LATE REQUEST FOR A SPECIAL PROJECT 2023–2025

MEMBER STATE: GREECE

Principal Investigator[1]: Stelios Myriokefalitakis

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Project Title: EC-Earth Atmospheric Composition developments

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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.)	2024	
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)		4,176,000	3,757,500
Accumulated data storage (total archive volume)[2]	(GB)		8,000	7,500

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.

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Extended abstract

The Institute for Environmental Research and Sustainable Development at the National Observatory of Athens (NOA) is a member of the EC-Earth consortium (http://www.ec-earth.org/). NOA actively participates in the Atmospheric Composition Working Group, and for this special project, we primarily focus on the development and implementation of new parameterizations that are expected to improve aerosol simulations within the EC-Earth climate model. We propose here to use EC-Earth to conduct a series of targeted simulations that will provide new insights into the role of atmospheric aerosol parameterizations through the implementation of high-precision chemistry/emission modeling schemes. In this regard, targeted improvements will be made to the model's atmospheric composition parameterizations, specifically the primary and secondary sources of atmospheric aerosols. For this purpose, we will utilize the latest version of EC-Earth, which incorporates various corrections and developments to enhance atmospheric process modeling and climate feedback representation.

Motivation

Atmospheric aerosols exert a net cooling impact on climate that offsets part of the warming effect from greenhouse gas (GHG) emissions (Foster et al., 2021). Aerosols show, nevertheless, a larger geographical variation in their radiative forcing compared to CO_2 due to their short lifetime of the order of a few days, resulting in inhomogeneous forcing on regional climate, contrary to the relatively homogeneous spatial influence of CO_2 and other WMGHGs (well-mixed greenhouse gases) on climate (Shindell et al., 2015). However, the effects of aerosol changes on regional and local climate are sensitive to several model uncertainties concerning parameterizations of processes, such as wet and dry removal, aerosol-cloud interactions, and the particulate chemistry added to those of the aerosol-radiation and aerosol-photolysis interactions. Such uncertainties are likely to be further magnified by the variability among models in the underlying regional climate and circulation patterns, leading to greater intermodel spread at regional scales than at a global scale. Moreover, estimates of radiative forcing from aerosols are highly sensitive to poorly constrained emission estimates for the preindustrial era, particularly from wildfires and biological processes (IPCC, 2021). Therefore, accurately quantifying the extent to which aerosols currently counteract greenhouse gas warming is crucial, whether through anthropogenic/natural emissions or as feedback induced by warming (Schwartz, 2018).

For this special project, we aim to improve the following aerosol components and associated parameterizations:

- ***Organic aerosol (OA):*** Organic compounds constitute ~50% of the sub-micrometer aerosol mass, thus necessitating an accurate representation of OA in climate models to capture their climate impacts, especially in radiative forcing calculations. The secondary fraction of OA (SOA) is formed via the oxidation of a wide variety of volatile organic compounds (VOCs) of both natural and anthropogenic origins, resulting in the production of hundreds of thousands of organic constituents in the atmosphere, making the description of SOA challenging (Kanakidou et al., 2005). Most climate models still assume either a non-volatile SOA produced with a constant yield from known precursors, or a simplistic representation of their volatility from biogenic VOCs. However, the primary fraction of OA (POA) is treated as non-reactive and non-volatile, failing to reproduce the observed atmospheric measurements (Tsigaridis et al., 2014). Therefore, given the significance of OA in aerosol forcing and its impact on climate, there is an urgent need to enhance OA parameterizations in climate models.
- ***Wildfires****:* Even though wildfires occur nearly everywhere on Earth and have always been present, they are still one of the most poorly understood components of the Earth system. When it comes to radiative forcing and climate effects of fire, the current understanding is even poorer due to the insufficient understanding of fire-air pollution linkages and the absence of global systematic studies employing coupled wildfire-atmosphere modeling systems. Without such coupled models, the feedback between wildfires and climate cannot be simulated, which means that the corresponding climate predictions may not be reliable (Szopa et al., 2021). Thus, a scheme of appropriate complexity for application at large

spatial scales within an ESM will allow for a deeper understanding of wildfire emissions' impact on atmospheric chemistry, particularly on carbonaceous aerosols (black carbon and organic carbon), as well as on atmospheric physics and climate.

- ***Bioaerosols*:** Biological material, such as bacteria, viruses, fungal spores, or various fragments or products released from living organisms like pollen, has been widely found as part of atmospheric organic aerosols. These aerosols are emitted directly into the atmosphere by vegetation as part of biological processes (Huffman et al., 2012). Bioaerosols usually have sizes ranging from 1 nm to roughly 100 μm, depending on their origin, and their abundances vary both in space and time over several orders of magnitude. They also show diurnal and seasonal variability. Currently, the total global flux of bioaerosols is estimated to be 35-1,000 Tg yr^{-1}, spanning almost two orders of magnitude with great uncertainties in its climate implications. According to experimental data, their emissions depend on ecosystem types, Leaf Area Index distributions, air temperature, specific humidity, precipitation, and wind speed. Airborne bacteria, fungal spores, pollen, archaea, algae, and other bioaerosols serve also as nuclei for cloud droplets, ice crystals, and precipitation. Recent findings also reveal their importance for climate via the supply of nutrients to marine ecosystems with a potential but profound implication for marine life.

Model configuration and technical characteristics

The modelling system used in this project is the FORCeS version of EC-Earth, which incorporates interactive aerosols and atmospheric chemistry. Specifically, the well-documented European ESM EC-Earth3 (Döscher et al., 2022), known for its contribution to the Aerosols and Chemistry Model Intercomparison Project (AerChemMIP), will be extended to include state-of-the-art organic aerosol schemes. These schemes will account for secondary aerosol formation based on the VBS parameterization as well as improve representations of emissions from wildfires and biological processes (bioaerosols).

The atmospheric General Circulation Model (GCM) of EC-Earth is based on cycle 36r4 of the Integrated Forecast System (IFS) from the European Center for Medium-Range Weather Forecasts (ECMWF). This model includes the H-TESSEL land surface model and the NEMO 3.6 ocean model, which incorporates the Louvain-la-Neuve sea ice model (LIM) for sea ice processes. The Ocean Atmosphere Sea Ice Soil version 3 (OASIS3) coupler is responsible for handling data exchange and interpolation between these modules.

The Tracer Model version 5 release 3.0 (TM5 MP 3.0) is used to represent the atmospheric chemistry and transport of aerosols and reactive species. Both aerosols and atmospheric chemistry are described using a two-way coupling to TM5. The direct and indirect radiative effects of tropospheric aerosols in IFS are calculated based on optical properties as well as mass and number concentrations simulated by TM5. The model will be run with the following resolutions for each component: T255 with 91 levels for IFS, ORCA1 with 75 levels for NEMO, and 3x2 degrees (longitude x latitude) with 34 levels for TM5. The exchange between the different components is facilitated through OASIS3-MCT.

Table 1. Planned simulations

	2024	**2025**
Atmosphere only simulations	**SBU / Storage**	**SBU / Storage**
CONTROL (2000-2014); *time-slice simulation with the initial version of the model, along with recent updates*	1,044,000 / 2 Tb	
SOA-VBS (2000-2014); *time-slice simulation with the new SOA-VBS scheme*	1,044,000 / 2 Tb	
FIRE EMISSIONS (2000-2014); *time-slice simulation with the new biomass burning scheme*	1,044,000 / 2 Tb	
BIOAEROSOLS (2000-2014); *time-slice simulation with the bioaerosol emission schemes*	1,044,000 / 2 Tb	
Coupled atmosphere-ocean simulations	**SBU / Storage**	**SBU / Storage**
pi-CONTROL (1850-1864); *time-slice preindustrial simulation with the initial version of the model*		1,252,500 / 2.5 Tb

pi-NEW (1850-1864); *time-slice preindustrial simulation with the new version of the model*		1,252,500 / 2.5 Tb
pd-NEW (2000-2014); *time-slice present-day simulation with the new version of the model*		1,252,500 / 2.5 Tb
Estimated Total	**4,176,000 / 8 Tb**	**3,757,500 / 7.5 Tb**

Justification of requested compute resources

The computational resources needed for this special project have been estimated using previous tests conducted by other members of the Atmospheric Composition Working Group of the EC-Earth Consortium. These simulations have shown that the best balance between computational performance and costs is achieved by using 180 CPUs for IFS, 135 CPUs for TM5, and an additional 72 CPUs for NEMO in atmosphere-ocean coupled mode. Based on these CPU numbers, a one-year simulation costs approximately 69.6 kSBU in atmosphere-only mode and 83.5 kSBU in the coupled ocean (see Table 1).

The data storage amounts provided in the tables are estimates based on the model's previous CMIP6 data requests and software tools. We used these tools to estimate the data volume required for the output requested for the different simulations at the resolutions of the EC-Earth model configurations. The data volumes are presented as raw model data volumes without any data compression. Lastly, we would like to mention that the post-processing and eventual publication of the model results will be conducted outside of ECMWF facilities. All specific numbers are given in Table 1.

Relevance to ECMWF

The request for this project is related to previous special projects involving the participation of the EC-Earth model's climate simulation in the AerChemMIP; however, no duplicate simulations exist between this project and the previous ones. The number of simulated years per SBU may vary due to different model developments during the intervening period. We note, however, that some of the development of this special project will also be incorporated into the new version of the EC-Earth model, EC-Earth4, that is already being developed on the ECMWF facilities by other groups of the consortium.

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