

REQUEST FOR AN EMI R&D PROJECT 2027–2029

Country/Organisation: Denmark / Aarhus University.....

Principal Investigator¹: Ulas Im

Affiliation: Department of Environmental Science.....

Address: Frederiksborgvej 399, Roskilde, 4000.....

Other researchers: Carl Svenhag.....

Project Title:
Improvement of OpenIFS on new particle formation and biomass burning emissions within the ReaIESM project.....

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	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2027	
Would you accept support for 1 year only, if necessary?	YES <input type="checkbox"/>	NO X <input type="checkbox"/>

Computer resources required for project year:	2027	2028	2029
High Performance Computing Facility [SBU]	80 million	260 million	
Graphics Processing Unit Cluster-A [GBU]			
Graphics Processing Unit Cluster-B [GBU]			
Accumulated data storage (total archive volume) ² [GB]	200 000	300 000	

¹ The Principal Investigator will act as contact person for this EMI R&D 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.

³The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

EWC resources required for project year:		2027	2028	2029
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs ³	[#]			

Continue overleaf.

Principal Investigator:

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Project Title:

Improvement of OpenIFS on new particle formation and biomass burning emissions within the RealESM project.....

Extended abstract

Climate change is progressing ever faster, with recent years setting unprecedented records in global temperatures, extreme weather events and their consequences (Forster et al., 2025). While the Paris Agreement aim of keeping global warming well below 2°C above preindustrial is still being sought through global action on greenhouse gas emissions, it is clear coming decades will see the most rapid rates of climate change in human history to date. At the same time, adaptation to new climate conditions is generally progressing slowly. Partly because of a lack of timely information necessary for reducing the resulting climate risk (Shaw et al., 2024), in turn partly due to a lack of realistic simulations of the most impactful events. While global-mean evolution of temperature and precipitation are well simulated by current Earth System Models (ESMs), regional patterns of change, including extreme events such as unprecedented precipitation episodes, are much more complex. They depend on greenhouse gas driven warming, other anthropogenic factors such as emissions of air pollutants (aerosols) and changes in land cover through urbanization and deforestation, as well as internal variability in the climate system, and in particular ocean-atmosphere interactions on timescales from years to decades (IPCC, 2022).

A key knowledge gap in current climate science is therefore how weather and climate features may evolve, regionally, through the coming period of very rapid changes. In particular, the coming decades will be influenced by changes in the atmospheric interactions between aerosols, clouds and circulation, in oceanic circulation, heat uptake and variability, and in atmosphere-ocean linkages in energy, moisture and particle exchange. All these processes, and their representation in ESMs, have major knowledge gaps.

To improve our capability to capture regional climate phenomena leading to damaging extreme weather, we need realistic, fine-grained representation of atmospheric and oceanic processes, and their interactions, under anthropogenic and natural forcing. However, it is neither practical nor efficient to rely only on increasing the resolution and complexity of climate models. For realistic projections of rapid climate evolution, and effective communication of the physical hazards and socioeconomic consequences, a novel, integrated approach is needed, optimally combining traditional ESMs and AI tools, alongside efficient analysis methods that deliver the benefits of high-resolution state-of-the-art modelling whilst moderating CPU and storage costs.

The aim of the Horizon Europe funded RealESM project is to advance European capability for Earth System Modelling, underpin long-term science, and contribute to the global effort to reduce the consequences of climate change. The overall objective of RealESM is to enhance our ability to anticipate global and regional climate conditions and extreme events in the coming years and decades, by realistically and efficiently simulating atmospheric and ocean processes, and their interactions, under anthropogenic and natural forcing. RealESM will deliver (i) advances in process representation in Earth System Models at varying resolutions, (ii) step changes in model capabilities to efficiently simulate and project global and regional climate change on decadal scales, (iii) detailed quantification of physical hazards in the atmosphere and ocean, and the role of atmosphere-ocean interactions in their development, under realistic conditions, and (iv) science-based communication of a broader set of possible climate outcomes for the coming decades, in support of adaptation and risk mitigation.

RealESM gives particular focus to Earth System components undergoing, or likely to undergo, rapid change in current and coming decades, such as anthropogenic and natural emissions of aerosols, and complex interactions and physical processes known to be sensitive to spatial resolution, such as marine heatwaves and their interlinkages with jets, cyclones and regional extreme precipitation. Building on advances in Earth System modelling, and novel techniques, we expect breakthroughs in the representation of extreme precipitation, storms and sea surface temperatures, in efficient simulations and projections, and in high resolution spatially aware emulation. Building on these breakthroughs, RealESM will enable the climate science community to efficiently and comprehensively simulate the broader climate evolution possible over the coming decades, including high-impact low-likelihood (HILL) climate and weather conditions brought about by the interactions of emissions changes, atmospheric and oceanic processes, and internal variations in the climate system.

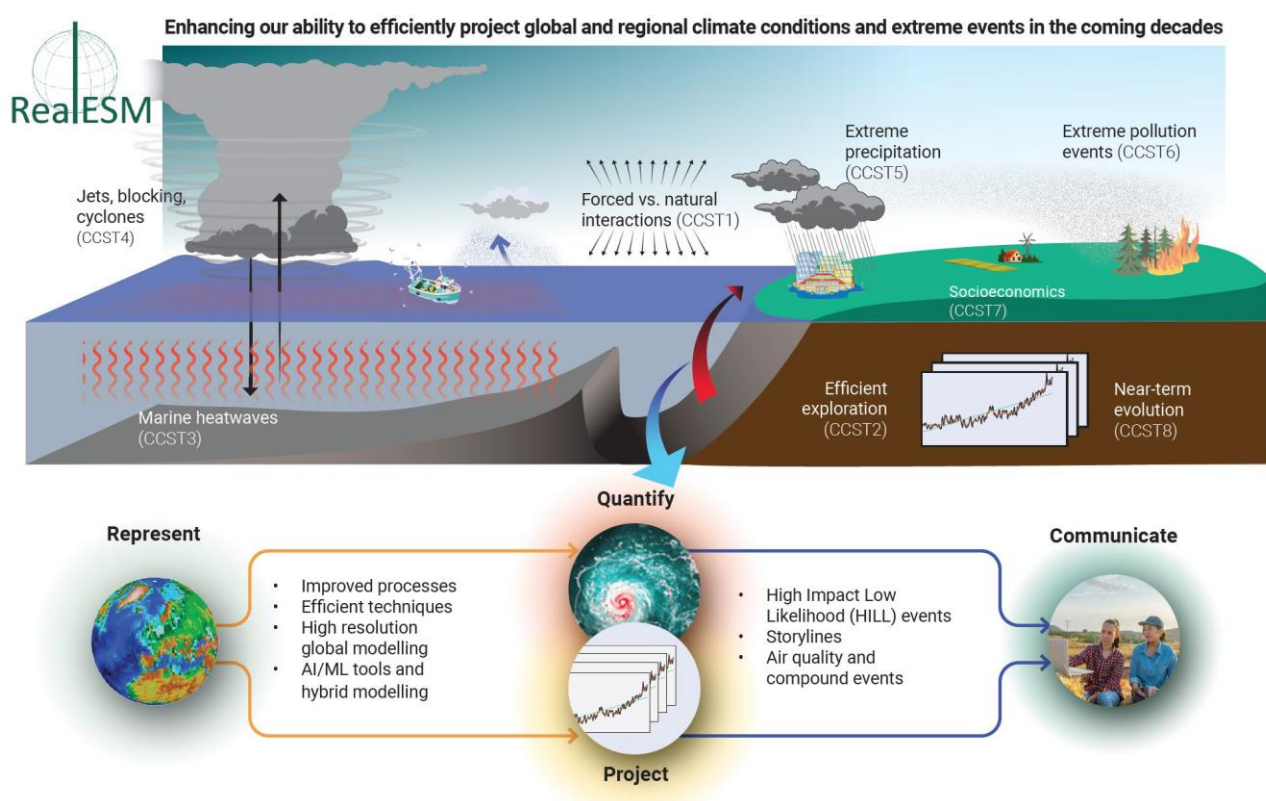


Figure 1. RealESM will represent, quantify and project global and regional climate conditions and extreme events in the coming years and decades, and communicate rapidly evolving climate risk.

To establish and build on the state-of-the-art, RealESM sets cross-cutting science topics (CCSTs; Figure 1) that are derived from the knowledge gaps. CCSTs start from the need to further understand the interplay between anthropogenically forced changes and internal variations in the climate system (CCST1), and, relatedly, how these can only be fully explored in Earth System Models through a compromise between complexity and cost efficiency (CCST2). We single out marine heatwaves (CCST3) and atmospherically driven hazards such as jet position changes, blocking episodes and cyclones (CCST4) as examples of critical phenomena in rapid change, at the intersection between atmosphere and ocean processes. Next in the progression towards climate risk, we identify extreme precipitation events (CCST5) and extreme pollution events (CCST6) as focus areas for high-impact low likelihood (HILL) near term consequences. We go on to consider the wider socioeconomic consequences of physical hazards and climate risk (CCST7), and finally

how climate science dissemination can be enhanced through wider inclusion of possible near-term change combined with science-driven example storylines (CCST8).

Among these, this special project application addresses CCST6. The development of ESMs with interactive chemistry and aerosols has enabled more robust simulations of feedback between meteorological variability, long-term climate trends, and pollutant concentrations. Yet, persistent uncertainties in emissions inventories, chemical mechanisms, and physical parameterizations limit confidence in future air quality projections. Multi-model intercomparison projects have advanced understanding of model biases and uncertainties, but harmonization of modelling frameworks across regions—particularly between the Global North and Global South—remains insufficient. Modelling extreme events—such as wildfires, dust storms, and compound climate–pollution episodes—remains a key frontier (Im et al., 2022). Compound events in the context of air quality and extreme weather refer to the co-occurrence or sequence of multiple environmental stressors that together amplify health and ecological risks. For example, a heatwave combined with high levels of ground-level ozone or fine particulate matter (PM_{2.5}) can lead to significantly greater public health impacts than either event alone. Understanding the probability and impact of such compound events is critical for improving forecasting systems, public health preparedness, and environmental policy, especially in the context of climate change, which is expected to increase the frequency and intensity of these overlapping hazards. Improving models to capture these episodic events, and their health impacts, is an ongoing challenge.

The oxidative potential (OP) of atmospheric particles refers to their ability to generate reactive oxygen species (ROS) upon inhalation, which can induce oxidative stress and promote acute/chronic inflammation, leading to strokes, heart attacks, asthma, dementia and other adverse health outcomes. The OP of particles depends on chemical composition, which is related to sources and atmospheric processing. Understanding the OP spatial and temporal variability helps identify high-risk pollution sources and inform targeted mitigation strategies to reduce adverse health effects of air pollution exposure (Liu et al., 2024).

Representation of secondary aerosol processes on a global scale remain limited and highly uncertain, both within individual models and across the CMIP6/CMIP7 framework. Mechanisms governing new particle formation (NPF), the growth of ultrafine particles, and biological particles (bioaerosols) are underrepresented or missing. Modules that predict the concentration and temporal variability of bioaerosols and OP from all aerosol types (e.g., biomass burning, dust, bioaerosols) are needed. [Svenhag et al., 2025].

In this special project, we will implement more pathways to new particle formation, as well as a machine-learning based interactive biomass burning module, both of them to improve air quality simulations of OpenIFS.

We will implement additional nucleation parameterization pathways in EC-Earth4 to capture a wider range of NPF pathways, adapted from established frameworks involving ammonia, iodine, and amine-mediated nucleation. We explore microphysical mechanisms for growth of ultrafine aerosols and quantify fine particulate matter under different warming regimes. Computational limitations are mitigated by employing an existing look-up table approach (Svenhag et al., 2024).

We will also investigate the changes in fire emissions driven by increasing wildfire activity under future climate conditions, and the downstream impact on air quality from increased aerosols and trace gases, and related toxicity. We couple ECMWF's recent SPARKY fire prediction model to its

system for predicting aerosol and gas emissions from fires, and validate the coupled system by using the IFS to simulate recent extreme wildfire events from multiple regions worldwide (e.g. Australia 2019, Canada 2023/2024, and California 2024, as well as European extreme fires e.g. in Portugal in 2022). We will then perform simulations to quantify how much more extreme the same events would be under plausible future climate conditions (CMIP7 forcings), including changes in land use and population. We implement SPARKY in EC-Earth4 (with OpenIFS) to perform a wider range of climate experiments to investigate how much more frequent and extreme fires will become in all regions of the globe.

Work programme and estimation of resources

In RealESM, we will first implement an existing new particle formation (NPF) based on earlier work in EC-Earth3 by Carl Svenhag (Svenhag et al., 2023). We will test this NPF pathway in OpenIFS and then improve the module by adding additional NPF pathways described above. Based on the project timeline, the NPF development and testing will be heavily performed in 2027, while the future simulations will be mainly performed in 2028. After implementations and further development, we will in 2027 perform historical simulations in order to benchmark the model comparing against available observations. We will test the individual pathways as well as their combinations. Our current OpenIFS simulations on other projects show that our current configuration requires 0.25 Million SBUs per simulation year. After implementation, we will test the improved OpenIFS over 2 years including spin-up, and with 10 experiments with different combinations of pathways and sensitivities. This will give us 0.25 M SBU/year x 2 years x 10 experiments, resulting in 5 Million SBUs. The historical period we will be studying will be 20 years from 2000s to 2020s. This gives us 0.25 M SBUs/year x 20 years x 10 experiments, resulting in 50 Million SBUs. In total, all the experiments will require 55 Million SBUs. We expand this to 60 Million SBUs due to unforeseen problems such as crashes, bug fixes and re-testing and calibration. In 2028, we will perform the future simulations and different climate and emission scenarios. These simulations will be performed for 50 years. This will give us 125 Million SBUs for 10 experiments based on different emission pathways from CMIP7 as well as sensitivity experiments to different NPF pathways. To be on the safe side, we ask 130 000 Million SBUs for bug fixes, crashes, etc.

The biomass burning work will start in 2028 and the SPARKY model will be first improved by other partners (ECMWF). However, we will start testing and implementing the available versions by the end of 2027, where we estimate 20 Million SBUs for implementation, testing and sensitivity simulations of 2 years. In 2028, we will largely focus on future simulations as in the NPF case, requiring 125 Million SBUs. We also extend. This to 130 Million to be on the safe side.

In total, these adds up to 80 Million SBUs in 2027, and 260 Million SBUs in 2028. Based on current experience on the system, we estimate 200 000 Gb disk space in 2027 and 300 000 Gb in 2028.

REFERENCES

- Forster, P.M., et al., Earth System Science Data, 2025. 10.5194/essd-17-2641-2025
Im, U., et al., Frontiers in Environmental Science, 2022. 10.3389/fenvs.2022.954045
IPCC, 2022. 10.1017/9781009325844.00
Liu, J., et al., Atmospheric Chemistry and Physics, 2024. 10.5194/acp-24-10849-2024.
Shaw, T.A., et al., Frontiers in Climate, 2024. 10.3389/fclim.2024.1391634.
Svenhag, C., et al., Geoscientific Model Development, 2024. 10.5194/gmd-17-4923-2024.
Svenhag, C., et al., Atmospheric Chemistry and Physics, 2025. 10.5194/acp-25-11483-2025.