EUROPEAN SPACE AGENCY

EarthCARE 2026 Science and Validation workshop

8–12 June 2026 | Rhodes House | Oxford, UK

Assimilation of ATLID L2A Particulate Backscatter in ECMWF’s IFS-COMPO

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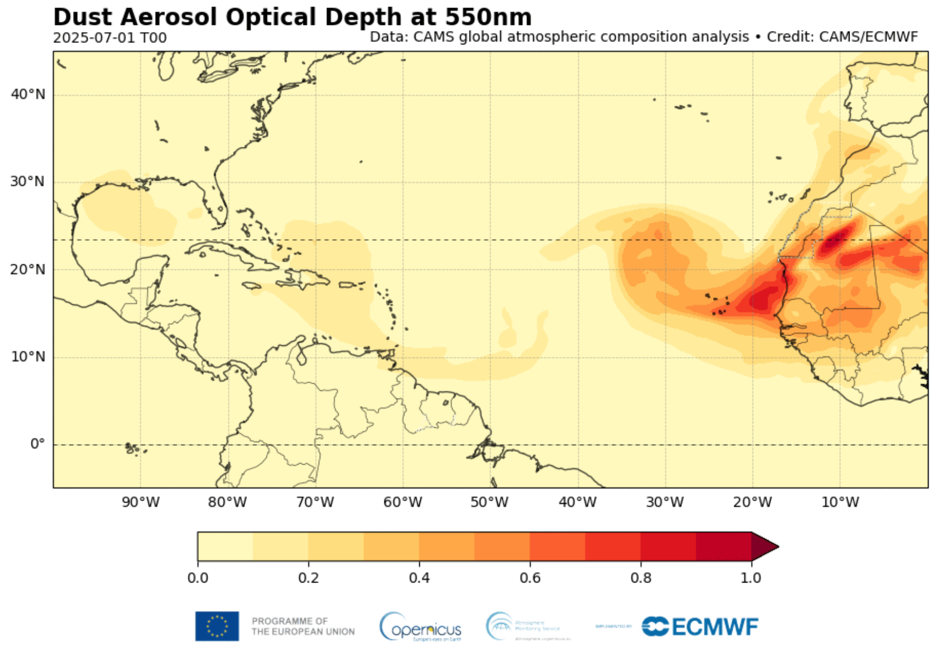
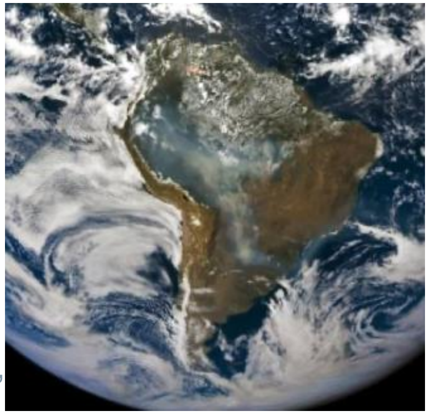
Background and motivation

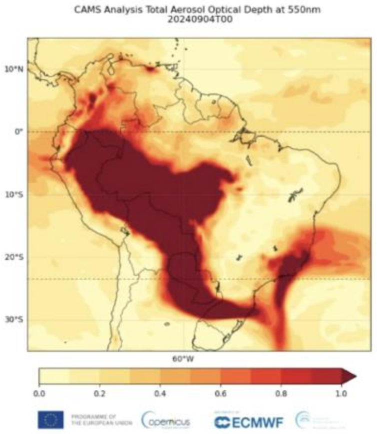
- Aerosols affect health, and influence cloud formation, weather, and climate through both direct and indirect radiative effects.

- The Copernicus Atmosphere Monitoring Service (CAMS) assimilate AOD products, providing information on the content of aerosols in an atmospheric column.

- AOD is a vertically-integrated quantity, giving total aerosol content. Assimilation of the ATLID EBD L2A particulate backscatter aims to improve the vertical placement, which can impact short-to-medium-range predictions of aerosol backscatter profiles and total AOD, and could lead to improvements to the representation of global aerosol transport.







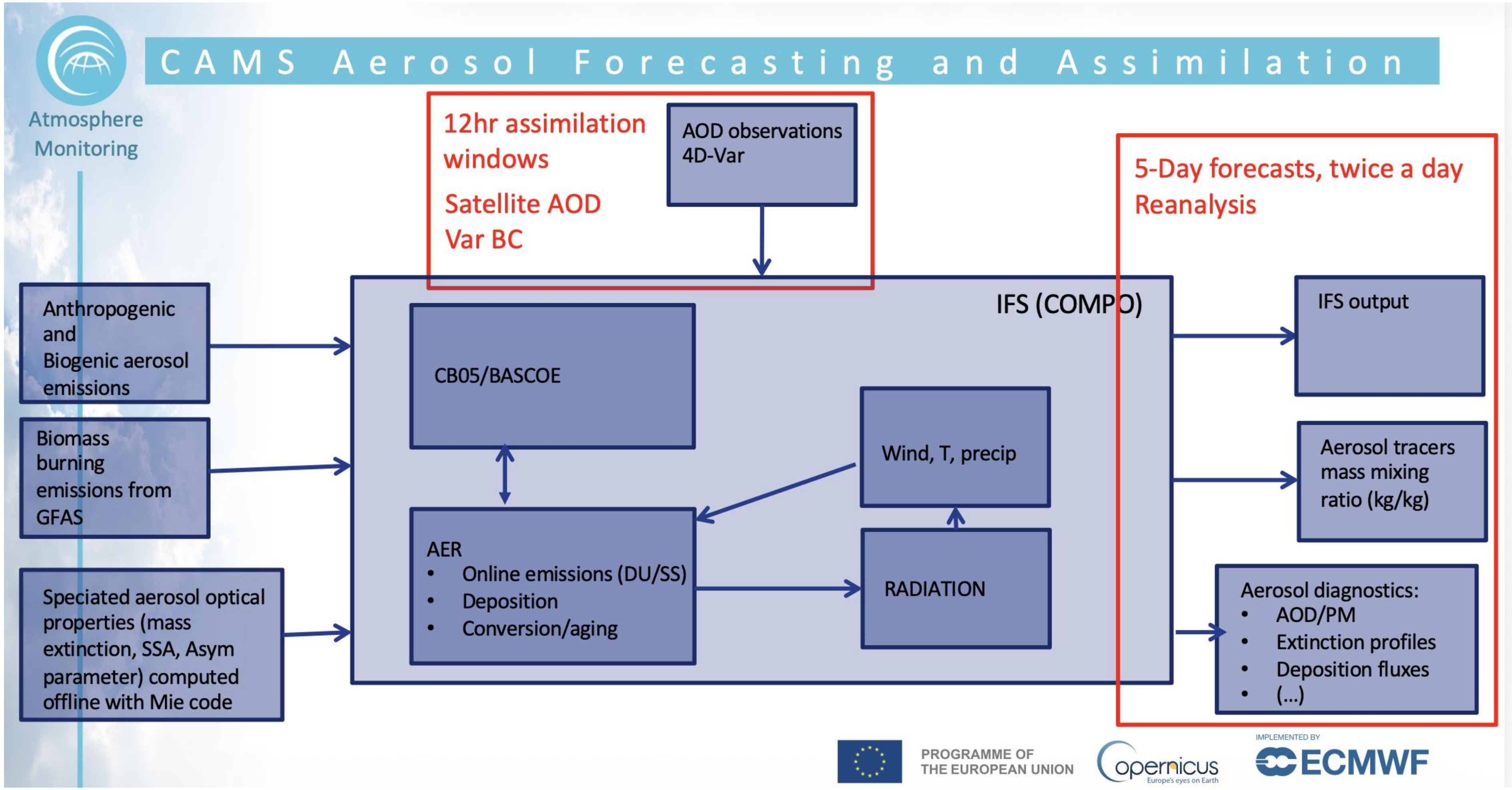
Top: CAMS global analysis of dust in July 2025. Bottom: smoke over South America; left image is from NASA's DSCOVR EPIC from 3 September 2024, and the right image the corresponding CAMS total AOD analysis. EPIC image: (https://earthobservatory.nasa.gov/images/153295/smoke-fills-south-american-skies),

Methodology and definitions

- Several Observing System Experiments (**OSEs**) were run in IFS-COMPO, the atmospheric composition configuration of the IFS used by CAMS.
- Various observation error assumptions were trialled; some OSEs used fixed errors, whilst others used errors varying as a function of the backscatter.
- In 4D-Var data assimilation, observation influence depends strongly on the assigned error. Lower observation errors give the data more weight relative to the model background, therefore appropriate error assignment is critical.
- Results are shown for four OSEs: three ATLID backscatter assimilation experiments and one CAMS-like control experiment.
- The ATLID experiments assimilate only observations classified as aerosol using the product simple classification flag.

OSE ID	Observation error used (units are $m^{-1}\,sr^{-1}$)	OSE number
iyj4	N/A, Control experiment, no ATLID assimilation	1
iz05	Experiment with constant error of $5{\times}10^{-7}$	2
j080	Experiment with constant error of $1{\times}10^{-6}$	3
j2xs	Experiment with dynamic error of $\frac{1}{4}\beta + 5{\times}10^{-7}$	4

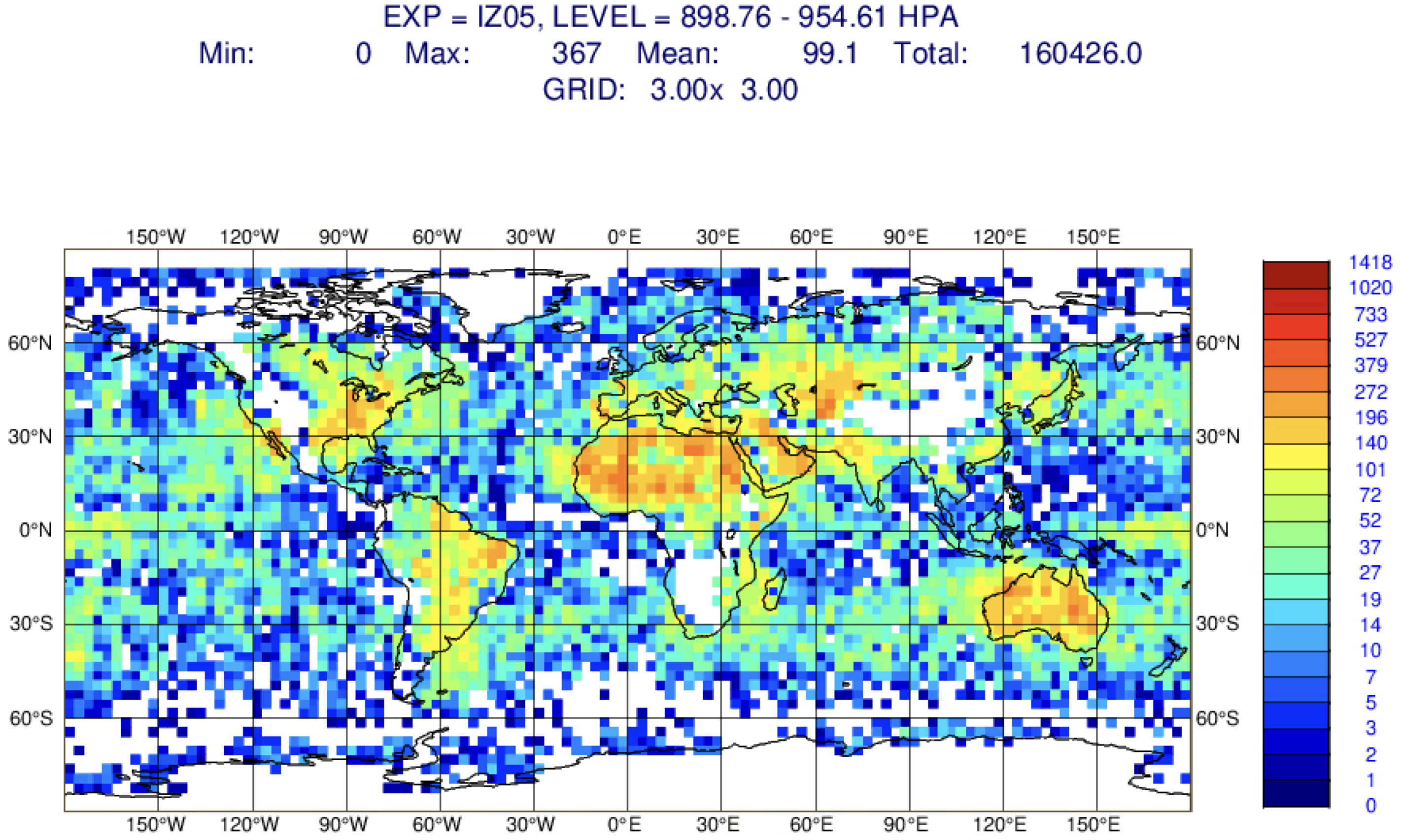
Schematic of the IFS-COMPO observing system



All OSEs were carried out in, at the time, the ECMWF/CAMS operational cycle CY49R1; future OSEs will be set up in CY50R1.

Average number of observations used in October 2025

The number of observations used in **OSE 2**, in the pressure range between about 955 and 899 hPa, corresponding on average to a range-bin of 0.5 to 1 km; the mean number of used data in a 3° by 3° latitude/longitude bin is 99.1.

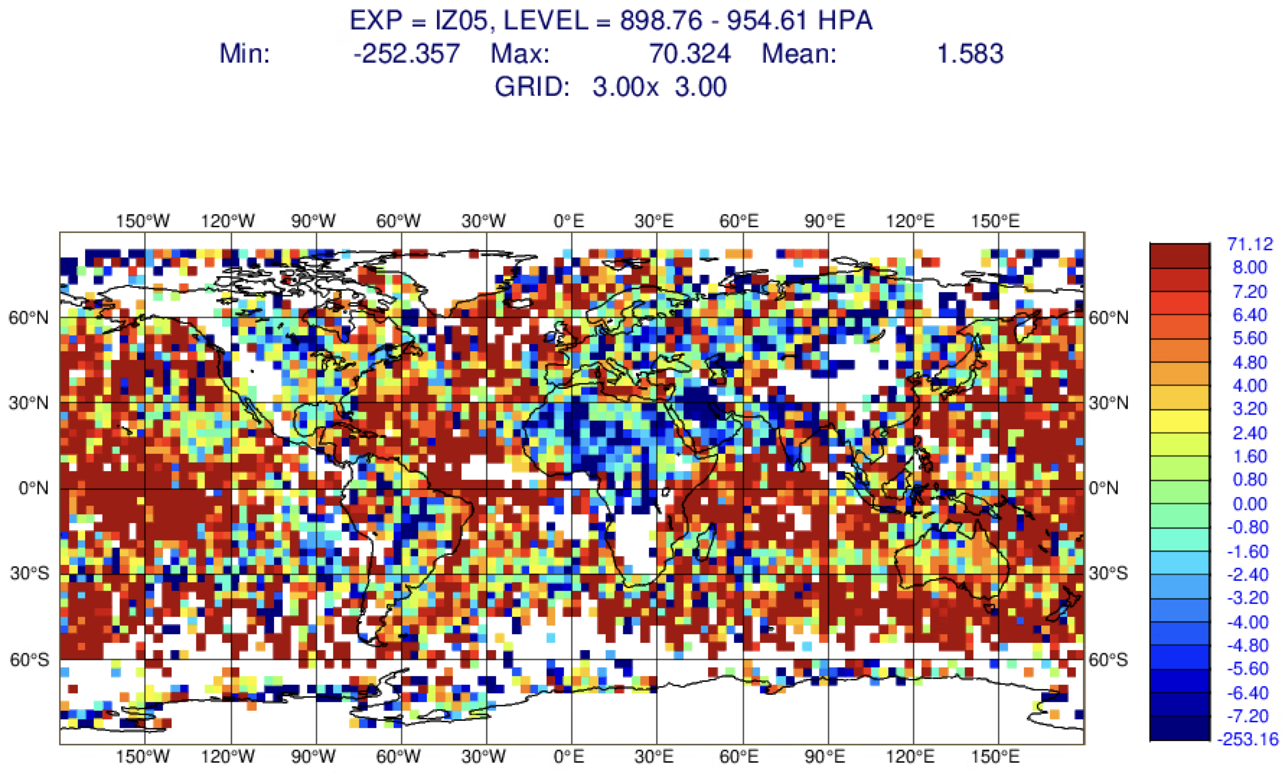


- The observation error and background errors determine the relative weight given to the observation and the background in the analysis; larger errors reduce observational weight, and QC can reject these observations..
- We do not assimilate data below 0.5 km nor above 8 km, a model-based cloud screening with additional quality control screens the observations, and this plot shows only the amount of data passing these checks.
- In addition, the ATLID data are re-gridded prior to the analysis, a procedure known as *super-obbing*, where the data are mapped to the ECMWF model grid, allowing for direct comparison of the ATLID observations to the model backscatter.

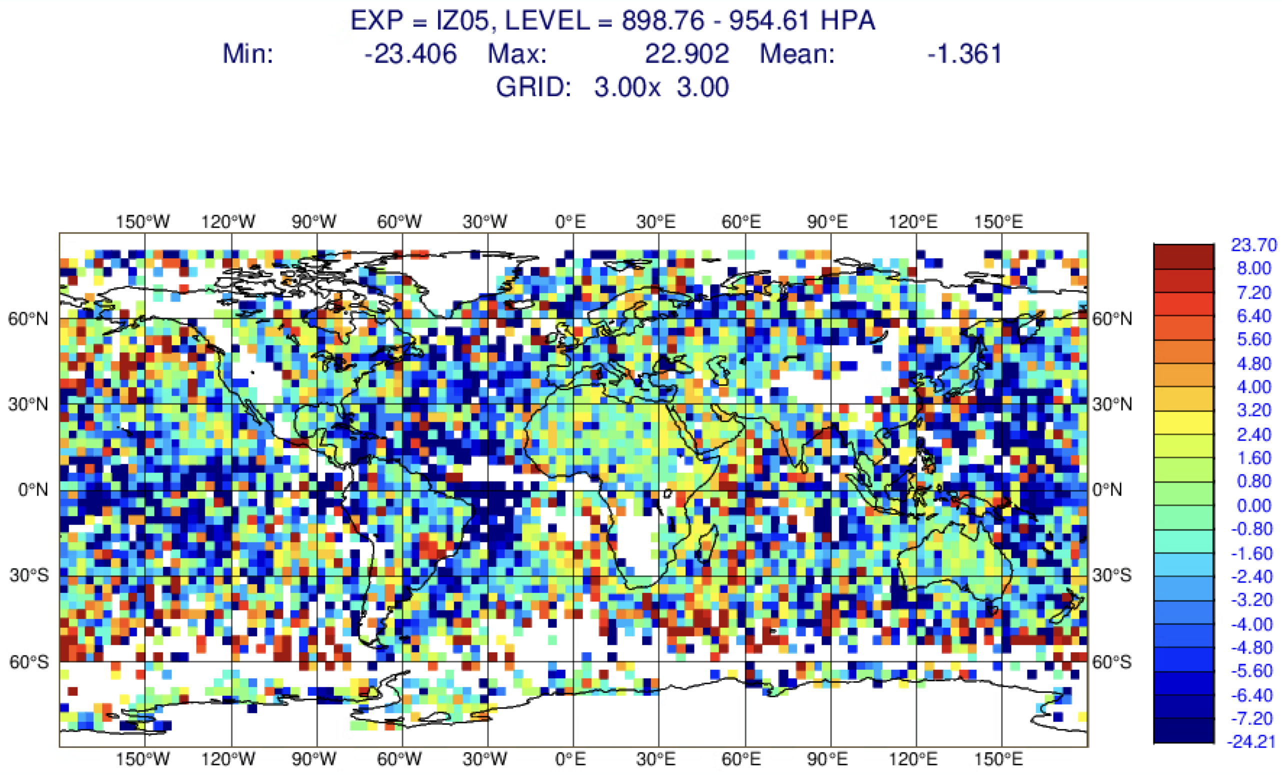
Average first-guess and analysis departure maps, October 2025

Data are from **OSE 2**, using the constant error of $5 \times 10^{-7} \mathrm{m\ sr}^{-1}$, in the same pressure range 955 to 899 hPa, which on average corresponds to 0.5 to 1 km above the surface.

First-guess departures (difference between ATLID and the model with no ATLID assimilation.) Mean departure is 1.583$\times 10^{-7}\ \mathrm{m}^{-1}\ \mathrm{sr}^{-1}$.

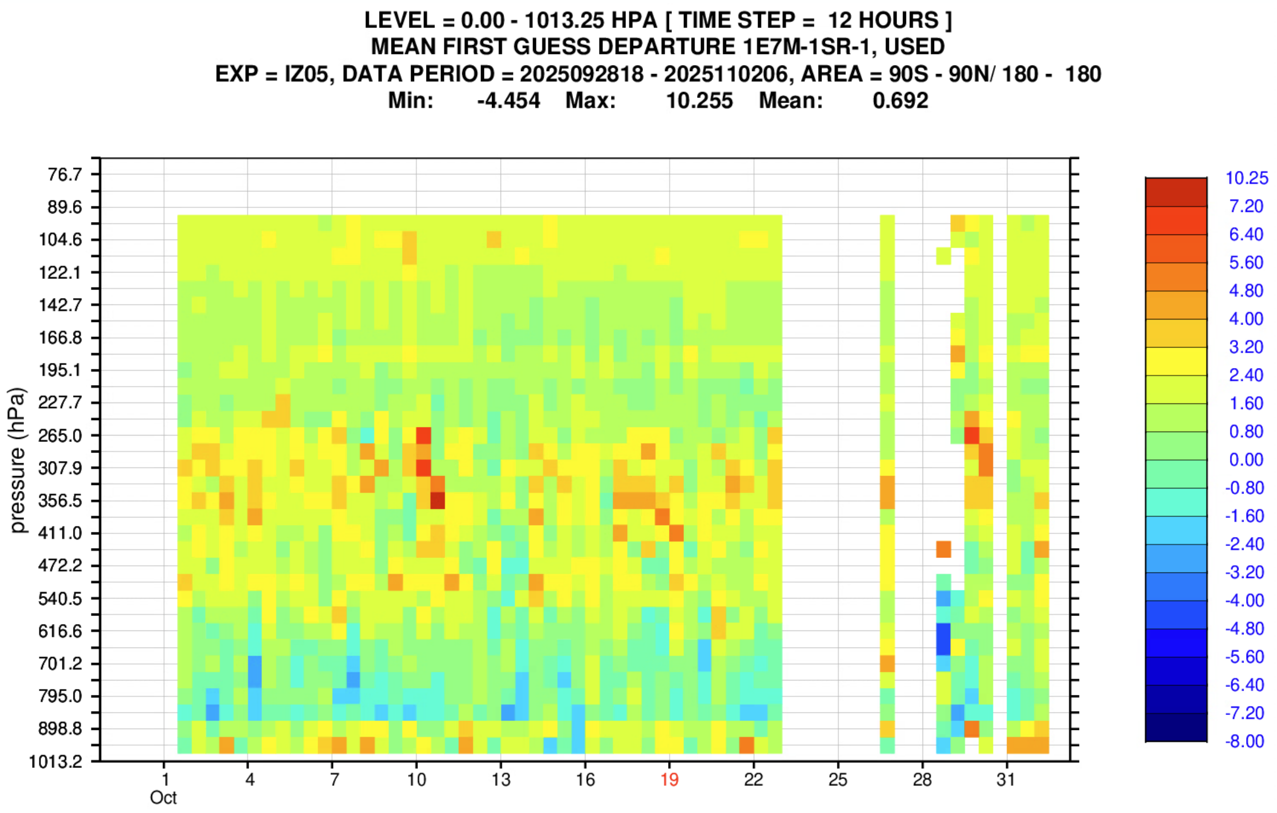


Analysis departures (difference between ATLID and the model with ATLID assimilation.) Mean departure is -1.361$\times 10^{-7}\ \mathrm{m}^{-1}\ \mathrm{sr}^{-1}$.

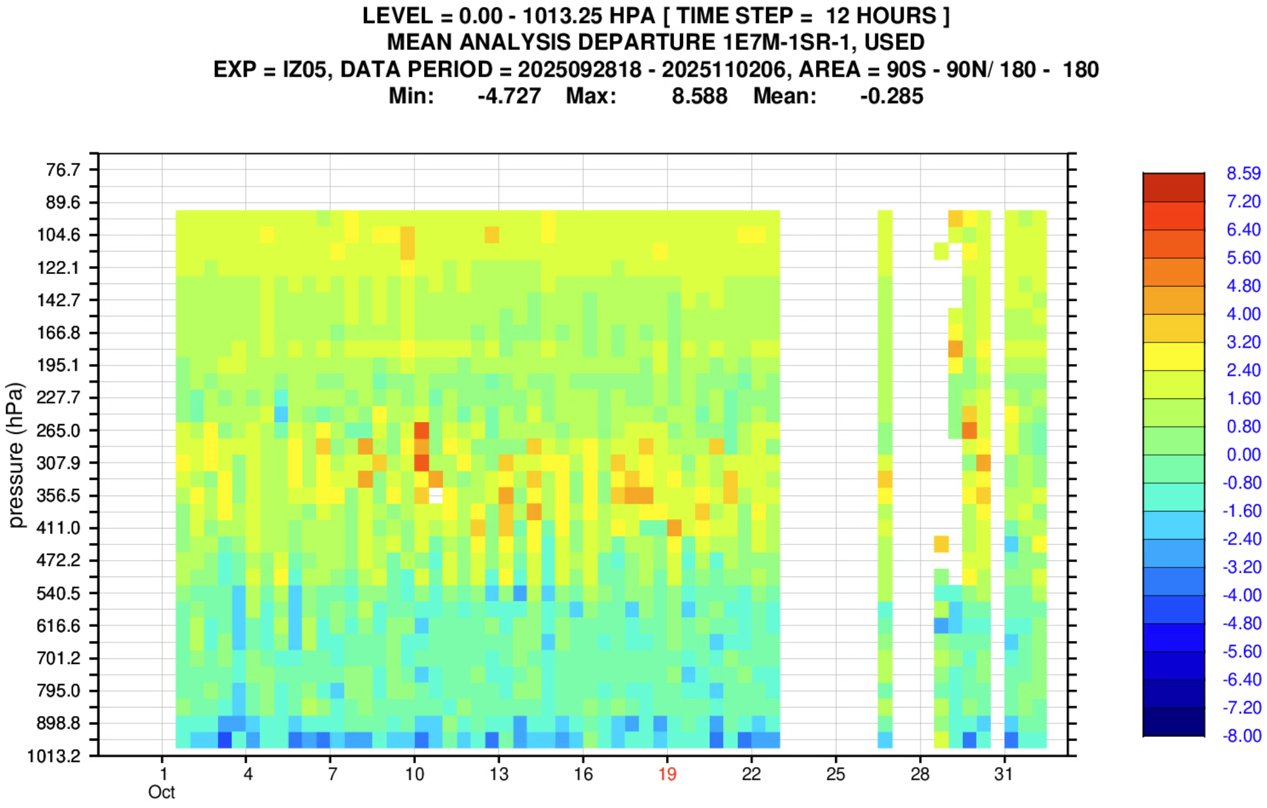


Hovmöller plots of departures, October 2025

Plots from **OSE 2** (fixed error of $5 \times 10^{-7}\ \mathrm{m}^{-1}\ \mathrm{sr}^{-1}$).



First-guess departures (difference between ATLID and the model with no ATLID assimilation).



Analysis departures (difference between ATLID and the model with ATLID assimilation).

Comparison of profiles over Limassol, 14 October 2025 at 23:00

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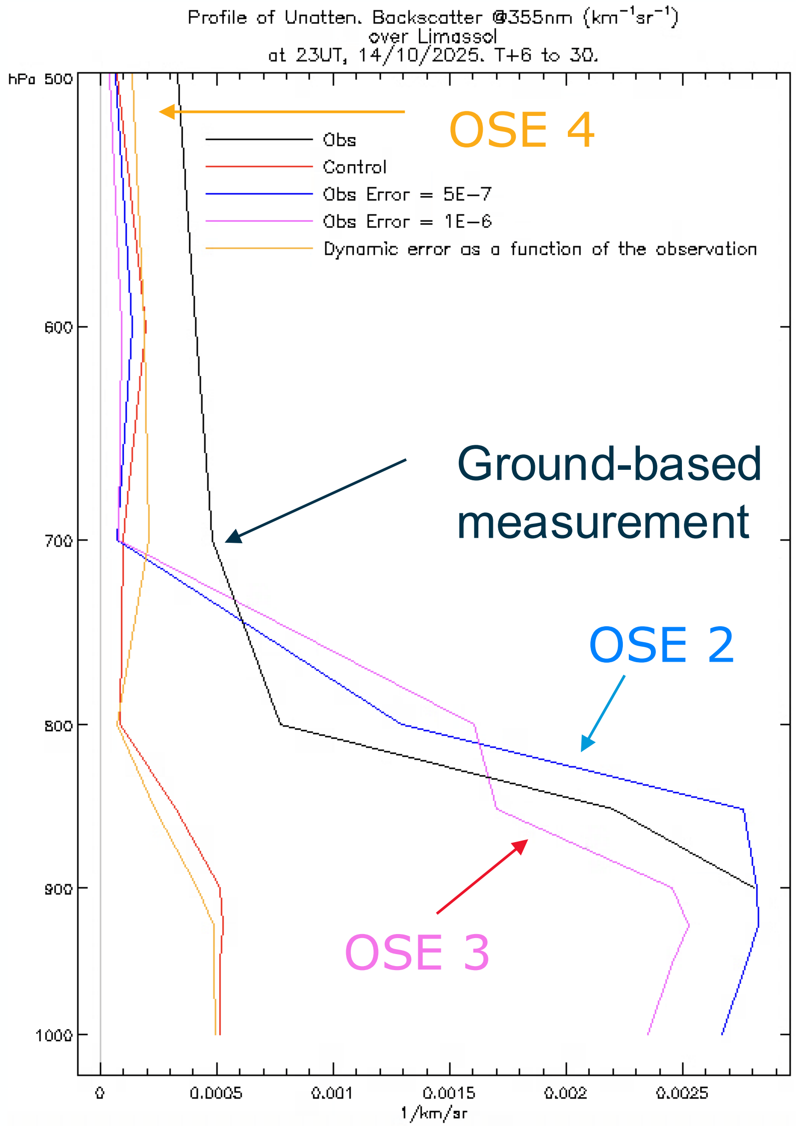
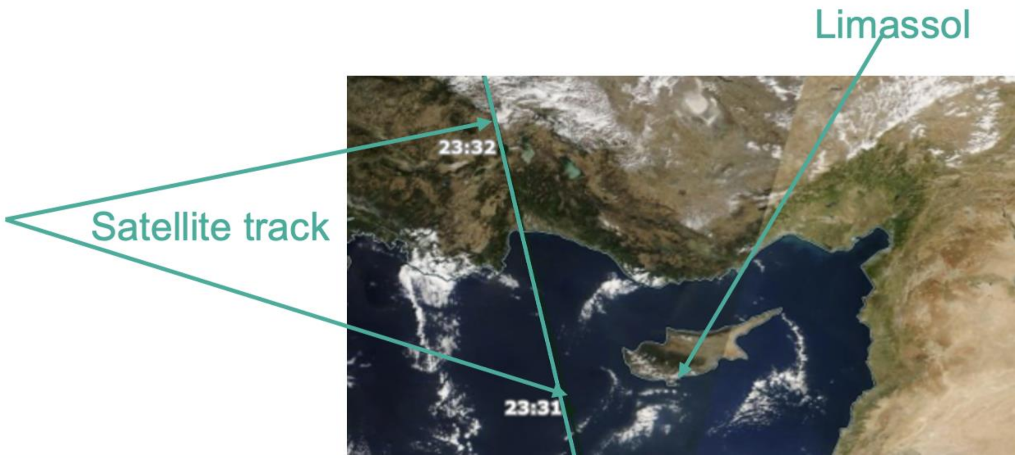


- A single profile of unattenuated backscatter over Limassol shown in black, with the aerosol backscatter from the four IFS-COMPO OSEs in their respective colours defined in the table.
- Above the 700 hPa level, the aerosol backscatter from **OSE 4** is closer to the ground-based measurement, and at lower altitudes **OSEs 2** and **3** draw closer to the Limassol profile, as lower observation errors give a higher weighting to the ATLID data.
- This demonstrates the sensitivity of 4D-Var assimilation to observation error specification; larger observation errors reduce the influence of the satellite observations, which may prevent valuable boundary-layer aerosol information from being effectively assimilated.

No.	Error
1	N/A
2	5×10^{-7}
3	1×10^{-6}
4	Dyn err

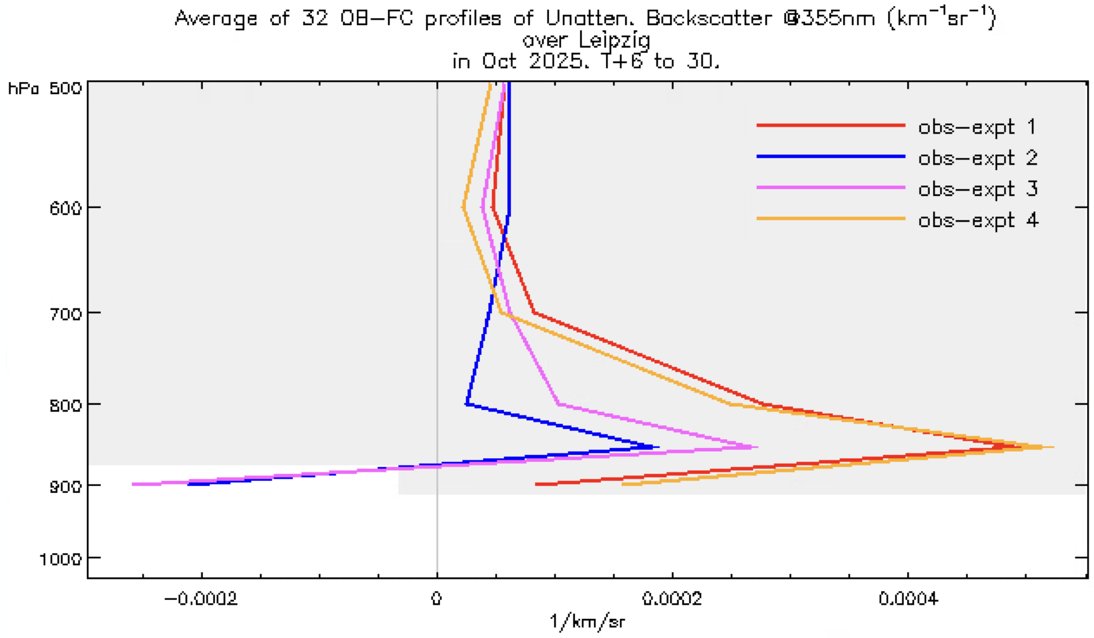


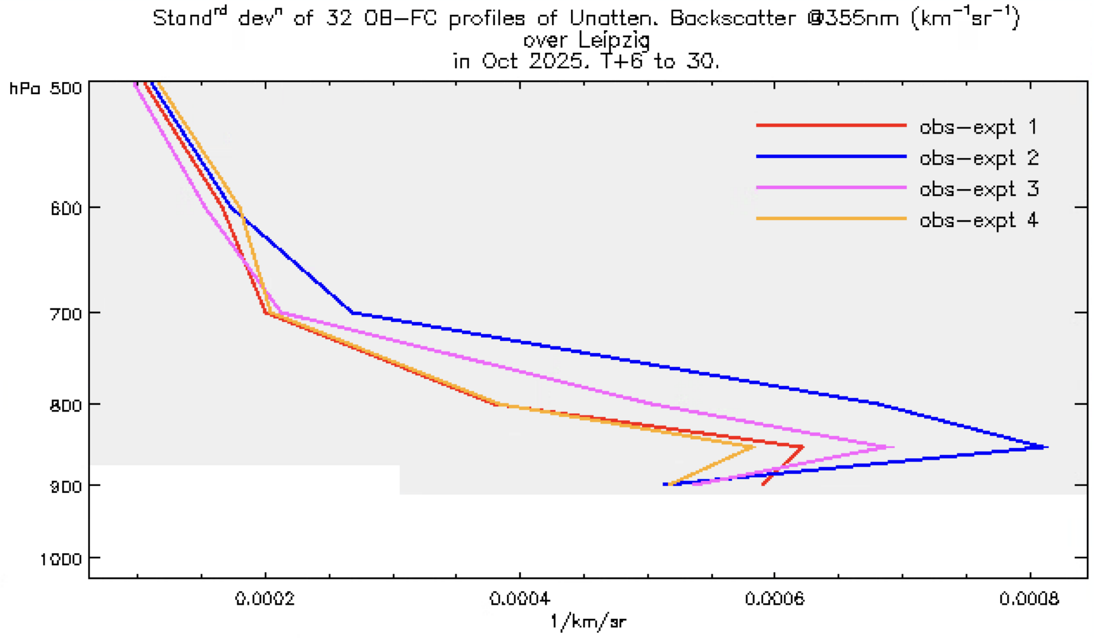
Differences between observed and model profiles for Leipzig in October

$$\text{'Dynamic error'} = \frac{1}{4}\beta + 5 \times 10^{-7}\ \mathrm{m^{-1}\,sr^{-1}}$$

Average difference between ground-based and ECMWF model profiles ($\mathrm{km^{-1}\,sr^{-1}}$)

Standard deviation of the differences ($\mathrm{km^{-1}\,sr^{-1}}$)

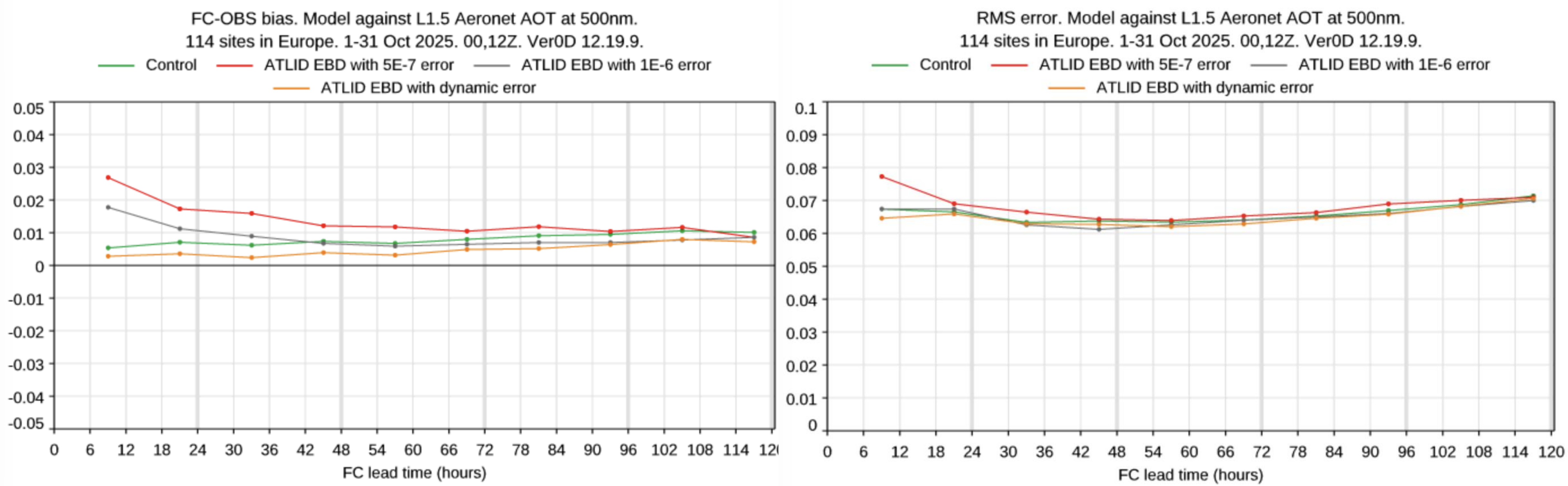




No.	Error
1	N/A
2	5×10^{-7}
3	1×10^{-6}
4	Dyn err

The reduction in bias with the ground-based observations at higher altitudes from **OSE 4** is apparent in the difference plots on the left, as are the lower biases in **OSE 2** and **OSE 3** between 700 and ~900 hPa. The standard deviation on the right-hand plot is lower for **OSE 1** and **OSE 4** below 700 hPa, irrespective of the larger biases in the backscatter from **OSE 1** and **OSE 4** shown in the left-hand plot.

AOD at 500 nm: five-day forecast range bias with respect to AERONET, October 2025 for Europe



AOD forecast lead time at 500 nm over Europe from assimilating the ATLID aerosol profiles using a constant observation error introduces a positive bias, whereas the AOD from **OSE 4** using the **dynamic error** reduces the forecast bias with respect to the control for some times, particularly out to three days. The RMS error is not improved everywhere, especially after day three.

$$\text{'Dynamic error'} = \frac{1}{4}\beta + 5 \times 10^{-7}\ \mathrm{m}^{-1}\,\mathrm{sr}^{-1}$$

Conclusions and further work required

- ATLID assimilation can improve aerosol vertical placement, but the **impact depends strongly on observation-error specification**

- The same analysis will be applied for different periods throughout the to-date ATLID lifespan.

- The IFS-COMPO aerosol backscatter and AOD will continue to be verified against ground-based stations, with the addition of regional averages to assess impact on the IFS-COMPO derived fields.

- OSEs with different observation errors than the ones trialled thus far will be set up to run for longer periods of time, in the current IFS-COMPO operational cycle.

- Use of the synergistic classification to determine whether ATLID modifies the amount of different aerosol species that make up the total AOD.

Detailed summary and work plan from early June 2026

- Assimilation experiments continue to run, with more planned, to eventually cover the whole period since ATLID became operational, and assimilating data using the synergistic AC-TC target classification will be investigated, as a priori information on aerosol species could improve the model AOD speciation.
- OSEs carried out so far indicate (tentatively) promising results, with some error prescriptions drawing the model aerosol backscatter profiles closer to the ground-based measurements of the particulate backscatter.
- AOD five-day forecast shows lower bias in some cases, including a reduced bias over Europe in October 2025.
- Verification of model aerosol profiles against ground-based lidar measurements will continue, for individual stations and for multiple stations averaged together, e.g. for all stations across Europe with data available.
- Additionally, the verification of the model AOD with AERONET as a function of time, location, and forecast range will be assessed for different OSEs.
- Porting of cycle changes to enable work to continue in the latest IFS-COMPO cycle, CY50R1, are underway, and similar OSEs will run in this cycle, with various observation error prescriptions; **the goal is to determine the optimal error assignment maximising improved vertical placement of the aerosol backscatter, as well as the AOD and particulate matter forecasts (PM 2.5 and PM 10).**