Proposal for a SCOR working group on
Biogeochemical Exchange Processes at the Sea-Ice Interfaces (BEPSII)

Climate change has a strong impact on the polar regions. Current models are inadequate to quantify the role of ice-covered oceans in climate change scenarios, which is at least partly due to a lack of the representation of biogeochemical processes. This SCOR WG has the aim to identify the feedbacks between biogeochemical and physical processes at the ocean-ice-snow-atmosphere interfaces and within the sea-ice matrix. By bringing together experimentalist and modellers, a major improvement of sea-ice biochemistry models from the micro to the global scale will be achieved.

<u>Background and rationale</u>

Near-future climate change is predicted to have its strongest impact in polar regions due to direct changes in surface area of ice sheets and open water and to subsequent feedback processes. Our understanding of these processes and the accuracy of dedicated models is still in its infancy. Due to inherently different properties of the polar regions, climate change affects the North and South Pole significantly different. In the Arctic region, both sea-ice extent and thickness are reducing rapidly, with a record low summer ice extent in 2007 and dramatic shifts from multi-year ice to first-year ice. In the Antarctic, a modest increase of the total sea-ice extent is observed, but with strong regional deviations: major reductions in sea-ice extent are observed along the west coast of the Antarctic Peninsula (Cavalieri and Parkinson 2008) with dramatic shifts in plankton biomass and diversity (Montes-Hugo et al. 2009). With these ongoing rapid changes, it is important to realize that while sea ice will not completely disappear from polar regions, it will definitively experience a profound change in seasonality with subsequent changes in its biogeochemical and physical properties.

Current global models include the seasonal wax and wane of sea ice, but restrict associated properties to only a few physical features without considering biogeochemical effects. In such models, the major climatic effects of sea ice are associated with its albedo, deep water formation and air-sea heat exchanges. In terms of gas exchange, sea ice is represented as a “lid” on the ocean surface (e.g. Stephens and Keeling 2000). In many respects, Earth System Models (ESMs) are characterized by important uncertainties in the polar regions: The observed reductions in Arctic sea ice appear to be accelerated with respect to current model forecasts (Perovich and Richter-Menge 2009); simulated primary production is systematically less realistic in polar regions compared to the rest of the ocean (Carr et al., 2006); end-of-the-century scenarios do not even agree on the sign of change of primary production in the Arctic Ocean (Steinacher et al., 2010). Also the impact on CO_2 fluxes when ice cover reduces is still unknown, with indications for both increased (Bates et al. 2006) and decreased (Cai et al. 2010) uptake. These examples not only illustrate the rapidity of the observed change, but also the difficulty of understanding and modelling the feedbacks involved in the change.

Emerging views indicate the importance of biogeochemical processes in and associated with sea ice for physical properties and exchange processes at the interfaces. Some examples:

- Sea-ice physical properties (porosity and strength) are affected by biology through the formation of exopolymeric substances (EPS) by algae and bacteria (Krembs et al. 2011).
- Trace metals, iron in particular, released from sea ice together with EPS during the spring ice melt are likely to play a pivotal role in triggering ice edge phytoplankton blooms (Lannuzel et al. 2010, Hassler et al. 2011).
- Model calculations have shown that phytoplankton blooms that occur concomitantly with the ice retreat along the Arctic coastal shelves strongly impact the Arctic climate through the trapping of

solar heat. The resulting surface warming triggers a reduction of sea-ice thickness and concentration with subsequent feedback processes (Lengaigne et al. 2009).

- The recent discovery of marine gels as precursors for cloud condensation nuclei, extends the coupling between biology and climate through the production of dimethylsulfide (DMS) to a new source of organic compounds (Leck & Bigg 2010)
- Although the mechanism remains enigmatic, sea-ice surfaces are involved in the photochemical production of reactive halogen species and subsequent destruction of ozone in the boundary layer. This has important implications for the oxidative capacity of the atmosphere and influences the atmospheric composition of trace gases (Simpson et al. 2007). Recent observation show that sea ice is also an important source for volatile organic compounds such as DMS (Tison et al. 2010), whereas areas of ice melt are sources for bromocarbons (Hughes et al. 2009). Bromocarbons may be important precursors for BrO. Since BrO oxidises DMS to DMSO, thereby reducing its potential to form cloud condensation nuclei, the potential simultaneous, biology driven, production of these volatile compounds may shed a different light on atmospheric processes, with direct consequences for current climate models (Breider et al. 2010).
- The complex inorganic carbon system in seawater is even more complex in sea ice, as extreme salinities and temperature result in precipitation of ikaite (Dieckmann et al 2008). The complexity of the brine structure, the biological activity in brines and composition of the ice will ultimately determine whether the net effect of ice will be a sink or source of CO_2 (Delille et al. 2007, Miller et al. 2011).

These are only a few examples that show the complexity of the processes we have to face when trying to understand the role of sea ice in the earth's system: processes at the micro scale have far-reaching implications for the regional to global scale. Hence, in order to understand this system it is a prerequisite that the main processes and feedbacks at each and every scale are examined from an integrated perspective. This is the aim of this working group, accomplished by active interaction between experimentalists and modellers. The experimentalists will need to assess the quality of the data that have been assembled and translate these in order to make them useful for modellers. The modellers will need to find ways to improve the flexibility of their models in order to translate processes from one scale to the other. Together they will identify, evaluate and parameterize the main biogeochemical and physical properties at the different scales, with the ultimate goal of realistically implementing polar biogeochemical processes in both ocean biogeochemistry and ESMs.

To achieve this, a multidisciplinary approach is needed. In the proposed SCOR WG, we intend to bring together sea-ice specialists from multiple disciplines and modellers of sea ice systems at the different scales, in order to:

- explore existing knowledge on the role of sea ice in influencing climate-relevant elemental fluxes,
- discuss and formulate the relevant biogeochemical processes and indentify gaps in our knowledge,
- explore and compile available field data needed for model validation, and
- stimulate integrated model development.

The primary objective of SCOR is "to focus on promoting international cooperation in planning and conducting oceanographic research, and solving methodological and conceptual problems that hinder research". These are exactly the needs of the sea-ice community. Sea-ice biogeochemistry is an emerging topic, for which the scientific community is small, not organized and spread all over the world. A SCOR working group will give a strong impulse to assembling current expertise around this highly interdisciplinary topic.

Terms of reference

The proposed working group will bring together experimentalists and modellers that each have their own and combined goals.

1. In order to evaluate currently available data of important parameters affecting sea ice physics and biochemistry and to make recommendations for further data collection needed for the validation of models, a thorough evaluation of existing and new methods is required. The need for an evaluation arises from the specific challenges involved in sea-ice studies: sea ice is a complex medium, including ice matrices, brines, gases and solid salt precipitates and it exhibits substantial variability on all spatial and temporal scales. A comprehensive review of the current state-of-the-art in sea-ice biogeochemical methodology including an assessment of their relative strengths and weaknesses will be synthesised.
2. There is an urgent need to translate relevant processes from small-scale models to global ESMs. Since investment in development time for the insertion of new mechanisms into ESMs can be high, modellers not only need to develop simplified parameterizations, but also to develop small to intermediate scale models that are able to prioritize ice biogeochemistry to climate linkages.
3. Together experimentalists and modellers will summarize existing knowledge on biogeochemical and physical processes at the ocean-ice-snow-atmosphere interfaces and within sea-ice and identify gaps in model parameterizations of these processes. This also includes recommendations for improved data collection and analysis by preferred methods for model calibration and validation.
4. From this collaboration, models will be developed that will quantify our knowledge on the impact of sea ice biogeochemistry on climate and how climate change feeds back onto sea ice.

Timeline and products

We will initially be focusing on synthesising current knowledge and identifying gaps including the comparison of methods and available model parameterisations. Based on that we will proceed to bridging gaps by developing improved parameterisations and synthesize methods. We envision the work to be supported by funding on national levels with support for international collaboration via SCOR funding.
We intend to organise special sessions during larger scientific meetings such as AGU, EGU, ASLO, IGS-sea ice conference and SOLAS-OSC. Additional funding for a 1-day discussion session preceding or succeeding an ASLO meeting will be investigated through ASLO's new Emerging Topics initiative.
At least 3 meetings are scheduled: 1. To evaluate sea-ice biogeochemical methods and formulate a guide of best practice. 2. To identify gaps in model parameterizations and make recommendations for improvements. 3. To discuss and formulate the up scaling of relevant processes in models.

A final report in the form of a special issue of a peer-reviewed journal will be published, in which the major findings of the thematic workshops are summarized and new parameterizations for coupled sea ice-ocean-atmosphere models are presented.

Relevance to other activities of SCOR or other international organizations

The initiation of a sea-ice biogeochemistry network took place during a workshop organized under the aegis of the European COST Action 735 ('Tools for Assessing Global Air–Sea Fluxes of Climate and Air Pollution Relevant Gases'; a SOLAS-related activity), 12-14 April 2011, where sea-ice specialists from Europe, Canada, USA and Australia met. During this meeting, both modellers and

experimentalists presented their work and discussed the need to form a network for future collaboration. As a result, the current SCOR proposal was formulated. It was also concluded that SCOR support may not be sufficient to achieve all our goals. Therefore, effort will be put in finding additional sources for collaboration in the coming months.
The proposed working group is closely related to the IGBP core-project SOLAS (Surface Ocean - Lower Atmosphere Study), which is co-funded by SCOR. SOLAS' primary objective is: "*To achieve quantitative understanding of the key biogeochemical-physical interactions and feedbacks between the ocean and atmosphere, and of how this coupled system affects and is affected by climate and environmental change.*" SOLAS has recently formulated several new topical areas that deserve special attention because of their urgency in global change. With this initiative, SOLAS intends to stimulate international collaboration. One of these topics concerns sea-ice biogeochemistry. The proposed SCOR WG is therefore timely and would provide an important boost for this SOLAS initiative. Funding by SOLAS itself for such activities is very limited.
It is important to mention here that this initiative intends to benefit from the momentum generated by the IPY programs. One such program is the Ocean-Atmosphere-Sea Ice- Snow Pack (OASIS) project and several of its associated investigators are listed on this working-group membership list. During the OASIS-Telluride meeting in June 2011, further collaboration will be investigated.
The research in this proposal is also endorsed by the Nordic Top-level Research Initiative (Initiativehttp://www.toppforskningsinitiativet.org/en) programme on interaction between the climate change and the cryosphere.

Working group composition

The working group members have been chosen for their expertise in studying sea-ice associated biogeochemical cycles. They are chosen such as to cover a wide spectrum of sea-ice disciplines, but with an emphasis on disciplines dealing with biogeochemistry at the ocean-ice-snow-atmosphere interfaces. Since the collaboration between modellers and experimentalists is a prerequisite for this WG to succeed, the composition of the group of full members reflects this. Members are leading in her/his field of research, are involved in many ongoing international polar programs and capable of encouraging and involving other specialists and collaborators in their field of research. We made an effort in involving young scientists in this new network of sea-ice biogeochemists. Associate members are those who have previously declared support to the SOLAS Mid-term Strategy on "Sea-ice biogeochemistry and interactions with the atmosphere".

Full members	**Institute**	**Country**	**Specialization**
Jacqueline Stefels* (chair)	Univ of Groningen	Netherlands	Ocean-ice, S-cycle
Delphine Lannuzel*[1]	Antarctic Climate & Ecosystems CRC, University of Tasmania	Australia	Ice-ocean trace metal biogeochemistry
Jean-Louis Tison*	Univ Libre Brussel	Belgium	Ice physics and gas composition
Martin Vancoppenolle*[1]	Université catholique de Louvain	Belgium/ France	Small-scale modelling, ice physics
Nadja Steiner*	IOS (Fisheries and Oceans Canada) and CCCma	Canada	Sea-ice, biogeochemical and earth system modelling
Gerhard Dieckmann*	Alfred Wegener Institute for Polar Research	Germany	Sea-ice ecology, C-cycle
Sang Heon Lee	Pusan National University	Korea	Ice and ocean prim prod
Paul Shepson	Purdue University	USA	Atmospheric chemistry, ozone, halogens
Lynn M. Russell	Scripps Inst. of Oceanography	USA	Organic aerosols
Kevin Arrigo	Stanford University	USA	Biogeochemistry, remote sensing

Associate members	Institute	Country	Specialization
Klaus Meiners	Antarctic Climate & Ecosystems CRC, University of Tasmania	Australia	Ecology, optical properties
Bruno DeLille*	University of Liege	Belgium	Biochemistry, C-fluxes
Francois Fripiat*[1]	Univ Libre Brussel	Belgium	Sea-ice, isotopic biogeochemistry
JiaYun Zhou*[1]	Univ Libre Brussel	Belgium	Gas transfer in sea ice
Jan Bottenheim*	Environm Canada, Toronto	Canada	Atmospheric chemistry, OASIS
Michel Gosselin*	University of Quebec, Rimouski	Canada	Ice biology
Maurice Levasseur	Université Laval, Québec	Canada	Ocean-ice biochemistry
Lisa Miller*	Institute of Ocean Science, Sidney	Canada	Atmospheric chemistry, CO2 fluxes
Tim Papakyriakou	University of Manitoba	Canada	ice-atmosphere gas fluxes
Michael Scarratt	Université Laval	Canada	ocean S-cycle
Gauthier Carnat[1]	Dept of Environment & Geography, University of Manitoba	Canada	Glaciologist, S-cycle
Lise-Lotte Soerensen*	Aarhus University	Denmark	air-ice exchange of CO2
Søren Rysgaard	Greenland Climate Research Centre & University of Manitoba	Greenland/ Canada	Biogeochemistry, microbiology, C-cycle
Letizia Tedesco[1]	Finnish Environment Institute	Finland	Small-scale modelling, ice ecosystems
Christine Provost*	LOCEAN, Paris	France	physical oceanography
Christoph Garbe*	University of Heidelberg	Germany	Image Processing and modelling polar regions
Michael Fischer[1]	Alfred Wegener Institute for Polar Research	Germany	C-biogeochemistry
Lars Kaleschke	University of Hamburg	Germany	Sea-ice remote sensing, atmospheric chemistry, modeling
Dieter Wolf-Gladrow	Alfred Wegener Institute for Polar Research	Germany	C- Fe chemistry, modelling
Jun Nishioka	Hokkaido University	Japan	Fe biogeochemistry, Sea of Okhotsk
Daiki Nomura[1]	Japan National Institute of Polar Research	Japan	Ice DMS fluxes
Hyoung Chul Shin	KOPRI	Korea	biogeochemistry and ecosystem processes
Veronique Schoemann*	Royal Netherlands Institute for Sea Research	Netherlands	Ocean-ice biochemistry, Fe-cycle
Maria van Leeuwe*	Univ of Groningen	Netherlands	photophysiology
Igor Semiletov	Pacific Ocean. Institute, Russian Academy of Sciences	Russia	Atmospheric CO2 and CH4 balance
Agneta Fransson*	University of Gothenburg	Sweden	Inorganic carbon dynamics
Caroline Leck	Stockholm University	Sweden	Atmospheric chemistry, aerosols
Claire Hughes*[1]	Univ East Anglia	UK	halocarbon chemistry
Lucie Carpenter	Univ of York	UK	Atmospheric chemistry, halogens
Stathis Papadimitriou	Bangor University	UK	Ice biochemistry, C-cycle, isotopes
David Thomas	Bangor University	UK	Biochemistry, nutrients, C-cycle
Roland von Glasow	Univ East Anglia	UK	Atmospheric chemistry and physics, modeling
Eric Wolff*	British Antarctic Survey	UK	palaeoclimatology, atmospheric chemistry
Stephen Ackley	University of Texas at San Antonio	USA	SCAR-Aspect, ice biogeochemistry
Clara Deal*	IARC, Univ of Alaska Fairbanks	USA	Sea-ice biogeochemical modeling
Scott Elliot*	Los Alamos Nat Lab	USA	Sea-ice and global ocean modeling
Paty Matrai*	Bigelow Laboratory for Ocean Sciences	USA	Ocean-ice ecosystem processes, S-cycle

* Participants of the COST-Action workshop, 12-14 April 2011, on Sea-ice biogeochemistry and exchange with the atmosphere.

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