LATE REQUEST FOR A SPECIAL PROJECT 2026–2028

MEMBER STATE: Denmark……………………………………………………………………………………

Principal Investigator[1]: Ulas Im ……………………………………………………………………………………

Affiliation: Aarhus University, Department of Environmental Science…………….

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

………

Other researchers: Carl A. Svenhag…………………………………………………………………………………

………

Project Title: Contribution of EC-Earth4 to CMIP7 Aerosol-cloud Interactions Perturbed Parameter Ensemble Model Intercomparison Project (ACI-PPEMIP)………………………………

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.)	2026	
Would you accept support for 1 year only, if necessary?	YES X☐	NO ☐

Computer resources required for project year:		**2026**	**2027**	**2028**
High Performance Computing Facility	[SBU]	45000000		
Accumulated data storage (total archive volume)[2]	[GB]	100000		

EWC resources required for project year:		**2026**	**2027**	**2028**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

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: Ulas Im………………………………………………………

Project Title: Contribution of EC-Earth4 to CMIP7 Aerosol-cloud Interactions Perturbed Parameter Ensemble Model Intercomparison Project (ACI-PPEMIP)

Extended abstract

Aerosols exert a substantial influence on Earth's radiation balance through interactions with both radiation and clouds. Overall, aerosols have negative radiative forcing, i.e., cooling the climate. The latest IPCC report provided a best estimate of the total ERF_{aer} of −1.1 W m^{-2} over 1750–2019 (Forster et al., 2021). This aerosol-induced cooling partially offsets warming due to greenhouse gases, slowing down the ongoing warming (Szopa et al., 2021).

Despite sustained advances in observations, modeling, and process understanding over recent decades, the magnitude of ERF_{aer} remains highly uncertain. Since IPCC AR5, the observational estimation of ERF_{aer} has substantially progressed along several axes (Boucher et al., 2013; Forster et al., 2021), leading to improved estimates and reduced uncertainty (Hasekampet al., 2019; Bellouin et al., 2020; Jia et al., 2026). In contrast, progress on the modeling side has been more limited: from phase 5 to phase 6 of the Coupled Model Intercomparison Project (CMIP), the spread in ERF_{aer} has narrowed only marginally. This implies that advances in our fundamental understanding have not yet been translated meaningfully into reduced model uncertainty and reliable climate projections, despite increases in model complexity and resolution (Carslaw et al., 2025).

Climate model uncertainty arises from two primary sources: the representation of subgrid-scale processes such as aerosol activation, cloud microphysics and convection through parameterizations (structural uncertainty), and the parameter values used within those parameterizations (parametric uncertainty). Both remain poorly constrained by observations, leading to large differences in modelled ERF_{aer}.

A key approach for address the parametric uncertainty is the use of perturbed parameter ensembles (PPEs). In a PPE, uncertain model physical parameters are simultaneously varied across plausible ranges to generate an ensemble of model variants. By analysing the spread in model outputs across these variants, PPEs provide a systematic framework for quantifying parametric uncertainty and identifying the processes that dominate it. Observations can then be further used to constrain this uncertainty by identifying parameter combinations that best match observations. Structural uncertainty, however, cannot be addressed in single-model PPEs where parameterizations are fixed. Instead, coordinated multi-model PPE (MMPPE) experiments are required, where models with different structures perturb same parameters across consistent ranges following consistent experimental designs. This enables parametric and structural uncertainties to be more clearly separated and quantified; however, a coordinated aerosol-cloud MMPPE framework does not yet exist. The ISSI team proposed here is currently preparing the first coordinated aerosol-cloud MMPPE experiments within AeroCom and CMIP7 intercomparison projects (see 'ACI-PPEMIP' https://wcrp-cmip.org/mips/#registered_mips), with the model data expected to become available by August 2026.

At the same time, recent advances in satellite remote sensing offer new opportunities to constrain climate model uncertainty. New missions such as EarthCARE and PACE, provide global observations of aerosol and cloud properties, including aerosol optical depth, size, absorption, and hygroscopicity as well as cloud microphysical and macro-physical. These observations, along with long-term observations from other instruments such as MODIS and VIIRS, offer unprecedented potential to constrain aerosol-cloud properties and processes represented in climate models.

Although several studies have attempted to constrain single-model PPEs using observations, effectively integrating new satellite observations into MMPPE frameworks remains largely unexplored. Developing robust approaches to combine satellite data with coordinated MMPPE experiments therefore represents a key opportunity to reduce uncertainty in ERF_{aer} and improve the reliability of climate projections.

Research goals and impact

Key objectives are:

i. Quantifying parametric uncertainty in different models, and assessing relative contributions of parametric and structural uncertainties
ii. Constraining parametric uncertainty with new observations from PACE, EarthCARE and other satellites
iii. Identifying structural deficiencies and informing model development

Specifically, we aim to answer the following research questions:

1. Which parameters and processes dominate uncertainty in ERF_{aer} across different climate models?
2. Which parameterizations can be improved through parameter optimization, and which require structural adjustment or development of new parameterizations?
3. To what extent can the spread in ERF_{aer} within MMPPE be attributed to parametric and structural uncertainties, respectively?
4. Which satellite-observed quantities provide the most effective constraints on ERF_{aer}?
5. How can observational uncertainties (measurement errors, retrieval assumptions, and differences between observed quantities and model diagnostics) be incorporated consistently into MMPPE constraining?
6. To what extent can satellite observations reduce uncertainty in ERF_{aer} across multiple models?
7. What is the added value of more accurate but spatially limited field campaign observations in addition to satellite observations?
8. What are the implications of reduced uncertainty in ERF_{aer} for climate predictions and projections?

The outcome of this project will contribute to improved model performance, narrowed ERF_{aer} spread, and more reliable climate predictions and projections. The coordinated MMPPE analyses and methodologies developed through the ISSI team are expected to provide a valuable foundation for future community efforts and contribute to the scientific basis of upcoming IPCC AR7 assessments.

The Aerosol-Cloud Experiment Protocol

Participants

1. ICON-HAM (SRON)
2. ECHAM-HAM (SRON)
3. **EC-Earth (Aarhus University/EPFL)**
4. UKESM (UK Met Office/Leeds University)
5. NorESM (MET Norway)
6. CAM6 (UC San Diego)
7. MIROC-SPRINTARS (RIAM)
8. ECHAM-HAM-SALSA (FMI)
9. ECHAM-MESSy (MPI&ETH)
10. CIESM-PAM (Tsinghua University)

Timeline
Data submission: June 2026

Model set-up

Period
The reference year for the Present Day (PD) simulations is set to 2025 (2025.01.01–2025.12.31), allowing comparison with satellite observations from EarthCare and PACE. The Pre-Industrial (PI) baseline year is 1850 (why not 1750?).

Input data
https://wcrp-cmip.org/cmip-phases/cmip7/cmip7-forcing-datasets/

- **Anthropogenic emission**: CEDS v2025-04-18 (available through 2023; 2023 repeated for 2025)
- **Biomass burning emission**: GFED5.1 daily for PD
  CMIP7 biomass burning for PI
- **GHGs and ozone**: CMIP7 M or H
- **SST/SIC**: use ERA5 for up-to-date 2025 data (monthly updates).
-

Nudging
Only winds (but not temperature) are nudged towards reanalysis data,, in order to diagnose rapid adjustments and ERF. Nudging to ERA5 (relaxation time ~6 hours) is recommended, though other reanalyses are also acceptable.

Spin-up: 1 yr CTL run (spin-up) + 3 months PPE run (spin-up) + 12 months PPE run (final results)

PPE size: number of parameters x 5 ~ 100 (PI+PD ~ 200)

Model perturbations
We focus on multiple aerosol- and cloud-related processes. For aerosols, they are aerosol emissions, optical and hygroscopic properties, wet and dry depositions, nucleation, aging and chemistry, with a special focus on emissions from biomass burning and natural sources. For clouds, the targeted processes/schemes include activation, cloud microphysics, cloud cover, convection, optical processes, and turbulence.

Parameter list

aerosol parameters
cloud parameters

Mandatory (19):

Variable	Description	Process
emi_ant_so2	Scale factor for anthropogenic so2 emission without shipping emissions	Emission
emi_ant_bc	Scale factor for anthropogenic bc emission	Emission
emi_ant_oc	Scale factor for anthropogenic oc emission	Emission
emi_bb_so2	Scale factor for biomass burning so2 emission	Emission
emi_bb_bc	Scale factor for biomass burning bc emission	Emission
emi_bb_oc	Scale factor for biomass burning oc emission	Emission
emi_dms	Scale factor for DMS emission	Emission
emi_ss_acc	Scale factor for accumulation mode sea salt emission	Emission
emi_ss_coa	Scale factor for coarse mode sea salt emission	Emission
emi_du_fricv	Scale factor for friction velocity in the parameterization of dust emission	Emission
emi_cmr_ff	Emitted particle size for fossil fuel emissions (unit: nm)	Emission
emi_cmr_bb	Emitted particle size for biomass burning emissions	Emission
rad_bc_ni	BC imaginary refractive index	Aerosol Opt
rad_oc_ni	OC imaginary refractive index	Aerosol Opt
wetdep_ic	Scale factor for in-cloud wet deposition rate	Deposition
activ_aero	Scale factor for activated aerosols	Activation
activ_cwturb	Scale factor for vertical velocity for activation	Activation
micro_ccraut	coefficient of autoconversion from cloud droplets to rain in stratiform clouds	Microphysics
micro_ccsaut	coefficient of aggregation from cloud ice to snow in stratiform clouds	Microphysics
conv_cprcon	conversion rate from cloud water to rain in convective clouds	Convection
conv_entrpen	entrainment rate for deep convection	Convection

References

Bellouin, N., Quaas, J., Gryspeerdt, E., Kinne, S., Stier, P., Watson-Parris, D. et al.: Bounding Global Aerosol Radiative Forcing of Climate Change, Rev. Geophys., 58, e2019RG000 660, 2020.

Boucher, O., Randall, D., Artaxo, P., Bretherton, C., Feingold, G., Forster, P. et al.: Clouds and aerosols, in: Climate change 2013: The physical science basis. Work. Gr. I to Fifth Assess. Rep. Intergov. Panel Clim. Change, Cambridge University Press, 571–658, 2013.

Carslaw, K. S., Regayre, L. A., Proske, U., Gettelman, A., Sexton, D. M. H., Qian, Y. et al.: Opinion: The importance and future development of perturbed parameter ensembles in climate and atmospheric science, EGUsphere, 2025, 1–31, https://doi.org/10.5194/egusphere-2025-4341, 2025.

Forster, P. M., Storelvmo, T., Armour, K., Collins, W., Dufresne, J. L., Frame, D. et al.: Chapter 7: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity, Clim. Change 2021 Phys. Sci. Basis. Contrib. Work. Gr. I to Sixth Assess. Rep. Intergov. Panel Clim. Change, 2021.

Hasekamp, O. P., Gryspeerdt, E., and Quaas, J.: Analysis of polarimetric satellite measurements suggests stronger cooling due to aerosol-cloud interactions, Nat. Commun., 10, 5405, 2019.

Jia, H., Quaas, J., Kroese, W., van Diedenhoven, B., Gryspeerdt, E., Böhm, C., Block, K., and Hasekamp, O.: Optimal choice of proxy for cloud condensation nuclei reduces uncertainty in aerosol-cloud-climate forcing, Science Advances, 12, eaea4828, 2026.

Szopa, S., Naik, V., Adhikary, B., Artaxo, P., Berntsen, T., Collins, W. D. et al.: Short-Lived Climate Forcers, in: Climate Change 2021: The Physical Science Basis, Work. Gr. I to Sixth Assess. Rep. Intergov. Panel Clim. Change, Cambridge University Press, 817–922, 2021.