SCOR Working Group Proposal on
Measuring Essential Climate Variables in Sea Ice (ECVice)

Summary/Abstract

Observations over recent decades suggest that sea ice plays a significant role in global biogeochemical cycles, providing an active biogeochemical interface at the ocean-atmosphere boundary. However, a pressing need exists to perform methodological intercalibration experiments in sea ice in order to obtain reliable measurements of basic biogeochemical properties [e.g., Arrigo et al., 2010; Miller et al., 2015], including many of the Essential Climate Variables of the Global Climate Observing System. With newly emerging techniques, and pressed by the rapid changes in sea ice, the time has come to evaluate and improve our approach to studying sea-ice systems. An international working group is required to synthesize past intercalibration exercises and to design and coordinate new experiments. Our ultimate goal is to provide the international community with standardized protocols for processing sea-ice samples and collecting data for key variables, including partial pressure of CO_2, nutrients, algal biomass and production, and gas exchange. We will also establish the effectiveness of new techniques to deal with the great heterogeneity (often referred to as "patchiness") found in sea ice. These tasks will directly serve a long-term community goal of understanding variations in polar marine environments severely affected by ongoing global change.

Scientific Background and Rationale

Sea ice is one of the largest and most dynamic ecosystems on Earth, covering ~10% of the ocean and harboring, in some locations, standing crops similar to productive oceanic regions. In addition to affecting climate through physical processes, sea ice plays a significant but still poorly understood role in the biogeochemical dynamics of the polar oceans [Vancoppenolle et al., 2013]. For example, sea ice contributes up to 60% of the primary production in some parts of the Arctic Ocean [Fernandez-Méndez et al., 2015] and 50% of the CO_2 uptake south of 50°S [Delille et al., 2014]. The algae communities that grow within and on the bottom of sea ice are a fundamental contributor of halogens and aerosols to the polar atmosphere [Abbatt et al., 2012], and the role of sea-ice brine rejection in the global overturning circulation spreads the impact of sea-ice biogeochemical processes throughout the world ocean.

The Global Climate Observing System (GCOS) program has developed a list of essential climate variables (ECVs) and called for systematic observations of these critical variables, in order to support assessment of climate changes. The ECVs have been identified based on relevance for characterizing the climate system and its changes, while maintaining feasibility and cost effectiveness. In the ocean domain the ECVs are: temperature, salinity, sea level, sea state, sea-ice concentration, currents, ocean color, carbon dioxide partial pressure, ocean acidity, nutrients, oxygen, phytoplankton, and tracers. However, GCOS has not been able to provide adequate guidelines for measuring the ECVs in sea ice, a gap this working group will address for a number of variables.

Analyzing biogeochemical properties in sea ice is fundamentally complicated by its inherent heterogeneity and multiphase nature (composed of solid ice, brines, gas bubbles, solid mineral salts, and organic matter), which also introduce difficulties in performing biochemical incubations (which require that the sea ice be homogenized and melted), and thorough evaluations of the various methods used to study sea ice are crucially needed [Miller et al., 2015]. Sea ice is a semisolid matrix permeated by a network of channels and pores, strongly responding to variations in temperature [Golden et al., 2007]. The brine-filled spaces are colonized by sympagic (ice-associated) communities that are both taxonomically diverse and metabolically active [Arrigo et al., 2010], with multiple trophic levels, efficiently consuming, reprocessing, and redistributing chemicals within the ice and exchanging with both the overlying atmosphere and the underlying ocean. Sympagic microbial adaptations involve changes in intracellular processes, but also in extracellular controls, in particular the secretion of extracellular polymeric substances, which modify how the microbial community functions (i.e., by introducing biofilms) and the physical-chemical properties of the ice [Krembs et al., 2011; Ewert and Deming, 2013]. Traditionally, sea-ice ecological studies have been based on methods and concepts from planktonic research. However, in terms of organism distributions, fluid (and nutrient) transport, and predator-prey interactions, the seawater model is less useful than, perhaps, soils or sediments for conceptualizing the sympagic community.

Sea-ice physical, chemical, and biological properties are also extremely variable, both temporally and spatially. Spatial and temporal changes in physical properties are among the largest observed in the oceans, with temperature varying by up to 40 °C over a meter and brine salinity varying by as much as 200 over centimeters. Biomass can vary by an order of magnitude on the sub-meter scale [Eicken et al., 1991], making it difficult to (i) acquire representative measurements or (ii) compare parallel analyses on adjacent cores. In addition, because sea-ice structure is so strongly dependent on temperature, both physical and chemical properties of the ice are easily altered upon sampling or even upon deployment of in-situ sensors (which affect the energy balance).

Numerous approaches have been developed to address these concerns, and there is now a need to rigorously compare them and develop standardized protocols for assessing biological and biogeochemical parameters in sea ice. The following issues are of particularly high priority:

- *Storage of sea-ice samples* can affect measurements in ways that are still difficult to predict. Not only do melting (or even just warming) and refreezing after sampling change the samples, possibly irreversibly (i.e., brine loss, chemical speciation, mineral stability), but bacterial activity has been recorded in intact cores stored in the dark at temperatures below -20°C months after sampling [S. Becquevort, unpublished results]. Instability of the samples affects both biological properties and abiotic compounds.
- *Processing of sea-ice samples* often involves melting them, but many analytes, organisms, and processes are strongly affected by the drastic changes in temperature and salinity that results when sea ice melts [Miller et al., 2015], and quantification of those impacts has been elusive. For example, early studies showed that the drop in salinity with melting can cause losses of 13 to 97% of eukaryotic cells [Garrison and Buck, 1986], but other studies have found no such impact [Rintala et al., 2014].
- *Assessing sea-ice patchiness* and recovering representative data by traditional methods is labour intensive and confined to relatively small areas [e.g., Miller et al., 2015], as well

as largely excluding thicker and highly deformed ice categories [Williams et al., 2015]. New methods using remotely operated vehicles and non-invasive equipment [Külh et al., 2001; Mundy et al., 2007] need to be directly compared with traditional transect and nested sampling techniques.

- *Sea-ice primary production measurements* are scarce, span three orders of magnitude, and have used numerous, distinctively different methods ranging from in-situ sensors to in-vitro isotope labeling studies [e.g., Arrigo et al., 2010; Fernandez-Méndez et al., 2015], for which largely varying results are reported. In addition, preliminary comparisons between incubation protocols (i.e., using melted, crushed, or intact ice sections) for determining metabolic rates in sea-ice communities have identified large differences between treatments [A. Roukaerts, unpublished results]. Additional data need to be collected to evaluate the relative ability of these approaches to estimate sea ice primary productivity.
- *Gas flux measurements over sea ice* using chamber and eddy covariance techniques give results that differ by up to an order of magnitude. In addition to the different spatial scales of the two methods [Nomura et al, 2013], specific technical limitations of both methods impact the measurements [Miller et al., 2015]. These methodological gaps are still not yet fully understood.
- *Measurements of CO_2 partial pressure* in sea ice also use a number of different techniques that give different results [e.g., Miller et al., 2011; Brown et al., 2015], with implications for predictions of carbon release to either the atmosphere or the underlying water. Unlike more inert gases, CO_2 undergoes complex chemistry within ice brines, hydrating to form dissolved carbonate species and precipitating carbonate minerals, and different methods respond differently to that chemistry.

These problems must be solved jointly at the international level, by bringing together sea-ice specialists in these analytical fields to synthesize existing information and determine the best ways to evaluate the differences. Individual, small initiatives are not sufficient to effectively test and evaluate the methods in question, as experts in each of the techniques need to be involved. In addition, the high financial and logistical costs of working in the sea-ice environment requires extensive collaboration. By working together, we will thus be able to deliver to the international community standardized protocols for some of the basic biogeochemical parameters in sea ice.

Terms of Reference

The proposed working group will gather international experts on chemical and biological measurements in sea ice to design and coordinate the required intercomparison and intercalibration experiments. The group will synthesize the results of past experiments, identify what type of new experiments are needed, and support the community in executing those experiments.

- **Publish synthetic reviews compiled from measurements demonstrating large, unresolved discrepancies.** These detailed reviews will draw on both the literature and unpublished studies to evaluate the strengths and weaknesses related to each methodology.

- **Design and coordinate intercalibration experiments to evaluate different methods for key parameters.** In addition to organizing field experiments, we will pursue use of ice tank facilities and stimulate and support applications for funding, at both national and international levels, to further facilite the experiments.
- **Design intercomparison studies to facilitate validation and adoption of new technologies for assessing the complexity and heterogeneity of sea ice at various spatial and temporal scales.**
- **Create a guide of best practices for biological and biogeochemical studies in the sea-ice environment.** This will be accomplished using a web-based forum for compiling and disseminating the outcomes of past and new intercomparison studies.

Working plan

A representative panel of the international community studying sea-ice biogeochemistry will gather at annual meetings to discuss methodological discrepancies, determine priorities for new intercomparison experiments, and develop funding applications. As further detailed below, the primary tasks will be to (i) synthesize available intercalibration experiments, (ii) to design and coordinate intercalibration experiments, and (iii) develop standardized protocols for biogeochemical studies in sea ice. Some of these meetings will be held in conjunction with other conferences, such as the annual meetings of BEPSII (Biogeochemical Exchange Processes at the Sea-Ice Interfaces; a newly designated SOLAS-CliC (Surface Ocean-Lower Atmosphere Study; Climate and Cryosphere)) consortium or sea-ice summer schools.

Task 1: Synthesize current knowledge of discrepancies between methods (years 1-2)

Both published and unpublished studies report large discrepancies between methodologies, especially around protocols for melting ice samples, determining primary production, and measuring gas exchanges. In addition to collating available information from the literature and recent, unpublished experiments, we will attempt to develop mechanistic understandings of the observed discrepancies. The following subjects are our priorities:

- Ice storage and processing (i.e., melting protocols) for basic biogeochemical parameters: biomass, nutrients, microbial community, organic matter, carbonate chemistry, gas concentrations, and primary production.
- Gas exchanges: gas-flux chambers vs. eddy covariance methods.
- Primary Production: a comprehensive critical analysis of the perceived strengths and weaknesses of the methods used to date.

These syntheses will allow us to define the needs for further intercalibration experiments, to test and validate our concepts and assumptions about the methods.

Task 2: Design and coordinate intercalibration excercises (years 1-4)

We will design specific intercalibration experiments to produce funding applications at both national and international levels for intercalibration experiments in readily accessible sea-ice locations (Cambridge Bay, Canada (lead B.T. Else); Tvärminne zoological station, Finland (lead J.-M. Rintala); and Saroma-Ko lagoon, Japan (lead D. Nomura)), as well as joint experiments at the ASIBIA (Atmosphere-Sea-Ice-Biogeochemistry in the Arctic) mesoscale chamber facility at the University of East Anglia (lead J. France). Our initial priorities will be:

- Comparison of storage conditions and the processing of sea ice for accurate determination of basic biological and biogeochemical parameters.
- Comparison of the available methods (including emerging techniques) to assess primary production in sea ice: isotopic tracer incubations, O_2 fluxes by under-ice microelectrodes and eddy covariance, O_2:Ar budgets, and biomass accumulation. We will also assess the most suitable tracer incubation protocols for general metabolic rate determinations in sea ice (e.g., bacterial production, nutrient transformations). That is, how to collect a representative in-situ sea-ice microbial community and to ensure tracer homogenization within the brine network prior incubation.
- Comparison of the available methods for determining pCO_2 in sea ice. Preliminary experiments comparing results from in-situ silicone chambers, solid-headspace equilibration, and calculations based on analyses of brines and melts could be conducted under controlled laboratory conditions. However, complex, high-molecular weight organic matter, as well as precipitated carbonate minerals, likely impact measurements of pCO_2 in natural sea ice, and therefore, parallel intercalibration experiments will also be required at one or more of the field sites.

We hope to organize our third meeting in conjunction with an intercalibration excercise. If we are sufficiently successful in raising supplementary funding, we aim to hold that meeting in Cambridge Bay, Canada; Tvärminne zoological station, Finland; or Saroma-Ko, Japan. Otherwise, we would hold the meeting at the experimental sea-ice facility, at the University of East Anglia. Funding for access to the ASIBIA chamber facility has already been solicited through a European Research Council large consortium proposal (EUROCHAMP 2020). A funding decision for EUROCHAMP 2020 is anticipated in mid-to-late 2016.

Task 3: Produce a framework for a living guide of best practices for sea ice biogeochemical studies (years 3-4)

Throughout the lifetime of the working group, we will explore and experiment with frameworks for disseminating the evolving understandings of the best approaches to measure biogeochemical parameters in sea ice in a format that is open-access and updatable. This framework might be hosted on the BEPSII, CliC, or SOLAS websites and will include the strengths and weaknesses associated with each method. The first large-scale implementation and testing of this guide to best practices will be during MOSAIC, a one-year time-series in the central Arctic Ocean scheduled for 2019-20.

Deliverables

- Individual review papers on strengths, weaknesses, and uncertainties in the methods used to process and store sea-ice samples before analysis, as well as measurements of primary production in sea ice and gas fluxes over sea ice.
- Concrete, executable designs for intercomparison and intercalibration experiments on ice processing and storage, primary production and incubation methods, gas fluxes, and

CO_2 partial pressure of sea ice.

- Recommendations for evaluation of spatial variability in sea-ice characteristics, based on traditional transect and nested sampling strategies coupled with new non-destructive technologies.
- Web-based framework for dissemination of evolving standards of best practices.
- Sea-ice biogeochemical sampling plan and recommended protocols for the 2019-2020 MOSAiC expedition, and other programs that follow it.

Capacity Building

Reliable measurements are a necessity if we want to properly describe the changes and forcing in the global environment and climatic system, in general. Our main goal is to provide the international sea-ice research community with standardized protocols for collecting, preserving, and processing sea-ice samples. The tasks we have described contribute directly to a long-term goal of accurately sensing variations in polar regions, which are among the environments most sensitive to ongoing global change. In addition to our immediate goal of informing the MOSAIC science plan (Task 3), the protocols ECVice will develop will contribute directly to the efforts of all long-term programs coordinating research in the polar oceans, including SOOS (the Southern Ocean Observing System), SCAR (the Scientific Committee on Antarctic Research), and IASC (the International Arctic Science Committee), as well as GCOS.

Support of young scientists is in the genes of ECVice. More than half of the proposed full members are less than 35 years old. The young scientists involved in this working group have carried out pioneering work on sea ice, establishing creative new methods to assess key variables at the beginning of their carriers. With the mentorship of the senior scientists in this working group, these young scientists are in a position to discuss and refine these innovative methods to produce widely-acceptable, extensively tested standardized protocols, a prerequisite for long-term coverage of these variables. The proposed membership of the working group also includes young experts in sea-ice analyses (i.e., trace metals and genetics) which are not among our focused list of initial priorities, but have, nonetheless, been identified as requiring intercalibration and intercomparison [Miller et al., 2015]. Our hope is that association with ECVice will also help those scientists develop the approaches needed to resolve their methodological issues.

We will also pass this consolidated expertise to new scientists interested in sea ice through a collaboration with a planned international sea-ice summer school to be held in Longyearbyen, Svalbard (to be organized by the BESPII SOLAS-CliC consortium). We hope to hold one of our annual meetings in conjunction with that summer school, with working group members delivering lecturers.

We are also committed to encouraging sea-ice research in nations with emerging polar research programs. Unfortunately, polar research, including investigations of sea-ice biogeochemistry, is still largely an endeavour of wealthy nations, and this is reflected in the proposed membership list. Despite our difficulties in identifying many suitable candidates from developing nations for initial membership in this working group, we will continue to actively seek out and support new sea-ice researchers working in countries that do not already dominate in polar research. Along these lines, we hope to hold at least one of the annual meetings in Asia and include teaching activities. We also hope to invite a few young scientists from under-represented countries, including Russia, to Saroma-Ko, Japan, in conjunction with our intercalibration experiment there, for a short course to expose them to the study of sea-ice biogeochemistry (e.g., through funds from the Japan Society for the Promotion of Science, as well as other sources).

Collaboration with Arctic communities is also fundamental to sea-ice research, and our plan to hold one of our intercalibration experiments in Cambridge Bay (Nunavut, Canada) will provide ECVice with an ideal opportunity to further that collaboration. Cambridge Bay is the location of the Canadian High Arctic Research Station (CHARS), which will be completed in 2017. Once operational, CHARS will employ numerous staff researchers, many of whom will be hired from Arctic communities, who will be tasked with monitoring aspects of the Arctic marine ecosystem and cryosphere. We will integrate CHARS staff scientists into our operations to help build their capacity to accurately measure essential climate variables in sea ice. We will also report back to CHARS the results of our intercalibration experiments to help ensure that the progress we make is integrated into the long-term monitoring conducted at the station. During our work in Cambridge Bay, we will also employ student assistants from Nunavut Arctic College's Environmental Technology Program. By involving these students we will be building the capacity of Inuit scientists to lead and participate in future Arctic research activities.

Working Group composition.

Full Members

Name	Gender	Place of work	Expertise relevant to proposal
1 Daiki Nomura (co-chair)	Male	Hokkaido University, Japan	Gas concentrations and fluxes
2 François Fripiat (co-chair)	Male	Max Planck Institute for Chemistry, Germany (until June 1st 2016, Vrije Universiteit Brussel, Belgium)	Primary production and nutrient cycles
3 Brent Else (co-chair)	Male	University of Calgary, Canada	Gas fluxes, primary production, and emerging technologies
4 Bruno Delille	Male	Université de Liège, Belgium	Gas concentrations and fluxes
5 Mar Fernandez-Méndez	Female	Norwegian Polar Institute, Norway	Primary production, Microbiology
6 Lisa Miller	Female	Institute of Ocean Sciences, Fisheries and Oceans Canada, Canada	Gas concentrations and fluxes, Geochemistry
7 Ilka Peeken	Female	Alfred Wegener Institute Helmholtz Center for Polar and Marine Research, Germany	Primary production, microbiology

8 Janne-Markus Rintala	Male	University of Helsinki, Finland	Primary production and microbiology
9 Maria van Leeuwe	Female	University of Groningen, Netherlands	Primary production, microbiology
10 Fan Zhang	Female	Polar Research Institute of China, China	Microbiology

Associate Members

Name	Gender	Place of work	Expertise relevant to proposal
1 Katarina Abrahamsson	Female	Göteborgs Universitet, Sweden	Gas fluxes
2 Jeff Bowman	Male	Lamont-Doherty Earth Observatory, USA	Genetics, Microbiology
3 James France	Male	University of East-Anglia, UK	Gas fluxes Sea ice optics
4 Agneta Fransson	Female	Norwegian Polar Institute, Norway	Gas concentrations and fluxes, microbiology, nutrient cycles
5 Delphine Lannuzel	Female	University of Tasmania, Australia	Trace metals
6 Brice Loose	Male	University of Rhode Island, USA	Gas fluxes
7 Klaus Meiners	Male	Australian Antarctic Division, Australia	Primary Production, microbiology, and emerging technologies
8 Christopher J. Mundy	Male	University of Manitoba, Canada	Primary production, emerging technologies
9 Hyoung Chul Shin	Male	Korea Polar Research Institute, Korea	Microbiology
10 Jean-Louis Tison	Male	Université Libre de Bruxelles, Belgium	Gas concentrations and fluxes, physics

Working Group contributions

Daiki Nomura (co-chair): Dr. Nomura's research focuses on the carbon cycle within the ocean-atmosphere system, especially in the polar oceans. He has studied sea ice in the Southern Ocean, the Arctic Ocean, and the Sea of Okhotsk, in addition to conducing laboratory experiments on sea-ice freezing processes.

François Fripiat (co-chair): Dr. Fripiat's primary interest is in the application of stable isotopes (N, Si, C, O, …) to unravel biogeochemical cycles both in the modern and past polar oceans. He uses both natural variations of isotopes and isotopic-tracer incubations.

Brent Else (co-chair): Dr. Else's primary interests are in gas exchange across the ocean-ice-atmosphere interface, with particular expertise in the use of eddy covariance techniques, both for atmospheric and underwater gas flux measurements. His strong connections to the Canadian High Arctic Research Station and other research organizations located in Cambridge Bay will allow him to facilitate collaborative field research activities in the region.

Bruno Delille: Dr. Delille's research focuses on gases dynamics within sea ice. Since 1999, he has participated in numerous bipolar sea-ice field surveys and sea ice tank experiments, using both extractive and in-situ methods.

Mar Fernández-Méndez: Dr. Fernández-Méndez is a marine microbiologist with a special interest in carbon and nutrient uptake rates, and her current work is focused on sea-ice algae and phytoplankton primary productivity in the Arctic Ocean. She is actively involved in field campaigns every year and is engaged with development and training of early career scientists.

Lisa Miller: Dr. Miller is a classically trained analytical chemist whose research focuses on the role of sea-ice in controlling air-sea partitioning of climatically active gases. She currently serves on the Scientific Steering Committee of the Surface Ocean-Lower Atmosphere Study, as an advocate for polar research, and she was co-lead of the methodologies task group of SCOR Working Group 140 on Biogeochemical Exchange Processes at Sea-Ice Interfaces.

Ilka Peeken: Dr Ilka Peeken is trained as phytoplankton ecologist with a broad experience in the investigation of sea-ice covered pelagic ecosystems with a recent focus on the effect of climate change on sea ice biota in the Arctic Ocean. She conducted and led sea-ice field campaigns in the Arctic and is actively involved in writing the science and implementation plan of the field campaign MOSAIC.

Janne-Markus Rintala: Dr. Rintala is specialized in species identification, i.e., he has described a new cryptophytes (*Rhinomonas nottbecki*), a new dinoflagellate subspecies (*Heterocapsa arctica* subsp. *Frigida*) and a new cyst *Scrippsiella hangoeii*. In addition to field work he has been doing experimental research as well, i.e., investigating the dark survival and photosynthetic efficiencies and published a methodological comparison that is confronting the earlier methods used for melting sea ice samples. Currently he has become interested in identifying key species responsible for gas exchange and CO_2 uptake as well as DMSP production.

Maria van Leeuwe: Dr. van Leeuwe is marine biologist with a specific interest in the photophysiology of microalgae. She is currently working on the application of the stable isotope ^{13}C in tracing carbon fluxes in sea-ice ecosystems.

Fang Zhang: Dr. Zhang is marine ecologist with special interest in microbiology. Her current work focuses on sea-ice biota in the Arctic Ocean, including community composition and diversity, their environmental correlations, and gene functions.

Relationship to other international programs and SCOR Working groups

This proposed working group is a direct follow-up to a broad review of methods used to study sea-ice biogeochemistry [Miller et al., 2015], which was a product of SCOR Working Group 140 on Biogeochemical Exchange Processes at Sea-Ice Interfaces. That paper clearly identified a number of methodological uncertainties that could be resolved by further focused, international coordination. This new proposal is supported by BEPSII, a newly designated network on sea-ice biogeochemistry that is sponsored by both the Climate and Cryosphere (CliC) program and the Surface Ocean-Lower Atmosphere Study (SOLAS).

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Appendix

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