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solas event report

Report 14 I July 2019

SOLAS Open Science Conference 2019

21 - 25 April, 2019
Sapporo, Japan

In this report

Discussion session reports

Award recipients research profiles


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The 7th SOLAS Open Science Conference was held in Sapporo, Japan, from 21-25 April 2019 at the Hokkaido University Conference Hall. Organised and run by a committee of 17 nationalities, the conference welcomed 190 attendees from 30 countries to share their research and knowledge of SOLAS science (Figure 1). The conference participants were treated to the arrival of the cherry blossoms in northern Japan, a truly unforgettable experience.

The plenary sessions ranged over the whole spectrum of SOLAS science covering the following themes:

Core theme one, **"Greenhouse gases and the oceans,"** featured a keynote lecture from Siv Lauvset, from the Norwegian Research Centre (NORCE), Norway, on the role of humans and the ocean in the carbon cycle.

Core theme two, **"Air-sea interface and fluxes of mass and energy,"** is dedicated to oceanic and atmospheric processes, driven for instance by waves, bubbles or surfactants, which influence the transfer of mass and energy between the ocean and atmosphere. Daiki Nomura of the University of Hokkaido, Japan, introduced this theme with his talk on gas exchange in ice-covered oceans.

Core theme three, "**Atmospheric deposition and ocean biogeochemistry**," explores the impact of particles which enter the ocean from the

Figure 1: Participants of the SOLAS Open Science Conference 2019. © A. Murayama

atmosphere. These particles can be from natural processes, such as dust or volcanic eruptions, or human activities, such as the burning of fossil fuels (including ship plumes) and biomass or agriculture. The keynote for this session was given by Ying Chen, from Fudan University, China. Her talk focused on the impact of atmospheric nitrogen and trace metals on marine phytoplankton.

Core theme four focuses on the **“Interconnections between aerosols, clouds, and marine ecosystems”** and how these components form a system as a whole. Jonathan Abbatt of the University of Toronto, Canada, gave the keynote talk on how the ocean, aerosols, and clouds are connected in the summertime Canadian Arctic.

Core theme five is dedicated to “**Ocean biogeochemical control on atmospheric chemistry**,” exploring how marine aerosols and reactive gases impact the atmosphere. Anoop Mahajan, from the Indian Institute of Tropical Meteorology, India, and one of the latest additions to the SOLAS Scientific Steering Committee, introduced this theme with a look through time at how the ocean regulates atmospheric chemistry.

In addition to these five core themes, the conference included three sessions on cross-cutting themes:

Figure 2: Keynote speaker Andrew Lenton (right) and Geoengineering session convener Philip Boyd (left). © A. Murayama

A session on **Geoengineering** and **Science and Society** explored the interface between SOLAS science, societal priorities, and policy proposals. Andrew Lenton from the Commonwealth Scientific and Industrial Research Organisation, Australia, gave a keynote talk on geoengineering, the ocean and SOLAS (Figure 2). Kathryn Mengerink**,** Waitt Institute, USA, introduced the Science and Society topic with her keynote on marine spatial planning as a tool to advance science-based decision-making.

Figure 3: Sharing knowledge during the poster sessions. © J. Gier

The SOLAS **Integrated Topics** on upwelling systems, polar oceans, and coastal waters filled two sessions. The keynote talk was given by Marcela Cornejo, Pontificia Universidad Católica de Valparaíso, Chile, and focused on nitrous oxide changes in the Humboldt Current System.

The four-day conference encompassed not only plenary sessions but also afternoon poster sessions (Figure 3). The best two student posters were given awards during the conference banquet (Figure 4). Prizes were awarded to George Manville (University of Exeter, UK) for “High-resolution spatial variability lengthscales of surface ocean dimethylsulfide (DMS) concentrations” (see page 32) and to Lumi Kinjo (Wellesley College, USA) for “Measuring noble gas fluxes at high wind speeds in the sustain wind-wave tank” (see page 30).

Figure 4: A, The two student poster winners, George Manville (left) and Lumi Kinjo (right), receiving their awards from Yoav Lehahn, Mitsuo Uematsu, and Maurice Levasseur (left to right) during the conference banquet. © K. Gier

Furthermore, the OSC provided a venue for nine formal discussion sessions on current projects and new ideas. The outcomes of these sessions are published on pages 9 - 28. In addition to the main conference, an Early-Career Scientist Day (see page 5) and a Geoengineering Workshop (see page 7) were held the day before the conference.

SOLAS would like to thank all who contributed to making the SOLAS Open Science Conference 2019 a success: the Local Organising Committee, the Scientific Organising Committee, the Early Career Scientist Day Committee, the poster judges, all plenary and discussions session chairs, all speakers, and all who attended!!

Again, congratulations to the winners of the student poster competition George Manville (University of Exeter, UK), Lumi Kinjo (Wellesley College, USA) and the winners of the Early Career Scientist Day talk competition Hannah Horowitz (University of Washington, USA; see page 35), Stephanie Schneider (University of Toronto, Canada; see page 37), and Pat Wongpan (Hokkaido University, Japan; page 39).

SOLAS International Project Office

SOLAS Open Science Conference 2019

Photo Gallery


SOLAS national representatives dinner


Sapporo and Odori Park


The 1st SOLAS OSC Fun Run


At the registration desk


Plenary session


Conference banquet


Some of the conference organisers


Sapporo TV Tower


Banquet honoree, Mitsuo Uematsu

Taiko drummers at the banquet


Poster session


Ice breaker in a Beer Keller

© A. Murayama, E. Rickert, J. Gier, K. Gier, K. Mengerink, H. Tanimoto

Early-Career Scientist Day

Sohiko Kameyama [a], Yoko Iwamoto [b], and Martine Lizotte [c]

[a] Hokkaido University, Japan. Contact: skameyama@ees.hokudai.ac.jp
[b] Hiroshima University, Japan. Contact: y-iwamoto@hiroshima-u.ac.jp
[c] Laval University, Canada. Contact: martine.lizotte@qo.ulaval.ca

Before the main SOLAS Open Science Conference, an Early-Career Scientist Day (ECSD) was organised on 21 April, 2019. The ECSD was planned by the ECSD committee composed of Dr. Sohiko Kameyama (Hokkaido University, Japan), Dr. Yoko Iwamoto (Hiroshima University, Japan), and Dr. Martine Lizotte (Laval University, Canada). It brought together 25 doctoral students and postdoctoral researchers from 15 countries to network, discuss, and share their respective research.

At the registration desk in the morning, souvenirs that had been specially designed for the ECSD were offered to the participants (Figure 5). After the welcoming introduction, Dr. Anoop Mahajan (Indian Institute of Tropical Meteorology, India) gave a lecture entitled “Making Science ‘Cool’” which delved into the reasons why science needs to remain fun and accessible from the point of view of connections between scientist and society. Mr. Namba Naoki (Hokkaido University, Japan), who has been involved in knowledge mobilization of research activities within the public at large, gave a talk on the importance of “Writing about your research for a non-academic audience”. During the lecture, participants actively discussed with the lecturers (Figure 6).

Figure 6: Invited lecturers at the ECSD. A, Dr. Anoop Mahajan; B, Mr. Namba Naoki. © A. Murayama and L. Li

Figure 5: Souvenirs specially designed for the ECSD. © Y. Iwamoto

Following the lectures, each participant presented their research during three-minute talks which were accompanied by two-minute Q&A, and Early-Career peer evaluations. As a result, the best three talks were given awards during the conference banquet (Figure 7A). Prizes were awarded to Dr. Hannah Horowitz (University of Washington, USA) for “Where does mercury in fish come from?”, Ms. Stephanie Schneider (University of Toronto, Canada) for “Heterogeneous oxidation of the surface microlayer with ozone”, and Dr. Pat Wongpan (Hokkaido University, Japan) for “Using under-ice spectra to determine land-

Figure 7: A, The three winners of the Early-Career Scientist Day three-minute talks receiving their awards. From left to right: Pat Wongpan, Stephanie Schneider, Hannah Horowitz, Mitsuo Uematsu, and Yoko Iwamoto. B, The awards were created by Hokkaido glass crafts. © K. Gier and S. Kameyama

fast ice algal biomass in Lake Saroma, Japan", along with special trophies created by Hokkaido glass crafts (Figure 7B).

After the three-minute competition, the Early-Career Scientists went on a field trip to Lake Shikotsu, a caldera lake created by a volcanic eruption that remains ice-free throughout the year despite its northern latitude (Figure 8). The day was calm and sunny, and the participants enjoyed the glass boat outing and the walk around the lake. After the excursion, the participants returned to Sapporo and the ECSD ended with the SOLAS Open Science Conference Ice-Breaker.

The entire activities during the ECSD were made possible through the financial support of PICES. The organizing committee would like to thank PICES for its patronage and for providing the SOLAS Early-Career Scientists with an unforgettable experience.

Figure 8: The participants of ECSD at the Lake Shikotsu. © Y. Iwamoto

SOLAS Research and Geoengineering workshop

Philip Boyd [a], Cliff Law [b], and Lisa Miller [c]

[a] Institute of Marine and Antarctic Studies, University of Tasmania, Australia. Contact: philip.boyd@utas.edu.au
[b] National Institute of Water and Atmospheric Research, New Zealand. Contact: cliff.law@niwa.co.nz
[c] Institute of Ocean Sciences, Fisheries and Oceans Canada, Canada. Contact: lisa.miller@dfo-mpo.gc.ca

SOLAS researchers Cliff Law, Philip Boyd, and Lisa Miller organised a one-day workshop on ”SOLAS Research and Geoengineering” on Sunday 21 April 2019, to take advantage of the many scientists travelling to participate in the SOLAS Open Science Conference (OSC) in Sapporo. The workshop follows a tradition of discussing this topic at OSC’s started by Peter Liss’s talk, and Cliff Law’s & Phil Williamson’s discussion session at Barcelona in 2009, and followed by a discussion session in Kiel by Boyd and Law in 2015. However, this was the first time that an entire day had been dedicated to this topic, which was in part prompted by the release in 2018 of the SOLAS position statement on Climate Intervention. The event was attended by around 35 people ranging from graduate students and summer school alumni to researchers who have been with SOLAS since its inception (Figure 9).

The day started with background information on geoengineering, followed by a historical perspective on prior SOLAS contributions to the geoengineering debate, and a presentation on how the current SOLAS science plan relates to the debate into climate intervention (Figure 10). Invited lectures were presented on modelling (CDRMIP – Carbon Dioxide Removal-Model Intercomparison Project; and GeoMIP – the Geoengineering Model Intercomparsion Project) by Andrew Lenton (Australia) and on societal issues by Erik van Doorn (Germany) that provided valuable food for thought for the subsequent breakout groups. In the second half of the workshop general discussion sessions were interspersed with more

Figure 9: The participants of the SOLAS Research and Geoengineering workshop. © J. Gier

breakouts, and the event closed with a summing up session by the organisers.

Figure 10: Cliff Law and Philip Boyd give background information on climate intervention. © J. Gier

During the era covered by the previous SOLAS science plan, SOLAS played a key role in developing research and informing policy on ocean iron fertilisation as a potential climate intervention approach. However, over the last 15 years a number of reports have been published by national academies and intergovernmental bodies on additional geoengineering proposals, noting the lack of required scientific underpinning. As geoengineering approaches have been proposed for the lower atmosphere, ocean surface, and upper ocean, SOLAS is perhaps best placed within Future Earth to conduct the necessary scientific research. There also appears to be a willingness to pursue such research, particularly in recognition of the need for additional actions beyond emissions reductions to achieve the Paris Agreement target. However, it will be essential to provide a “safe operating space” (i.e., within the existing legislation) for such research by SOLAS scientists.

The modelling presentation by Andrew Lenton on CDRMIP revealed that an Earth System Model framework is the only tool we have to integrate what we know on the scales relevant to any planned eventual climate intervention deployments. The MIP component provides confidence in the robustness of the model outcomes and gives insights into the pro’s and con’s of each approach; however, it was clear that in many cases, the CDRMIP & GeoMIP communities are information-poor for a wide range of geoengineering approaches. The societal presentation by Erik van Doorn introduced the workshop to a range of concepts such as modes of opinion, governance principles, ocean jurisdictions, and in particular the observation that the Law is almost exclusively reactive, which has major ramifications for the legal basis for geoengineering.

The breakout groups focussed on “Terminology, Perceptions and Ethics”; “Methods: Bubbles and ocean alkalinisation” and “Models: Sensitivity and fundamentals”. The discussions were freewheeling and in each case demonstrated that SOLAS has a multi-faceted vision to offer the geoengineering debate.

In summing up, it was clear from the workshop that SOLAS, with our multidisciplinary expertise across the lower atmosphere and its interface with the surface ocean, is well positioned to address many of the issues that are hindering useful debate on geoengineering. Potent synergies with the modelling community are particularly evident. The five themes of the SOLAS science plan provide a ready framework with which to develop an inventory of ideas that could be linked to a wide range of geoengineering approaches, aspects of which can be tested readily within laboratory and contained field settings. The science plan structure could therefore double as a synthesis tool for these findings to ensure they are organised coherently.

Can long-term observatories be used to study the processes controlling air-sea exchange?

Conveners: Christa Marandino [a], Arne Körtzinger [b], Tom Bell [c], and Jin-Yong Jeong [d]
Rapporteurs: Kerstin Krall [e] and Sonja Friman [f]

[a] GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany. Contact: cmarandino@geomar.de
[b] GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany. Contact: akoertzinger@geomar.de
[c] Plymouth Marine Laboratory, UK. Contact: tbe@pml.ac.uk
[d] Korean Institute of Ocean Science and Technology, South Korea. Contact: jyjeong@kiost.ac.kr
[e] Institute of Environmental Physics, Heidelberg University, Germany. Contact: kerstin.krall@iup.uni-heidfelberg.de
[f] Institute of Environmental Physics, Heidelberg University, Germany. Contact: sonja.friman@iup.uni-heidelberg.de

The boundary between the ocean and atmosphere is one of the Earth's most important interfaces. Nonetheless, the controls upon mass and energy fluxes across this interface are not fully understood or quantified. Researchers from GEOMAR, Plymouth Marine Laboratory, and the Korea Institute of Ocean Science and Technology hosted this discussion, drawing on varying levels of experience running integrated air-sea exchange observatories to tackle these unknowns. During this session, we identified the benefits and challenges associated with the data collected at these and similar sites around the world. The goal of the workshop was to publicize ongoing activity and to encourage community interest and participation at these sites. The main outcome of this session was to organize a SOLAS workshop on how to intercompare time-series observatories, specifically with regard to air-sea flux measurements by eddy covariance, with the intention to apply for a SCOR working group on the topic.

There were approximately 50 people in attendance (Figure 11). Each convener gave a brief description of their observatory (Helmholtz International Ocean-Atmosphere Network, Penlee Point Atmospheric Observatory, Korea Ocean Research Stations) and gathered a list of others that should be considered. These included:

- Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) Station for Climate Observation (Roberto Sarao)
- Canadian Arctic (Brent Else, Lisa Miller)
- Bermuda Institute of Ocean Sciences (BIOS)
- Sweden - Östergarnsholm, Gotland (Anna Rutgersson, Uppsala University)
- Finland - Utö
- Ireland - Mace Head
- South of Iceland & Svalbard (both dimethylsulfide)
- Ships: Integrated Carbon Observation System (ICOS) Voluntary Observing Ships (VOS) (UK), Oceania (Poland)

The open discussion began with the questions: How should these observatories be used? What measurements should be included? Suggestions were that many long-term sites are coastal and can be used for footprint characterization and standardization between stations. Measurements should include: physical parameters - waves, bubbles, turbulence, and surfactants, friction velocity, SST, upwelling (wave modeling is a possibility at some sites); and chemical parameters - greenhouse gases, oxygen, other trace gas surface concentrations, dissolved organic matter. Aerosols must also be considered – both amount and composition – as well as investigating how

Figure 11: Discussion session on long-term observatories. © J. Gier

land and ocean interact differently with aerosols (feedbacks between the regions). Gradients in both air and water of the different variables should also be obtained when possible. Finally, microlayer sampling should be attempted at these sites when possible.

As long-term observatories were deemed essential for air-sea interaction research, the idea of intercomparability was raised. This was clearly a motivating topic and many scientists in the room were enthusiastic about the idea of performing intercomparison exercises. These should include both physical measurements and data processing. Some specifics discussed include: fixed location vs. moving measurements; reliable standardized flux measurements are generally difficult to make; often different instruments at one location give different results; the sites require standardization. The community stated that we need unified protocols and best practice guides, which should include software (e.g., the ICOS land based eddy covariance community has this standardization, but it should be highlighted that the ocean eddy covariance community faces different challenges). We should also attempt to devise a best practice guide for the intercomparisons themselves. We must also consider the life cycle management of measurement devices and emerging technologies.

The group determined that there is experience with these types of intercomparisons. For example, joint measurements in a single location for cross-calibrate has been done repeatedly. We can also take a reference sensor to various sites or take site sensors to a reference sensor when possible. A way to evaluate whole sites, including tower logistics, should also be identified. Regarding software, it is possible to perform a data analysis intercomparison from a common raw dataset. Additionally, ICOS already institutes that practice that data is evaluated by someone not involved in obtaining the data. It was also suggested that we can back calculate physical parameters from the retrieved data, (e.g., wave height, ship movement) or perform a simulated training data set exercise.

The final point discussed was how to optimise the stations, given community needs. The following needs were discussed: CO_2 flux contamination, presenting calibrated fluxes to global modelers, long term data storage and data science, platforms developed to tackle special tasks, missing geographical locations, networking to coordinate international science questions, long term international funding, and the need for an international effort.

Final thoughts were that this idea should be further discussed at the OceanObs’19 meeting in September 2019 on Hawaii and that the global air-sea interaction community needs to be more engaged to solve funding issues. It was tentatively decided to ask SOLAS for a workshop on long-term air-sea interaction observatories to lead up to a Scientific Committee on Oceanic Research (SCOR) working group.

Impacts of ocean plastic and microfibers on air quality and climate

Convener: Sarah-Jeanne Royer [a]
Co-convener: Dimitri Deheyn [b]
Rapporteur: Kathryn Mengerink [c]

[a] SCRIPPS Institution of Oceanography, UCSD, San Diego, USA. Contact: sroyer@ucsd.edu
[b] SCRIPPS Institution of Oceanography, UCSD, San Diego, USA. Contact: ddeheyn@ucsd.edu
[c] Waitt Institute, San Diego, USA. Contact: mengerink@waittinstitute.org

Plastic pollution has been a growing concern recently as it is found everywhere, impacting all forms of life, including humans (Figure 12). While many studies have investigated the extent of plastic pollution in aquatic environments and wildlife, very few studies have looked at the interplay between plastics and the atmosphere. It was recently proven that greenhouse gases are emitted from plastic degradation, which may potentially affect the global budget of methane, and thus link plastics to climate change (Royer *et al*., 2018).

Similarly, synthetic microfibers are ubiquitous in the environment, including in the oceans and the atmosphere. Microfibers are invisible to the naked eye given their small size, and thus we breathe, eat and drink them without being aware of it. There is clearly an urgent need for increasing our knowledge regarding plastics and synthetic microfibers in the ocean and their transfer to the atmosphere, especially in the wake of environmental and human health issues already increased by climate change.

Figure 12: Plastic marine debris at Kamilo Beach (Big Island, Hawaii, USA) off-gassing greenhouse gases. © S.-J. Royer

Figure 13: Conveners of the session: Sarah-Jeanne Royer (right) and Dimitri Deheyn (left). © A. Murayama

The goal of this session was to engage SOLAS scientists to explore potential collaborations to better assess the effect of the synthetic materials on climate processes in linked with SOLAS themes. The discussion session, with 40+ participants, was introduced with a brief presentation on the state of plastic production globally and the amount of plastic discarded in the environment followed by a brief summary of the emissions of greenhouse gases by plastics and a short overview on microfibers by both conveners (Figure 13). Following the brief introduction, three SOLAS participants kindly accepted to present their work with a special emphasis on their expertise could be linked to plastic and microfibers in the environment. Erik van Doorn from the Walther Schücking Institute for International Law at Kiel University presented on “SOLAS, plastic and law” followed by Prof. William Landing on the “Atmospheric sampling for microplastics and microfibers” and Kathryn Mengerink, the executive director of Waitt Institute who presented on “Marine debris legal frameworks”. These presentations showed how interrelated are the scientific topics covered by the SOLAS community and plastic in the environment.

The remaining time of the discussion session was devoted to an open discussion about questions in relation with plastics and microfibers and: the scope of SOLAS, oceanic and atmospheric models, the carbon budget, the sampling and the environmental and public health aspect. During the discussion, several important questions were raised and debated.

1) How can we integrate plastic and microfiber research in the interest of SOLAS research?
2) How can we add the plastic component in SOLAS modelling studies?
3) Given recent studies showing interactions between plastic and the carbon pool, should we integrate hydrocarbon compounds in the carbon cycle?
4) Are there efficient ways of sampling at a greater scale than the current techniques?
5) Would mesocosm experiments be an efficient tool to understand better the effect of plastics and fibers on biological processes?
6) Is plastic a possible vector for the propagation of viruses, bacteria and algae?

The general consensus of the discussion session was that we need to move forward on many fronts to include the plastic components into SOLAS objective, this is with both lab-based and field-oriented studies and also modelling studies that should now consider possible interactions between plastic and atmospheric/oceanic components.

For fieldwork measurements, a collaborative approach will be needed that involves the international community with many lab groups employing different sampling techniques working on same sample sets to include the measurements of microplastics to nano- and picoplastics which also include the measurements of microfibers (Figure 14).

Many methodological barriers exist at the moment, especially when measuring small plastic particles release in the environment, and the contribution of different science fields may also help to develop proper techniques to capture these small particles. Developing consistent methodologies (guide of best practices) is also an important task and will be the step following the establishment of collaborative work between different SOLAS entities.

Figure 14: A, Coriolis air sampler (Bertin Instruments) to measure microfibers in air at Lake Altausse, Austria. B, Microfibers in air collected at Lake Altausse (Austria) using the Coriolis air sampler (Bertin Instruments). © S.-J. Royer

Reference

Royer, S., Ferrón, S., Wilson, S. T., *et al*. (2018), Production of methane and ethylene from plastic in the environment. *PLoS One*, 13(8): e0200574. doi: 10.1371/journal.pone.0200574

The coupling of ocean, sea ice and atmospheric chemistry and biogeochemistry - a cross-disciplinary research challenge

Convener: Markus M. Frey [a]
Co-conveners: Paul Zieger [b] and Daiki Nomura [c]
Rapporteur: Nadja Steiner [d]

[a] Natural Environment Research Council, British Antarctic Survey, UK. Contact: maey@bas.ac.uk
[b] Department of Environmental Science and Analytical Chemistry, Stockholm University, Sweden. Contact: paul.zieger@aces.su.se
[c] Faculty of Fisheries Sciences, Hokkaido University, Japan. Contact: daiki.nomura@fish.hokudai.ac.jp
[d] Institute of Ocean Sciences, Fisheries and Oceans Canada, Canada. Contact: nadja.steiner@dfo-mpo.gc.ca

The goal of the session was to assess ways to improve links within the more atmospheric focused research community Cryosphere and Atmospheric Chemistry (CATCH) and the more sea ice - ocean oriented research community Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII). Both communities focus on polar and cold regions.

Based on 1-slide introductions and follow-up discussions, the following key research areas were identified by the participants (Figure 15):

- Flux uncertainties and inventories (i.e., monthly maps) of CO_2 and trace gas fluxes;
- quantify (better) deposition (including scavenging) and vertical fluxes of trace gases, create a deposition network to help to help constrain models;
- Aerosol emissions (e.g. sea salt, biological marine particles, secondary particle formation including new particle formation via volatile organic compounds (VOC), dimethylsulfide, isoprene) and respective changes with a changing climate;
- Treatment of VOCs in cloud physics and aerosol processes in earth system models (ESMs);
- Estimating ice algal biomass on higher spatial and temporal resolution to improve spatial coverage of marine and sea-ice sources;
- Enhanced field measurements including mesocosm experiments;
- Marginal ice zone: improve physical processes, how physical processes impact biogeochemistry and vice versa;
- Sea-ice internal processes: how sea-ice is changing and how it affects and is affected by biogeochemistry;
- Snow on sea-ice: bring snow physicists and snow chemists together;
- Link different biogeochemical cycles and assess impacts of (micro-) biology on biogeochemical cycling / atmospheric chemistry.

To address the challenges, community field / lab studies and research networks were highlighted as the best way to encourage collaboration. The Canadian Network of climate and aerosols (NETCARE) and the upcoming international drift expedition - the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) were highlighted as successful atmosphere-ocean collaborations to initiate a discussion on lessons learned and recommendations on atmosphere-ocean as well as modeller-observer collaboration for future projects.

Recommendations included the need to involve all parties from the beginning and have discussions together to clarify what is wanted versus what is realistic. For example, MOSAiC empha-

Figure 15: Discussion session participants. © A. Murayama

sises identification and discussion of cross-cutting themes so researchers seek solutions with colleagues in neighbouring disciplines. It was highlighted that to involve the best science for the research agenda, project partners should be primarily science driven (i.e., include new/upcoming researchers). In the Canadian example a strong collaboration between government and academic institutions was mentioned as an asset, as well as the need for regular network meetings and student/early career researcher (ECR) interactions, e.g., via allocated funding for students to spend time in different labs to expand their expertise, provide students / ECRs with opportunities to learn specialized methods. To enhance their involvement in the community encourage students to attend summer/winter schools (SOLAS, BEPSII-Cambridge Bay, MOSAiC programme) and student mentoring at conferences (e.g., early career days within SOLAS, Association for Polar Early Career Scientists (APECS), ArcticNet, Gordon Research seminars) and join research communities such as BEPSII and CATCH, organisations like the APECS and apply for International Arctic Science Committee fellowships. BEPSII makes a strong effort on involving ECRs in leadership positions for synthesis papers, model intercomparisons and /or data collations.

To better connect atmospheric and physical (snow) scientists with the biological community and to ensure all relevant expertise comes to the table a joint CATCH-BEPSII workshop was recommended.

With respect to ESMs there is a need to identify (via community discussions) the relevant/important/key processes to be studied, parameterized and implemented and what is important to projecting future changes. A hierarchical list reflecting the importance of processes (a pecking order for research) was recommended. The need for experimentalists and modelers to communicate was highlighted; BEPSII spent a significant effort on this subject (see e.g., Steiner *et al*. 2016). Other successful model-model and model-measurement evaluation exercises such as AeroCom were mentioned together with the need for parties to get involved and the use of a hierarchy of models to test sensitivities and assess high-impact processes from the modeling side (see also discussion in Steiner *et al*., 2016).

Long-term observations, in addition to dedicated field campaigns in undersampled/under-represented winter and fall months, were highlighted as to be important, e.g., MOSAiC, Ny-Ålesund. A network of such sites would be helpful to identify and assess seasonal impacts. Also, there should be better use of opportunities to access data from hard-to-access regions (e.g., via a site/repository collating information on research cruises and possible berth availability for external researchers) and coordination of measurements (send equipment/students, revisit sites, e.g., Pacific Arctic Distributed Biological Observatory) as well as data sharing, (e.g., via coordinated data bases, meta data catalogues, open data policies). Given funding uncertainties, opportunities maybe short notice, hence it was suggested to build flexibility into projects and use research networks to allow consistent/continuous collaboration and communication.

Reference

Steiner, N., Deal, C., Lannuzel, D., *et al*. (2016), What sea-ice biogeochemical modellers need from observationalists. *Elementa Science of Anthropocene*, 4:84.
doi: 10.12952/journal.elementa.000084

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SOLAS Science & Society: achievements, present status & future possibilities

Conveners: Erik van Doorn [a] and Christa Marandino [b]
Rapporteur: Josefine Maas [c]

[a] Walther Schücking Institute for International Law, Kiel University, Kiel, Germany. Contact: edoorn@wsi.uni-kiel.de
[b] GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany. Contact: cmarandino@geomar.de
[c] GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany. Contact: jmaas@geomar.de

SOLAS has grown in recent years to include more disciplines as well as a diversity of stakeholders. It has recognised that greater efforts are needed to increase interaction between natural scientists and social scientists – especially in the light of anthropogenic influence on the ocean-atmosphere system. At the last Open Science Conference, we organised a discussion session to probe the interest in this topic. Multiple workshops have followed, focusing on bridging the gap between SOLAS science and the societal realm. The current SOLAS Science Plan contains a cross-cutting theme on science and society. In this discussion session, we wanted to outline how SOLAS scientists can participate in deepening and widening this range of topics. First, we hoped to identify SOLAS scientists interested in pursuing this integrating effort. Second, we aimed to broaden the topics to include in this cross-cutting theme. Future efforts can include furthering the co-operation between natural and social scientists or taking the step to increased transdisciplinarity (e.g., communication with policy makers).

There were approximately 30 people at the session (Figure 16). It started with a short introduction to the SOLAS Science and Society activities,

Figure 16: The SOLAS Science and Society discussion session. © A. Murayama

including a description of the relevant UN sustainable development goals (SDGs). Three main topics are currently part of the Science & Society umbrella within SOLAS: valuing carbon in the ocean, air-sea interaction and policy, and the influence of ship emissions on biogeochemical cycling. These were first discussed at a workshop in Brussels in October 2016. The resulting paper from this workshop – Marandino *et al*., Bridging the gap between natural sciences and society via social sciences – will be submitted in the summer of 2019. Subsequent workshops occurred in March 2017 – carbon valuation in Monaco, June 2017 – air-sea policy in Rome, and October 2017 – ship emissions in Gothenburg. The Monaco and Rome participants hope to submit papers in 2019, while the ship emissions participants have already published (Endres *et al*., 2018).

The discussion then opened with a question about which SOLAS core themes are most related to SOLAS Science and Society and if the name of the initiative is appropriate. It was pointed out that SOLAS has included more interdisciplinary topics in its programme since 2016, starting for instance with early career scientists at the summer schools to raise awareness about the importance of societal aspects. However, more students with an interdisciplinary education are needed and it is not clear how to achieve this yet. Regarding future research possibilities, it was suggested that we must make use of the grass-roots nature of SOLAS to find topics, but that we should get the best mileage out of our established expertise. Research design - especially in relation to the SDGs - could benefit from direct discussion with social scientists and policy makers, so this effort should be made in the future. In order to facilitate this process, scientists can consider using the services of COMPASS (www.compassscicomm.org) to obtain training in the best ways to communicate to these sectors. A major question was how SOLAS should be involved in research to reduce climate change. The convergence with climate engineering in the marine environment is obvious. Ideas for new topics included plastics in the ocean, in cooperation with Sarah-Jeanne Royer (see the report of her discussion session at this Open Science Conference), and harmful algal blooms (HAB) from Dave Kieber. HAB has clear potential to be an integrated topic with impacts on human health, fisheries, etc. Furthermore, research in remote areas, where indigenous people must be considered (e.g., conducting science on sea-ice and in the Arctic Ocean where Inuit tribes are living), has direct connections with society. It is important to share experience and expertise with local communities. Overall, one should also learn from society what is important to people and talk about a variety of opinions. It was also suggested that SOLAS Science and Society should be represented at the United Nations Ocean Week in New York City.

The main outcomes of the workshop were that:

1) the initiative should continue;
2) more people are interested in joining the original three topics;
3) more co-design should be utilized in framing research topics;
4) plastics and HAB should be incorporated as new topics.

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Endres, S., Maes, F., Hopkins, F., *et al*. (2018), A New Perspective at the Ship-Air-Sea-Interface: The Environmental Impacts of Exhaust Gas Scrubber Discharge. *Frontiers in Marine Science*, 5:139. doi: 10.3389/fmars.2018.00139

Enhanced air-sea interaction in the emerging Marginal Ice Zone

Conveners: Phil B. Hwang [a] and Takenobu Toyota [b]

[a] University of Huddersfield, United Kingdom. Contact: B.Hwang@hud.ac.uk
[b] Institute of Low Temperature Science, Hokkaido University, Japan. Contact: toyota@lowtem.hokudai.ac.jp

This discussion session was aimed to gather ideas to address the potential impacts of the changing ice conditions in the Marginal Ice Zone (MIZ) on air-sea ice interactions, including gas and aerosol exchanges. Although the MIZ is formally defined as the region of sea ice cover which is affected by waves and swell penetrating into the ice from the open ocean (WMO, 2014), it is also defined as a dynamic area with small ice floes and low ice concentration (15 to 80%) (Zhang *et al*., 2015; Aksenov *et al*., 2017; Strong *et al*., 2017). Recent trends in the Arctic Ocean show a rapid expansion of the MIZ, estimated at 12% per decade (Strong and Rigor, 2013; Zhang *et al*., 2015), and it is projected to continue to increase the future. The expanding MIZ allows an intensification of momentum (Martin *et al*., 2016) and heat exchange between atmosphere and ocean (Gallaher *et al*., 2016), which enhances solar warming in the upper ocean (Perovich *et al*., 2011), generates stronger ocean surface waves (Overeem *et al*., 2011; Thompson and Rogers, 2014; Stopa *et al*., 2016) and promotes smaller ice floes by wave-induced breakup (Langhorne *et al*. 1998; Kohout *et al*., 2016) or thermodynamic melt (Hwang *et al*., 2017) and ice banding at various scales (Wadhams, 1983; Saiki and Mitsudera, 2016). These conditions enhance turbulent mixing in the upper ocean (Lincoln *et al*., 2016). By contrast, intense sea ice melt in the MIZ forms a stratified surface layer and subdues the exchanges of momentum and matter between the ocean surface and the deeper ocean (Randelhoff *et al*., 2017). The MIZ also modifies the atmospheric boundary layer (Kantha and Mellor, 1989; Inoue *et al*., 2005) and surface ocean convection-induced external forcing within the atmosphere-ice-ocean system (Buckley *et al*. 1979; Shapiro *et al*., 1989). The ice conditions in the MIZ also affect the air-sea interactions and biogeochemistry. The reduced ice cover increases ice melting, and the melt water enhances the stratification of the upper ocean, suppressing the nutrient supply from below. At the same time, the reduced ice cover and stronger wind/wave promote vertical mixing and nutrient supply from below and also increase aerosol flux to the atmosphere. During freeze-up in winter in the MIZ, frazil ice can form at depth during turbulent conditions, and subsequently bring chemical components to the upper ocean and to the ice, contributing to the ice algal bloom in spring (Clarke and Ackley, 1984). Low ice conditions also create a favorable light environment for primary production.

In the discussion session, we had the 28 participants from 10 different countries with various expertise including sea ice physics, aerosol and gas exchange, and biogeochemistry (Figure 17). With the background information above, our discussion raised the following questions:

1. What are the key processes in the MIZ, especially for physical-biogeochemical coupling?
2. What are the potentials and difficulties in understanding the key processes both in observation and modelling?

Our discussion clearly highlighted the importance of the MIZ as a ‘hot spot’ for aerosol and gas fluxes (in addition to heat exchanges). Higher surface waves, stronger winds and more open water will promote more sea spray and bubbles, enhancing gas and particle exchange between air and sea. The potentially increased flux of primary and secondary aerosol particles at the sur-

Figure 17: Participants of the Marginal Ice Zone discussion session. © A. Murayama

face may affect cloud formation. Increased primary production also adds an important source for organic particles. Despite its importance, aerosol and trace gas fluxes in the MIZ have not been well observed and modelled.

Our current understanding based on perennial ice conditions may no longer be applicable to the MIZ. For example, the expanding MIZ means that the Arctic Ocean is transforming to a thin and saline first-year ice dominated area from a thick and fresh multi-year ice dominated area. As gas transfers primarily through brine channels within the first-year ice, this change likely increases gas exchange between atmosphere and ocean. Thin first-year ice is more saline than multi-year sea ice and is also more prone to flooding. Both factors will lead to more saline snowpacks on sea ice that contains more sea salt aerosol and associated organic matter including organic pollutants that can be released to the air. Changing ice conditions will affect ice thermodynamics and the associated dimethyl sulfide (DMS) and exopolysaccharide (EPS) movements. Advances in the MIZ physics, observations and modelling are on the way, including floe size distribution from observations (Toyota *et al*., 2006, 2011, 2016; Hwang *et al*. 2017) and modelling (Williams *et al*., 2013; Zhang *et al*. 2016). These advances will potentially improve our understanding and prediction of MIZ physics, which can be also used toward improving our understanding of air-sea interactions, and aerosol/gas exchange in the MIZ. The discussion session concluded with identifying the significant knowledge gaps and requirements to form a focus group to understand air-sea interactions in the MIZ.

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The high resolution measurement for the ocean-atmosphere interfacial layers

Conveners: Chuqun Chen [a] and Eric Achterberg [b]

[a] State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanology, University of Chinese Academy of Sciences, China. Contact: cqchen@scsio.ac.cn
[b] GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany. Contact: eachterberg@geomar.de

This discussion session, with about 40+ attendees at peak time, included several parts: a) the importance of improving measurement resolution, b) the BEST (Buoyant Equipment for Skin Temperature), a new instrument for temperature measurements in the ocean-atmosphere interfacial layers at 0.6 mm resolution in vertical direction, c) the true sea surface temperature (SST) structure measured by the new instrument BEST--there is a strong thermocline layer at the top of water, which depends on the temperature difference between the water and the atmosphere, d) possible applications of the new instrument BEST. Then the discussion topics include: a) What do you think of increasing measurement resolution? b) What is the requirement of measurement resolution for your research? c) Are you interested in applying the high vertical resolution temperature in-situ data for your research? d) Any other suggestions and comments?

Figure 18: Session convener Chuqun Chen, China. © A. Murayama

With the discussion, it is believed that the studies on ocean-atmosphere interaction (OAI), a continuous process with molecular activities, require in-situ data collection with higher temporal and spatial resolution. It will be helpful for better understanding the OAI mechanism with observational data of higher resolution. At present, it is difficult to improve the vertical resolution of chemical or biological measurements or sampling. However, the high resolution temperature in-situ data could be useful for chemical or biological research of the ocean-atmosphere interfacial layers. Temperature is the most important parameter of surface ocean, it affects many other marine physical, chemical & biological processes in surface ocean and low atmosphere. The temperature profile data measured by BEST could be applied for many subjects, such as, development of algorithm for retrieving SST from satellite data, validation of remotely-sensed SST products, In-situ calibration of satellite thermal sensors, studies on heat flux and CO_2 flux, marine micro-surface chemical processes, microbe responses to strong temperature variation (in the strong thermocline layer), and so on.

If anyone interested in employing BEST for temperature measurements at ocean-atmosphere interfacial layers, please feel free to contact with Dr. Chuqun Chen (Figure 18), the designer of BEST, which can synchronously to measure the temperature of the bottom layer of the air, the skin layer and subsurface layer of the water at 0.6mm resolution in vertical direction with frequency of once a second.

What is Ocean KAN?

Conveners: Kaela Slavik [a], Mitsuo Uematsu [b], and Anna Zivian [c]

[a] Future Earth, Science Officer, Paris Hub, France. Contact: kaela.slavik@futureearth.org
[b] Ocean Knowledge-Action Network Development Team, Co-chair; Emeritus Professor, University of Tokyo, Japan. Contact: uematsu@aori.u-tokyo.ac.jp
[c] Ocean Knowledge-Action Network Development Team, Co-chair; Senior Research Fellow, Ocean Conservancy, USA. Contact: azivian@oceanconservancy.org

This lively discussion session presented information on Future Earth and its role in supporting Global Research Projects (GRPs), including SOLAS, as well as several Knowledge-Action Networks (KANs); the Ocean KAN; and the way Future Earth, the Ocean KAN, and the GRPs can engage in the upcoming United Nations (UN) Decade of Ocean Science for Sustainable Development. It also explored ways in which the Ocean KAN can work cooperatively and synergistically with SOLAS. It included presentations by Mitsuo Uematsu and Anna Zivian, co-chairs of the Ocean KAN Development Team, and Kaela Slavik, Science Officer at the Future Earth Global Hub in Paris. Fumiko Kasuga, Global Hub Director for the Future Earth Global Hub in Japan, also contributed information on Future Earth to the discussion, in which over 20 people participated (Figure 19).

A good portion of the session was dedicated to understanding the Future Earth ecosystem, including how the Future Earth Secretariat and GRPs are connected: note that Future Earth science officers are assigned to GRPs as liaisons. There are also meetings with GRP/KAN /Future Earth representatives, of which some examples include:

- Future Earth Summit, last held in August 2018, a two-day meeting in Bonn – it was noted that this is one of the most valuable things Future Earth can do
- Four GRP representatives and one KAN representatives were present at the 2019 meeting of the Future Earth Advisory Committee and Governing Council in Stockholm in April

In some ways, the outcome is the exchange; there are also other opportunities, like help with communications, networking/connections for science, etc. The Future Earth Communications team, in particular, can support GRPs in communicating their achievements – Future Earth Communications team (note that sharing science

Figure 19: Session conveners: Anna Zivian (left) and Kaela Slavik (right). © F. Kasuga

can help lead to funding). In addition, Future Earth has routes for engaging in science-policy processes and conferences (e.g., Future Earth is accredited in various UN fora and can provide credentials for people interested in attending).

Beyond Future Earth, the Ocean KAN has sponsorship from World Climate Research Programme, Intergovernmental Oceanographic Commission, and Scientific Committee on Oceanic Research, and was set up, along with other KANs, to respond to needs from the community, connect to policy/society/decision-makers; and link to industry as well as other organizations and non-governmental organizations (NGOs) like Ocean Conservancy and other boundary organisations. Some of these functions overlap with the SOLAS Science and Society group, so it was noted that both groups will make sure to connect via science officers, joint membership, and both formal and informal channels.

SOLAS and other GRPs can help provide the substance, and that substance can help inform decision-makers and the public. The Ocean KAN can amplify that science through blogs, webinars, engaging in global science and policy efforts, linking early career researchers in the GRPs with early career researchers and professionals in business, NGOs, government, and other academic organizations, and facilitating connections and networks (Figure 20). Just as co-production and co-design are important in designing research for society, it is important that the various initiatives in Future Earth and the Ocean KAN are connected and complementary, and this meeting helped set the stage for that moving forward.

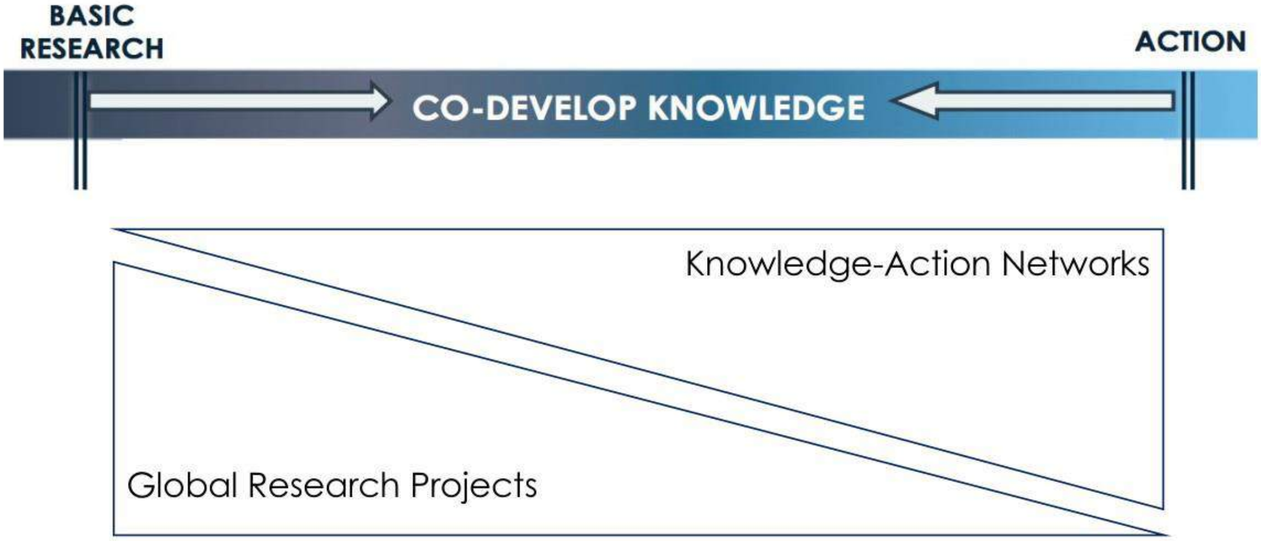

Figure 20: Global Research Projects (GRPs) and Knowledge-Action Networks (KANs) on the basic research to action spectrum

Atmospheric deposition of iron, ocean biogeochemistry and marine emission of biological aerosols

Convener: Akinori Ito [a]
Co-convener: William Landing [b]
Rapporteur: Douglas Hamilton [c]

[a] Yokohama Institute for Earth Sciences, JAMSTEC, Yokohama, Kanagawa 236-0001, Japan. Contact: akinorii@jamstec.go.jp
[b] Florida State University, Tallahassee, FL 32306, USA. Contact: wlanding@fsu.edu
[c] Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, NY 14853, USA. Contact: dsh224@cornell.edu

This session focused on the coupling between the deposition of aerosol iron to the ocean and subsequent emission of marine aerosol and precursor gases to the atmosphere via ocean primary productivity. The atmospheric deposition of iron plays a key role in this coupling because it is a major new source of this limiting nutrient in many remote ocean regions.

The presentation section started with showing recent the United Nations Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) results; atmospheric concentrations of total iron are dominated by mineral dust sources, but combustion sources can make up the dominant labile (bioavailable) fraction in many regions (Myriokefalitakis *et al*., 2018; Ito *et al*., 2019). It was shown that water column inventories can be used to further our understanding of atmospheric deposition rates; which are currently poorly constrained (Figure 21). The presentation section finished with a discussion on how modelled cloud condensation nuclei concentrations, and hence cloud properties and radiative forcing, are likely to be most sensitive to changes in oceanic dimethylsulfide (DMS) over the Southern Ocean and Southern Hemisphere sub-tropical gyres (Mahajan *et al*.,

Figure 21: The atmospheric iron deposition discussion session. © A. Murayama

2015; Hamilton, 2017). However, the role of DMS in altering cloud albedo depends on whether it nucleates to form new particles or is lost via condensation and grows existing particles instead. The quantification of the oceanic iron residence time is a key uncertainty in linking iron deposition with ocean productivity (Tagliabue *et al*., 2017), and hence marine emissions to the atmosphere. If the dissolved iron residence time is short, on the order of several days, then localised deposition is important (Wingenter *et al*., 2004) and models will need to have high temporal resolution. However, if the dissolved iron residence time is longer, then it becomes regionally well-mixed and the link between aerosol iron deposition and marine emissions will be obscured.

During the discussion section many questions were discussed and future undertakings were proposed, with a clear overlap between the SOLAS and GEOTRACES projects motivating future collaborations. In general, more observations are needed from remote regions, more specifically over the Pacific, Indian, and the Southern Oceans. Barbados, Bermuda and Cape Verde make excellent natural laboratory sites for continuous measurement. However, as aerosol sources, distributions and properties are spatially heterogenous it is important to consider regions outside the North Atlantic. For example, new data from Australia (presented in the poster session by Morgane Perron) showed that the magnitude and solubility of iron emissions from fires is likely to be underestimated over the Southern Hemisphere.

Laboratory studies will continue to be important in elucidating the impacts of different aerosol solubilization processes. In particular, it was suggested that incubation experiments can be used to understand the role of ligands in aerosol iron solubility or in varying the supply of N/P/Fe to determine production rates of marine aerosols and precursor gases. Other novel ideas such as the use of biogeochemical sensors on ARGO floats and ocean gliders, and aircraft measurements were highlighted. Investigating the iron limitation tipping point in different models could also help in quantifying the importance of different processes that can be further investigated in the field or laboratory.

Finally, beyond iron, other metals (e.g., cobalt or copper) are co-limiting nutrients or toxic to primary producers. While oceanic distributions of biologically-essential dissolved trace elements (including Mn, Fe, Co, Ni, Cu, Zn, and Cd) are now freely available from the GEOTRACES 2017 Intermediate Data Product, atmospheric emission and deposition inventories are still sparse (Mahowald *et al*., 2018).

Standardising lab and field experiments dealing with aerosol solubility and bioavailability was discussed. To aid this Bill Landing and Peter Morton (both at Florida State University) have been distributing subsamples of a large batch of ultra-fine Arizona Test Dust (ATD, a mineral dust surrogate) to people doing such research, encouraging them to report their measurements of total and soluble trace element concentrations and to use it in incubation experiments. They expect to submit a paper later in 2019 summarising the analytical results and promoting ATD as a “consensus reference material”. It would be useful to expand this type of collaboration to include “reference” aerosols from anthropogenic combustion sources, ship’s exhaust, biomass burning, etc. which also deliver trace elements to the oceans.

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Oceanic greenhouse gases: The present situation and future initiatives

Conveners: Parv Suntharalingam [a], Arne Koertzinger [b], and Guiling Zhang [c]
Rapporteur: Yassir Eddebbar [d]

[a] University of East Anglia, United Kingdom. Contact: p.suntharalingam@uea.ac.uk
[b] GEOMAR Helmholtz Centre for Ocean Re-search Kiel, Germany. Contact: akoertzinger@geomar.de
[c] Ocean University of China, China. Contact: guilingzhang@ouc.edu.cn
[d] Scripps Institution of Oceanography, USA. Contact: yeddebba@ucsd.edu

The aims of this SOLAS Theme 1 discussion session were to provide an overview of SOLAS-relevant greenhouse gas (GHG) related activities, and to identify and prioritize key areas of future research. A specific session aim was also to provide recommendations from the SOLAS community to the new Intergovernmental Oceanographic Commission (IOC) Working Group on Integrated Ocean Carbon Research, a joint program initiative sponsored by the Climate and Ocean-Variability, Predictability, and Change (CLIVAR), the Global Carbon Project (GCP), the Integrated Marine Biosphere Research (IMBeR), SOLAS, the International Ocean Carbon Coordination Project (IOCCP), and the World Climate Research Programme (WCRP). The session began with an introductory presentation on ongoing GHG observational and synthesis activities (e.g., Surface Ocean CO_2 Atlas (SOCAT), the MarinE MethanE and NiTrous Oxide database (MEMENTO), and the Surface Ocean pCO2 Mapping intercomparison (SOCOM)). Key questions for SOLAS-relevant GHG research were then posed, including: (1) Are we making oceanic GHG measurements in the right places? (2) Which surface ocean biogeochemistry-climate feedbacks should be priorities for investigation? (3) What are the significant modeling challenges in estimating ocean-atmosphere GHG fluxes on regional and global scales?

A lively discussion ensued among the ~40 participants (Figure 22) in which the following issues were highlighted:

a) Despite recent observational campaigns and synthesis efforts, relevant ocean biogeochemical variables are under-sampled in the open ocean and in regions especially critical for GHG fluxes; these regions include the polar oceans, coastal and marginal seas, and coastal upwelling zones (e.g., the Northwest Arabian Sea). It was noted that autonomous sampling technologies (e.g., Bio-Argo) can help alleviate under-sampling in the open ocean, but are less effective in polar and coastal regions.

b) Significant open questions remain in predicting how future oceanic GHG fluxes will evolve in response to changing physical and biogeochemical processes in the surface ocean. Participants discussed the need for greater understanding of the links between ocean physical and biogeochemical variability, the role of decadal variability in ocean circulation, and the impacts of multiple-stressors (e.g., warming, ocean deoxygenation, and acidification) on GHG sources and sinks. Large ensemble modeling efforts provide powerful tools to address prediction of GHG fluxes, but are often limited by insufficient links to observations and incomplete mechanistic understanding of the biogeochemistry.

The above issues led to a broader discussion on the need for improved integration of currently available oceanic GHG measurements (e.g.,

Figure 22: Participants in the Greenhouse Gases discussion session. © A. Murayama

CO_2, N_2O, CH_4) together with relevant biogeochemical measurements (e.g., oxygen, nutrients) in consistent and accessible databases that could provide improved support for GHG data analyses and model simulations.

The session concluded with a discussion on evaluating the impacts of multiple environmental changes on marine ecosystems and GHG fluxes. Previous efforts have focused on perturbation experiments such as manipulated laboratory culture studies, and multiple-mesocosm analyses. Participants highlighted the need for also exploiting 'natural laboratories' (e.g., in regions of distinct biogeochemical gradients such as ocean eddies, or following climate and ecosystem perturbations induced by volcanic eruptions) to investigate the response of marine GHG flux changes to multiple environmental stressors.
We thank all participants for their contribution to a productive session, and note that many of the issues raised in the discussion align well with the GHG Theme 1 priorities outlined in the SOLAS 2015-2025: Science Plan and Organisation (Breviere *et al*. 2016).

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Lumi Kinjo majors in Chemistry at Wellesley College, Wellesley, USA. She studies air-sea gas exchange using noble gases as part of the Stanley laboratory at Wellesley College. Her undergraduate thesis work was based on experiments conducted at the SUrge Structure Atmospheric InteractioN (SUSTAIN) wind-wave tank at the University of Miami, USA. She is excited to go on her first research cruise this summer.

Measuring noble gas fluxes at high wind speeds in the SUSTAIN wind-wave tank

Kinjo, L. [a]*, Alt, H. [a], Kopp E. [a], Aldrett, D. [a], Krevanko, C. [a], Wyatt-Smith, A. [b], Haus, B. [b], Stanley, R. H. R. [a]

[a] Wellesley College, Wellesley, USA
[b] University of Miami, Miami, USA

* lkinjo@wellesley.edu

Gas exchange at high wind speeds is not well understood—few studies have been conducted at wind speeds above 20 m s^{-1}, and significant disagreement exists between gas exchange models at high wind speeds. In particular, the flux due to bubbles is not explicitly included in many gas exchange models, even though bubble-mediated gas exchange becomes increasingly important at higher wind speeds. The goal of my project is to quantify air-sea gas exchange under high wind speeds and to examine the relationship between noble gas measurements, bubble spectra, wave-type, and water temperature. Noble gases serve as excellent tracers for this purpose, as they are biologically and chemically inert, and have a wide range of solubility and diffusivity that responds differently to physical forcing (Stanley and Jenkins, 2013).

Over the course of five days in July 2018, we conducted 35 experiments at the SUrge Structure Atmospheric InteractioN (SUSTAIN) wind-wave tank with wind speeds at U_{10} = 20 - 50 m s^{-1} (5 m s^{-1} increment), water temperatures at 20, 26, and 32 °C, and wave conditions including uniform (regularly breaking) waves and JONSWAP (random) waves. Continuous Ne, Ar, Kr, and Xe ratio measurements were obtained by a Gas Equili-

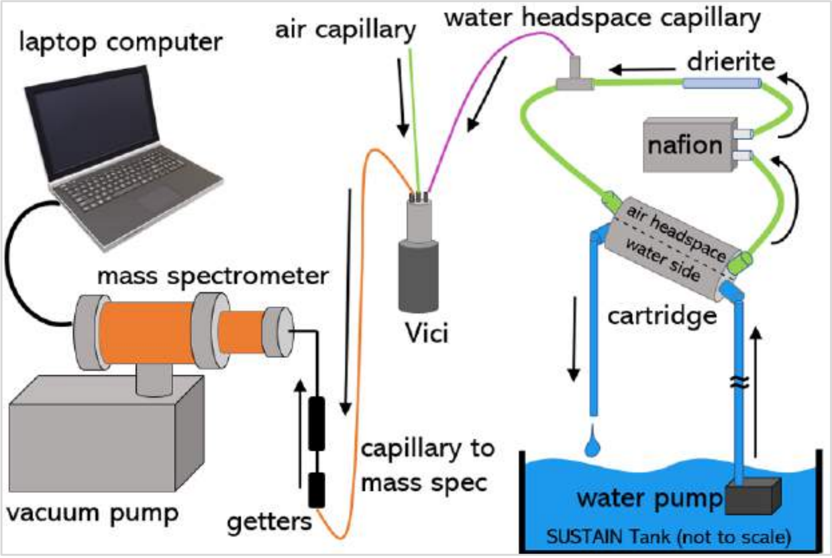

Figure 23: Schematic of the Gas Equilibration Mass Spectrometer (GEMS) instrumental set-up (not drawn to scale).

bration Mass Spectrometer (GEMS) (Figure 23). Additionally, discrete noble gas measurements were collected at the beginning of select experiments and at the end of all experiments for He, Ne, Ar, Kr, and Xe. Bubble size and volume spectra were obtained using an underwater shadowgraph imaging device. Other physical measurements such as continuous salinity, water temperature, wind/wave velocities, and atmospheric pressure were also obtained.

Our result from the conditions with the highest saturation anomalies suggests that steady state saturation anomalies of gases level off as wind speed increases (Figure 24). Additionally, both the temperature dependence of noble gas saturation anomalies and the coherence between bubble surface area spectra and saturation anomalies suggest that partially dissolving bubbles may have an important flux contribution at higher wind speeds.

As the next step, we will construct a box model to calculate the gas fluxes and steady state saturation anomalies of the noble gases in order to quantitatively explore the relationship between gas flux, bubble spectra, and wind speed. A few studies conducted at high wind speeds showed that gas flux increased dramatically as wind speed increased (McNeil and D'Asaro, 2007; Iwano *et al*., 2013; Mesarchaki *et al*., 2015). Therefore, it will be interesting to see the response of the gas transfer velocity to the different wind and wave parameters. We also will examine how other physical measurements such as wave height, wave spectral slope, turbulent kinetic energy, etc. affect both diffusive gas exchange and bubble-mediated gas exchange.

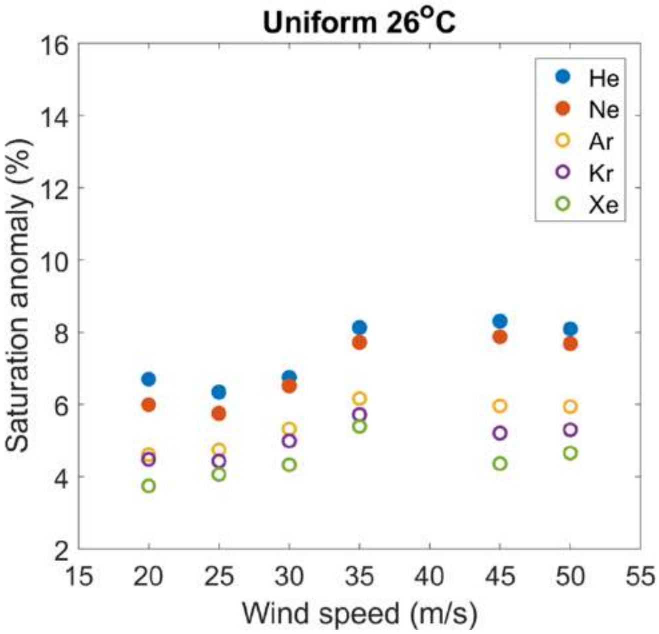

Figure 24: Saturation anomalies of five discrete noble gases (He, Ne, Ar, Kr, and Xe) from the end of each experiment in the SUSTAIN tank are plotted as a function of wind speed for experimental condition with uniform waves and water temperature at 26℃.Saturation anomalies level off as wind speed increase.

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Acknowledgements

I am very grateful to my advisor Professor Rachel Stanley for her mentorship and encouragement. I would also like to thank the National Science Foundation (Grant OCE-1634467), and Wellesley College for their generous support.

George Manville completed his undergraduate degree and masters in Ocean Sciences at the University of Liverpool, United Kingdom, in 2015. He started his PhD in 2018 at the University of Exeter, United Kingdom, to investigate whether natural marine aerosols, notably dimethylsulfide (DMS), can be used to explain Southern Ocean climate.

Spatial variability lengthscales of surface ocean dimethylsulfide (DMS) concentrations in mid-high latitudes

Manville, G.[a*], Bell, T. [b], Halloran, P. [a], Mulcahy, J. [c], Majahan, A. [d], Saltzman, E. [e]

[a] University of Exeter, Exeter, United Kingdom
[b] Plymouth Marine Laboratory, Plymouth, United Kingdom
[c] Met Office, Exeter, United Kingdom
[d] Indian Institute of Tropical Meteorology, Pune, India
[e] University of California Irvine, Irvine, USA

* gm441@exeter.ac.uk

Dimethylsulfide (DMS) makes a significant contribution to natural marine aerosol by adding mass to existing particles or forming new ones. These sulphate particles can scatter light and, as cloud condensation nuclei (CCN), can modify cloud optical properties and alter the Earth's radiation budget (Charlson *et al*., 1987). The role of climate-active biogenic aerosols, such as those formed by DMS emissions, on modulating the radiative balance, is the largest source of uncertainty in the latest global climate projection estimates (Boucher *et al*., 2013).

DMS is ubiquitous in marine surface waters, however its temporal and spatial distribution are highly variable and hard to predict due to complex biological processes that control its production and consumption (Asher *et al*., 2011). The most widely used DMS climatology, produced by Lana *et al*. (2011), herein referred to as L10, applies a large-scale smoothing, with a radius of 555 km. The radius of influence is the area over which interpolation between measurements is applied in L10, largely due to a sparsity in global DMS concentration measurements. The L10 climatology is used by a number of coupled earth system and climate models, either to validate DMS concentrations or to directly determine DMS input into the atmosphere. This is of critical importance because the amount and distribution of preindustrial DMS emissions determines the sensitivity of climate models to anthropogenic aerosol.

DMS concentration variability coupled with a large-scale smoothing approach combine to create uncertainty in the estimates of global DMS concentration distribution and ocean–atmosphere fluxes produced by L10. Improving understanding of the spatial variability of seawater DMS will help improve climatological flux estimates. High frequency data enables an assessment of the variability lengthscale (VLS) of DMS (Royer *et al*., 2015). VLS indicates the pre-

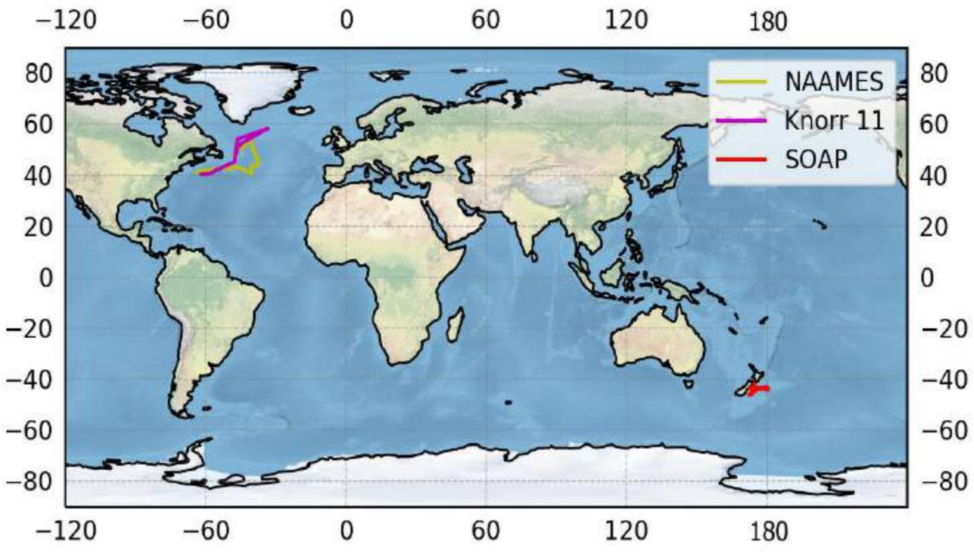

Figure 25: Map showing cruise transect locations.

dictability of spatial DMS concentration distribution, over increasing interpolation distances (Tortell *et al*., 2011). We use high frequency data (max. distance between samples: 1-2 km), including measurements made using a chemical ionization mass spectrometer (CIMS) (see Bell *et al*., 2015; Saltzman *et al*., 2009 for details) from cruises during NAAMES (North Atlantic Aerosol and Marine Ecosystem Study) and SOAP (Surface Ocean Aerosol Production study), to assess the VLS in high latitude environments at different stages of the seasonal cycle. Figure 25 shows the cruise transect ship tracks.

The Knorr 11, NAAMES, and SOAP cruise datasets are broken into underway (ship speed >4 ms^{-1}), continuous transects. A binning scheme applied to each transect produces average DMS concentrations which, when interpolated back to the original data resolution, are associated with interpolation errors. Calculating the mean squared error (MSE) between interpolated and original data at each interpolation distance, produces a linear relationship between MSE and increasingly coarse binning distance, up to an inflection point in the regression. The point at which the linear relationship breaks down indicates the point at which MSE can no longer be predicted as a function of interpolation distance, and defines the characteristic VLS for DMS. Figure 26 is an example VLS plot for one of the transects from the Knorr 11 cruise dataset. This is repeated for each transect, and for each data set. The distribution of VLS values within, and between, cruise datasets is analysed, and mean VLS values for each cruise taken. Despite differences between the three cruises (seasonality, location, spatial resolution, cruise style), mean DMS VLS is similar between datasets, with a range of just 3 km between mean values.

The example plot provided in Figure 26 highlights how DMS varies over as little as ~4 km in the North Atlantic. At even <10 km scale, climatological products that apply smoothing, averaging and interpolation techniques are likely to miss much of the small-scale variability. The use of a 555 km radius of influence in L10 for example, is simply too coarse to resolve many of the

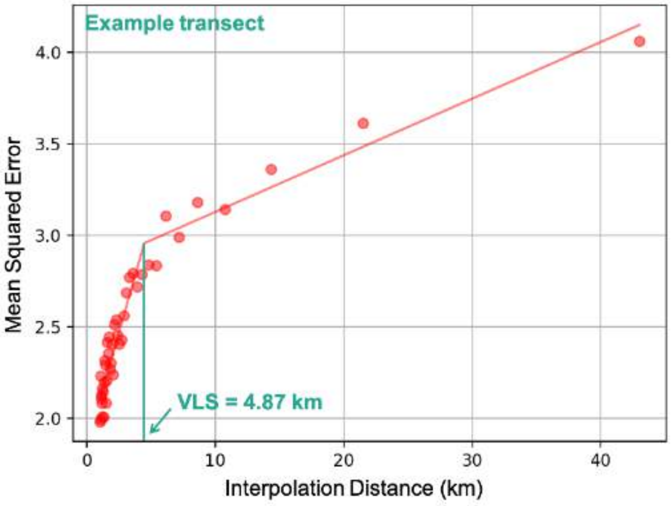

Figure 26: DMS interpolation mean squared errors (MSE) as a function of interpolation binning distance (km).

mesoscale and sub-mesoscale processes and short-lived patches of biological activity that occur ubiquitously in the surface ocean. The understanding of these small-scale processes, and the spatial lengthscales over which they vary, may prove key in understanding the biological and physical drivers of DMS production and emission.

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Hannah M. Horowitz studied Earth and Planetary Sciences at Harvard University (BA, PhD). Since 2017, Hannah has been an National Science Foundation and Joint Institute for the Study of the Atmosphere and Ocean postdoctoral fellow at University of Washington, USA, researching the climate and chemistry impacts of sea salt aerosol in two contexts: blowing snow in polar regions and marine cloud brightening.

Blowing snow sea salt aerosol emissions and radiative effects

Horowitz, H. M.

University of Washington, Seattle, WA, USA

hmhorow@uw.edu

Evidence from ice cores (e.g., Wagenbach *et al*., 1994; Rankin and Wolff, 2003) and atmospheric observations (e.g., Huang and Jaegle, 2017) suggests that blowing saline snow on sea ice is a major source of sea salt aerosol in polar regions. This source is not represented in climate models. In addition to aerosol-radiation and -cloud interactions, sea salt aerosols release reactive halogens that destroy ozone and increase the atmospheric lifetime of methane. Blowing snow sea salt aerosol in particular is smaller in size than open ocean sea salt (Yang *et al*., 2008), meaning it can also be transported farther distances. In my postdoctoral research, I am quantifying the climate-atmospheric chemistry feedbacks of blowing snow sea salt aerosol in the present-day and future climate under changing sea ice conditions. The fate of blowing snow sea salt emissions under climate change is unclear, as declining sea ice cover decreases emissions, while younger ice and thinner snow cover increase emissions by increasing snow salinity (Krnavek *et al*., 2012; Nandan *et al*., 2017). To address this, I simulate blowing snow sea salt aerosol under present and future climate scenarios within the Community Earth System Model (CESM2.1). I have implemented size-dependent blowing snow sea salt aerosol emissions based on Huang and Jaegle (2017) into the 4-mode Modal Aerosol Model (Liu *et al*., 2016) within the atmospheric component (CAM6). To calculate present-day radiative effects from blowing snow sea salt, I have performed historical atmospheric simulations from 1997 - 2010 (following 2 years of spin-up time) at 1° resolution with prescribed historical sea surface temperatures and sea ice fraction and satellite phenology for the land surface.

Figure 27 shows preliminary model results for sea salt aerosol emissions from blowing snow in the Arctic during winter 2009. With the addition of blowing snow sea salt aerosol, shortwave cloud forcing, longwave cloud forcing, aerosol optical depth (AOD), cloud liquid water path, and downwelling longwave flux at the surface all increase in absolute magnitude in the wintertime Arctic, with largest changes in shortwave cloud forcing (10.9%; from -1.63 to -1.83 W m^{-2}) and longwave cloud forcing (20.7%; from 10.6 to 13.3 W m^{-2}). In the Antarctic, smaller changes in wintertime cloud forcings are seen (shortwave: -1.48 to -1.52 W m^{-2}; longwave: 12.3 to 13.0 W m^{-2}), with negligible changes in downwelling longwave flux at the surface; AOD and cloud liquid water path decrease. I am still investigating the processes behind the changes in AOD and cloud liquid water path over Antarctica, which are opposite of those seen over the Arctic.

I am currently evaluating simulated present-day sea salt aerosol concentrations against surface, ship, and satellite observations. Ultimately, I will quantify the change in blowing snow sea salt aerosol concentrations and radiative effects under climate change in polar regions. To do this, I am developing a new parameterization of surface snow salinity as a function of snow depth and sea ice surface salinity based on observations of hundreds of vertical profiles of snow salinity. In implementing this parameterization in CESM, I will couple additional processes between the dynamic sea ice and snow model (CICE5) and the atmosphere model (CAM6) and allow simulated surface snow salinity to respond to changes in sea ice and snow properties for the first time.

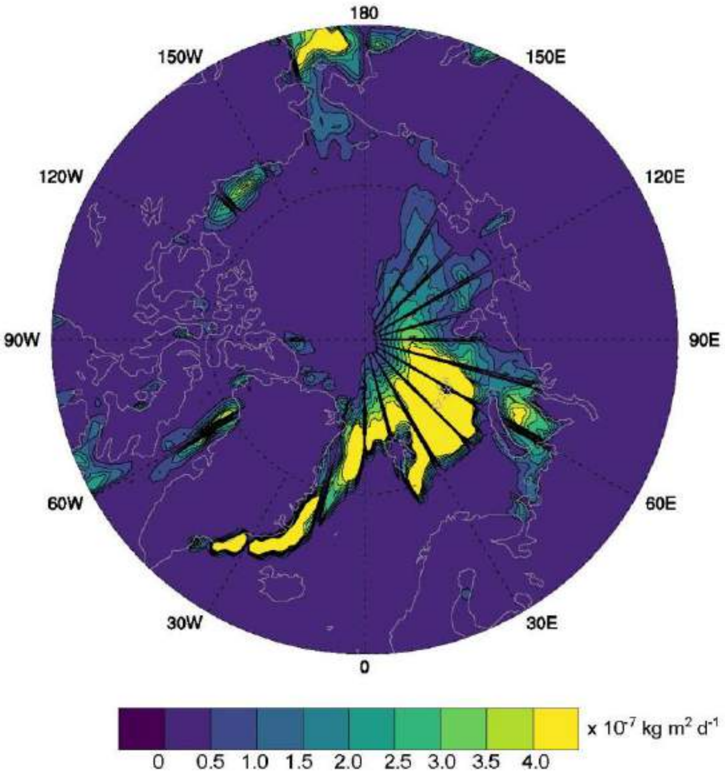

Figure 27: Modelled sea salt aerosol emissions from blowing snow (10^{-7} kg m^{-2} d^{-1}) in the Arctic in winter 2009.

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Stephanie Schneider studied chemistry at the University of Alberta, Canada, before moving to Toronto, Canada, to pursue her PhD in environmental chemistry in 2017. Her current PhD project focuses on the chemical mechanisms which release volatile organic compounds from the sea-surface microlayer.

Formation of secondary aerosol from the oxidation of T. pseudonana cultures

Schneider, S.[a*], Collins, D. B.[b], Abbatt, J. P.D.[c]

[a] University of Toronto, Toronto, Canada
[b] Bucknell University, Lewisburg, USA
[c] University of Toronto, Toronto, Canada

* steph.schneider@mail.utoronto.ca

The sea surface microlayer (SML) is an important mediator of the interaction between the bulk aqueous phase of the ocean and the gaseous phase of the atmosphere. Field observations in the Canadian Arctic during the Canadian Network of climate and aerosols (NETCARE) campaign found evidence of this interaction from the presence of gas-phase organic species originating from secondary marine source. (Abbatt *et al*. 2019) For example, increased concentrations of secondary oxygenated volatile organic compounds (VOCs) correlating with an enriched SML suggests chemical mechanisms, such as photochemistry or heterogeneous oxidation, are likely the cause (Mungall *et al*. 2017). While the photochemical production of VOCs from the SML is known (Ciuraru *et al*. 2015), the heterogeneous oxidation of the SML has been less well studied. The formation of gas-phase carbonyls is observed from the oxidation of linoleic acid monolayers and natural SML samples with ozone (Zhou *et al*. 2014), however it is difficult to determine the identity and abundance of precursor compounds to this reaction.

The sources of VOCs to the atmosphere are important to understand, as they can undergo further oxidation in the atmosphere and condense into the liquid or solid phase to contribute to aerosol mass. The relative organic composition of aerosol is an important factor in determining the likelihood of the aerosol acting as a cloud condensation nuclei or an ice nuclei, which can lead to indirect climate effects.

To answer these questions, it is important to accurately capture the complexity of the SML. (Engel *et al*. 2017) We aim to study the formation and fate of gaseous products from the oxidation of the SML with ozone, using a complex but controlled proxy for the SML. Axenic cultures of Thalassiosira pseudonana, a common diatom, are used to generate relevant organic material to simulate the biological origin of material present in the real SML (Figure 28).

We observed gas-phase products of the ozonolysis of the T. pseudonana cultures. Only mature cultures (~3 weeks old) produced significant amounts of carbonyls compared to the growth media compared to new cultures (~1 week old). Most notably, the larger carbonyls saw the most

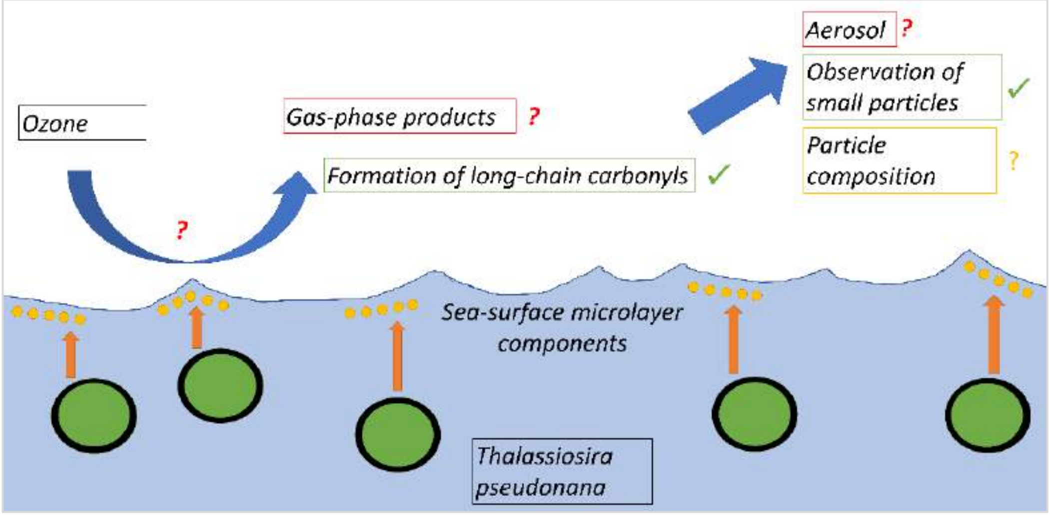

Figure 28: Schematic representing the production of organic material from T. pseudonana, its subsequent oxidation with ozone at the ocean surface, and its fate in the atmosphere to outline the project goals.

change in signal in the presence of phytoplankton cultures. Larger carbonyls are less volatile, making them more likely to condense and contribute to organic aerosol mass.

Furthermore, in initial experiments we observe the formation of ultrafine aerosol particles after oxidation of T. pseudonana cultures with ozone. Particles above our detection limit of 14 nm are observed only with mature cultures, which aligns with our gas-phase results. In later experiments, ozone was mixed downstream of the cultures to verify that primary emissions were not responsible for the reactive precursors. The absence of particle formation in this case shows that it is heterogeneous oxidation at the surface of the cultures that is responsible for aerosol and VOC formation.

This preliminary study shows that biological material from phytoplankton is reactive towards ozone. This reaction pathway can form gaseous compounds that are secondary aerosol precursors, which can contribute to aerosol growth. These results continue to help us understand the influence of chemical processes in the SML that may have contributed to atmospheric observations made during the NETCARE campaign.

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Pat Wongpan obtained his PhD from University of Otago in New Zealand and was a David Crighton fellow at University of Cambridge. He is a Japan Society for the Promotion of Science (JSPS) Postdoctoral fellow at the Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan. He is interested in sea ice–ice shelf–ocean interaction and its consequences on ecosystem.

Using under-ice transmitted hyperspectra to determine land-fast ice algal biomass in Saroma-ko Lagoon, Hokkaido, Japan

Wongpan, P.[a*], Nomura, D. [bc], Toyota, T. [a], Tanikawa, T. [d], Ishino, T. [e], Tamura, T. [e], Tozawa, M. [e], Hirawake, T. [bc], Ooki, A. [bc], Aoki, S.[a]

[a] Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan
[b] Faculty of Fisheries Sciences, Hokkaido University, Hakodate, Japan
[c] Arctic Research Center, Hokkaido University, Sapporo, Japan
[d] Meteorological Research Institute, Japan Meteorological Agency, Tsukuba, Japan
[e] School of Fisheries Sciences, Hokkaido University, Hakodate, Japan

* wongpan@lowtem.hokudai.ac.jp

The phenology of sea ice is the largest interannual variability exhibited by the Earth's surface. Land-fast ice, sea ice fasten to the coastline, is a key component of coastal ecosystems in polar regions, providing habitat for ice algal communities (Arrigo, 2017). The first-year to multiyear ice ratio in the Arctic is increasing (Maslanik *et al.*, 2011) and sea ice is thinning (Labe *et al.*, 2018) towards the predicted summer ice-free Arctic in this century. To date, the estimation of algal biomass by satellites has only applied to the unfrozen ocean using the ocean color. The ocean color cannot be used with sea ice due to the high albedo of snow hiding the 'sea ice color'. This study examines the relationships between the normalized difference indices calculated from under-ice hyperspectral measurements, and ice algal biomass for land-fast first-year ice in Saroma-ko Lagoon, Hokkaido, Japan in Spring 2019 (Figure 29). Saroma-ko Lagoon is one of the lowest-latitude areas where sea ice forms in the northern hemisphere (e.g., Liu *et al.*, 2018). Its surface area is 150 m^2 (e.g., Nomura *et al.*,

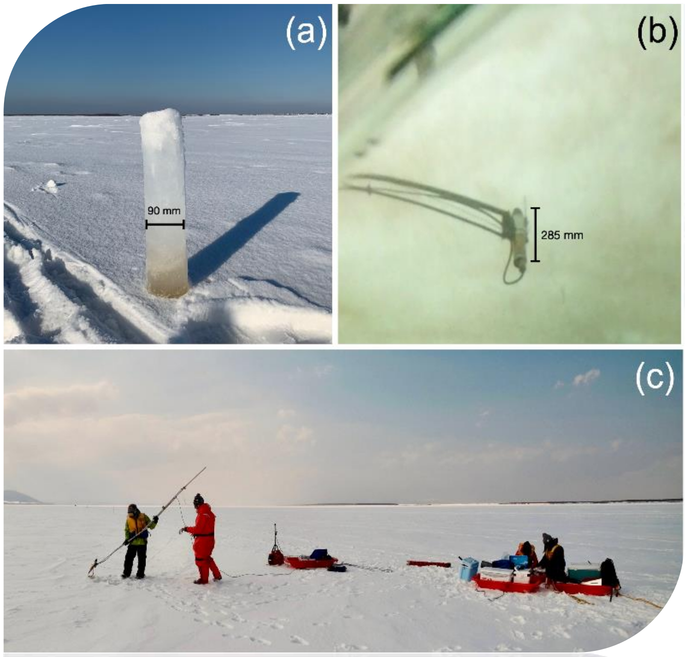

Figure 29: (a) A typical sea ice core from Saroma-ko Lagoon, Japan. (b) Under-ice irradiance sensor measuring the light transmits through snow, sea ice, and is absorbed by sea ice algae. (c) The irradiance sensor was installed through the borehole while the temperature of the drilled core was measured in concert.

2010). The methodology used in this study has been successfully applied in the Arctic (Mundy *et al*., 2007) and Antarctic (Wongpan *et al.*, 2018) land-fast ice. During the study period, we examined the physical properties of snow and ice supporting 27 paired optical and biological measurements along four transect lines across multiple scales covering over 250 m × 250 m area. The results of the under-ice hyperspectral transmittance and the integrated chl-*a* are illustrated in Figure 30. Trends between spectra and chl-*a* at typical wavelength ranges are indicated in Figure 30. This is the first step towards the algorithm development. The new observation-based algorithms can be applied to non-invasively estimate land-fast ice algal biomass which will fill the gap of monitoring sea ice algal biomass for thin first-year ice. Together with the ocean color remote sensing, our algorithms will help improve the understanding of the temporal and spatial variability of algal biomass using moorings and underwater vehicles (Meiners *et al*., 2017) focusing with the thin Arctic sea ice scenario.

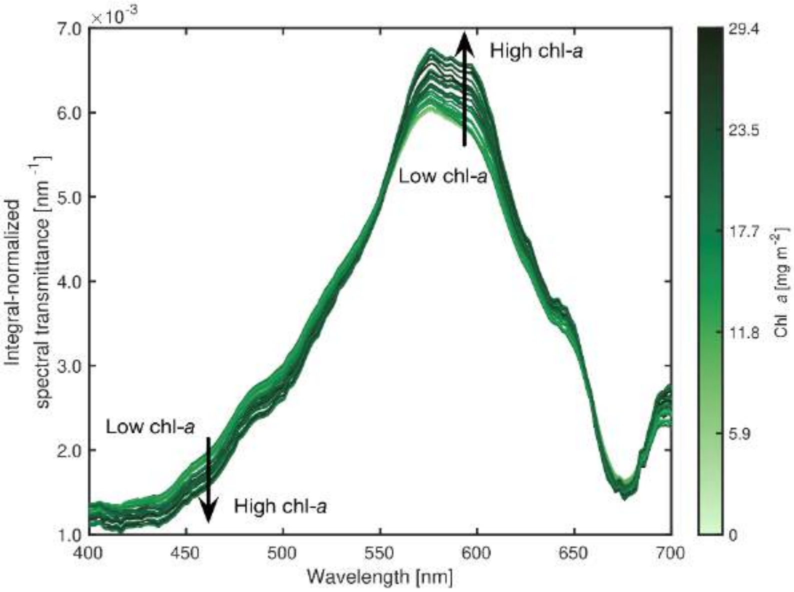

Figure 30: Results of 27 hyperspectral transmittances against wavelengths colored by integrated chl-*a* values.

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SOLAS International Project Office

GEOMAR Helmholtz Center for Ocean Research Kiel, Germany
State Key Laboratory of Marine Environmental Science, Xiamen University, China
solas@geomar.de

Editors:
Jessica Gier
Li Li