frontiers | Frontiers in Marine Science

TYPE Editorial
PUBLISHED 24 October 2025
DOI 10.3389/fmars.2025.1720638

OPEN ACCESS

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RECEIVED 08 October 2025
ACCEPTED 13 October 2025
PUBLISHED 24 October 2025

CITATION
Olivé Abelló A and Machín F (2025) Editorial: Physical processes in the Southern Ocean: dynamics, interactions, and climate change. *Front. Mar. Sci.* 12:1720638. doi: 10.3389/fmars.2025.1720638

Editorial: Physical processes in the Southern Ocean: dynamics, interactions, and climate change

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KEYWORDS

Southern Ocean (SO), physical oceanographic processes, observational oceanography, submesoescale instabilities, long-term temperature records, Antarctic sea ice, ocean heat loss, ERA5

Editorial on the Research Topic

Physical processes in the Southern Ocean: dynamics, interactions, and climate change

With great pleasure, we introduce this Frontiers in Marine Science Research Topic dedicated to the physical processes of the Southern Ocean and their connections to global climate variability. The Southern Ocean plays a central role in regulating Earth's climate, acting as a key gateway for the exchange of heat, freshwater, gases, and nutrients between polar regions and lower latitudes. It is also the birthplace of some of the densest water masses in the global ocean, tightly coupling surface processes with abyssal circulation. Despite its importance, this ocean remains among the least observed and least understood regions of the planet, making sustained efforts in modeling, observations, and innovative techniques essential to advancing our understanding.

This Research Topic brings together five contributions that reflect the diversity of approaches and questions currently being addressed in Southern Ocean physical oceanography.

First, Ferris et al. investigate how topographic forcing modulates submesoscale instabilities in the Antarctic Circumpolar Current (ACC). Using a high-resolution hindcast model of the Drake Passage and Scotia Sea region, they reveal how symmetric and centrifugal instabilities can arise near continental slopes and seamounts, facilitating vertical mixing in regions of low potential vorticity. Specifically, the model suggests that both types of subsurface instabilities are widespread along the northern continental margins of the ACC and develop as a result of topographic shearing of the anticyclonic side of Polar Front jets.

Then, Werner-Pelletier et al. present a technological innovation and methodological advance in observational oceanography. By deploying 3D-printed hydrodynamic sensor housings aboard the historic sailing vessel *Pen Duick VI* during the Ocean Globe Race (2023–2024) to mitigate physical disturbances, and combining it with an automated filtering technique based on wavelet-based denoising algorithm, they demonstrate how opportunity vessels can provide high-quality sea surface temperature and salinity data in undersampled regions of the Southern Ocean.

Luengo-S et al. analyze long-term seawater temperature records (2015-2024) at Livingston and Deception Islands, highlighting the interplay between regional climate trends, glacial melt, and local volcanic activity. Their decade-long dataset reveals consistent warming signals and pronounced seasonality, underlining the combined influence of large-scale drivers and local geophysical processes in shaping thermal variability across the South Shetland Islands. The contrasting patterns between both islands also reveal how local topography and volcanic dynamics modulate the regional oceanic response to atmospheric warming and freshwater fluxes.

Guo et al. examine decadal transformations in Antarctic sea ice modes, documenting a significant transition from growth (1.7% per year) to widespread decline (an overall average of -4.6% per year) in the past decade across most of the Southern Ocean, except the Amundsen Sea. Their Empirical Orthogonal Function (EOF) and Singular Value Decomposition (SVD)-based analysis, over the period 2014-2023, links these changes to rising sea surface and surface air temperatures, and points to a shift in dominant patterns of variability, with critical implications for understanding tipping elements in the climate system.

Finally, Machín and Olivé Abelló use ERA5 reanalysis output (1980–2024, focusing on March–October) to quantify long-term reductions in oceanic heat loss over the four main dense-water formation regions of Antarctica. Their results reveal a consistent and marked decline since the mid-2010s across all four regions, particularly in the Weddell Sea (-32%), and identify a weakening of turbulent heat exchanges driven by decreasing sensible heat fluxes, which is directly associated with notable increases in 2-m air temperature (atmospheric warming) as a key mechanism reducing dense shelf water production.

Together, these contributions expand our understanding of how the Southern Ocean interacts with the atmosphere, sea ice, and topography, and how these processes are evolving under the influence of anthropogenic global warming.

We would like to express our sincere gratitude to all contributing authors for their high-quality work, and to the reviewers for their careful assessments that ensured the rigor of this Research Topic. We also extend our thanks to Dr. Donglai Gong, who supported the editorial process of one of the manuscripts and whose expertise helped improve the final outcome.

As editors, we hope this Research Topic not only advances the state of knowledge but also encourages further interdisciplinary collaboration in the study of the Southern Ocean. By deepening our understanding of its processes and variability, we are better prepared to anticipate the far-reaching consequences of ongoing climate change.

Author contributions

AOA: Writing – review & editing, Writing – original draft. FM: Writing – original draft, Writing – review & editing.

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