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An initiative to better understand the future ice-ocean-atmosphere interactions between the Southern Ocean and Antarctica from the past critical periods

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Context

Understanding the exchange of heat and mass between the Southern Ocean (SO) and Antarctica facilitated by dynamicallydriven currents, such as Antarctic Circumpolar Current (ACC), is critical for constraining the stability of Antarctic Ice Sheet (AIS) (Martinson 2012) (Fig. 1). As the instrumental records that would inform ice-ocean-atmosphere interactions are minimal, the Southern Ocean-Antarctic Interactions (SOAS) subcommittee, formed in the framework of the SCAR Instabilities and Thresholds in Antarctica (INSTANT) Programme, aims to circumvent this limitation by examining past critical periods, and facilitate the dialogue and collaboration between the proxy and modeling communities. To lay out the objectives and identify the priorities for the subcommittee, the first in-person workshop was held during the SCAR-INSTANT conference on 11 September 2023 in Trieste, Italy. The following sections highlight the objectives of the program, and existing knowledge gaps.

Objectives of the SOAS program

The main science questions that the subcommittee aim to address are as follows: a) What can we learn from new and emerging records of past AIS, ACC and Southern Hemisphere Westerly Wind dynamics?; b) What is the role of changing winds, and surface-, intermediate- and deep-water circulation of the ACC on the growth and decay of the AIS?; c) How do we integrate SO records with those from the Antarctic continent (e.g. from ice cores), and the Southern Hemisphere mid-latitudes (e.g. lakes, moraines)?; d) How do recent findings for the geologic past inform numerical modeling of AIS mass loss, global sea-level rise and thermohaline circulation, and help assess their impacts on global climate?

A major goal is to bring the paleoclimate communities together to decipher past tipping points of climate as the most critical periods where model calibration, and general understanding of involved processes, is required. Such periods of interest include millennial-scale variability, the last glacial termination, the last interglacial, the Mid-Brunhes, Mid-Pleistocene Transition, the Mid-Pliocene warm period, and the Mid-Miocene. Those were periods when the changes in CO_2, temperature and sea level were significant – all possible scenarios to constrain the sensitivity of future AIS.

Research and collaboration gaps: Paleo-proxy and modeling perspectives

Accurately modeling ice-atmosphere-ocean interactions in different past climatic states is challenging due to technical and computational limitations, as well as gaps in our process understanding (Colleoni et al. 2018). Experiments from Paleoclimate Modelling Intercomparison Project (PMIP) Phase 4 have highlighted paleo-bathymetry, sub-surface melt rates, sea ice, polynya and bottom-water formation, and the timing and amount of meltwater entering the polar ocean, as some of the major factors that contribute to uncertainty in paleoclimate model simulations (Kageyama et al. 2018).

While the models remain notably sensitive to the choice of meltwater scenario (e.g. Chadwick et al. 2023), sea-ice conditions and paleo-bathymetry, there are only limited constraints on these parameters (e.g. Weber et al. 2014). New proxies, as well as more spatial coverage in the SO for traditional proxies, are essential.

A major challenge for the proxy community is to fill gaps in observational data by increasing the spatial coverage from what currently exists in the International Ocean Discovery Program, and its predecessor programs, as regional variability in the ice-ocean-atmosphere processes can be significant. Furthermore, while marine records provide proxy-based information on processes happening at the ice margin, they do not provide direct observations of inland ice retreat. This knowledge on inland ice retreat ultimately helps quantify sea-level contributions from the various Antarctic catchments that modeling experiments aim to assess for future projections (Patterson et al. 2022). Land-based geological and ice-core drilling efforts are the only means to ground truth-modeling experiments that examine such contributions, and reduce uncertainty surrounding the extent of ice retreat under future warming scenarios.

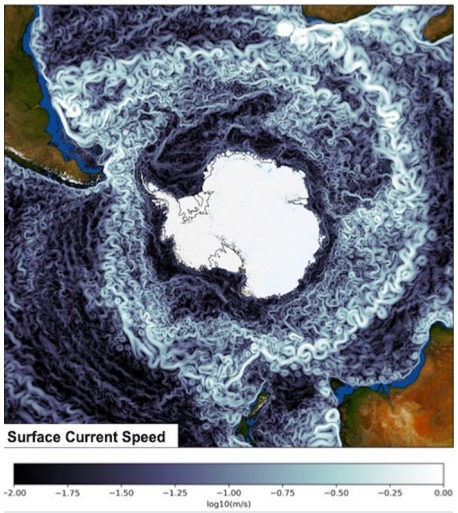

Figure 1: Visualization of the ACC showing modeled modern-surface current velocities with prominent eddies shaping ocean transport ,and exchange among SO and Antarctica.
Model: FESOM2 (Finite-volumE Sea ice-Ocean Model, formulated on unstructured mesh, fesom.de)
Setup: ROSSBY4.2; Simulations: Dmitry Sein (AWI); Visualization: Nikolay Koldunov (AWI). Image credit: Nikolay Koldunov.

Improved modeling of the evolution of the Antarctic-SO system would require identifying regions of highest priority to target for traditional and/or new proxy data, which may be better facilitated through the accessibility of paleoclimate model data by the proxy community. The paleoclimate community has identified that accessing model outputs acts as a major limitation to performing data-model intercomparison studies that may facilitate site selection, and proxy development.

Through this seven-year-long program, we plan to provide a timely synthesis of progressive knowledge of SO-Antarctic interactions, and provide a platform to foster collaborations that would minimize the knowledge gaps identified here.

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