<u>LATE</u> REQUEST FOR A SPECIAL PROJECT 2023–2025

MEMBER STATE:	GREECE

Principal Investigator:	Dr. Vassilis Amiridis
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Other researchers:	Eleni Drakaki, Thanasis Georgiou, Anna Kampouri, Alexandra Tsekeri
Project Title:	IMPROVING **DUST** TR**A**NSPO**R**T MODELS USING AEOLUS DATA ASSIMILATION (**DUSTAR**)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2023	
Would you accept support for 1 year only, if necessary?	Yes	NO

Computer resources required for the years: (To make changes to an existing project please submit an amended version of the original form.)		**2023**	**2024**	**2025**
High Performance Computing Facility	(SBU)	8 millions	12 millions	4 millions
Accumulated data storage (total archive volume)[2]	(GB)	300	300	300

Continue overleaf

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

Scientific Plan

The European Space Agency's (ESA) wind satellite mission, Aeolus, carries the first space-based Doppler wind lidar. Its main objective is to improve Numerical Weather Prediction and advance the understanding of atmospheric dynamics, through the provision of high-quality wind profile measurements. The main data product consists of horizontally projected line-of-sight wind speeds, starting from the surface and up to 30 km. Aeolus has been used in daily weather forecasts since 2020 and despite consisting of a tiny subset (<1%) of the measurements utilized by ECMWF, it demonstrates a disproportionately large and positive impact on the predictions [1], [2].
In addition to the primary wind product, Aeolus also provides profiles of cloud and aerosol optical properties. The Aeolus aerosol product, L2A [3], has been utilized to study smoke transport (e.g., from the 2019 Californian Wildfires [4]) and to enhance volcanic ash forecasting systems, among other applications. Furthermore, it has been shown in the ADD-CROSS EUMETSAT project that the L2A product has a positive impact on NWP (interactive aerosols) and especially in desert dust outflow regions. However, due to the omission of a cross-polar component channel in the design of Aeolus lidar, the instrument significantly underestimates the atmospheric aerosol load, especially in cases of strongly depolarizing targets, such as desert dust [5]. This is shown in Figure 1.

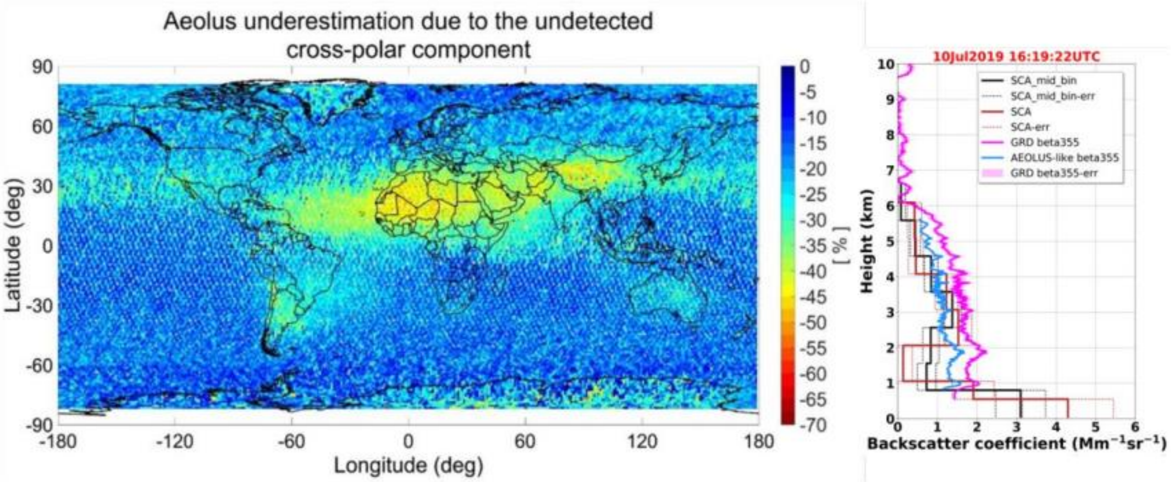

Figure : Aeolus underestimation due to the missing cross-polar channel, presented both in theoretical calculations and in observations.

The **ESA-funded L2A+ project**, implemented by the National Observatory of Athens **(NOA)**, the European Centre for Medium-Range Weather Forecasts **(ECMWF)** and the Leibniz Institute for Tropospheric Research **(TROPOS)**, aims to produce a refined Aeolus aerosol product (named L2A+), to correct for the lack of a cross-polar channel. The improved product will be developed by utilizing new algorithms and employing fusion of Aeolus data with other data sources such as CAMS, to accommodate for the Aeolus missing cross-channel. The project aims not only to enhance the value of Aeolus today, but also demonstrate the usefulness of improved aerosol and dust measurements in Numerical Weather Prediction and the impact of having a joint wind-and-aerosol dataset on dust transport modelling.

During the L2A+ project, for the first time, we will be able to examine the impact on NWP of both Aeolus wind and aerosol products. Assimilation algorithms are under development to incorporate the HLOS and the L2A and L2A+ datasets into a regional coupled NWP model. We aim to demonstrate the increased value offered by L2A+ by comparing forecasts that utilized L2A+ assimilation with forecasts that utilized either the original L2A product, or no aerosol assimilation at all. In addition, the performance of the WRF model will be examined both through the direct assimilation of the Aeolus wind product and through different initialization of the model with the IFS-with and without Aeolus wind assimilation. Finally, we aim to study the effects of radiative forcing on aerosol transport by repeating the experiments with both the radiation calculations on and off.

The regional modelling experiments will be compared with ground-based measurements from the ESA-ASKOS (Figure 2) and NASA-CPEX-CV campaigns over the Cabo Verde region, to further demonstrate the impact of AEOLUS on NWP.

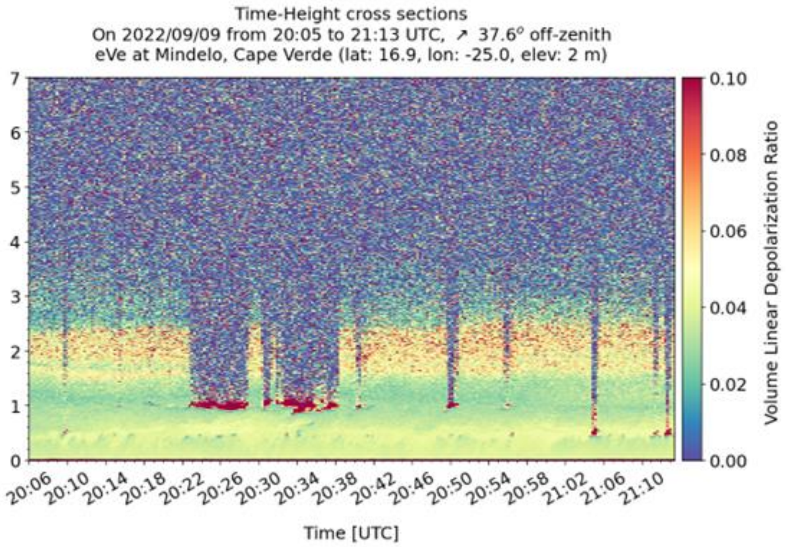

Figure 2: measurements of Volume depolarization Ratio taken on 9/9/2022, from the EVE Lidar in Cabo Verde during the ASKOS-CPEX campaign in 2022.

Advances and benefits

The present study aims to exploit the potential advances and benefits of utilizing Aeolus in enhancing the accuracy of dust modeling and elucidating the relative contribution of these products to numerical weather prediction. Through this study, we aim to further expand the Aeolus investment return, which is already estimated to reach €3.5bn [6], by demonstrating improvements in dust transport modelling, dust deposition and highlight the value of joint wind and aerosol datasets in atmospheric sciences.

Ultimately, the development of a coupled dust transport and numerical weather prediction model based on the findings of this study can prove to be a valuable addition to the existing suite of weather forecasting models utilized by the National Observatory of Athens and the Hellenic National Meteorological Service (HNMS). This can lead to more comprehensive and improved desert dust forecasts, which can aid decision-making processes in a wide range of sectors including agriculture, aviation, transportation, emergency management and air quality.

Technical characteristics: WRF simulations and DART assimilation

Assimilation of Aeolus product will be done using the Ensemble Kalman Filter (EnKF) algorithm, as implemented in the DART toolkit [7] in combination with the Weather Research & Forecasting model (WRF), a version of the model that includes the GOCART-AFWA dust scheme (WRF-Chem). A schematic visualization of the assimilation procedure is depicted in Figure 3.

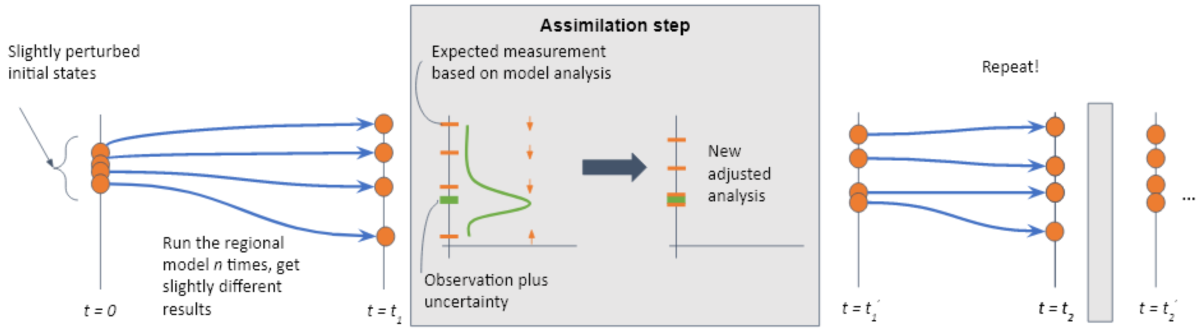

Figure 3 : Visual representation of the Ensemble Kalman Filter algorithm

The WRF model is well tested and parallelized with both MPI and OpenMP. We will rely on the MPI implementation since it is the most commonly used one and development efforts are usually focused on this scheme. DART toolkit is written in FORTRAN by NCAR and is also parallelized with MPI. DART will represent around 10 to 15% of the total runtime for each experiment and the developed operators on top of DART should not impact performance.
Based on EnKF for each assimilation experiment, a 32-members ensemble run is required, which will be completed utilizing the WRF-Chem model. WRF-Chem ensemble members.
We aim to perform two different simulations:

CTRL: Simulation without any AEOLUS input

EXP-0: Simulation using initial and boundary conditions what have assimilated AEOLUS wind profiles (ECMWF IFS)

And five different assimilation experiments:

EXP-WIND: Same setup w/ EXP-0 but additionally assimilating AEOLUS wind product (HLOS).

EXP-L2A: Same setup w/ EXP-0 but additionally assimilating AEOLUS L2A aerosol product.

EXP-L2A+: Same setup w/ EXP-0 but additionally assimilating AEOLUS L2A+ aerosol product.

EXP-L2A/or L2A+: Same setup w/ EXP-0 but additionally assimilating AEOLUS L2A/L2A+ aerosol product with activated aerosol radiation interactions

EXP-L2A/or L2A+: Same setup w/ EXP-0 but additionally assimilating AEOLUS L2A/L2A+ aerosol product with activated aerosol cloud interactions

Region of interest and computational resources

The region of interest, which is depicted in Figure 4, includes the Saharan Desert and the Atlantic Ocean. Since L2A suffer the most for strongly depolarizing targets such as desert dust, the Atlantic offers a representative environment to study this effect due to the long-range transport of Saharan dust. In addition, the positive impact of Aeolus' wind product is demonstrated to be over the Tropics [8]. The experiments will be conducted for two periods, the Septembers of 2021 and 2022. The model spatial resolution will be 20×20 km and the time step will be 60 seconds. Table 1 shows the domain size in terms of grid points and Figure 4 shows the model domain.

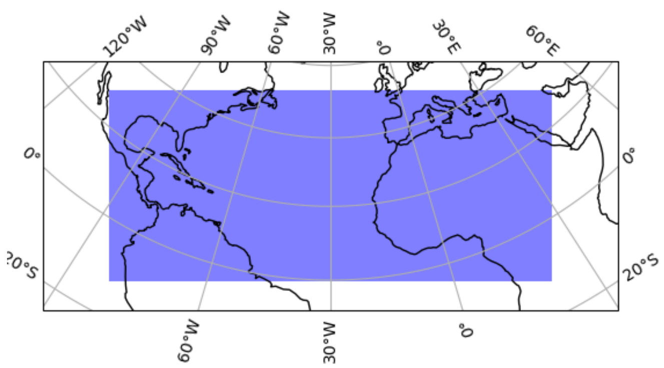

Figure 4: Region of interest. The shaded area represents the domain of the regional model.

WRF and DART will operate in independent SLURM jobs in order to minimize wasteful allocation of resources. The workflow is presented in Figure 5, with green boxes representing datasets and gray boxes representing computations in independent SLURM jobs.

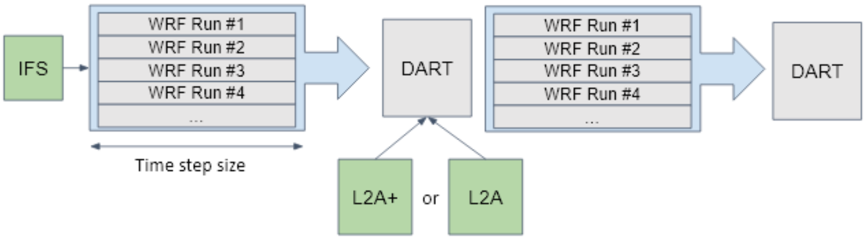

Figure 5: Workflow of WRF /w DART assimilation

In a test that we performed for an assimilation experiment (in a server other than the one of ECMWF), for 1-day simulation the simulation elapsed time was about 0.63 h using Fortran Intel compiler and 160 cores. Each assimilation experiment consists of 32 ensembles of 76 days of simulation, which in total is 2432 simulation days for each experiment. This yields in 4.6 MSBUs for each assimilation experiment, based on the following equation:

Table 1: Domain

	Horizontal resolution	**Grid points**	**Vertical levels**	**Size output (MB)**
Domain	20x20 km	718x311	45	5GB/76-day run

<u>References</u>

[1] 'Aeolus winds now in daily weather forecasts'. https://www.esa.int/Applications/Observing_the_Earth/FutureEO/Aeolus/Aeolus_winds_now_in_daily_weather_forecasts (accessed Jan. 30, 2023).

[2] 'Keeper of the winds shines on'. https://www.esa.int/Applications/Observing_the_Earth/FutureEO/Aeolus/Keeper_of_the_winds_shines_on (accessed Jan. 30, 2023).

[3] T. Flament, D. Trapon, A. Lacour, A. Dabas, F. Ehlers, and D. Huber, 'Aeolus L2A aerosol optical properties product: standard correct algorithm and Mie correct algorithm', Atmospheric Meas. Tech., vol. 14, no. 12, pp. 7851–7871, Dec. 2021, doi: 10.5194/amt-14-7851-2021.

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[5] P. Paschou et al., 'The eVe reference polarisation lidar system for the calibration and validation of the Aeolus L2A product', Atmospheric Meas. Tech., vol. 15, no. 7, pp. 2299–2323, Apr. 2022, doi: 10.5194/amt-15-2299-2022.

[6] 'Putting a value on ESA's Aeolus wind mission'. https://www.esa.int/Applications/Observing_the_Earth/FutureEO/Aeolus/Putting_a_value_on_ESA_s_Aeolus_wind_mission (accessed Jan. 30, 2023).

[7] J. Anderson et al., 'The Data Assimilation Research Testbed: A Community Facility', Bull. Am. Meteorol. Soc., vol. 90, no. 9, pp. 1283–1296, Sep. 2009, doi: 10.1175/2009BAMS2618.1.

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