surface.ocean solas lower.atmoshpere.study

solas event report

Report 03 I June 2017

Annual meeting of:

"Biogeochemical Exchange Processes at Sea Ice Interfaces (BEPSII)"

3 – 5 April, 2017
La Jolla, United States

The Biogeochemical Exchange Processes at Sea Ice Interfaces (BEPSII) research community is a global community of sea-ice researchers including biogeochemists, atmospheric scientists, oceanographers and sea-ice physicists, which was initiated as Scientific Committee on Oceanic Research (SCOR) working group 140 to address fundamental communication and methodological issues in sea-ice biogeochemistry. BEPSII was then approved by SOLAS and the Climate and Cryosphere project (CliC) as a longer-lived activity with additional endorsement from the Scientific Committee on Antarctic Research. The second phase of BEPSII is focused on developing the tools to tackle big-picture questions about the global relevance of biogeochemical processes within and around sea ice, including climate-change feedbacks. The current BEPSII objectives are to:

- Develop dedicated consistent methodologies for sea ice biogeochemical research;
- Establish effective sea-ice biogeochemical data archiving approaches and databases;
- Foster process studies to determine impacts on ecology and biogeochemical cycles;

In this report

Figure 1: Participants of the Biogeochemical Exchange Processes at Sea Ice Interfaces annual meeting.
Front row left to right: Jeff Bowman, Jacqueline Stefels, Letizia Tedesco, Maria Vernet, Daiki Nomura, Melissa Chierici, Agneta Fransson, Ana Aguila-Islas, Nadja Steiner, Marie Kotovitch, Lisa Miller, Daniella Koenig, Marion Lebrun, Bonnie Raffel, James France.
Back row left to right: Klaus Meiners, Max Thomas, Martin Vancoppenolle, Eric Mortenson, Ollie Legge, Florian Deman, CJ Mundy, Brent Else, Jens Ehn, Francois Fripiat, Lynn Russel, Janne Rintala

- Foster technological developments and international knowledge transfer towards large-scale, autonomous and high-frequency sampling of sea-ice biogeochemical parameters;
- Improve the representation and evaluation of sea-ice biogeochemistry in regional and Earth system numerical models;
- Synthesise and integrate observational and modeling efforts; and
- Develop conceptual models describing sea-ice interactions in or with the Earth system.

With additional support from the International Arctic Science Committee, BEPSII held a 3-day workshop in April 2017, joined by the new SCOR working group 152 on Measuring Essential Climate Variables in Sea Ice, financially supported by SCOR. Twenty-six scientists from Australia, Belgium, Canada, Finland, France, Germany, Japan, the Netherlands, Norway, Switzerland, the United Kingdom, and the United States gathered in La Jolla, California to discuss the results of the past year's activities, plan upcoming activities, and to present scientific talks and posters.

Some of the biggest activities planned for the coming three years include:

- Method intercalibration experiments for the measurement of gas exchange, primary production and trace metals;
- Advising the Multidisciplinary drifting Observatory for the Study of Arctic Climate field program;
- 1-D and 3-D model intercomparisons of sea ice algae production; and
- Afield school (tentatively scheduled for summer 2019);

In addition, new experimental and modelling approaches will be fostered to enhance our understanding of biogeochemical exchange processes

at sea-ice interfaces. A set of five task groups have been formed to forward the BEPSII objectives, which comprise the basis of a 5-year science plan currently being drafted. The task groups and their leaders are:

- Essential Climate Variables in Sea Ice: Francois Fripiat (Germany), Daiki Nomura (Japan), Brent Else (Canada)
- Data Collation: Klaus Meiners (Australia), Lisa Miller (Canada)
- Modelling and Observational Process Studies: Nadja Steiner (Canada), Hauke Flores (Germany)
- Syntheses: Delphine Lannuzel (Australia), Martin Vancoppenolle (France)
- Outreach: Letizia Tedesco (Finnland), Bruno Delille (Belgium)

We encourage anyone interested in getting involved with BEPSII or Essential Climate Variables in Sea Ice to send a message to the chairs Jacqueline Stefels and Nadja Steiner or to the leaders of the relevant task groups. In the meantime, for additional entertaining reading, see the BEPSII special feature in *Elementa: Science of the Anthropocene* (http://bit.ly/2qHK7QZ).

Nadja Steiner
(Co-chair, Institute of Ocean Sciences, Canada)

Link to the event page
http://bit.ly/2qHo2lp

The outcomes of the meeting contribute to the Cross-Cutting Theme ‘Integrated Topics’ (polar oceans and sea ice) of the SOLAS 2015-2025: Science Plan and Organisation.

Event sponsors

Ollie Legge studied oceanography at the National Oceanography Centre, Southampton, United Kingdom. Currently, he is doing his PhD at the University of East Anglia, Norwich, United Kingdom, focussing on carbonate system processes in the Southern Ocean.

Seasonal sea-ice impacts carbon dioxide uptake in the coastal Southern Ocean

Legge, O.J.[a,*], Bakker, D.C.E.[a], Johnson, M.T.[b], Meredith, M.P.[c], Venables, H.J.[c], Brown, P.J.[d], Jones, E.M.[e], and Lee, G.A.[a]

[a]Centre for Ocean and Atmospheric Sciences, University of East Anglia, Norwich, United Kingdom
[b]British Antarctic Survey, Cambridge, United Kingdom
[c]Centre for Environment Fisheries and Aquaculture Science, Lowestoft, United Kingdom
[d]National Oceanography Centre, Waterfront Campus, Southampton, United Kingdom
[e]Centre for Energy and Environmental Sciences, Energy and Sustainability Research Institute Groningen, University of Groningen, Groningen, Netherlands

*o.legge@uea.ac.uk

Approximately 15 million km^2 of the Southern Ocean is seasonally covered by sea-ice, yet the processes affecting carbon cycling and gas exchange in this climatically important region remain inadequately understood. The uptake of atmospheric carbon dioxide (CO_2) by the seasonally ice-covered Southern Ocean is poorly constrained due to a scarcity of observations (Bakker *et al*., 2016) and is not well represented in models (Lenton *et al*., 2013). Most estimates are largely based on the open ocean and do not account for the variability and importance of the coastal ocean. A unique coastal time series provides insights into the mechanisms controlling ocean-atmosphere CO_2 flux in this complex and under-sampled environment (Legge *et al*., 2017). Dissolved Inorganic Carbon (DIC) and Total Alkalinity (TA) measurements from the surface water of Ryder Bay on the West Antarctic Peninsula (Fig. 2) show strong, asymmetric seasonal cycles, driven by physical processes and primary production. In summer, the dominant process affecting the carbonate system is net photosynthesis which reduces DIC. Melting glacial ice and sea ice, and a reduction in mixing with deeper water further reduce DIC. This rapid decrease in DIC indicates that the ocean is a sink of atmospheric CO_2 in summer (Fig. 3). In winter, net heterotrophy and mixing with deeper water increase surface water DIC concentrations, making the ocean a source of CO_2 to the atmosphere. The direction of CO_2 exchange between the ocean and the atmosphere depends on the difference in the fugacity of CO_2 between the water and the

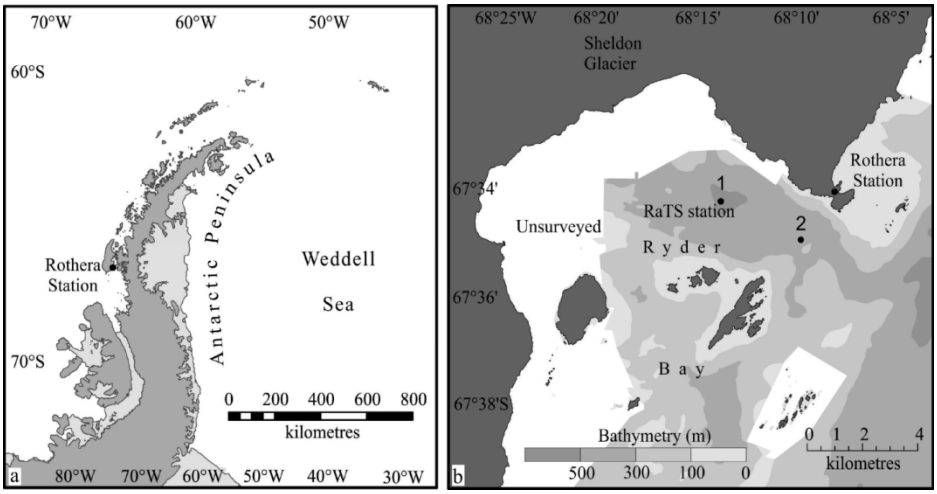

Figure 2: (a) Location of the Rothera Station on Adelaide Island at the West Antarctic Peninsula. (b) Location of the Oceanographic and Biological Time Series (RaTS) sites 1 and 2 in Ryder Bay.

air, but the rate of this exchange is strongly dependent on physical conditions such as wind speed and, importantly in this region, ice cover. Sea ice is present during winter in Ryder Bay (Fig. 2) which reduces the rate of winter outgassing. However, much uncertainty remains around how sea ice affects ocean-atmosphere gas exchange (Loose *et al*., 2014). Overall, Ryder Bay is found to be a net sink of atmospheric CO_2 of 0.90–1.39 mol C m^{-2} yr^{-1} (Legge *et al*., 2015) and the observed inter-annual variability in the time series demonstrates the influence of various processes on the strength of this sink. For example, during the winter of 2013, surface water CO_2 was higher than during the two preceding winters due to greater upwelling of DIC rich Circumpolar Deep Water. Also, sea ice cover was lower during this winter, allowing more CO_2 to be released to the atmosphere. As a result, winter outgassing was greater in 2013 than in the two preceding years, causing a weaker net annual sink of atmospheric CO_2. The DIC and TA time series in Ryder Bay was initiated in December 2010 and is ongoing, with a sampling interval

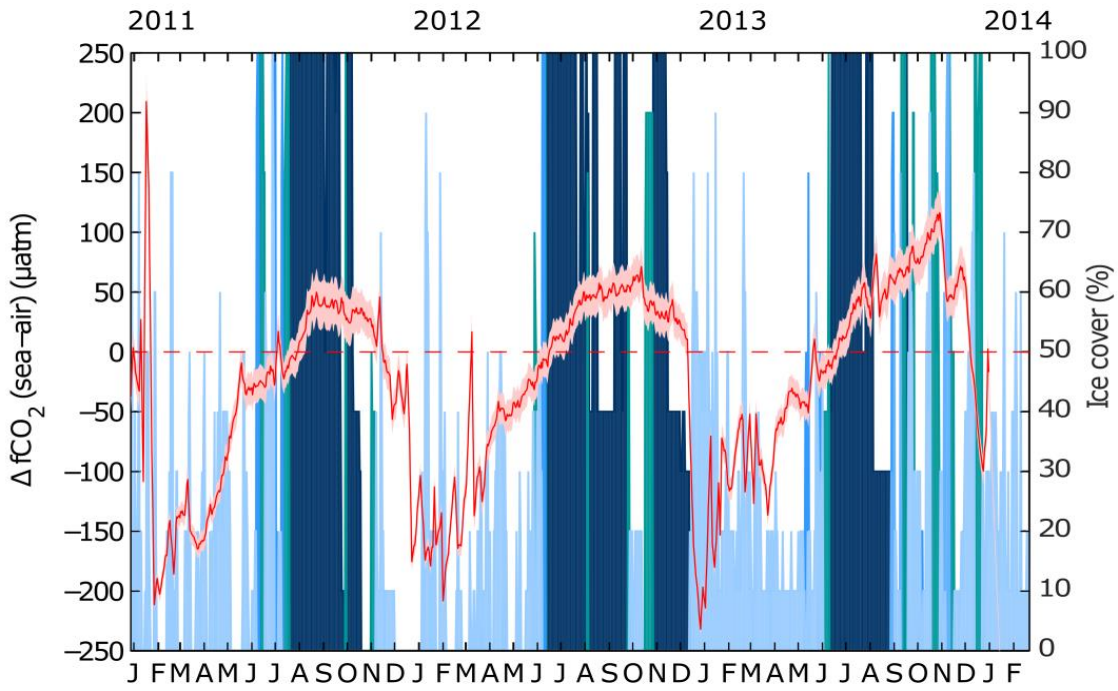

Figure 3: The difference in CO_2 fugacity between the air and the sea surface (red line), with negative values representing an ocean sink of atmospheric CO_2. Blue bars show percentage of ice cover in the bay with dark blue representing fast ice, turquoise representing pack ice and light blue representing brash ice.

of a few days to a few weeks. This growing dataset will continue to help us develop a better mechanistic understanding of the carbonate system in seasonally sea-ice covered waters.

References

Bakker, D. C. E., Pfeil, B., Landa, C. S., *et al*. (2016), A multi-decade record of high-quality fCO_2 data in version 3 of the Surface Ocean CO_2 Atlas (SOCAT). *Earth System Science Data*, 8, 383-413, doi:10.5194/essd-8-383-2016.

Legge, O. J., Bakker, D. C. E., Johnson, M. T., *et al*. (2015), The seasonal cycle of ocean-atmosphere CO_2 flux in Ryder Bay, west Antarctic Peninsula. *Geophysical Research Letters*, 42, 2934-2942, doi:10.1002/2015GL063796.

Legge, O. J., Bakker, D. C. E., Meredith, M. P., *et al*. (2017), The seasonal cycle of carbonate system processes in Ryder Bay, west Antarctic Peninsula. *Deep–Sea Research Part II*, 139, 167-180, doi:10.1016/j.dsr2.2016.11.006.

Lenton, A., Tilbrook, M., Law, R. M., *et al*. (2013), Sea-air CO_2 fluxes in the Southern Ocean for the period 1990–2009, *Biogeosciences*, 10, 4037-4054, doi:10.5194/bg-10-4037-2013.

Loose, B., McGillis, W. R., Perovich, D., *et al*. (2014), A parameter model of gas exchange for the seasonal sea ice zone, *Ocean Science*, 10, 17-28, doi:10.5194/os-10-17-2014.

Follow us on twitter
@SOLAS_IPO

Marie Kotovitch is a PhD student at the University of Liège, Belgium and at the Université Libre de Bruxelles, Brussels, Belgium. During her master thesis, Marie was working on the exchanges of fluxes of carbon dioxide at the air-sea ice interface. Now as a PhD student, she expanded her focus by also taking other greenhouses gases, such as nitrous oxide and methane,

Greenhouse gases exchange at the air-sea ice interface

Kotovitch, M.[a,b,*], Delille, B.[a], Tison, J.L.[b], Moreau, S.[c], and Van der Linden, F.[a,b]

[a]Interfacultary Center for Marine Research, University of Liège, Liège, Belgium
[b]Université Libre de Bruxelles, Brussels, Belgium
[c]Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Australia

*marie.kotovitch@ulg.ac.be

While greenhouse gases play an elemental role in climate change and global warming, sea ice is involved in gas exchanges between the ocean and the atmosphere. To investigate the relationship between these two processes, a tank experiment was conducted (Kotovitch *et al*., 2016). This tank allowed the controlled freezing of seawater and has been used to reproduce ice growth and decay over the course of 19 days. The temperature of the atmosphere above the tank water was set to -15 °C for 14 days. After 14 days, the temperature was set to -1 °C until the end of the experiment (day 19). During the time of the experiment, the *in situ* ice temperature, the temperature above the ice, the underwater salinity, and the air-ice carbon dioxide (CO_2) flux were measured continuously (Fig. 4). Additionally, ice cores were collected on a regular basis to measure biogeochemical variables. Results indicate that sea ice shifts from: (i) being a sink for CO_2 during the first crystals formation, (ii) to being a source for CO_2 during ice growth and, finally (iii) return to a CO_2 sink during ice melt. To mimic the observed air-ice CO_2 fluxes, we used a 1D model (Fig. 5, Moreau *et al*., 2015). The inversion between outward CO_2 fluxes during ice growth and

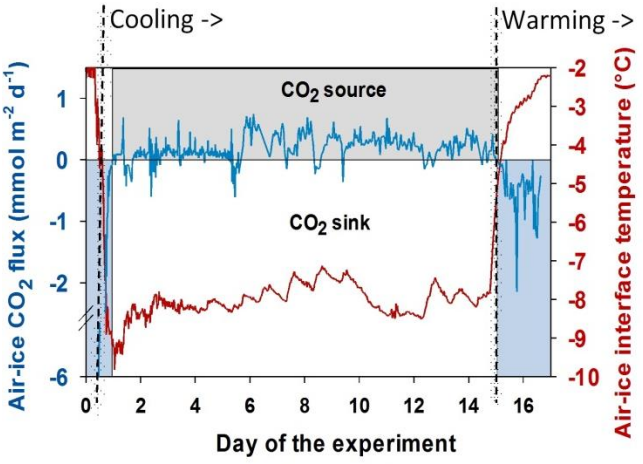

Figure 4: Air-ice CO_2 fluxes and air-ice interface temperature during the cooling and the warming stages. Air-ice CO_2 above 0 mmol m^{-2} d^{-1} represent a CO_2 source and values below represent a CO_2 sink.

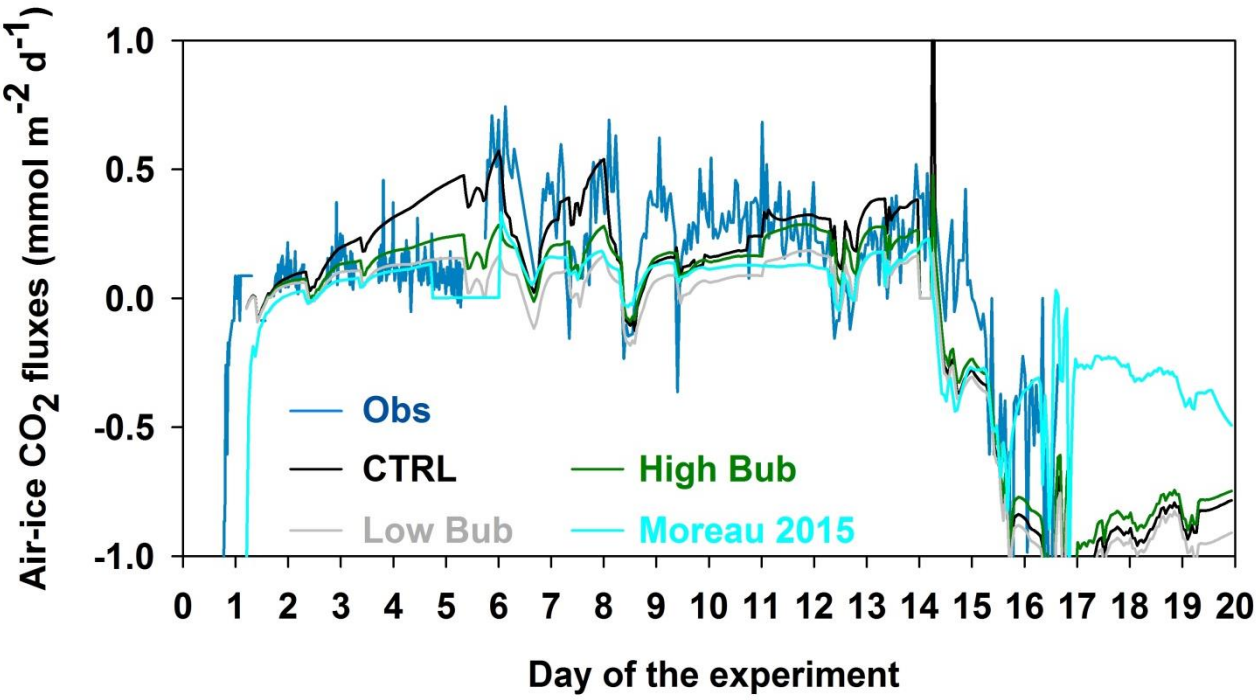

Figure 5: Observed (Obs, dark blue) air-ice CO_2 fluxes and simulated air-ice CO_2 fluxes including: low and high gas bubble formation rate (Low Bub, grey; High Bub, green), the control simulation (CTRL, black) and with the bubble formation rate by Moreau *et al.* (2015) (light blue).

inward CO_2 fluxes during ice melt depicts well the observations. However, the model (Moreau *et al*., 2015) strongly underestimates the fluxes during the cold phase if the formation rate of gas bubbles is low. Since ice is permeable throughout the cold phase, higher gas bubble formation rates lead to higher CO_2 fluxes (i.e. gas bubbles escape the ice surface and add to the outward CO_2 flux).

Our final aims are to develop air-sea ice fluxes measurements for other greenhouse gases and to compute global budget for each of these gases.

References

Kotovitch M., Moreau S., Zhou J., *et al.* (2016), Air-ice carbon pathways inferred from a sea ice tank experiment. *Elementa: Science of the Anthropocene*, 4, 1-15, doi:10.12952/journal.elementa.000112.

Moreau S., Vancoppenolle M., Delille B., *et al.* (2015), Drivers of inorganic carbon dynamics in first-year sea ice: A model study. *Journal of Geophysical Research: Oceans*, 120, 471-495, doi:10.1002/2014JC010388.

James Lawrence France studied geosciences at Royal Holloway, University of London in 2000-2004 and continued for a PhD in snow chemistry and subsequent post-docs in photochemistry and then Arctic methane. He moved to the University of East Anglia, Norwich, United Kingdom in 2014 to help build a new experimental sea-ice facility which he now runs.

Methane fluxes from sea-ice in the Roland von Glasow Air-Sea-Ice Chamber

France, J. M.*, and Thomas, M.

University of East Anglia, Norwich, United Kingdom

*j.france@uea.ac.uk

The Roland von Glasow Air-Sea-Ice Chamber (RvG ASIC) is a purpose-built sea-ice facility designed to allow investigations into young sea-ice within the relative safety and comfort of a controlled laboratory environment. The facility was the brainchild of Professor von Glasow, who sadly passed away very suddenly in late 2015. The facility couples the ocean, sea-ice and atmosphere making it ideal for investigating processes that occur across the sea-ice interface, which is technically and logistically very challenging in the field. Other sea-ice facilities exist around the world (such as the Sea-ice Environmental Research Facility at Manitoba, Canada), but we have aimed to create something new by building a coupled ocean-sea-ice-atmosphere system illuminated by optional ultraviolet and visible lighting to create a microcosm of the Polar oceans. The sea-ice tank is 2.4 m length by 1.4 m wide by 1 m deep with optional additional up to 1 m high polytetrafluoroethylene-fluorinated ethylene propylene atmosphere and housed in an environmental chamber capable of temperatures -55 to +35°C with stability of ~ ±0.3°C (Fig. 6).
The key features of the facility are:

- Coupled ocean and atmosphere;
- Capable of growing sea-ice to ~30 cm;
- Programmable, temperature controlled environmental chamber;
- Each section (ocean, ice or atmosphere) can be sampled separately;
- Focus on continuous/non-destructive sampling where possible; and
- Real-time data collection.

We have been performing a range of proof of concept experiments for the last 12 months in order to demonstrate the viability of the facility for a range of research uses. Various experimental set ups have been tested in order to validate the methodologies used at the facility. However, for this experiment we focused on investigating the uptake in sea-ice and flux to the atmosphere of dissolved greenhouse gases as sea-ice grows and melts (other work undertaken has included investigating sea-ice physics, sea-ice radiative-transfer and chemical pollutant uptake into sea-ice). Previous work on gas transfer through sea-ice has shown that methane can be released from the sea to the air during sea-ice break up

Figure 6: The sea-ice chamber under visible light illumination. In this instance, a polytetrafluoroethylene-fluorinated ethylene propylene atmosphere is partly enclosing the tank which measures 2.4 m x 1.4 m x 1.1 m and contains ~3,500 litres of sea-water saturated with methane.
© James Lawrence France.

(Kort *et al.*, 2012; Damm *et al*., 2015), so to test this hypothesis the tank was filled with North Sea water. The water was sand filtered and treated with ultraviolet C radiation to remove biology and then supersaturated with methane to reproduce Arctic Ocean conditions (Damm *et al.*, 2015). Sea-ice was then allowed to form to a thickness of ~14 cm with an atmospheric temperature of -18°C above the tank. The tank is fully insulated at the sides and base to prevent supercooling and platelet ice forming within the water column, and to ensure that ice can only form due to cooling at the top of the water column, as occurs in the real-world system. Continuous measurements of methane were made above the ice, and spot samples from the ocean taken from beneath the ice using a heated line through the side of the tank. Post experiment, ocean samples and sea-ice samples were then sent for analysis at University of Liège (Liège, Belgium) and Alfred Wegener Institute (Bremerhaven, Germany). In collaboration with these two institutions, we have seen a methane efflux above the ice upon the initial warming stage of the experiment, post-ice formation (Figure 7). The increased methane mixing ratios were ~10% increase over atmospheric background, but it is uncertain as to whether it is methane from the water column travelling through the ice or from release of methane in brine or air pockets trapped within the ice. Experiments to further investigate this are required and planned for later in the year as well as detailed analysis of the spot samples taken during the experiments. As part of BEPSII and the new SCOR working group 152 on Essential Climate Variables in Sea-Ice, we are now in the planning stages for a large intercalibration experiment at the RvG ASIC to measure concentrations of climatically important gases in the sea-ice using a variety of methods to test their robustness and intercomparability. The RvG ASIC is open for collaborative science and can also be accessed through the transnational access scheme run through EUROCHAMP 2020

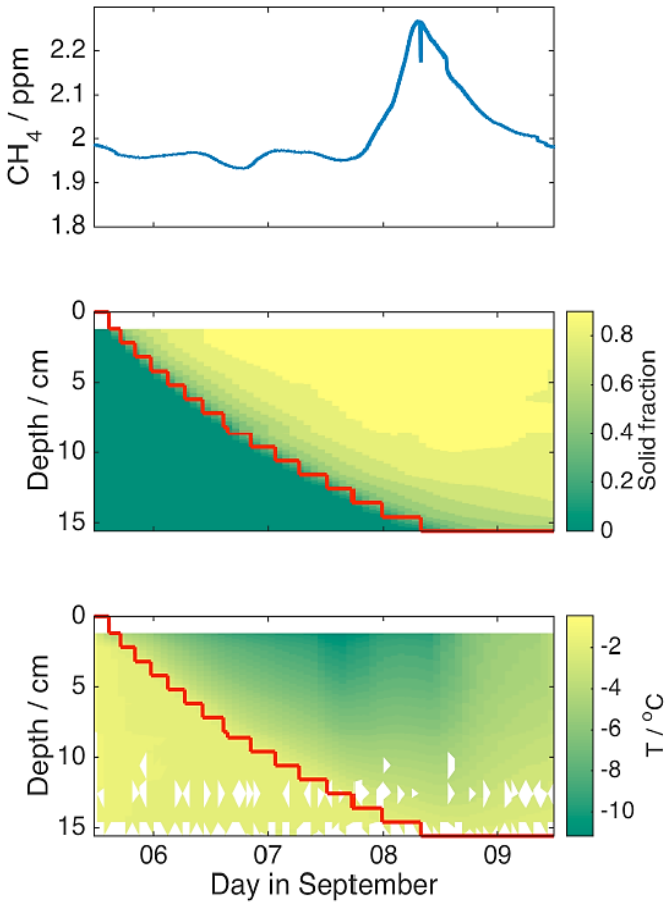

Figure 7: Timeline of the experiment by various parameters. Top: Methane mixing ratio in the atmosphere above the tank. Middle: The solid fraction of ice versus depth into the ice. Bottom: In-ice temperature versus depth and ice thickness (red line). Note that the methane efflux coincides with the ice beginning to warm.

(http://www.eurochamp.org/). Please contact James France for further details about potential collaborative work using the facility.

References

Damm, E., Rudels, B., Schauer, U., *et al.* (2015), Methane excess in Arctic surface water-triggered by sea ice formation and melting. *Scientific Reports*, 5, doi:10.1038/srep16179.

Kort, E. A., Wofsy, S. C., Daube, B. C., *et al.* (2012), Atmospheric observations of Arctic Ocean methane emissions up to 82° north. *Nature Geoscience*, 5, 318-321, doi:10.1038/ngeo1452.

Acknowledgements

This work and the existence of the facility would not have been possible without the hard work of the late Prof. Roland von Glasow, to whom the facility is devoted. His European Research Council Consolidator Grant (ERC 616938) allowed the construction of the chamber and we hope that it will contribute to sea-ice interface research. We would also like to thank Bruno DeLille, Ellen Damm, Jean Louis Tison and Marie Kotovitch for their extensive time and input into this ongoing work.