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Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII) General Meeting 2023

12-14 March 2023
La Jolla, USA and Online

Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII) is a science-driven international expert community focusing on improving our understanding of biogeochemical processes in and around sea ice and how they are impacted by climate change. BEPSII also assesses methods to observe sea-ice biogeochemical variables and processes, synthesizes available observations and develops model parameterizations. BEPSII was initiated in 2012 as a working group (WG) of the Scientific Committee of Ocean Research (SCOR) and subsequently continued with the support from SOLAS, the Climate and Cryosphere Program (CliC) and the Scientific Committee of Antarctic Research (SCAR). BEPSII meets annually, but recently moved to having an in person meeting only every second year and holding an online meeting every other year. Following the Coronavirus disease (COVID) hiatus, the group finally met in person again at the Scripps Institution of Oceanography (La Jolla, USA) on 12-14 March 2023, after the Gordon Research Conference on Polar Marine Science (Ventura, USA).

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Figure 1: Group photo of meeting attendees. Back row: Eeva Eronen-Rasimus, David Thomas, Jeff Bowman, Klaus Meiners, Antoine Haddon, Brent Else, Jo Laenger, Sebasten Moreau, Francois Fripiat, Patrick Farnole; Middle row: Emiliano Cimoli, Laura Dalman, Zoe Koenig, Lisa Miller, Daiki Nomura, Karley Campbell, Josephine Rapp; Front: Pauline Latour, Emelia Chamberlain, Nadja Steiner, Ilka Peeken, Letizia Tedesco.

BEPSII Steering Committee (SC) Early Career Researchers (ECRs) Eeva Eronen-Rasimus and Pat Wongpan organised ahead of the meeting (11 March 2023) a workshop to debrief on the first BEPSII sea-ice field school (organizers: Letizia Tedesco, Bruno Delille, Odile Crabeck), which was held on 14-23 May 2022 at the Canadian High Arctic Research Station (CHARS) in Cambridge Bay (Nunavut, Canada), and to discuss plans and potential improvements or changes for a potential next BEPSII sea-ice field school in 2026 at Saroma-Ko lagoon in Japan (Daiki Nomura presented the location and amenities to the ECRs and other meeting participants). Letizia Tedesco presented the results of the feedback forms filled by the students. The 2022 school was very well received with predominantly positive responses, despite a COVID outbreak within the group, which severely impacted the proceedings and ability of some students and teachers to actively participate. Suggested improvements include a group specific emergency response plan, the need to properly set expectations for work and life in a remote community with little amenities, and ideally an online pre-workshop to help clarify those expectations. It was also noted that combining the school with the ongoing Measuring Essential Climate Variables in Sea Ice (ECV-Ice) intercomparison experiment at CHARS (to save on funding and reduce carbon emissions) left insufficient room for some of the teachers involved in the ECV-Ice experiment to interact with the students. The learning-content was generally approved with suggestions of more field work as well as local engagement (which was planned but didn't happen due to the COVID outbreak at the school). The school received about 40k EUR in funds through: the International Arctic Science Committee (IASC), CliC, ECV-Ice, the National Science Foundation (NSF), SCAR, SOLAS, and Polar Knowledge Canada. Several videos, podcasts, interviews and pictures of the school are available on the dedicated BEPSII webpage (bit.ly/3HzQKy8).

The general meeting started off with a class on effective communication for scientists, which

ranged from giving presentations to creating websites, Twitter posts, media interviews, etc., and then moved into discussions of active and completed projects. Multiple data compilations, papers and reports have been identified, and are in various stages of completion. We highlight here a few of the larger joint group efforts that are currently being finalized.

1. Sian Henley reported on the circumpolar data compilation of macronutrient biogeochemistry in Antarctic land-fast sea ice, which was 4 years in the making and is now in revision with Marine Chemistry. The compilation includes 245 fast-ice cores from 1997-2021. The data show a discernible seasonal cycle, and an overall trend of seasonal drawdown when Chlorophyll *a* (Chl *a*) increases, but overall accumulation in November/December. It covers platelet ice and interstitial waters where platelet ice shows overall higher values than seawater.

2. In combination with a data synthesis of dissolved inorganic carbon (DIC) and total alkalinity (TA) in sea ice, BEPSII is re-visiting sea-ice carbon pump research (lead Sebastien Moreau). Data come from about 400 ice cores which cover almost the entire annual cycle and allow a comparison between Arctic and Antarctic sea ice. Results show the impacts of desalination throughout the season and colder ice in the Arctic. The observations show some correspondence between TA and salinity, but also clear divergences. The carbon chemistry was re-calculated based on updates in recent years and includes a focus on the temporal evolution of carbon processes in brine including ikaite formation and dissolution.

3. The Ice Algae Model Intercomparison Project phase 2 (IAMIP2) compares simulations of ice algal phenology in a changing climate from various models, which have been run with coordinated forcing. Several groups are participating, and analyses of historical and future runs are now in progress. Interested groups are invited to join (IAMIP contact, lead Hakase Hayashida).

The meeting included the final meeting of SCOR WG ECV-Ice. The leads Daiki Nomura, Brent Else and Francois Fripiat summarised the method intercomparisons that have been performed throughout the lifetime of ECV-Ice, including the first results from the intercomparison project at CHARS in April-June 2022. Several historical data collations are linked to ECV-Ice and results were presented for the world-wide compilation of air-sea ice carbon dioxide (CO_2) flux with the enclosure method (lead Daiki Nomura). Results indicate good correspondence among the various enclosure systems. The data include comparisons across the season and between the Arctic and Antarctic. Finalisation of the data compilation is delayed to allow the inclusion of data from the Multidisciplinary Drifting Observatory for the Study of Arctic Climate (MOSAiC) experiment. This also holds for the sea-ice Chl (lead Ilka Peeken, Alfred Wegener Institute) and sea-ice primary production (lead Rosalie Dawn Mckay, University of Tromso) data compilation. A comprehensive compilation of Antarctic dissolved and particulate organic carbon (DOC/POC) is also in progress and will be led by Laura Dalman (PhD student, University of Tasmania). Multiple ECV-Ice papers have been published and many more are in progress. The working group provided a big boost to our understanding of how to measure sea-ice biogeochemical variables and greatly supported data compilations in alignment with BEPSII's goals. BEPSII's outlook is very good as there is a lot of enthusiasm for the synthesis work, however it was noticed that more data compilations/meta-analyses are still needed, especially in the Arctic.

Together with SOLAS, a hybrid seminar was organised on new insights into polar sulfur cycling that is changing our understanding of how the polar oceans and sea ice impact atmospheric chemistry, cloud formation, and hence global climate. Besides the on-site participants, the meeting was attended by over 70 online participants. Three invited speakers presented the latest insights: Sakiko Ishino (Kanazawa University, Japan) gave an overview of the role of sea ice in atmospheric sulfur cycles; Steve Archer

(Bigelow Laboratory, USA) presented new data from the MOSAiC campaign in the Arctic; and Marti Galí (Institute of Marine Sciences, Spain) and Daniela del Valle (National Scientific and Technological Research Council, Argentina) introduced the recently established SCOR WG on sulfur compounds (Developing resources for the study of Methylated Sulfur compound cycling PROcesses in the ocean, DMS-PRO).

Nadja Steiner provided a brief update on the new SCOR WG-Coupling of ocean-ice-atmosphere processes: from sea-Ice biogeochemistry to aerosols and Clouds (CIce2Clouds) which had a successful and productive in person meeting in connection with the SOLAS Open Science Conference in Cape Town, South Africa, September 2022 (see SOLAS Event Report Issue 27). Participants reported on upcoming field campaigns with some invitations to participate or receive samples, including a sea-ice training cruise on the Norwegian research vessel Kronprins Haakon associated with the BREATHE project.

Sian Henley and Sebastien Moreau provided feedback on the BEPSII participation in the 27th session of the Conference of the Parties of the United Nations Framework Convention on Climate Change (COP27) and some discussions started on potential participation in COP28. Unfortunately, we do not expect the Antarctic perspective paper and policy brief to be ready in time for COP28.

The meeting was well attended with 30+ participants in person and about 10 participants online. There was general agreement that the meeting re-energised the collaborative spirit in BEPSII and managed well to integrate new and old early-career scientists. Those attending in person were thrilled to re-connect and discuss active research projects, data syntheses and collaborative papers, as well as go for early-morning surf sessions or afternoon swim and beach walks.

The SC indicated some reshuffling in the SC, including a replacement of Nadja Steiner (Canada) by Letizia Tedesco (Finland) as the new co-chair with Jacqueline Stefels (Netherlands). With the end of SCOR WG ECV-Ice, Francois Fripiat is stepping off the steering committee. A call for 2 new ECR representatives to replace current ECR members, Eeva Eronen-Rasimus and Pat Wongpan, will be sent out in the fall. The SC decided to dedicate the 2024 online meeting to the development of a new science plan reflecting recent science plan updates in CliC, and in support of the upcoming renewal of the SOLAS science plan. BEPSII is excited to be working on this and invites interested researchers to consider participating. As with the current SC, the leads of task groups which will be identified or re-defined in the new science plan will then form the future BEPSII SC.

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Laura Dalman is a PhD candidate at the Institute for Marine and Antarctic Studies in Tasmania, Australia investigating the physical controls of ice-associated primary production in the Southern Ocean. Her previous Master's degree and research associate position at the University of Manitoba focused on nutrient dynamics linked to tidal straits and freshwater input on Arctic sea ice algae.

Physical controls of Southern Ocean ice-associated primary production

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Sea ice covers vast areas of the Southern Ocean and exerts strong controls on the magnitude and spatial-temporal variability of Antarctic primary production. Ice-associated primary production provides a concentrated energy source for higher trophic levels and holds an important role in carbon cycling. During the winter-spring transition (bloom commencement), ice algal communities are initially light limited where growth is largely a function of snow depth due to its high albedo and attenuation properties (Mundy *et al.*, 2005). Antarctic pack ice studies suggest a seasonally changing role of snow on biomass accumulation (Meiners *et al.*, 2017), and similar controls are hypothesised for Antarctic fast ice but haven't been tested. As seasonal insolation increases, photoinhibition can occur in typically low-light adapted communities or self-shading can occur from increasing ice algal biomass (Arrigo *et al.*, 2014). Ice algae experience variable light environments and adopt coping mechanisms, by altering pigment compositions to either maximise photosynthesis under optimal conditions or implement photoprotection under high irradiances (Petrou *et al.*, 2011).

Satellite ocean colour remote sensing is unable to detect ice algae and under-ice phytoplankton blooms due to the overlying ice cover. Therefore, the current satellite-derived primary production estimates are likely underestimates. Unlike in Arctic systems, melt ponds are rare on Antarctic sea ice (Vancoppenolle *et al.*, 2013). However, the presence of snow-covered sea ice interrupted with leads may be a suitable environment to support under-ice blooms analogous to those observed in the Arctic under snow-covered ice (Assmy *et al.*, 2017). The Southern Ocean needs improved assessment of the impacts and predicted changes in sea-ice conditions on Antarctic marine primary production and Southern Ocean ecosystem function. The overarching goal of my PhD project is to better understand the physical drivers of the spatio-temporal variability of ice-associated primary production, inclusive of ice algae and phytoplankton. One aspect of my PhD focuses on understanding photoacclimation in algae throughout the sea ice profile in two regions of the Southern Ocean, and another aspect investigates under-ice phytoplankton off East Antarctica.

To tease apart the potential shifts in ice algal photoacclimation and community composition throughout the vertical ice profile, we examined two regions, the East Antarctic and the Weddell Sea (Figure 2, Dalman *et al.*, 2023). We found that early in the season algal communities are already employing photoprotection strategies by increasing photoprotective pigments and using the xanthophyll cycle (Figure 3). We investigated community composition through the vertical ice

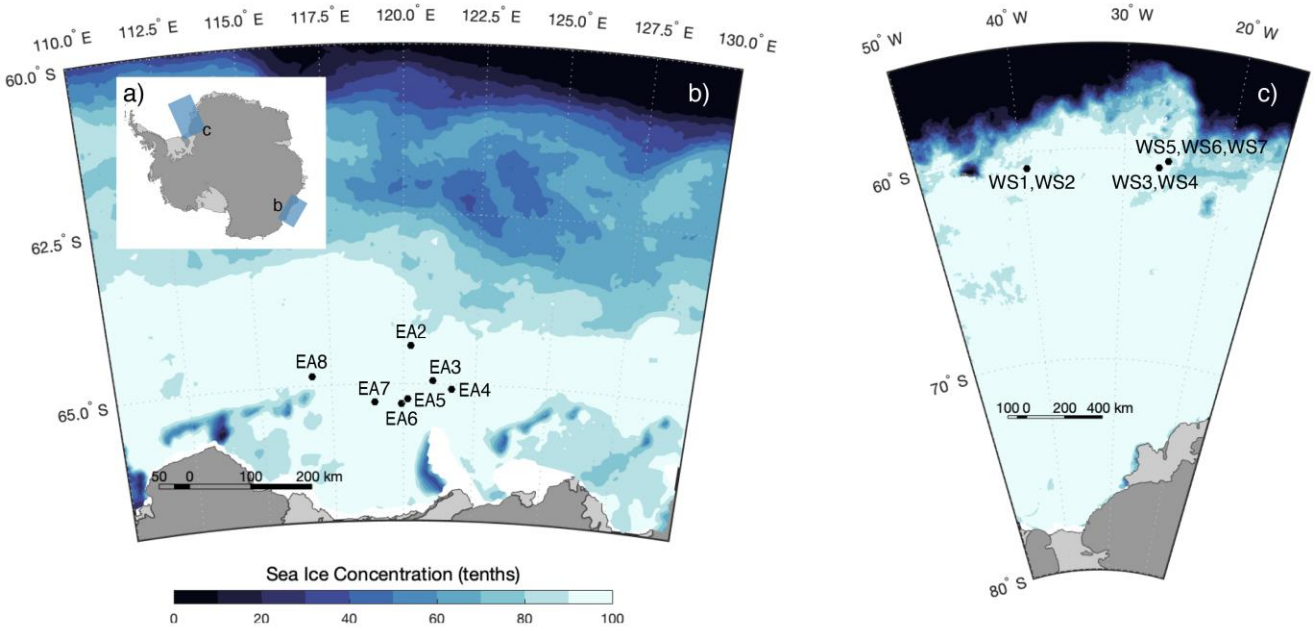

Figure 2: Map of Antarctic (a) sea ice sampling locations in East Antarctica (n = 6; b) and the Weddell Sea (n = 7; c).

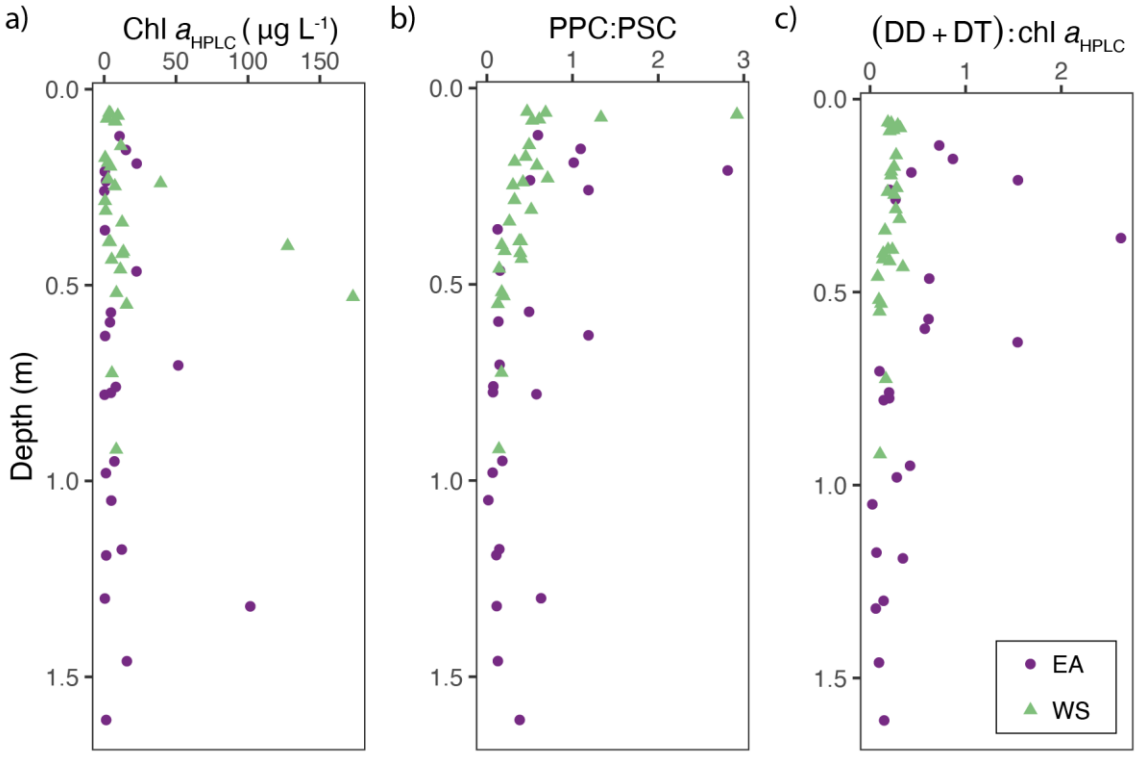

Figure 3: Pigment concentrations of Chlorophyll *a* (Chl *a*) (a), ratios of photoprotective to photosynthetic carotenoids (PPC: PSC) (b), and xanthophyll pigments to Chl *a* ((DD+DT): Chl *a*) (c) through the sea ice profile.

profile and observed that the surface horizon is typically dominated by flagellates, while the bottom communities are dominated by diatoms, specifically pennate diatoms. This suggests that these communities are better adapted to their respective light environments, but other factors may also play a role.

To understand potential under-ice phytoplankton dynamics, we utilise southern elephant seals tagged with Conductivity, Temperature, and Depth (CTD)-fluorescence sensors to investigate phytoplankton in seasonally ice-covered areas. This work will give us insight into potential under-ice phytoplankton accumulation in the East Antarctic, where we are limited in field observations and remote sensing capabilities. It fills critical gaps for surface sampling where autonomous profilers like Argo floats are unable to sample (Hague & Vichi, 2021). Gaining further understanding into these under-ice phytoplankton communities is required to understand and predict how ice-associated production may be impacted by a changing climate. Overall, these analyses will contribute to an improved assessment of the impacts of predicted changes in sea-ice conditions on Antarctic marine primary production and Southern Ocean ecosystem function.

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Manami Tozawa studied marine biogeochemistry at Hokkaido University in Japan and completed her master's degree in 2022. Manami is studying for her PhD at Hokkaido University, where she is conducting research on the carbon cycle in the polar oceans.

Quantitative assessment of factors contributing to seasonal variations in sea surface partial pressure of carbon dioxide

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The ocean has absorbed about 25% of the CO_2 emitted to the atmosphere as a result of human activities via gas exchange with the atmosphere at the ocean surface (Friedlingstein *et al.*, 2022). Especially, the Arctic Ocean and the Southern Ocean are responsible for about 10% and 40% of the total oceanic CO_2 absorption, respectively (Bates & Mathis, 2009; Khatiwala *et al.*, 2009).

Air−sea CO_2 exchange is determined by the difference in partial pressure of CO_2 (pCO_2) between the atmosphere and sea surface (Wanninkhof, 2014). Because pCO_2 in the atmosphere doesn't vary in a short time, sea surface pCO_2 determines the CO_2 flux. Sea surface pCO_2 varies due to temperature variation, dilution by freshwater, and biological activity. Several previous studies have pointed out these seasonal effects. For example, Nakaoka *et al.* (2009) indicated that the stratification and biological activity influence sea surface pCO_2. However, the effects of each factor have not been quantified.

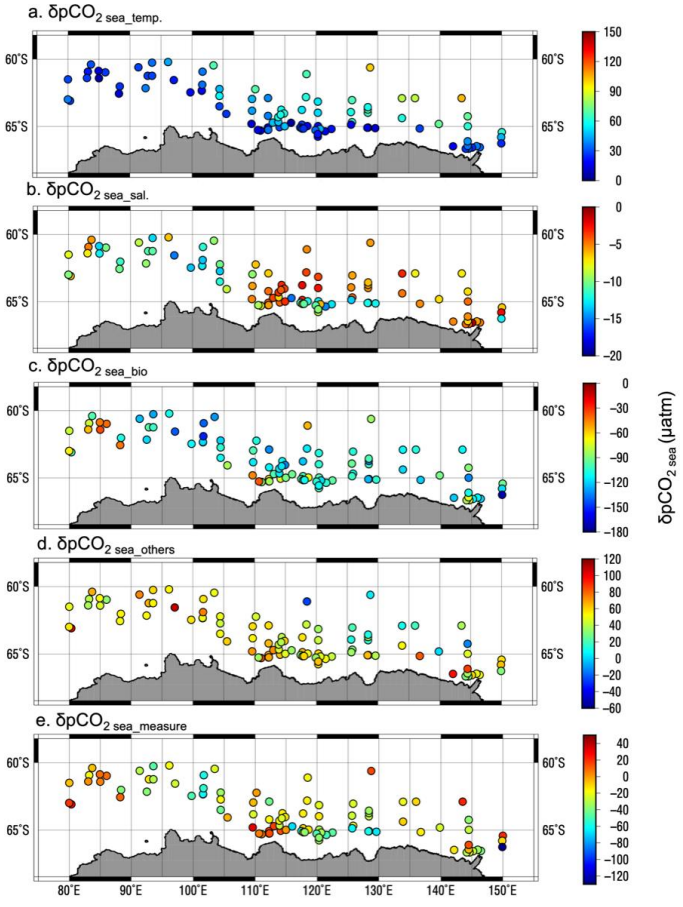

Figure 4: Spatial distribution for change in sea surface partial pressure of CO_2 ($\delta pCO_{2\ sea}$) due to (a) temperature ($\delta pCO_{2\ sea\_temp}$), (b) salinity ($\delta pCO_{2\ sea\_sal}$), (c) biological activity ($\delta pCO_{2\ sea\_bio}$), (d) other factors ($\delta pCO_{2\ sea\_others}$), and (e) measured δpCO_2 sea ($\delta pCO_{2\ sea\_winter\text{-}summer}$). SACCF: Southern Antarctic Circumpolar Current Front indicated by the dotted line. SB: Southern Boundary of Antarctic Circumpolar Current indicated by the dashed line. ASF: Antarctic Slope Front indicated by the solid line. (Tozawa *et al.*, 2022)

Tozawa *et al.* (2022) estimated the seasonal variations of sea surface pCO_2 from winter to summer in the eastern Indian sector of the Southern Ocean (south of 60˚S, 80−150˚E). We also assessed quantitatively the change in pCO_2 due to water temperature changes, freshwater inflow, and biological activity by calculating pCO_2 from changes in temperature, salinity, and carbonate chemistry (δpCO_2, Figure 4). In the western part of the study area (80−120˚E) observed from December to early January, biological activity controlled the pCO_2 distribution. On the other hand, in the eastern part (120−150˚E) observed from the end of January to February, temperature change influenced the pCO_2 distribution. These results may reflect the seasonal and regional characteristics such as phytoplankton bloom and temperature increase following the sea ice distribution.

Currently, we are trying to clear the factors of pCO_2 distributions in the Arctic Ocean with this method. However, there are many types of freshwaters in the Arctic Ocean, such as river water and snow meltwater. We need to consider the difference in the effects of each factor and improve our quantitative method.

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