solas event report

Report 27 I February 2023

SOLAS Open Science Conference 2022

25 - 30 September, 2022
Hybrid in Cape Town, South Africa

In this report

Figure 1: Participants of the SOLAS Open Science Conference 2022. Photo credit: SOLAS IPO.

The Surface Ocean-Lower Atmosphere Study (SOLAS) held its **8th Open Science Conference (OSC)** from 25-29 September 2022, hybrid in Cape Town, South Africa - a first SOLAS OSC in the Southern Hemisphere. Organised by a committee of 28 people from 15 countries, the conference welcomed nearly 200 ocean-atmosphere scientists from over 30 countries to share their research work and knowledge of SOLAS science and connect with colleagues from all over the world (Figure 1).

At the 8th instalment of the conference, the five Core Themes and three Cross-Cutting Themes outlined in the SOLAS 2015-2025 Science Plan and Organisation (Figure 2) were covered by 33 plenary talks and 124 poster presentations (Figure 3). Seven discussion sessions were convened to identify new frontiers to explore under the framework of the United Nations Decade of Ocean Science for Sustainable Development 2021-2030 (the Decade) and other international platforms. The conference also featured an Early Career Scientists Day (ECSD), which brought together 30 early career scientists during dedicated early career workshops on Grant and proposal writing and on Equality, Diversity, and Inclusion, as well as a networking event. Additionally, a 2-day side meeting was organised by the Working Group 163 of the Scientific Committee on Oceanic Research (SCOR) on Coupling of ocean-ice-atmosphere processes: from sea-Ice biogeochemistry to aerosols and Clouds (CIce2Clouds).

Core Theme 1, "Greenhouse gases and the oceans", focuses on the most significant long-lived greenhouse gases, such as CO_2, CH_4 and N_2O and their natural cycles in the ocean and atmosphere, which interact with anthropogenic inputs and lead to climatic feedback and environmental impacts. The session featured a keynote talk from Precious Mongwe from the Council for Scientific and Industrial Research, South Africa, on the impact of anthropogenic forcing on the Southern Ocean CO_2 sink.

Core Theme 2, "Air-sea interface and fluxes of mass and energy", is dedicated to oceanic and atmospheric processes, driven for instance by waves, bubbles or surfactants, which influence the transfer of mass and energy between the ocean and atmosphere. Meghan Cronin from the National Oceanic and Atmospheric Administration, USA, introduced her work on large-scale patterns of warm layer vs. cool skin corrections to bulk sea surface temperature and reflections on the Observing Air-

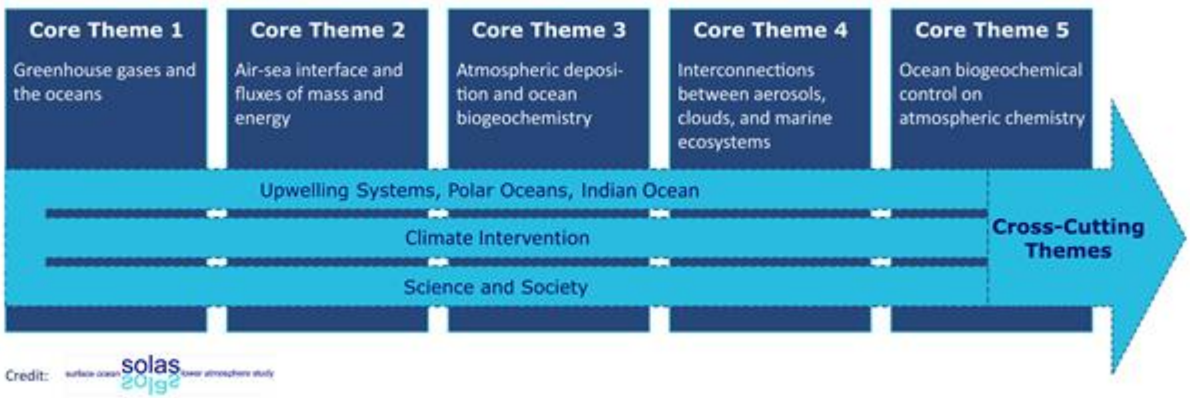

Figure 2: The five Core Themes and three Cross-Cutting Themes of the SOLAS 2015-2025 Science Plan and Organisation.

Sea Interactions Strategy (OASIS).

Core Theme 3, “Atmospheric deposition and ocean biogeochemistry”, explores the impact of particles of continental origin which enter the ocean from the atmosphere. These particles can be from natural processes, such as dust or volcanic eruptions, or human activities, such as the burning of fossil fuels and biomass or agriculture. The keynote talk of this session was given by Minako Kurisu from the Japan Agency for Marine-Earth Science and Technology, Japan, on application of iron isotope ratios for a better understanding of the iron cycle in the surface ocean and lower atmosphere.

Core Theme 4, “Interconnections between aerosols, clouds, and marine ecosystems”, is dedicated to understanding how aerosols, clouds, and marine ecosystems form a system as a whole, in which change in one component is manifested in another. Bingbing Wang from Xiamen University, China, gave a keynote talk on micro-spectroscopic characterisation and ice formation potential of marine related aerosol particles.

Core Theme 5, “Ocean biogeochemical control on atmospheric chemistry”, focuses on ocean emissions of aerosols and reactive gases and their impacts on atmospheric photochemistry, air quality and stratospheric ozone. Taking the upper-ocean dimethylsulfide cycling and its impact on aerosols in polar regions as an example, the keynote speaker of this session, Martí Galí, from the Institut de Ciències del Mar, Spain, talked about the gaps in ocean biogeochemistry-atmospheric chemistry studies from weather to climate scales.

Cross-Cutting Theme on Integrated Topics is dedicated to regional, high sensitivity, and high-priority oceanic systems where 5-Core Theme integrated studies are required and urgent, such as upwelling systems, polar oceans and sea ice and the Indian Ocean. The keynote talk given by Moagabo Ragoasha from the University of Cape Town, South Africa, addressed the inconsistencies of observations and climate models in the impacts of climate change on the Eastern Boundary Upwelling Systems. Odile Crabeck from the Université de Liège, Belgium, gave a broad overview of the role of sea ice biogeochemistry processes in the polar ocean and presented how the sea ice communities tackle the challenges. Zouhair Lachkar from New York University Abu Dhabi, United Arab Emirates, talked about examples of recent advances and gaps in understanding of the air-sea interaction and physical-biogeochemical coupling in the Indian Ocean.

Cross-Cutting Theme on Science and Society focuses on SOLAS research with social relevance and on activities which have a direct impact on society, such as air quality, human health, ship emissions, marine resources, and climate regula-

Figure 3: Photo gallery of plenary sessions and poster sessions. Photo credit: SOLAS IPO.

tion. The keynote talk given by Edem Mahu from the University of Ghana, Ghana, discussed ways by which science can effectively contribute to addressing immediate and unforeseen societal challenges.

Cross-Cutting Theme on Climate Intervention explores climate intervention approaches and their environmental and societal impacts. The keynote talk given by Nadine Mengis from the Helmholtz Centre for Ocean Research Kiel, Germany, was about the feasibility, uncertainties, and contribution of carbon dioxide removal to net-zero.

Cape Town was the ideal coastal city to host the SOLAS OSC. The South Africa's "Mother City" is surrounded by the Atlantic and Indian Oceans, which strongly influence the local climate, and is also a gateway city to the Southern Ocean and Antarctica. The Benguela upwelling system on South Africa's west coast is one of the world's most productive ecosystems, supporting a diversity of socio-economically important fisheries, and is the focus of active cross cutting SOLAS research. To the east is the Agulhas Current, the strongest western boundary current on Earth, that transports heat and salt from the Indian to the Atlantic Ocean, thus playing a critical role in global ocean circulation. South Africa also has a strong geographic advantage for conducting research in the Southern Ocean, as many SOLAS scientists will know from time spent in Cape Town harbor before and after sampling expeditions. SOLAS scientists have explored the approximately 4000 km^2 of open and ice-covered ocean that separate Cape Town from Antarctica in the context of all the SOLAS science themes. Additionally, the Cape Point Global Atmosphere Watch station, located 60 km south of Cape Town, hosts a variety of research platforms developed to investigate the marine atmosphere. Attended by over 40 scientists from South Africa, the OSC will further boost SOLAS science in the country and the region.

After the conference, the 17 members of the International SOLAS Scientific Steering Committee met in a hybrid mode. This 2-day meeting focused on discussions of current research issues and their implementation, as well as the future of SOLAS science and organisation. For example, for the Core Theme 3, SOLAS intends to focus more intensively on fire emissions as a source of nutrients to different ocean basins and their societal impacts. Following a discussion session at OSC 2022 on "UN Decade of Ocean Science Proposal: Aerosol Exchange with Marine Ecosystems" and a COP27 side event on "Wildfire increase, a challenge for Earth system and societies", SOLAS will organise a workshop on Fire science Learning AcRoss the Earth system (FLARE) in 2023, and eventually target on a Decade programme around this topic.

The next international SOLAS Open Science Conference is scheduled for 2024.

Authors

Dr. Li Li
SOLAS Co-Executive Director
State Key Laboratory of Marine Environmental Science, China
lili34@xmu.edu.cn

Dr. Jessica Gier
SOLAS Co-Executive Director
University of Galway, Ireland
jessica.gier@universityofgalway.ie

Dr. Katye Altieri
SOLAS SSC member, Chair of the OSC 2022 Local Organising Committee
University of Cape Town, South Africa
katye.altieri@uct.ac.za

Early Career Scientist Day

Inge Deschepper[a], Dr. Moagabo Ragoasha[b], Sive Xokashe[b], Raquel Flyn[b] and Asmita Singh[c]

[a] Université Laval, Quebec. Contact: inge.deschepper.1@ulaval.ca
[b] The University of Cape Town. Contact: moagaboragoasha@uct.ac.za, sive.xokashe@gmail.com, flyraq001@myuct.ac.za
[c] University of Stellenbosch, South Africa and Southern Ocean Carbon-Climate Observatory, CSIR. Contact: Asmita.Singh0907@gmail.com

The SOLAS OSC 2022 started off with the Early Career Scientist Day (ECSD), which was held on the 25th of September, with 23 in-person and 10 online participants (Figure 4). The day was organised by the ECSD committee that consisted of Inge Deschepper (committee chair, Université Laval), Raquel Flynn (University of Cape Town), Dr. Moagabo Ragoasha (University of Cape Town), Sive Xokashe (University of Cape Town) and Dr. Asmita Singh (University of Stellenbosch and SOCCO, CSIR).
The ECSD was designed to upskill the SOLAS ECS's in different areas of their professional career. The day commenced with a workshop on "Grant and Proposal Writing: Tips and Tricks", presented by Dr. Ramontsheng Rapolaki, a researcher at the Agricultural Research Council in South Africa (Figure 5A). Dr. Rapolaki provided guidance on where and how to start with a proposal as well as tips to ensure you are as successful as possible, but with the knowledge that you may not receive all the grants you apply for. The workshop ended with the organisational committee providing the participants with a book-

Figure 4: Group photo of all Early Carrer Scientist Day participants following Dr. Rapolaki's Grant and Proposal workshop. Photo credit: Jessica Gier.

let collated with all the tips and tricks collected from both experienced and young ECS's that have written and assessed grant applications. Some of the main tips provided were: start early, follow the rules and guidelines as closely as possible, be clear about your objectives, be realistic in your budget, and ensure you have a good proofreader.

The second workshop was on "Diversity, Equity and Inclusion (DEI)", presented by Kirsten Klopper, a Change Management Coach (Figure 5B). The workshop was to raise awareness of one's privilege and bias within our personal and professional careers. We participated in a couple of exercises to identify our privileges depending on our origin and institutional reputation at different levels of the scientific framework. We were also given tools to become more cognisant of our own bias and become allies to those who experience inequality and discrimination, whether outright or subtle within the field of science.

At the end of the workshops, the in-person participants headed to the Cape Point National Park to visit the South African Weather Station (SAWS), which is part of the NOAA Global Monitoring Laboratory program (Figure 6). The participants were given a tour of the facility, learning how measurements were taken for carbon dioxide, methane, nitrous oxide, and ozone with various instrumentation. Due to the station's position, it is ideal for measuring air masses that have passed over the South Atlantic and the Southern Ocean in winter and the air masses that come from the Southern African land mass in summer. Once the tour was over, the ECS's could hike to Cape Point and enjoy some of the nature and breathtakingly tranquil scenery the area has to offer.

The ECSD was funded by SCOR and travel grants that enabled participants to participate in-person and online were funded by both PICES and SCOR. The ECSD committee would like to thank the funding agencies as well as the SOLAS IPO and Local Organising Committee for all their help and guidance throughout the organisational process.

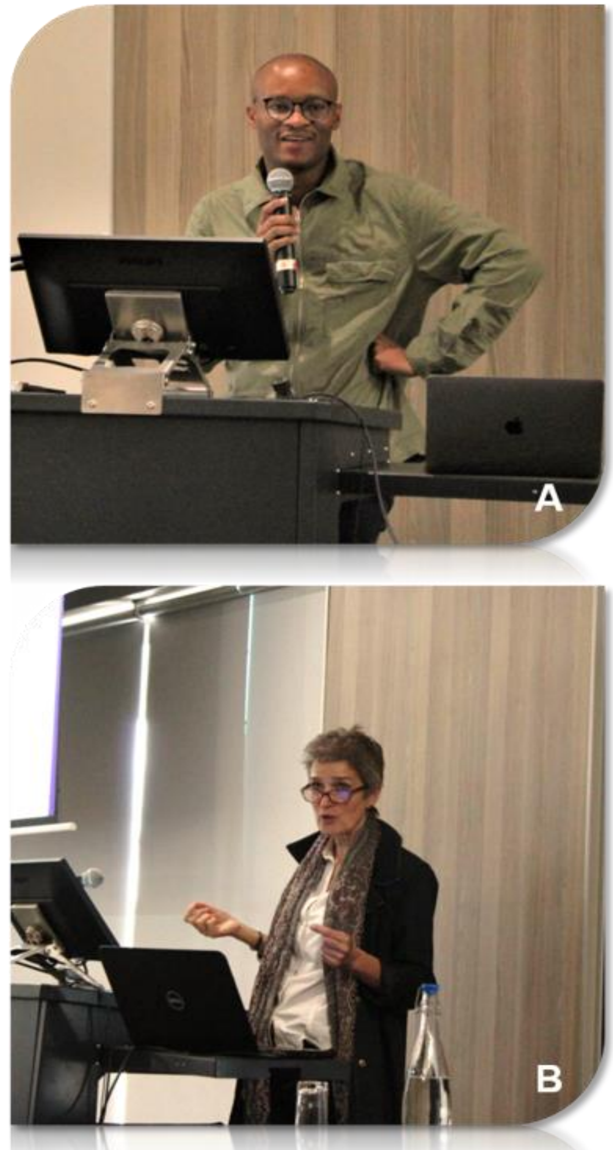

Figure 5: **A:** Dr. Ramontsheng Rapolaki giving the ECS participants invaluable advice on writing grants and proposals. **B:** Kirsten Klopper engaging with the ECS participants on DEI within science. Photo credit: Raquel Flynn.

Figure 6: Group photo of the Early Carrer Scientist Day participants at the South African Weather Service weather station at Cape Point. Photo credit: Raquel Flynn.

SOUTH AFRICA | 2022

CIce2Clouds workshop

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

Nadja Steiner[a], Jessie Creamean[b], Jennie Thomas[c], Megan Willis[b], Lisa Miller[a]

[a] Institute of Ocean Sciences, Fisheries and Oceans Canada, Victoria, Canada.
Contact: Nadja.Steiner@dfo-mpo.gc.ca, Lisa.Miller@dfo-mpo.gc.ca
[b] Colorado State University; Fort Collins, U.S.A.. Contact: jessie.creamean@colostate.edu, Megan.Willis@colostate.edu
[c] Institute of Environmental Geosciences (IGE), Grenoble, France.
Contact: jennie.thomas@univ-grenoble-alpes.fr

A discussion session at the SOLAS conference in Sapporo, Japan, in 2018 brought together the ocean and sea-ice oriented BEPSII (Biogeochemical Exchange Processes at Sea-Ice Interfaces) community and the atmospheric chemistry and sea-ice oriented CATCH (Cryosphere and ATmospheric CHemistry) community. This session triggered efforts to propose a new SCOR working group, Coupling of ocean-ice-atmosphere processes: from sea-Ice biogeochemistry to aerosols and Clouds (CIce2Clouds, www.cice2clouds.org), which was granted in fall 2021.

The working group aims at (1) synthesising and refining the conceptual representation of relevant processes and, (2) addressing key uncertainties in the biological and chemical controls on atmospheric chemistry, aerosol and clouds in polar ocean environments.

The group had its first hybrid meeting attached to the SOLAS Open Scienec Conference in Cape Town, September 23-24, 2022 (Figure 7). Through this report we are taking the opportunity to introduce ourselves. Following several online meetings since initiation this hybrid meeting was driven by the CIce2Clouds working group objectives:

O1: To prioritise key coupled biological and chemical systems that drive atmospheric reactive trace gas, aerosol, and cloud properties in polar ocean environments. Synthesise expertise from ocean, sea-ice, snow, and atmospheric chemistry communities to provide a hierarchy of chemical species that reflect common overlapping science questions.

O2: To identify similarities and differences in controls on exchange processes between the Arctic and Antarctic ocean-sea ice-snow-atmosphere (O-SI-S-A) systems. Compare and contrast common sea-ice and snow properties at both poles. Use this polar ocean comparison to describe how sea-ice properties control exchange processes, and constrain projections of future changes.

O3: To develop a conceptual model of exchange processes in O-SI-S-A systems, focusing on key reactive trace gas and aerosol species prioritised in O1. Conceptual model evolution will be based on existing observational and numerical expertise, and will reflect the impact of heterogeneity in sea-ice environments at present and under future climate change scenarios.

O4: To develop interdisciplinary campaign planning recommendations to guide future studies and address model and measurement gaps. Building on the conceptual model (O3), we will identify future needs in observations and model parameterisations, and outline requirements for fully integrated, multidisciplinary and collaborative O-SI-S-A field, laboratory, and modeling research.

And **O5** to facilitate community and capacity building opportunities for sustainable multidisciplinary science at the O-SI-S-A interface. Engage scientifically emerging countries and early career scientists in both observational and modeling communities.

Figure 7: Group photo of the CIce2Clouds workshop participants associated with the SOLAS Open Science Conference 2022 in Cape Town, South Africa. Names of participants (on screen, left to right, top to bottom): Kerri Pratt, Ilka Peeken, Jacqueline Stefels, Xin Wang??, Remy Lapere, Hyung-Gyu Lim, Markus Frey, Julia Asplura, Hakase Hayashida, Anisbel Leon Marcos, Mark Mallet, Sakiko Ishino, Antoine Haddon, Koj Tajimara, Louis Marelle. In-person left to right: Lisa Miller, Jessica Burger, Nadja Steiner, Katye Altieri, Marcello Vichi, Inge Deschepper, Jennie Thomas, Paul Zieger, Jessie Creamean. Photo credit: Jesica Gier.

During the workshop, we began collaboration on a tutorial-style review paper, focused on fundamental concepts that link sea-ice biogeochemistry with atmospheric chemistry and clouds (i.e., "what atmospheric chemists need to know about the ocean/snow/sea-ice system and what ocean biogeochemists need to know about the polar atmosphere"). In order to facilitate the paper, the first day of workshop was a series of fundamental talks on processes that link atmospheric chemistry and ocean/ice biogeochemistry. These talks covered atmospheric mixing and oxidation, new particle formation, aerosols as cloud nuclei, sea-ice brine transport, organic source materials, sea ice microbes, the seasonal cycle of biogenic gases in polar oceans, snow lofting, air-sea gas exchange in ice-covered regions, wave breaking and bubble bursting, and atmospheric particle deposition. The follow-up discussion identified additional topics that should be included in the paper, specifically cloud physics, meteorology and boundary layers, melt ponds and frost flowers, microlayers, , long range material transport, and seasonal cycles. The paper is intended to provide the basic understanding necessary for our communities to effectively work together to identify research gaps and pursue new investigations . Given the relatively small but enthusiastic group of experts present, we made a good start on the paper.

In addition, the working group discussed progress in three CIce2Clouds subgroups: 1) Sulfur cycle, 2) Nitrogen cycle, and 3) Primary aerosols and links to ice nucleating particles and cloud condensation nuclei. Subgroup discussions were formatted in joined online and in-person break-out groups. Building on earlier subgroup meetings, the groups discussed joined atmosphere-ice-ocean conceptual models and outlines of coupled synthesis papers. Again, the comparison of the Arctic and Antarctic is a key component. To support this discussion, a keynote lecture comparing Arctic and Antarctic sea ice was provided by Dr.

Christian Haas and a related discussion session was hosted at the SOLAS conference later in the week.

One component of CIce2Clouds is to support the planning of an interdisciplinary field campaign. Leveraging experience from past interdisciplinary studies and scientific expertise within the working group, we aim at developing recommendations to guide future interdisciplinary studies, focussing on approaches to campaign planning that best facilitate integration of atmospheric and sea-ice biogeochemical observations and modelling. At the workshop, it was decided to host an online community workshop in 2023 that focuses on developing these recommendations.

Towards the end of the meeting the group reviewed plans, SCOR terms of references, and future work and meetings. The latter includes plans for an Early Career Scientist field school at Saroma-Ko Lagoon in Hokkaido, Japan, ideally co-organised with BEPSII and CATCH. Ideas are evolving and discussions have started, so stay tuned. CIce2Clouds will have its next meeting in September 2023 in Grenoble, linked to the Horizon2020 project Climate relevant interactions and feedbacks: the key role of sea ice and snow in the polar and global climate system (CRIceS). CIce2Clouds embraces new participants, particularly earlier career scientists who feel their work might contribute or benefit from the group. Just check out our website (www.cice2clouds.org/) and get in touch.

UN Decade of Ocean Science Proposal: Aerosol Exchange with Marine Ecosystems

Conveners: Douglas Hamilton[a], Cecile Guieu[b], Erik van Doorn[c]
Rapporteurs: Morgane Perron[d]

[a] North Carolina State University, Raleigh, North Carolina, USA. Contact: dshamil3@ncsu.edu
[b] Laboratoire d'Océanographie de Villefranche, Sorbonne University, Villefranche sur Mer, France. Contact: cecile.guieu@imev-mer.fr
[c] Walther Schücking Institute for International Law, Kiel University, Kiel, Germany. Contact: edoorn@wsi.uni-kiel.de
[d] Laboratoire des Sciences de l'Environnement Marin, Institut Universitaire Européen de la Mer, 29280 Plouzané, France. Contact: morgane.perron@univ-brest.fr

Research priorities of SOLAS are at the heart of the UN Decade of Ocean Science for Sustainable Developement, directly addressing the Ocean Decade challenges #1, #5, #7 and #10. To date, only 2 of the 304 UN Ocean Decade actions investigate the atmosphere-ocean interface, and none of them is based on field and laboratory observations. The motivation behind this session (Figure 8) was that SOLAS seems to hold the best position to lead a programme endorsement proposal focusing on interactions at the air-sea interface to the next relevant UN Decade of Ocean Science call.

To maximise the impact of a successful endorsement, this session proposed to assess the community interest and to open discussions around a future SOLAS programme endorsement, its scope, and key partners. Initially, the impact of fire emissions on ocean ecosystems and societies was proposed, with a set of scientific and societal questions to be addressed raised to SOLAS community by the convenors.

The community was unanimous on that SOLAS should lead a programme proposal for endorsement by the UN Decade of Oceans. Such endorsement would shed light on SOLAS work to a wider audience while enabling easier communication with policymakers and easier access to research funds. A UN Decade programme endorsement would also encourage new investigations from developing countries on SOLAS research topics.

A contrasting debate took place on whether a single focus on fire emissions was too specific to constitute a programme proposal or to raise a wide interest within the SOLAS community. A wider SOLAS programme proposal was therefore suggested, the latter could endorse more focused projects on specific research topics at the air-sea interface, for example wildfires, shipping emissions and agricultural emissions.

The community agreed that a UN Decade programme should explore beyond the scientific aspects of SOLAS research and include future changes at the air-sea interface, the associated impact on marine ecosystems, including the upper trophic levels, and, ultimately, the impact on humans (through fisheries, ocean ecosystem services, coastal tourism, blue economy). The legal aspect of atmospheric pollution should also be addressed in this future programme.

A UN Decade programme needs to reach a wide audience. To reach this goal, it was recommended that the future SOLAS programme proposal addresses tangible research and societal questions spanning over short timescale of a decade or two (maximum). Community science was also mentioned as a key tool to involve the public and young generations into a future SOLAS programme.
At the end of the session, the question on how to best coordinate diverse topics under a UN Decade programme endorsement proposal, remained of. One suggestion under consideration is for SOLAS to host a broad programme on the air-sea interface. Such programme would enable the endorsement of more focused projects proposed by the SOLAS community or by other re-

Figure 8: Discussion session on a future UN Ocean Decade programme proposal. Photo credit: Jessica Gier.

search groups such as GEOTRACES or the new SCOR WG167. This programme would therefore facilitate coordination and discussion between projects. We welcome suggestions from the community on this idea.

SOUTH AFRICA | 2022

SOLAS Science & Society: building upon past achievements & future possibilities

Conveners: Erik van Doorn[a], Christa Marandino[b]

[a] Walther Schücking Institute for International Law, Kiel University, Kiel, Germany. Contact: edoorn@wsi.uni-kiel.de
[b] GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany. Contact: cmarandino@geomar.de

Since the 2015 SOLAS Open Science Conference in Kiel, SOLAS Science & Society has worked on how to increase interaction between natural scientists and social scientists on the one hand and the interaction with society as a whole - especially stakeholders - on the other. In this session, we engaged the broader SOLAS community in this work. One important consideration is how we present ourselves and ask what SOLAS can bring to new topics. These new topics provide the opportunity to make our case as a large group and could be used to advertise SOLAS. In relation to the former, ideas were proposed to form a network or write a white paper. Regarding the latter, we should consider attending Future Earth's Sustainability Research & Innovations Congress(es).

We introduced the achievements so far, mainly about three main topics: valuing carbon in the ocean, air-sea interaction and policy, and ship emissions. Moreover, we discussed if and how we could build upon these achievements by addressing different opportunities for cooperation. We asked the community about which new topics should be explored, such as harmful algae blooms and the effects of marine plastics at the ocean-atmosphere interface (Figure 9). This conversation laid the ground-work for a second SOLAS Science & Society workshop that we would like to organise in October 2023, in Galway, Ireland. The attendees of this workshop should be diverse. It might be a good idea to continue the topic of nature-based solutions to climate change but this topic is in need of further definition. This topic would, however, link directly to what some participants in the discussion session called 'the climate emergency' and commented that now is a good time to work on this crucial theme. For the publication of any scientific outcomes, we could consider Nature Scientific Reports, which has begun a Collection 'Ocean-based climate actions'.

Figure 9: Discussion session on SOLAS Science & Society: building upon past achievements & future possibilities. Photo credit: Jessica Gier.

Within the topics on climate, it is also necessary to consider the environmental consequences of reaching net zero emission of greenhouse gases. SOLAS Science & Society might also be useful to increase observations of the ocean, for the good of society.

Suggested new topics are the ocean and human health, even though much work is already going on concerning this topic, ocean cities and citizen science. Crucial is also funding to engage the Global South. Society as a whole also includes the involvement of industry, for example. Yet it can be difficult to convince stakeholders to join. Some participants are of the opinion that we should not include non-scientific stakeholders as along as we have not sorted out ourselves within the scientific community.

Another link to society is the commu-nication of institutional frameworks and gaps in policy. SOLAS is well set-up to contribute to this. We should consider cooperation with the World Maritime University in Malmö, Sweden, and research the possibilities that exist within the United Nations Decade of Ocean Science for Sustainable Development.

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Strengthening Partnerships between OASIS and the Global South

Conveners: Christa Marandino[a], Meghan Cronin[b], Warren Joubert[c], Sebastiaan Swart[d]

[a] GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany. Contact: cmarandino@geomar.de
[b] NOAA Pacific Marine Environmental Lab, Seattle, USA. Contact: Meghan.F.Cronin@noaa.go
[c] South African Weather Service, Cape Town, ZA. ContactWaren.Joubert@weathersa.co.za
[d] University of Gothenburg, Gothenburg, Sweden. Contact: Sebastiaan.Swart@marine.gu.se

Observing Air-Sea Interactions Strategy (OASIS) works over many channels to build a sustainable air-sea observations network, complete with FAIR data and products. Observations of air-sea interactions are used to forecast floods, droughts, marine heatwaves, severe storms, and climate variability, as well as to monitor ocean CO_2 absorption and resulting impacts on marine ecosystems. This network will revolutionise our ability to interrogate impacts from multiple stressors on ecosystems and build state-of-the-art ecological forecasts. However, we must work together to achieve these goals. Our "Theory of Change" turns the challenge of measuring multiple co-located parameters into a transformative opportunity to co-design a fit-for-purpose observing system. Multi-functional platforms are not only more economical than multiple single-function platforms, they also encourage collaborations across expertise. By developing best practices and technical readiness procedures, and a culture of mentorship and partnership, the capacity of the observing system could be significantly expanded while providing opportunities for Early Career Ocean Professionals and scientists from the Global South, as well as to engage industry partners.

During the discussion session (Figure 10), OASIS

Figure 10: Discussion session on Strengthening Partnerships between OASIS and the Global South. Photo credit: Jessica Gier.

presented its structure and working format. We highlighted that we want to make global observations that are used globally and for this we want to foster a culture of mentorship and partnership. Some of the tools we would like to use for these purposes are best practices and FAIR principles. Also, we introduced some of the recent OASIS accomplishments.

Finally, we asked the audience for input on how OASIS can strengthen its partnership with the Global South. Our objectives were/are to connect with the air-sea interactions community in the Global South and increase our mutual visibility. In addition, we would like to engage and listen to the needs of Global South scientists and stakeholders. We seek increased participation on our Theme Teams from the Global South and from SOLAS and we would like to develop materials/actions targeting the OASIS-related needs of the Global South.

Some of the issues and ideas that came of the discussion are as follows:

- Problems with repairs/standards - calibration facilities are needed
- More regional science should get published
- Bolstering more regional communities to avoid reliance on the international community
- More engineering or technical partnership/collaboration
- Understand and avoid helicopter science
- In some Global South areas, the cost of one publication is equivalent to salary for 6 months - how can this be alleviated?
- Internationally, we should amplify, connect, partner, and elevate
- Develop best practices that can be used by everyone
- Facilitate better money flows
- Facilitate open data, cloud computing, open servers (also with software and curricula)
- Summer schools to fill gaps in the countries/regions where needed
- Better supply chains in Global South

This is just a sampling of the discussion and OASIS will try to make some strides in tackling these important topics. We thank all the participants for their frank and open discussion and hope to engage further in the near future.

Acknowledgements

We would like to thank Sebastiaan (Seb) Swart for sponsoring our follow up dinner with early career researchers from the Global South.

Differences and commonalities in air-ice-ocean processes in the Antarctic and Arctic

Conveners: Nadja Steiner[a], Jessie Creamean[b], Jennie Thomas[c]
Rapporteurs: Lisa Miller[a], Megan Willis[b]

[a] Institute of Ocean Sciences, Fisheries and Oceans Canada,Sidney, BC V8L. Contact: Nadja.steiner@dfo-mpo.gc.ca, Lisa.miller@dfo-mpo.gc.ca
[b] Colorado State University, Fort Collins, CO 80526, USA. Contact: jessie.creamean@colostate.edu, megan.willis@colostate.edu
[c] The Institute of Environmental Geosciences (IGE), 38 058 Grenoble, France, Contact: Jennie.Thomas@univ-grenoble-alpes.fr

The polar regions are experiencing rapid climatic changes, shifting the coupled physical and chemical ocean-sea ice-snow-atmosphere system into an unprecedented and uncertain regime. Sea ice and snow are key features of the ocean-atmosphere interface in the polar regions, controlling the chemical, physical, and biological drivers of ocean-atmosphere gas and aerosol exchanges.

In the remote polar atmosphere, natural aerosols resulting from ocean (including ice and snow) emissions are key factors in clouds, which in turn impact the surface energy balance and resulting climate feedbacks through modification of sea-ice and ocean processes (melt and freeze-up, primary production, photochemistry, etc.).

The physical drivers of the Arctic and Southern Ocean icescapes are different (e.g., turbulence, snow accumulation, meteorological conditions), leading to differences in ice and snow microstructure and biogeochemistry, which in turn impact gas/aerosol exchange processes. However, our understanding of these interactions is limited, based on few observations, and this lack of fundamental understanding inhibits our ability to accurately represent polar gas and aerosol exchanges and their impacts on polar clouds in numerical models. To improve model descriptions, reproduce observed changes at both poles, and make accurate climate projections, we need to understand the Arctic and Southern Oceans' impact on the polar regions and the Earth system.

The goal of this session was to discuss conceptual differences between the Arctic and Antarctic and identify knowledge within icescapes, ocean, and atmosphere (Figure 11). Following the interests of the audience, the discussion also included polar-to-subpolar differences and what examples in the world ocean may be applicable for the poles.

During our session, we conducted Mentimeter surveys hosted an Etherpad, in addition to moderating more traditional discussion among both in-person and on-line participants. Aware that many of the participants were not already familiar with polar air-sea exchange science, we first provided some background information on the differences in sea ice extent, and physical differences in the sea ice, ocean, and atmosphere, between the Arctic and Antarctic. This, in addition to our Mentimeter surveys and questions we posed to the audience, were used to fuel discussion and incentivise audience members to participate. The Figure 12 shows word clouds from the Mentimeter surveys before and after the session, demonstrating how the audience responses changed with the discussion. The questions we posed and discussed included:

- What do you think are the main differences between exchange processes between the ocean, ice, and atmosphere in the sea ice environment in the Arctic and Antarctic?
- How would the processes that you study change if sea ice was involved?
- What processes within other regions may translate to the polar ocean-atmosphere system? Arctic? Antarctic? Both?

Figure 11: Discussion session on Differences and commonalities in air-ice-ocean processes in the Antarctic and Arctic. Photo credit: Jessica Gier.

- How can air-sea exchange in coastal regions inform this discussion?
- What advice/suggestions do you have for undestanding the coupled ocean-atmosphere polar system?

Specific topics that were discussed included: effects on continents, sea-ice gap layers, remoteness and accessibility, polynas, riverine/coastal inputs, CO_2 measurements, turbulence and stratification (in both the atmosphere and the ocean), and ozone holes.The audience was very engaged and many of us, both conveners and the audience, learned something.

Figure 12: Results from Mentimeter word clouds in response to the question, “What do you think the main differences are between the Arctic and Antarctic sea-ice environment?” at the beginning (left) and the end (right) of the discussion session.

Crosswinds in safe landing climates

Conveners: Lisa Miller[a], Neil Harris[b], Erik van Doorn[c]
Rapporteurs: Tonya Burgers[d], Ashwini Kumar[e], Mishka Rawatlal[f], Anna Rutgersson[g], Wang Zhixuan[h]

[a] Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, BC V8L 4B2, Canada. Contact: lisa.miller@dfo-mpo.gc.ca
[b] Centre for Environmental and Agricultural Informatics, School of Water, Energy & Environment, Cranfield University, Cranfield MK43 0AL, UK. Contact: neil.harris@cranfield.ac.uk
[c] Walther Schücking Institute for International Law, Kiel, 24118 Kiel, Germany. Contact: edoorn@wsi.uni-kiel.de
[d] Department of Environment and Geography, University of Manitoba, Winnipeg, MB R3T 2N2, Canada. Contact: tonya.burgers@umanitoba.ca
[e] Geological Oceanography Division, National Institute Of Oceanography, 403 004, Goa, India. Contact: ashwinik@nio.org
[f] Department of Oceanography, University of Cape Town, Rondebosch 7701, South Africa. Contact: mishka.rawatlal@gmail.com
[g] Department of Earth Sciences, Uppsala University, 752 36 Uppsala, Sweden. Contact: anna.rutgersson@met.uu.se
[h] State Key Laboratory of Marine Environmental Science, Xiamen University, Xiamen 361102, China. Contact: wangzhixuan@stu.xmu.edu.cn

Regardless of any commitments (or lack thereof) to eliminate greenhouse gas emissions, we are already facing a global climate which will be different from that which existed during the pre-industrial period. The questions we must ask ourselves now are what will this new climate be like, and what can we do to assure that we all can live with it.

In attempting to answer that question, the World Climate Research Programme (WCRP) has launched a lighthouse activity on Safe Landing Climates to explore routes to “safe landings” for future human and natural systems. The Safe Landing Pathways working group is formulating a climate gaming exercise to synthesise the feedbacks, trade-offs, and co-benefits in climate change mitigation and adaptation and is gathering insights from different sectors of the climate change research community to inform the development of this research and teaching tool. As the first step in that process, we convened a discussion session at the SOLAS Open Science Conference to hear the SOLAS community’s hopes and fears about ocean-atmosphere interactions in the coming decades.

We framed the discussion around the classical game of Snakes and Ladders (Figure 13), in which some factors move us toward a safer climate (ladders), others move us backwards (snakes), while some tipping points could flip us onto completely different boards, with either more snakes or more ladders, making it easier or more difficult to reach a safe climate. We asked the audience, "What are the issues and factors operating in the SOLAS realm that need to be considered in climate mitigation and adaptation?", or phrased less formally, "Where are the snakes and ladders hiding in the air-sea interface?". Separate discussions were held for the in-person and online attendees, in order to encourage full participation, and both discussions were rich and imaginative.

Much of the discussion focussed on general issues of the earth system and social sciences, including politics and education. A particularly useful concept to surface was the idea of floppy ladders and asklepians (things that initially appear to move us in the right direction but actually set us back, and vice versa). Other points that were made included the need for education that lever-

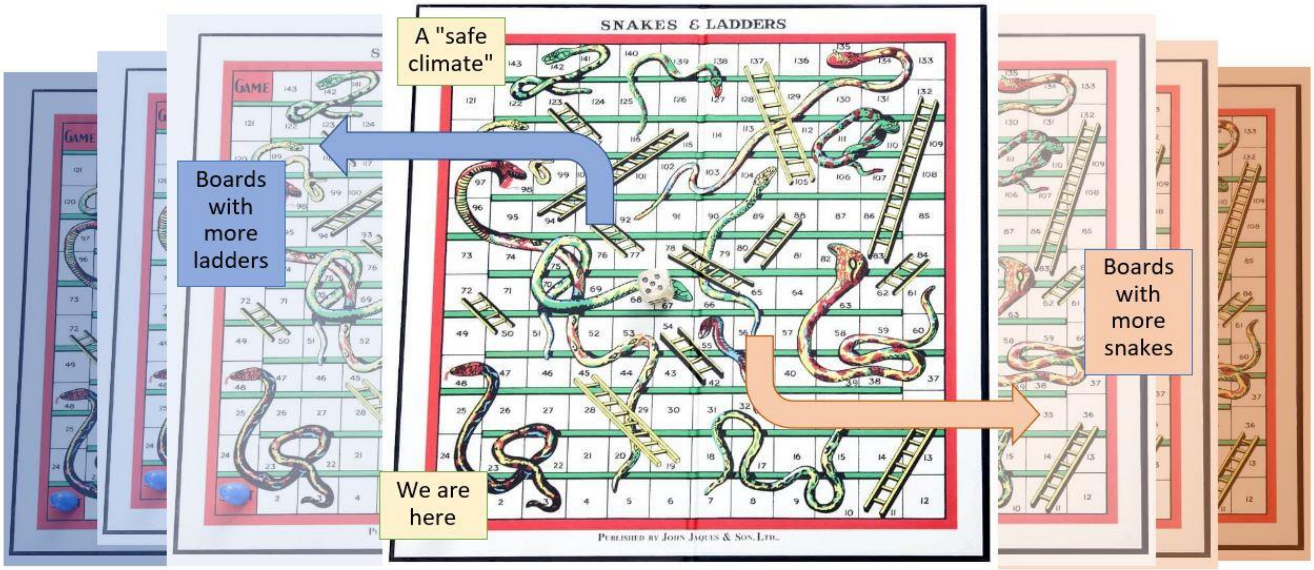

Figure 13: Climate Snakes and Ladders. What moves us towards a safe climate and what moves us away from it? What game-changing tipping points might move us to a different board? Image credit: central gameboard image from John Jacques & Son, Ltd.

ages natural curiosity and interest in the surrounding world, the dangers of degrading mental health with the climate crisis leading to anxiety and paralysis, and the need for the scientific community (natural, social, and together) to have the flexibility to respond to surprise events and to explore "unknown unknowns".

A number of potentially useful research directions in SOLAS science also emerged. Areas in which the expertise of SOLAS community may be particularly valuable include:

- Efficacy and side effects of blue carbon and climate intervention initiatives;
- How future oceanic and atmospheric composition is likely to be determined by yet unknown consumer trends;
- The trade-offs between health and climate impacts of aerosols;
- Marine environmental degradation due to terrestrial climate adaptation efforts; and
- A potential for biomimicry in adaptive technology to foster synergism with natural processes (e.g., similar to green roofs, is there potential for naval engineering to adapt more natural forms?).

Finally, an important question raised was "How do we know when the game is over and whether or not we won?" The conclusion from the group is that the game will never be over, it will just change, and we need to be ready to keep playing.

Reference

www.wcrp-climate.org/safe-landing-climates

Acknowledgements

We thank SOLAS and the WCRP for the opportunity to explore these ideas, and all the participants in the SOLAS Open Science Conference for such a lively and imaginative discussion!

SOLAS science and global ship emissions - common challenges and next steps

Conveners: Christa Marandino [a], Tom Bell [b], Anna Rutgersson [c], Zongbo Shi [d]

[a] GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany. Contact: cmarandino@geomar.de
[b] Plymouth Marine Laboratory, Plymouth, UK. Contact: tbe@pml.ac.uk
[c] Uppsala University, Uppsala, Sweden.Contact: Anna.Rutgersson@met.uu.se
[d] University of Birmingham, Birmingham, UK. Contact: Z.Shi@bham.ac.uk

Shipping is the most widely used medium for transport of goods internationally and, although it is a carbon-efficient transport medium, there is an increasing focus on its broader environmental consequences. Ship exhausts are a significant source of sulfur, nitrogen, and other gaseous pollutants, as well as sulfur(S)-containing aerosols, to the marine atmosphere and to the ocean. Global modelling suggests ship emissions cause a negative radiative forcing by forming sulfate aerosols and by modifying cloud properties. The range of SOLAS endorsed ship emissions projects seek to investigate the role of these emissions on atmospheric and oceanic processes. Because this topic has both economic and legal aspects, the proponents seek to engage a range of stakeholders (e.g., shipping companies, ports, policy-makers), with mixed success. Lessons learned within the community could help other researchers facing the same challenges. In addition, there appears to be significant interest within the SOLAS community on this topic and we could benefit from an open discussion on results to-date and future perspectives.

We aim to outline strategies to better engage a broader range of stakeholders. In addition, we would like to identify possible future research directions on ship emissions within the SOLAS framework, which may lead to collaborative research projects.

During the discussion we identified the following current needs:

- Database of reference emission factors, ID of plumes, etc.
- Network of interested SOLAS researchers (inc. discussion organisers plus Jurgita Ovadnevaite / Kirsten N Fossum; shipping emission inventory model (SEIM) model researcher (Huan Liu)).
- Low cost tech/monitoring.

The following issues were raised:

- Naval technologies can be used - cameras that are sensitive to bright spots could be useful for monitoring/can see ships from satellite.
- We should use/identify global fishing connections - open data about illegal boats or boats without GPS.
- Why are there no sulfur emissions control areas (SECAs) in certain areas - like South Africa?
- What is the connection between reduced sulfur and warming?
- We need to practice talking with each other (transdisciplinarity).
- Should shipping be a separate theme in the new SOLAS science plan?

Some ideas for future directions were discussed:

- Identify a robust tracer for all fuels.
- Look at the influence on turbulence/ bubbles/surfactants from ships.
- Impact of higher trophic levels following boats and feeding cycles.
- Black carbon, especially in polar regions.
- Light and noise pollution.

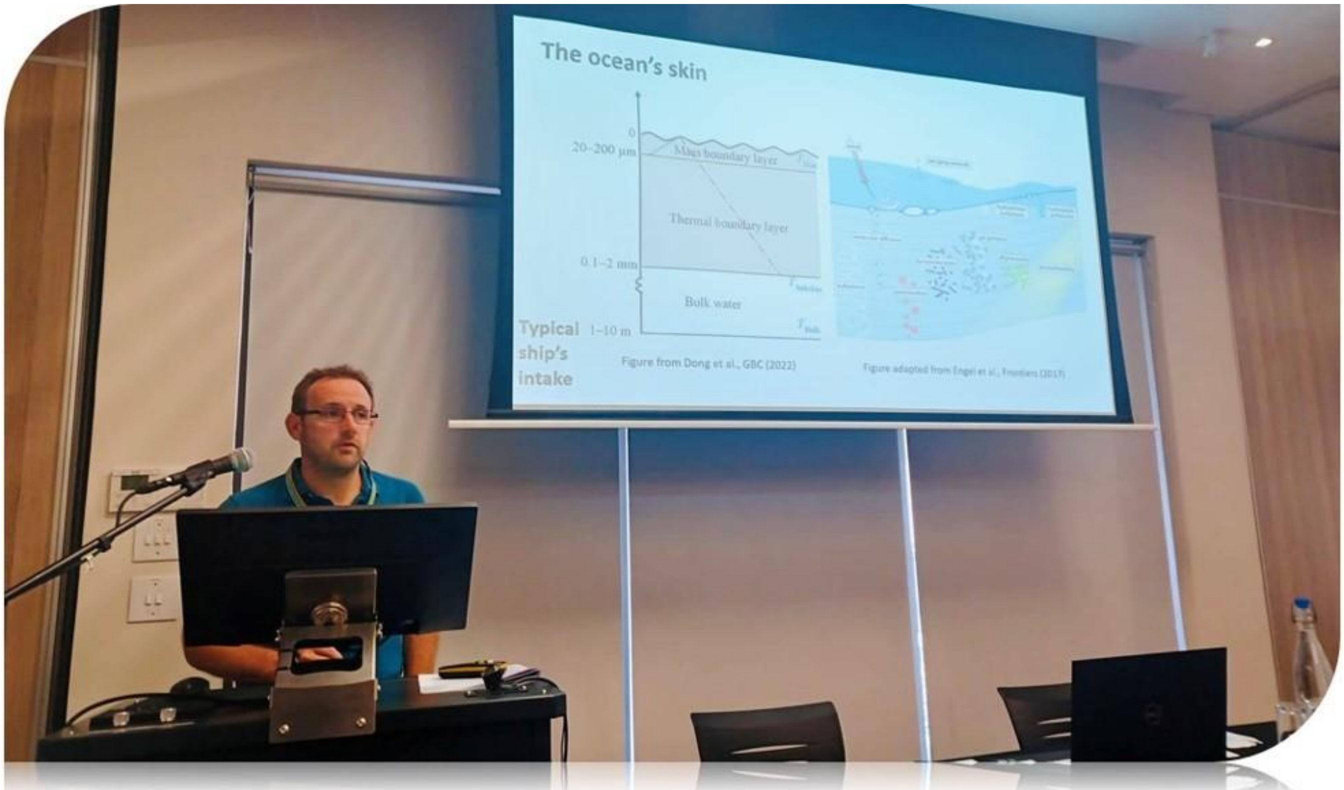

Figure 14: Discussion session on SOLAS science and global ship emissions - common challenges and next steps. Photo credit: Jessica Gier.

SOLAS

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Inge Deschepper is a Ph.D. candidate at Université Laval in Québec City, Canada. She studies the interactions between Arctic marine biogeochemistry and the physical environment. She uses biogeochemical models coupled with regional oceanographic models to understand interactions between the ocean, sea ice and biochemistry within a subarctic system, Hudson Bay. She is currently working remotely from South Africa.

Impact of physical controls on nutrient availability on ecosystem productivity in the seasonally ice-covered Hudson Bay region

Inge Deschepper[a*], Paul G. Myers[b], Tim Papakyriakou[c], Diane Lavoie[d], Frédéric Maps[a]

[a] Université Laval, Quebec, Canada / IRL Takuvik, CNRS (France) - ULaval (Canada)
[b] University of Alberta, Edmonton, Canada
[c] University of Manitoba, Winnipeg, Canada
[d] Maurice Lamontagne Institue, Department of Fisheries and Oceans Canada, Mont-Joli, Canada

* inge.deschepper.1@ulaval.ca

Multiple factors influence the chlorophyll a productivity in marine systems. The Hudson Bay Complex is a large inland sea in the middle of northern Canada that has historically been seen as a low-productivity ecosystem. However, recent field campaigns led by research teams from the Hudson Bay System Study (BaySys) have revealed that the region is more productive than once thought (Barbedo *et al*., 2020; Matthes *et al*., 2021). Due to the Hudson Bay complex's latitude, it experiences seasonal sea-ice cover leading to recurrent spring and ice-edge phytoplankton blooms (Ardyna *et al*., 2020). Moreover, many rivers drain into Hudson Bay, and this freshwater input has been predicted to increase with enhanced snow and rain precipitation owing to climate change (Stadnyk *et al*., 2019).

We use the simplified phosphate-based biogeochemical model BLINGv0+DIC, coupled to the online regional oceanographic and sea-ice models, NEMOv3.6 and LIM2 with the Arctic Northern Hemisphere Atlantic (ANHA4) configuration (Buchart *et al*., 2022). The models were forced with two bias-corrected Climate Model Intercomparison Project 5 (CMIP5) climate forcing datasets (MIROC5 and MRI) to simulate primary production during 2018. The simulation's outputs were compared to chlorophyll-a satellite imagery and in situ observations obtained during the 2018 BaySys campaign. The simulations present similar spatio-temporal patterns of the phytoplankton bloom, i.e. a progression from west to east and from north to south, but with a slight delay in this dynamics induced by delayed sea-ice melt compared to the satellite data.

The simulated output was then further analysed with Empirical Orthogonal Functions (EOF) to summarise the major spatio-temporal modes of variability and better understand the underlying physical forcing of chlorophyll-a production in

2018. The first EOF explains 48% for the MIROC5 simulation (resp. 54% for MRI) of the chlorophyll-a production and is related to the seasonal light and nutrient levels (not shown). The mixed layer depth dynamics (shoaling and sinking) explained respectively 18% and 14%, as seen in the second EOF (Figure 15). The third EOF matched well with the nutrient supply from rivers explaining 13% and 8% of the chlorophyll-a production (Figure 16) for the MIROC5 and MRI simulations, respectively. The sea-ice dynamics and river runoff play a significant role in the system's productivity in different areas of the Hudson Bay Complex, and with future climate change and river regulation projects (dams) underway, up to 20% of overall production could be impacted in the future.

The full paper has been submitted to JGR Biogeoscience.

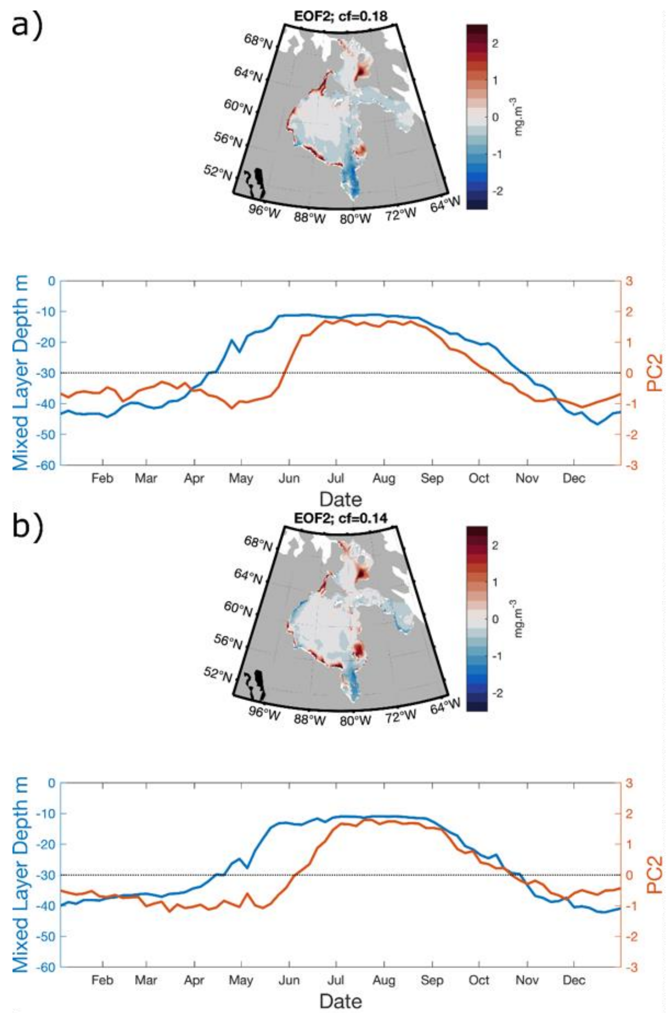

Figure 15: EOF 2 for the a) MIROC5 simulation and the b) MRI simulations. The mode shows the surface chlorophyll-a associated with the EOF in mgm-3 and the principle component shows the average mixed layer depth (m) in blue and with the principle component in orange plotted for their respective simulations for the Hudson Bay Complex. cf indicates the percentage of the variability explained by the mode.

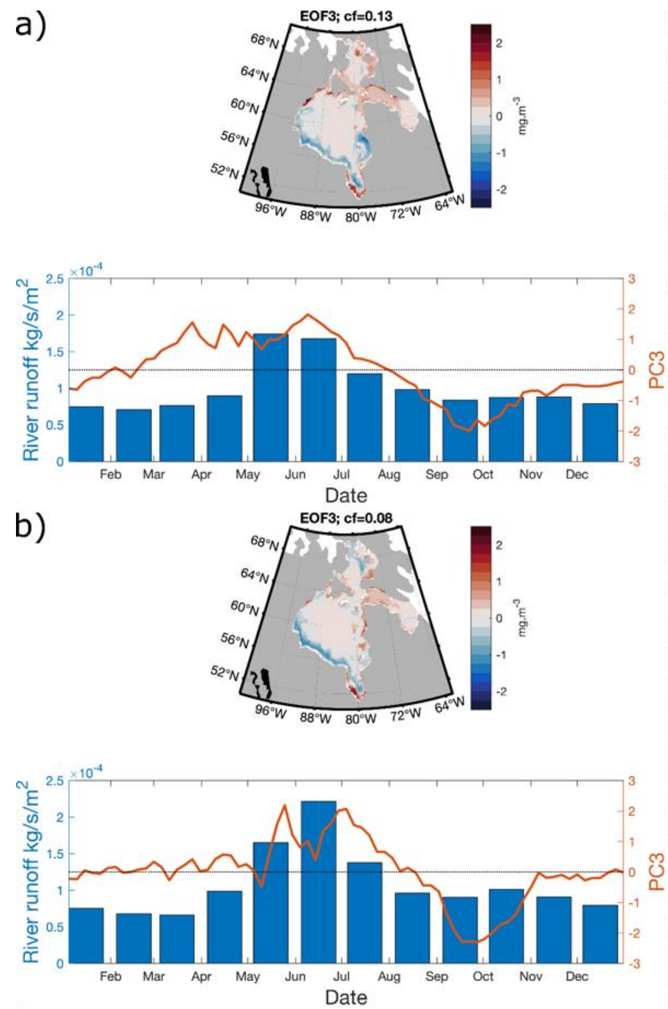

Figure 16: EOF 3 for the a) MIROC5 simulation and the b) MRI simulations. The mode shows the surface chlorophyll-a associated with the EOF in mgm-3 and the principle component shows the average monthly river runoff (kgs-1m-2) in the blue bars and with the principle component in the orange line graph plotted for their respective spatial modes for the Hudson Bay Complex. cf indicates the percentage of the variability explained by the mode.

References

Ardyna, M., Mundy, C. J., Mayot, N., *et al.* (2020), Under-Ice Phytoplankton Blooms: Shedding Light on the “Invisible” Part of Arctic Primary Production. *Frontiers in Marine Science*, 7 (November):1-25.
doi: 10.3389/fmars.2020.608032

Barbedo, L., Bélanger, S., and Tremblay, J. É. (2020). Climate control of sea-ice edge phytoplankton blooms in the Hudson Bay system. *Elementa*, 8(1):1–25, doi:10.1525/elementa.039

Buchart, L., Castro de la Guardia, L., Xu, Y., *et al.* (2022). Future Climate Scenarios for Northern Baffin Bay and the Pikialasorsuaq (North Water Polynya) Region. *Atmosphere-Ocean* , 60(2):102–123.
doi: 10.1080/07055900.2022.2067028

Matthes, L. C., Ehn, J. K., Dalman, L. A., *et al.* (2021). Environmental drivers of spring primary production in Hudson Bay. *Elementa*, 9(1):1-25. 20.
doi: 10.1525/elementa.2020.00160

Stadnyk, T., Dery, S., MacDonald, M., and Koenig, K. (2019). From science to policy in the greater Hudson Bay marine region. *Technical report*, Québec, Canada.

Tanya Marshall is conducting her doctoral research at the University of Cape Town, South Africa, where she studies ocean biogeochemistry. Using nitrate isotope ratios, nutrient stoichiometry and ocean physics, Tanya's research explores nutrient fluxes, particularly nitrogen, in the South Atlantic and Indian Oceans.

The Angola Gyre is a hotspot of N_2 fixation in the South Atlantic Ocean

Tanya Marshall[a*], J. Granger[b], K. Casciotti[c], K. Dähnke[d], K.-E. Emeis[e], D. Marconi[f], M. McIlvin[g], A. Noble[h], M. Saito [i], D. Sigman [f], S. Fawcett [a]

[a] University of Cape Town, Cape Town, South Africa
[b] University of Connecticut, Groton, United States
[c] Stanford University, Stanford, United States
[d] Helmholtz-Zentrum Hereon, Geesthacht, Germany
[e] Helmholtz-Zentrum Hereon, Geesthacht, and Universität Hamburg, Hamburg, Germany
[f] Princeton University, Princeton, United States
[g] Schmidt Ocean Institute, Palo Alto, United States
[h] Woods Hole Oceanography Institution, Woods Hole and California Department of Toxic Substances Control, Sacramento, United States
[i] Woods Hole Oceanography Institution, Woods Hole, United States

* mrstan001@myuct.ac.za

Dinitrigen (N_2) fixation and atmospheric deposition can be major sources of new nitrogen to marine systems. Across much of the global ocean, nitrogen is the major element limiting primary production and as such, its availability controls ocean productivity and modulates climate. Constraining the distribution and global rate of N_2 fixation is challenging owing to uncertainty surrounding the controls thereon and the similar biogeochemical signatures of N_2 fixation and atmospheric deposition. Uncertainties around N_2 fixation, in turn, cloud our understanding of drivers of ocean fertility and biological carbon sequestration.

Observations of N_2 fixation are limited, owing to the expanse and variability of the ocean. There is a particular paucity of N_2 fixation rate measurements from the South Atlantic, with the general perception being that N_2 fixation is low in this ocean and predominantly occurs in the western basin (Deutsch *et al*., 2007; Wang *et al*., 2019) (Figure 17). Our measurements of nutrients and nitrate isotope ratios from across the tropical South Atlantic reveal a stoichiometric excess of nitrogen relative to phosphorus (i.e., N*) and low-δ15N nitrate in the thermocline of the eastern (but not the western) tropical South Atlantic, specifically, the Angola Gyre (Figure 18). We rule out atmospheric deposition as a

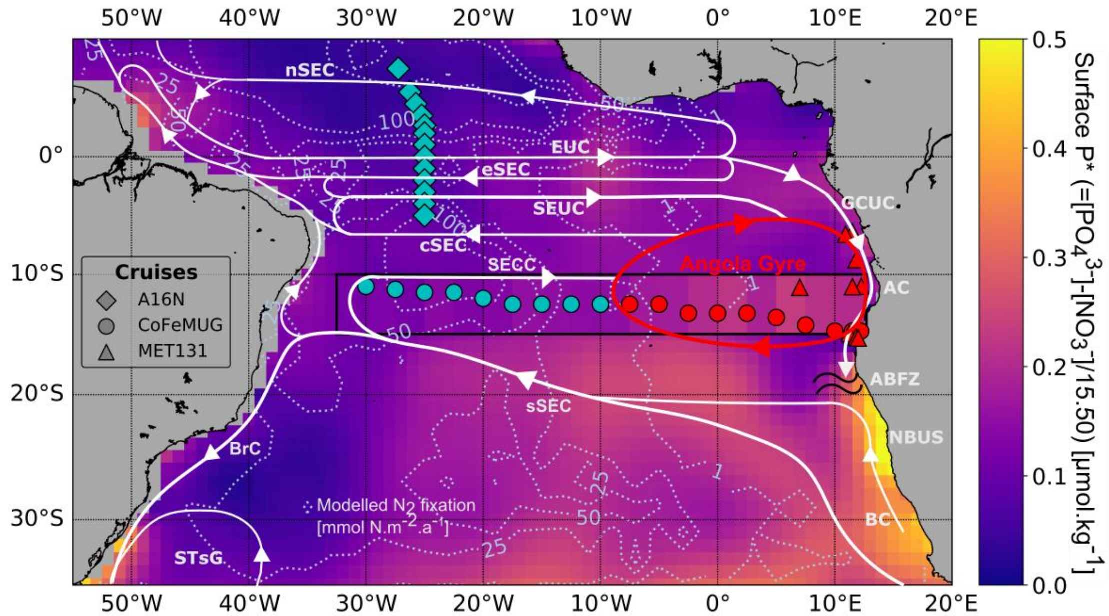

Figure 17: Map of surface P* across the South Atlantic Ocean.

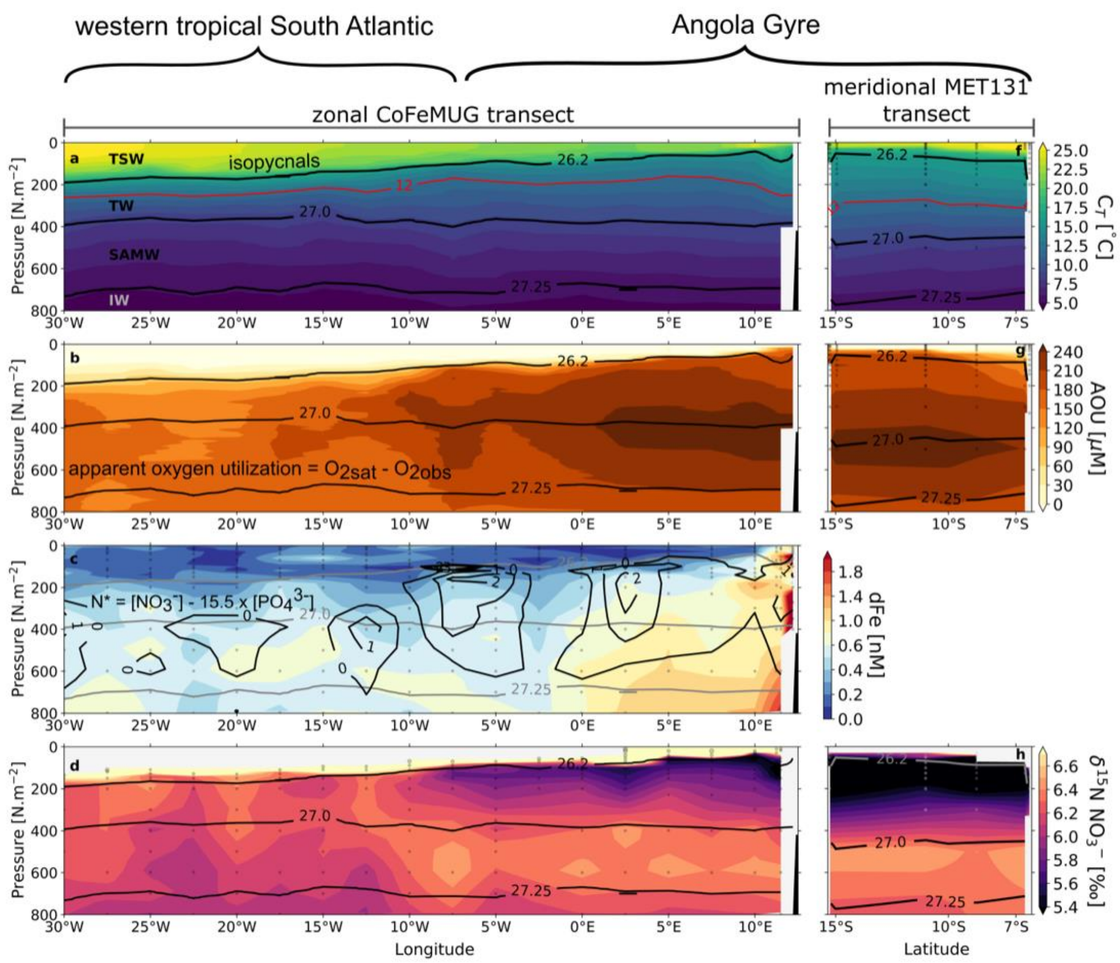

Figure 18: Zonal trends in physical and biogeochemical properties across the tropical South Atlantic.

major source of the high N* and low-δ15N thermocline nitrate in the Angola Gyre and show instead that these waters host an N_2 fixation rate of 1.4–5.4 Tg N a^{-1}, 28-108% of the existing (albeit highly uncertain) South Atlantic estimates. We find no evidence of N_2 fixation occurring in the western tropical South Atlantic, in direct contrast to results from models.

Conditions particular to the Angola Gyre must favour N_2 fixation. We propose that the remote supply of excess phosphorus relative to nitrogen from the Southern Ocean (Deutsch *et al*., 2007), augmented by a regional supply from the low-oxygen northern Benguela upwelling system (Flohr *et al*., 2014), and the local supply of sedimentary iron from the nearby African margin (Noble *et al*., 2012) jointly promote N_2 fixation in the Angola Gyre. We predict that N_2 fixation will occur where analogous conditions of excess phosphorus occur in tandem with elevated iron (Marshall *et al*., 2022), and conclude that understanding the controls on N_2 fixation at the regional scale is critical for determining its global distribution.

References

Deutsch, C. *et al*., 2007 Spatial coupling of nitrogen inputs and losses in the ocean. *Nature* 445, 163–167.

Flohr, A. *et al*., 2014. Spatio-temporal patterns of C:N:P ratios in the northern Benguela upwelling system. *Biogeosciences* 11, 885–897.

Gordon, A. & Bosley, K. 1990. Cyclonic gyre in the tropical South Atlantic. *Deep Sea Res*. 38, S323–S343.

Marshall, T. *et al*., 2022. The Angola Gyre is a hotspot of dinitrogen fixation in the South Atlantic Ocean. *Nature Communications Earth & Environment*, 3(151), pp. doi.org/10.1038/s43247-022-00474-x

Noble, A. *et al*., 2012. Basin-scale inputs of cobalt, iron, and manganese from the Benguela-Angola front to the South Atlantic Ocean. *Limnol. Oceanogr.* 57, 989–1010.

Wang, W. *et al*., 2019. Convergent estimates of marine nitrogen fixation. *Nature* 566, 205–211.

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Mansi Gupta completed her undergraduate degree in Physics in 2017 from Delhi and masters in Ocean and Atmospheric Sciences in 2020 from Hyderabad, India. In 2020, she started her PhD at the Physical Research Laboratory, Ahmedabad, India, to study the air-sea flux of dimethylsulfide and volatile organic compunds and controlling processes over the northern Indian Ocean.

Spatio - temporal variation of DMS and VOCs over the northern Indian Ocean during post - monsoon season

Mansi Gupta[a*], N. Tripathi[b], T. G. Malik[c], A. Singh [c], L. K. Sahu [c]

[a] Physical Research Laboratory, Ahmedabad, India;
Indian Institute of Technology Gandhinagar (IITGn), Gandhinagar, India.
[b] Max Planck Institute of Chemistry, Mainz, Germany
[c] Physical Research Laboratory (PRL), Navarangapura, Ahmedabad, India

* mansigupta@prl.res.in

Oceans are the major source of Volatile Organic Compounds (VOCs), like dimethylsulfide (DMS) and isoprene, in remote marine environment. Despite being present in trace amounts, DMS and VOCs play a significant role in atmospheric chemistry of the lower troposphere and climate. The oxidation products of these gases produce secondary organic aerosol (SOA). SOAs further can alter the radiation budget of the earth by directly interacting with the solar radiation, or indirectly as cloud condensation nulei (CCN) and participating in cloud condensation (Charlson *et al*., 1987).

The main production mechanisms involve biogeochemical (Palmer and Shaw, 2005) and photochemical (Ciuraru *et al*., 2015) processes in surface seawater near the air-sea interface. However, its release into the atmosphere is largely controlled by kinetic conditions near the air-sea interface (Liss and Merlivat, 1986; Wanninkhof, 1992). Apart from having peculiar meteorological conditions like seasonal reversal of winds (monsoon) and cyclones activity, the Northern Indian Ocean, particularly the Arabian Sea, in also one the most productive oceanic regimes of the world oceans. Therefore, the region is potentially a significant marine source of DMS and VOCs emissions. But flux data over the region is sparse (Shenoy and Kuman, 2007; Tripathi *et al*., 2020a; Tripathi *et al*., 2020b) and lack of studies could be a large source of uncertainty in chemistry-climate models.

We participated in two cruise campaigns over the Arabian Sea and Bay of Bengal during September-November 2021 to investigate the spatio-temporal distributions of DMS and VOC in the marine air (Figure 19). High time resolution (20-40 min) in-situ measurements to study the relations of oceanic emissions with major meteorological and oceanic factors that controls air-sea exchange of gases. Strong diurnal dependence observed, with significant photochemical loss during noon period. Background concentration indicated

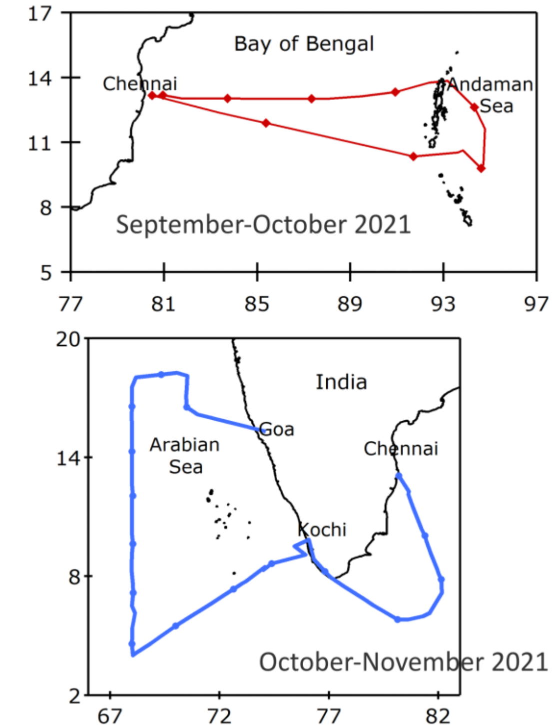

Figure 19: Map of study region showing the cruise tracks for campaigns over the Bay of Bengal and Arabian Sea.

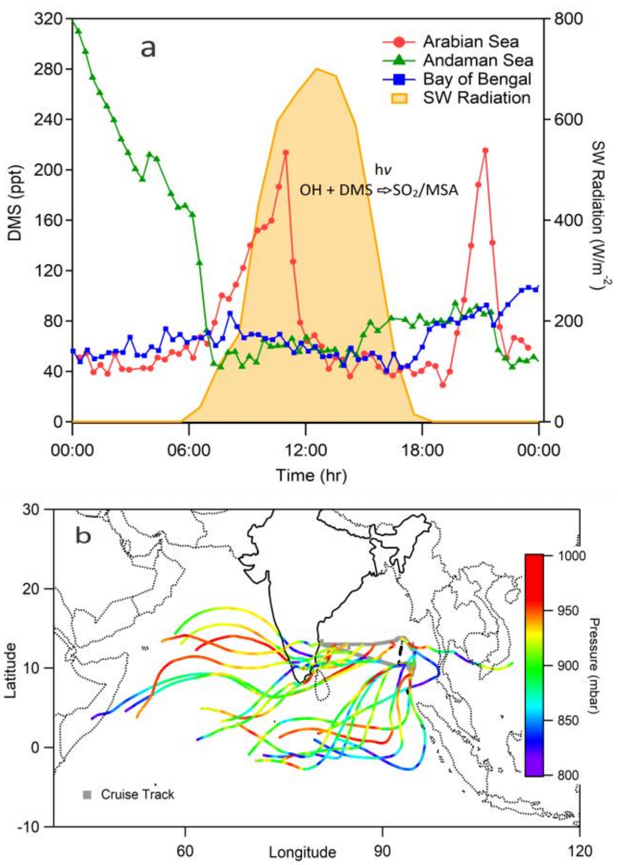

Figure 20: (a) Typical diurnal variation in DMS over different oceanic regimes, (b) 5-day backward trajectory from NOAA's HYSPLIT model at 500m amsl.

night time DMS activity in Arabian Sea. In the Bay of Bengal, the variation of DMS concentration follows that of relative humidity parameter, indicating the influence of fresh oceanic emissions. Relatively high level of DMS (>400 ppt) was observed over the Andaman Sea region, is suspected to be due to enhanced local biological productivity and the transport of air masses from the southern/equatorial Indian Ocean as seen form the back trajectory analysis. Isoprene and DMS showed almost opposite variability trend over the Bay of Bengal, attributing to the change in local biogeochemistry including dissolved organic matter and phytoplankton species composition (Figure 20) Overall, the level of DMS and Isoprene was found to be higher over the Arabian Sea.

References

Charlson, R. J., Lovelock, J. E., Andreae, M. O., & Warren, S. G. (1987). Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate. *Nature*, 326(6114), Article 6114. doi.org/10.1038/326655a0

Ciuraru, R., Fine, L., Pinxteren, M. van, D'Anna, B. *et al*. (2015). Unravelling New Processes at Interfaces: Photochemical Isoprene Production at the Sea Surface. *Environmental Science & Technology*, 49(22), 13199–13205. doi.org/10.1021/acs.est.5b02388.

Liss PS, Merlivat L. 1986. Air-sea gas exchange rates: introduction and synthesis. In *The Role of Air-Sea Exchange in Geochemical Cycling*, ed. P Buat-Menard, pp. 113–29. Boston, MA: Reidel.

Palmer, P. I., & Shaw, S. L. (2005). Quantifying global marine isoprene fluxes using MODIS chlorophyll observations. *Geophysical Research Letters*, 32(9). doi.org/10.1029/2005GL022592

Shenoy, D. M., & Kumar, M. D. (n.d.). Variability in abundance and fluxes of Dimethyl sulphide in the Indian Ocean. 35.

Tripathi, Nidhi & Sahu, Lokesh & Singh, Arvind & Yadav, Ravi & Karati, Kusum. (2020a). High levels of isoprene in the marine boundary layer of Arabian Sea during spring inter-monsoon: Role of phytoplankton blooms. ACS Earth and Space Chemistry. XXXX.10.1021/acsearthspacechem.9b00325.

Tripathi, Nidhi & Sahu, Lokesh & Singh, Arvind & Yadav, Ravi & Patel, Anil & Patel, Kashyap & Meenu, P. (2020b). Elevated Levels of Biogenic Nonmethane Hydrocarbons in the Marine Boundary Layer of the Arabian Sea During the Intermonsoon. *Journal of Geophysical Research: Atmospheres*. 125. 10.1029/2020JD032869.

Wanninkhof R (1992) Relationship between gas exchange and wind speed over the ocean. *J Geophys Res* 97 (C5):7373–7382. doi:10.1029/92JC00188.

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www.arl.noaa.gov/ready/ hysplit4.html

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Tesha Toolsee, originally from the island of Mauritius, studied Ocean and Atmospheric Science followed by a Master's in Physical Oceanography at the University of Cape Town, South Africa. She joined the Southern Ocean Carbon - Climate Observatory (SOCCO) in 2022 to pursue a PhD, researching the synoptic scale variability of the carbon flux in the Southern Ocean.

Synoptic phasing of the parameters of the bulk CO_2 flux equation during storm events across different seasons in the Southern Ocean

Tesha Toolsee[a,b]*, Pedro M. S. Monteiro[c], Sarah-Anne Nicholson[a]

[a] Southern Ocean Carbon-Climate Observatory (SOCCO), CSIR, Cape Town, South Africa
[b] Department of Oceanography, University of Cape Town, South Africa
[c] School for Climate Studies, Stellenbosh University, Stellenbosch, South Africa

* teshatoolsee@gmail.com

The Southern Ocean has proven to be the largest anthropogenic carbon dioxide (CO_2) sink (~ 1 Pg C yr^{-1}) by accounting for 40-50% of the global oceanic carbon uptake (Gruber *et al.,* 2019). This carbon uptake, however, varies considerably on different timescales which has been shown to have significant impact on the sensitivity of the global ocean carbon budget (Landschützer *et al.,* 2015).

The sampling patterns of air-sea flux of CO_2 (fCO_2) observations in the Southern Ocean are highly biased towards summer, mostly relying on logistics cruises (Gregor *et al*., 2017). Notwithstanding the growing contribution from autonomous Southern Ocean Carbon and Climate Observations and Modelling (SOCCOM) floats (Bushinsky *et al*., 2019), this seasonal gap is mostly filled using machine learning methods, which come with their own set of uncertainties such as significantly exaggerating the winter fCO_2 outgassing (Djeutchouang *et al*., 2022). In addition to the seasonal gap, most existing floats have a temporal sampling frequency of 10 days (Bushinsky *et al*., 2019), which may not be enough to capture mixed layer responses associated with storm events.

The Southern Ocean Seasonal Cycle Experiment (SOSCEx) was brought forward in an attempt to address this intra-seasonal to sub-mesoscale uncertainty that connects the carbon cycle in the Southern Ocean to the global climate variability (Swart *et al*., 2012, Monteiro *et al*., 2015, Nicholson *et al*., 2022). The current study focuses on the SOSCEx-III deployment of a wave glider which recorded high resolution hourly CO_2 atmospheric and oceanic measurements at 8˚E and 45˚S (sub-Antarctic zone; SAZ) in a pseudo-mooring pattern from 14th August 2015 to 8th February 2016.

The fCO_2 at the ocean-atmosphere boundary layer is governed by the bulk flux equation (Wanninkhof, 2014).

$$FCO_2 = k_w k_o \Delta pCO_2$$

Where k_w and k_o are the wind-driven gas transfer velocity and the solubility constant respectively and drive the magnitude of the fCO_2. ΔpCO_2 is the gradient of the partial pressure of the CO_2 in the atmosphere and the ocean, which controls the direction of the fCO_2, i.e., whether outgassing (positive fCO_2) or ingassing (negative fCO_2) will occur.

In the sub-Antarctic zone (SAZ) of the Southern Ocean, frequent storm events (4-10 days) induce short but strong wind stress over the surface ocean. These strong winds have been shown to increase the magnitude of the fCO_2 through the k_w, but it is not well understood, nor observed, how ΔpCO_2 responds to those storms. The first chapter of my PhD aims to show that in the SAZ, strong wind stress associated with storms impact the magnitude of the fCO_2 through both the k_w and ΔpCO_2 instead of the k_w only (Figure 21). Some of the preliminary results have shown that in winter and spring, all storm events showed the rapid increase in pCO_{2sea} with inconsistent lag ranging between 0 hour to 12 hours with a rise in wind stress. This increase was likely due to the entrainment of Dissolved Inorganic Carbon (DIC) caused by a deepening of the mixed layer depth from storm momentum dissipation. Not accounting for this change in pCO_{2sea} during storm events, which is the current situation in Global and Earth System Models, could overestimate fCO_2 in winter (by 6.64 - 18.34 %) and in spring (by 6.54 - 26.56 %) (results not shown). This study will expand to include summer storm events and investigate how these responses of ΔpCO_2 to storms vary spatially across the entire Southern Ocean using high-resolution models.

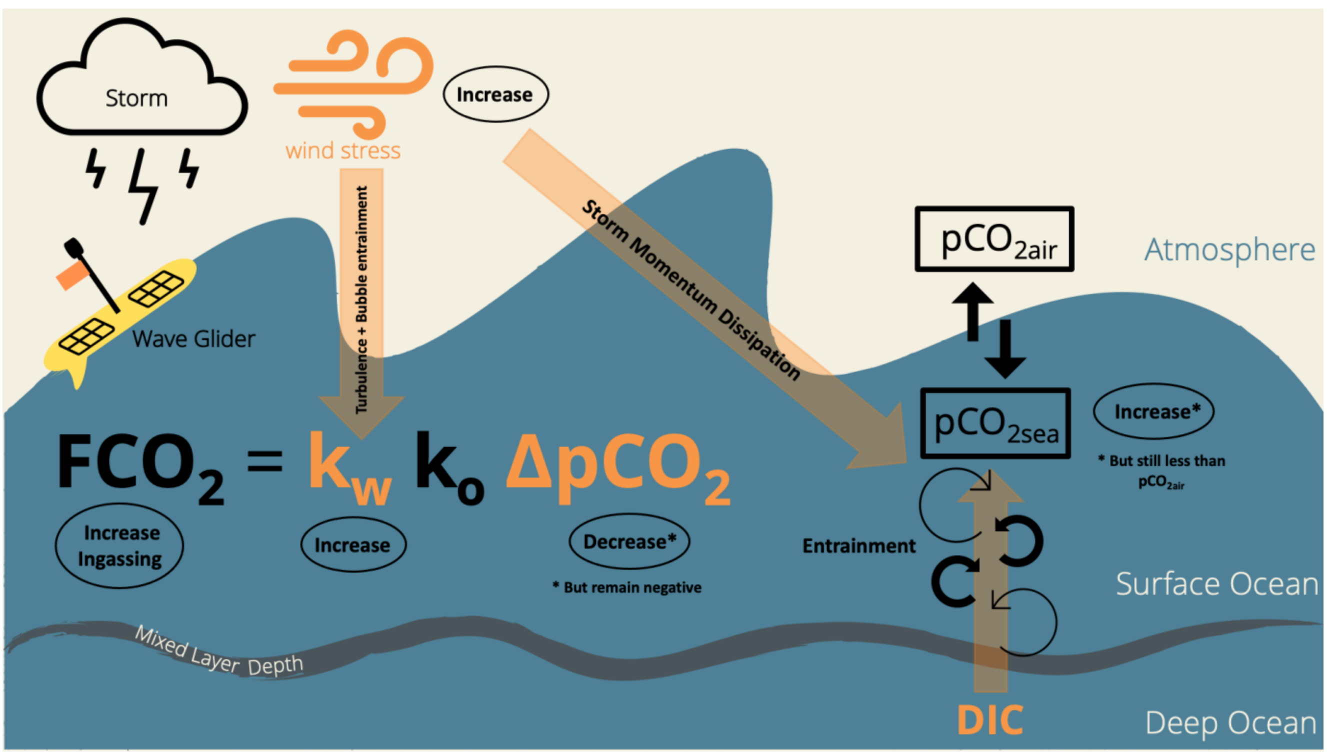

Figure 21: Schematic illustrating the parameters influencing the FCO_2 in the sub-Antarctic Southern Ocean during a winter and spring storm event.

References

Bushinsky, S. M., Landschützer, P., Rödenbeck, C. *et al.* (2019), Reassessing Southern Ocean Air-Sea CO2 Flux Estimates with The Addition of Biogeochemical Float Observations. *Global Biogeochemical Cycles*, 33, 1370-1388, doi:10.1029/2019GB006176

Djeutchouang, L. M., Chang, N., Gregor, L. *et al.* (2022), The Sensitivity of pCO2 Reconstructions in The Southern Ocean to Sampling Scales: A Semi-Idealized Model Sampling and Reconstruction Approach. *Biogeosciences*, 19, 4171-4195, doi: 10.5194/bg-19-4171-2022.

Gregor, L., Kok, S. & Monteiro, P. 2017. Empirical Methods for The Estimation of Southern Ocean CO2: Support Vector and Random Forest Regression. *Biogeosciences*, 14, 5551-5569, doi:10.5194/bg-14-5551-2017

Gruber, N., Clement, D., Carter, B. R., *et al.* (2019), The Oceanic Sink for Anthropogenic CO2 from 1994 to 2007. *Science*, 363, 1193-1199, doi: 10.1126/science.aau5153

Landschützer, P., Gruber, N., Haumann, F. A., *et al.* (2015), The Reinvigoration of The Southern Ocean Carbon Sink. *Science*, 349, 1221-1224, doi: 10.1126/science.aab2620

Monteiro, P. M., Gregor, L., Lévy, M., *et al.* (2015), Intraseasonal Variability Linked to Sampling Alias in Air‐Sea CO2 Fluxes in the Southern Ocean. *Geophysical Research Letters*, 42, 8507-8514, doi: 10.1002/2015GL066009

Nicholson, S.-A., Whitt, D. B., Fer, I., Du Plessis, M. D., Lebéhot, A. D., Swart, S., Sutton, A. J. & Monteiro, P. (2022), Storms Drive Outgassing Of CO2 In The Subpolar Southern Ocean. Nature Communications, 13, 1-12, doi: 10.1038/s41467-021-27780-w

Swart, S., Chang, N., Fauchereau, N., *et al.* (2012), Southern Ocean Seasonal Cycle Experiment 2012: Seasonal Scale Climate and Carbon Cycle Links. South African *Journal of Science*, 108, 11-13, doi: 10.4102/sajs.v108i3/4.1089

Wanninkhof, R. (2014), Relationship Between Wind Speed And Gas Exchange Over The Ocean Revisited. *Limnology And Oceanography: Methods*, 12, 351-362, doi: 10.1029/92JC00188

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State Key Laboratory of Marine Environmental Science, Xiamen University, China

solas@geomar.de

Editor:
Dr. Esther Rickert