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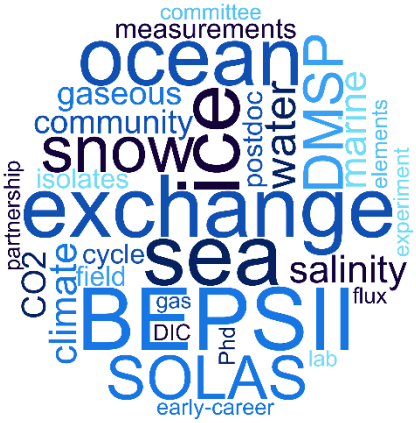
Report 23 I September 2022

The 2021 Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII) Exchange Awards:

Supporting Early Career Networking in Sea-Ice Biogeochemistry



BEPSII is an open network for international knowledge exchange related to Biogeochemical Exchange Processes at Sea-Ice Interfaces. BEPSII aims to identify the feedback between biogeochemical and physical processes at the ocean-ice-snow-atmosphere interfaces and within the sea-ice matrix, as well as quantify the role of sea ice in polar ecosystems – from biodiversity impacts to climate change – and communicate these globally-relevant issues (Figure 1).

First launched in 2012 as a Scientific Committee on Oceanic Research (SCOR) working group, BEPSII is now a long-lived activity jointly sponsored by SOLAS, the Climate and Cryosphere program (CliC), and the Scientific Committee of Antarctic Research (SCAR). BEPSII promotes the publication of scientific papers and reviews, conducts cross-cutting community workshops, compiles and releases observational databases, initiates model inter-comparisons, and identifies critical requirements for methodological developments. Support for the next generation of sea-ice biogeochemists is integral to all BEPSII activities; indeed, capacity-building is

In this report

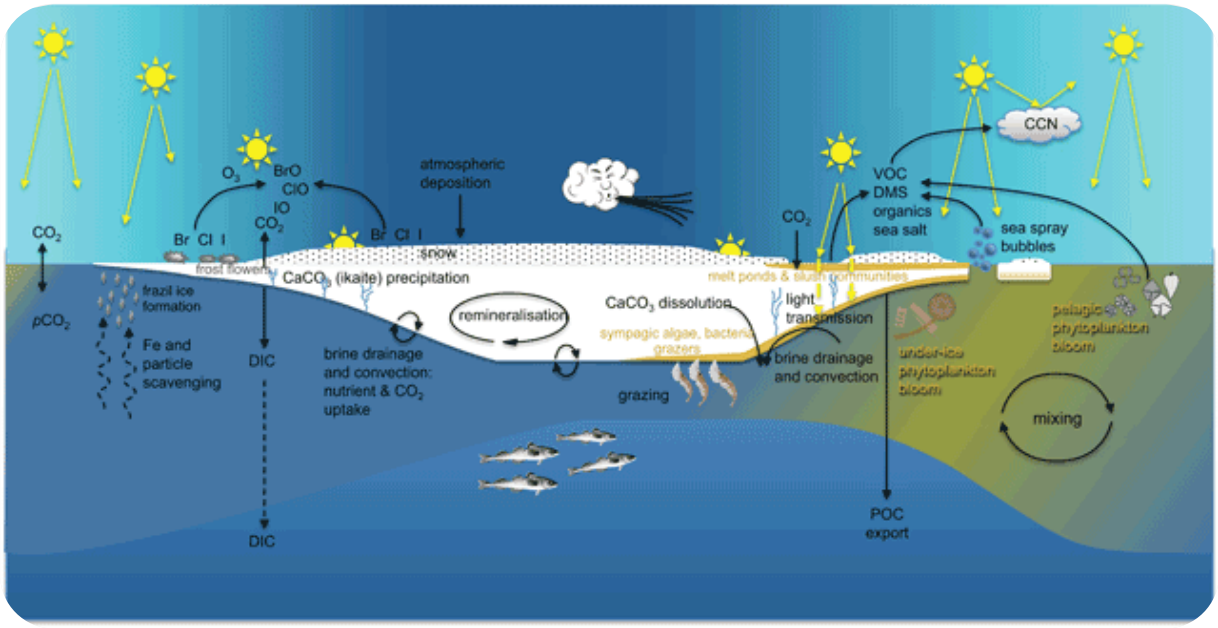


Figure 1: Schematic representation of biogeochemical processes at sea-ice interfaces and within sea ice over the seasons. DIC indicates dissolved inorganic carbon; POC, particulate organic carbon; VOC, volatile organic carbon; DMS, dimethylsulfide; and CCN, cloud condensation nuclei. https://doi.org/10.1525/elementa.272.f1

part of the BEPSII "DNA", as many of the founding members were early-career scientists at the time. BEPSII continues to explicitly foster early-career scientists through two dedicated positions on the steering committee, financial support to attend annual meetings, and early career workshops in conjunction with those annual meetings. With SOLAS support, BEPSII also organised a sea-ice biogeochemistry winter school in May 2022 in Cambridge Bay, Canada.

In 2021, BEPSII launched its first exchange programme award to support early-career scientists in research collaborations. Motivated by a realisation that the coronavirus disease 2019 (COVID-19) pandemic had severely hobbled network-building for early-career scientists, the programme supported short visits between institutions to learn new techniques, develop joint experiments, and exchange knowledge. A call for proposals was issued through the BEPSII, SOLAS, SCAR, and CliC mailing lists, and the BEPSII steering committee selected the awardees. Funding from SOLAS was awarded to four scholars:

- Dr. Deborah Bozzato, a postdoc at the University of Groningen, The Netherlands, to visit the lab of Prof. Hendrik Schäfer and Dr. Alison Webb at the University of Warwick, in the UK.
- Ms. Johanna Länger, a PhD student in Canada at the University of Victoria, to visit the lab of Prof. Brent Else at the University of Calgary, Canada.
- Dr. Pat Wongpan, a postdoc at the University of Tasmania, Australia, to visit the lab of Dr. Matt Pinkerton at the National Institute of Water and Atmospheric Research, in New Zealand.
- Ms. Veronica Amoruso, a master's student in Italy at the University of Bologna, Italy, to visit the lab of Drs. Andrea Spolaor and Warren Cairns at the Institute of Polar Sciences, in Venezia-Mestre, Italy.

The stories of their journeys are included below.

Two additional scholars' exchanges were funded through CliC and SCAR.

We congratulate our exchange scholars and wish them all of the best in their careers. After the success of this inaugural exchange programme, BEPSII hopes to offer additional exchange

awards in the coming years. Finally, BEPSII thanks all of our sponsors, and particularly SOLAS, for supporting our work!

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Deborah Bozzato studied Biotechnology in Verona, Italy. She moved to Leipzig, Germany, for her PhD to investigate the effect of climate change on the carbon balance in Antarctic microalgae. Since 2019, Deborah has been working as a Postdoc on the project “Arctic sea ice-pelagic coupling of the carbon and sulfur cycles”.

The effect of salinity shifts on DMSP production in two Arctic diatom isolates

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Dimethylsulfoniopropionate (DMSP) is an organic osmolyte, cryoprotectant and anti-oxidant (Stefels, 2000) produced globally by many groups of marine phytoplankton and particular groups of bacteria (Curson *et al*., 2018). Moreover, DMSP is a precursor of the semi-volatile compound dimethylsulfide (DMS). Once DMS is released into the atmosphere, it contributes to the formation of cloud condensation nuclei, with a possible climate-cooling effect. The Arctic is particularly affected by climate change: here temperature is increasing at a rate 3 times the global average and sea-ice is declining at an alarming rate (Post *et al*., 2019). In summer, the melting of sea-ice and snow creates a surface layer of low salinity on top of the existing upper mixed layer (Popova *et al*., 2013). These freshwater inputs to the water column, together with the thinning and weakening of the pack ice, stimulate the opening of leads and the formation of melt ponds on the ice surface. Leads and melt ponds provide areas of gas exchange between the atmosphere and the underlying water column (Steiner *et al*., 2003). Furthermore, rapid changes in sea ice and surface water salinity can result in an extremely challenging environment for the under-ice microbial community.

DMSP has previously been studied *in situ*, in both sea-ice and sea-water, for its cryoprotectant and osmolyte function. Higher concentrations in the ice, rather than in the water, highlight the significant importance of this molecule for the sea-ice microbial community (Gourdal *et al*., 2019).

The sea-ice sulfur cycle is one of the core parameters of the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) field campaign (https://mosaic-expedition.org/). Alison Webb and I were on board during summer time, respectively on Legs 5 and 4. With support through the BEPSII Early Career Exchange Programme, I had the opportunity to further develop some of the research questions we raised during the expedition, in collaboration with my colleagues at the University of Warwick, UK, namely, which are the microorganisms responsible for DMSP uptake and/or production in the Arctic Ocean, and what is the impact of the Arctic freshwater stratification during Summer?

We undertook stable isotope DMSP incubations for 24 hours with two monoclonal isolates obtained from a marginal-ice-zone algal culture.

These incubations were coupled with different salinity shifts, as illustrated in Figure 2. A suite of parameters was taken at the beginning and the end of each experiment. The isolates were identified as species of *Attheya* using ribosomal Ribonucleic Acid (RNA) gene sequencing. Microscopy and flow cytometry cell count measurements and particulate organic carbon (POC) concentrations gave us an indication of biomass growth. Furthermore, chlorophyll a, pigments and photophysiological parameters (e.g. maximum quantum yield of photosystem II, Fv/Fm) were measured to check the status of the cultures. DMSP and other sulfur compounds are currently analysed at the University of Groningen, to determine the capacity of these isolates to produce/uptake DMSP and how this is affected by salinity. RNA samples for transcriptome analysis are being analysed to identify genes responding to the dynamic changes in growth conditions.

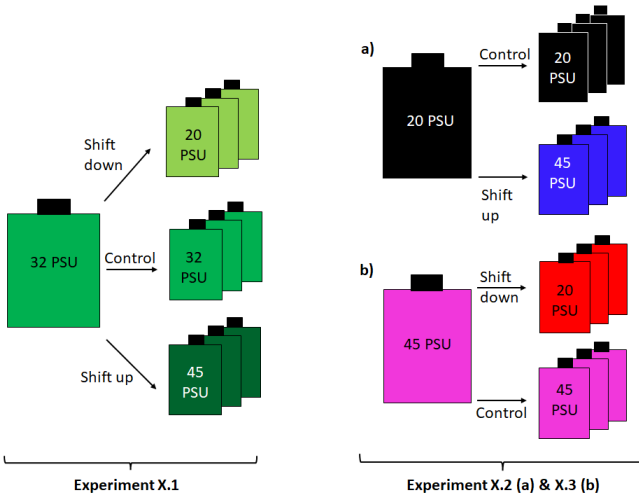

Figure 2: Overview of the experimental design, showing the salinity shifts during the stable isotope incubation experiments.

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Acknowledgements

The BEPSII exchange program award 2021.

All the persons involved in the MOSAiC expedition (AWI_PS122_00), as listed in MOSAiC Extended Acknowledgement. https://doi.org/10.5281/zenodo.5179739

Johanna Länger studied Geoecology in Germany and decided to focus on the Arctic after an exchange year at the University of Tromsø, Norway, during her master's study. In 2019, she started her PhD at the University of Victoria, Canada, investigating the marine carbon budget in the Canadian Arctic using numerical models.

Investigating the sea ice carbon content – an intercomparison experiment

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The marine sink for atmospheric carbon dioxide (CO_2) and the gas transfer between the ocean and the atmosphere is a highly relevant topic when talking about global carbon budgets. In the Arctic Ocean, sea ice imposes major influence on the air-sea flux of CO_2. It is often assumed that a closed sea ice cover with a low ice temperature is impermeable to gases and is therefore expected to prevent gas fluxes (Miller *et al*., 2015). During sea ice formation, brine enriched with CO_2 and its solution products Carbonate and Bicarbonate (summarised as DIC – dissolved inorganic carbon) gets rejected and drains into the water column (Sea Ice Carbon Pump – SICP (Rysgaard *et al.,* 2011)). The remaining sea ice and its meltwater are relatively depleted in DIC and are therefore potentially capable to dissolve atmospheric CO_2 well.

However, sea ice biogeochemistry is still a relatively young scientific field and many methods for measuring Essential Climate gases Variability in sea ice (ECV-ice) are still being developed and improved. There is still a lot of uncertainty about the sea ice carbon budget and its contribution to fluxes, due to the remoteness of the system and the harsh environments that complicate sampling procedures. A part of the community of BEPSII, therefore, conducts a method inter-comparison on the ice near Cambridge Bay, Canada, based at the Canadian High Arctic Research Station (CHARS).

Led by Brent Else, the ECV-ice working group runs an intercomparison between different methods to measure the carbon fluxes. The flux measurements are done by different Eddy Covariance (Else B. & Nomura D.) towers and closed chambers to measure the gas flux (Nomura D.) are set up in close proximity (Figure 3). Based on the gradient of the partial pressure of CO_2 (pCO_2) between the sea ice and the atmosphere, fluxes can be calculated. Therefore, different methods to measure the pCO_2 in sea ice are compared: Peepers (Simpson K. & Crabeck O.), Sackhole brine-pCO_2 and DIC/TA ratios (Delille B.). These measurements are also taken within proximity to the flux measurements.

Primary production is an important part of the sea ice carbon budget. In parallel to the ECV-ice project, a method intercomparison for primary production was conducted with the potential to improve our understanding of the connections betw-

Figure 3: Intercomparison between different methods for measuring the CO_2-flux and the sea ice carbon content. Peepers (near the left group of people) are deployed near an eddy-covariance (EC) tower (centre) with a partial pressure of CO2 (pCO_2) chamber in its footprint (right). All measurements are within the footprint of a permanent EC tower (background). Ice cores for dissolved inorganic carbon and alkalinity measurements are taken in close proximity. Credit: Nomura D.

een the different parts of the sea ice carbon budget. A comparison of Underwater Eddy Covariance for oxygen-fluxes (Else B. & Campbell C.), incubations with the 13-C carbon isotope and Argon-Oxygen ratios (Campbell C.) was conducted.

The aims of these experiments are to determine the uncertainty of measurement methods, to get a grasp of the spatial variability of the sea ice carbon content, and to gain insights into the differences between the methods for measurements. With the funding of SOLAS, I was able to join the first part of the experiment.

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Acknowledgements

I would like to thank Brent Else, Bruno Delille and Daiki Nomura, and the rest of ECV-ice for their patient explanations and help with writing this report.

Pat Wongpan obtained his PhD from the University of Otago in New Zealand and was a David Crighton fellow at the University of Cambridge. He was a Japan Society for the Promotion of Science (JSPS) Postdoctoral fellow at the Institute of Low Temperature Science (ILTS), Hokkaido University, Sapporo, Japan. He is interested in sea ice–ice shelf–ocean interaction and its consequences on the ecosystem, particularly sea ice fastened to the coastline of Antarctica. He is a research associate (postdoc), quantitative sea ice biogeochemist/ecologist, at the Australian Antarctic Program Partnership (AAPP), University of Tasmania in Hobart, Australia.

Antarctic sea ice and its role as a driver of Southern Ocean primary production

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As a postdoc, a quantitative sea ice biogeochemist/ecologist, I have been working on sea-ice biogeochemical modelling at AAPP, University of Tasmania in Hobart, Australia. I was awarded the BEPSII exchange programme award 2021 supported by SOLAS. The proposed research visit would help me to learn novel methods in studying Antarctic sea ice and its role as a driver of Southern Ocean primary production. I plan to work alongside Dr. Matt Pinkerton at the National Institute of Water and Atmospheric Research (NIWA), Wellington, New Zealand to learn new approaches for satellite-based estimates of Southern Ocean ice algal primary production.

The plan was that I first attend the 13th International Conference on Southern Hemisphere Meteorology and Oceanography (ICSHMO), which took place from 8-12 February 2022 in Christchurch, New Zealand, before visiting Dr. Pinkerton. However, due to the coronavirus (COVID-19) pandemic, the conference was moved to online. I did present my current work on (i) Estimation of Primary Production in Antarctic Landfast Sea Ice during 2005-2006 and (ii) Sub-Ice Platelet Layer Physics: Insights from a Mushy-Layer Sea Ice Model at the online conference. Finally, the Australian-New Zealand border was reopened, and I visited Dr. Pinkerton 13-17 June 2022. My round-trip airfare was funded by AAPP while the accommodation was supported by BEPSII and SOLAS.

Dr. Pinkerton recently published the data of satellite-based sea ice primary production, which covers the period from 1987 to 2017 (Pinkerton & Hayward, 2021, Figure 4). This work includes dates between 2000-2018 for which the high-resolution mapping of circum-Antarctic land-fast sea ice distribution is also available (Fraser *et al*., 2020). At NIWA and working with Dr. Pinkerton, I (i) discussed and compared two recently developed approaches by Pinkerton & Hayward (2021) and Wongpan *et al*. (in preparation) to estimate primary production in Antarctic land-fast sea ice and (ii) evaluated the primary production in sea ice simulated by the ACCESS-OM2-01, which is a Consortium for Ocean-Sea Ice Modelling in Australia (COSIMA)'s flagship Australian high-resolution (0.1°) ocean-sea ice model (Kiss *et al*., 2020) with the remote-sensing-based estimates from

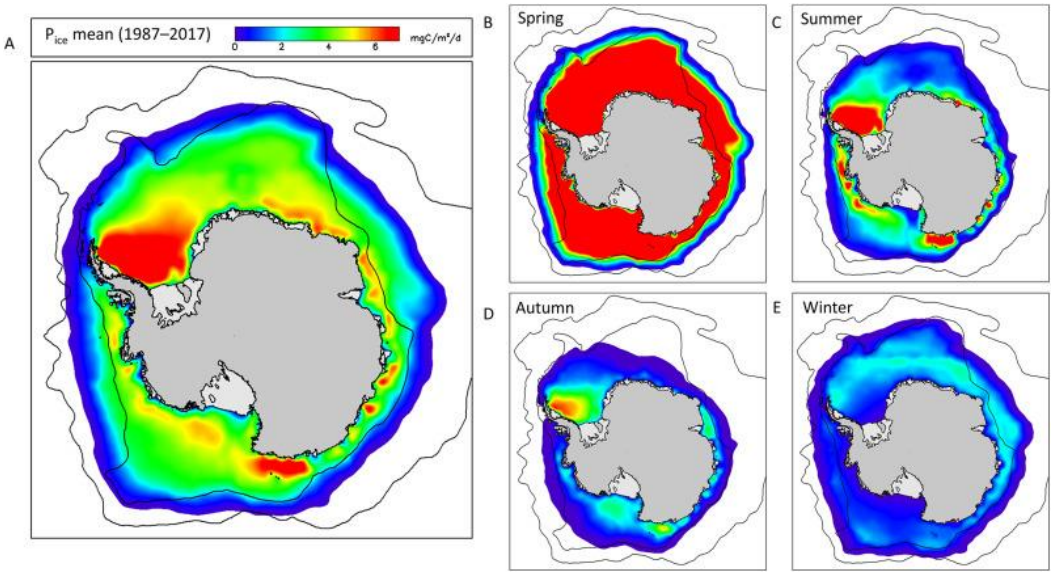

Figure 4: A) 1987-2017 mean satellite-based estimation of ice algal production; B-D) are seasonal means. Figure courtesy of Pinkerton & Hayward (2021).

Pinkerton & Hayward (2021). I also gave an invited seminar speech entitled "Primary Production in Antarctic Sea Ice" at NIWA on 15 June.

Lastly, since 20 April 2020, I have been appointed as a Topic Coordinator of the Frontiers for Young Minds' Antarctica and the Southern Ocean Collection (Figure 5, https://fro.ntiers.in/AntarcticaCollection) hosted together by Nick Golledge, Eileen Hofmann, Marilyn Raphael, and Letizia Tedesco. This collection aims to inform young readers about fundamental knowledge and digested cutting-edge science that will help increase their understanding of Antarctica and its central role as a global climate driver.

Figure 5: Cartoon abstract of the Frontiers for Young Minds' Antarctica and the Southern Ocean Collection. Courtesy of Frontiers.

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Acknowledgements

This research visit will be supported by BEPSII, SOLAS, and AAPP. I acknowledge the assistance from Laura Henderson, Will Savage and Noor Fellah from Frontiers for Young Minds.

Veronica Amoruso is currently studying for a master's degree in "Environmental management and assessment" at the University of Bologna, Italy. Her BEPSII-funded exchange was hosted by the Institute of Polar Sciences - National Research Council (ISP-CNR) at the Ca' Foscari University Venice, Italy, where she studied the geochemical cycle of mercury at the poles. The main activity was to analyse snow samples by inductively coupled plasma sector field mass spectrometry (ICP-SFMS).

The possible effect of sea ice dynamics on mercury cycle in the Antarctic plateau

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Mercury (Hg) is an element of scientific concern because of the toxicity of its organic species. Both the elemental form Hg(0), also known as Gaseous Elemental Mercury (GEM), and the oxidised form Hg(II), existing as Reactive Gaseous Mercury (RGM) or associated with particles, are found in Antarctica. GEM is persistent in the atmosphere and travels long distances, while RGM undergoes wet and dry deposition, altering the Hg concentration in the upper snow strata. A snow-air exchange between the two species in polar regions is suggested (Spolaor *et al*., 2018) and the role of the photochemical reactions has been observed (Brooks *et al*. 2008a; Dommergue *et al*., 2012), as well as a seasonal pattern (Angot *et al*., 2016). However, the geochemical cycle of Hg between polar surface snow and lower atmosphere is not fully understood.

"Atmospheric mercury depletion events" (AMDEs) were first discovered by Schroeder *et al*. (1998) in the Arctic and consist of a dramatic decrease of Hg(0) concentrations in the atmosphere during the spring season. Angot *et al*. (2016) investigated AMDEs, by measuring gaseous mercury for one year at Concordia Station. They recorded stable concentrations in winter and oscillations in summer, moreover, phenomena of AMDEs during the springtime were observed. They concluded that the snowpack acts as a sink of GEM during winter, due to the dry deposition, while photochemical reactions, occurring during summer and spring, cause the reduction of Hg(II) to Hg(0) and its reemission from the snow surface into the atmosphere. RGM or Gaseous Oxidised Mercury (GOM) is found in the air at high concentration levels when GEM decreases and peaking around midday.

The negative correlation between atmospheric Hg(0) and Hg(II) in surface snow has also been observed by Spolaor *et al*. (2018). The conversion between the two species can be addressed by the high oxidation capacity of the polar atmosphere during the spring. The springtime oxidation processes involve halogens, such as bromine (Br), which are responsible for the ozone depletion events (ODE) and the ozone hole. Ebinghaus *et al.* (2002) observed an increase in hypobromite (BrO) radicals during the AMDEs. The same was observed by Brooks *et al*. (2008b), who also detected a higher deposition

near the coast, highlighting the role of the sea-ice surface, predominantly responsible for the release of reactive bromine in polar areas in spring, known as the “bromine explosion”.

The aim of this study is to investigate the mercury depositional processes in the Antarctic Plateau (Concordia Station) and the possible link with the spring sea-ice dynamics. For this purpose, together with mercury analysis, we will detect the concentrations of bromine (Br, because of its role in the AMDEs), iodine (I, which has similar behaviour to mercury in a polar environment), sodium (Na, as a coast air mass tracer) and trace elements (tracers of the origin of the mercury found) from the available samples.

Samples of surface (0-3 cm) and sub-surface (3-6 cm) snow were collected, together with snow depositions, during the Austral summer (from 5th to 24th January 2019) at Concordia Station, the Italo-French station on the Antarctic Plateau. Snow samples were collected twice a day, at around 10 am and around 4 pm, to compare the high and low irradiation hours. Deposition samples were taken in the morning from raised deposition tables to avoid sublimation losses. These samples are a mixture of snow and frost that forms overnight. High-resolution meteorological data will be provided by partner institutions, e.g. Energy and Sustainable Economic Development (ENEA), Italy.

Total Hg concentrations in the snow samples shall be determined using a Thermo ICP-SFMS (Element XR) operating in low-resolution scanning mode using 202Hg as the analytical mercury mass. The instrument will be calibrated using standards prepared from a mono-elemental Hg solution. Considering the high volatility of Hg in solution, the samples will be acidified at 2% v/v with ultrapure hydrochloric acid. The concentrations of I, Br and Na in non-acidified samples will be determined by ICP-SFMS. Each analysis starts and ends with an ultra-pure water (UPW) cleaning session to ensure a stable background level throughout the analysis. The external standards for the calibration are prepared by diluting a 1000 parts per million (ppm) stock ion chromatography standard solution.

The analyses are being carried out in the Ca’ Foscari laboratories and the results will be available soon.

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Acknowledgements

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