The 7th DMS(P) Symposium: Sulfur - Carbon Nexus in the SOLAS Sphere

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Background and Rationale

The sulfur and carbon cycles are inextricably linked in the ocean. The organosulfur compound dimethylsulfoniopropionate (DMSP) ignited an entire subfield of biogeochemistry to investigate the precursor of the "anti-greenhouse gas" dimethylsulfide (DMS). Since then, decades of research have unveiled extensive and unexpected links of DMSP and related compounds, collectively referred to here as DMS(P), to ocean ecosystem functions and global biogeochemistry. DMS(P) cycling is initiated via biosynthesis, conducted by almost all of the major coastal and open ocean phytoplankton functional types, including taxa that generate harmful algal blooms. DMS(P) comprises a significant 10-20% of cellular carbon in these organisms and goes on to play important physiological and biogeochemical roles in the ocean's food web. DMS(P) compounds are exchanged within and between trophic levels and rapidly remineralized, making them central components of labile organic carbon cycling. DMS(P) are also powerful chemoattractants for both marine microorganisms and megafauna. Just as important, after DMS(P) is exchanged with the atmosphere, volatile organosulfur emissions have significant impacts on atmospheric chemistry, cloud properties, and the Earth's radiation balance. *Thus, DMS(P)'s role in the carbon cycle and air-sea interactions make an outsized contribution to global climate.*

DMS(P) and the carbon cycle: The DMS(P) research community made important and early contributions to our understanding of the ocean's carbon cycle by quantifying DMS(P)'s input to the organic carbon cycle and the organisms harboring the enzymes responsible. The field leveraged the highly sensitive sulfur moiety for rate measures of DMS(P) turnover using ^{35}S which have provided novel insights into labile carbon fluxes. Early characterization of the genetic pathways for DMSP degradation responsible for these fluxes inspired development of in situ qPCR quantifications paired with direct rate measurements. More recently, the field has advanced to make predictions of DMS(P) concentrations based on the genetic capacity of microbial community members using next-gen sequencing. This research reflects broader community efforts to link molecular-level processes defined by 'omics' approaches to global biogeochemical fluxes (e.g. BioGeoSCAPES, Bio-GO-SHIP).

DMS(P) and the air-sea exchange: DMS(P) research has moved well beyond the simplistic connection between DMS(P) volatilization and cloud condensation nuclei. Recent advances include: 1) the discovery that other volatile products of DMS(P) catabolism, including methanethiol, significantly contribute to the organosulfur flux to the atmosphere; 2) atmospheric oxidation of DMS and methanethiol is more complex than thought, for instance 30% of DMS from the ocean may form the newly discovered product hydroperoxymethyl thioformate (HPMTF), with a global impact on new aerosol particle formation and growth; 3) the recognition that DMS(P) transformations influence climate-relevant aspects of the biogeochemical cycles of Br, I and N; for instance, DMS may inhibit enzymatic production of organohalogens (e.g. bromoform) in seawater, reducing emission to the atmosphere; while volatile organonitrogen compounds, particularly methylamines and ammonia emitted from the ocean, interact with DMS oxidation products in the atmosphere to greatly enhance aerosol formation.

These recent advances align with OCB's direct interest in air-sea interactions science formalized through the OCB subcommittee on Ocean-Atmosphere Interactions (OAIC). Historically, OCB has indirectly supported this topic through the OCB summer workshop sessions on carbon cycling in polar waters (2014), a joint OCB-SOLAS session on atmospheric deposition (2015), and a session on air-sea interactions in 2024. All OCB-relevant topics are in the 2022 report produced by the US SOLAS program in a workshop convened by the OAIC. As such, our proposed symposium would strengthen ties between DMS(P) research and the OCB and OAIC communities as well as with the US and international SOLAS communities. DMS(P) research has been an important component of international SOLAS since its inception in 2000.

Expansion of the sulfur-carbon nexus: Organosulfur is emerging as an important mediator of biogeochemistry in different oceanic systems. For example, gonyol and 2,3-dihydroxypropane-1-sulfonate are two organic

sulfur metabolites with similar algal abundances as DMSP and thus likely to make important, but currently unquantified, contributions to labile carbon cycling. Organosulfur compounds also appear to play an important role in seagrass-mediated carbon cycling as a mechanism for detoxification when growing in sulfidic sediments. Finally, isotopic evidence very recently suggested that organosulfur's contributions to recalcitrant carbon has a biotic origin, breaking away from long-assumed abiotic sulfurization origins. These are just a few examples of how the importance of marine organosulfur to carbon and climate is expanding to the forefront of a wide diversity of investigators' interests. Thus, the need to synthesize this research, incorporate the advances into biogeochemical and climate models, and identify crucial gaps in understanding, is more imperative than ever.

DMS(P) cycling reflects OCB research priorities: DMS(P) research directly addresses the overarching goals of OCB. The symposium will synthesize and stimulate novel research in these areas, broadening OCB's portfolio. As such, we have designed our Symposium to center on three central themes that integrate DMS(P) into *current OCB research priorities* as follows:

1. *molecular, physiological, ecological, and evolutionary responses* of DMS(P) *to environmental change*
2. the role of DMS(P) in *changing ocean chemistry and associated impacts on marine ecosystems, carbon cycling and biological pump* (C, S, N) *along the aquatic continuum of air-sea interactions*, *including extreme events*
3. mathematical *synthesis of carbon* and sulfur *fluxes from cellular to global scales*

Proposed OCB Activity

We propose to host a four-day workshop in Fall 2026 at the Center for Ocean Education and Innovation, Bigelow Laboratory for Ocean Sciences. The overarching goal is to facilitate talks, poster sessions, discussion groups, and informal networking to discuss the current state of the field and novel new research directions. Based on previous symposia, the large size of the marine organosulfur community, and the interdisciplinary nature of the field, we expect approximately 100 participants, both in person and online attendees. Given the international breadth of the field, we will host a hybrid meeting to ensure all interested parties can participate.

Each day will include morning and afternoon talk sessions. We will invite a senior researcher to present an overview of both the historical context and an assessment of the current state of knowledge. This will be followed by talks featuring early career researchers (ECR) selected from the pool of submitted abstracts that best reflect the session's theme and novelty of research. Each day will also include a poster session and associated lightning talks presented by a mix of career stages from students to senior researchers.

To facilitate more informal interactions throughout the day, discussion leaders will pose daily research questions to the attendees. During coffee and meal breaks, in person and virtual participants will be asked to brainstorm thoughts on virtual sticky notes posted on an online note board, soliciting new ideas for the afternoon discussion sessions. Breakout discussion sessions will center on consensus emerging topics generated from the note board related to the day's theme.

Informal networking opportunities outside of the formal science days will include a pre-workshop mixer. Time will also be allotted during lunch on day 1 for round robin, 5 minute meetings for ECS to develop a network of peer mentors; and on day 2 for ECS to participate in small group discussions with senior mentors. The third day of the symposium will include science in the morning followed by an afternoon excursion where attendees can participate in one of following trips: a local hike, a coastal boat trip, a visit to the Coastal Maine Botanical Gardens or the Maine Maritime Museum. The third day will culminate with a symposium reception.

The organizing committee will facilitate the link between the in-person and virtual participants. We will solicit two virtual-only leaders to track and provide real-time feedback for remote participants to ensure an effective interaction. Virtual participants can participate in talks, write ideas to the virtual board, and join poster and discussion sessions through Zoom for direct conversation, and with Canvas and LucidSpark as possible platforms for information gathering and exchange. We will solicit OCB's guidance to implement this plan.

To reach the diverse group of interested scientists nationally and internationally, we will advertise widely through a recently updated DMS(P) community list and with SOLAS, ASLO, IMBER, CATCH, OAIC and OCB. We intentionally set the symposium to start on a Tuesday so that those with family care responsibilities can travel on a Monday. We will also advertise widely that we welcome caregivers and families to attend. The

workshop will follow the Bigelow Laboratory's code of conduct for meetings, and supplement it with any workshop-specific additions following the structure of the successful code used at OCB annual meetings. The code of conduct will be signed by participants at registration and discussed at the beginning of each day.

Planned Outcomes (at the meeting) **and Benefits to the Broader Community** (within 1 year after the meeting)

- Gather researchers from diverse fields to discuss and synthesize all aspects of sulfur-carbon cycling, spanning microscale processes to global scale impacts; and reunite this research community.
- Identify key knowledge gaps in a series of discussion sessions, to prioritize future research and develop necessary collaborations and opportunities.
- Build collaborations by connecting with similarly-focused community efforts, including OCB, OAIC, SOLAS, BioGeoSCAPES and others. Specifically, we will invite a representative from the SCOR PRIMO working group and the OCB OAIC sub-committee to co-chair relevant sessions to make direct connections with the broader community's interests.
- Provide training at the symposium by presenting and discussing results of the SCOR DMS-PRO working group's SOPs and contribution to an expanded DMS(P) database.
- Stimulate networking across the career continuum and bolster international collaborations.
- Publish a special issue in *Elementa, Science of the Anthropocene* in 2027. Confirmed with the Editor.
- Create an on-line record of the meeting via an OCB-based webpage, with talk recordings, articles on key aspects and a workshop report to further liaise with the broader OCB and ocean science communities.
- Propose a session on DMS(P) importance in marine carbon cycling at the next OCB meeting.

A stand-alone symposium on DMS(P) research is essential. This symposium will allow us to host the diversity of researchers involved in understanding and synthesizing the multiple facets of sulfur-carbon cycling (e.g. earth system modelers, phytoplankton ecologists, microbial physiologists, atmospheric chemists, biogeochemists, and chemical ecologists). It is not feasible to bring together this diversity of researchers in a special session at a larger meeting (e.g. AGU, ASLO) and cover the wide ranging topics in the DMS(P) field. Large meetings cannot accommodate the time and space needed to focus solely on DMS(P) research in the way that a dedicated symposium would. It is precisely for this reason that six stand-alone DMSP symposia were held, with the first in Mobile, AL, nearly 30 years ago. Subsequent symposia were organized and hosted in Groningen, Rimouski, Norwich, Goa and most recently Barcelona, in 2014. Key insights into ocean biogeochemistry and air-sea interactions have evolved from DMS(P) research, in large part, promoted by the community built through the DMS(P) Symposia. It has now been more than 10 years since the last DMS(P) meeting. During this time, tremendous advances in the topic have been made and the importance of the sulfur-carbon nexus has been expanded, as outlined above. Importantly, our proposed symposium, like similar OCB workshops in other fields (e.g. Leaky Deltas, Nucleic Acid 'Omics S&I', Fish, Fisheries, and Carbon), will provide easily-accessed, high-quality interactions and networking opportunities for ECS and scientists from developing countries.

Logistical needs

Our budgetary needs include: 1) Meeting spaces: a large meeting hall (Burgess Forum) and 4 separate rooms for breakout sessions at Bigelow Laboratory for Ocean Sciences; 2) Food and beverage for participants including 2 breaks and 1 lunch per person per day for 4 days; and 1 evening reception; 3) Travel support for approx. 10 ECR, 10 students, 2 invited speakers and 2 session leaders; 4) Lodging for approx. 10 ECR, 10 students, 2 invited speakers and 2 session leaders for 4 nights; 5) Local transportation for i) a bus for hotel-Bigelow-hotel for 4 days and ii) 2 minivans for Portland- East Boothbay, for some participants on arrival and departure; and 6) Publication fee for the prologue of the *Elementa* SI (all other publication fees to be covered by individual authors). We expect a maximum of 100 participants, but not all in person. If needed, we calculate that a modest registration fee (~USD$50 per person) would offset costs enough to expand the budget maximum allowed by OCB. Additional funding has been approved by SCOR (up to 10 DMS-PRO members) and by international SOLAS (2 persons). Previous workshops were supported by hosting institutions, national environmental funders (e.g. US NSF, UK NERC, Spain ICM-CSIC), and international SOLAS, which highlights the broad implications of DMS(P) research for the scientific priorities of these funding agencies. Additional requests will be pursued.