surface ocean solas lower atmosphere study

Report for the year 2021 and future activities

SOLAS *Belgium*
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This report has two parts:

- Part 1: *reporting of activities in the period of January 2021 - Jan/Feb 2022*
- Part 2: *reporting on planned activities for 2022 and 2023.*

The information provided will be used for reporting, fundraising, networking, strategic development and updating of the live web-based implementation plan. As much as possible, please indicate the specific SOLAS 2015-2025 Science Plan Themes addressed by each activity **or specify an overlap between Themes or Cross-Cutting Themes.**

1 Greenhouse gases and the oceans;
2 Air-sea interfaces and fluxes of mass and energy;
3 Atmospheric deposition and ocean biogeochemistry;
4 Interconnections between aerosols, clouds, and marine ecosystems;
5 Ocean biogeochemical control on atmospheric chemistry;
Integrated studies of high sensitivity systems;
Environmental impacts of geoengineering;
Science and society**.**

IMPORTANT*: This report should reflect the efforts of the SOLAS community in the* ***entire country*** *you are representing (all universities, institutes, lab, units, groups, cities).*

First things first…Please tell us what the IPO may do to help you in your current and future SOLAS activities. ?

PART 1 - Activities from January 2021 to Jan/Feb 2022

1. Scientific highlight

Half of global methane emissions come from aquatic ecosystems

Methane plays a major role in controlling the Earth's climate. But methane concentrations in the atmosphere today are 150% higher than before the industrial revolution. Rosentreter et al. (2021) showed as much as half of global methane emissions come from aquatic ecosystems. This includes natural, human-created and human-impacted aquatic ecosystems — from flooded rice paddies and aquaculture ponds to wetlands, lakes and salt marshes. Rosentreter et al. (2021) looked at inland, coastal and oceanic ecosystems around the world. We found the combined emissions of natural, impacted and human-made aquatic ecosystems are highly variable, but may contribute 41% to 53% of total methane emissions globally. In fact, these combined emissions are a larger source of methane than direct anthropogenic methane sources, such as cows, landfill and waste, and coal mining. This knowledge is important because it can help inform new monitoring and measurements to distinguish where and how methane emissions are produced. Rosentreter et al. (2021) also found methane emissions from impacted, polluted and human-made aquatic ecosystems are higher than from more natural sites.

For example, fertiliser runoff from agriculture creates nutrient-rich lakes and reservoirs, which releases more methane than nutrient-poor (oligotrophic) lakes and reservoirs. Similarly, rivers polluted with nutrients also have increased methane emissions.

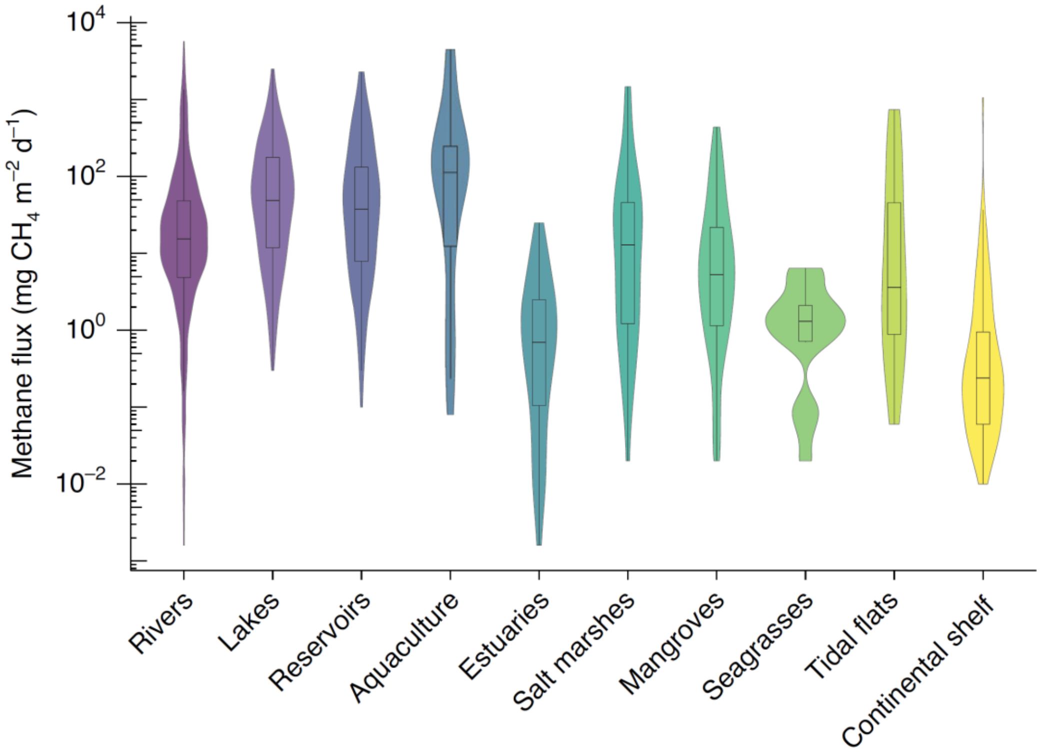

Figure: Inland water and coastal ocean areal methane fluxes. The violin plots include box plots showing median, lower (Q1) and upper (Q3) quartiles and 1.5 times the length of the interquartile range of methane fluxes from streams and rivers, lakes, reservoirs, aquaculture ponds (coastal and freshwater), estuaries, mangroves, salt marshes, seagrasses, tidal flats and continental shelves.

Citation: Rosentreter JA, AV Borges, PA Raymond, BR Deemer, MA Holgerson, CM Duarte, S Liu, C Song, GH Allen, J Melack, B Poulter, D Olefeldt, TI Battin, BD Eyre (2021) Half of global methane emissions come from highly variable aquatic ecosystem sources, Nature Geoscience, 14, 225-230

The coastal carbon cycle through a global ocean circulation model

The global ocean biogeochemistry model HAMburg Ocean Carbon Cycle was enhanced by explicitly representing riverine loads of carbon and nutrients, as well as improving the representation of organic matter dynamics in the coastal ocean. The resulting simulations reveal a relatively short globally averaged shelf water residence time (RT) of 12–17 months, which induces primarily through outer shelf regions with large oceanic inflows. This promotes an efficient offshore transport of terrestrial and marine organic carbon (0.44 $PgCyr^{-1}$) and a dissolved inorganic carbon sink from the organic cycling of carbon on the global shelf (net ecosystem productivity [NEP] equal to +0.20 $PgCyr^{-1}$). In turn, this autotrophic state of continental shelves contributes to a weak global preindustrial sink of atmospheric CO_2 (0.04 $PgCyr^{-1}$), dominated by extensive regions with large oceanic inflows and positive NEPs. The contemporary global shelf CO_2 uptake of 0.15 PgCyr−1 furthermore suggests that the anthropogenic CO_2 uptake (0.11 $PgCyr^{-1}$) on the global continental shelf is less efficient than that of the open ocean.

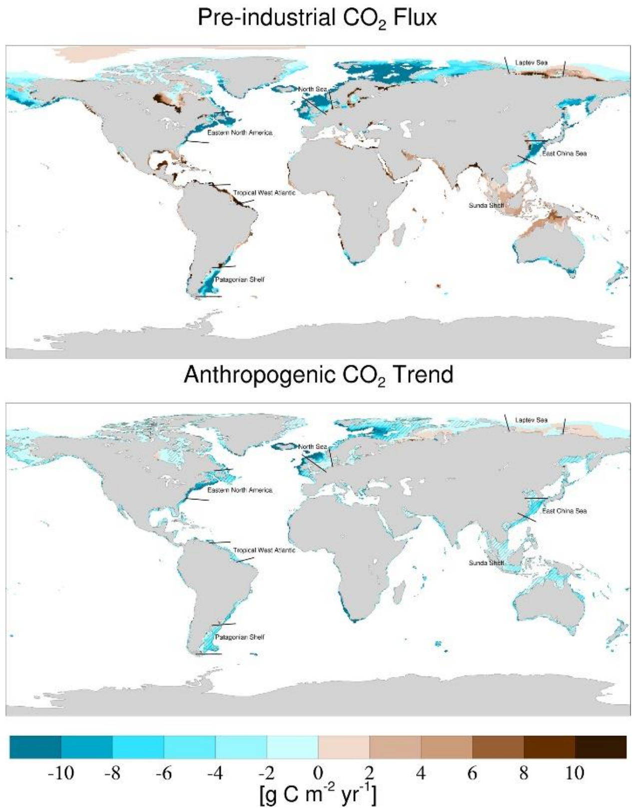

Figure: (a) Preindustrial continental shelf air-sea CO2 exchange (FCO_2), (b) anthropogenic FCO_2 estimated by calculating the FCO_2 trend over the 1800–2015 period and multiplying the trend by the total amount of simulation years. A positive CO_2 flux represents a flux from the ocean to atmosphere.

Using the same model, we also performed a series of simulations to quantify the effects of (1) increasing atmospheric CO_2 levels, (2) a changing physical climate and (3) alterations in inputs of terrigenous P and N on marine carbon cycling over the 1905–2010 period. Our simulations reveal that increased terrigenous nutrient inputs are the largest driver of change for the CO_2 uptake at the regional scale in the coastal ocean and enhance its global CO_2 uptake by 0.02 $PgCyr^{-1}$.

Citation:

Lacroix F., Ilyina T., Laruelle G.G. and Regnier P. (2021) Reconstructing the preindustrial coastal Carbon cycle through a global ocean circulation model: Was the global continental shelf already both autotrophic and a CO2 sink? Global Biogeochemical Cycles, 35 (2), doi: 10.1029/2020GB006603.

Lacroix F., Ilyina T., Mathis M., Laruelle G.G. and Regnier P. (2021) Historical increases in land-derived nutrient inputs may alleviate effects of a changing physical climate on the oceanic carbon cycle. Global Change Biology 27(21), 5491-5513, doi: 10.1111/gcb.15822.

Microbial biofilm to explain paradox observed in highly productive sea ice

A paradox is commonly observed in productive sea ice in which an accumulation in macro-nutrients (i.e., nitrate and phosphate) coincides with an accumulation of biomass. This paradox requires a new conceptual understanding of the biogeochemical processes operating in sea ice. we investigate This paradox has been investigated at three time series in Antarctic landfast sea ice, in which massive algal blooms are reported (with particulate organic carbon concentrations up to 3000 µmol l^{-1}) and with bulk nutrient concentrations exceeding seawater values up to 3 times for nitrate and up to 19 times for phosphate. Using a NPZD model approach, the presence of the microbial biofilm as a working explanation has been propose for this paradox. By creating micro-environments with distinct biogeochemical dynamics, as well as favouring nutrient adsorption onto decaying embedded organic matter, the biofilm allows the accumulation of the remineralization products (i.e., nutrients) in proximity of the sympagic community. In addition to provide a substrate that allow the sympagic community to grow attached to sea ice and to modify the intrinsic physical-chemical properties of the ice, the biofilm is suggested to play a role on the flux of matter and energy in this environment.

A schematic of the temporal evolution of the biofilm is shown below. In an early stage, the biofilm is thin and diffusive transport of metabolic substrates and products is fast. As the biofilm grows, diffusion can no longer bring substrates to the deeper layers. In these deeper layers, algal growth will cease, and cells will die. When the generation of metabolic products from respiration exceeds the loss by diffusion through the biofilm, nitrate can start accumulating and lead to the accumulation of nitrate observed at the bottom of highly productive sea ice. If the heterotrophic respiration in the biofilm is large enough, oxygen can even be depleted. In case the diffusion of oxygen from the seawater and brines is insufficient, anoxic zones could appear in areas with strong respiration.

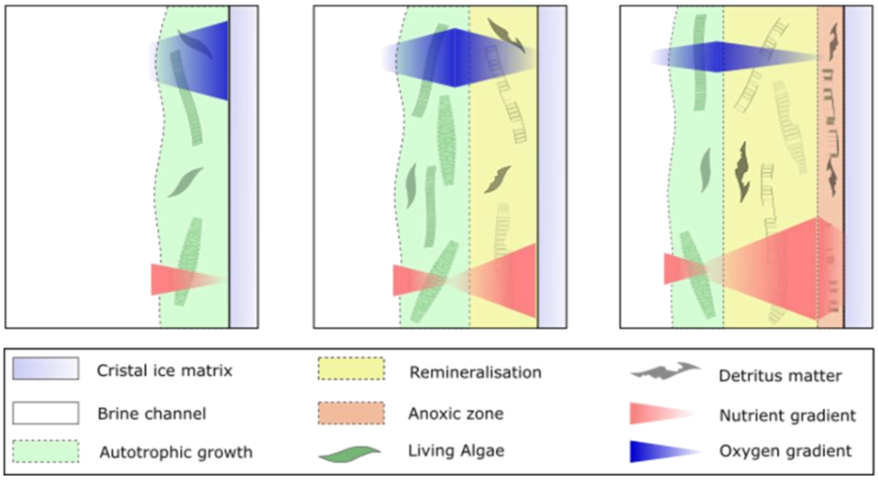

Figure: A temporal evolution of a biofilm can explain the localisation of different zones due to chemical heterogeneity. a Early in the season the biofilm is thin and substrates can diffuse deep into the film before being consumed. b As the season proceeds, the biofilm thickness increases and substrates can no longer penetrate full depth, algae in the deeper layers will start dying and a heterotrophic microbial community is established. C A strong recycling can consume all the oxygen in the deepest layer of the biofilm. If diffusion of additional oxygen into this layer is slow compared to remineralisation, this might result in anoxic zones in the deepest parts of the biofilm.

Citation: Roukaerts, A., F. Deman, F. Van der Linden, G. Carnat, A. Bratkic, S. Moreau, D. Lannuzel, F. Dehairs, B. Delille, J.-L. Tison, and F. Fripiat (2021). The biogeochemical role of a microbial biofilm in sea ice: Antarctic landfast sea ice as a case study. Elementa: Science of the Anthropocene 9(1):00134. doi:10.10525/elementa.2020.00134.

2. Activities/main accomplishments in 2021 (e.g., projects; field campaigns; workshops and conferences; model and data intercomparisons; capacity building; international collaborations; contributions to int. assessments such as IPCC; collaborations with social sciences, humanities, medicine, economics and/or arts; interactions with policy makers, companies, and/or journalists and media).

17-19 Aug. 2021:Annual BEPSII and ECV-Ice meeting (Bruno Delille and François Fripiat as co-organizer), online; ECV-Ice (SCOR working group) and BEPSII (SOLAS, SCAR and CLIC-supported research community)

20 Jan 2022: Kick-off meeting of Ice2Clouds, online, new SCOR working group (Bruno Delille and François Fripiat) on ": Coupling of ocean-ice-atmosphere processes from sea-ice biogeochemistry to aerosols and clouds".

3. List SOLAS-related publications published in 2021 (only PUBLISHED articles).
If any, please also list weblinks to models, datasets, products, etc.

Belliard J-P, S Hernandez, S Temmerman, RH Suello, LE Dominguez-Granda, AM Rosado-Moncayo, JA Ramos-Veliz, RN Parra-Narera, KP Ramirez, G Govers, **AV Borges** & **S Bouillon** (2022) Carbon dynamics and CO_2 and CH_4 exchange in the mangrove dominated Guayas river delta, Ecuador, Estuarine, Coastal and Shelf Science, https://doi.org/10.1016/j.ecss.2022.107766

Campbell, K., I. Matero, C. Bellas, T. Turpin-Jelfs, P. Anhaus, M. Graeve, **F. Fripiat**, M. Tranter, J.C. Landy, P. Sanchez-Baracaldo, E. Leu, C. Katlein, C.J. Mundy, S. Rysgaard, L. Tedesco, C. Haas, and M. Nicolaus (2021). Monitoring a changing Arctic: Recent advancements in the study of sea ice microbial communities. Ambio 51, 318-332.

Champenois W & **AV Borges** (2021) Net community metabolism of a Posidonia oceanica meadow, Limnology and Oceanography, 66, 2126–2140, https://doi.org/10.1002/lno.11724

Deman, F., D. Fonseca-Batista, A. Roukaerts, M.I. Garcia-Ibanez, E. Le Roy, E.P.D.N. Thilakarathne, **M. Elskens, F. Dehairs**, and **F. Fripiat** (2021). Nitrate supply routes and impact of internal cycling in the North Atlantic Ocean inferred from nitrate isotopic composition. Global Biogeochemical Cycles 35, doi:10.1029/2020GB006887.

Farmer, J.R., D.M. Sigman, J. Granger, O.M. Underwood, **F. Fripiat**, T.M. Cronin, A. Martinez-Garcia, and G.H. Haug (2021). Arctic Ocean stratification set by sea level and freshwater inputs since the last ice age. Nature Geoscience 14, 684-689.

Fay A. R., Gregor L., Landschützer P., McKinley G. A., Gruber N., Gehlen M., Iida Y., **Laruelle G**. G., Rödenbeck C., **Roobaert A.** and Zeng J. (2021) SeaFlux: harmonization of air–sea CO_2 fluxes from surface pCO2 data products using a standardized approach. Earth Syst. Sci. Data, 13, 4693–4710, doi: 10.5194/essd-13-4693-2021.

Fripiat, F., A. Martinez-Garcia, D. Marconi, S.E. Fawcett, S. Kopf, V.H. Luu, P.A. Rafter, R. Zhang, D.M. Sigman, and G.H. Haug (2021). Nitrogen isotopic constraints on nutrient transport to the upper ocean. Nature Geoscience 14, 855-861.

Geilfus N.-X, K.M. Munson, E. Eronen-Rasimus, H. Kaartokalli, M. Lemes, F. Wang, S. Rysgaard, **B. Delille**, 2021, Landfast sea ice in the Bothnian Bay (Baltic Sea) as a temporary storage compartment for greenhouse gases, 9(1):00028, Elementa doi.org/10.1525/elementa.2021.00028

Jacques, C., **C.J. Sapart, F. Fripiat, G. Carnat**, **J. Zhou, B. Delille**, T. Röckmann, C. Van der Veen, H. Nieman, and **J.-L. Tison** (2021). Sources and sinks of methane in sea ice: insights from stable isotopes. Elementa: Science of the Anthropocene 9(1), 00167. doi:10.1525/elementa.2020.00167.

Lacroix F., Ilyina T., **Laruelle G.G**. and **Regnier P.** (2021) Reconstructing the preindustrial coastal Carbon cycle through a global ocean circulation model: Was the global continental shelf already both autotrophic and a CO_2 sink? Global Biogeochemical Cycles, 35 (2), doi: 10.1029/2020GB006603.

Lacroix F., Ilyina T., Mathis M., **Laruelle G.G.** and **Regnier P**. (2021) Historical increases in land-derived nutrient inputs may alleviate effects of a changing physical climate on the oceanic carbon cycle. Global Change Biology 27(21), 5491-5513, doi: 10.1111/gcb.15822.

Ricour, F., **A. Capet**, F. D'Ortenzio, **B. Delille, M. Grégoire**, 2021. Dynamics of the deep chlorophyll maximum in the Black Sea as depicted by BGC-Argo floats. Biogeosciences 18, 755–774. doi:10.5194/bg-18-755-2021

Rosentreter JA, **AV Borges**, PA Raymond, BR Deemer, MA Holgerson, CM Duarte, S Liu, C Song, GH Allen, J Melack, B Poulter, D Olefeldt, TI Battin, BD Eyre (2021) Half of global methane emissions come from highly variable aquatic ecosystem sources, Nature Geoscience, 14, 225-230 https://doi.org/10.1038/s41561-021-00715-2

Roukaerts, A., F. Deman, F. Van der Linden, **G. Carnat**, A. Bratkic, S. Moreau, D. Lannuzel, F. **Dehairs, B. Delille, J.-L. Tison**, and **F. Fripiat** (2021). The biogeochemical role of a microbial biofilm in sea ice: Antarctic landfast sea ice as a case study. Elementa: Science of the Anthropocene 9(1):00134. doi:10.10525/elementa.2020.00134.

Royer C, AV Borges, Lapeyra Martin J, & **N Gypens** (2021) Drivers of the variability of dimethylsulfonioproprionate (DMSP) and dimethylsulfoxide (DMSO) in the Southern North Sea, Continental Shelf Research, 216, 104360, https://doi.org/10.1016/j.csr.2021.104360

Royer C. , N Gypens, P Cardol, AV Borges & **S Roberty** (2021) Response of dimethylsulfoniopropionate (DMSP) and dimethylsulfoxide (DMSO) cell quotas to oxidative stress in three phytoplankton species, Journal of Plankton Research, https://doi.org/10.1093/plankt/fbab052

Richir J, W Champenois, J. de Fouw & **AV Borges** (2021) Dimethylsulfoniopropionate and dimethylsulfoxide in Posidonia oceanica, Marine Biology, 168:159, https://doi.org/10.1007/s00227-021-03961-5

Sigman, D.M., F. Fripiat, A.S. Studer, P.C. Kemeny, A. Martinez-Garcia, M.P. Hain, X. Ai, X. Wang, H. Ren, and G.H. Haug (2021). The Southern Ocean during the ice ages: A review of the Antarctic isolation hypothesis, with comparison to the North Pacific. Quaternary Science Reviews 254, 106732, doi:10.1016/j.quascirev.2020.106732.

Terhaar J., Lauerwald R., **Regnier P**., Gruber N. and Bopp L. (2021) Around one third of current Arctic Ocean primary production sustained by rivers and coastal erosion. Nature Communications 12, 169, doi:10.1038/s41467-020-20470-z.

Wilson ST, AN Al-Haj, A Bourbonnais, C Frey, RW Fulweiler, JD Kessler, HK Marchant, J Milucka, NE Ray, P Suntharalingham, BF Thornton, RC Upstill-Goddard, TS Weber, DL Arévalo-Martínez, HW Bange, HM Benway, D Bianchi, **AV Borges**, BX Chang, PM Crill, DA del Valle, L Farías, SB Joye, A Kock, J Labidi, CC Manning, JW Pohlman, G Rehder, KJ Sparrow, PD Tortell, T Treude, DL Valentine, BB Ward, S Yang, LN Yurganov (2020) Ideas and perspectives: A strategic assessment of methane and nitrous oxide measurements in the marine environment, Biogeosciences, 17, 5809-5828, https://doi.org/10.5194/bg-17-5809-2020

4. Did you engage any stakeholders/societal partners/external research users in order to co-produce knowledge in 2021? If yes, who? How did you engage?

PART 2 - Planned activities for 2022 and 2023

1. Planned major national and international field studies and collaborative laboratory and modelling studies (incl. all information possible, dates, locations, teams, work, etc.).

- ECV-ice intercalibration of air-ice CO_2 fluxes and primary production in May 2022 in Cambridge Bay – Canada
- POLARCHANGE cruise on the RV Hesperides led by Manuel Dall'Osto and Rafel Simó from the Institut de Ciències del Mar/Spanish National Research Council in the northern part of the Weddell Sea in January-February 2023
- TANGO cruise led by Bruno Danis and the TANGO consortium in the West Antarctic Peninsula in February 2023 onboard the RV Australis

2. Events like conferences, workshops, meetings, summer schools, capacity building etc. (incl. all information possible).

- Annual BEPSII and ECV-Ice meeting (Bruno Delille and François Fripiat as co-organizer) likely in San Diego in April 2023; ECV-Ice (SCOR working group) and BEPSII (SOLAS, SCAR and CLIC-supported research community)
- BEPSII field school associated with the ECV-Ice intercalibration experiment in Cambridge Bay, May 2022
- CATCH online meeting, 9-13 May 2022 (https://www.catchscience.org/OpenScienceWorkshop)

3. Funded national and international projects/activities underway.

- **Multidisciplinary drifting Observatory for the Study of Arctic Climate** (MOSAiC, 2020-2021) research project funded by the F.R.S.-FNRS
- **Estimating Tipping points in habitability of ANtarctic benthic ecosystems under GlObal future climate change scenarios** (TANGO, Brain project, 2021-2025, funded by the Belgian Science Policy
- **SOurces and siNks of methAne and niTrous oxIde in the southerN oceAn** (SONATINA, 2022-2023) research project funded by the F.R.S.-FNRS
- **Budgeting source and sinks of CH4 and N2O in polar oceans** (Aquatic), Bilateral collaboration with China funded by the F.R.S.-FNRS, co-coordinator

4. Plans / ideas for future national or international projects, programmes, proposals, etc. (please indicate the funding agencies and potential submission dates).

- New SCOR working group Ice2Cloudds on ": Coupling of ocean-ice-atmosphere processes from sea-ice biogeochemistry to aerosols and clouds".
- BEPSII and CATCH communities are aiming to coordinate one (possibly several) survey in the Southern Ocean. There is a consensus that synergies between both communities are critical to unlock current key questions on air-sea exchange in ice-covered areas

5. Engagements with other international projects, organisations, programmes, etc.

- BEPSII (Biogeochemical Exchange Processes at the Sea ice Interfaces) joint SOLAS-CLIC-IASC-SCAR working group
- ECVice (Essential Climate Variable for sea ice) SCOR working group
- Ice2Cloud (Coupling of ocean-ice-atmosphere processes from sea-ice biogeochemistry to aerosols and clouds) SCOR working group

- SOOS – SO_FLUX task group on Air-Sea Fluxes
- CATCH (The Cryosphere and Atmospheric Chemistry) sponsored by SOLAS and IGAC

Comments