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Linkage between the Antarctic Sea Ice Decline and the Dense Shelf Water salinity rebound in the Ross Sea

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The Dense Shelf Water (DSW) in the Ross Sea Continental Shelf (RSCS) is the second largest source of the Antarctic Bottom Water (AABW) which is a key component of the lower cell of global ocean circulation. The brine rejection during the sea ice formation process is pivotal for gravity-driven ocean circulation and significantly impacts on various aspects of the marine environment. The freshening trend of DSW persisted for over several decades, but since the mid-2010s, DSW salinity in the Ross Sea has rebounded sharply. Meanwhile, the Antarctic Sea Ice Extent (SIE) has exhibited an increasing trend since the satellite era. However, the Antarctic SIE experienced an abrupt decline in mid-2010s. We have inspired by the fact that both phenomena in Antarctica appeared at mid-2010s and have been persisted until recently. The purpose of this study is to investigate the relationship between the salinity rebound of the DSW in the Ross Sea and the decline in sea ice across the Antarctic region. During the Salinification Period (SP) since 2016, there were significant increases in sea ice advection and divergence from the RSCS toward the open ocean, along with enhanced sea ice formation in expanded Ross Sea polynya. To analyze the dominant atmospheric changes during the SP that impact the wind system and sea ice coverage over the Antarctica, the components representative of Southern Hemisphere atmospheric variability were identified and traced. Overall, westerly winds have strengthened over the entire Antarctic Ocean during the SP, while meridional winds exhibited asymmetric responses. In the Ross Sea, southerly wind anomalies prevailed, while northerly wind anomalies were dominant in other Antarctic regions during the SP. The broadly intensified northerly winds led to a significant decrease in total Antarctic sea ice cover. In contrast, the strengthened southerly wind in the Ross Sea sustained the offshoreward sea ice export and active sea ice formation on the RSCS during the cold season, driving the recent increasing trend in DSW salinity.

Key words: Antarctic Ocean, Sea Ice Decline, Dense Shelf Water

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Intermodel diversity of Southern Meridional Overturning Circulation in CMIP models

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In response to anthropogenic emissions, Southern Ocean (SO) has been recognized as an important basin for absorbing the excess heat. The Meridional Overturning Circulation (MOC) plays a key role in regulating heat uptake, which subsequently redistributes global energy. Unlike previous studies conducted under historical and global warming scenarios, this study explores the mean state of the SO MOC without external forcing. Using the global climate models from Coupled Model Intercomparison Project (CMIP), we examine the model diversity of SO MOC through inter-model EOF analysis. The first EOF mode highlights the dominant inter-model differences in the wind-driven Deacon cell, upper circulation of the SO MOC. Enhanced Deacon cell intensity increases cold meridional advection in mid-latitudes, while contributing to warmer sea surface temperature (SST) at higher latitudes via warm water upwelling. These SST changes modify influence meridional temperature gradients, leading to intensification and shifts of wind stress. This ocean dynamic feedback, along with low-level cloud feedback plays a significant role in shaping the SO mean state.

Key words: Southern Ocean, Meridional Overturning Circulation, wind-driven Deacon cell, ocean dynamic feedback

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Sea ice-free Antarctic subregions in the 2070s under high emission scenarios

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Antarctic sea ice plays a critical role in preventing the disintegration of Antarctic ice shelves from ocean swells or wave extremes, thereby controlling Antarctic ice sheet collapses and associated sea level rise. This study aims to project the timing of ice-free conditions across five sub-regions using Coupled Model Intercomparison Projection phase 6 (CMIP6) model simulations under different shared socioeconomic pathways (SSP) scenarios. CMIP6 models tend to simulate February's Antarctic sea ice area (SIA) lower than the observations in all regions and seven models are selected which can capture the observed SIA climatology. We project the timing of ice-free conditions as the first year when most of the coastal line is exposed to the open ocean (i.e. coastal exposure index > 0.9). In the Amundsen and Bellingshausen Seas region, sea ice is projected to be the fastest in ice-free conditions in the 2070s in the high emission scenario. Although we projected the ice-free condition using the selected models, the uncertainty about the future projection remains because CMIP6 models exhibit diversity in simulating the Antarctic SIA changes and may not adequately reflect the teleconnection between climate variability and Antarctic SIA variability.

Key words: Antarctic sea ice, sea-ice free, CMIP6, costal exposure index

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Long-term stability of Greenland and Antarctic ice sheets in a warmer world

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The question of how the Greenland ice sheet (GrIS) and Antarctic ice sheet (AIS) will respond to rising global temperatures remains unsolved, largely due to the complexity of feedback mechanism and a long response timescale of cryosphere system. Here, we present the long-term responses of GrIS and AIS to increasing CO_2 concentrations, using a series of 100-kyr transient simulations which were conducted with the Community Earth System model (CESM, version 1.2) coupled to the bi-hemispheric Penn State University ice sheet-ice-shelf Model (PSUIM). Our simulation reveals distinct mechanisms of GrIS and AIS, governed by both the mechanisms “warmer-get-snowier” and “warmer-get-melter”. Notably, the former, which was previously underestimated compared to the latter, contributes more significantly to eastern AIS than reported previously. As a result, despite a global mean temperature ~ 11℃ warmer than present-day, the eastern AIS remains stable and even increases with an intensification of precipitation sensitivity associated with the nonlinear Clausius-Clapeyron relationship. Whereas the enhanced precipitation sensitivity in GrIS is mostly driven by the thermodynamic factor, that in AIS is controlled together by the dynamic factor related to surface topography. We further discuss the polar hydrological nonlinearity, and their potential impacts in response to global warming.

Key words: Greenland ice sheet, Antarctic ice sheet,global warming, coupled climate-ice sheet model

Why is sea level irreversible?: Role of deep ocean warming-induced SST pattern

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Anthropogenic emissions are expected to rise global mean sea level, and despite mitigation efforts such as carbon dioxide removal, this rise is projected to be irreversible on human time scales. This irreversibility is primarily attributed to huge thermal inertia of the deep ocean; even if global warming is reversed, it takes a long time for the ocean to release a large amount of accumulated heat, resulting in continued ocean thermal expansion. When the heat is released, its efficiency is known to be controlled by oceanic stability, with active vertical heat exchanges concentrated in high-latitude regions. Consequently, sea surface temperature (SST) warming could evolve with a specific spatial pattern. The SST pattern is known for its crucial role in controlling climate feedbacks, so-called pattern effect. Therefore, sea level irreversibility may depend on the pattern and subsequent feedback. Here, we utilize a state-of-the art climate model to investigate the irreversibility of sea level and find that even persistent sea level rise is possible with pattern-induced climate feedback. Specifically, the SST pattern induced by deep ocean warming surprisingly coincides with regions where climate feedback occurs. This disrupts the SST damping at the surface, leading to continued ocean thermal expansion and consequently in sea level rise. Atmosphere-only simulation further support the role of the SST pattern. By decomposing the contributions of the SW increase into the pattern effect and the mean warming effect, we find that the pattern effect is the major cause of the SW increase, while the mean warming effect on the SW is negative. We suggest that how the SST pattern evolves under climate mitigation affects the future behavior of sea level rise. This underscores the importance of more accurately simulating the low cloud feedbacks, which are highly uncertain in climate models, for future sea level projections.

Key words: Global mean sea level rise, SST pattern, climate feedback, deep ocean warming

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Irreversible contraction of Silicate Front to CO_2 forcing and its resultant global nutrient depletion

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Recent rapid climate change has led to increased global efforts to reduce anthropogenic carbon dioxide (CO_2) emissions. However, many of the not only physical but also biological climate factors exhibit different responses after the return of CO_2 concentrations. Marine phytoplankton in the oceans play a role in regulating climate by absorbing carbon dioxide from the atmosphere. The role of the biological pump depends on changes in phytoplankton biomass as well as their communities. Here, we evaluate the irreversibility of phytoplankton communities in a CO_2 Removal (CDR) experiment and elucidate its mechanisms and global impacts. We assess changes in silicate fronts in the Southern Ocean, which consists of multiple fronts with varying physical and chemical gradients, and the irreversible changes in marine phytoplankton communities. Irreversible changes in the physical factors of the atmospheric — ocean in the Southern Ocean are accompanying biological impacts, in particular, they cause diatom enhancement. The enhancement of the biological pump by diatoms can lead to a collapse of the global nutrient cycle, which in turn leads to a vicious cycle of weakening global ocean productivity.

Key words: Marine bio-geochemistry, Global Warming, Climate Irreversibility, Southern Ocean, Nutrient