Trends, patterns, and climate effects of aerosols in the Arctic

D02

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1. Summary

D02's mission is to improve the **process understanding and model representation** of **relevant aerosol types and aerosol-cloud interactions** in the Arctic:

Phase I: Long-range transport, black carbon (BC), and low-level, mixed-phase clouds

Phase II: Local marine aerosol sources and their impact on clouds

Phase III: Aerosol trends, patterns, and aerosol-climate interactions in the Arctic

Contributions to CCA3 and CCA4, & SQ1–3.

Research questions

Q1 How well do global ICON–HAM simulations represent recent aerosol and cloud observations when consolidating model developments during phase I and II?

Q2 Do current and future trends and extremes in anthropogenic/natural aerosol emission and transport contribute to Arctic amplification?

Q3 Do changing patterns of aerosol forcing impact air mass transport and energy budget in the Arctic?

2. Achievements phase II

Marine organic aerosol and its impact on cloud active aerosols

- Quantification of the impact of key primary marine aerosol species on Arctic cloud formation from ICON-HAM aerosol-climate simulations.
- Projections into the future to investigating potential feedback on Arctic amplification.

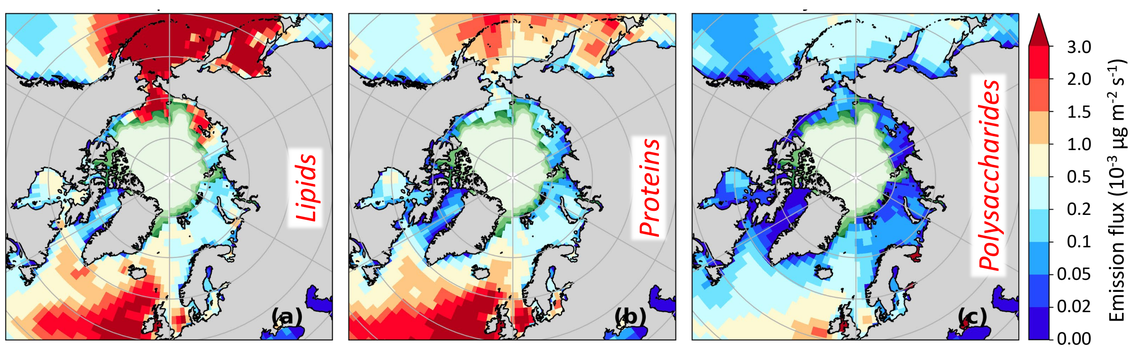

Fig. 1: Emissions of key marine organic aerosol (MOA) species at annual sea ice minimum in ICON-HAM, serving as potential cloud condensation nuclei and ice nucleating particles.

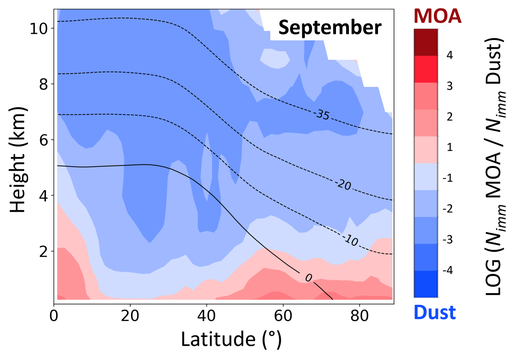

Fig. 2: Zonal mean ratio of MOA to desert dust, immersed in cloud droplets, from ICON-HAM.

Sources of ice crystal formation in Arctic low-level clouds

- Application of novel satellite retrieval of ice crystal numbers in the Arctic indicates strong local ice nucleating particle sources over sea ice like melt ponds, blowing snow, sec. ice production.
- Employ kilometer-scale ICON simulations to explore and attribute the differences in cloud ice formation between sea ice and open ocean to above mentioned causes.

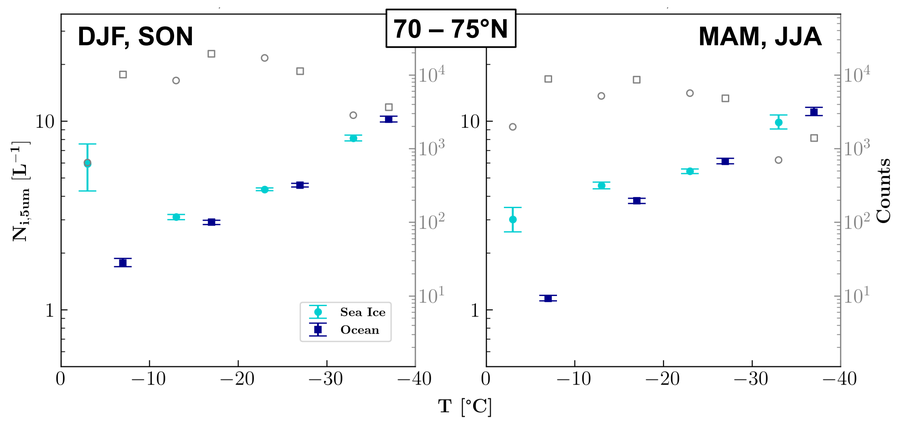

Fig. 3: Satellite analysis of median daily numbers of cloud ice crystals (> 5 µm) at 70–75°N, binned in temperature intervals for cold and warm season for 2006–2016.

4. Legacy & Major expected results

Project Legacy

- D02 plays a key role to integrate progress in the understanding of aerosol and aerosol-cloud processes into modeling across scales.
- Major improvements of ICON-HAM in the Arctic (BC and MOA related processes).

Hypothesis

Trends in anthropogenic and natural aerosols and their feedback on atmospheric dynamics modulate Arctic amplification by changes in effective radiative forcing.

3. Research plan phase III

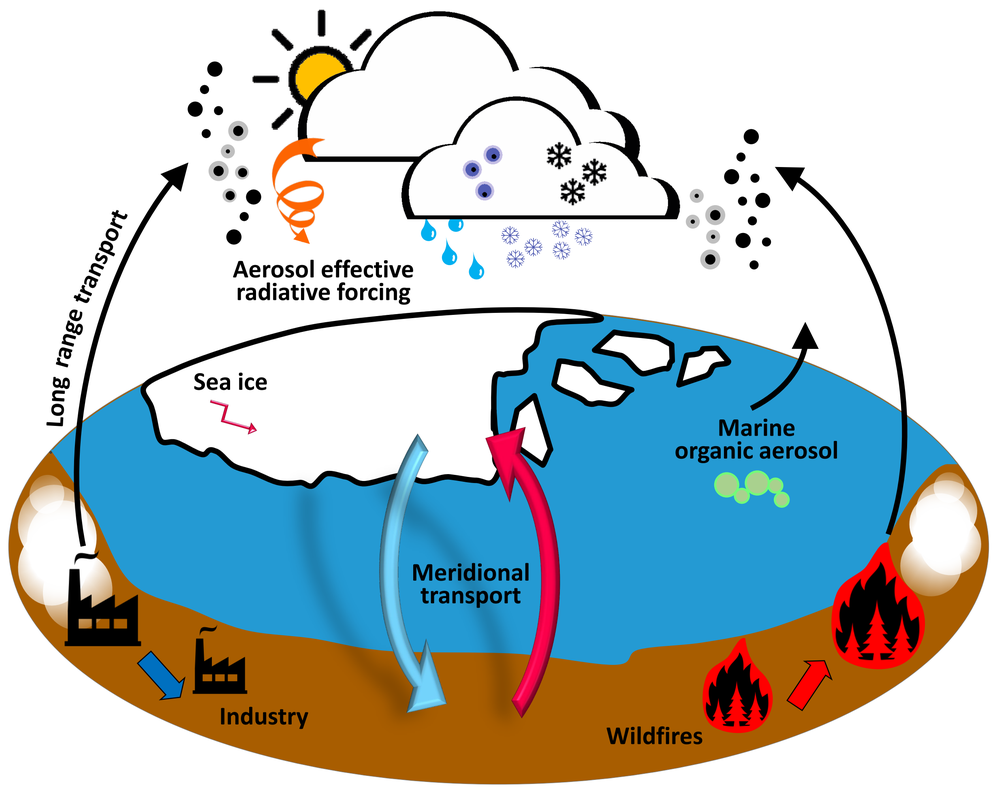

Fig. 4: Role and interaction of natural and anthropogenic aerosols in the changing Arctic.

WP1 Present distribution of aerosol and effective radiative forcing

- Consolidating aerosol-climate model developments from phase I and II, including further work on primary marine organic aerosol and associated effects.
- Multi-decadal baseline ICON-HAM simulations for the past & present; evaluation of aerosol/cloud processes with MOSAiC (B04), HALO-(AC)³, and satellite data (B01).

WP2 Trends and extremes of Arctic aerosol

- Disentangling trends in anthropogenic Arctic aerosol concentration from ICON-HAM simulations, driven by changing lower latitude aerosol emission and transport pathways.
- Analysis of trends in Arctic natural aerosol from wildfires and marine sources (C03); quantification of the changing contributions to total aerosol load from ICON-HAM model runs.
- Detection and trend analysis of extreme episodes of Arctic aerosol concentration in ICON-HAM and their relation to moisture intrusions (E04); CMIP6 analysis of trends in circulation patterns related to extreme aerosol events.

WP3 Aerosol–climate interactions

- Adaptation of simple plumes parameterization MACv2-SP in the fully coupled ICON Earth System Model (ESM) to represent future aerosol scenarios based on ICON-HAM.
- Investigation of the response of the Arctic energy balance and meridional transport (D01) due to past-to-future (1980 to 2050) aerosol forcing changes in ICON-ESM simulations.

Major expected results within phase III

- Advances in the understanding and aerosol-climate model representation of aerosol and aerosol-cloud processes in the Arctic.
- Assessment of trends & extremes of Arctic aerosol and their role in Arctic amplification.
- Attribution of atmospheric response to changing local & remote aerosol conditions.

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