Atmospheric chemistry in polar and maritime regions

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Introduction

- Marine and polar regions are major sources of aerosol particles that influence clouds and climate.
- Chemical processes in seawater, the sea surface microlayer (SML), aerosol particles and cloud water are strongly connected.
- Field campaigns provide real-world data, while laboratory experiments isolate and test specific processes. Modeling links observations and experiments and helps assess their wider relevance.
- Overall goal: Resolve the processes that connect marine chemistry to aerosol particles and cloud characteristics.

Highlights

Approaches

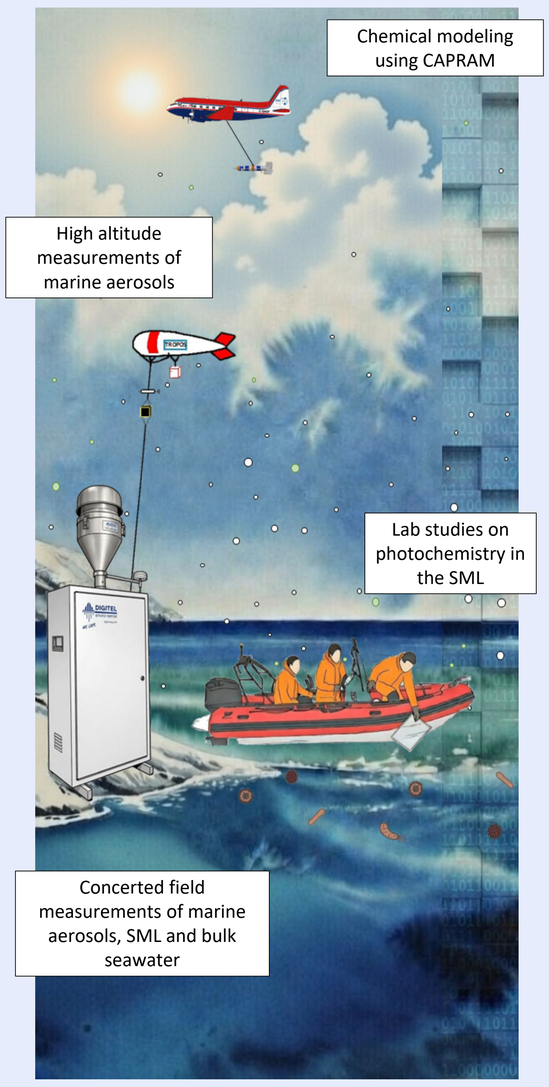
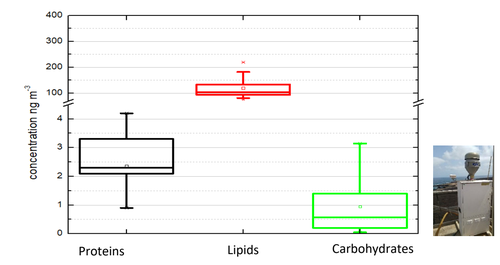
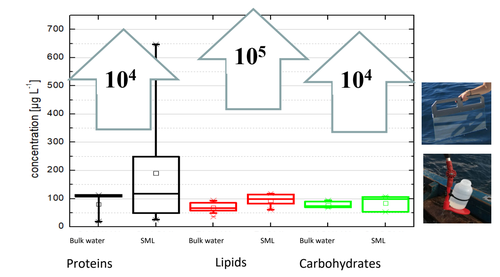


Fig. 1: Schematic of the approaches employed for oceanic and atmospheric studies.

High enrichment of oceanic organic matter in the atmosphere



Aerosol particle concentrations (PM_1)



Seawater concentrations

$$\text{EF aer.} = \frac{\text{OC aer.} \ / \ \text{Na}^+ \text{ aer.}}{\text{OC SML} \ / \ \text{Na}^+ \text{ SML}}$$

Fig. 2: Concentrations of organic matter components in the ocean, in the atmosphere and resulting enrichment factors.

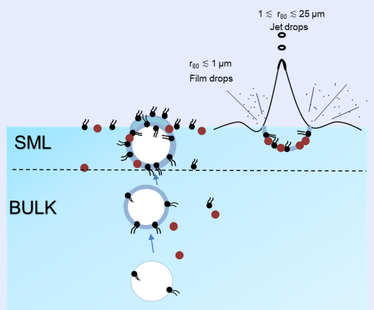
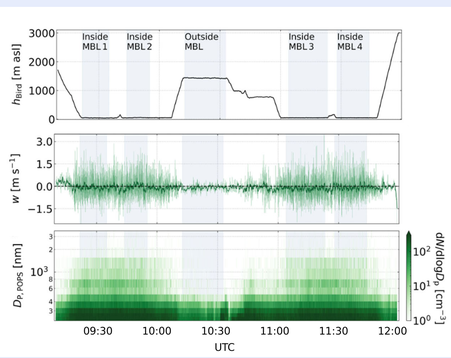


Fig. 3: Schematic of the transfer of organic matter to the atmosphere via bubble bursting, adapted and modified from Leon-Marcos, 2025.

- Marine aerosol particles selectively enrich oceanic organic matter, lipids dominate.
- Mechanisms are included in sea-air parameterizations (*van Pinxteren et al., ACP, 2023; Leon-Marcos et al., GMD, 2025).*

Turbulent Sea Spray Flux is an important source of accumulation mode aerosol



- Arctic airborne measurements reveal that fluxes of accumulation mode sea spray aerosols are considerably higher than models predict (*Simon et al., GRL, 2025).*

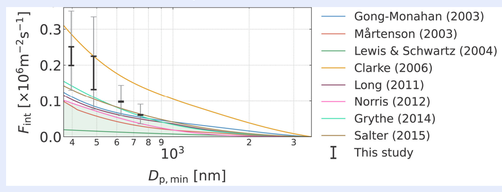


Fig. 4: Flight altitude above sea level, wind speed and particle number size distribution, shaded areas show analyzed flight sections (left). Comparison of size-resolved particle fluxes (top).

Ocean-derived (organic) matter can reach higher altitudes

- Sea spray constituents (e.g., sodium, chloride, carbohydrates) and other aerosol components are detectable at the ground, in the upper marine boundary layer, and in the free troposphere.
- Their vertical concentration profiles depend on the atmospheric mixing state and are consistent with variations in specific humidity (q), potential temperature (θ), and aerosol number concentrations (N_{150}). (*Zeppenfeld et al., ACP, 2026*).

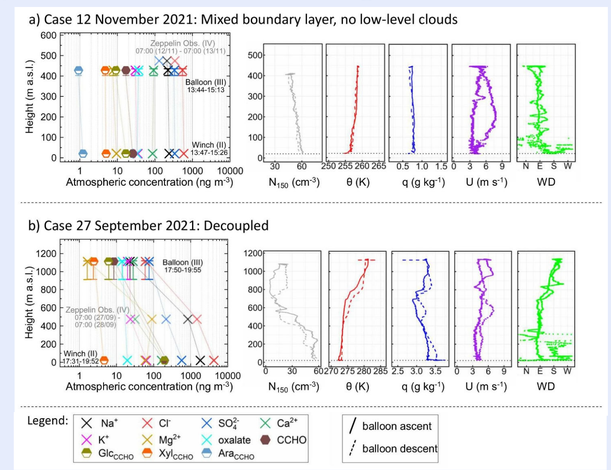
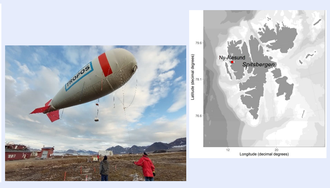


Fig. 5: Two case studies illustrating the vertical profiles of chemical and physical aerosol properties alongside meteorological parameters (top). TROPOS balloon and studied area (right).



Amino acids are present in polar marine environments

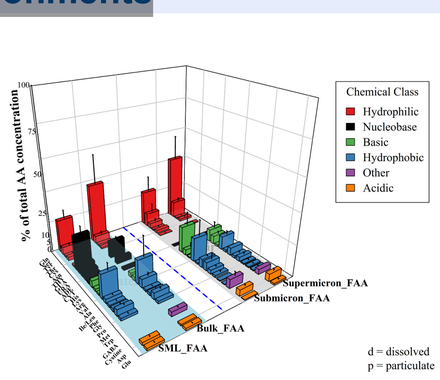


Fig. 6: Percentage contribution of the individual amino acid concentrations (FAA) in the ocean water, SML and aerosol particles.

- Free (FAA) and combined amino acids (CAA) studied.
- Ocean water (pH ≈ 8): hydrophobic FAA dominate (Val, Leu, Ala).
- Aerosols (pH ≈ 1-3): hydrophilic and basic FAA enriched (Gln, Ser), indicating atmospheric transformation and fragmentation *(Breitenstein et al., ACS, Earth and Space Chemistry, 2025*).

Reactivity of amino acids with •OH:

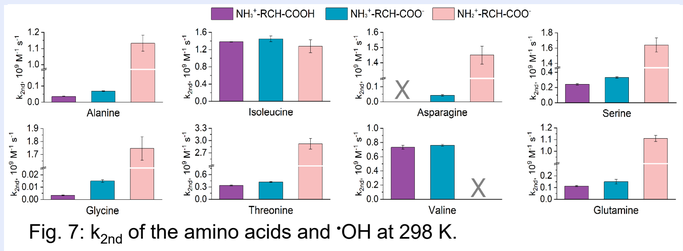


Fig. 7: k_{2nd} of the amino acids and •OH at 298 K.

- In general, the reactivity of amino acids with •OH in the aqueous phase increases with deprotonation.

Carbonyl photochemistry increased in the SML during blooms

- Higher carbonyl concentrations in the SML than in underlying water (ULW), particularly after irradiation.
- In general, increased carbonyl concentrations during a phytoplankton bloom.

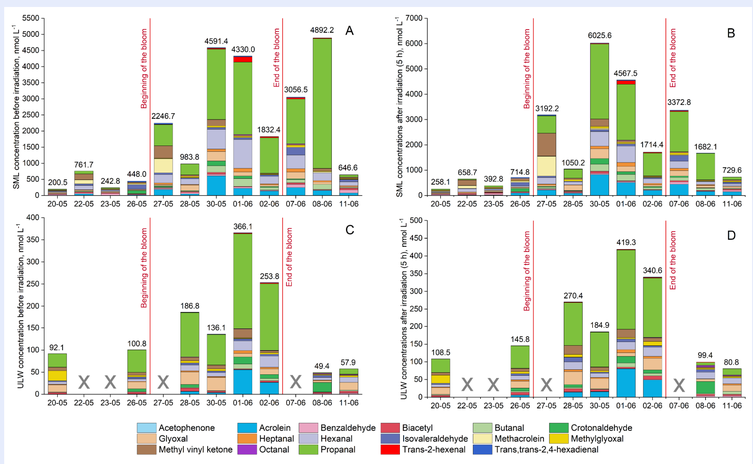


Fig. 8: Speciation of 17 carbonyl compounds in SML before irradiation (A), SML after 5 h of irradiation (B), ULW before irradiation (C), and ULW after 5 h of irradiation (D) (*Jibaja Valderrama et al., Biogeosciences, 2025).*

- Photooxidation capacity similar in both SML and ULW samples, with limited influence of the phytoplankton phases.

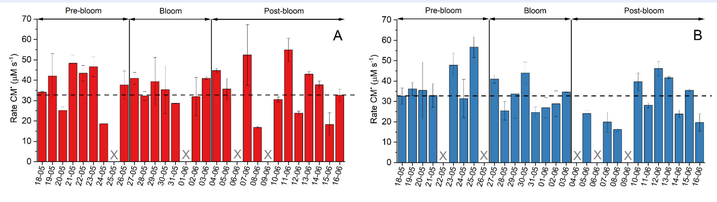


Fig. 9: Radical formation (CM•) for SML (A) and ULW (B) samples *(Jibaja Valderrama et al., Biogeosciences, 2025*).

CMH
Spin probe

CAPRAM simulations highlight the role of marine ozone in driving multiphase sulfur oxidation and aerosol formation

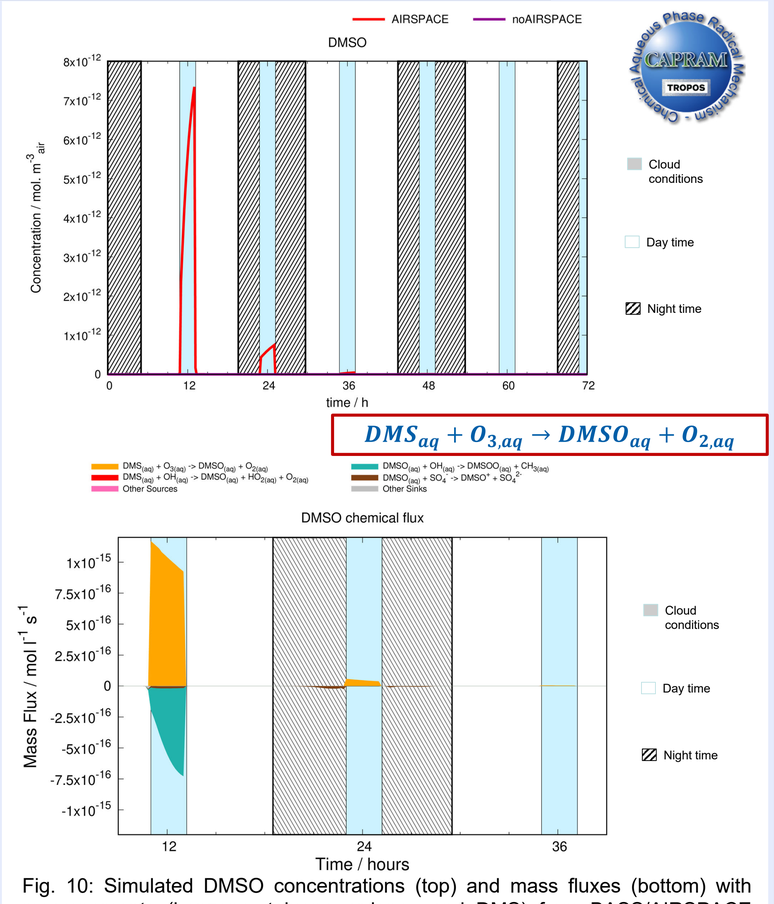


Fig. 10: Simulated DMSO concentrations (top) and mass fluxes (bottom) with measurements (benzene, toluene, xylene and DMS) from BASS/AIRSPACE campaign (Helgoland 2024).

- Observation-constrained initialization enhances aqueous DMSO production.