Ground-based validation of satellite-derived Aerosol Layer Height and Ozone profiles

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QA4EO Cal/Val WS#1: Rome, 19 - 21 Feb 2020

With contributions from K. Fragkos (INOE), I. Petropavlovskikh and Koji Miyagawa (NOAA)

Aristotle University of Thessaloniki

Long experience in satellite validation

Brewer & maxDOAS

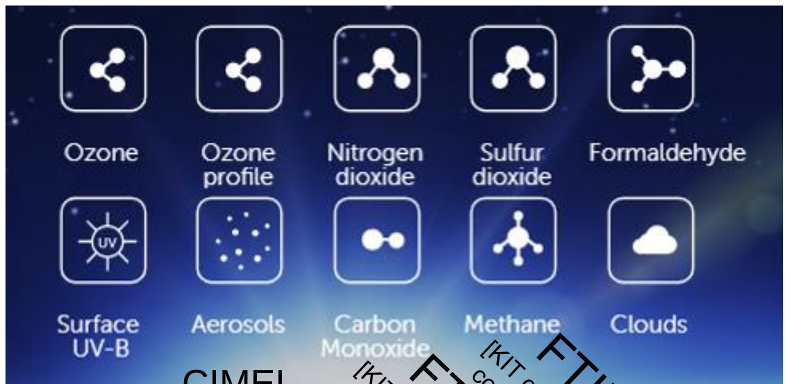
maxDOAS

maxDOAS [coming in 2019]

maxDOAS

Brewer & maxDOAS

Brewer



CIMEL
LIDAR
maxDOAS

FTIR [KIT collaboration coming in 2019]

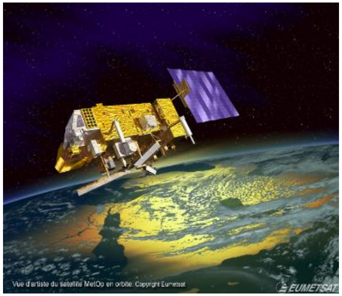
FTIR [KIT collaboration coming in 2019]

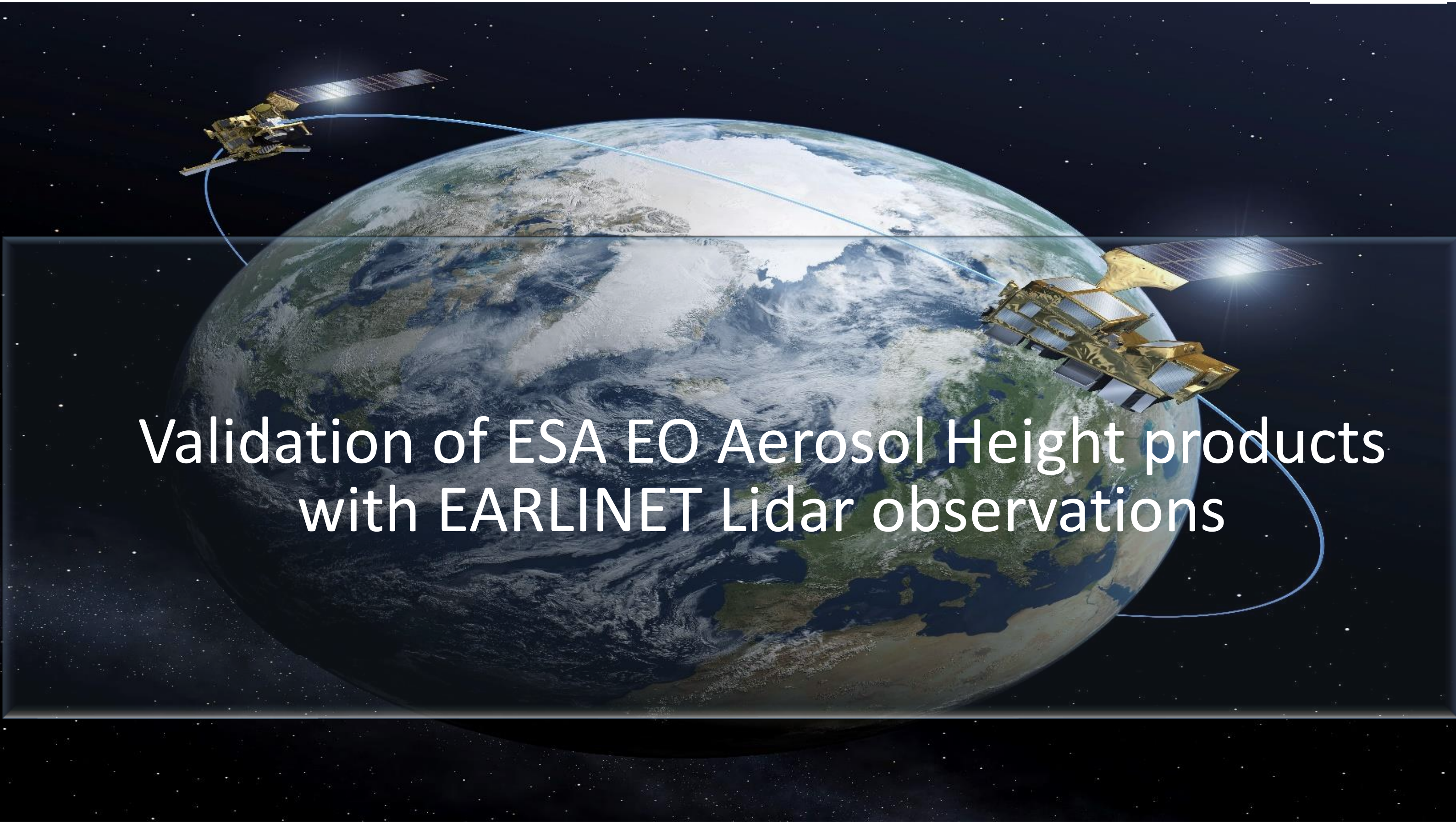
AUTH has been active in the validation of various GOME, OMI, SCIAMACHY, GOME-2, IASI, TROPOMI, CALIPSO, AEOLUS products in the frame of ESA and EUMETSAT's projects

Involvement of AUTH in QA4EO

WP1 Validation of ESA EO Aerosol Height products with EARLINET Lidar observations

WP2 Umkehr Ozone Profile Analysis and Satellite Validation for the time period 2007-2020





Validation of ESA EO Aerosol Height products with EARLINET Lidar observations

Work Package Layout

- Acquire lidar EARLINET records for the period 2007 to 2020.
- Post-process the lidar profiles with the LAP/Auth dedicated software in order to identify lofted aerosol layers and exclude all cases of cloud presence contamination.
- Acquire S5P/TROPOMI and GOME2/Metop products for the applied period.
- Post-process the TROPOMI/GOME2 profiles and study the possible effects of other geophysical parameters of the satellite L2 algorithm in order to clearly identify aerosol layers.
- Acquire auxiliary information for the dates of common valid measurements, such as CALIOP/CALIPSO or DREAM dust modelling which will further assist in identifying the provenance of the aerosol layer.
- Perform the validation activity via the **dedicated LAP/Auth Aerosol Validation Chain**.

EARLINET
(European Aerosol Research Lidar Network)

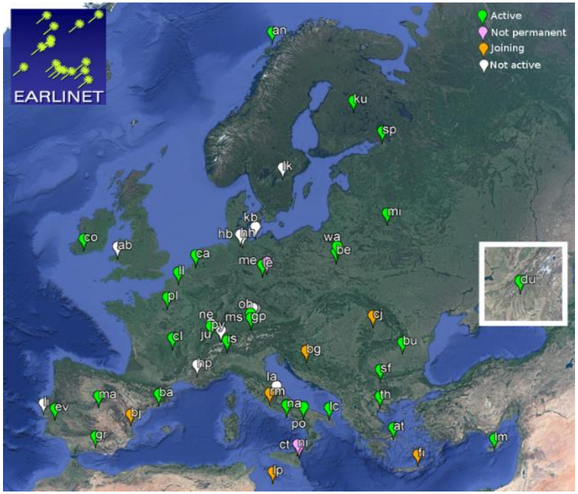
- **EARLINET** has coordinated ground-based lidar activities on the European continental and it holds a comprehensive database of European lidar data sets giving information on the **vertical**, **horizontal** and **temporal** distribution of aerosols on a continental scale.

- The network currently includes 30 active stations distributed over the European continent.

- The standard products of EARLINET include aerosol extinction and backscatter profiles.

- Observations are performed on a regular schedule (daytime/nightime) or to monitor special events over the continent, such as Saharan dust outbreaks, forest fires, photochemical smog, and volcanic eruptions.

- Lidar data from the EARLINET network (Pappalardo et al., 2014) are available at https://www.earlinet.org

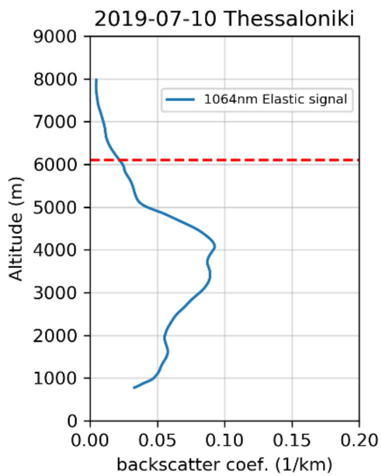


Data and Methodology

- The aerosol geometrical properties carry information about the structure of lidar profiles (e.g. Boundary layer height and lofted layers).
- Our analysis is based on the method of **Siomos et al., 2018** that applies the **wavelet covariance transform (WCT)** to the lidar data in order extract geometrical characteristics (PBL, lofted layers and clouds).
- We adapted **WCT** to determine the **top height of upper most lofted layers**.
- The satellite can detect only the top of the upper layer, the maximum value of lidar features is selected per measurement for the comparison.

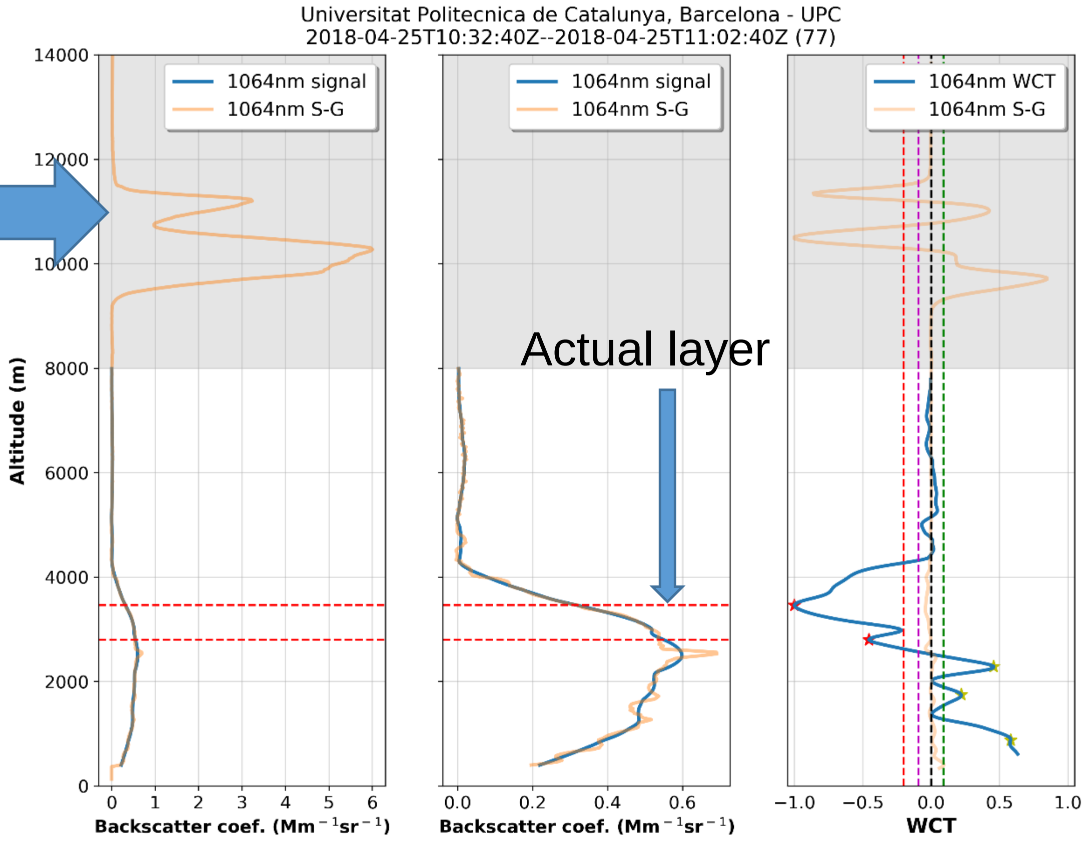
Site	Altitude (asl)	Lat (N)	Lon (E)	Domain Europe	Lidar data
Thessaloniki, Greece	50	22.95	4.63	SE	Jan 2007 – Dec 2018
Barcelona, Spain	115	41.39	2.12	SW	May 2007 – Feb 2017
Leipzig, Germany	90	51.35	12.40	N	Jan 2007 - Jan 2017
Bucharest, Romania	93	44.34	26.02	CE	May 2007 – Oct 2017
Minsk, Belarus	200	53.91	12.43	NE	Jan 2007 - May 2018

Locations of EARLINET lidar stations and their geographical coordinates



The EARLINET data is not plug & play…

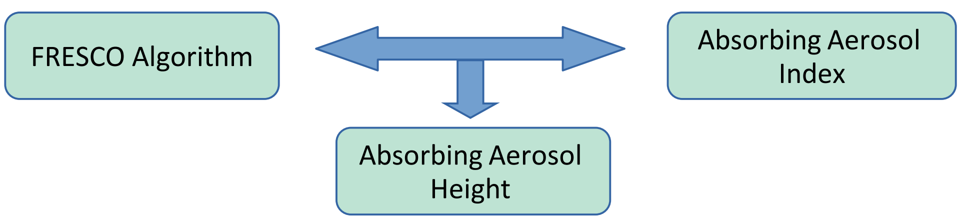
Cirrus contamination

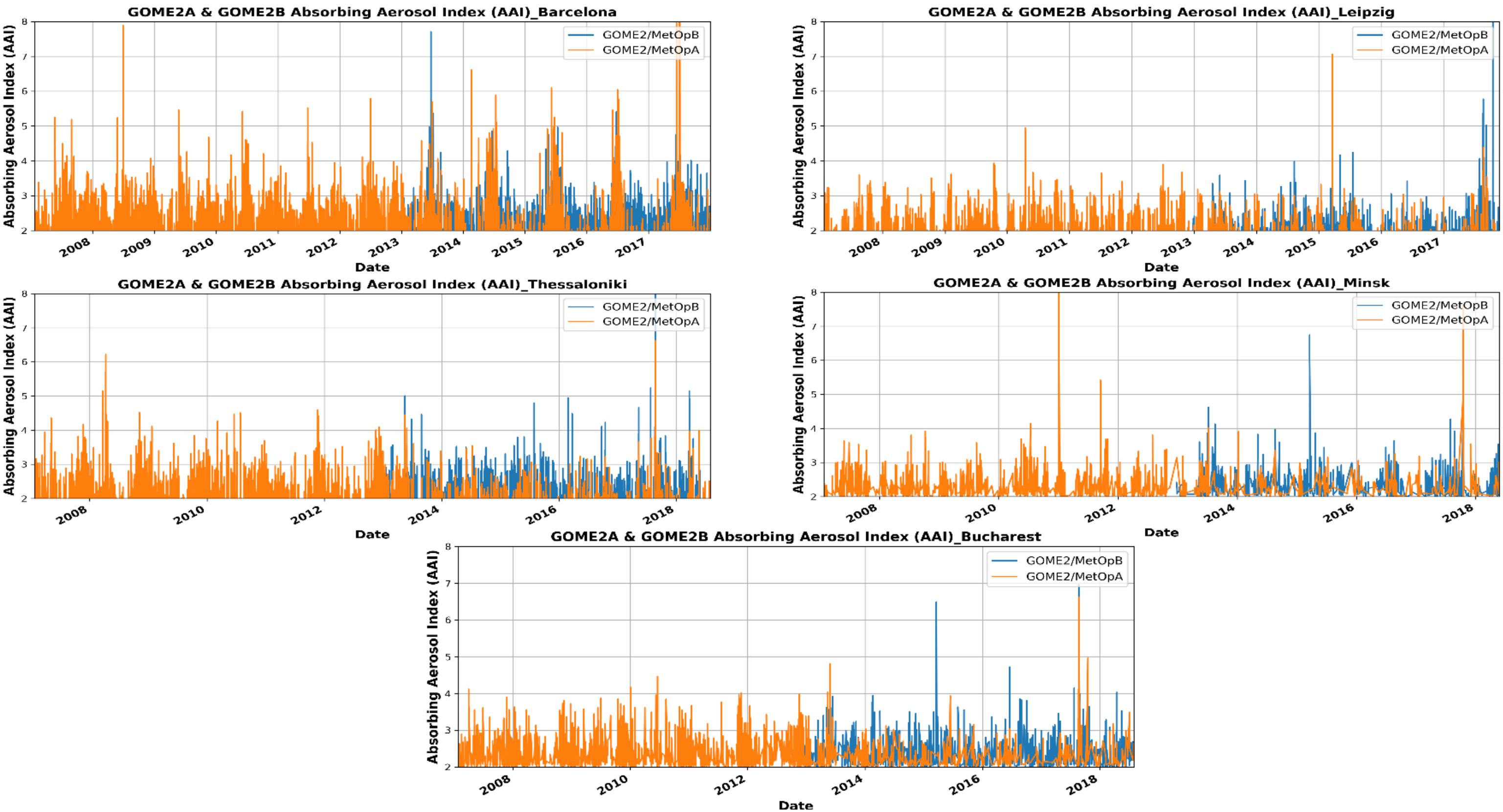


GOME-2 Absorbing Aerosol Height

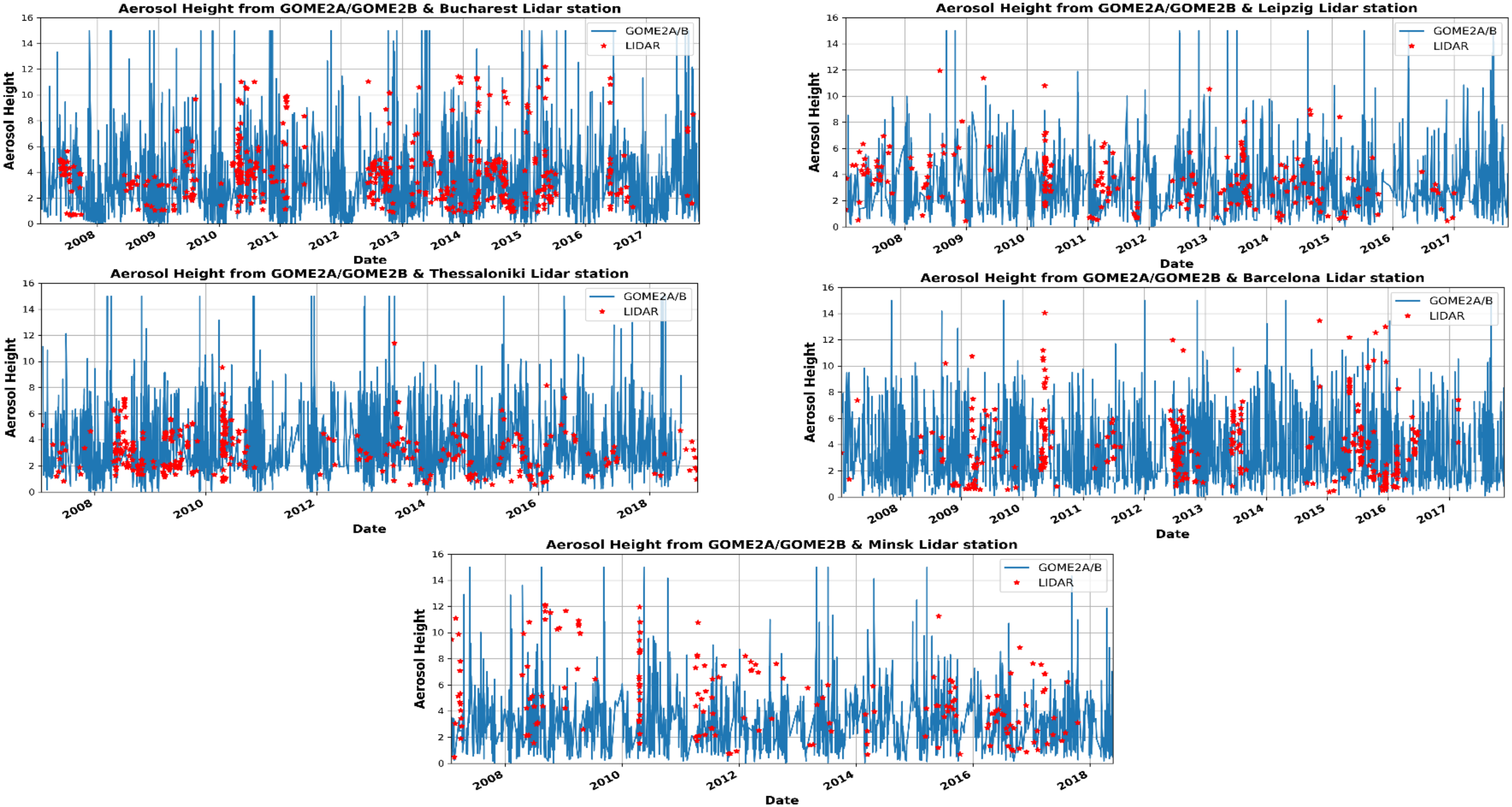
- The algorithm uses the GOME-2 **Absorbing Aerosol Index (AAI)** product to identify scenes containing sufficient amounts of absorbing aerosol.
- The **AAH** algorithm retrieves the parameters cloud fraction **(CF)**, cloud height **(CH),** scene albedo **(SA)** and scene height **(SH)**. These parameters are retrieved from simulated O2-A band reflectance spectra (Wang et al., 2012).
- To determine whether **CH / SH** should be reported as the **AAH**, the algorithm distinguishes three situations (regimes):

Regime A:	**CF** ≤ 0.25	→	**AAH** = CH	(High reliability)
Regime B:	0.25 < **CF** < 0.75	→	**AAH** = max(SH,CH)	(Medium reliability)
Regime C:	**CF** ≥ 0.75	→	**AAH** = CH	(Low reliability)





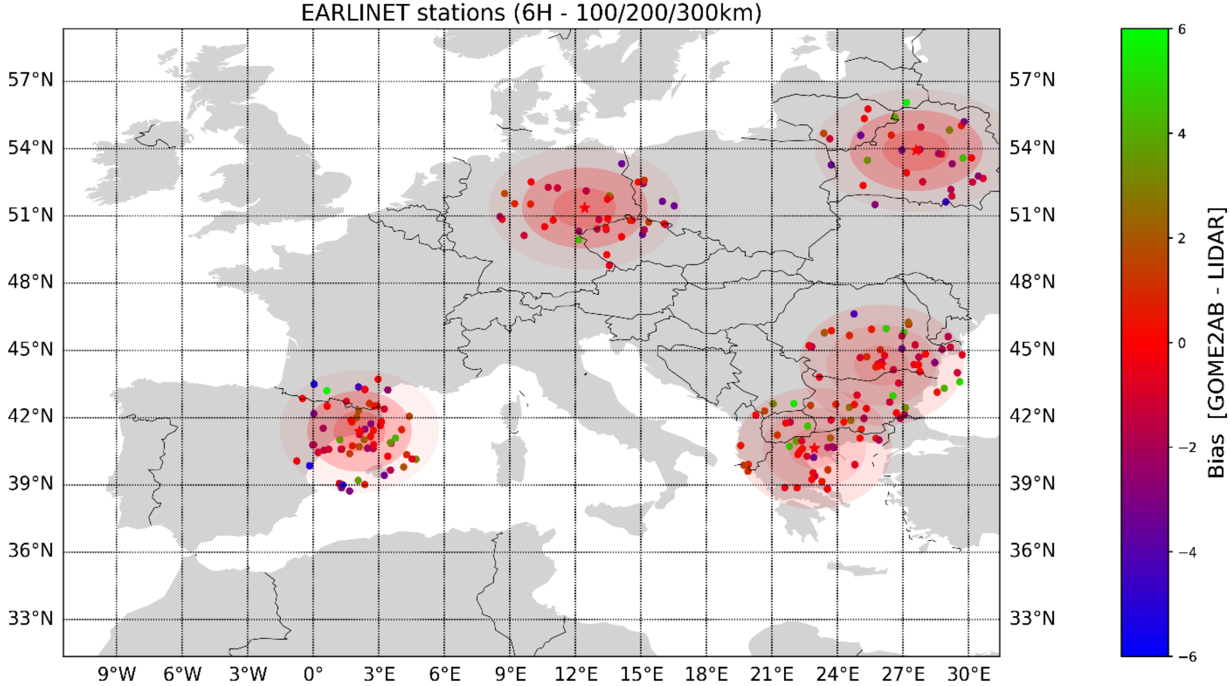
Timeseries of the GOME2AB Absorbing Aerosol Index (AAI) over the period 2007–2018. For satellite measurements, the spatial criterion is set at 300km spatial search radius around the station.



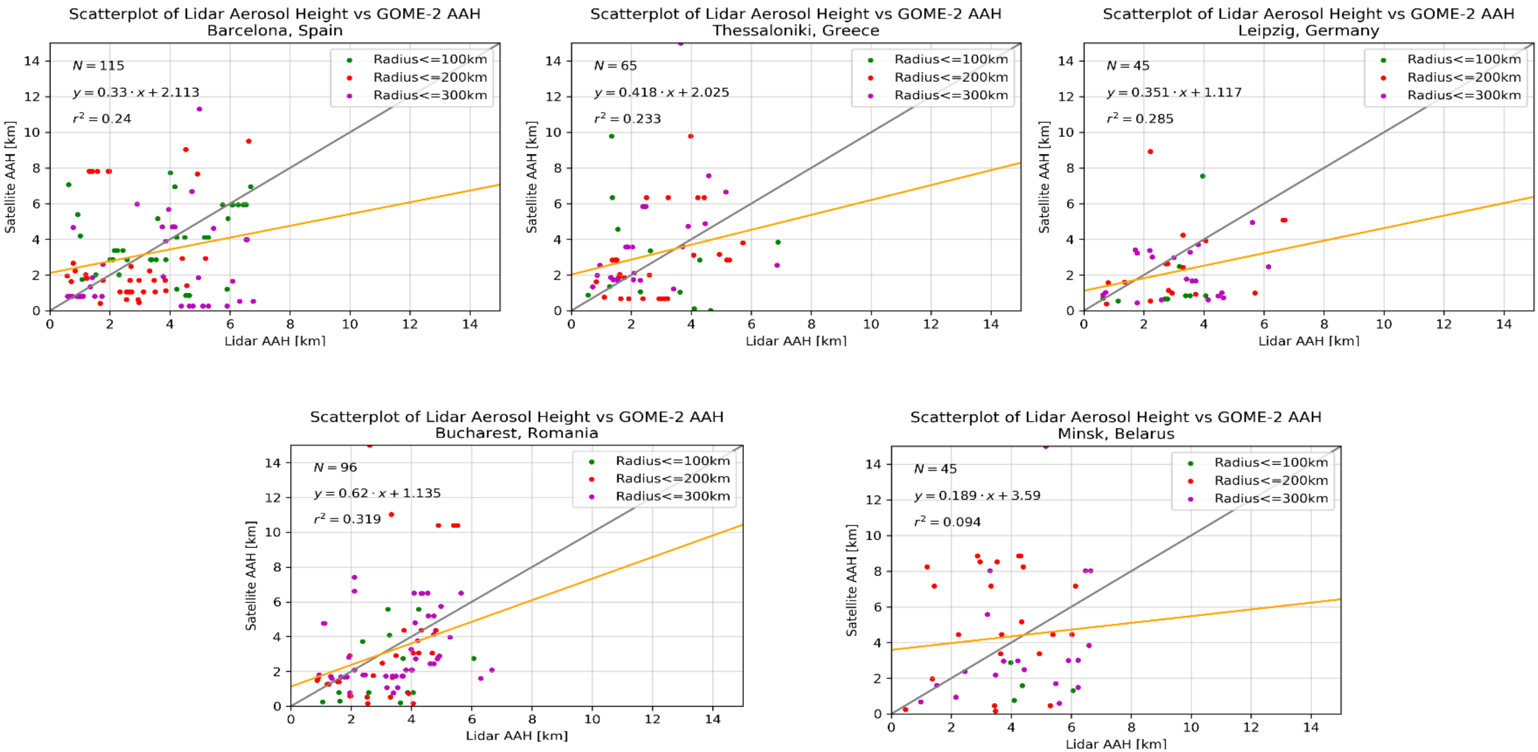
Timeseries of the GOME2AB Absorbing Aerosol Height (AAH) and aerosol height from EARLINET lidar station observations over the period 2007–2018.

Validation of the GOME2 AAH product

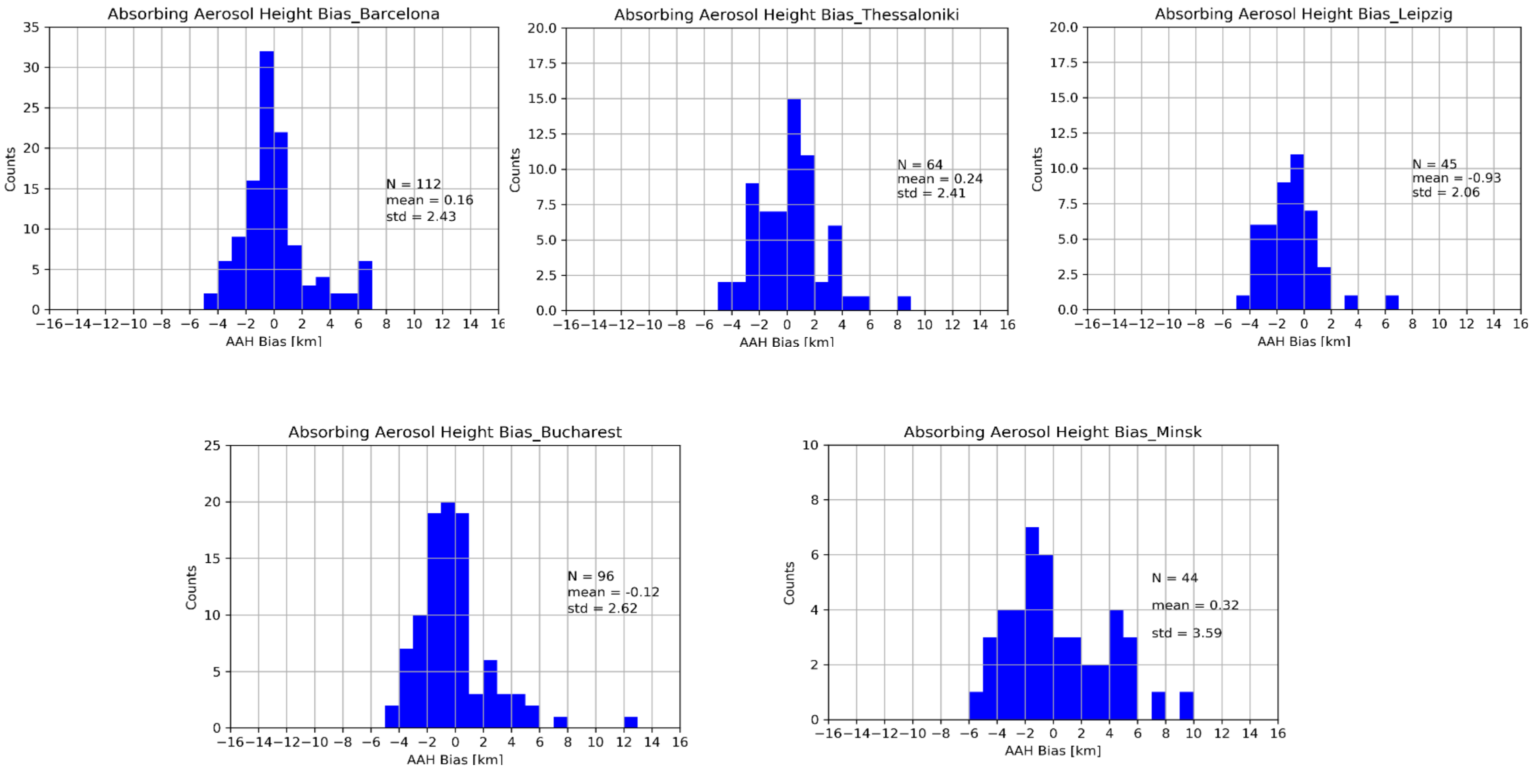
Station	Lon	Lat
Thessalonik i	22.95	40.63
Barcelona	2.12	41.39
Leipzig	12.43	51.35
Minsk	27.60	53.91
Buchares	26.02	44.34



Spatial distribution of collocated layers. The concentric red circles denote regions of 100, 200, 300km from the location of Thessaloniki, Leipzig, Barcelona, Minsk and Bucharest lidar stations.

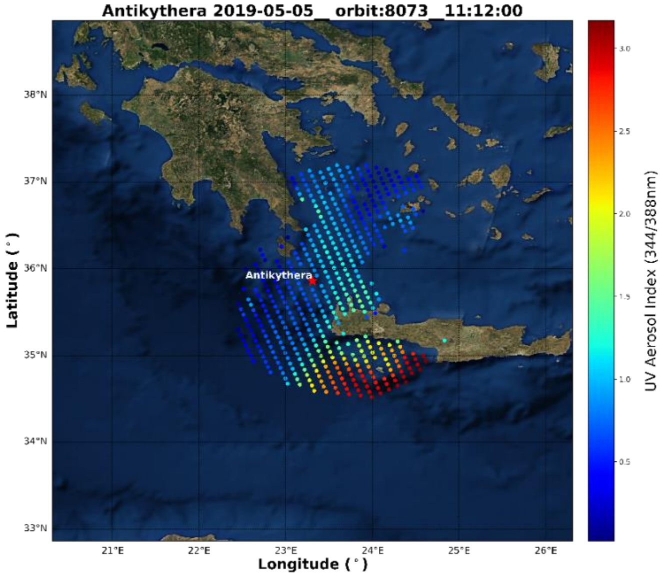


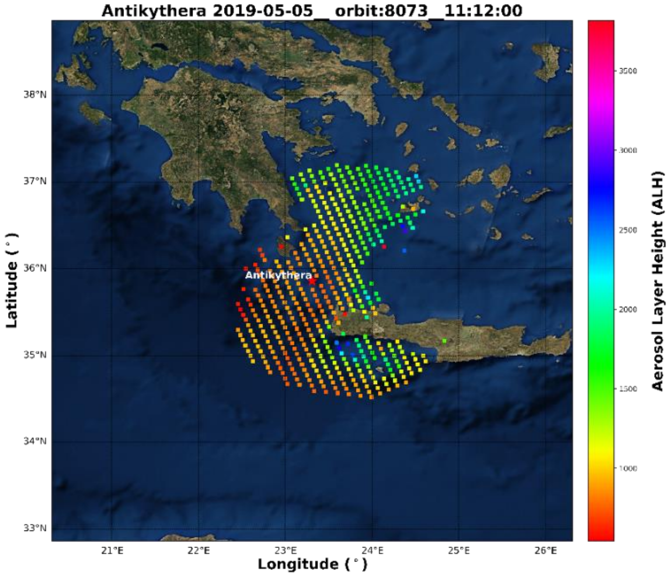
Scatterplots of collocated layers from EARLINET lidar observations against the satellite AAH or the collocated cases.

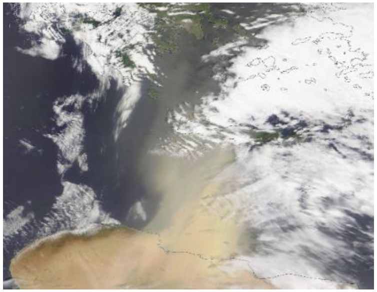


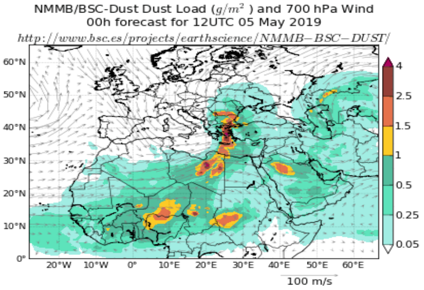
Histograms of the absolute bias between the lidar upper layer top from study stations and the satellite AAH for the collocated cases.

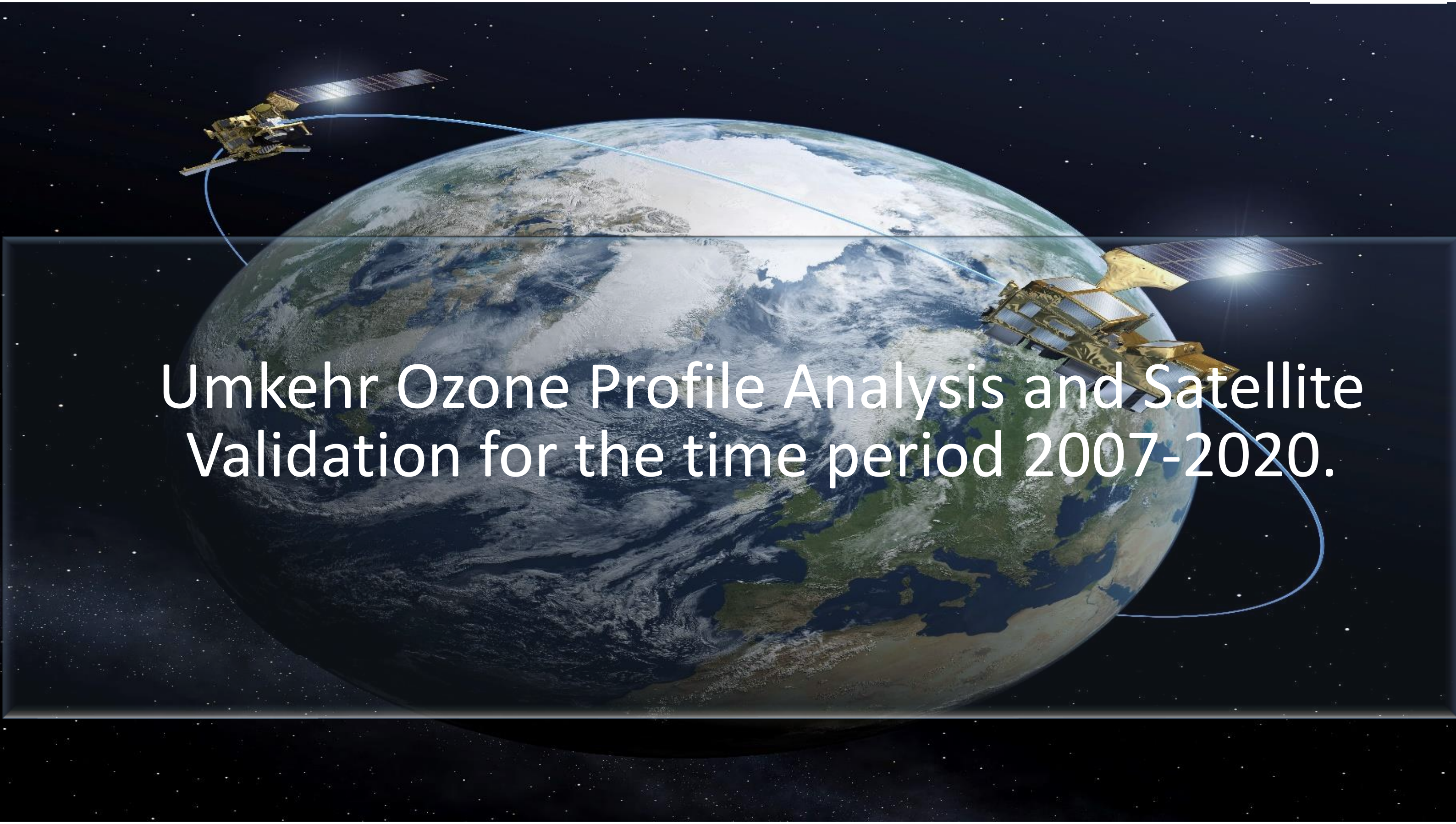
S5P example | ALH, AI & Dust transport









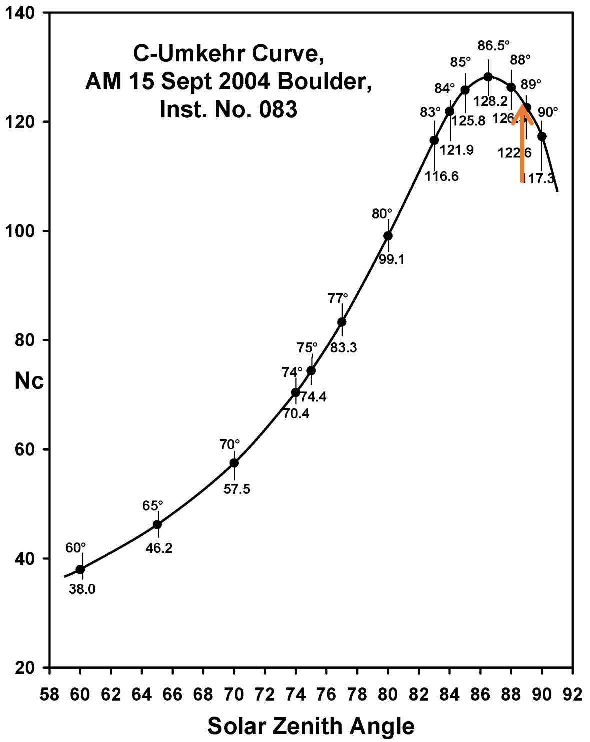


Umkehr Ozone Profile Analysis and Satellite Validation for the time period 2007-2020.

WP Layout

- Acquire Umkehr records for selected stations from the WOUDC archive for the period 2007 to 2020.
- Investigate the EuBrewNet database for possible Umkehr measurements that could be analyzed.
- Collect and ingest information about instrument calibrations and reports on inter-comparisons for selected station record so as to identify instrumental artefacts in the data record.
- Reprocess for selected stations the full 2007-2020 dataset and reduce a large part of the bias currently existing between satellite and Umkehr ozone profiles for e.g. due to stray light entering the spectrometer.

What is the Umkehr effect?



Umkehr means "reversal"

$$N(\theta) = 100x\log\left(\frac{I'(\theta)}{I(\theta)}\right)$$

I is strongly absorbed by ozone, while *I'* weakly

Brewer Umkehr Measurements

- Measurements of zenith sky radiance at 8 distinct wavelengths during sunrise and/or sunset.

Slit #	Short Umkehr wv (nm)	Long Umkehr wv (nm)
1	306.3	316.8
2	310.1	320.1
3	313.5	323.2
4	316.8	326.4
5	320.1	329.5

- The ratio of measurements at 320.1 is used for cloud screening
- The measurements from ~310 and ~326 nm form the single N-Value

Ozone Profile Retrieval

- The profile retrieval is based on UMK04 O3BUmkehr software for Brewers & Windobson for Dobsons and is reported in a 16 layer scheme with each layer being ~5 km thick.

Layer	Layer Boundary (km)	Pressure limits (hPa)
0	0 – 5.5	1013 – 506.5
1	5.5 – 10.3	506.5 – 253.25
2	10.3 – 14.7	253.25 – 126.63
3	14.7 – 19.1	126.63 – 63.31
4	19.1 – 23.5	63.31 – 31.66
5	23.5 – 28	31.66 – 15.83
6	28 – 32.6	15.83 – 7.91
7	32.6 – 37.5	7.91 – 3.96
8	37.5 – 42.6	3.96 – 1.98
9	42.6 – 47.9	1.98 – 0.99
10	47.9 – 53.2	0.99 – 0.49
11	53.2 – 58.3	0.49 – 0.25
12	58.3 – 63.1	0.25 – 0.12
13	63.1 – 67.8	0.12 – 0.06
14	67.8 – 72.2	0.06 – 0.03
15	72.2 – top of the atmosphere	0.03 – 0

0+1

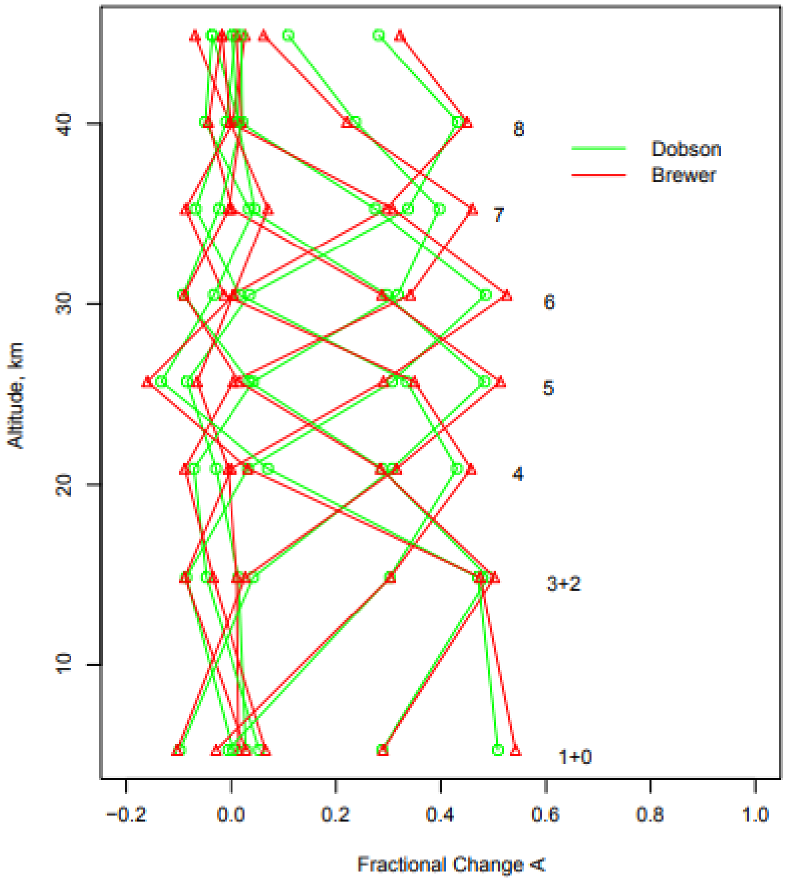
2+3

8+

Petropavlovskikh et al., 2005

http://o3soft.eu/ | https://ds.data.jma.go.jp/gmd/wcc/dobson/windobson.html

Sensitivity of the retrieval to ozone vertical information



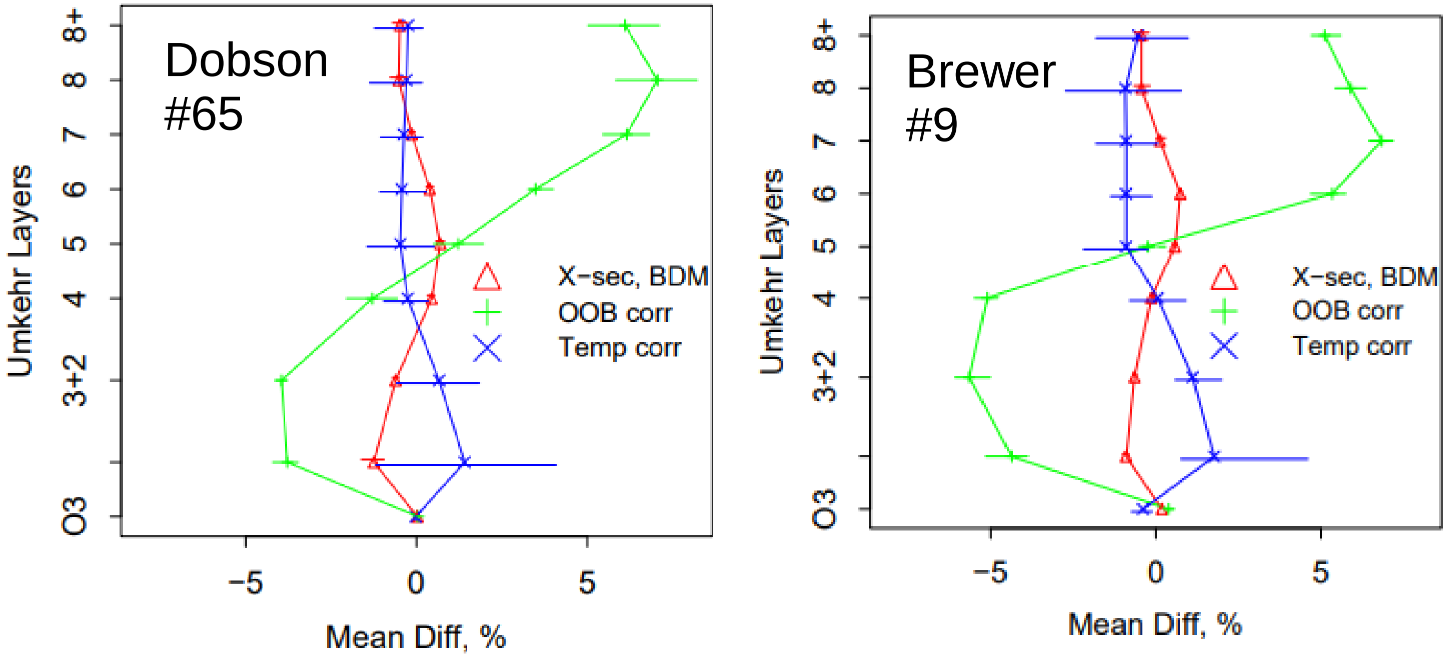
- Information in the layer is sensed at ~60–70 %, while the rest of the information comes from the adjacent layers.
- Vertical smoothing to the retrieved ozone profiles.

Petropavlovskikh et al. 2011

Retrieval errors

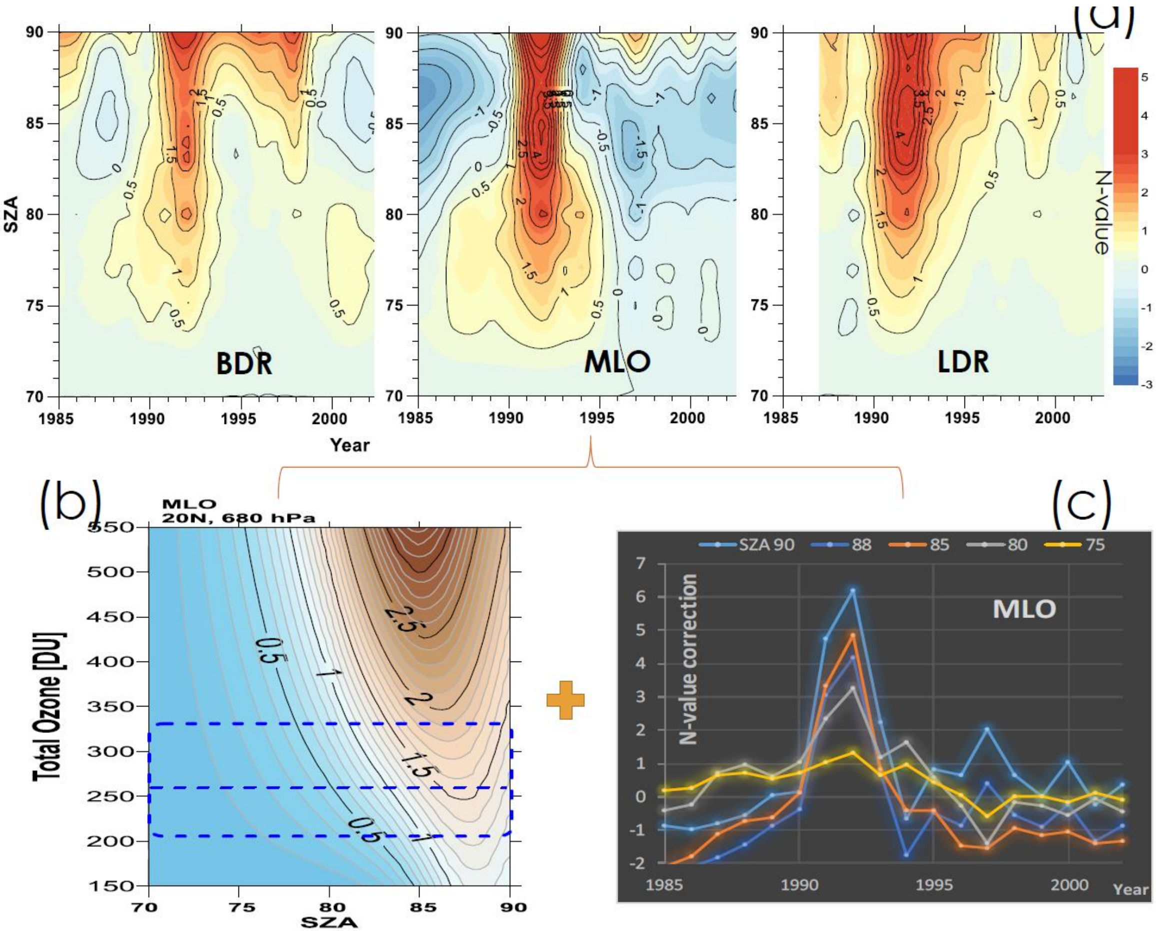
- **Forward model errors** (accuracy of the radiative-transfer code to produce correction tables, use of effective absorption and scattering coefficients instead of line-by-line spectroscopic data)
  - ✓ Aerosols (especially stratospheric aerosols)
  - ✓ Multiple scattering
  - ✓ Surface reflectivity
- **Inverse model errors**
  - ✓ A priori information and measurement noise
  - ✓ Atmospheric Temperature (temperature dependence of ozone cross sections)
- Overall uncertainty of the Umkehr method: 25% for the troposphere, 15% for the lower stratosphere, within ±10% for the middle and upper stratosphere, while errors increase further in layer 8 (~37.5 km)

Stray light and ozone cross sections effects



Petropavlovskikh et al. 2011

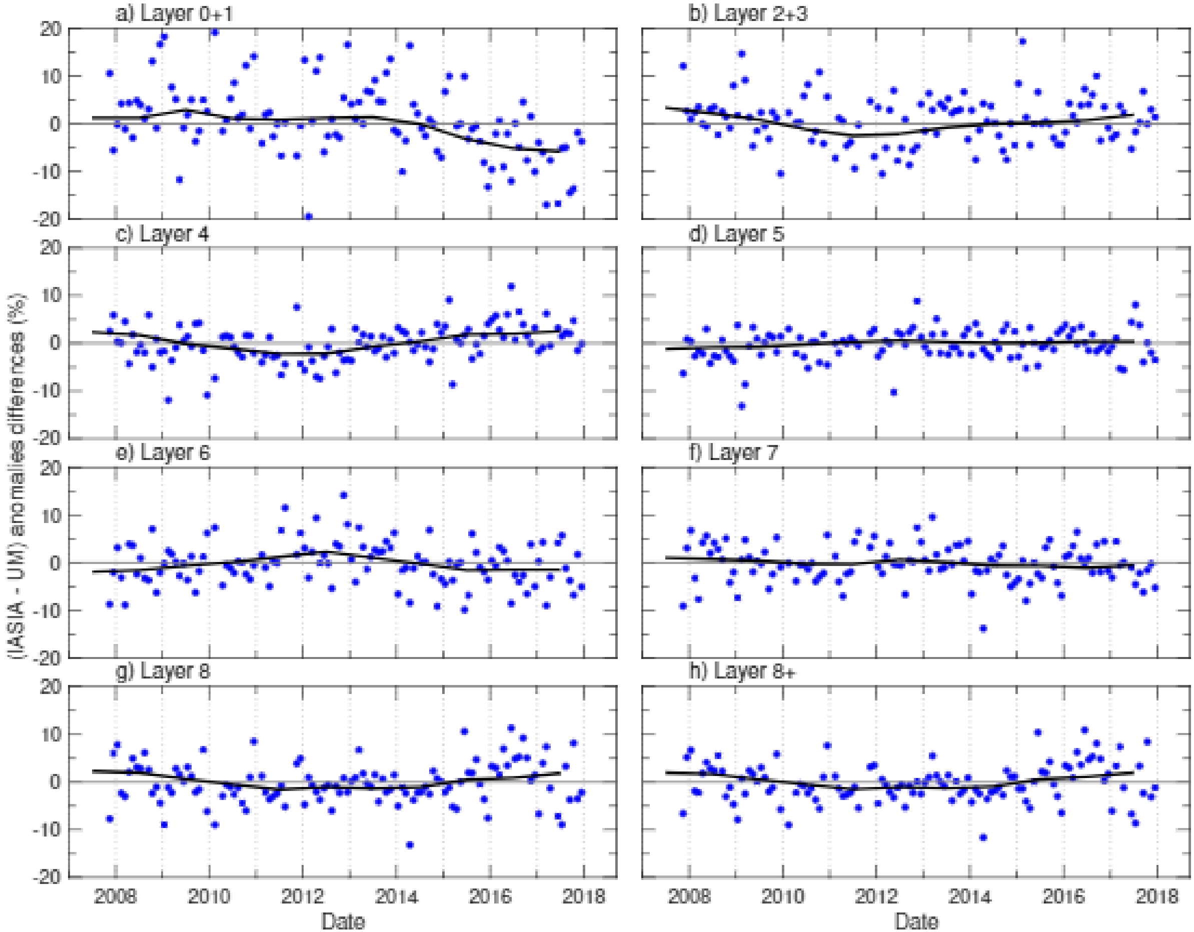
Umkehr correction for aerosols



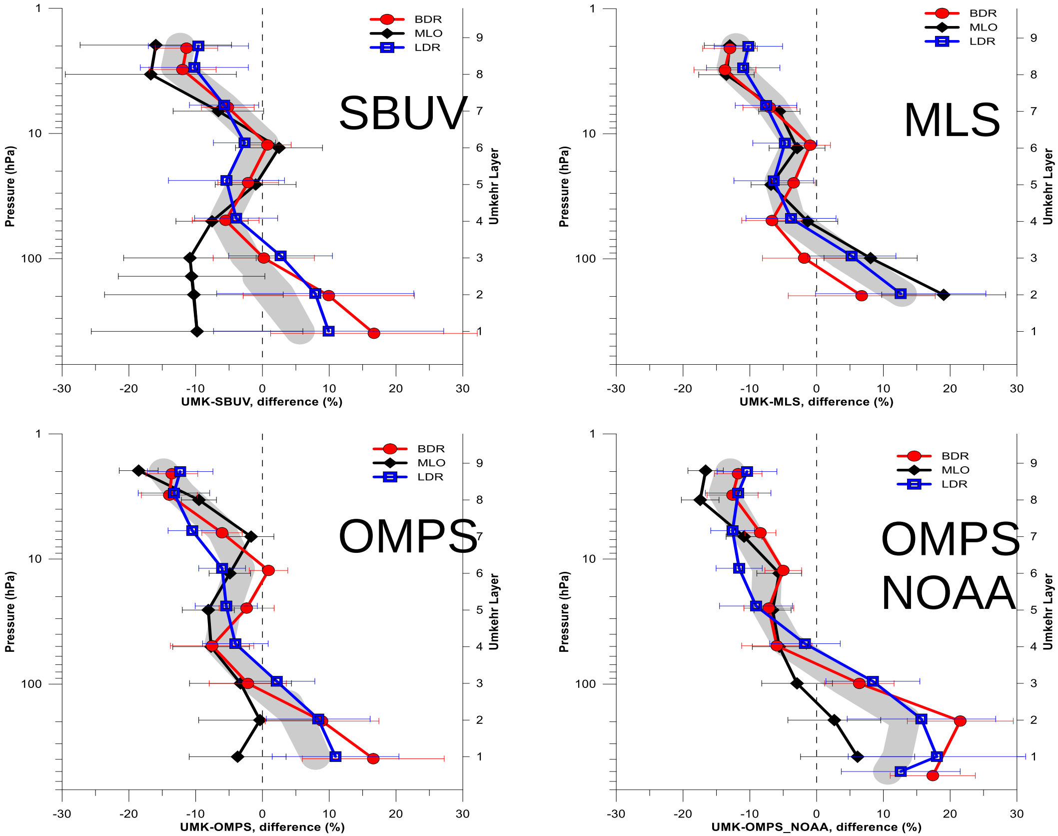
2. N-value correction optimized using the GMI model. Modeled correction is based on GMI model ozone profile data matched to the Umkehr observations.

Validation results from Brewer and Dobson retrievals

Differences of the monthly mean anomalies for IASI-A and Umkehr for Thessaloniki



Dobson retrievals against different satellite products



Plans for processing

- Investigate the EUBREWNET database for identifying stations with Umkehr measurements during the period 2007 – 2020.
- Extract the b-files of the stations and process them with the O3BUmkehr software.
- Apply empirical corrections for stray light effect for single monochromator Brewers.
- Investigate the temporal stability of the retrievals and identify possible instrumental issues that could affect the retrievals, examining the ratio between the N values at a specific SZA (the one used for the normalization) and TOC.
- Document any identified instrumental events that could affect the quality of the retrievals and subsequently the comparison with satellite datasets.


GRAZIE
THANK YOU
RAIBH MAITH AGAT
GRAZIE
NIRRINGRAZZJAK
KIA ORA
NIRRINGRAZZJAK
UA TSAUG RAU KOJ
MULTUMESC
MOCHCHAKKERAM
OBRIGADO
SPASIBO
SALAMAT
RAIBH MAITH AGAT
MOCHCHAKKERAM
TERMA KASIH
MAMANA
MATONDO
SPASIBO
MERCI
KIITOS
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CHOKRANE
MATONDO
KIITOS
CHOKRANE
GRAZIE
KIITOS
MATUR NUWUN
SALAMAT
CAM ON BAN
MOCHCHAKKERAM
RAIBH MAITH AGAT
ASANTE
MOCHCHAKKERAM
ARIGATO
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KIA ORA
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NIRRINGRAZZJAK
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MAAKE
JUSPAXAR
MAAKE
ARIGATO
MULTUMESC
SPASIBO
CHOKRANE
KIITOS
RAIBH MAITH AGAT
MERCI

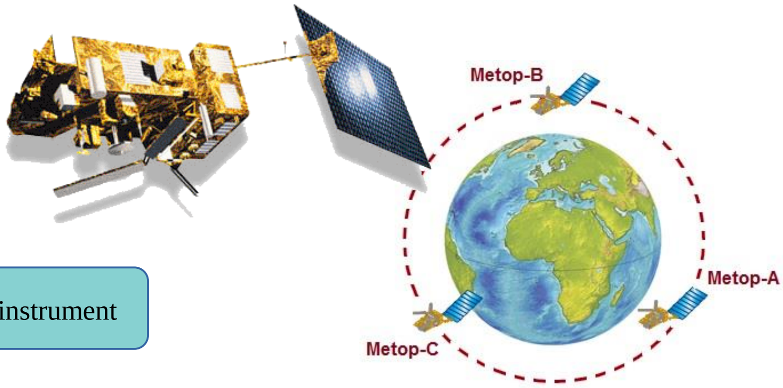
Back up slides

MetOp satellites

- MetOp is a series of three polar-orbiting meteorological satellites developed by the European Space Agency (**ESA**) and operated by the European Organization for the Exploitation of Meteorological Satellites (**EUMETSAT**).

- The Metop satellites, have 12 instruments and are flying in sun-synchronous polar orbits, at an altitude of 817km with Equator crossing times of approximately 09:30 LT (descending node) and Repeat cycle of 29 days.

  - **MetOp-A**, launched on October 19, **2006**
  - **MetOp-B**, launched on September 17, **2012**
  - **MetOp-C**, launched on November 7, **2018**



All three MetOp satellites host identical versions of the **GOME-2** instrument

GOME-2 Instrument characteristics

Table 2: Summary of the GOME 2 on MetopA/B/C instrument characteristics

	GOME-2 MetOp-A	GOME-2 MetOp-B	GOME-2 MetOp-C
Spectral band (nm)	MSC: 240-790 PMD: 300-800	MSC: 240-790 PMD: 300-800	MSC: 240-790 PMD: 300-800
Spectral channels	4096	4096	4096
Polarization channels	30	30	30
Spectral resolution (nm)	0.26-0.51	0.26-0.51	0.26-0.51
Spatial resolution MSC(1) (km^2)	80 x 40 40 x 40 (3)	80 x 40	80 x 40
Spatial resolution PMD(2) (km^2)	40 x 10 40 x 5(3)	40 x 10	40 x 10
Swath Width (km)	1920-960(3)	1920	1920
Equator crossing time	09:30am LT (descending)	09:30am LT (descending)	09:30am LT (descending)
Global coverage / repeat cycle (days)	1.5 / 29	1.5 / 29	1.5 / 29

[1]MSC= Main Science Channels
[2]PMD = Polarisation Measurement Device
[3]GOME-2A tandem operation since 15 July 2013

(more information: Munro et al., 2016)

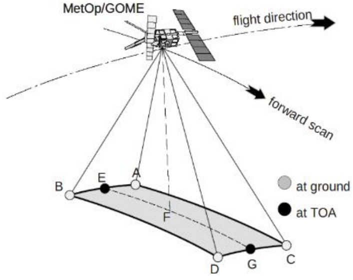


Figure 3: GOME-2 ground pixel geometry (image credit: ESA)

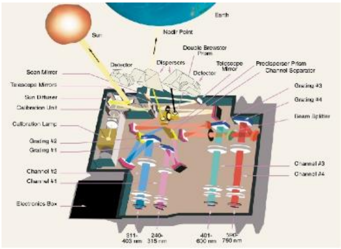


Figure 4: The GOME-2 instrument (image credit: ESA)

GOME-2 instrument on Metop

- The GOME-2 instrument is a nadir looking and scanning UV-VIS spectrometer that measures backscattered ultraviolet and visible (240-790nm) radiation from the earth / atmosphere system.

- Measurements are made in four spectral bands to retrieve amounts of both ozone and other trace gases, aerosols. The **fig. 5,** summarizes the GOME-2 measurements and shows the potential trace gases that may be detected.

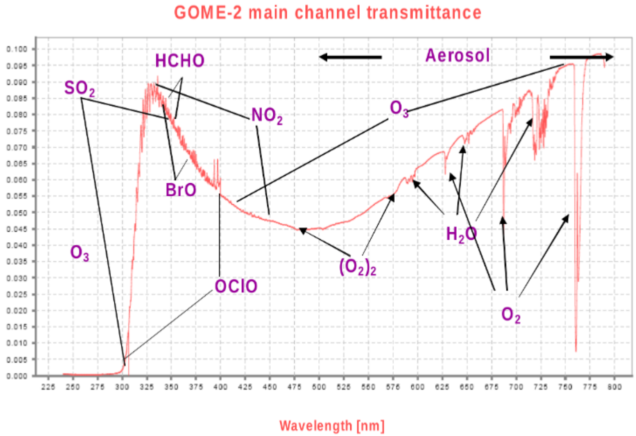


Figure 5 : GOME-2 transmittance as derived from the GOME-2 level 1b radiance product.

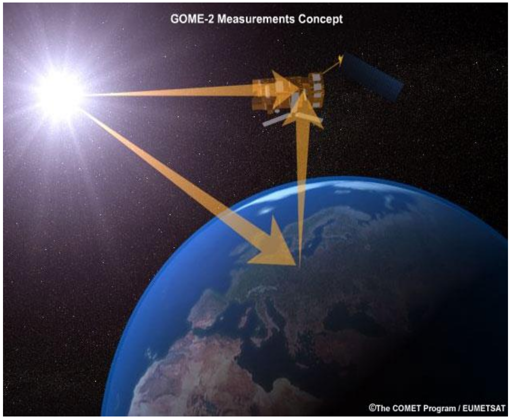


Figure 6: GOME-2 satellite sensor measurements concept

Absorbing Aerosol Index (AAI)

- The absorbing Aerosol Index (AAI) indicates the presence of elevated absorbing aerosols in the Earth's atmosphere.
- It separates the spectral contrast at two ultraviolet (UV) wavelengths caused by absorbing aerosols from that of other effects, including molecular Rayleigh scattering, surface reflection, gaseous absorption and aerosol and cloud scattering (Torres et al., 1998).

The aerosol types most clearly seen with **AAI**:

- ✓ Desert dust
- ✓ Biomass burning aerosols and
- ✓ Volcanic ash

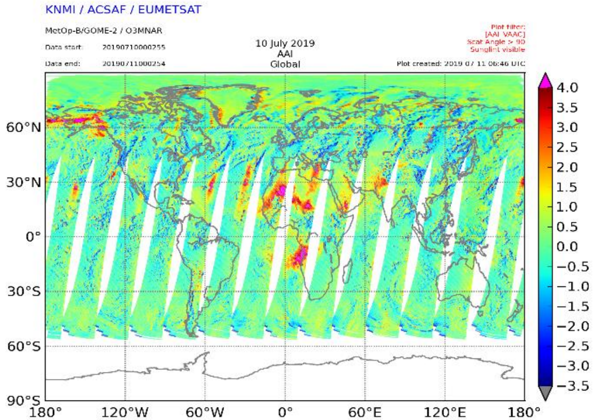


Figure 7: AAI from GOME-2 on Metop-B for the June 10th 2019.

- The AAI can be **retrieved over land and ocean surfaces,** even in the presence of clouds.
- **Clouds** & **scatttering aerosols** ⟶ **AAI negative values**.
- **Absorbing aerosols** ⟶ **AAI positive values**.

GOME-2 Absorbing Aerosol Index

- The operational GOME-2 Absorbing Aerosol Index (AAI), produced by the **ACSAF** of **EUMETSAT**, is derived from the 340/380 nm wavelength pair (Tilstra et al., 2010; De Graaf et al., 2010)

GOME-2 AAI product have a number of characteristics properties that need to take into account:

✓ The AAI is sensitive to **sunglint** and leads to anomalously high values. Observations affected by sunglint are skipped. Sunglint flag provided in the GOME-2 AAI product is used to filter sunglint cases.

Figure 8: Sunglint effect over Greece (image credits: ESA/NASA)

✓ Observations during a **solar eclipse** should be not used and the affected measurements need to be removed from the analysis. A solar eclipse flag is determined for each observation.

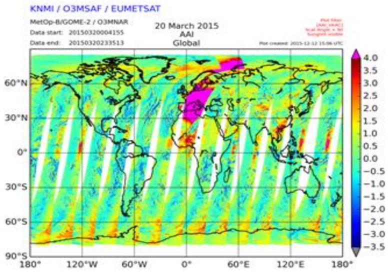


Figure 9: Solar eclipse event (image credit:TEMIS)

THELISYS
(Thessaloniki Lidar System)

- **THELISYS** is the lidar system that belongs to the Laboratory of Atmospheric Physics located in the Physics in Physics Department of Aristotle University of Thessloniki (40.63ºN, 22.96ºE, elevation 50 m).

- The lidar station of Thessaloniki currently provides a dataset of lidar profiles in the period 2000-2019 processed with the station's operational algorithm. This dataset is publicly available in the **EARLINET** database (https://www.earlinet.org).

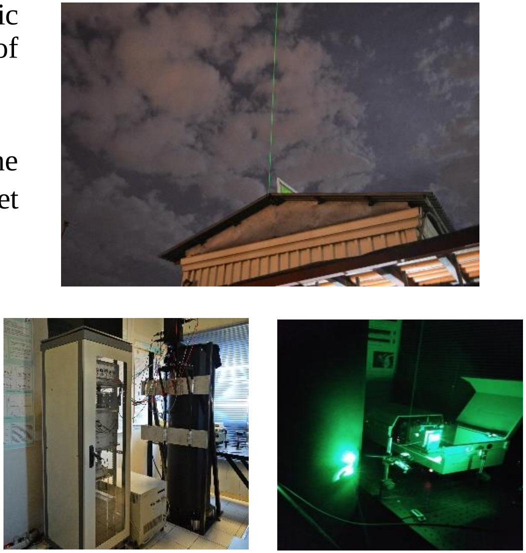
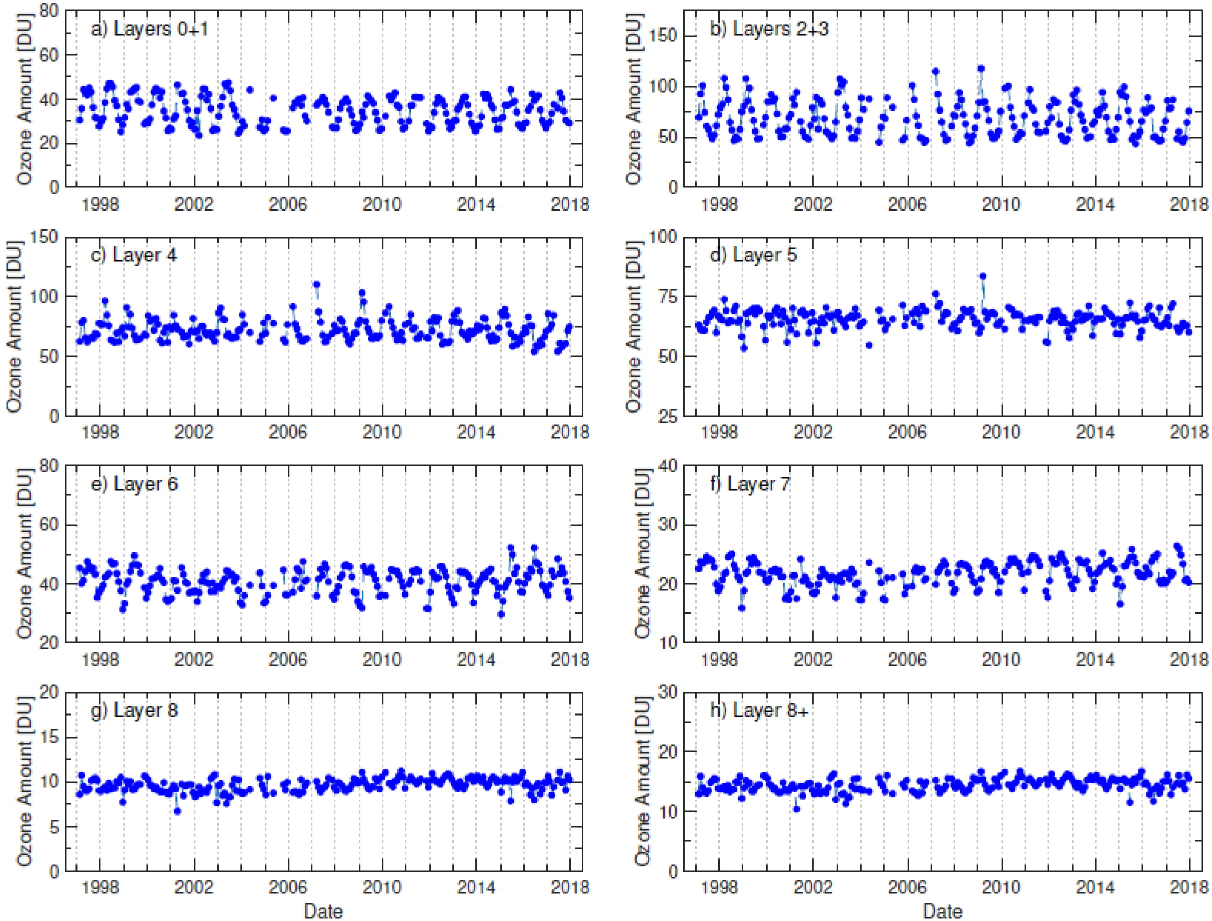


Figure 11: Thessaloniki lidar system (THELISYS)

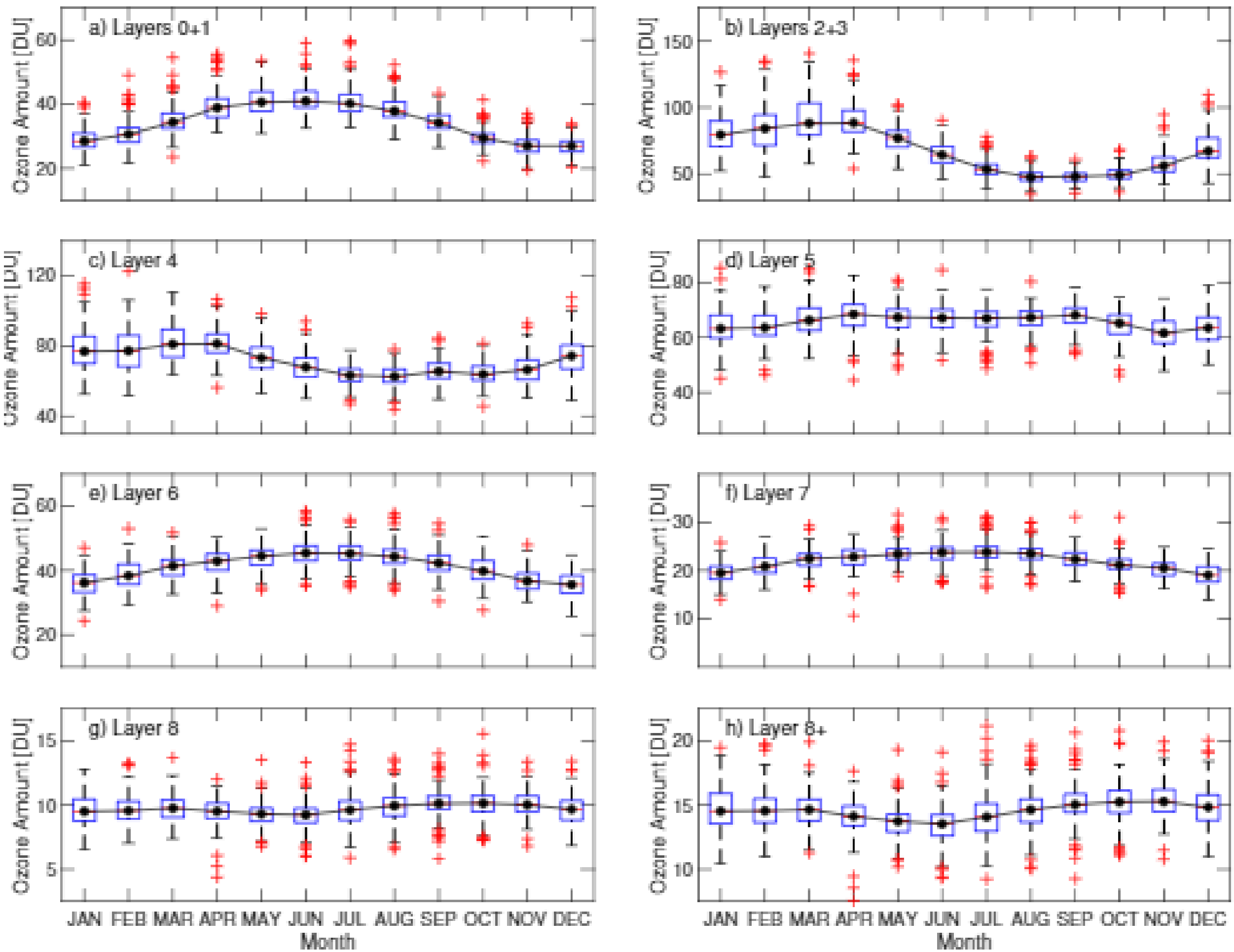
The current primary setup of the THELISYS included:

- Three elastic backscatter channels at **355nm, 532 nm** and **1064nm**,
- Two nitrogen Raman channels at **387nm** and **607nm** and
- Two channels for the measurement of cross/parallel polarized signal at **532 nm**

Thessaloniki time series
Brewer # 5, Station 261



Annual cycle over SKG



Umkehr vs IASI/MetopA ozone profiles

- Regular Umkehr measurements in Thessaloniki during sunset since 1997.
- The comparison based on the period 2007 – 2018.
- Daytime IASI profiles.
- Closest profile in a effective radius of 100 km.
- IASI vertical analysis is higher than Umkehr.
- IASI are smoothed with the Umkehr averaging kernels

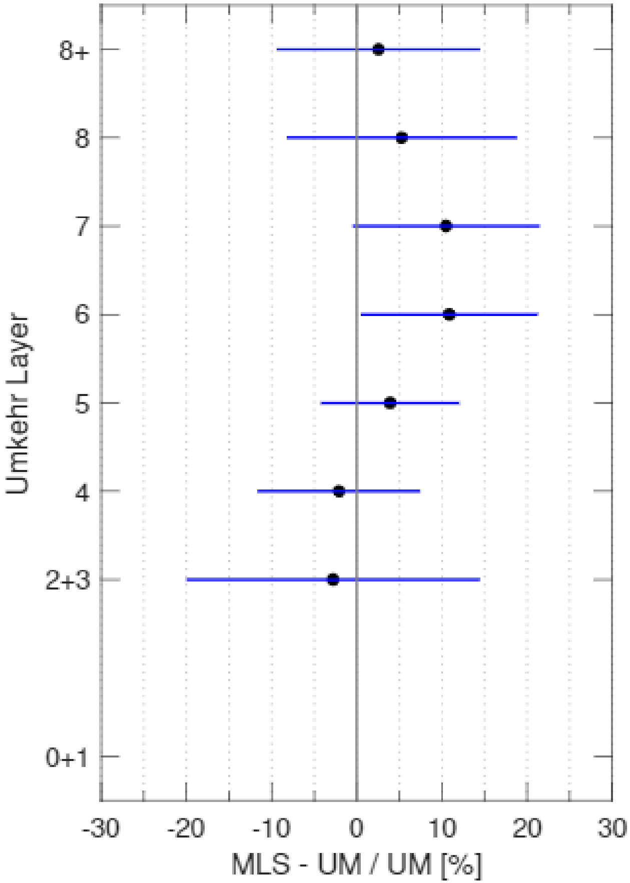
$$X\_sm(j) = \sum_k \left\{ AK\left(j,k\right) x \left[X_t(k) - AP(k)\right] \right\} + AP(j)$$

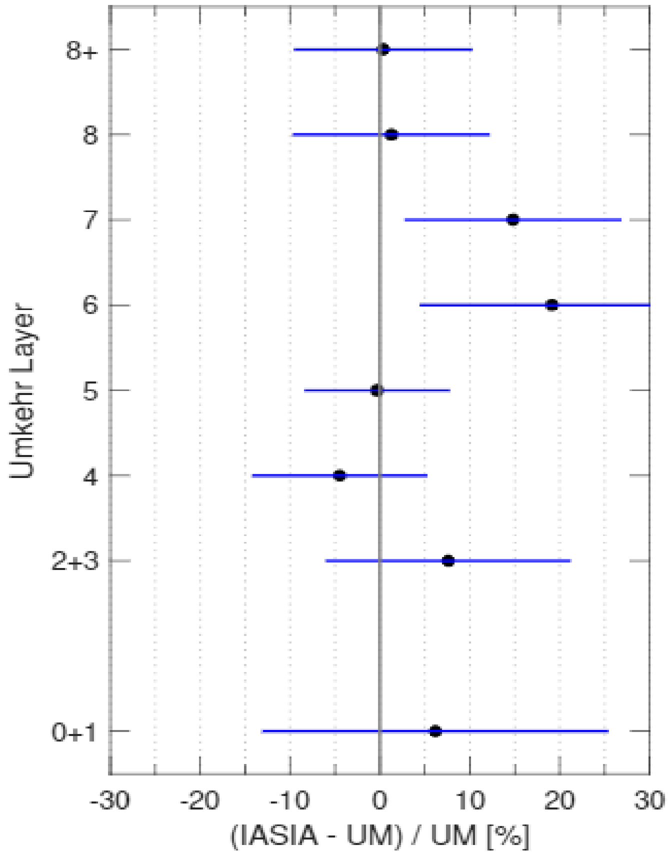
j: the Umkehr layer number
$X_t(k)$: IASI ozone profile in layer k
AP(*k*): Umkehr a priori in layer k
$\sum_k$: the integral of the smoothed differences in all layers

Mean differences in the vertical with

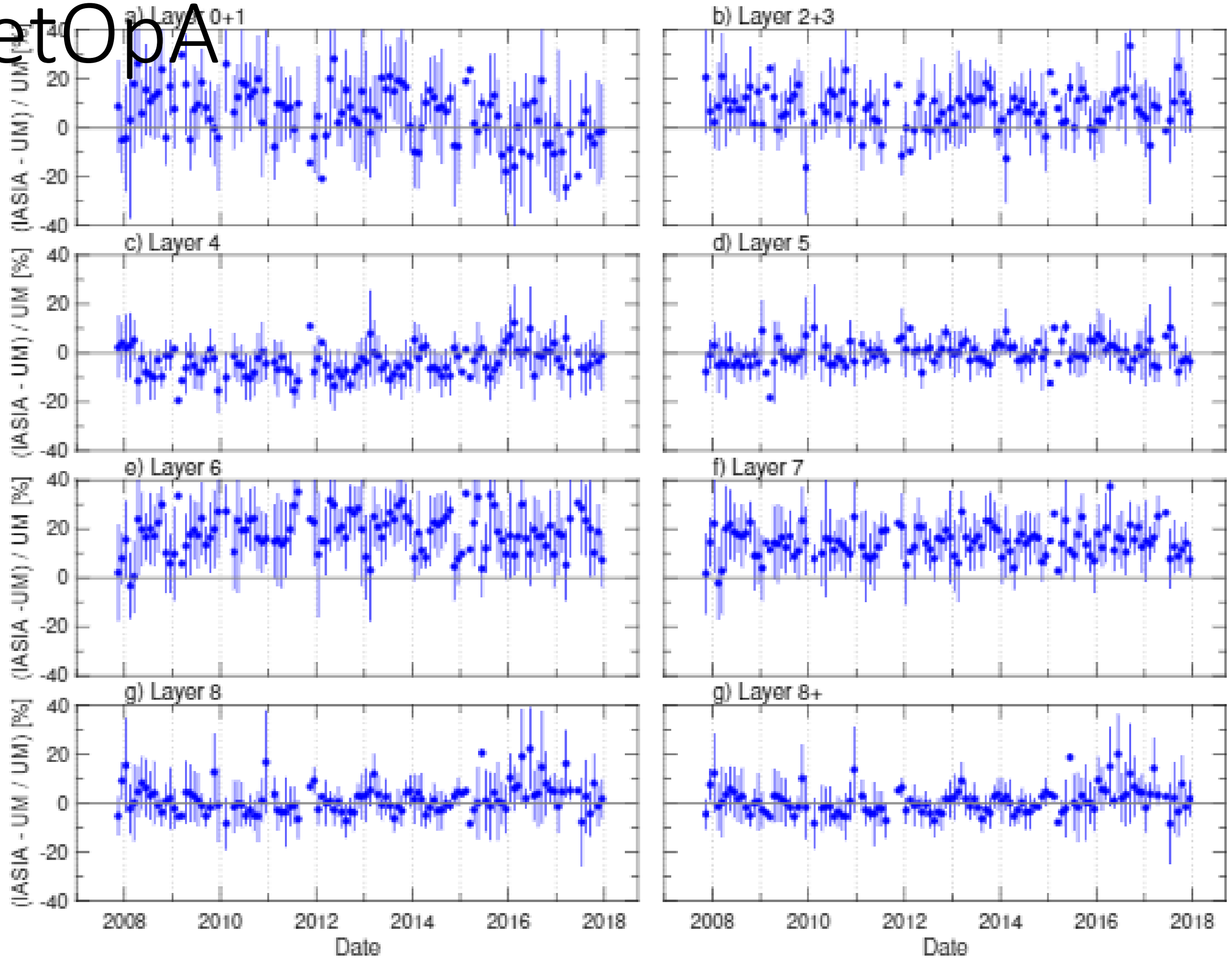
MLS/Aura -> left

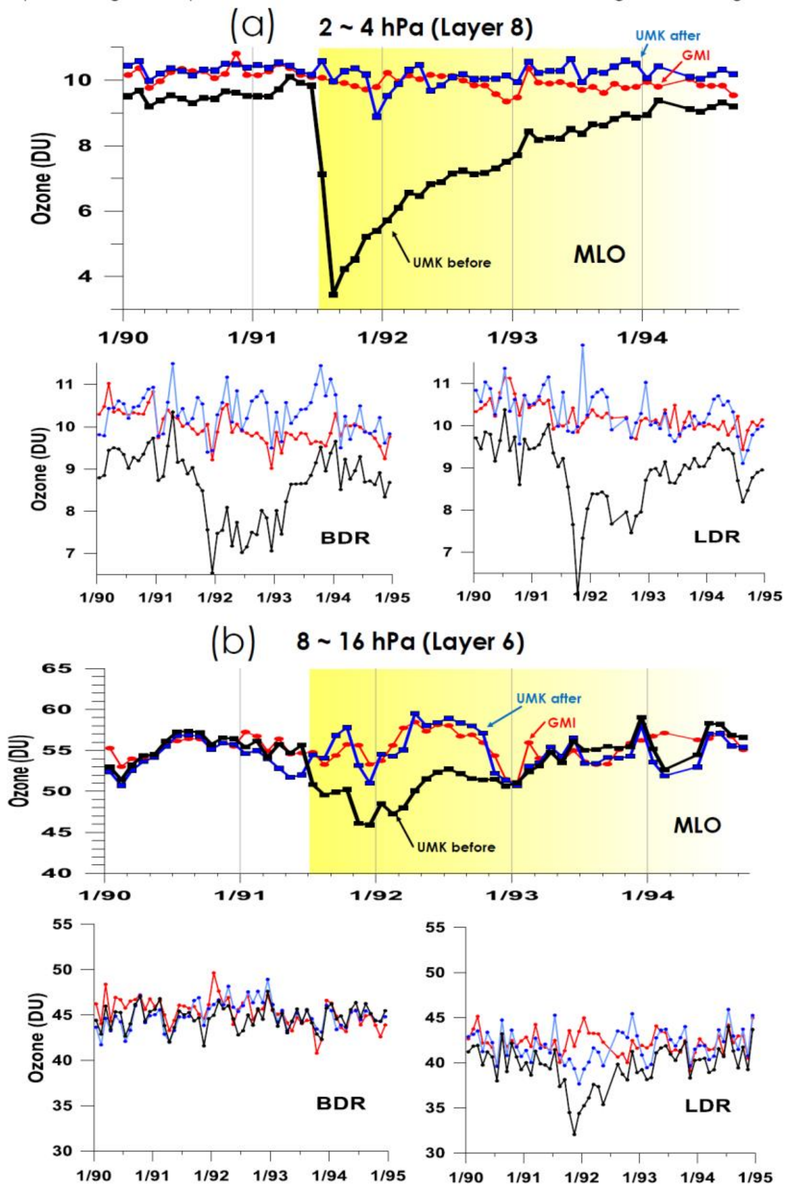
IASI/MetopA -> right





SKG Umkehr vs IASI MetOpA





3. Umkehr ozone profile during the period of 1991 Eruption of Mt. Pinatubo volcano: before and after correction