SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2024-2025
Project Title:	DUSTAR: Improving dust transport model models using Aeolus data assimilation
Computer Project Account:	spgramir
Principal Investigator(s):	Dr. Vassilis Amiridis vamoir@noa.gr
Affiliation:	National Observatory of Athens
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Dr. Angella Benedetti Dr. Will McLean
Start date of the project:	12 Sept. 2023
Expected end date:	30 Dec. 2025

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	12,000,000	4,355,394	4,000,000	1,915,426
Data storage capacity	(Gbytes)	1,000	800	1,000	900

Summary of project objectives (10 lines max)

The European Space Agency's wind satellite mission, Aeolus, carried the first space-based doppler wind lidar, with the goal of improving numerical weather prediction. Despite being a wind-focused mission, Aeolus also provided profiles of optical properties for atmospheric aerosols and clouds in the L2A product. ALADIN, the lidar aboard Aeolus, lacks a cross-polar channel and this causes an underestimation of backscatter when observing depolarizing targets, such as desert dust. The ESA study L2A+ investigates the improvement of the L2A product by correcting for this issue through data fusion techniques. The impact of the improved product is studied through data assimilation experiments, which make up the work of this special project. Studying the effect of dust data assimilation on NWP through radiative interactions is crucial for future lidar-based missions, as it puts a value on the remote sensing of aerosol observation in the context of weather forecasting.

Summary of problems encountered (10 lines max)

Scientific problems: Our assimilation system uses an Ensemble Adjustment Kalman Filter implementation for assimilating observations into the WRF-CHEM model. This requires an ensemble of forecasts that significantly differ from each other. This proved to be an involved procedure in the regional model due to the forcing from the boundary conditions 'clearing out' any perturbations on the initial condition fields. This caused a low ensemble spread, which in turn reduced the impact of the assimilated observations. A more robust technique is now trialed to resolve this problem.
Technical problems: We are encountering a hard-to-reproduce issue with I/O that we think is due to parallel filesystem syncing and locking. A common manifestation is the following: a) a process A writes a config file b) process A call process B c) process B looks for config file but cannot find it (doesn't exist) d) process B crashes. Re-running the whole code always works without any modifications. This is mainly a problem if it happens after midnight and you lose the wall time until next morning when you can re-queue the job.

Summary of plans for the continuation of the project (10 lines max)

Our team is working on resolving the final issues of the Aeolus assimilation experiments and will then move on to author a related journal article. In parallel, we have started experiments using the same developments but with EarthCARE lidar data. In addition, in order to help quantify the uncertainty ingrained in the optical properties assumed for aerosols, we have started experimenting with using a more realistic shape assumption for dust and the corresponding optical properties it produces. Early results indicate that the approach developed for Aeolus works for other Lidars as well. We plan to finalise these experiments by the end of the special project (end of 2025).

List of publications/reports from the project with complete references

Conferences:

- Georgiou, T., Tsikerdekis, A., Tsekeri, A., Gialitaki, A., Bantouna, A., Kourantos, A., Melas, D., and Amiridis, V.: Advances in Space-borne Lidar Data Assimilation for Atmospheric Composition and NWP, ESA Living Planet Symposium 2025, Vienna, Austria, 23-27 June 2025
- Georgiou, T., Tsikerdekis, A., Rizos, K., Proestakis, E., Gkikas, A., Drakaki, E., Kampouri, A., Baars, H., Floutsi, A. A., Marinou, E., Benedetti, A., McLean, W., Retscher, C., Melas, D., and Amiridis, V.: Joint Aerosol & Wind Data Assimilation of AEOLUS and impact on NWP, International Symposium on Data Assimilation 2024, Kobe, Japan, 21-25 October 2024
- Georgiou, T., Tsikerdekis, A., Rizos, K., Proestakis, E., Gkikas, A., Drakaki, E., Kampouri, A., Baars, H., Floutsi, A. A., Marinou, E., Benedetti, A., McLean, W., Retscher, C., Melas, D., and Amiridis, V.: Joint Aerosol & Wind Data Assimilation of AEOLUS and preparing for EarthCARE, ESA ATMOS, Bologna, Italy, 1-5 July 2024

- Georgiou, T., Tsikerdekis, A., Rizos, K., Proestakis, E., Gkikas, A., Drakaki, E., Kampouri, A., Baars, H., Floutsi, A. A., Marinou, E., Benedetti, A., McLean, W., Retscher, C., Melas, D., and Amiridis, V.: Using AEOLUS Aerosol Assimilation to pave the way for EarthCARE, EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-10363, https://doi.org/10.5194/egusphere-egu24-10363, 2024.

Summary of results

Since the last report, our team has been focused on (a) producing a better estimate of uncertainty for desert dust in our assimilation experiments, (b) trying new optical properties to better represent desert dust, and (c) assimilating EarthCARE data.

We originally used perturbations on the meteorological fields of the model (wind, temperature) to produce an ensemble of forecasts that diverged from the original fields used as initial conditions. This is a way to represent the uncertainty of our NWP model and in our understanding of dust transport, as different weather conditions will produce a different transport pattern. In addition to this approach, we developed scheme that allows the use of an arbitrary per-grid cell dust emission weight in WRF-CHEM. This allows the use of emission perturbation fields, thus creating ensembles that try to capture the uncertainty of our emission parametrisation schemes. Figure 1 shows an example of such an emission perturbation field, where a value of 1 would equal unchanged emissions from the parametrisation output. The presented perturbation field has a mean value larger than 1, which is an attempt to account for the model underestimating the amount of dust emitted. The fields are generated using the approach described in the supplement of Tsikerdekis et. al. 2021[1].

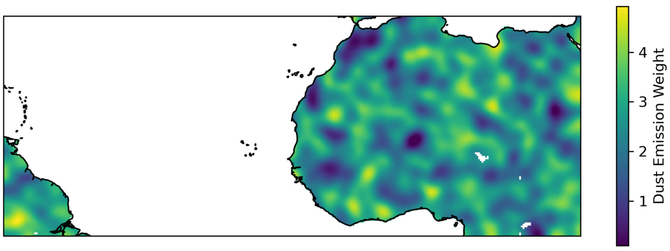

Figure 1: Example of the dust emission perturbation field. Each member of an ensemble would use a different field like the one presented.

Our work related to the optical properties of dust consists of using a mixture of particle shapes that can reproduce a set of lidar observations from the ESA-ASKOS campaign. Specifically, an optimisation algorithm is used to select the exact mixture of spheroidal and hexahedral particles that can reproduce the lidar observations, and then this mixture is used to compute Look-Up Tables of dust extinction efficiencies. Our model uses these LUTs for assimilation in the observational operator and also for outputting extinction and optical depth variables.

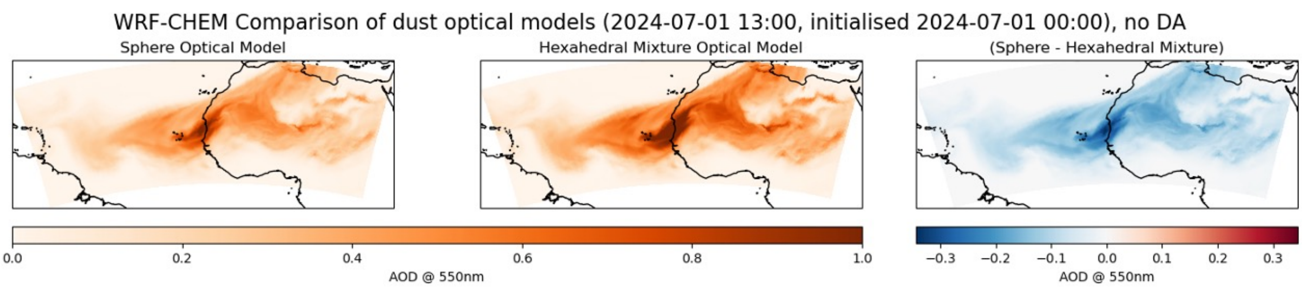

Figure 2: Comparison of Dust Optical Depth output for the same case but with different optical models. The hexahedral-spheroid particle mixture will produce a higher optical depth for the same dust field.

Using the above improvements, we have conducted experiments with EarthCARE ATLID lidar assimilation. The observational operator should work for any atmospheric lidar, with the only adjustment required being the use of an appropriate look-up table to match the lidar's wavelength. Below we present one case of assimilating an EarthCARE overpass on 2025-04-27, 03:00:00. The experiment was initialized on 2025-03-01 using ERA5 and CAMS-FC data for initial and boundary

[1] https://acp.copernicus.org/articles/21/2637/2021/

This template is available at:
http://www.ecmwf.int/en/computing/access-computing-facilities/forms

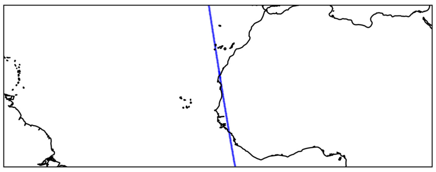

Figure 3: Overpass of EarthCARE for assimilation window at 2025-04-27, 03:00:00

conditions. EarthCARE’s overpass was in the middle of the model domain, crossing over the west edge of Africa (Figure 3). Before assimilating the ATLID EBD product, any bins of low retrieval quality or classified as not aerosols nor clear air were removed. Afterwards, the EarthCARE data were down sampled (super-orbing) to better match the model resolution. The results are presented in Figure 5, which shows the EarthCARE data before and after pre-processing, as well as the model’s prior and posterior for the same orbit. We observe that assimilation creates fine-details in the aerosol layer that the model could not resolve on its own. In total, these changes correspond to a difference of around 0.1 in integrated Dust Optical Depth, as shown in Figure 4.

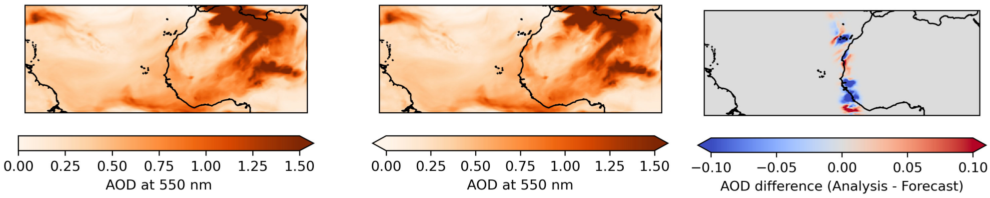

Figure 4: Dust Optical Depth maps for (a) the model prior and (b) the model posterior. The final panel shows the difference (posterior - prior).

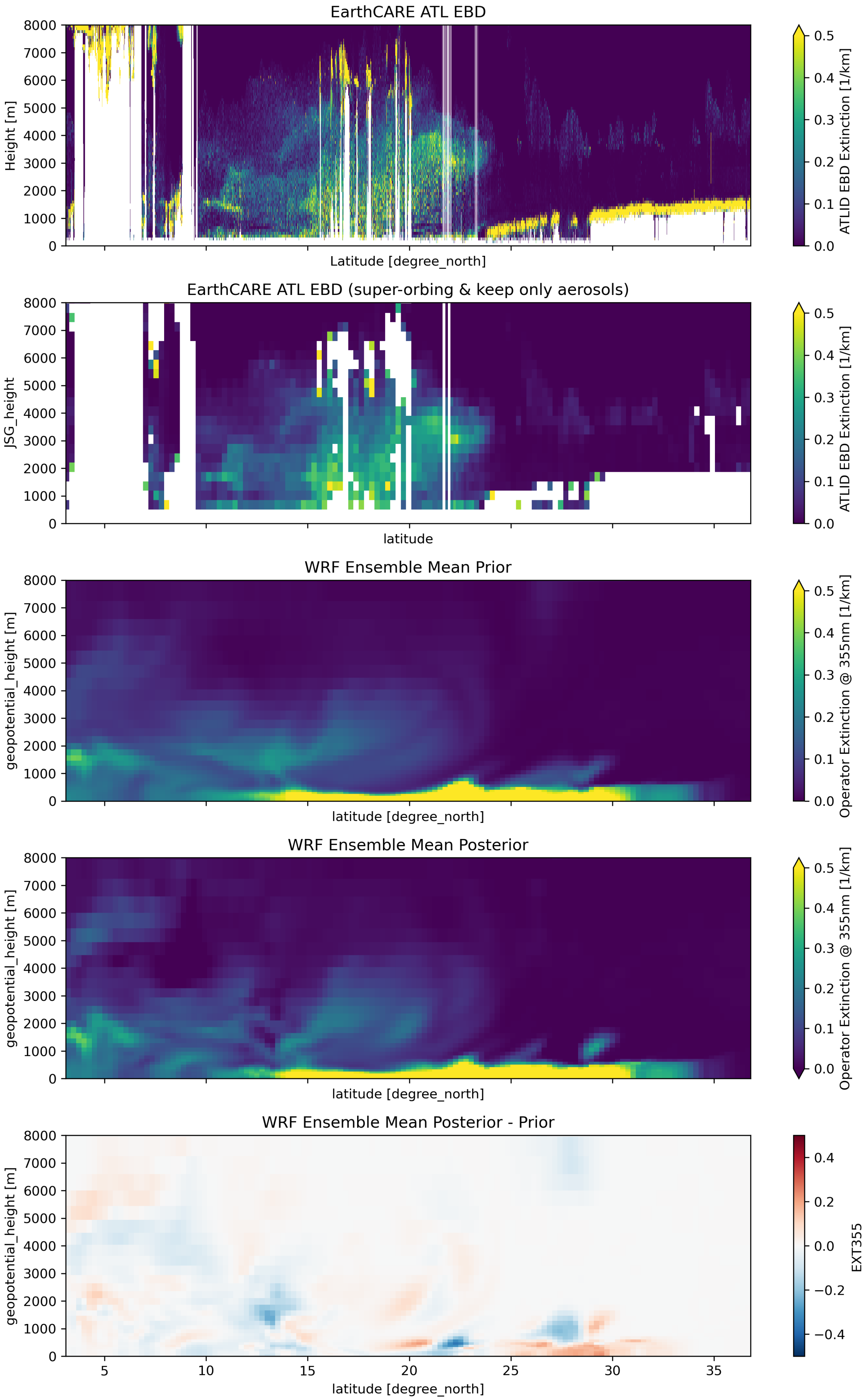

Figure 5: Curtain plots of (a) EarthCARE ATL EBD product, (b) the downsampled and filtered data, (c) the model's prior, (d) the model's posterior, and (e) the difference between the prior and the posterior.