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Editorial

Multiscale processes in polar oceans and their climate and ecological implications

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The Arctic and Antarctica are important components of the Earth system, and the snow and ice over the polar regions make the interactions between the spheres there extremely sensitive to climate change, with an amplifying effect on climate warming. Polar regions are the forefront of global climate and ecosystem changes. More than half of the identified climate tipping elements in our planet occur in the polar regions, with the losses of Arctic sea ice, Greenland ice sheet, permafrost, and western Antarctic ice sheet, being considered as tipping elements with global impacts that have already occurred (McKay et al., 2022). These changes in the polar regions affect the heat and material transfer, water and carbon cycles, as well as biological diversity at a global scale, closely related to global sustainable development. Therefore, polar regions are also considered the limiting factors in achieving the United Nations Sustainable Development Goals (Li et al., 2025).

Unlike other oceans, the interactions between ocean and cryosphere play an important role in the multiscale evolution of the Arctic or Antarctic systems. Sea ice greatly isolates the exchanges of material, energy, and momentum between atmosphere and ocean, and combining the unique scenery of the polar night, creats light restrictions for the production of marine organisms. The growth and decay of sea ice affect the stratification and circulation of the ocean by providing fresh water or producing dense brine. The reduction of Arctic sea ice enhances the heat exchanges between atmosphere and ocean, promotes the amplification of Arctic climate warming, changes the seasonality of polar marine ecosystems, and affects the weather and climate at low and medium latitudes through atmospheric/ocean circulations. The growth of Antarctic sea ice is the main driver for the formation of Antarctic Bottom Water, which drives global ocean circulation and the burial of anthropogenic carbon in the deep sea. The warming of the Southern Ocean and the enhanced poleward heat transfer have caused increased melt of the ice shelf bottom, and the triggered instability of ice sheet has promoted its mass loss to the ocean. The melting and mass loss of the Western Antarctic Ice Sheet and the Greenland Ice Sheet affect the stratification of the ocean and its ability to absorb heat and carbon from the atmosphere. The state of mass loss from the Antarctic Ice Sheet is spreading from West Antarctica towards East Antarctica, becoming the most uncertain in global sea level estimates (Pattyn and Morlighem, 2020). Meanwhile, the Antarctic sea ice has gone from stable and slightly increasing to a sharp decrease since 2014 (Parkinson, 2019). The Arctic sea ice has experienced increased interannual variability over the last decade. The changes in sea ice in polar regions are the comprehensive outcomes of human-induced climate change and internal variability of the climate system, which is an unsolved mystery in the climate projections (Turner and Comiso, 2017).

The evolution of the complex systems of Arctic and Southern Oceans involves multi-scale processes. The variabilities of water masses in the Arctic and Southern Oceans often exhibit patterns with scales of multi decades or even longer. However, their variabilities are often associated with some processes at transient, synoptic, and seasonal scales, e.g., the growth and decay of sea ice, evolution of polynyas, and submesoscale processes, etc. Therefore, there are complex energy and nutritious cascades in the evolution of the Arctic and Southern Oceans, as well as its associated global impacts. The Arctic and Southern Oceans have always been considered the waters with the least understood and weakest predictability over our planet. That is also considered the biggest unknown puzzle in the framework of the oceanographic knowledge system, full of unresolved scientific questions.

In the lead up to its 35th anniversary in 2025, the International Arctic Science Committee (IASC) is coordinating a multi-year planning process for the Fourth International Conference on Arctic Research Planning (ICARP Ⅳ) that will consider the most urgent knowledge gaps and research priorities that lie before us and to explore avenues to address these research needs in the Arctic regions for the next decade until 2035. Since 2023, the IASC and the Scientific Committee on Antarctic Research (SCAR) confirmed that preparatory work has started for the 5th International Polar Year (IPY) in 2032–2033. Organizing the 5th IPY, 25 years after the last IPY in 2007–2008, reflects the urgent need for co-

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ordinated international cooperation to tackle the biggest challenges of polar research, for both the Polar Regions and the world as a whole. IPY-5 in 2032–2033 aims to address urgent global challenges by advancing polar research, focusing on the impacts of climate change in the Arctic and Antarctica. In December 2022, the United Nations General Assembly declared this year (2025) is the International Year of Glacial Preservation, which marks the milestone of the beginning of the Decade of Action for Cryospheric Sciences (2025–2034). It is thus clear that, the earth scientists around the world, especially climatologists, have turned their attention to the Arctic and Antarctica, the regions with the most unknowns and the fastest changes in the Earth system.

2024 marks the 40th anniversary of Chinese National Antarctic and Arctic Research Expeditions (1984–2024). China has conducted 40 voyages in the Antarctica and 14 voyages in the Arctic for oceanographic surveys. Chinese scientists continue to cultivate and contribute to scientific explorations and researches in such waters of remote, barren, harsh, mysterious, and intriguing.

After the launch and commissioning of the R/V *Xuelong 2* in 2019, it greatly improved the investigative capabilities of Chinese scientists in the Arctic and Southern Oceans. The investigation areas and contents are expanding, and the observation and sampling capabilities are constantly improving. Chinese scientists have made significant scientific progresses in observation technologies, studies in changes of water mass, sea ice, ecosystem, and carbon cycle, and multi-scale numerical simulations and projections for the Arctic and Southern Oceans. Together with international peers, they are committed to solving the mysteries of polar oceanography. To commemorate and celebrate the 40th anniversary of China's polar research expeditions, the *Acta Oceanologica Sinica* is organizing two consecutive special issues in 2025, with the topic of "Multiscale processes in polar oceans and their climate and ecological implications". In the third issue of this journal in 2025, composed of 10 papers, it mainly focuses on multi-scale physical processes in the Arctic and Southern Oceans, particularly the interactions between the atmosphere, ice shelf, sea ice, and ocean. In the following issue, including 9 papers, it mainly focuses on the changes and current status of the ecosystems, biotic communities, and biogeochemical cycles, as well as the historical records of marine environments in the Arctic and Southern Oceans.

Under the guidance of Prof. Dake Chen, Editor-in-Chief of *Acta Oceanologica Sinica*, a guest editorial team consisting of 10 scholars from various sub fields of polar oceanography was formed to prepare, plan, and organize these two special issues. Professors Jiuxin Shi, Meng Zhou, Zexun Wei, Cunde Xiao, Xueyuan Tang, and myself contributed to the organization of the first issue. Professors Jianfang Chen, Rujian Wang, Jianfeng He, and Longshan Lin contributed to the subsequent issue. A wide range of anonymous domestic or foreign experts have made significant voluntary contributions to the reviews of the papers published in these two issues. On behalf of the guest editorial team, I would like to express my sincerest gratitude to them.

These two special issues focus on the multi-scale processes in the Arctic and Southern Oceans, collecting research papers from multiple disciplines. The discipline background of authors contributed to the issues includes physical oceanography, cryospheric science, atmospheric science, marine biology, marine ecology, marine chemistry, marine geology, numerical modelling, and satellite remote sensing, etc., reflecting the importance of interdisciplinary studies in polar oceanography. However, we also acknowledge that the studies that collected by two special issues are still very limited and cannot fully reflect the breadth and depth of disciplinary coverage of Chinese scientists in the studies on the Arctic and Southern Oceans.

Through these works, we have identified that there are still many observational gaps in the Arctic and Southern Oceans for scientists from China or around the world, such as the ice-covered oceans during winter, the oceans beneath the Arctic thickest multiyear ice, and the cavities beneath the Antarctic ice shelf, and so on. These are the investigation areas that we need to break through via technological innovations. From the perspective of numerical models, there is an extreme need for improvements in the coupling of multiple spheres of atmosphere, ice sheet, sea ice, ocean, and ecology, and in the fine descriptions and parameterizations of sub-grid processes of these elements. In terms of satellite remote sensing, it is necessary to enhance the observation capabilities of China's satellites in the polar regions and the retrieval capabilities of sea ice or oceanic multiparameters at sub-kilometer scales.

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