Aerosol (and cloud) R&D activities at ECMWF

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Will McLean, Liam Steele (now with the MW team), and Karen Henry (plus colleagues from ECMWF and other institutes)

Outline

- Assimilation of Aeolus L2A particle backscatter product

- Visible reflectance assimilation for aerosol applications

- Visible reflectance assimilation for cloud applications

Monitoring and assimilation of the Aeolus L2A particle backscatter product at ECMWF

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Acknowledgements to Karen Henry, Angela Benedetti, Julie Letertre -Danczak, Drasko Vasiljevic, Volkan Firat, Michael Rennie, and Saleh Abdalla (all ECMWF)

DISC

DLR cnrs DoRIT serco ABB s[&]t KNMI ECMWF

Motivation: why do we want to assimilate the lidar backscatter profile in IFS-COMPO?

- In atmospheric composition forecasting at ECMWF, AOD data from MODIS (AQUA and TERRA) and PMAp (METOP A,B,C) are assimilated

- The problem is the AOD is column integrated data; this does not provide us with information on the vertical distribution.

- Improving the vertical profiling of aerosols can improve atmospheric composition forecasts (e.g. evolution of a dust event).

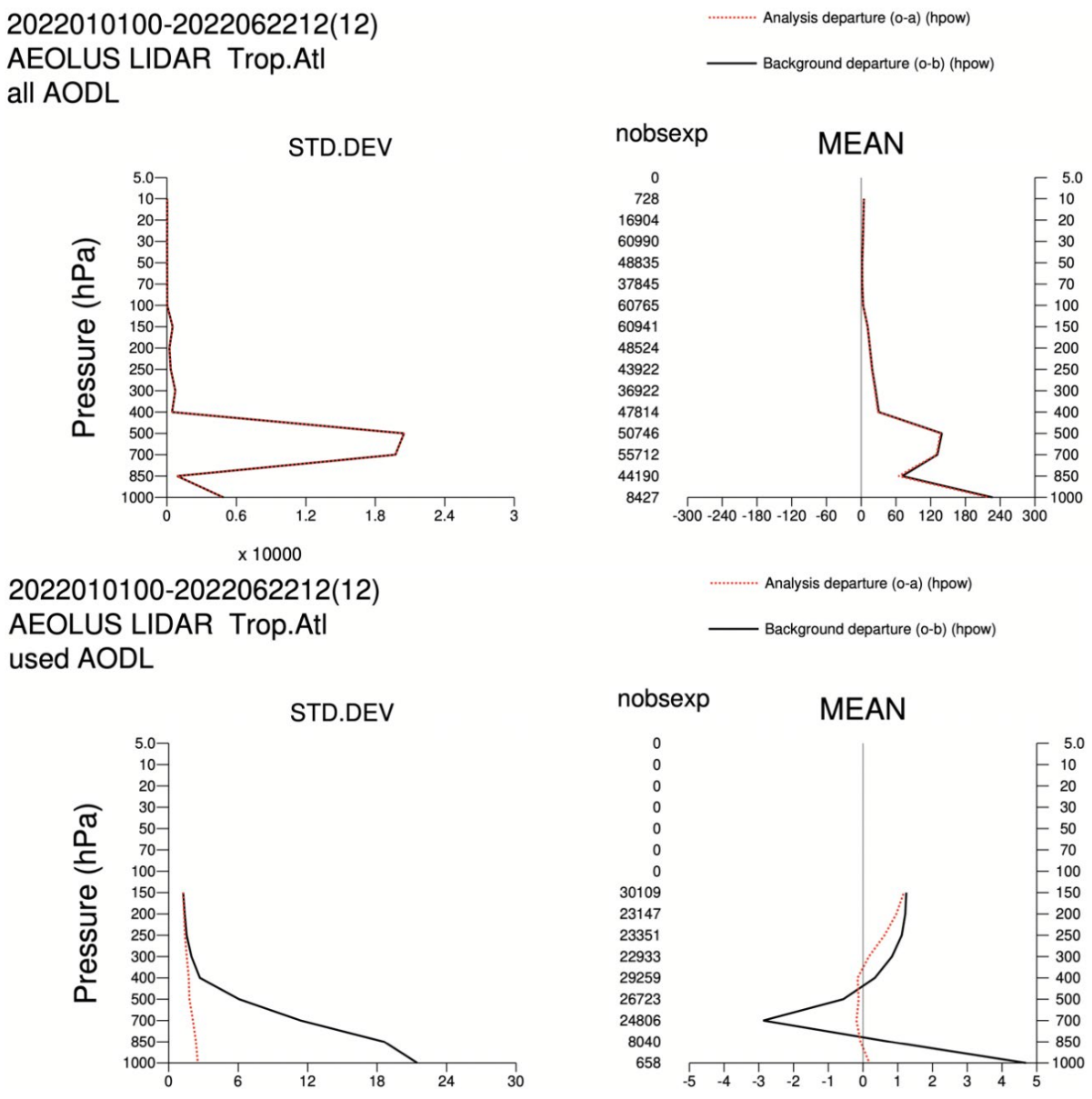
- The backscatter profile gives a vertically-resolved aerosol distribution, which has a positive effect in the assimilation.

NRT monitoring of the L2A particle backscatter product

- Aeolus has been providing particle backscatter data since August 2018
- Assimilation of Aeolus LoS winds has been ongoing operationally since January 2020
- Since January 2022, we have carried out NRT monitoring of the L2A particle backscatter.
- The particle backscatter is read in to IFS-COMPO, and compared with the value calculated by the forward model operator (monitoring).
- Assimilation is also carried out, to measure the effect on the short-range aerosol optical depth (AOD) forecast, compared to the CAMS operational product.

https://www.theguardian.com/science/2018/aug/23/satellite-aeolus-launched-space-map-earth-winds

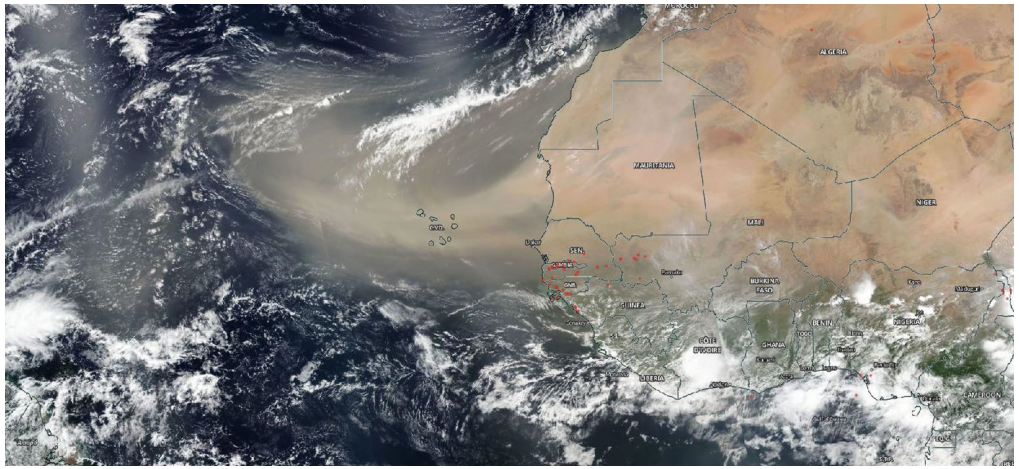
NRT monitoring and assimilation (example: Tropical Atlantic)



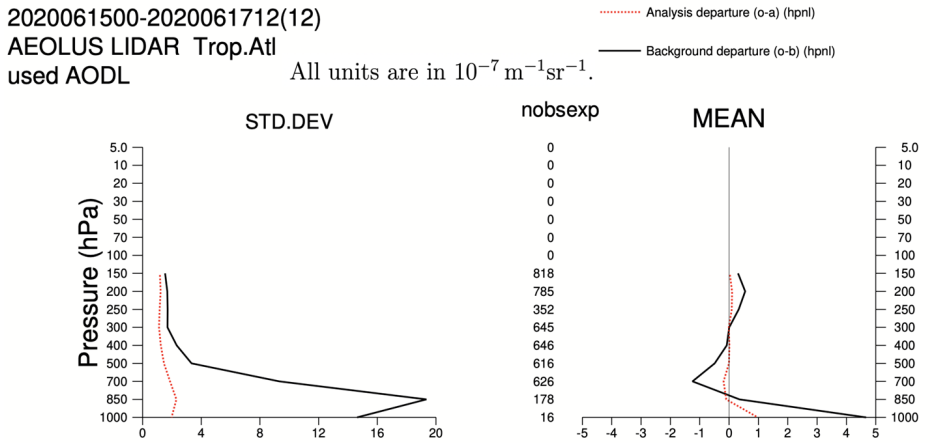
All units are in $10^{-7}\,\mathrm{m}^{-1}\mathrm{sr}^{-1}$.

- The solid black lines represent the first guess departures, i.e. the difference between the observation (Aeolus L2A particle backscatter) and the model first guess.
- In order to extract aerosol signal, a model-based cloud screening is applied.
- The red dashed line gives the difference between the measurement and the analysis, where the analysis includes the Aeolus L2A backscatter.
- Use of lidar data change the profile of the model aerosols in the analysis
- An (unrealistically) low error has to be used instead of the dynamic error in order for the data to have an impact on the assimilation

June 2020 “Godzilla” dust event: impact of Aeolus L2A on AOD forecast

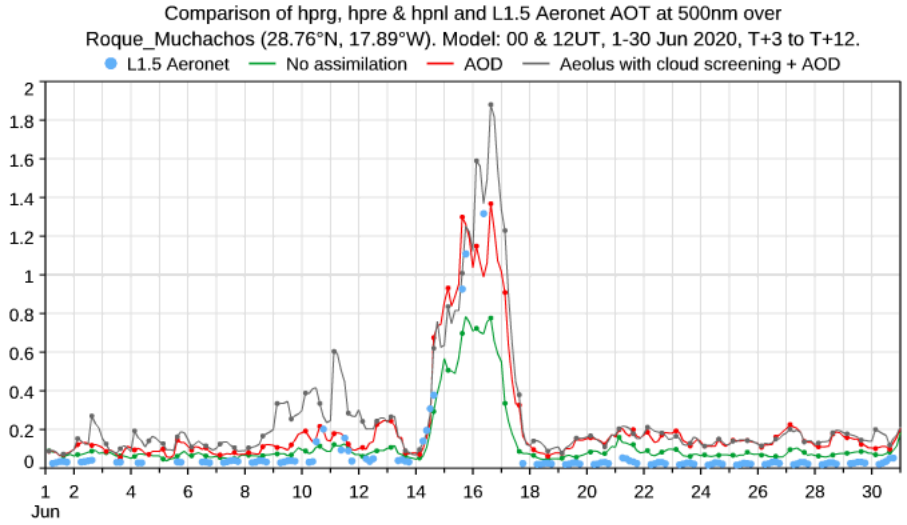


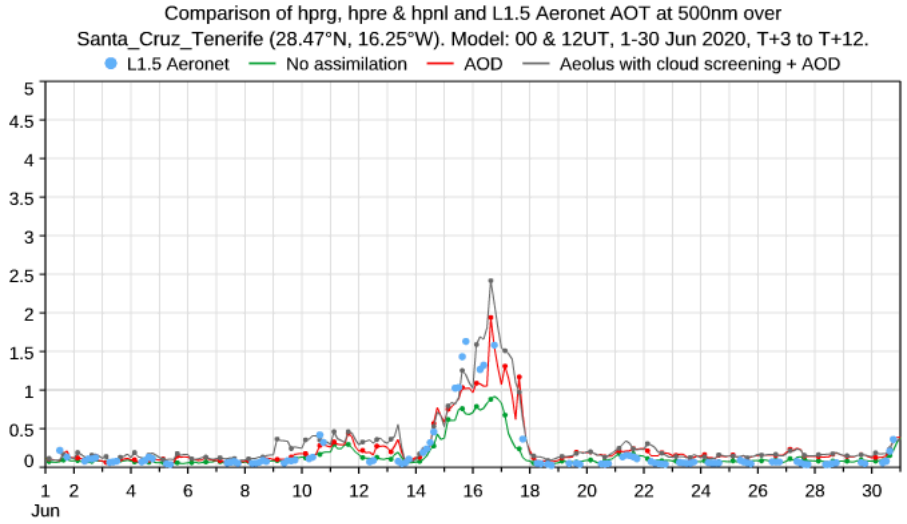
Left: NASA Suomi NPP/VIIRS visible image of Saharan dust over the tropical Atlantic region on 17 June 2020 (from NASA Worldview)



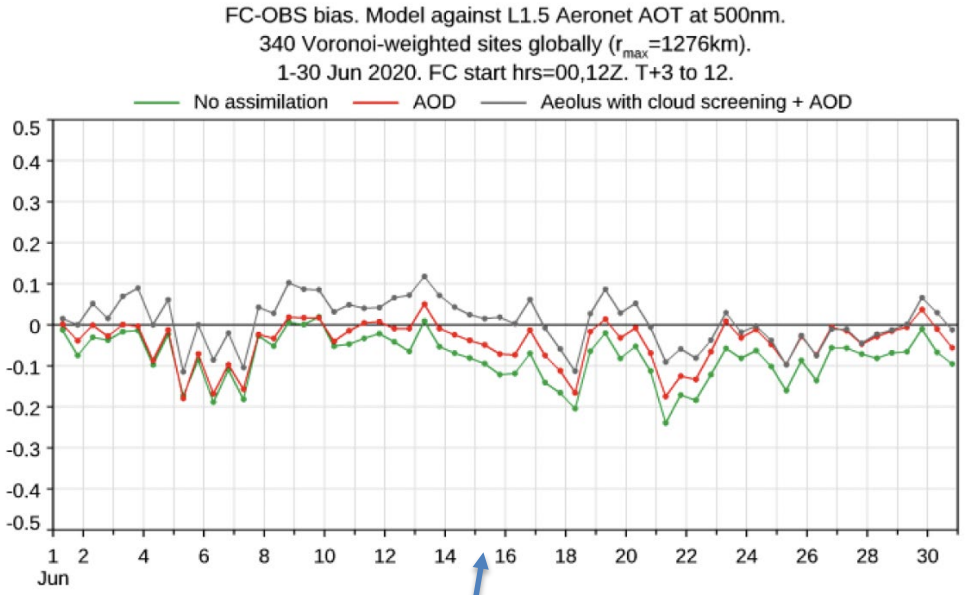
Vertical profiles of the Aeolus L2A backscatter over the tropical Atlantic region for June 15-17. The black line shows the first guess departures, clearly showing Aeolus measurements place the plume height differently than the model first guess.

Right-hand plots: AERONET measurements vs model AOD forecast for June 2020 The red curve is CAMS, and CAMS+Aeolus L2A is the grey. Results with no assimilation are shown in green. Top: data for Roque de los Muchachos, La Palma. Bottom: data for Santa Cruz de Tenerife.





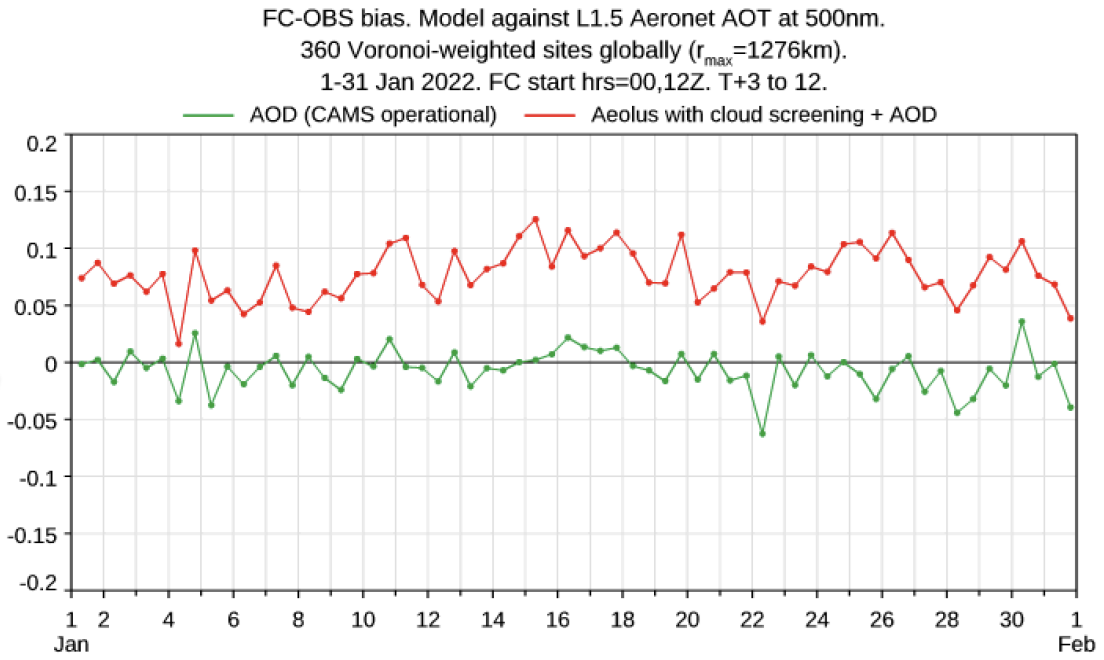
Bias monitoring

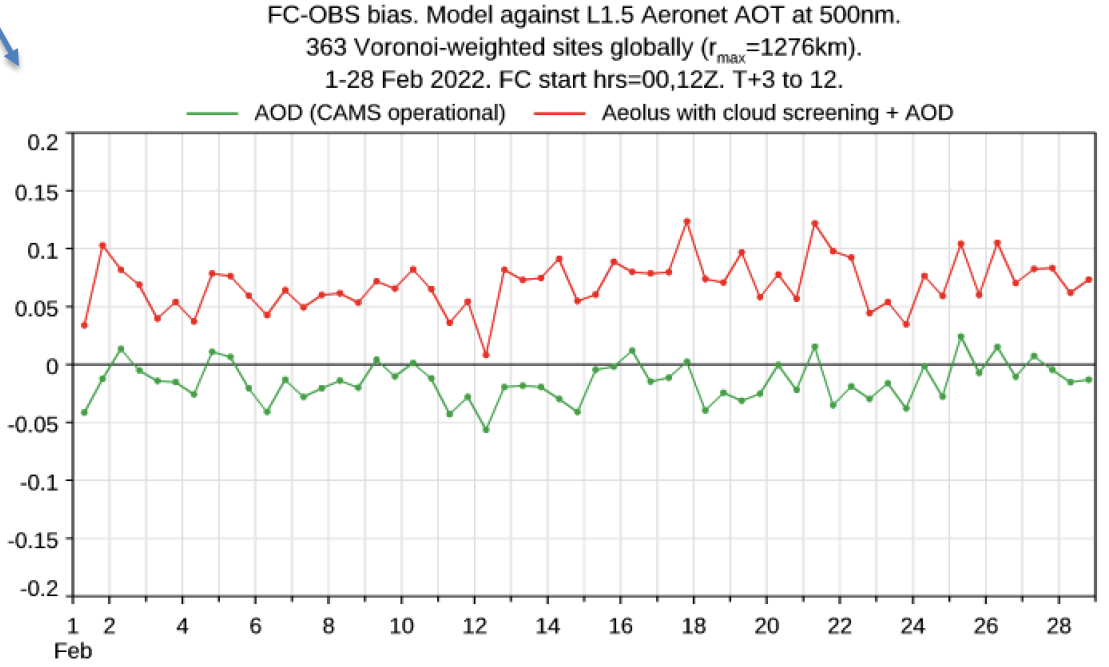


Grey: bias of Aeolus+AOD assimilation, compared with AOD only (red) and no assimilation (green) for June 2020, using IFS version CY47R1.

Top: bias for Jan 2022, bottom: bias for Feb 2022.

Red is Aeolus+AOD, green is AOD only.

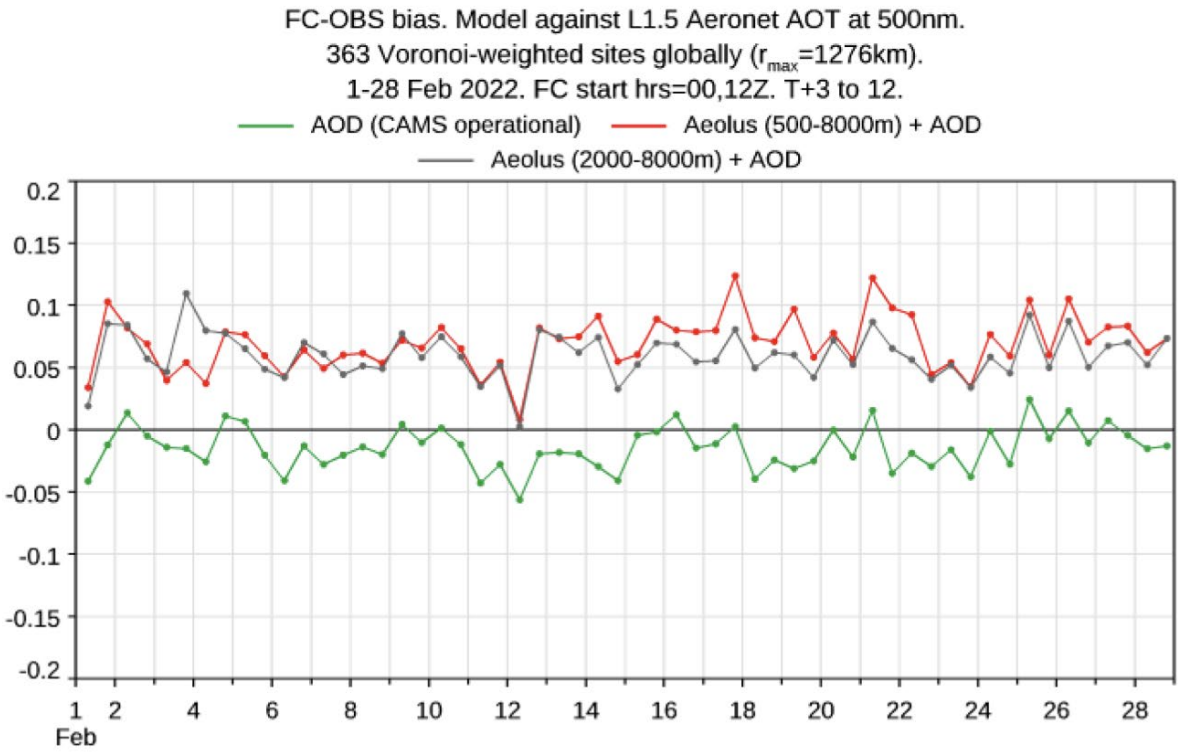




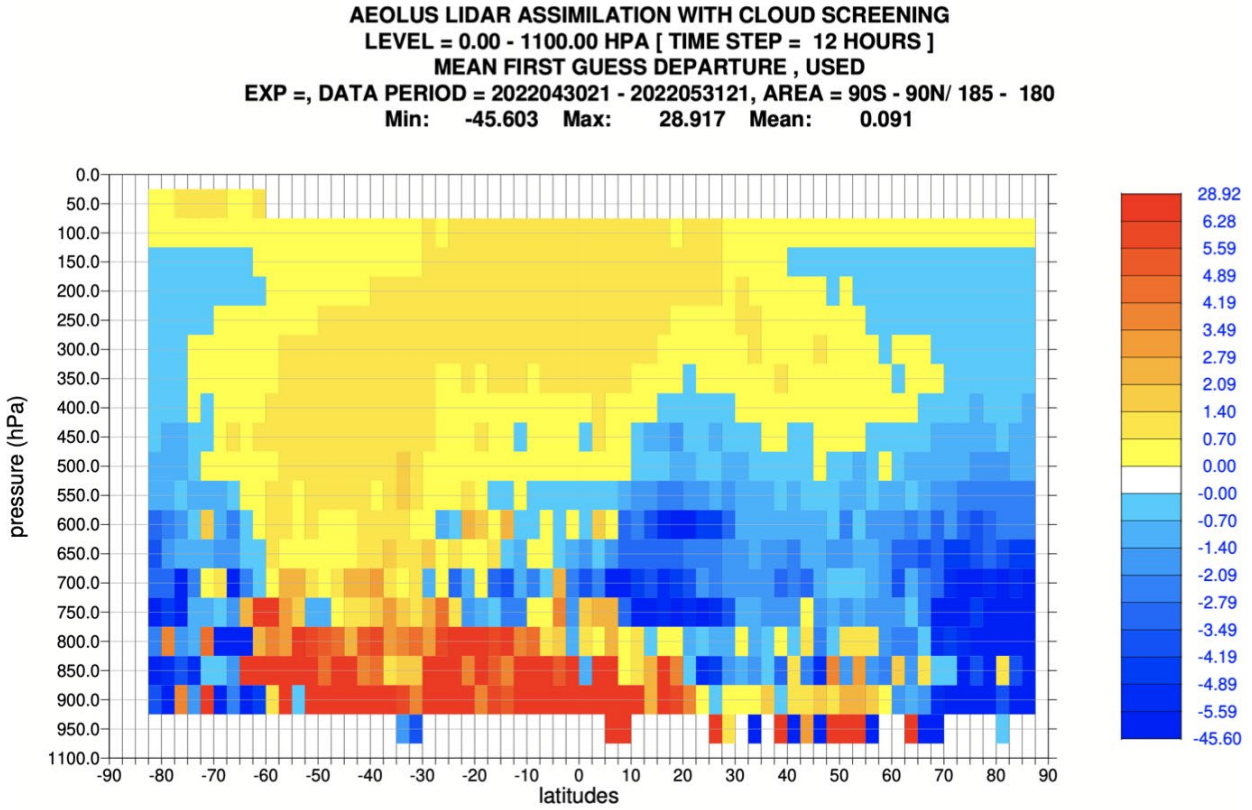
- Previous work in A3S showed the Aeolus L2A particle backscatter assimilation results in a positive bias in the AOD forecast.

- This bias is more apparent in the most recent data; always a positive bias when averaged over the globe.

First attempt at bias correction: exclude the PBL from the assimilation



Grey line shows experiment which excludes Aeolus L2A values below 2 km: slight reduction in bias.

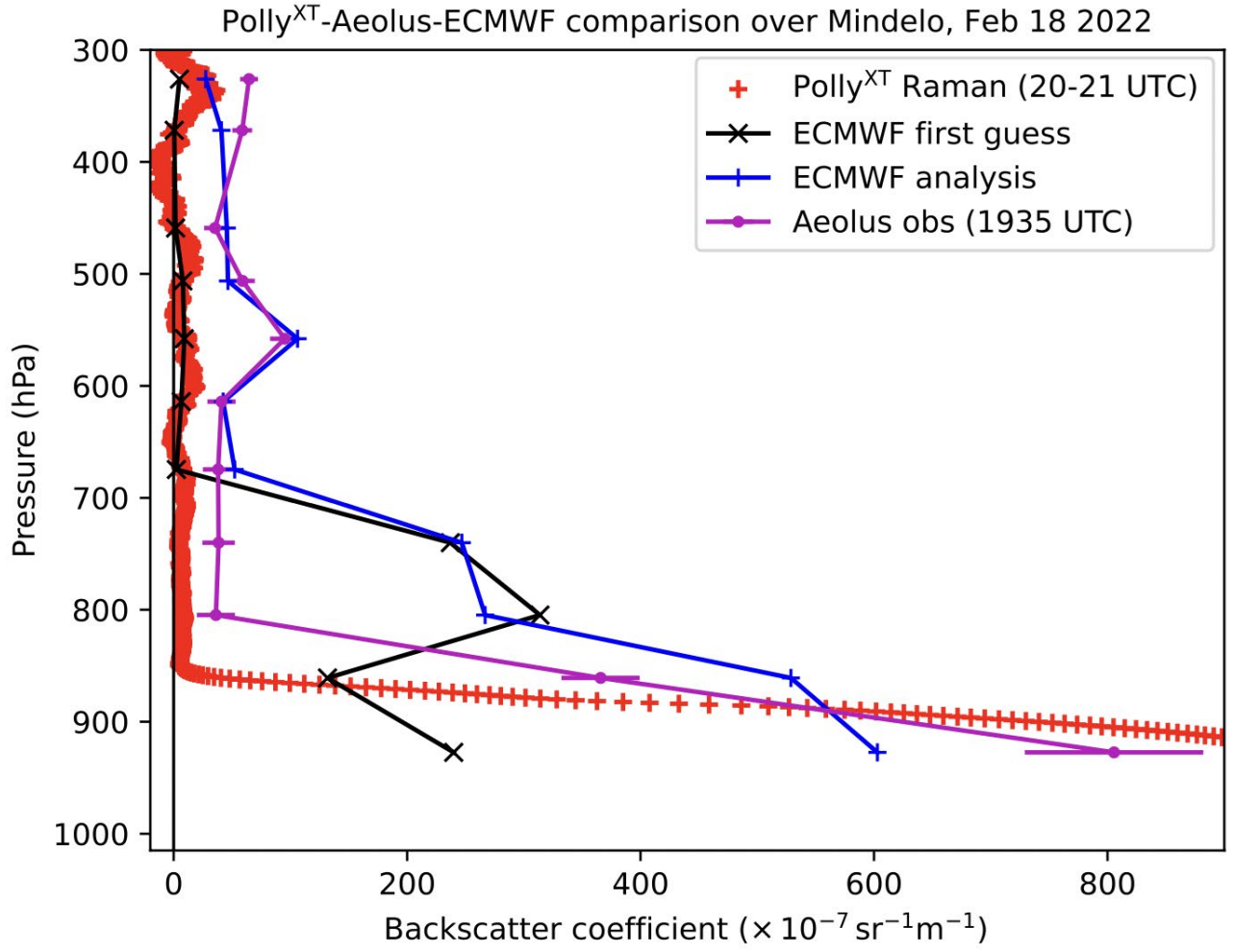


First guess departures for May 2022. Pressure is shown on the y-axis, and latitude on the x-axis.

Comparison of Aeolus L2A and ECMWF model with ground-based lidar

Comparison of Aeolus and ground-based Polly^{XT} 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.

Credit to Holger Baars and the Ground-based Remote Sensing Group (TROPOS; https://polly.tropos.de/) .



Summary and outlook for the Aeolus L2A assimilation

- Cloud screening is crucial for filtering out large signals of particle backscatter. Removal of these large values of backscatter allows us to extract vertical profile information on aerosols.
- Monitoring and assimilation of new retrieval products will begin AS.
- AOD calculated with the inclusion of Aeolus L2A on top of the CAMS model results in a positive bias (globally). Exclusion of PBL values reduces this, but it is not enough; work ongoing for a variational bias correction scheme for the L2A backscatter.
- Case studies of high Saharan dust events show potential of assimilating the Aeolus L2A particle backscatter in improving AOD forecasts and vertical profiling of the aerosols.

Assimilation of visible radiances for aerosol applications

Aerosol Radiance Assimilation Study

Final Meeting

15 April 2020

Samuel Quesada-Ruiz

- *Acknowledgements*: *Rossana Dragani, Philippe Lopez, Peter Lean, Gabor Radnoti, Marcin Chrust,*
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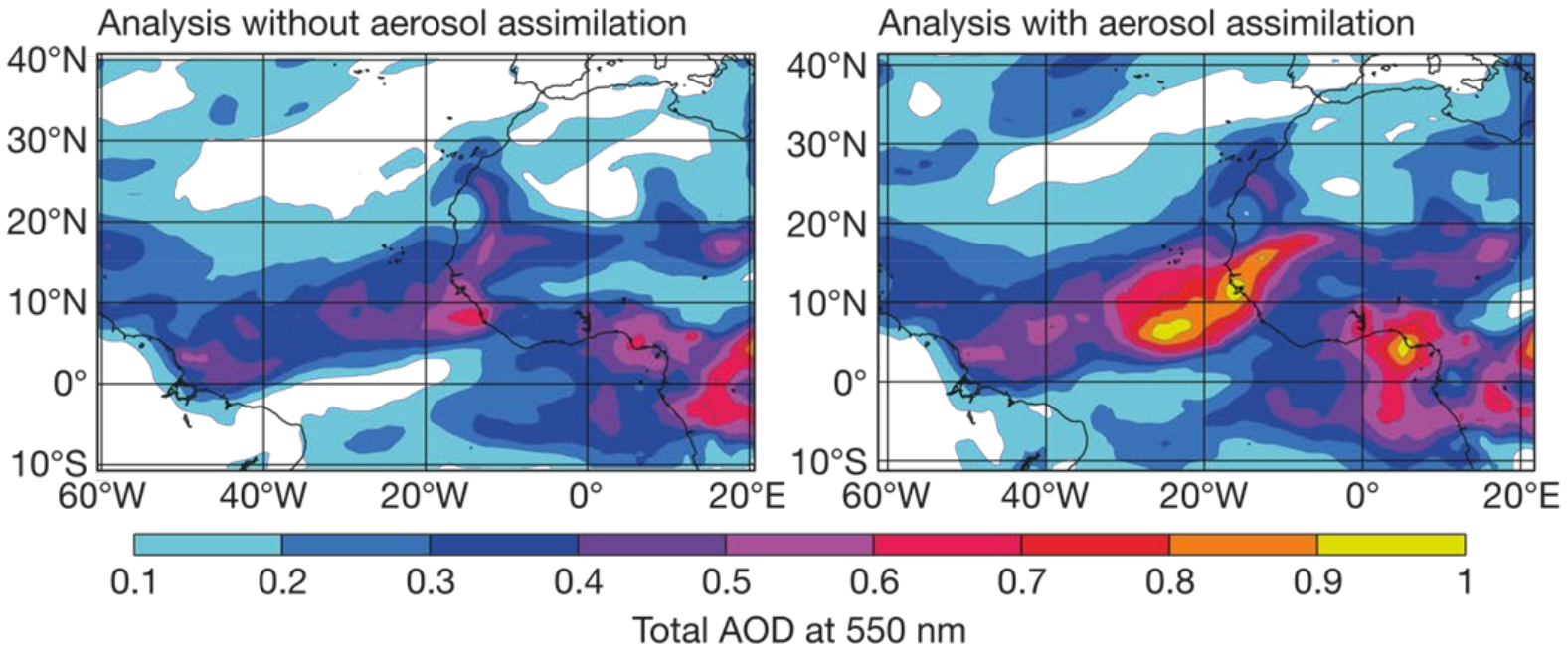
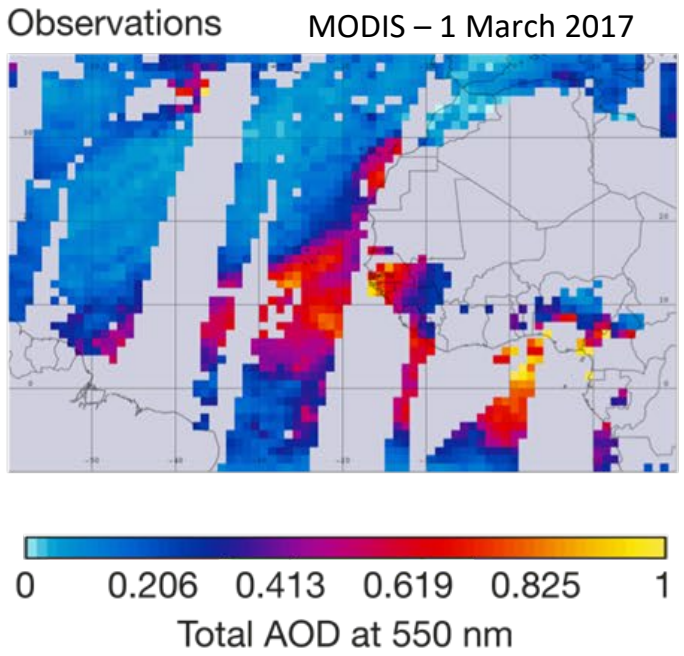
- Angela Benedetti
- Julie Letertre-Danczak
- Marco Matricardi
- Gareth Thomas

ARAS

European Space Agency

Assimilation of reflectances performs comparably to AOD assimilation

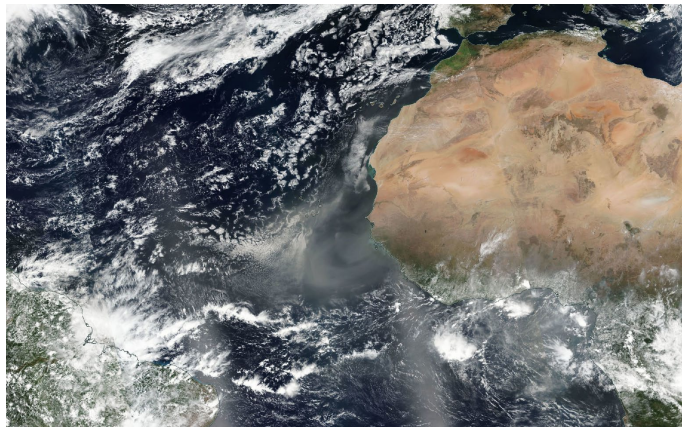




Progress towards assimilating visible radiances has been made in the context of the ARAS (Aerosol Radiance Assimilation Study) project funded by ESA from April 2018 to April 2020. An observation operator based on the Oxford-RAL Aerosol and Cloud (ORAC) satellite retrieval scheme has been developed and incorporated into ECMWF's IFS. It includes look-up tables in which reflectances at the TOA are stored as a function of aerosol optical properties.

- The assimilation of level 2 aerosol visible radiances increases AOD in the analysis to a level comparable to the MODIS AOD data
- A bias correction needs to be implemented
- Land assimilation is more problematic than ocean reflectance assimilation due to poor characterization of surface reflectivity

VIIRS true color image – 1 March 2017

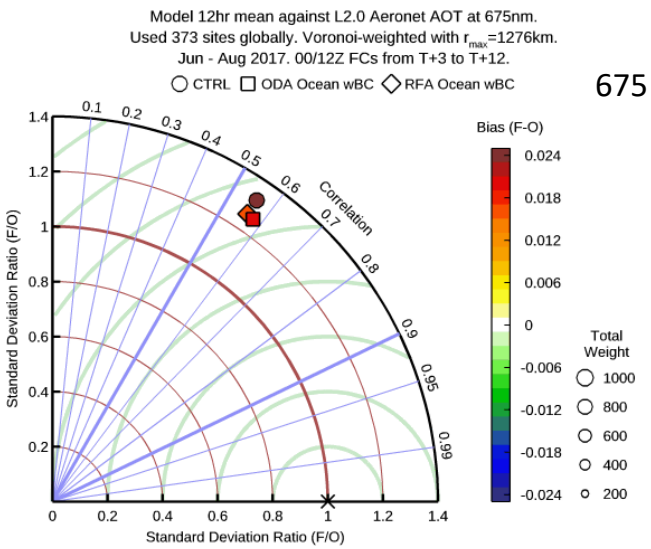


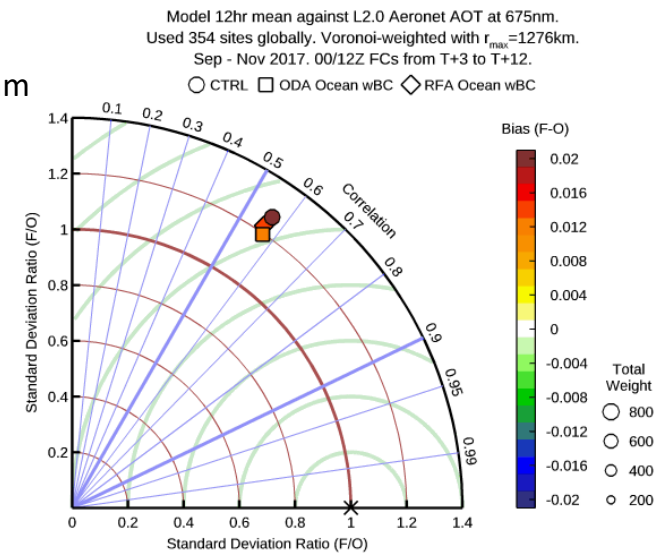
Evaluation of the analyses against AERONET AOD

summer 2017 (JJA)

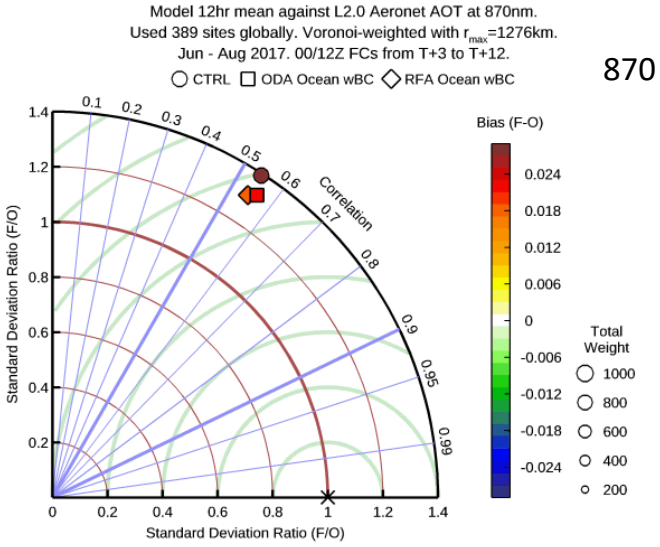
autumn 2017 (SON)

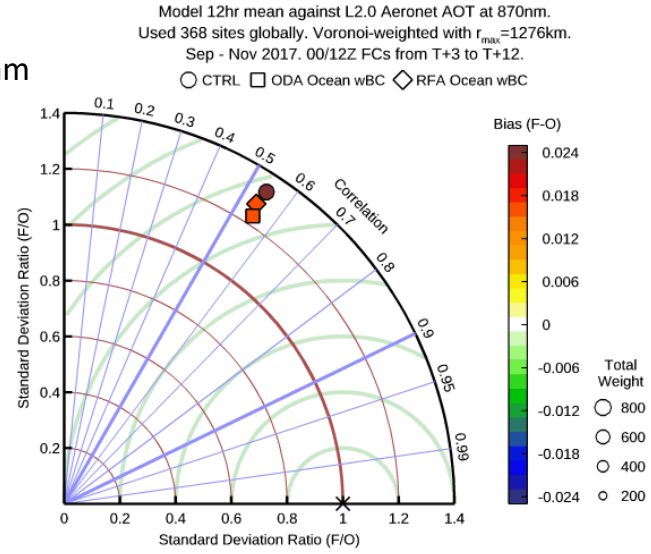
675 nm





870 nm





ARAS was an <u>exploratory</u> project to assess the benefits of the assimilation of aerosol-sensitive radiances

- Comparisons with AERONET AOD showed that the performance of the reflectance assimilation is comparable to that of the AOD. The performance varies depending on the metrics and period analysed.

- ARAS has been an extremely successful project that has lead to the assimilation of aerosol reflectances in the visible for the first time in a global 4D-Var assimilation system.
- The assimilation of reflectances has proven to be very successful exhibiting a remarkable performance for what is essentially a new development rolled out over the course of two years.
- More development is still necessary to bring the assimilation of reflectance at the same level (or possibly higher) of the assimilation of AODs -> CAMEO project led

In the next few years, with some investment, reflectance assimilation can become as mainstream as AOD assimilation

Assimilation of visible radiances for cloud applications

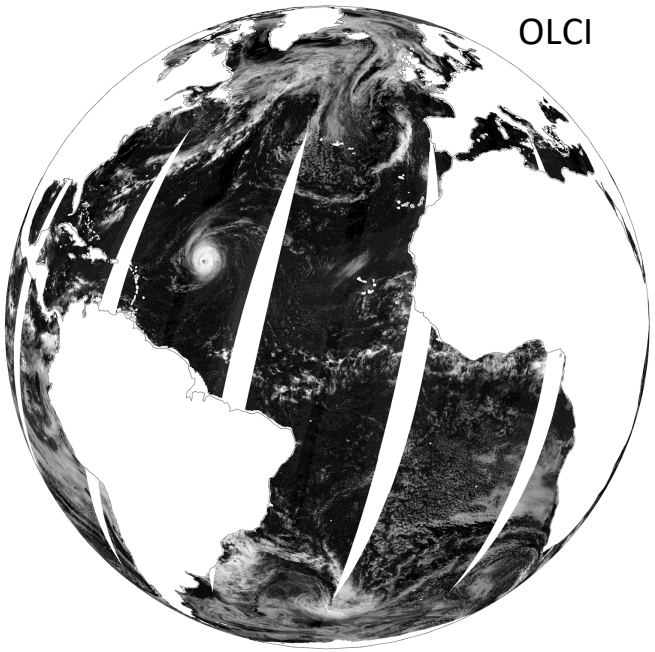
Monitoring visible cloudy radiances

One year project funded by ESA, using 665 nm radiances from the Ocean and Land Colour Instrument (OLCI) over oceans

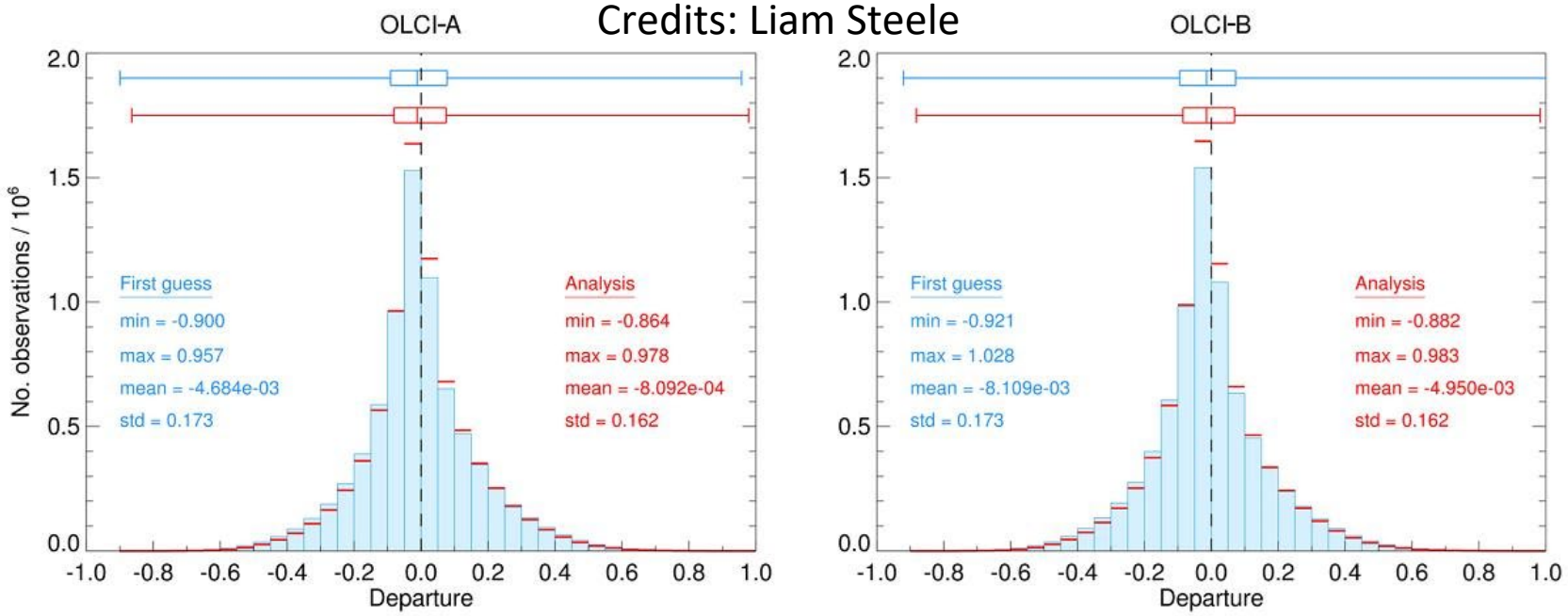
Perform month-long monitoring experiments using the Discrete Ordinates Method (DOM) and the much quicker Method for Fast Satellite Image Synthesis (MFASIS)

Assess the performance of MFASIS compared to DOM. Is it suitable for operational use at ECMWF?

Assess the performance of the IFS in predicting the correct cloud



Credits: Liam Steele



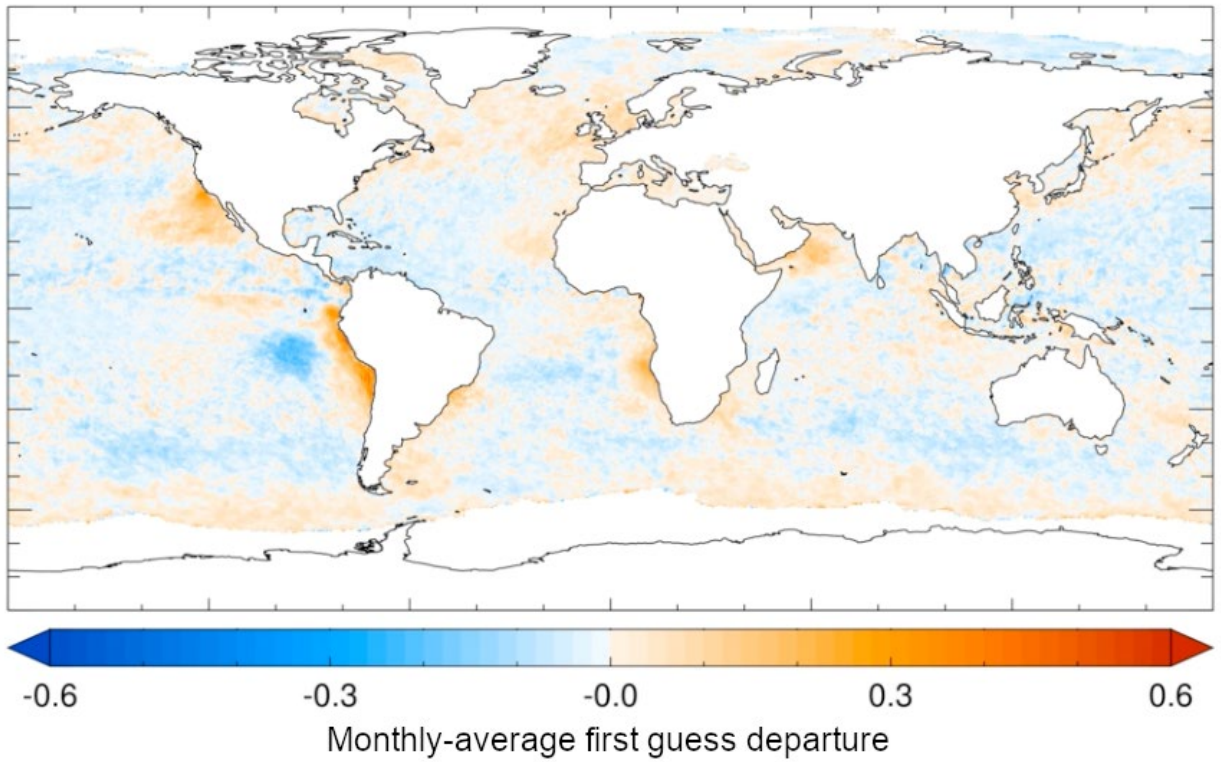
Analysis reduces standard deviations and brings the means closer to zero. No instrumental bias seen

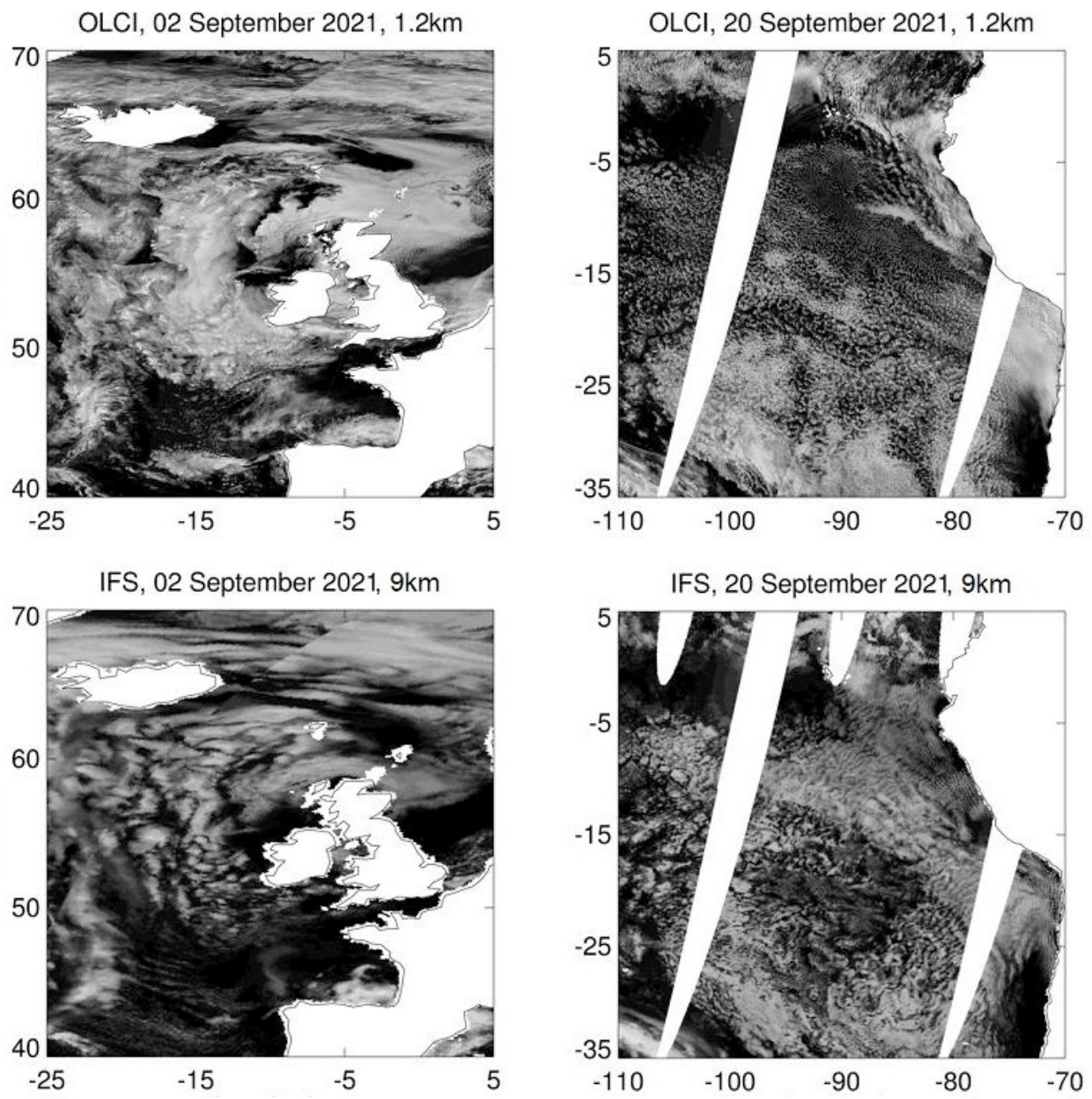
Daily and monthly comparisons (OLCI vs IFS)

Extensive stratus-like clouds around the UK, and stratocumulus off the western coasts of the Americas, are not captured in the IFS

Convective cells are too large in the IFS, even at 9 km resolution

These are mostly low-altitude liquid water clouds





Hurricane Larry

TCo1279 simulation with data superobbed to 9.6 km

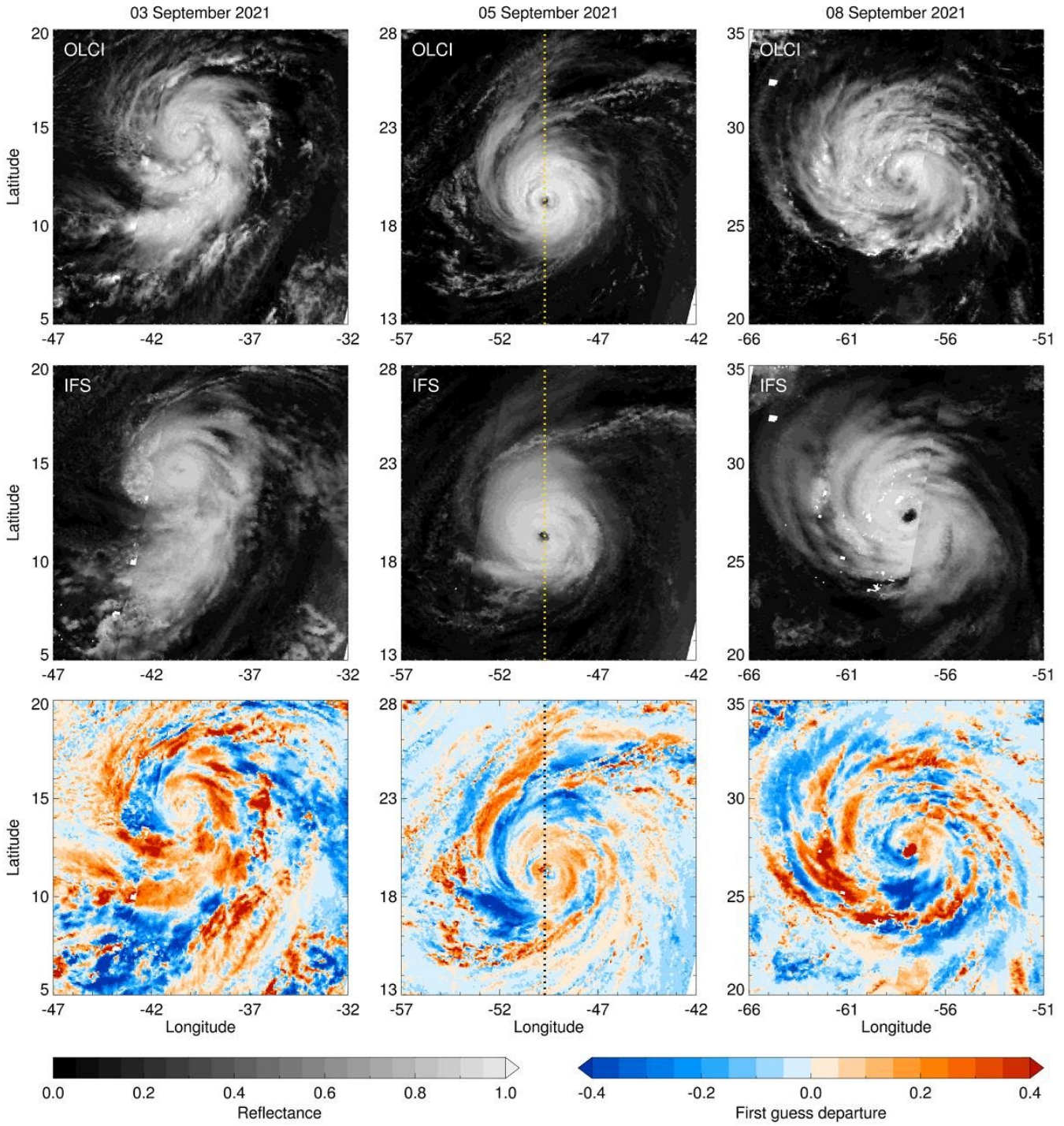
Good general agreement in the shape of Larry and the eye position on 5th September

First guess departures are largest on 3rd and 8th September

In general, the IFS produces a more homogeneous cloud field. Observations show more detailed gaps in the cloud and regions of brighter reflectance where there is strong upwelling and bright convective clouds

3D effects, including shading by clouds, are also present as resolution increases

Because the IFS cloud is more homogeneous, the first guess departures reveal alternating red and blue spiral bands



Currently testing visible monitoring with new instruments (with Cristina Lupu and Samuel Quesada-Ruiz)

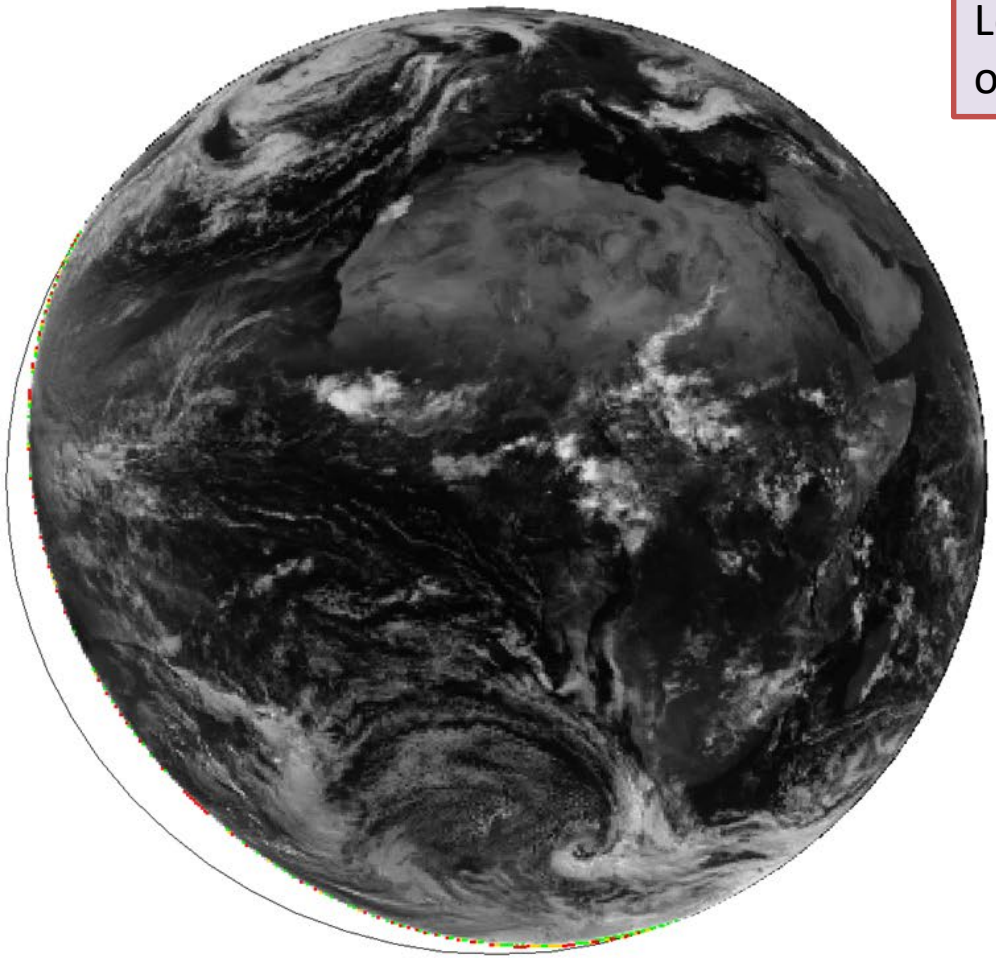
ABI (2 km res, GOES-18)

SEVIRI (3 km resolution, Meteosat-11)

Still in the testing stage (T399 exps)

Radiance (3 km)

Reflectance (30 km)



Looking into inclusion of data over land

1.0 < R < 1.5

1.5 < R < 2.0

R > 2.0