LATE REQUEST FOR A SPECIAL PROJECT 2025–2027

MEMBER STATE: Greece

Principal Investigator[1]: Dr. Vassilis Amiridis

Affiliation: National Observatory of Athens (NOA)

Address: Vas. Pavlou & I. Metaxa, GR-15 236 Penteli, Greece

Other researchers: Thanasis Georgiou
Areti Bantouna
Vassilis Spyrakos
Eleni Drakaki
Anna Gialitaki

Project Title: Developments in observational operators for atmospheric lidars

To make changes to an existing project please submit an amended version of the original form.)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** gramir	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2026	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:		**2025**	**2026**	**2027**
High Performance Computing Facility	[SBU]	0	6,000,000	6,000,000
Accumulated data storage (total archive volume)[2]	[GB]	0	0	0

EWC resources required for project year:		**2025**	**2026**	**2027**
Number of vCPUs	[#]	0	0	0
Total memory	[GB]	0	0	0
Storage	[GB]	0	0	0
Number of vGPUs[3]	[#]	0	0	0

Continue overleaf.

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.
[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.
[3] The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

Principal Investigator: Dr. Vassilis Amiridis

Project Title: Developments in observational operators for atmospheric lidars and constraining dust emissions through data assimilation

Extended abstract

All Special Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF and its Scientific Advisory Committee. The requests are evaluated based on their scientific and technical quality, and the justification of the resources requested. Previous Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests exceeding 10,000,000 SBU should be more detailed (3-5 pages).

Introduction

The EarthCARE mission has been in orbit since May 2024 and carries a high-spectral resolution atmospheric lidar, providing vertical profiles of atmospheric composition and offering insights into the distribution of aerosols and ice clouds while continuing the data legacy of NASA's CALIPSO and ESA's Aeolus missions. Although the primary objective of the mission is to advance scientific understanding of aerosol-cloud-radiation interactions, it has been demonstrated that data assimilation of lidar observations can improve forecasting of dust events [1] and initial conditions for weather prediction [2], [3]. Current operational models rely mainly on Aerosol Optical Depth assimilation and produce widely varying estimates of atmospheric dust loads, emissions, and deposition fluxes—with AeroCom reporting total dust burdens ranging from 7 to 30 Tg [4]. Additionally, most numerical models use spherical optical representations for desert dust, despite its complex and irregular particle shapes, with changes in optical modeling significantly affecting the dust load estimates required to reproduce observed optical properties.

The purpose of this study is two-fold: first, to advance lidar-related data assimilation capabilities by developing appropriate observational operators for depolarization and lidar ratio observations, and second, to investigate the impact of using advanced non-spherical optical models for desert dust representation in numerical models and their effects on dust emission, deposition, and data assimilation processes. These developments aim to maximize the scientific impact of assimilating EarthCARE's vertically resolved lidar parameters and reduce current uncertainties in dust forecasting within numerical weather models.

This study is done under the context of the EarthCARE Data Innovation and Science Cluster (DISC) project. The primary related work package is WP 7310, in which the National Observatory of Athens (NOA) is tasked to develop polarization capability in the observational operators used for Data Assimilation of ATLID observations. The output of this WP is used downstream in WP 7200, which is implemented by ECMWF and relates to operational assimilation of ATLID and CPR observations. The work related to the advanced optical properties for dust is done under the scope of the CERTAINTY EU HORIZON project.

Current work

The team at NOA has worked extensively with lidar assimilation, specifically under the scope of ESA's L2A+ (AEOLUS data assimilation) and AIRSENSE (synergetic LEO and GEO data assimilation). These projects have resulted in the development of observational operators for aerosol optical depth and lidar extinction. The observational operators have been published in a fork of the NCAR DART project and are available online [5]. NCAR DART [6] is a model-agnostic Ensemble Adjustment Kalman Filter [7] implementation, thus the operators are available to use with a variety of numerical weather models. Regardless, the functions themselves are easily portable to use in other assimilation systems. These operators have been tested in assimilation experiments using the regional WRF-CHEM model, where preliminary results show an improvement in the modelling of dust transport and deposition. Initial results show that DA of EarthCARE extinction profiles create fine-scale features in the model fields, and we are currently investigating the

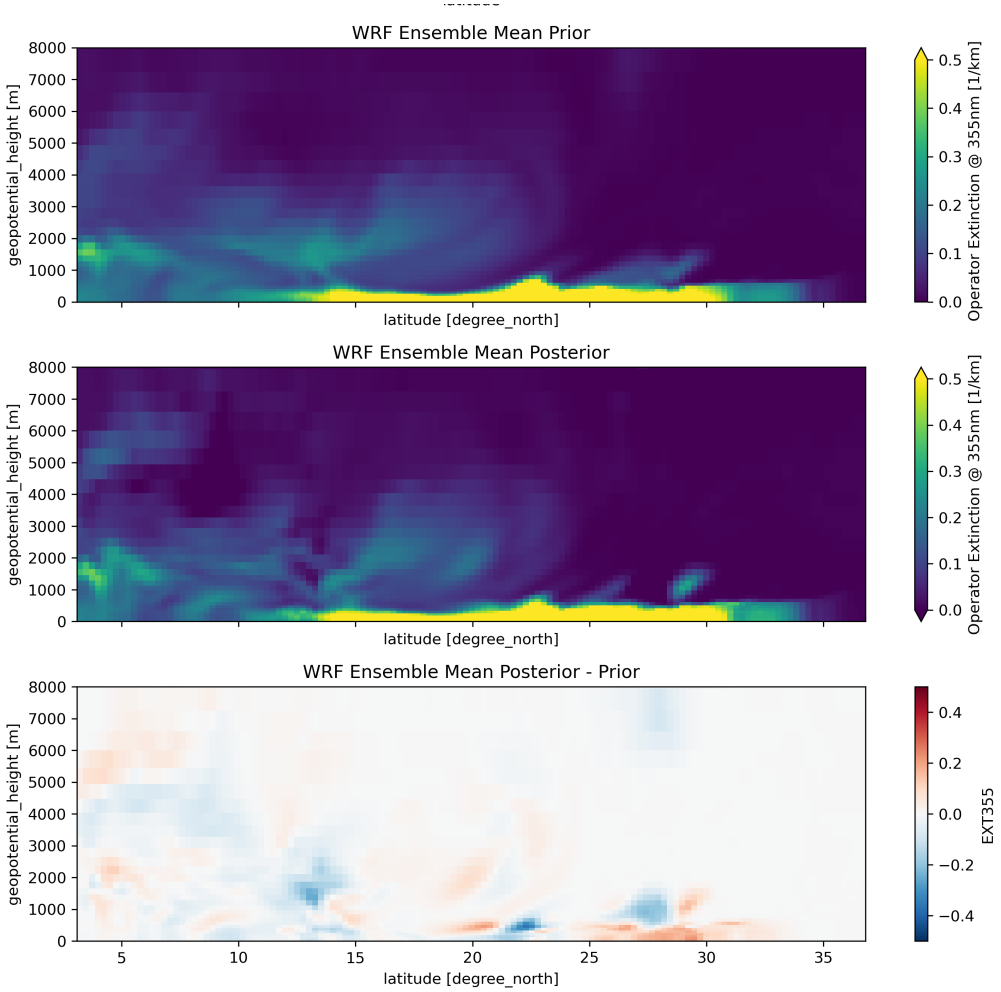

Figure 1: Model prior and posterior for an indicative overpass of EarthCARE. The posterior shows fine-scale features that do not appear as pronounced on the prior. Preliminary, unpublished results.

impact of this on aerosol's direct and indirect effects (shown in *Figure 1*). Parts of this work were completed during the `spgramir` special project and the team is currently working towards related peer-reviewed publications.

The operators support two sets of optical properties for dust, a classic spherical representation and a representation that consists of a random mixture of spheroids and hexahedral particles. The exact mixture of spheroid and hexahedral is chosen through an optimization procedure that selects the mixture that can reproduce lidar observations from the ESA ASKOS experimental campaign. *Figure 2* shows the relationship between size parameter and extinction efficiency ($\boldsymbol{Q_{ext}}$) for the two optical models. The Spheroid/Hexahedral optical model has higher extinction efficiency, which in turn means the model can reproduce a specific optical depth with smaller dust load. This difference directly affects the modelled dust load after data assimilation.

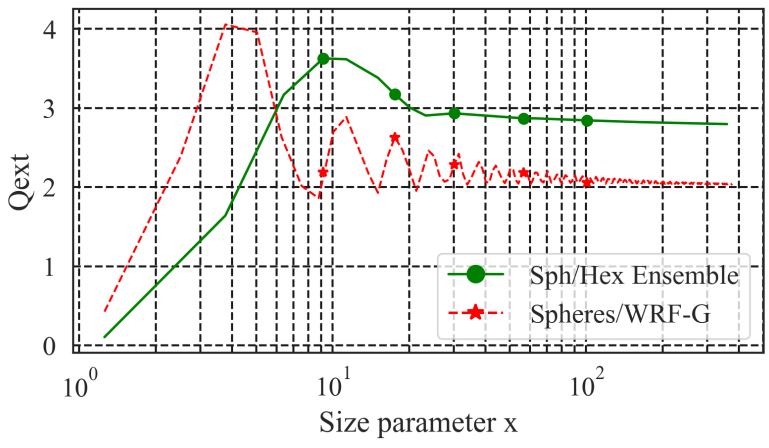

Figure 2: Extinction efficiency of dust as a function of the size parameter for the two optical models, Spherical and Spheroid/Hexahedral mixture.

Scientific Plan, Software

Under the scope of the requested special project, the team is planning to complete a set of data assimilation experiments regarding EarthCARE ATLID data, as so to test the new operator developments. Specifically, we aim to do multiple experiments to quantify the impact of EarthCARE assimilation (extinction, depolarization ratio, lidar ratio) on forecasting and verify the developed operators. The indicative experiment list follows, subject to change depending on the initial results:

- Control: No data assimilation (free run)
- AOD-only: Data assimilation of AOD observations from the PACE platform
- EarthCARE-E: Data assimilaton of AOD (PACE) and EarthCARE extinction profiles
- EarthCARE-ED: Data assimilaton of AOD (PACE) and EarthCARE extinction profiles, depolarization ratio profiles
- EarthCARE-EL: Data assimilaton of AOD (PACE) and EarthCARE extinction profiles, lidar ratio profiles

Some runs will be repeated to determine the optimal tuning parameters for EarthCARE DA, such as localization factor, observation error, etc. Our experiments will target the period of the PERCUSION experimental campaign (part of ORCHESTRA [8]), which took place on August and September of 2024. Thus, the assimilation experiment results will be validated using the airborne observations from the experimental campaign. Our ensembles will have 30 independent members with different dust emission fields and possibly, different physics configurations. Our model's horizontal resolution will be 30km for experiments during development, and 7km for the final experiments at the end of the project. Additionally, we aim to do specific nested runs with a target resolution of 1km, which will be used as initial conditions for cloud-resolving LES studies. These special experiments will shed light on how the improved dust fields change the modelling of indirect aerosols effect.

Our experiments will be done using the WRF-CHEM regional model, the NCAR DART assimilation toolkit, and the wrf-ensembly experiment orchestrator. WRF-CHEM and DART are accelerated using MPI and have been extensively tested on HPC systems of varying sizes. The orchestrator is developed by NOA in Python and uses a process-based parallelisation strategy. Since many orchestrator tasks involve I/O operations (copying variables between netCDF files, managing configuration files, etc.), these are parallelized using one process per file or ensemble member. The orchestrator is fully integrated with SLURM, and the data assimilation experiments can be executed using generated job files with fully managed dependency chains.

During the spiritual predecessor special project, `spgramir`, we have determined that one month of DA experiments at 30km requires approximately 50k SBUs at 30km horizontal resolutions, while an experiment at 9km requires 400k SBUs. We believe the requested resources would be sufficient for development and validation of the operators. The required toolkit is prepared in order not to have any delays at the start of the project.

A single assimilation experiment, with duration of 1 month and horizontal resolution of 30km, produces around 2TB of scratch data. These are post-processed on the HPC and the final output size is approximately 100GB. The resulting dataset is finally downloaded on NOA's local resources for analysis and validation. The default quotas for `hpcperm` and `scratch` filesystems are sufficient for this workflow, and we do not require long-term archival storage.

The timeline of the project consists of a 6-month operator development period, during which the experiments will be focused on checking whether the operators work correctly in well studies scenes and on tuning the model prior, while the remainder is focused on the final experiments and comparisons with the experimental campaign data.

Acknowledgements

Parts of the described research is being done for the EarthCARE - DISC project, which is funded from the European Space Agency under Contract No. 4000144997/24/I-NS, and other parts have received funding from Horizon Europe programme under Grant Agreement No 101137680 via project CERTAINTY (Cloud-aERosol inTeractions & their impActs IN The earth sYstem).

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