Aeolus Aerosol Assimilation in the DISC (A3D): project status and latest developments

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Acknowledgements to Michael Rennie, Angela Benedetti, Karen Henry, Julie Letertre-Danczak, Drasko Vasiljevic, Volkan Firat, Saleh Abdalla plus others in ECMWF, CAMS, and everyone in the Aeolus DISC

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Rhodes

Contents

Project definition and timeline for assimilation of Aeolus backscatter

- A3D project was undertaken from October 2021 – March 2023, under the umbrella of the wider Aeolus Data Innovation and Science Cluster (DISC; as explained in Oliver Reitebuch's talk on Monday).

- The project goals were to utilise the Level 2A (L2A) optical properties products retrieved from Aeolus measurements:

    - particle extinction coefficient
    - particle backscatter coefficient

- The aim was to monitor and assimilate these products in the Integrated Forecast System in atmospheric composition mode (COMPO-IFS), as used by the Copernicus Atmosphere Monitoring Service (CAMS), for operational composition forecasting at ECMWF.

- Timeline of near-real time monitoring and assimilation of the SCA mid-bin particle backscatter:

    - January 2022 - August 2022: using CY47R3 of COMPO-IFS.

    - End of August 2022: interrupted due to the move of the ECMWF data handling system from Reading to Bologna.

    - January 2023: commenced monitoring and assimilation on the new supercomputer, using an experimental version of the new COMPO-IFS cycle.

    - The final project technical memorandum was delivered to ESA in March 2023.

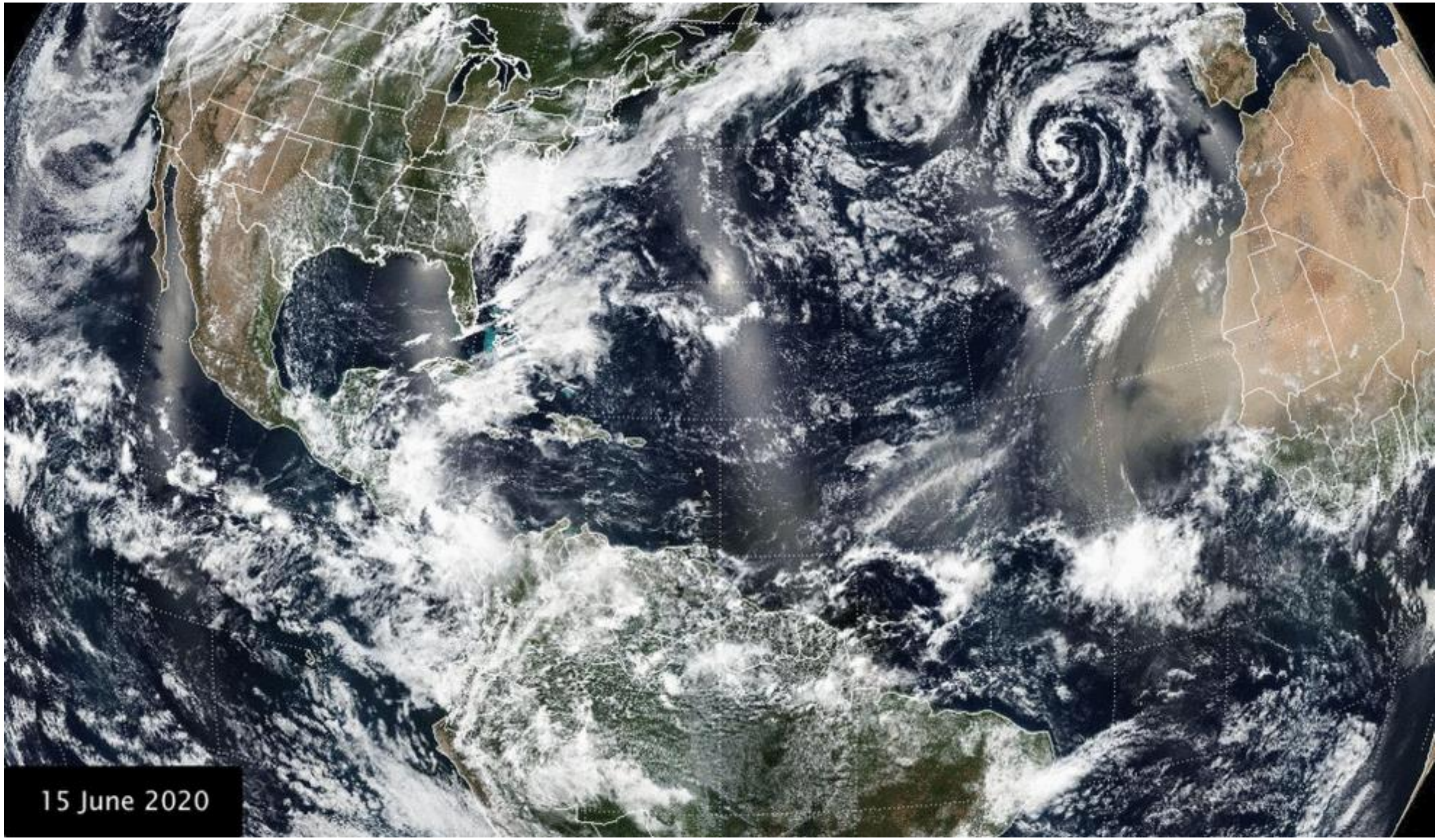
Motivation: why do we need lidar backscatter?

- Currently, in atmospheric composition forecasting at ECMWF, Aerosol Optical Depth (AOD) products from MODIS (AQUA and TERRA) and PMAp (METOP A,B,C) are assimilated into COMPO-IFS.
- Since February 2023 also VIIRS AOD is assimilated.

- AOD is column integrated data; it does not provide vertical profiling information.

- The particle backscatter at different altitudes is retrieved from Aeolus measurements.

- Assimilating this information into COMPO-IFS can better place the altitude of cloud and aerosol in a column of atmosphere.



Credit: NASA; https://www.nasa.gov/feature/goddard/2020/nasa-noaa-s-suomi-npp-satellite-analyzes-saharan-dust-aerosol-blanket

How is the particle backscatter used in COMPO-IFS?

- The project aim was to look at signals from aerosols, thus in our monitoring and assimilation an attempt was made to screen out the larger backscatter signal from clouds.

- Screened values of backscatter were monitored and assimilated in COMPO-IFS.

- Until we have our own ECMWF-developed BUFR (Karen Henry's work), we use CODA, developed by S&T (NL) for ESA, to extract the required data from the Earth Explorer files, then use our own in-house scripts to group the data in the format needed in COMPO-IFS.

- Monitoring:
  - The SCA MID-BIN particle backscatter is read in to COMPO-IFS and compared with the value calculated by the forward model operator.
  - The Aeolus backscatter and the ECMWF model are compared as a function of altitude, time, and location on the globe.
- Assimilation:
  - The particle backscatter is used in the analysis, i.e. in the 4D-VAR minimisation along with the other atmospheric composition retrieval products and NWP products used in the assimilation.
  - This allows us to assess the effect on the short-range AOD forecast, compared to the CAMS (or CAMS-like) operational product.

Some definitions (with equations minimised!)

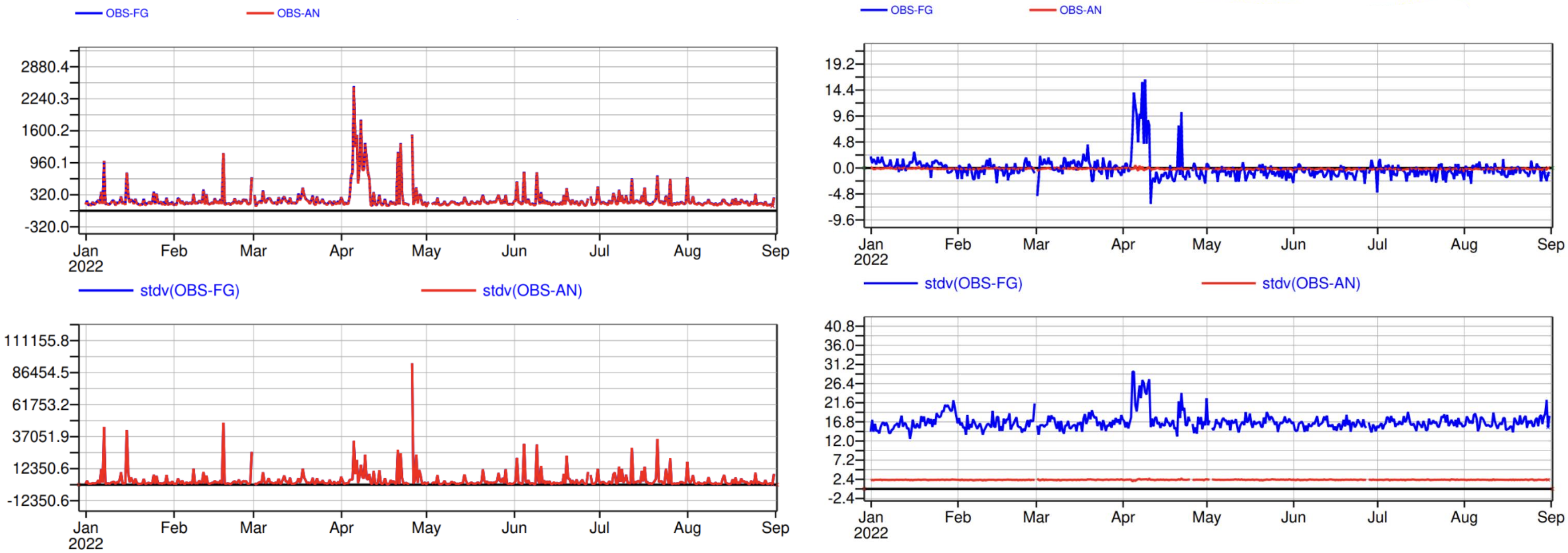
First-guess departures:
This is simply the difference between the “observation” i.e. the Aeolus L2A particle backscatter, and the model initialised from first guess. Positive values indicate a larger value of backscatter from Aeolus, negative values indicate a larger model value (i.e. an overestimation of backscatter in the model).

Analysis departures:
This is the difference between the “observation” and the model, but with the model from the analysis, i.e. from assimilating the particle backscatter in the 4D-VAR minimisation used at ECMWF.

Short-range AOD forecast:
This is the forecast of the aerosol optical depth (AOD) for a location corresponding to a particular AERONET station, for up to 12 hours following the forecast initialisation time.

Observing system experiment (OSE):
A diagnostic method to evaluate the effect of a particular observing system (e.g. a satellite instrument) on the forecast statistics. See Mike Rennie’s talk in particular.

Monitoring and assimilation as a function of time: January to August 2022



All units are in $10^{-7}\,\mathrm{m}^{-1}\mathrm{sr}^{-1}$.

First guess and analysis departures and standard deviation as a function of time for the period January 01 - August 31 2022, corresponding to the atmospheric pressure range 700-1013.25 hPa, for all observations. Left: all data, right: data passing the cloud and altitude screening criteria.

Monitoring and assimilation: January to August 2022

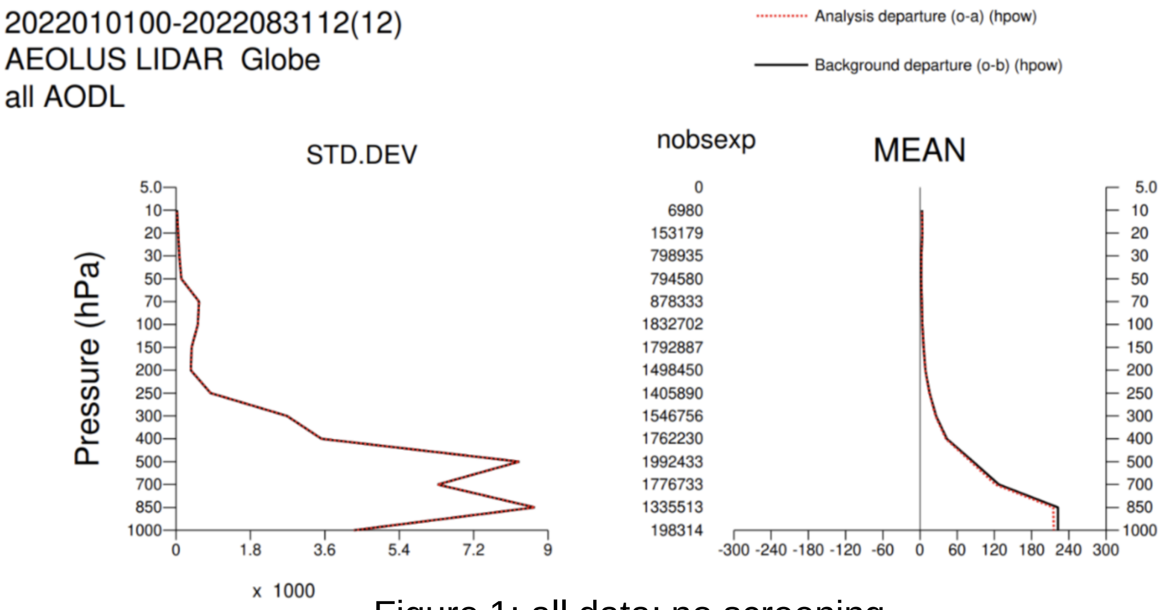


Figure 1: all data; no screening

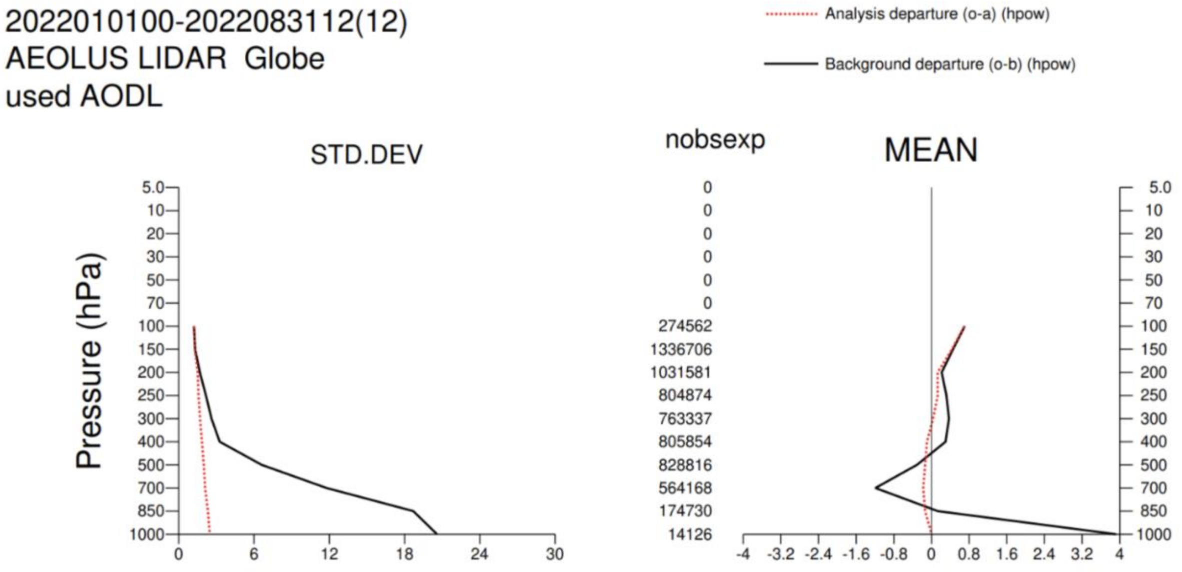


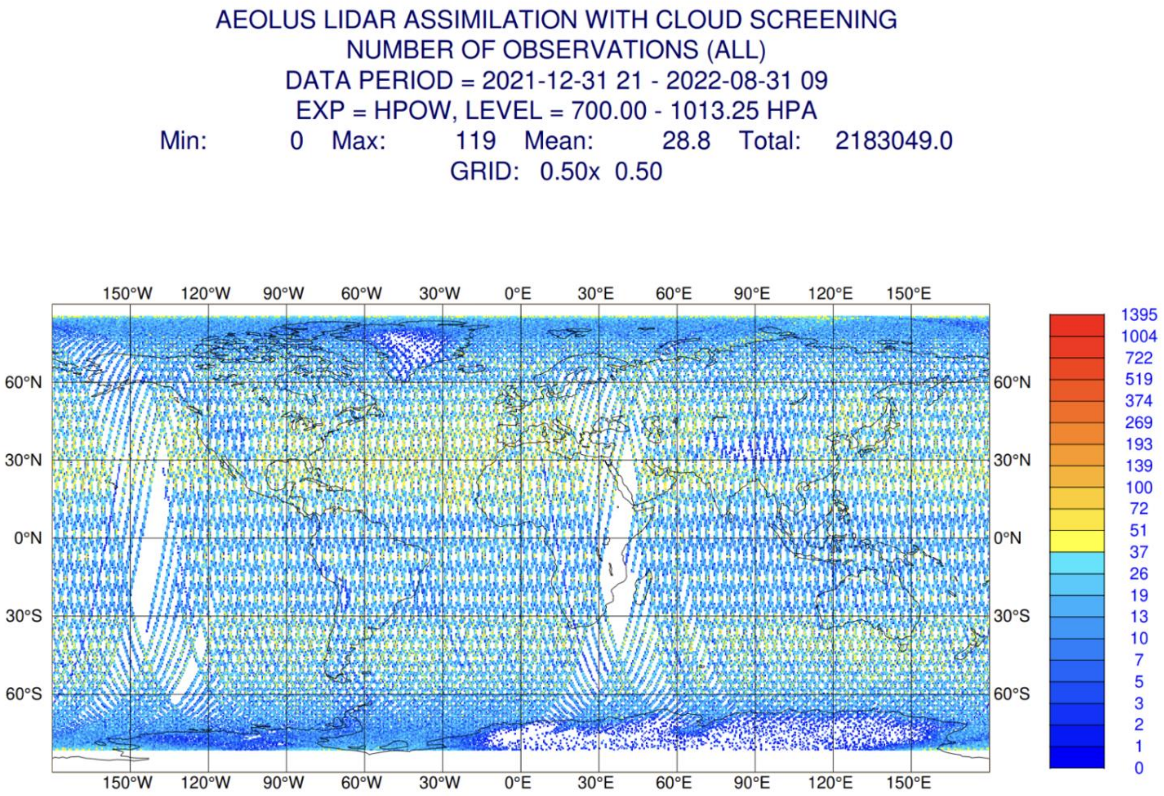
Figure 2: data with cloud and altitude screening applied

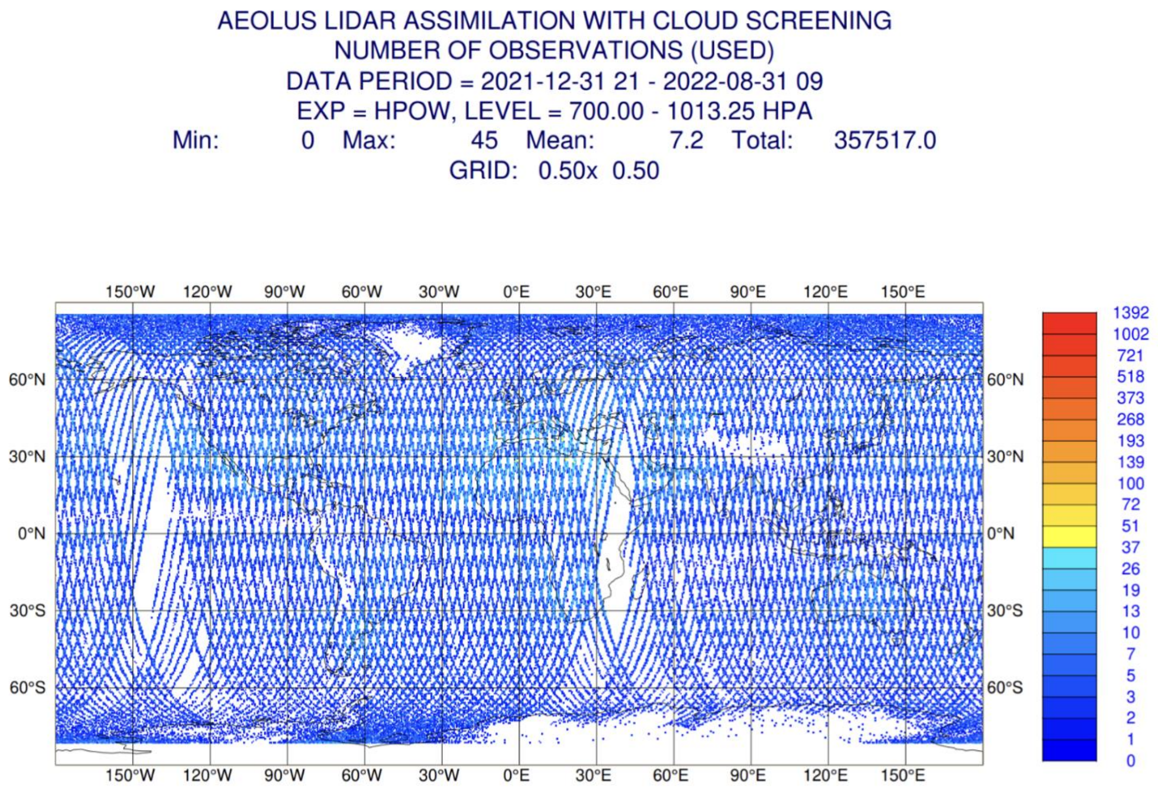
All units are in $10^{-7}\,\mathrm{m}^{-1}\mathrm{sr}^{-1}$.

The solid black lines represent the first guess departures, i.e. the difference between the observation and the model first guess.

The red dashed line gives the difference between the Aeolus backscatter and the analysis, where the analysis includes the Aeolus L2A backscatter coefficient in the data assimilation. A small error is assigned to the observations.

Monitoring and assimilation: observation coverage in lower troposphere



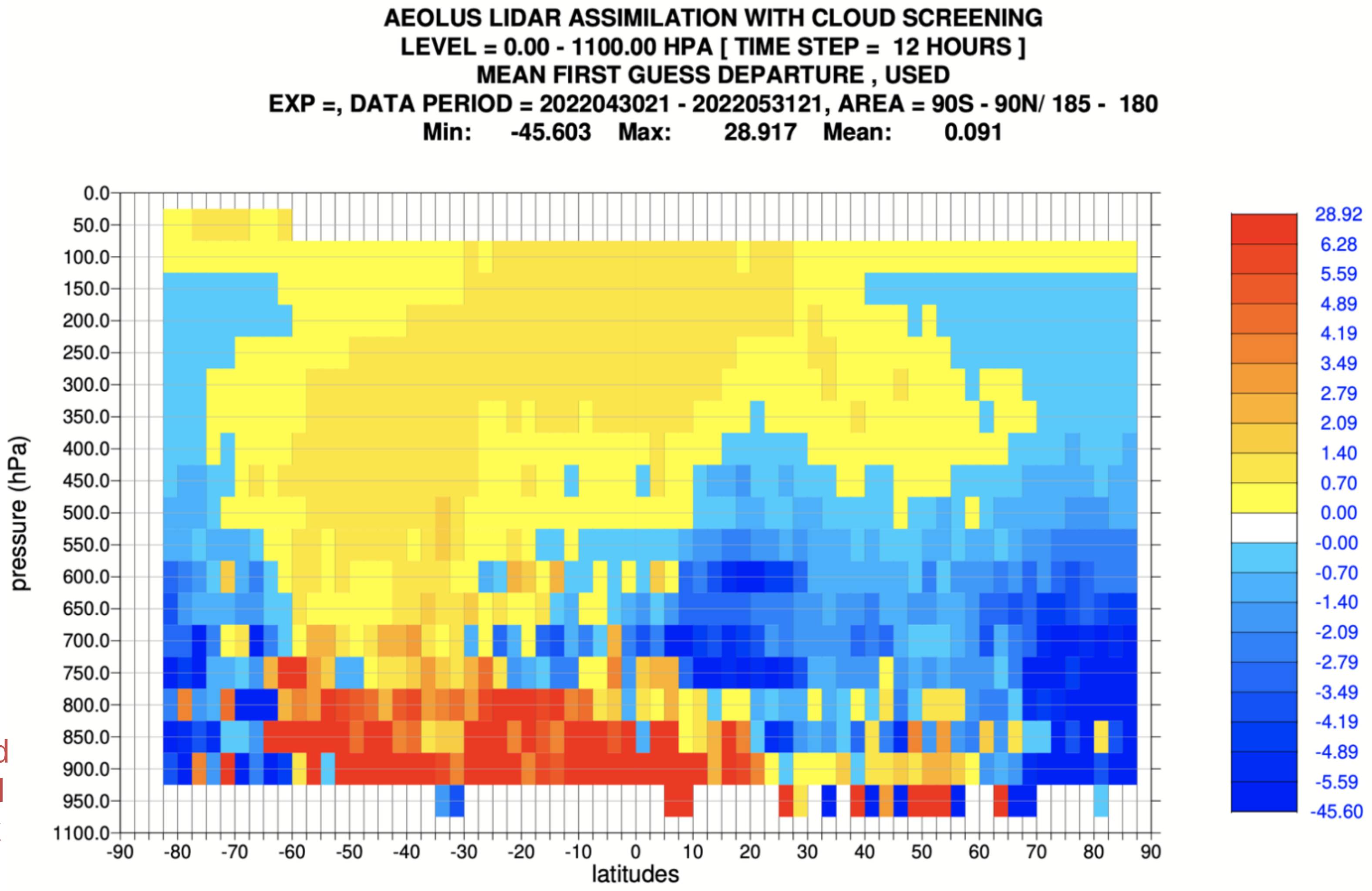


Bias monitoring

- First-guess departures (difference between the observation and the model initialised from background) appear to be larger in the planetary boundary layer.

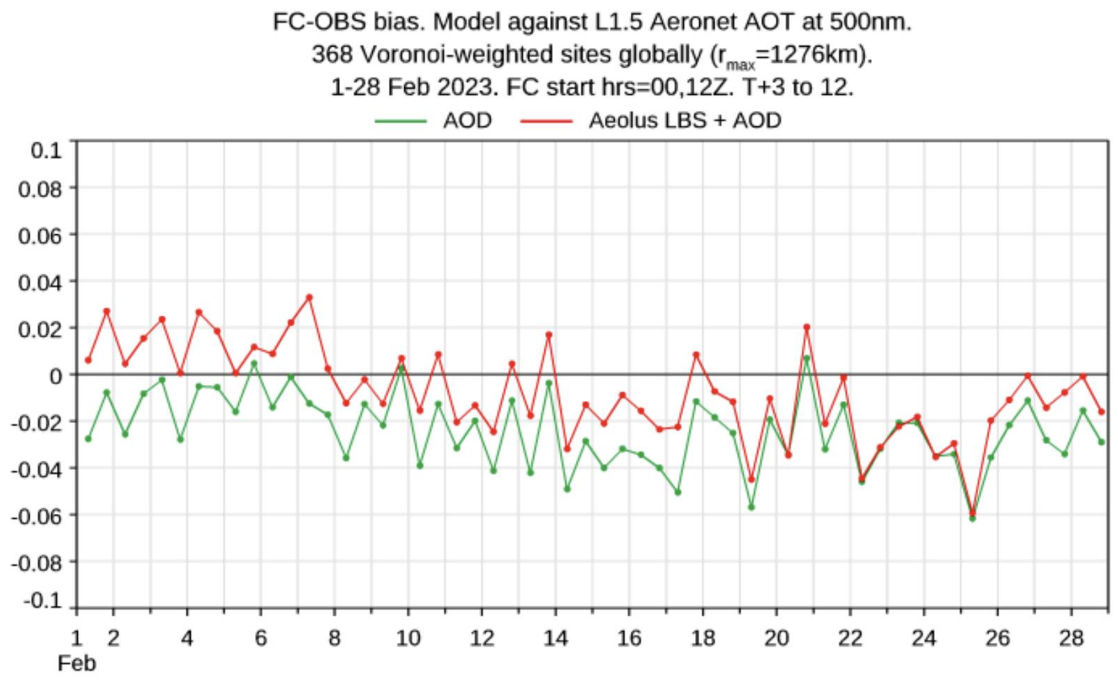
- Attempts to exclude values in lowest 2 km result in a slight reduction to the bias in AOD forecast, however, this is continuing to be investigated,

Right: first-guess departures for May 2022, shown as a function of latitude on the x-axis and atmospheric pressure on the y-axis. Red indicates the largest values where the model underestimates the Aeolus backscatter, dark blue is where the model is too large.



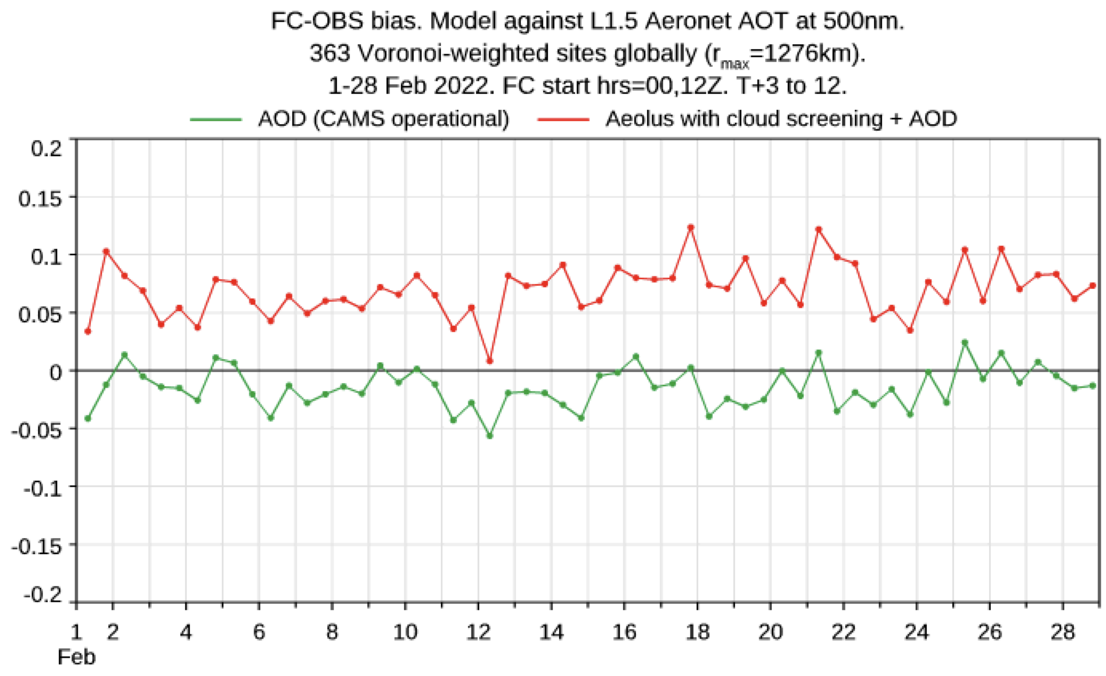
Bias monitoring, and comparison with the previous cycle

CY48R1; Feb 2023



Red: bias of Aeolus backscatter + CAMS-like AOD assimilation, compared with AOD only (green) for February 2023, using IFS version CY48R1 on the ATOS HPC.

CY47R3; Feb 2022

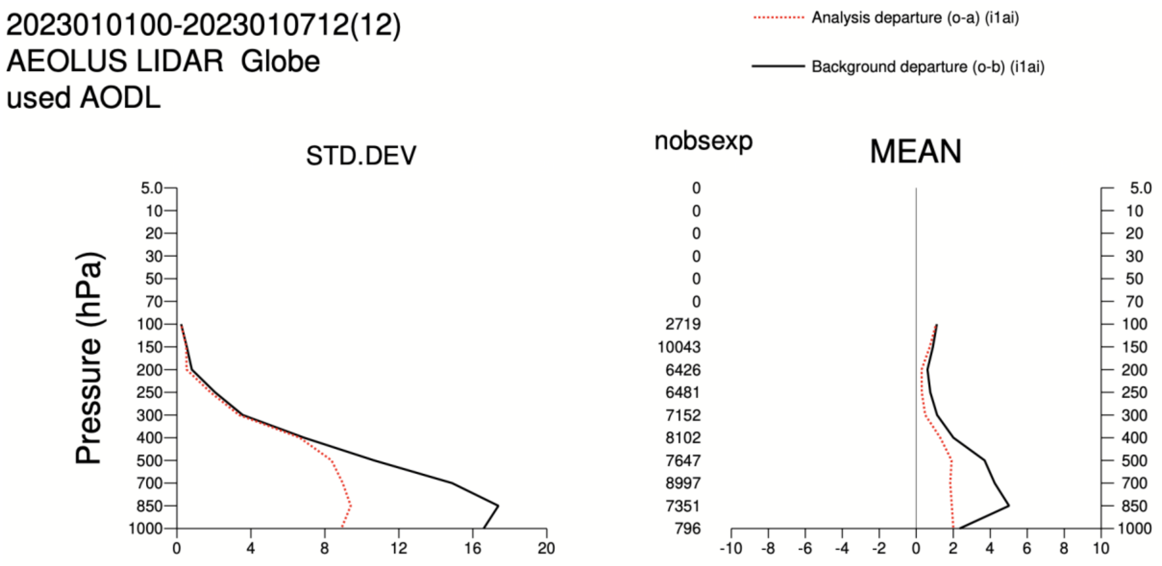


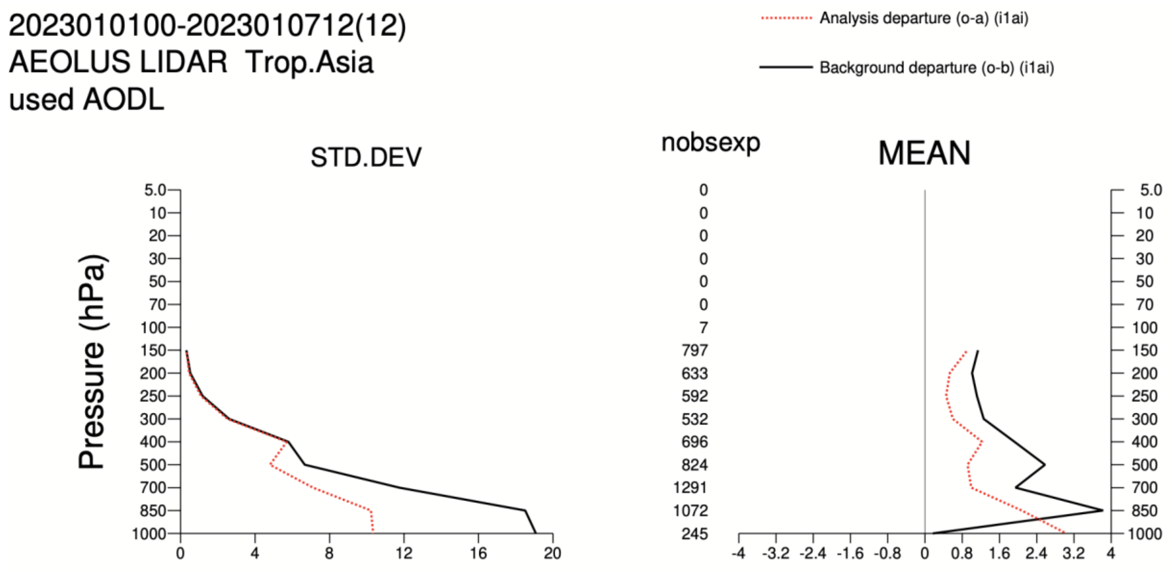
Red: Aeolus+AOD, green is AOD CAMS-like experiment, using IFS version CY47R3 on the Cray supercomputer, for February 2022.

These are preliminary results for an experimental version of COMPO-IFS. Many model changes were implemented in the new cycle and it will be necessary to run the same period to understand them. Note both the different year as well as the scale difference on the y-axis.

Assimilation with dynamic error: 01-07 January 2023.

All units are in $10^{-7}\,\mathrm{m}^{-1}\mathrm{sr}^{-1}$.





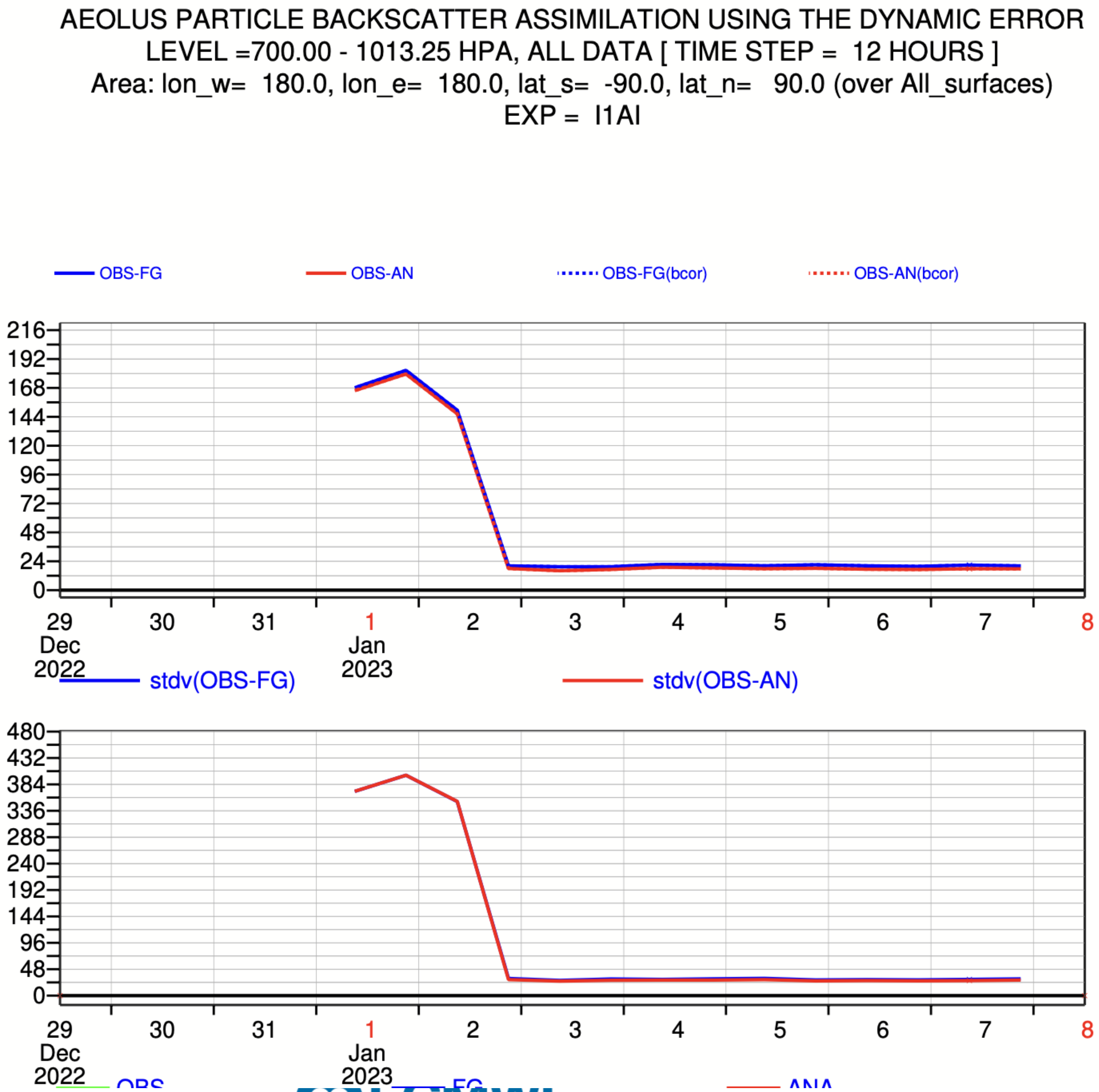
The red dashed line gives the difference between the measurement and the analysis, where the analysis is the model with the Aeolus L2A backscatter coefficient included in the data assimilation.

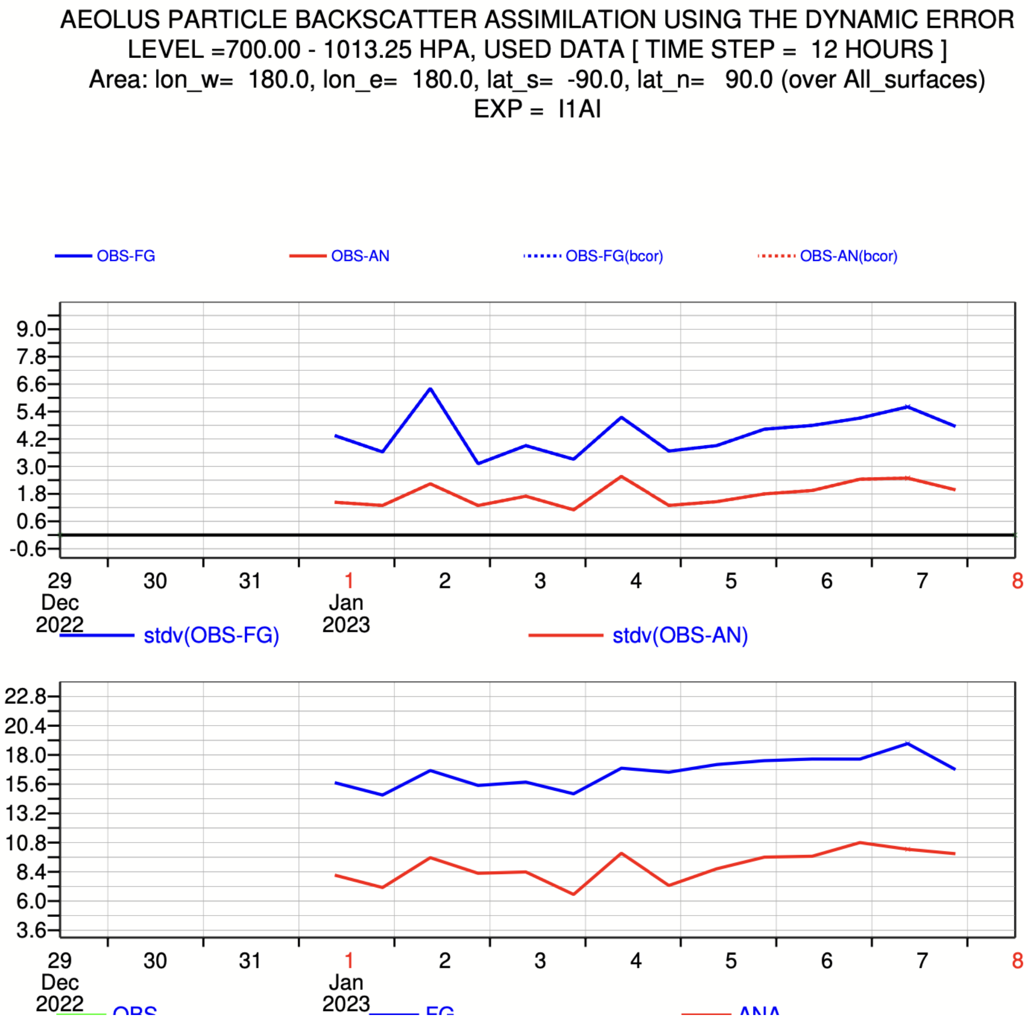
Assimilation of L2A backscatter with measurement error improves the model backscatter, where the error is sufficiently low.

Analysis (assimilation in the 4D-VAR system) draws the ECMWF CAMS model closer to the Aeolus particle backscatter, depending on the standard deviation at that atmospheric level: large values of standard deviation result in a lower weight given to the assimilation.

Time series of the assimilation with dynamic error: 01-07 January 2023

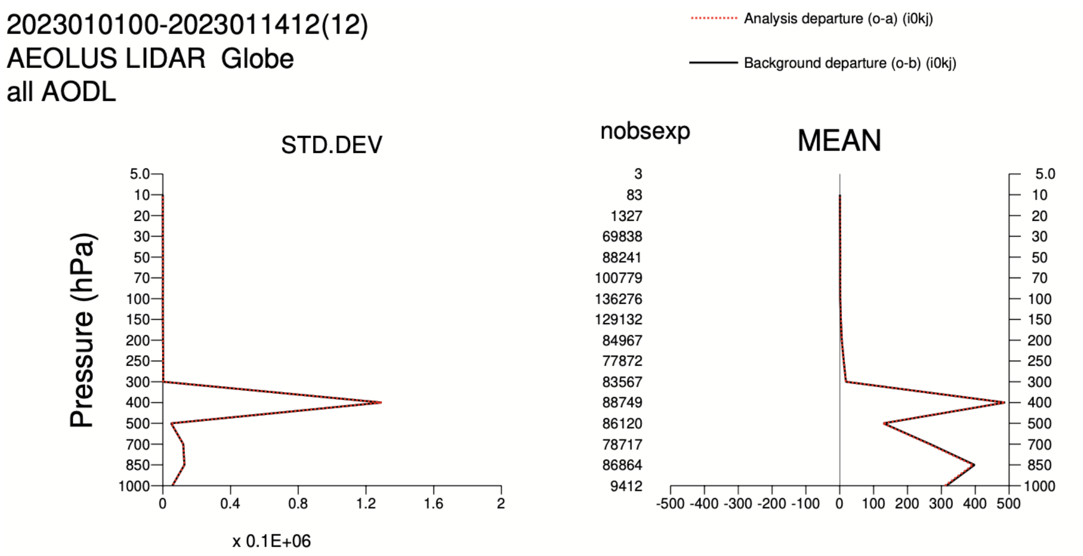
All units are in $10^{-7}\,\mathrm{m}^{-1}\mathrm{sr}^{-1}$.

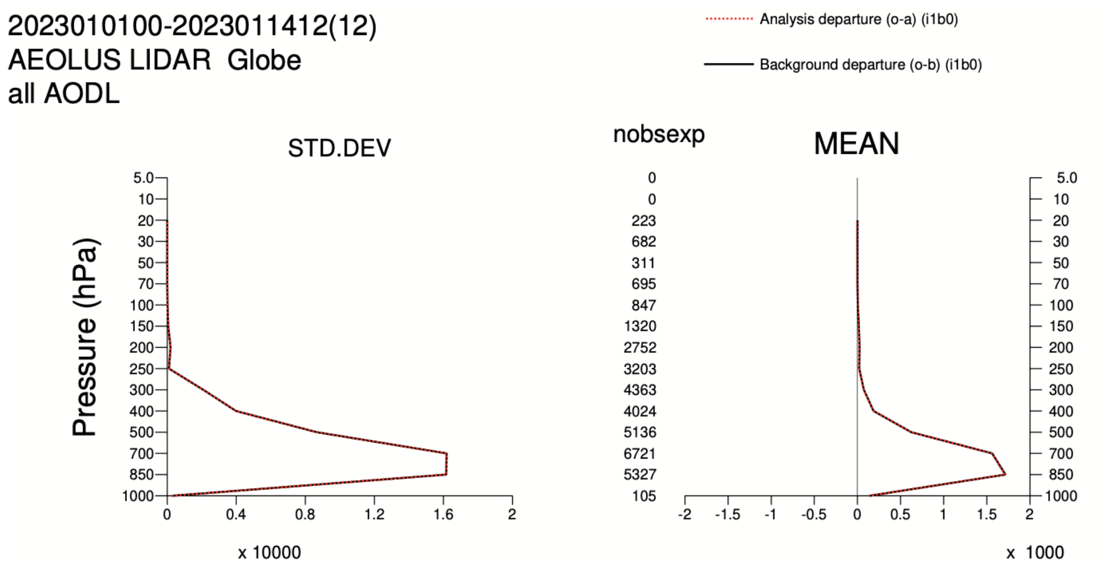


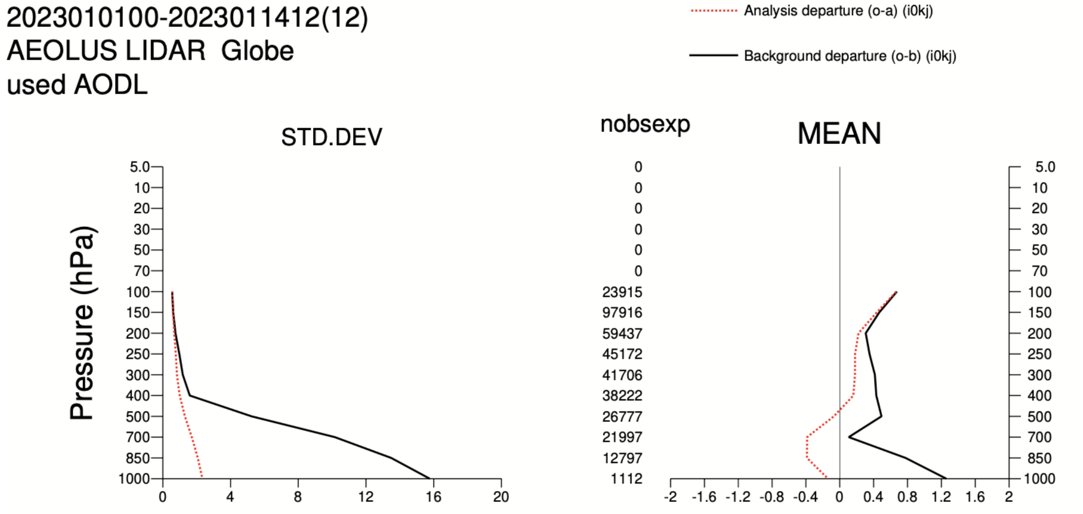


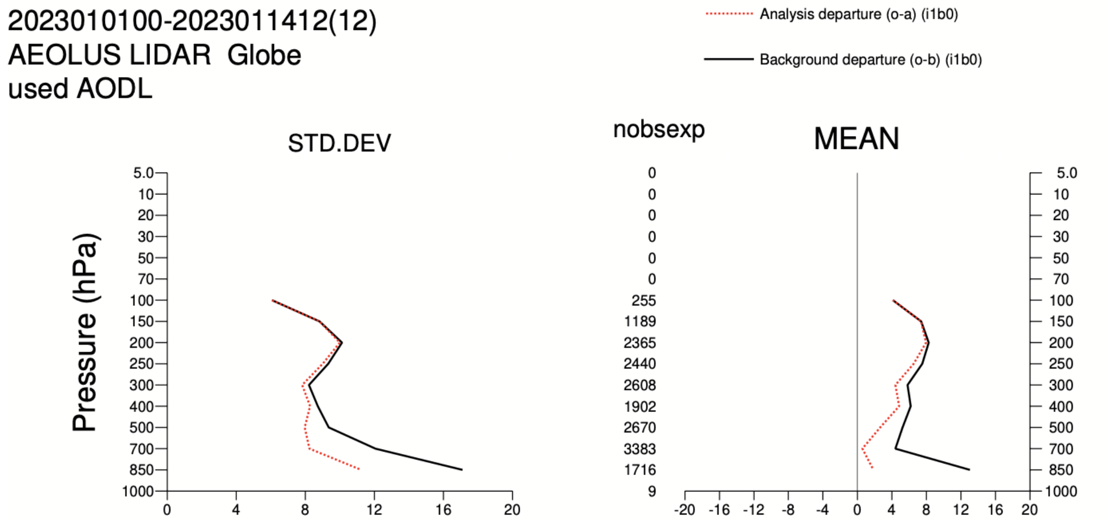
Assimilation of AEL-PRO product: initial results for 01-14 January 2023

SCA MID-BIN   All units are in $10^{-7}\,\mathrm{m}^{-1}\mathrm{sr}^{-1}$.   AEL-PRO

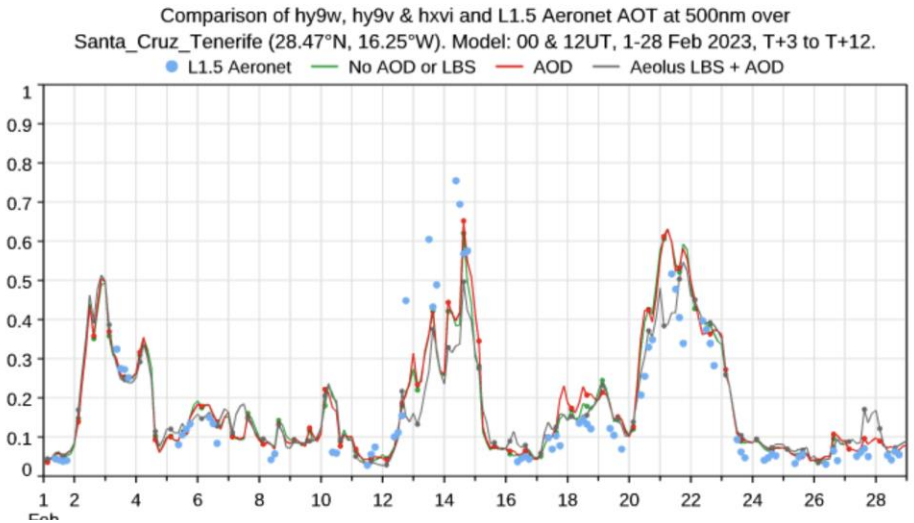


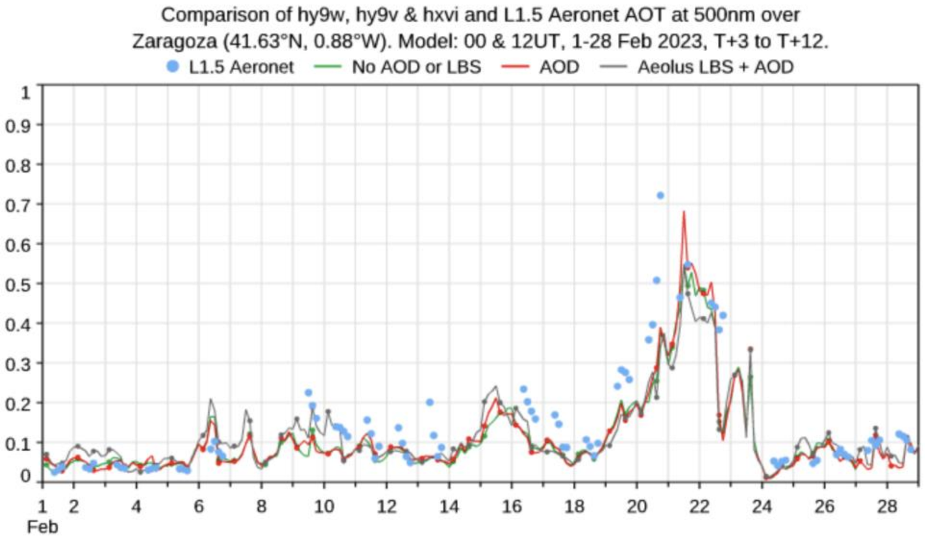






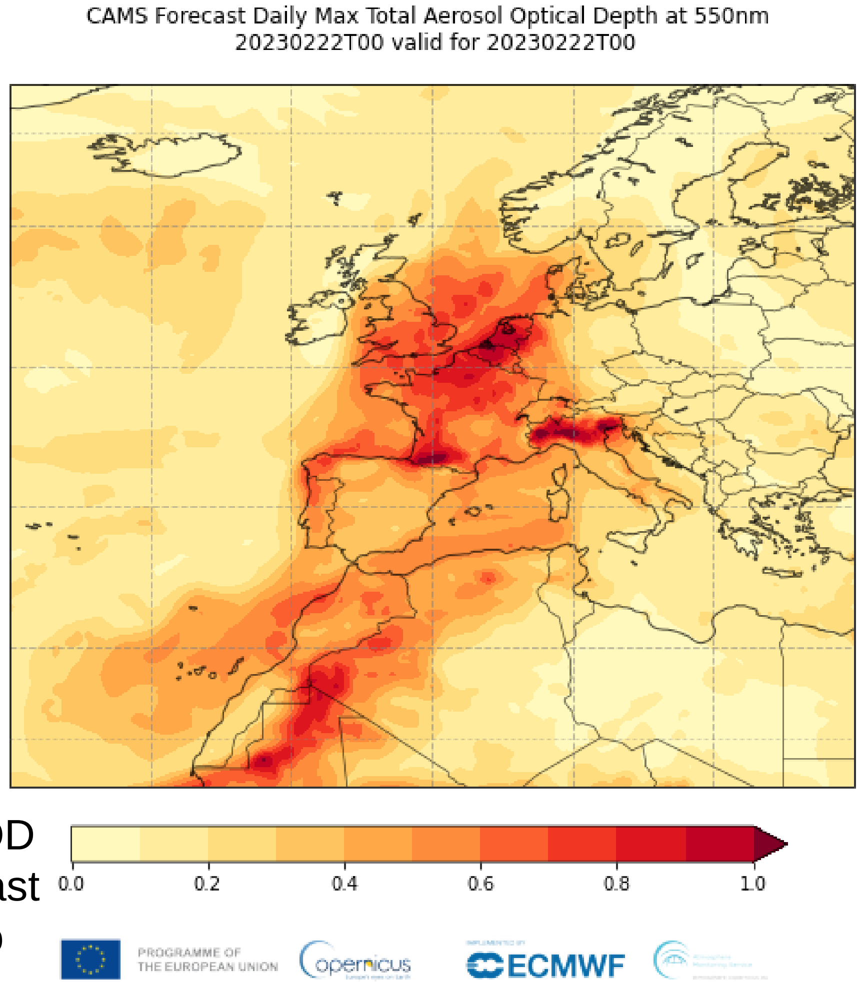
Impact of Aeolus L2A particle backscatter on AOD forecast in CY48R1





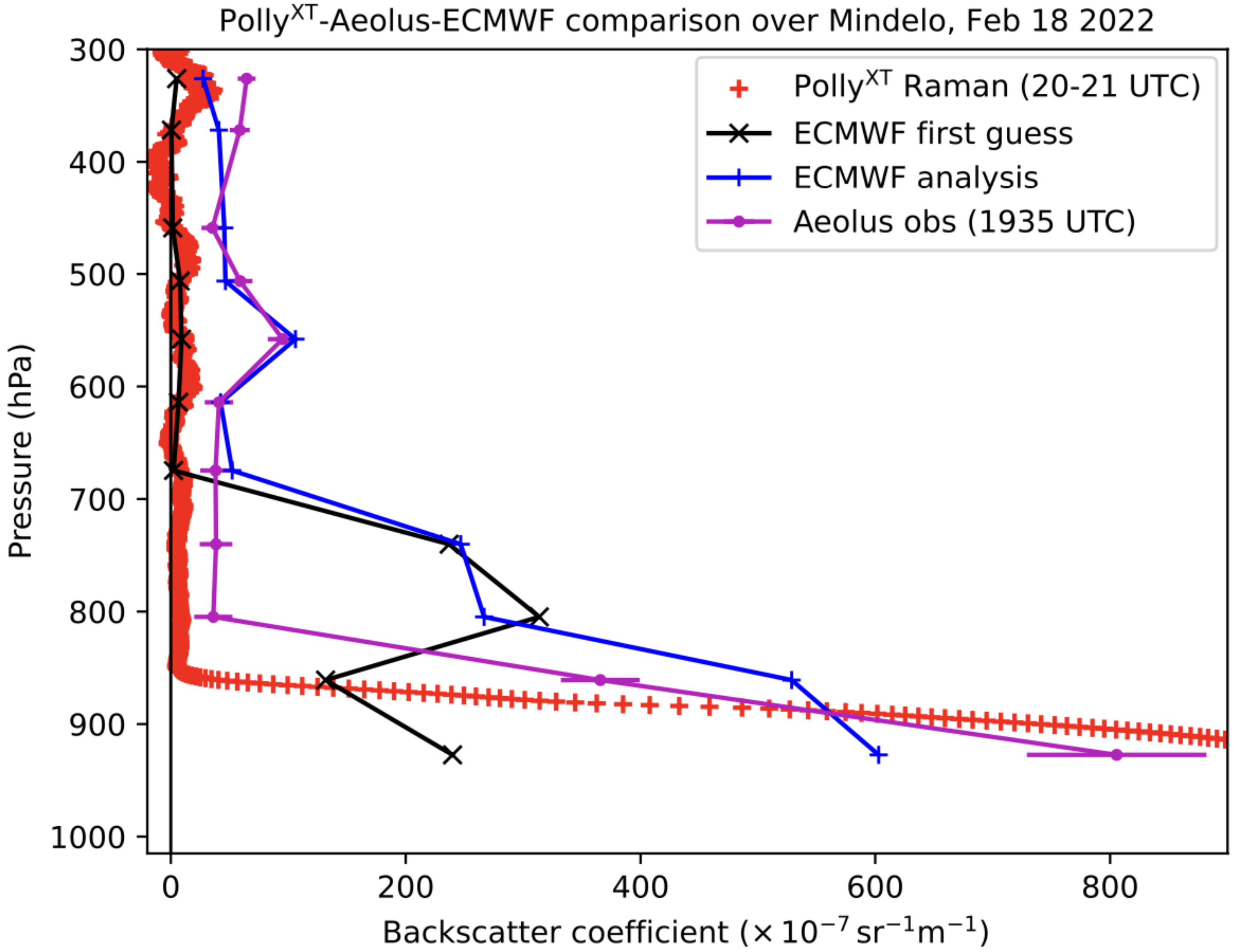
Top left: Feb 2023 short-range AOD forecast for Santa Cruz Tenerife, along with AERONET measurements.

Bottom Left: Zaragoza AOD forecast.



Right: Daily max total AOD from CAMS global forecast for 22 February. Credit to CAMS and Mark Parrington.

Comparison with ground-based lidar measurements



Comparison of Aeolus and ground-based PollyXT lidar measurements over Mindelo, Cabo Verde taken on February 18, 2022 between 20.00 - 21.00 UTC.

Aeolus measurements are shown from an overpass at 19.35 UTC, along with the ECMWF model from first guess, and the model analysis with assimilation of the Aeolus L2A particle backscatter.

PollyXT observations were provided by TROPOS. Credit to Holger Baars and the Ground-based Remote Sensing Group (TROPOS; https://polly.tropos.de/) for providing ECMWF with these data.

Summary and outlook

- A3D project completed in March 2023. NRT monitoring of Aeolus particle backscatter demonstrated, with nine monthly monitoring reports delivered.
- Assimilation changes the vertical placement of backscatter, and impacts the short-range AOD forecast.
- Assimilation experiments for the final months of Aeolus operations are running using the latest version of the CAMS system in CY48R1.
- Monitoring of the new retrieval products (AEL-FM/AEL-PRO and MLE) has commenced, with an experiment assimilating AEL-PRO underway. This is crucial to further understand bias in the particle backscatter, and the propagation of this bias into the analysis and AOD calculation. The feature mask provided by AEL-FM will be used instead of the model-based cloud screening.
- Continuing to study the impact of observation error on the assimilation, i.e. the amount of weight given in the analysis to the observation.
- Evaluation of changes between CY47R3 and CY48R1 is still underway. Changes to the CAMS model and the assimilation has a big impact on the control experiments.
- Continue to compare assimilation results with profiles from ground-based lidar; ECMWF is collaborating with TROPOS on this.

Thank you! Comments and questions are welcome, you can also contact me by email:
will.mclean@ecmwf.int