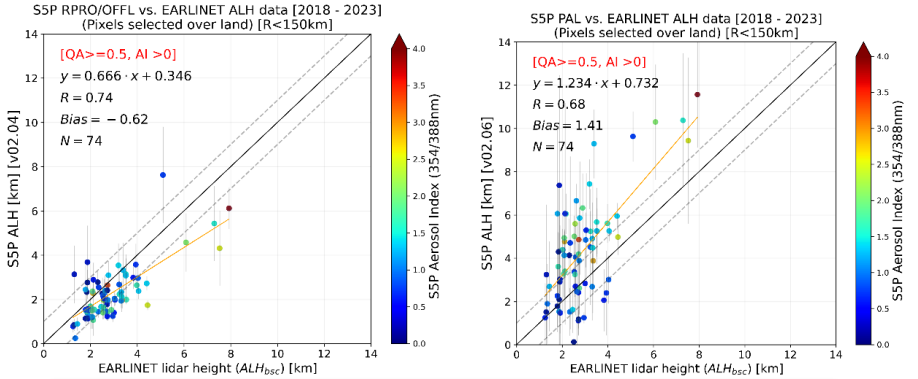


Selected stations close to the ocean

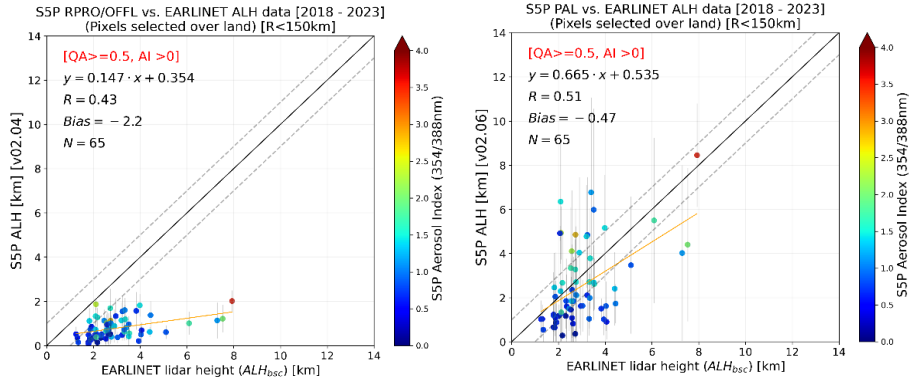


Why? Increasing surface albedo negatively influences the ALH

Over Ocean: (Left) v02.04/02.05 (Right) v02.06



Over Land: (Left) v02.04/02.05 (Right) v02.06



IDEAS-QA4EO

AER_LH Version	Number of Points	Mean Bias [km]	Pearson (R)
Over Ocean			
V02.04 / 02.05	74	-0.62±0.92	0.74
V02.06*	74	1.41±1.77	0.68
Over Land			
V02.04 / 02.05	65	-2.2±1.23	0.43
V02.06*	65	-0.47±1.59	0.51

AER_LH data processed **via S5P-PAL System,* includes the surface albedo in the optimal estimation fit

We compare the effective aerosol height with the TROPOMI ALH

Co-location criteria:

Spatial Δx: 150km

Temporal Δt: ±2hour

Flags: Sunglint effect, snow/ice pixels, Cloud screening, cirrus contamination, QA-value > = 0.5, ALH for only UVAI > 0

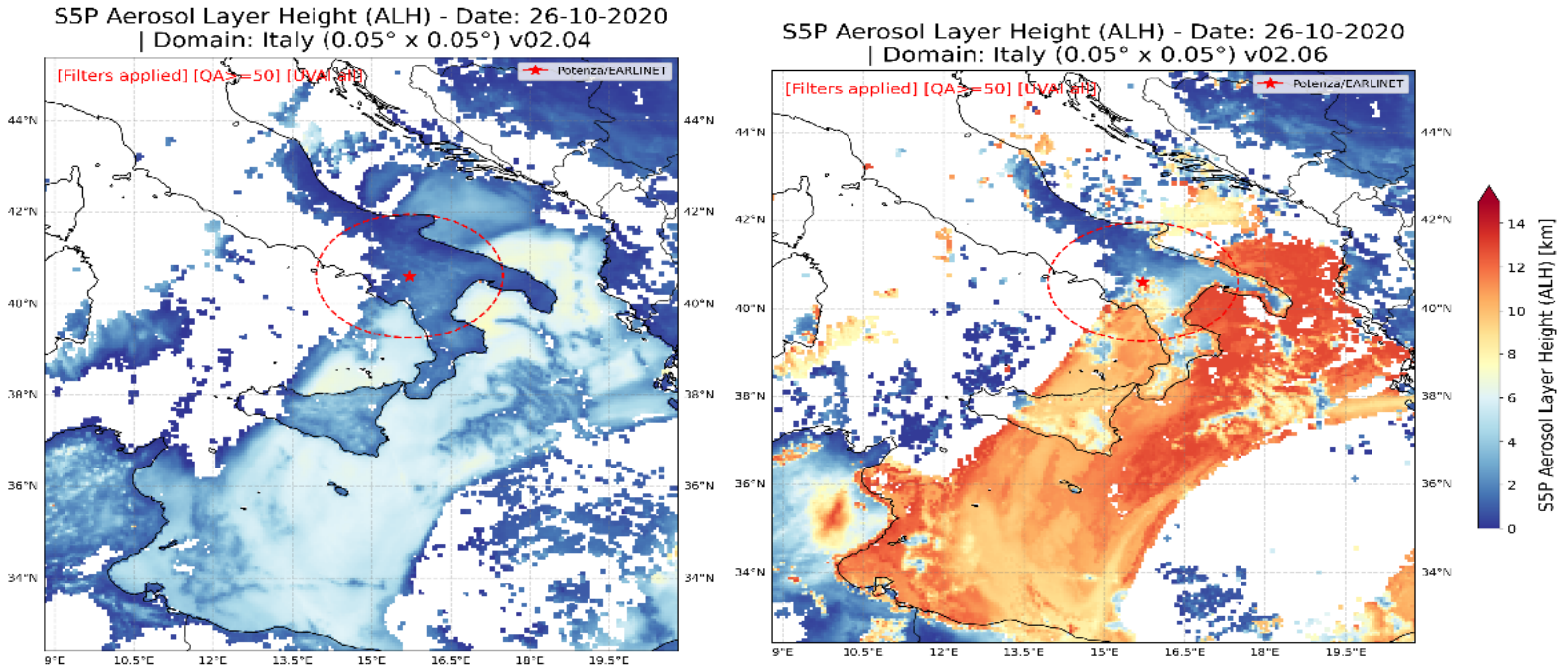
Michailidis et al, ACP, 2023

ATM-MPC

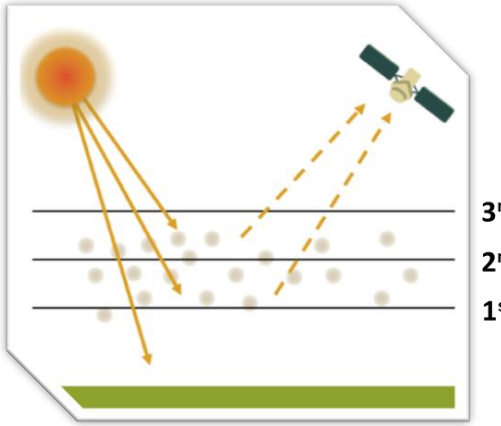
Validation of TROPOMI ALH 2/2

L2 RPRO version v02.04

L2 S5P-PAL version v02.06



Improvement when considering the surface albedo in the fit



The representativeness of the TROPOMI ALH when multiple layers are present is an issue for further investigation

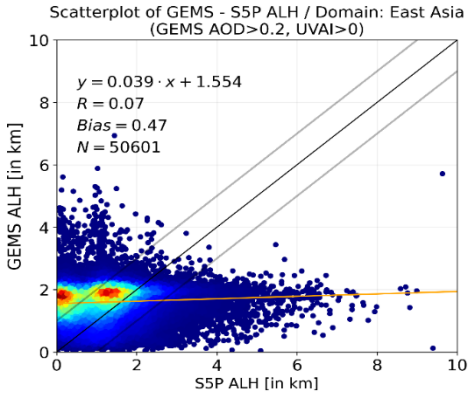
TROPOMI pixels over Ocean			
Number of layers	R	MB [km]	Y=Ax+b
1	0.8	-0.46	0.71x+0.38
>2	0.85	-0.55	0.67x+0.47

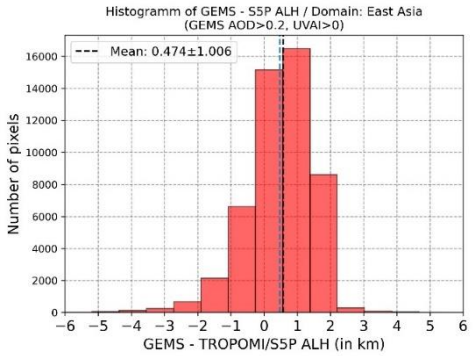
ATM-MPC

Validation of GEMS ALH

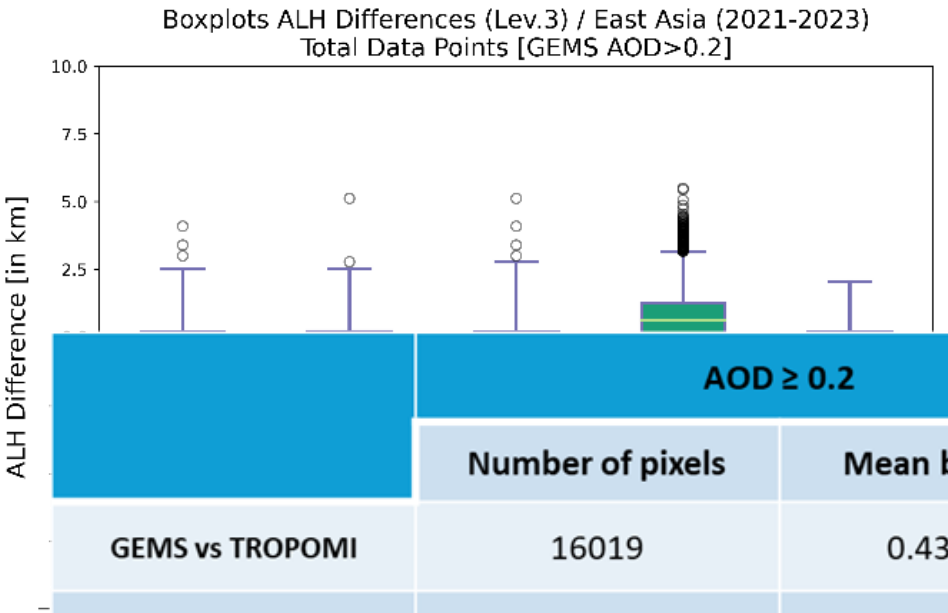
PEGASOS

GEMS AOD>0.2, UVAI>0

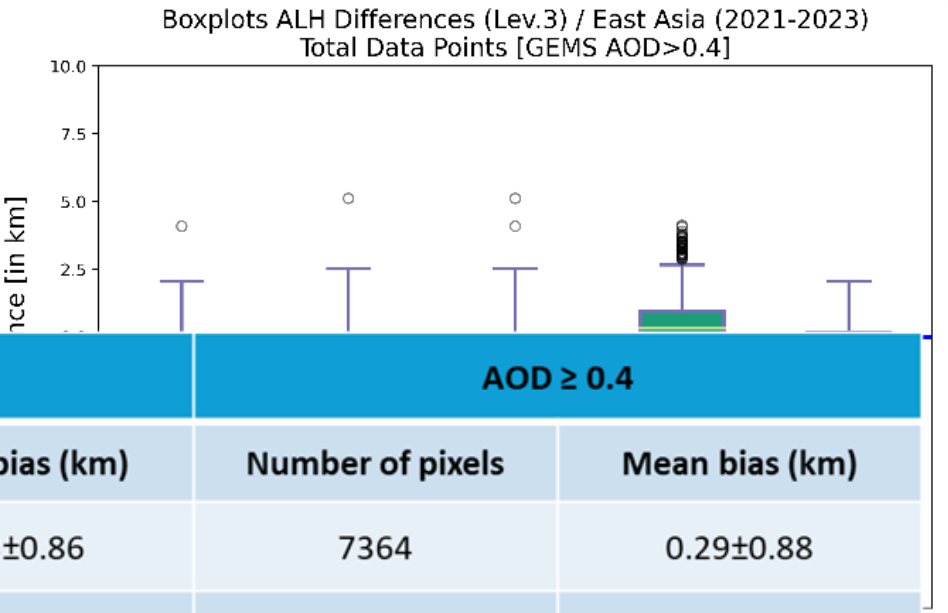




GEMS AOD>0.2



GEMS AOD>0.4



	AOD ≥ 0.2		AOD ≥ 0.4	
	Number of pixels	Mean bias (km)	Number of pixels	Mean bias (km)
GEMS vs TROPOMI	16019	0.43±0.86	7364	0.29±0.88
GEMS vs GOME2 B+C	7345	-0.76±1.36	3711	-1.00±1.37
GEMS vs CALIOP	1304	-0.6±1.15	930	-0.88±1.07

Similar for GOME-2, CALIPSO

L2 ALH products converted to 0.2° x 0.2° grid for the GEMS observational times closer to the other satellite crossing time

Concluding remarks and future plans

- EARLINET/ACTRIS database is valuable for the validation of aerosol layer height satellite products providing estimates with an uncertainty of about 100m
- GOME-2 AAH when compared with the top boundary of the upper most layer detected from the lidar has a bias of -0.5km
- Latest version of TROPOMI ALH when compared with effective aerosol height estimated from the lidar has a bias between -0.4km and 1.4km depending on the surface albedo and the number of aerosol layers
- GEMS ALH when compared to other satellite retrievals shows a negative bias (except TROPOMI). Important exercise for the validation of S4 products
- Certain scenes have been identified for Sentinel-3 OLCI ALH to be compared with EARLINET/ACTRIS
- EARTHCARE measurements of ALH will be integrated in the validation
- Investigate the performance in the absence of elevated layers and the effect of cloud contamination

Thank you for your Attention!