Proposal for a SCOR working group on
Sea ice biogeochemistry

This WG has the aim of understanding the coupling between ice physics and biogeochemical processes at the sea-ice-atmosphere interfaces as a prerequisite to quantify the role of ice-covered oceans in climate change scenarios, in the past, present and future.

<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 polar oceans and ice sheets and to subsequent feedback processes. At both poles, climate change is already apparent in reduced sea ice extent. In the Antarctic, reductions in sea-ice cover are observed in the Bellingshausen/Amundsen seas (Cavalieri and Parkinson 2008). In the Arctic region, both ice extent and thickness are reducing rapidly, with a record low summer ice extent in 2007. The observed reductions appear to be ahead in time of current model forecasts (Perovich and Richter-Menge 2009), illustrating both the rapidity of the observed change and the difficulty of understanding and modeling all the feedbacks involved in the change.

Current global models include the seasonal wax and wane of sea ice, but restrict associated properties to only a few physical features. In such models, sea ice's main impact is on Earth's radiative balance through its albedo, on deepwater formation and on air-sea-exchange processes of gases. The latter impact refers to sea ice as a "cap" on the ocean surface (Stephens and Keeling 2000). Emerging views indicate, however, that sea ice itself plays an important role in the biogeochemical cycling and exchange of climate gases. A better understanding of these processes is warranted in order to improve climate change models and associated feedbacks. It is important to realize that sea ice may not completely disappear from polar regions, but will definitively experience a profound change in its dynamics and properties.

Sea ice as a habitat, reaction surface, source, sink and barrier for gas exchange
Sea ice is not only an active site for important and specific conversion processes, but also a source and sink for climate gases. Although the mechanism remains enigmatic, sea ice is 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). In addition, sea ice is a potential major source for the climate-cooling gas dimethylsulfide (DMS), containing concentrations of DMS and associated compounds that are 3 orders of magnitude higher than observed in the water column (Trevena and Jones 2006; Stefels and Tison manuscripts in prep.). Recent evidence also shows that sea ice can be an important sink for CO_2 through physical ($CaCO_3$ precipitation as ikaite crystals (Dieckmann et al. 2008)) and biological processes (Delille et al. 2007). Several other trace gases have been measured in high concentrations at the ice edge, but the exact processes, in-ice and in-water, are largely unknown.

By definition, biology is the source of (volatile) organic compounds and the important role of sea ice can at least partly be explained by the high algal biomass found within confined ice layers. In Antarctic sea ice, high biomasses may be due to high in-ice iron concentrations, with concentrations an order of magnitude higher than in the underlying water (Lannuzel et al. 2007). Especially in the Arctic were sea ice is formed close to land, sea ice can become in important vehicle for capturing and concentrating material that originates from land and is transported through the atmosphere. This highlights another important role of sea ice in biogeochemical cycles, namely the seeding of surface waters with nutrients, iron and potentially other trace elements upon seasonal ice melt. As a result, such sea ice-influenced surface waters act as a CO_2 sink, which is irrespective of the sink within the ice itself (Arrigo et al. 2008).

Apart from the need for a better understanding of the biogeochemical cycles in sea ice for future climate models, this is also important for unraveling palaeoclimatology. Sea ice extent is an important indicator for past climate. Proxies in Antarctic ice cores are used to reconstruct regional sea ice extent. One of these proxies is methane sulfonic acid (MSA), an atmospheric oxidation product of DMS. The current idea is that extensive winter sea ice results in high plankton productivity and associated DMS production in surface waters during seasonal ice melt, with subsequent increased MSA levels deposited in nearby snow. The mechanisms that relate marine DMS to MSA in snow are however enigmatic (Preunkert et al. 2008) and both positive and negative MSA-sea ice correlations have been observed (Röthlisberger and Abram 2009). An explicit contribution from sea ice itself so far has not been considered, which seems unrealistic given the observed high DMS levels in ice.

Recently, also the previously mentioned hydrated carbonate crystal, ikaite, has been found in Antarctic ice cores (Sala et al. 2008). It is hypothesized to be derived from the sea ice surface, where ikaite typically forms at the early stages of sea ice formation. Combining knowledge on sea-ice related processes involved in the formation of both MSA and ikaite with data analyses from firn, will improve our understanding of palaeoclimate.

More specific, though by no means exclusive, questions that need to be addressed and that can be used to structure the discussions during the first meeting are:

- What are the main climate-relevant compounds and processes associated with sea ice?
  Until now, the main focus of the published studies was on DMS and CO2, but very little is known about other VOC's.
- How can we compare and quantify the relative contribution of different pathways of the main climate gases in time and space?
  Pathways to distinguish are direct ice/snow-atmosphere interactions, direct water-atmosphere interactions and indirect impact of ice melt on surface waters and subsequent sea-air fluxes.
- What is the difference between first-year ice and multi-year ice with respect to their quantitative contributions to gas fluxes?
  With ongoing climate warming, the relative contribution of multi-year ice will reduce, especially in the Arctic.
- How will major and minor elemental cycles influence in-ice food web structure and how will this feed back on ice structure and stability?
  Relevant topics are pigment layers that influence ice structure and stability via internal absorption and energy deposition; porous flow/transport of nutrients; the effects of organics and polymers on freezing; and special upper level habitats which cannot be captured in one dimensional models (rafting).
- What are the major differences in biogeochemical fluxes between the Arctic and Antarctic?
  There are distinct differences between Arctic and Antarctic sea ice, with respect to physical, chemical and biological features that largely can be attributed to difference in snow cover. With the expected increase in precipitation in the Arctic, this may change in the future.
- What is the relative contribution of sea ice and surface water to MSA and ikaite deposited on land?
  In order to improve a proxy-based reconstruction of past sea-ice extent, a mechanistic understanding of the transportation of ikaite and the flux of DMS and derived compounds from ice and water is needed.

  In addition to the above science questions, the working group should also critically address the technical challenge of measuring gas concentrations and production rates in ice.

In recent years, there has been an increasing awareness that understanding sea-ice biogeochemistry is crucial to understanding the controls of the Earth System (e.g. as formulated in the ESF LESC Exploratory Workshop (EW04-034) on "New perspectives on sea-ice research for the next 10 to 20 years", held in Germany, December 2005). 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 modelers of sea ice systems and the Earth system, in order to:

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

Given the international character of both the issue (climate change) and the scientists involved, a SCOR working group would be an excellent mechanism to assemble current expertise.

Relevance to other activities of SCOR or other international organizations

This 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. The European COST Action 735 ('Tools for Assessing Global Air–Sea Fluxes of Climate and Air Pollution Relevant Gases'), which is also a SOLAS-related activity, may provide additional funds for organizing workshops on this matter, which increases the possibilities for successful meetings.
It is also important to mention that this initiative intends to benefit from the momentum generated by the IPY programs. OASIS is one such a, closely related, IPY program and several of its associated investigators are listed on this working-group membership list.

Terms of reference

The proposed working group will

1. Summarize existing knowledge on climate-relevant gases in and associated with sea ice. This includes the identification of processes that control the production and fluxes of these gases and an inventory of quantitative data of gases as well as other biogeochemical parameters needed for model validation.
2. Identify gaps in our knowledge and assess what more should be done by further observational programs to improve this knowledge and to build on existing databases.
3. Bring together modellers and experimentalists to derive model parameterisations for climate-relevant gases from sea ice and water.
4. Quantify to the best of our knowledge the impact of sea ice on the production and loss of climate gases and how these will feedback on ongoing climate change.
5. Produce a comprehensive, published final report incorporating appropriate results from the above topics.

Products

Since it is the main objective of this working group to fill the last major gap in Earth's biogeochemical cycles, it is of great importance that both experimentalists and modelers are involved in this endeavor from the very start. Therefore we envision starting with a meeting to bring these specialists together in the first year. The meeting will be used to summarize existing knowledge on climate-relevant gases in and associated with sea ice, to identify the major processes that are needed for model development and to formulate a program for the next two years during which different thematic groups will work on the quantification of the identified processes.
During the first meeting, we will also identify scientists who are not yet but should be member of the proposed working group and identify existing science initiatives that can contribute to the goal of this SCOR working group. Each thematic group will have a responsible chair to organize her/his theme in the next year and keep track of progress. For the first meeting we will seek co-sponsorship from the EU's COST Action 735 (to which Stefels is member of the management committee) and other sources.

During the following 2 years thematic workshops will be organized to work on the identified processes, with the aim of developing important parameterizations for these processes and to build databases and, if possible, climatologies for climate relevant gases. We envision organizing these workshops as special sessions of larger interdisciplinary symposia, such as the AGU/EGU/ASLO conferences.

At the end of the third year, a special issue of a peer-reviewed journal will be published, in which the major findings of the thematic workshops are summarized and new, coupled sea ice-ocean-atmosphere models are presented. During the first, year opportunities will be sought to present the outcome of the working group during a symposium. The Alfred Wegener Institute for Polar research (Bremerhaven, Germany) is a potential organizing institute.

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 ice-atmosphere and sea-ice interfaces. Since the collaboration between modelers and experimentalists is a prerequisite for this WG to succeed, the composition of the group of full members reflect this. Each of the members, both full and associate, is leading in her/his field of research, is involved in many ongoing international polar programs and capable of encouraging and involving other specialists and collaborators in their field of research. At the time of this proposal's deadline, all proposed full members have been approached and confirmed their membership, unless stated otherwise. Proposed associate members are currently approached; several have already replied as indicated in the table below.

Full members	**Institute**	**Country**	**Specialization**	
Jacqueline Stefels (chair)	Univ of Groningen	Netherlands	Biochemistry, S-cycle	✓
Gerhard Dieckmann (co-chair)	Alfred Wegener Institute for Polar Research	Germany	Biochemistry, C-cycle, sedimentation	✓
Jean-Louis Tison	Univ Libre Brussel	Belgium	Glaciology, gas composition	✓
Lucie Carpenter	Univ of York	UK	Atmospheric chemistry, halogens	✓
Scott Elliot	Los Alamos Nat Lab	USA	Sea-ice and global ocean modeling	✓
Maurice Levasseur	Université Laval, Québec	Canada	Biochemistry, S-cycle, Fe	✓
Caroline Leck	Stockholm University NO REPLY YET	Sweden	Atmospheric chemistry, aerosols	
Kevin Arrigo	Stanford University	USA	Biochemical modeling, Fe- and C-cycle	✓
Igor Semiletov	NO REPLY YET	Russia	Atmospheric CO2 balance	
We are seeking suggestions of potential Full Members from developing countries and countries with economies in transition.				
Associate members	**Institute**	**Country**	**Specialization**	
Albert Gabric	Griffith Univ., Brisbane	Australia	Ecosystem modeling, S-cycle	
Veronique Schoemann	Univ Libre Brussel	Belgium	Biology and biochemistry, Fe-cycle	
Martin Vancoppenolle	Université catholique de Louvain	Belgium	Sea-ice biophysicochemical modeling (LIM)	
Bruno Delille	Université de Liège	Belgium	Chemistry, C-cycle	
Michel Gosselin	University of Quebec,	Canada	Biology, S- and C-cycle	

	Rimouski			
Lisa Miller	Institute of Ocean Science, Sydney	Canada	Atmospheric chemistry, CO_2 fluxes	
Nadja Steiner	Institute of Ocean Science, Sydney	Canada	Sea-ice modeling, S-cycle	
Søren Rysgaard	Greenland Institute of Natural Resources	Denmark / Greenland	Photobiology, microbiology, C-cycle	
Gerrit de Leeuw	University of Helsinki	Finland	Aerosols	✓
Bruno Jourdain	Univ Joseph Fourier, Grenoble	France	Atmospheric chemistry	
Ellen Damm	Alfred Wegener Institute for Polar Research	Germany	Methane chemistry	✓
Lars Kaleschke	University of Hamburg	Germany	Atmospheric chemistry, modeling	
Dieter Wolf-Gladrow	Alfred Wegener Institute for Polar Research	Germany	C- Fe chemistry modeling	✓
Shigenobu Takeda	University of Tokyo	Japan	Nutrient biogeochemistry	✓
Agneta Fransson	University of Gothenburg	Sweden	Inorganic carbon dynamics	
Eric Wolff	British Antarctic Survey	UK	palaeoclimatology	
Roland von Glasow	Univ East Anglia	UK	Atmospheric chemistry and physics, modeling	✓
David Thomas	Bangor University	UK	Biochemistry, nutrients, C-cycle	
Stathis Papadimitriou	Bangor University	UK	Chemistry, C-cycle, isotopes	
Paty Matrai	Bigelow Laboratory for Ocean Sciences	USA	Biology, S-cycle	✓
Paul Shepson	Purdue University	USA	Atmospheric chemistry, ozone, halogens	
David Kieber	State Univ of New York	USA	Photochemistry, aerosol chemistry	✓
Clara Deal	IARC, Univ of Alaska Fairbanks	USA	Sea-ice modeling, S-cycle	
Hajo Eicken	Geophysical Institute Univ of Alaska Fairbanks	USA	Sea ice physics	

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