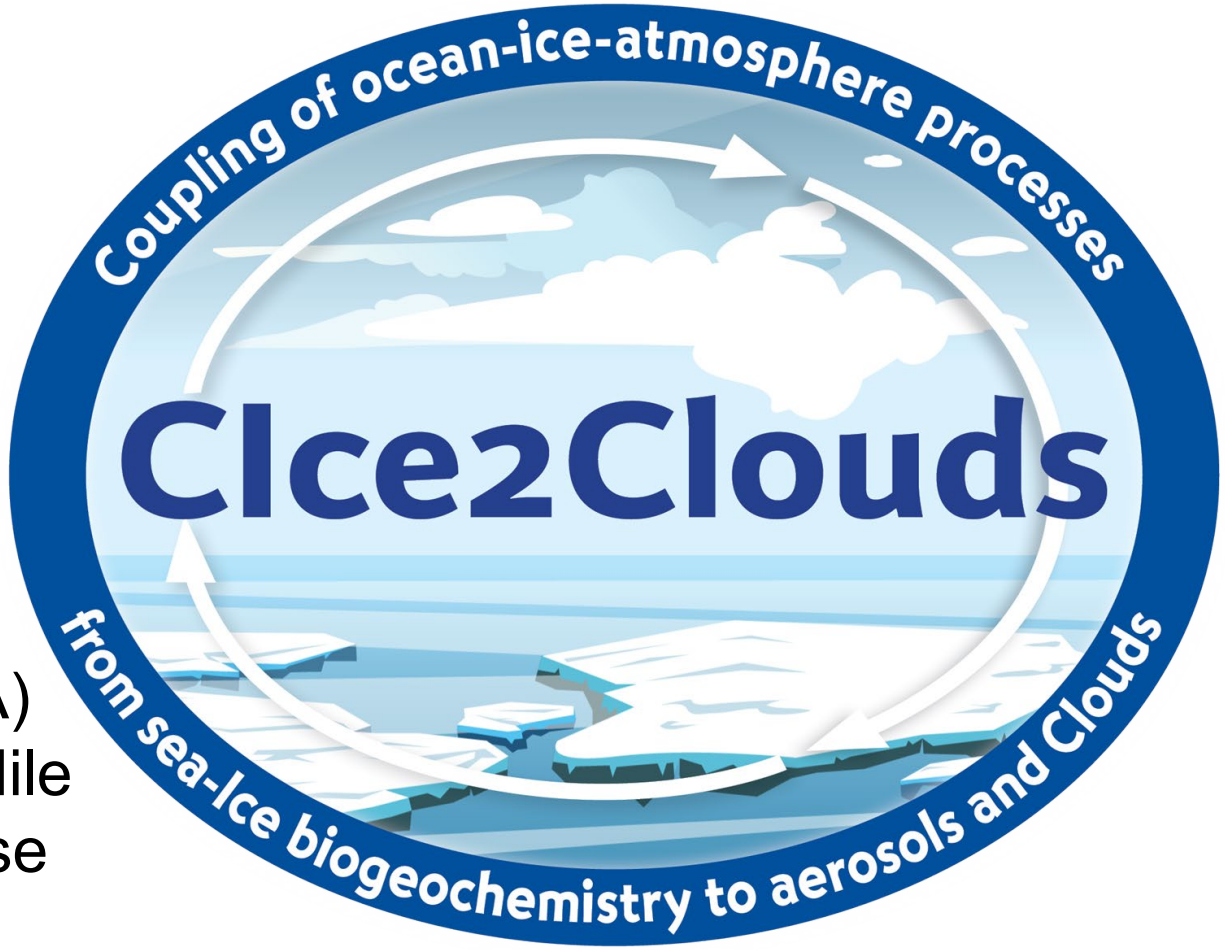
Coupling of ocean-ice-atmosphere processes: from sea-Ice biogeochemistry to aerosols and Clouds (CIce2Clouds)



Co-chairs:
Nadja Steiner (Canada) & Megan Willis (USA)
Full Members: Raul Cordero (Argentina), Odile Crabeck (Belgium), Markus Frey (UK), Hakase Hayashida (Japan), Anoop Marajan (India), Daiki Nomura (Japan), Jennie Thomas (France), Liyang Zhan (China) **+ associate members**

Website: www.cice2clouds.org

CIce2Clouds working group objectives (TORs)

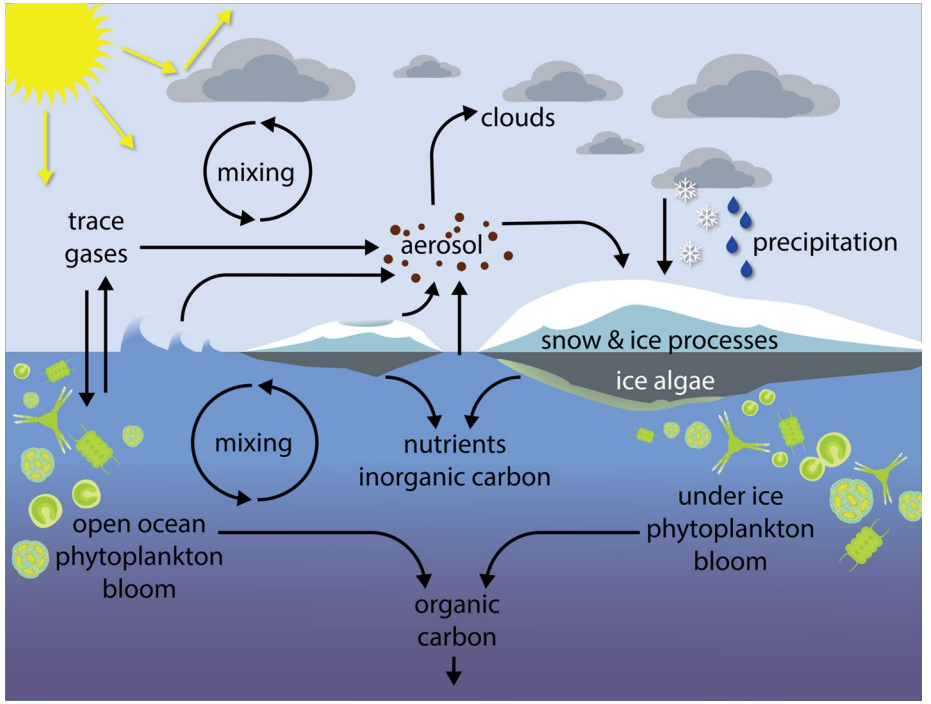
(O1) ***Synthesize key coupled biological and chemical systems that drive atmospheric reactive trace gas, aerosol, and cloud properties in polar ocean environments.***

(O2) ***To identify similarities and differences in controls on exchange processes between the Arctic and Antarctic O-SI-S-A systems.***

(O3) ***To develop a conceptual model of exchange processes in O-SI-S-A systems, focusing on key reactive trace gas and aerosol species prioritized in O1.***

(O4) ***To develop interdisciplinary campaign planning recommendations to guide future studies and address model and measurement gaps.***

(O5) ***To facilitate community and capacity building opportunities for sustainable multidisciplinary science at the O-SI-S-A interface.***



Key goal of CIce2Clouds is to improve communication and understanding among ocean, sea-ice and atmospheric scientists with respect to the exchange processes between interfaces and their impacts on clouds in the polar regions.

CIce2Clouds Activities since Fall 2022

1. ***Ongoing:*** subgroups for identified key compounds/processes (Sulfur-cycle, Nitrogen-cycle and Primary Aerosol) syntheses met regularly online to develop shared ocean-ice-atmosphere conceptual models and draft associated summary paper(s) (TORs 1 & 3). The tutorial paper started at the September 2022 meeting has progressed online and updated were presented at the September meeting (TOR4).
2. ***Online meeting*** to discuss potential S-cycle modelling experiments and an associated paper (continued at the September annual meeting)(TORs 1 & 3).
3. ***September 2023:*** 2nd in-person/hybrid meeting, Grenoble, France, before the Horizon2020 CRIceS meeting
    - **Outcomes:** Updates on subgroup and tutorial paper discussions, Discussions on CICe2Clouds processes in models, TOR 4 white paper writing session on CIce2Cloud campaign planning and recommendations
    - *Horizon2020-CRIceS meeting:* CIce2Clouds invited talk
4. ***Next meeting:*** November 2024 in Goa, India, before the SOLAS Open Science conference

Other activities: Maintained CIce2Clouds website; active/open community Slack Workspace and google drive; Encouraging participation outside WG membership. Recorded tutorial talks from the CIce2Clouds meeting in Cape Town and the online CATCH meeting (TOR5).

CIce2Clouds sub-groups (TOR1):

Synthesizing coupled systems

- **Primary aerosols**
- **Sulfur cycle**
- **Nitrogen cycle**
- **Other secondary aerosol precursors & reactive gases**

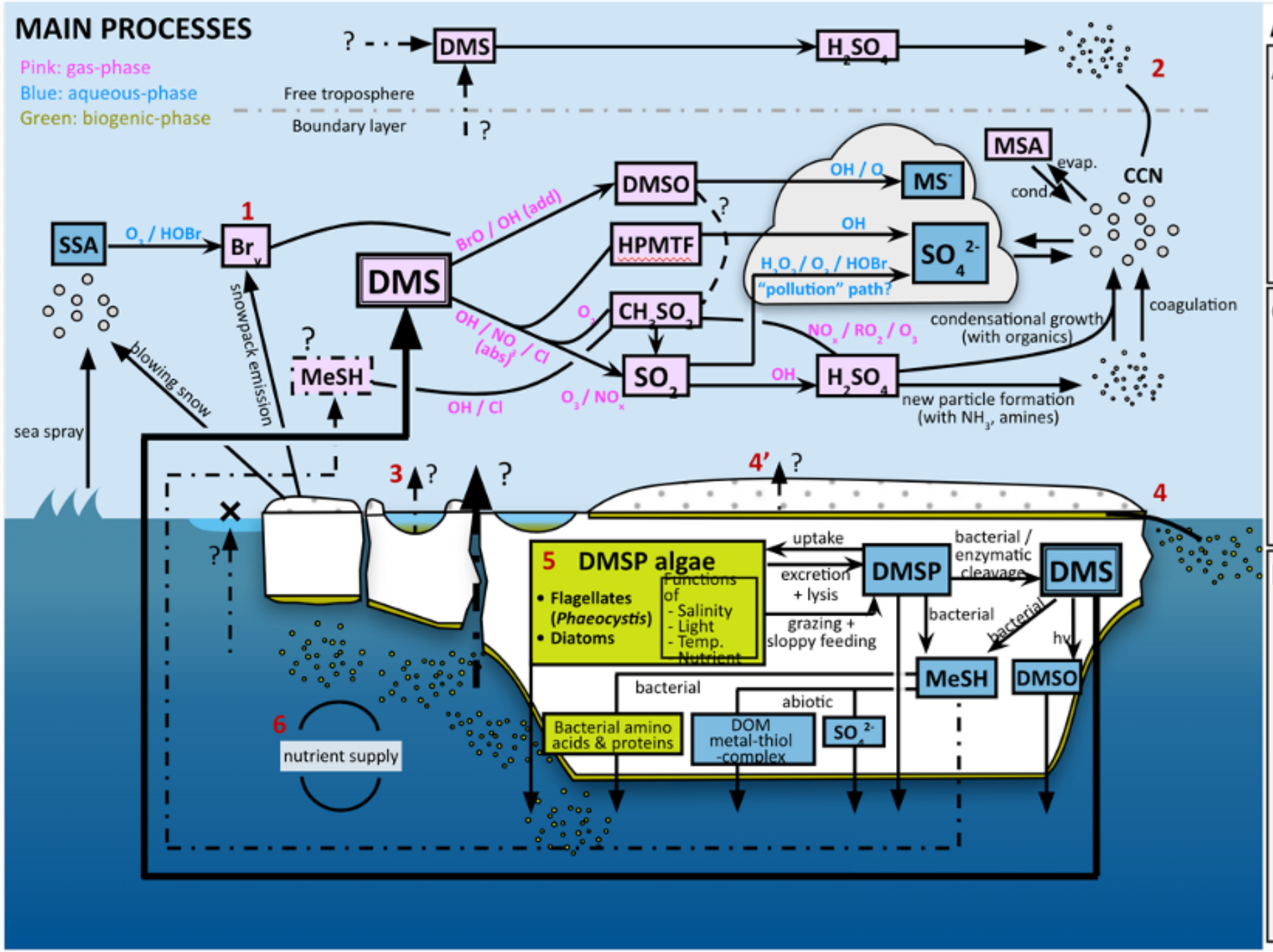
What understanding and parameterisations can we adopt from lower latitudes and which ones will need adjustment/revisions?

How do conceptual models differ in the Arctic and Antarctic? (TOR2, TOR3)

What are the key gaps in our knowledge that limit model representations of these key coupled systems?

Next slide: Example of in-development conceptual model from the S-cycle sub-group (TOR3)

Courtesy Sakiko Ishino and the S-cycle team



ARC/ANT DIFFERENCES

Atmosphere

1. Oxidants

- OH: common for both poles
- BrO: Arctic < Antarctic
- NO_3 (pollution): Arctic >> Antarctic

2. Contribution of FT-NPF

Frequently detected in the Antarctic, but less observational evidence in the Arctic.

OIA interface

3. Melt ponds

Arctic >> Antarctic

4. Slush layer intrusion and direct release

Arctic << Antarctic

In-sea-ice and ocean

5. Algae/Functional group and distribution(?)

6. Nutrient supply (?)

TOR3

CIce2Clouds sub-groups:

Anticipated Outcomes

1. Focused papers describing coupled conceptual models from each sub-group **(TOR3)**
   a. *Overarching goal:* Identify gaps and guide future observations and modelling efforts
   b. Focus on both poles – commonalities & differences across the O-SI-S-A interface **(TOR2)**
   c. Focus on seasonal pictures, perspectives for winter vs. summer, freezing and thawing seasons, including heterogeneity in ice-types

2. With respect to model parameterizations:
   a. How do mixed-surface processes need to be represented? Are spatial averages sufficient? – marginal ice zone, ice floes, PP patchiness

1. *"Overview of primary aerosol processes at the ocean-sea ice-snow-atmosphere interfaces in polar regions"*
2. *"Sulfur cycle in coupled ocean-sea ice-atmosphere systems"*
3. *"Nitrogen cycle in polar ocean-sea ice-atmosphere systems"*

- Significant involvement of Early Career Researchers (ECRs) in leadership of the sub-working groups, with support from more senior working group members
  - ➢ S-cycle & Primary aerosol sub-group conceptual model papers are led by ECRs

TOR4: Interdisciplinary campaign recommendations

Progress Toward CIce2Clouds Deliverable #2 ("A community driven framework…for designing joint oceanic and atmospheric observations …")

- *Initial steps:* Open discussion session CATCH Open Science Meeting (May 2022), leading to engagement with PICCAASO (piccaaso.org) and a white paper (Mallet et al 2023), discussion at the CICe2Clouds annual meeting in Sept 2022.
- *CIce2Clouds Workshop (Sept 10-11, 2023):*
  - White paper writing session, focus on:
    - Lessons learned from previous campaigns (ToDos and NotToDos)
    - Recommendations for "Add-Ons" to focused campaigns to close gaps in measurements across the O-SI-S-A interface
    - Modular and hierarchical guidelines for fully coupled experiments involving both communities
      - Key that such guidelines are available & peer-reviewed before a campaign is planned and executed
      - Build on exiting syntheses of methods, as available

TOR5: Community & skill building

- Overarching focus on diverse Early Career Researcher (ECR) engagement & training in a multidisciplinary context
- Open community meetings & open Slack Workspace
- **Progress Toward CIce2Clouds Deliverable #3 (Tutorial Review Paper & Associated Tutorial Lectures):**
  - **Goal:** Build a common language to facilitate sustainable multidisciplinary science across the O-SI-S-A interface and train ECRs ("What do we need to know from each other on either side of the O-SI-S-A interface?")
    - Tutorial-style review paper, *"From Sea Ice to Clouds: Fundamental Processes Underpinning Particle and Gas Exchange between the Polar Oceans and Atmospheres"*
    - *CIce2Clouds Workshop (Sept 23-24, 2022):* 12 tutorial talks on relevant (1) atmospheric processes, (2) ocean & sea-ice processes, and (3) exchange processes
    - These tutorial talks as well as tutorial lectures from the CATCH Open Science Meeting (May 2022) are available at https://www.cice2clouds.org/tutorials
    - *Sea-ice field school* preparation (collaboration with BEPSII - Biogeochemical Exchange Processes at Sea-Ice Interfaces and CATCH in March 2026, Saroma-Ko Lagoon, Japan)

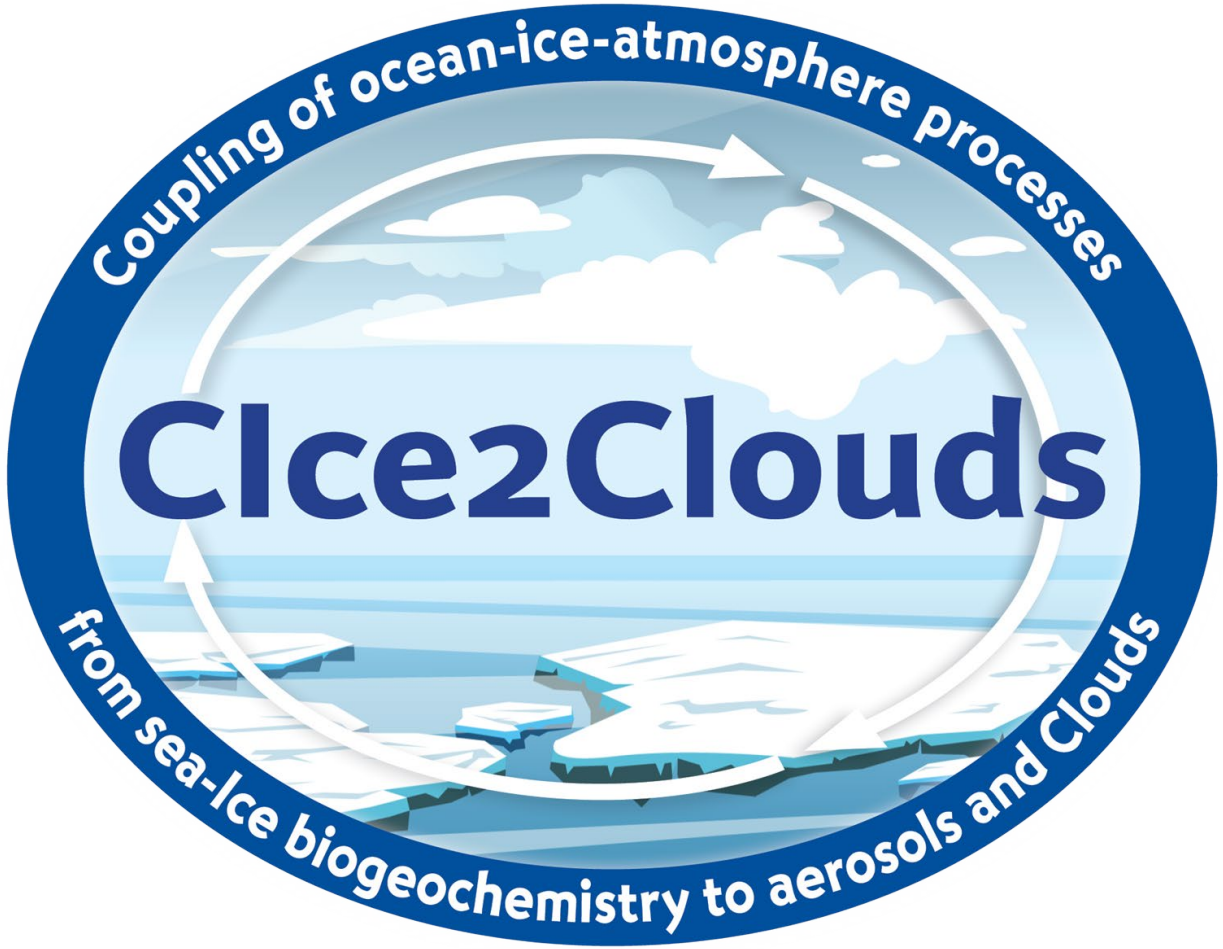
Publications

- *Differences and commonalities in air-ice-ocean processes in the Antarctic and Arctic, Discussion ses report, SOLAS OSC event report series: Nadja Steiner, Jessie Creamean, Jennie Thomas, Lisa Miller, Megan Willis, SOLAS OSC2022 - Event Report Issue27.pdf (solas-int.org)*
- *Coupling of ocean-ice-atmosphere processes: from sea-Ice biogeochemistry to aerosols and Clouds (CIce2Clouds) Nadja Steiner, Jessie Creamean, Jennie Thomas, Megan Willis, Lisa Miller, CIce2Clouds workshop report, SOLAS OSC event report series, SOLAS OSC2022 - Event Report Issue27.pdf (solas-int.org)*

CIce2Clouds Input:

- *Marc D. Mallet, Ruhi S. Humphries, Sonya L. Fiddes, Simon P. Alexander, Katye Altieri, Hélène Angot, N. Anilkumar, Thorsten Bartels-Rausch, Jessie Creamean, Manuel Dall'Osto, Aurélien Dommergue, Markus Frey, Silvia Henning, Delphine Lannuzel, Rémy Lapere, Gerald G. Mace, Anoop S. Mahajan, Greg M. McFarquhar, Klaus M. Meiners, Branka Miljevic, Ilka Peeken, Alain Protat, Julia Schmale, Nadja Steiner, Karine Sellegri, Rafel Simó, Jennie L. Thomas, Megan D. Willis, V. Holly L. Winton, Matthew T. Woodhouse;* ***Untangling the influence of Antarctic and Southern Ocean life on clouds****. Elementa: Science of the Anthropocene 5 January 2023; 11 (1): 00130. doi: https://doi.org/10.1525/elementa.2022.00130*
- *M.D. Willis, D. Lannuzel, B. Else, H. Angot, K. Campbell, O. Crabeck, B. Delille, H. Hayashida, M. Lizotte, B. Loose, K. M Meiners, L. Miller, S. Moreau, D. Normura, J. Prytherch, J. Schmale, N. Steiner, L. Tedesco, J.L. Thomas,* ***Polar Oceans and Sea Ice in a Changing Climate****, Accepted for the SOLAS Special Issue of Elementa: Science of the Anthropocene, 2023*

Several CIce2Clouds peer reviewed journal articles are in preparation and will be compiled within a special issue in Elementa Science for the Anthropocene, including an Introductory paper to CIce2Clouds



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BEPSII BIOGEOCHEMICAL EXCHANGE PROCESSES AT SEA ICE INTERFACES