Project: **1005**

Project title: **Model-based quantification of aerosol and cloud processes and their effects in the Arctic**

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Progress Report

The impact of aerosol on Arctic climate and the observed rapid climate change is explored by global and Arctic-focused simulations within the DFG Transregio TR 172 'Arctic Amplification (AC)³'. The aim of this HPC project is to perform and evaluate the simulations with the global aerosol-climate model ECHAM6-HAM2 and its successor ICON-HAM, which are used to investigate the sources and transport pathways of aerosols as well as their impact on Arctic climate. In this phase of the project, the focus has been on modelling marine organic aerosol and its effects on Arctic clouds.

During the last two allocation periods, ECHAM6.3-HAM2.3 was extended to include an advanced scheme for marine emissions to take into account primary marine organic aerosol (PMOA) by species groups, in particular cloud-active compounds. For this purpose, the module OCEANFILMS (Organic Compounds from Ecosystems to Aerosols: Natural Films and Interfaces via Langmuir Molecular Surfactants) module by S. Burrows (PNNL) was implemented, which describes the submicron organic mass fraction in sea spray aerosol. The emission scheme uses marine precursors as lower boundary conditions from current and future scenarios of the marine biogeochemical model FESOM2-REcoM2, developed by the Alfred Weger Institute (AWI) and applied with a 4.5 km pan-Arctic setup. The key components of PMOA, considered now in the aerosol-climate model, are dissolved acidic polysaccharides (PCHO), dissolved combine amino acids (DCAA), and dissolved polar lipids (PL). The new aerosol species are allowed to impact the cloud microphysics. In parallel, this implementation was also carried out in ICON-HAM. A detailed model description together with a comprehensive evaluation of the modelled PMOA aerosol emissions and concentrations using in-situ observational data has now been published in Leon-Macros et al. (2025a).

The so-extended ECHAM6.3-HAM2.3 model was employed to analyse 30-year trends (1990–2019) in PMOA across the Arctic. The results show that the retreat of Arctic sea ice has driven a general increase in PMOA emissions across most regions in the Arctic (> 63°N). Over the 30-year period from 1990 to 2019, PMOA emissions have risen by at least 24% (Figure 1), with increases of 34%, 39%, and 28% observed for polysaccharides, dissolved combine amino acids, and polar lipids, respectively. These long-term trends highlight the strong dependence of PMOA emissions on sea ice changes.

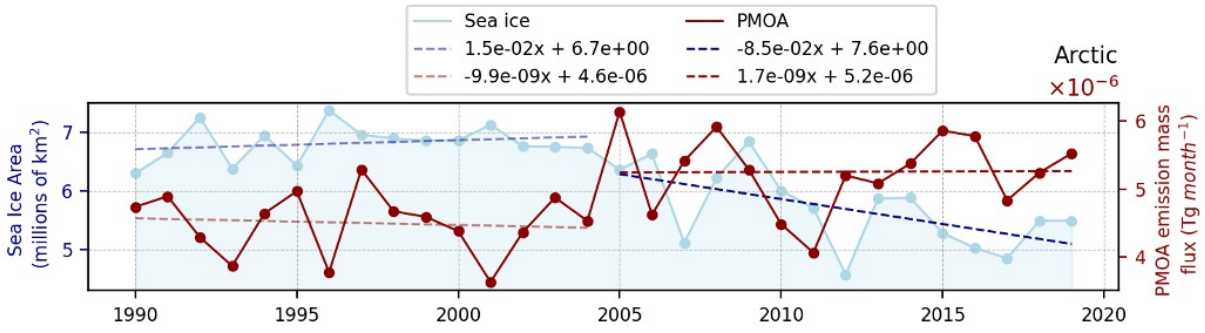

***Figure 1**: Time series of Arctic sea ice area and modelled PMOA emissions within the months July to September for the period 1990 – 2019.*

The analysis also reveals pronounced regional and temporal differences in the evolution of individual PMOA components. These differences are influenced by sea ice characteristics, biological activity, and aerosol wet removal (Figure 2). Since each PMOA species group exhibits distinct potential to affect mixed-phase clouds and thus the Arctic climate, these findings underscore the necessity of treating different PMOA types separately.

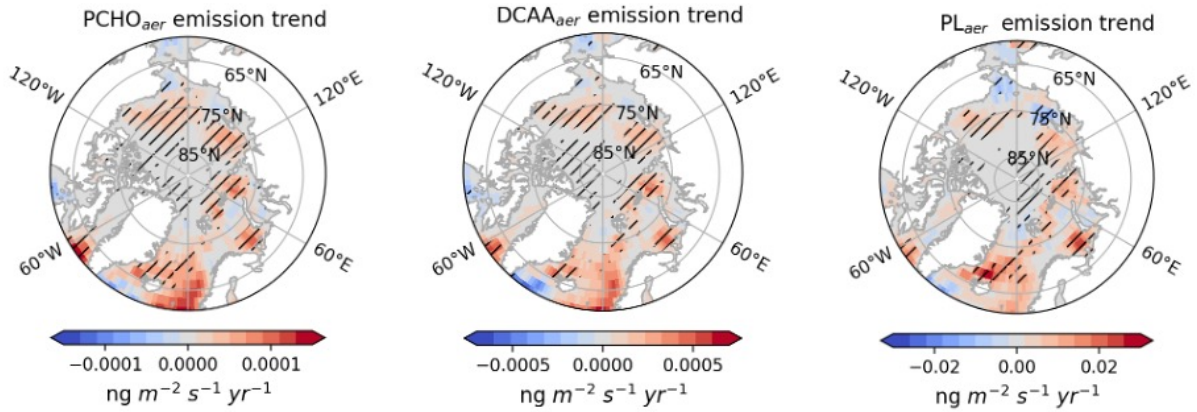

***Figure 2**: Species-specific trends of Arctic PMOA emissions in the months July-August-September for the years 1990 – 2019. The hatched areas indicate a statistically significant trend (t-test, p<0.05).*

Perspectives

In the next allocation period, it is planned to further investigate past and future trends in the distribution and variability of PMOA using the extended models ECHAM-HAM and ICON-HAM. A particular focus of the investigation will be on how the increasing PMOA affects the budget of cloud condensation and freezing nuclei in the Arctic and effective radiative forcing. These effects will be put into the context of other aerosols in the Arctic, in particular that of smoke aerosol from boreal fires, which have increased dramatically in recent years.

References

Leon-Marcos, A., Zeising, M., van Pinxteren, M., Zeppenfeld, S., Bracher, A., Barbaro, E., Engel, A., Feltracco, M., Tegen, I., and Heinold, B.: Modelling emission and transport of key components of primary marine organic aerosol using the global aerosol-climate model ECHAM6.3–HAM2.3, Geosci. Model Dev., https://doi.org/10.5194/egusphere-2024-2917, accepted, 2025a.

Leon-Marcos, A., van Pinxteren, M., Zeppenfeld, S., Zeising, M., Bracher, A., Laurent, O., Tegen, I., and Heinold, B.: Thirty Years of Arctic Primary Marine Organic Aerosols: Patterns, Seasonal Dynamics, and Trends (1990–2019), Atmos. Chem. Phys., to be submitted, 2025b.