

Reconstructing Antarctic sea ice from 130,000 years ago

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Past warm periods serve as an analog for the impacts of future warming. Reconstructions of Antarctic sea ice from 130,000 years ago show a reduction in sea-ice extent relative to the present, with the patterns of retreat varying between regions of the Southern Ocean.

Why 130,000 years ago?

Between 130,000 and 116,000 years ago was the time interval known as Marine Isotope Stage (MIS) 5e. Global average temperature during MIS 5e is estimated to have been 2°C warmer than the pre-industrial (Fischer et al. 2018) and similar to what is predicted for 2100 (Meredith et al. 2019). Therefore, investigating the environmental conditions during MIS 5e can provide an analog for the likely environmental and climatic impacts of current and future anthropogenic warming. High latitudes have a greater sensitivity to climatic changes and can amplify the impacts of rising temperatures through feedbacks in the ocean and cryosphere; therefore, studying polar regions is particularly important to understand the climatic impacts of a warming world.

Why Antarctic sea ice?

Antarctic sea ice is a crucial component of the global climate system, due to its high

albedo (reflectivity) and the influence it has as a barrier to gas exchange between the atmosphere and ocean (Rysgaard et al. 2011). Sea ice also helps to stabilize Antarctic ice shelves and ice streams by protecting them from wave and ocean swell (Massom et al. 2018) and is a key habitat for many Antarctic organisms (Arrigo 2014).

How is past Antarctic sea ice reconstructed?

As discussed by Armbrecht (p. 78), McClymont et al. (p. 82), and Nixon (p. 84) numerous proxy records can be used to reconstruct past changes in polar sea ice. For the Antarctic, the most robust and well-studied of these proxies are the species assemblage of diatoms, a group of photosynthesizing siliceous microalgae, preserved in marine sediments. Different species of diatoms have different environmental preferences and by studying the species assemblages in seafloor sediments throughout

the modern Southern Ocean, a reference database can be built comparing seafloor sediment species assemblages to present environmental conditions (Crosta et al. 1998; Esper and Gersonde 2014). The diatom assemblages preserved in marine sediments from 130,000 years ago can be compared to this reference dataset to reconstruct the past sea-ice concentrations (Chadwick et al. 2022a).

How did winter sea-ice concentrations vary throughout the Southern Ocean during MIS 5e?

The reconstructed patterns and trends in Antarctic winter sea-ice concentrations in Chadwick et al. (2022a) show substantial variation between the three ocean basin sectors (Atlantic, Indian and Pacific) of the Southern Ocean (Fig. 1). The Atlantic-sector sea-ice records (lightest blue shading in Fig. 1) show very low winter sea-ice concentrations in early MIS 5e (~131,000–130,000

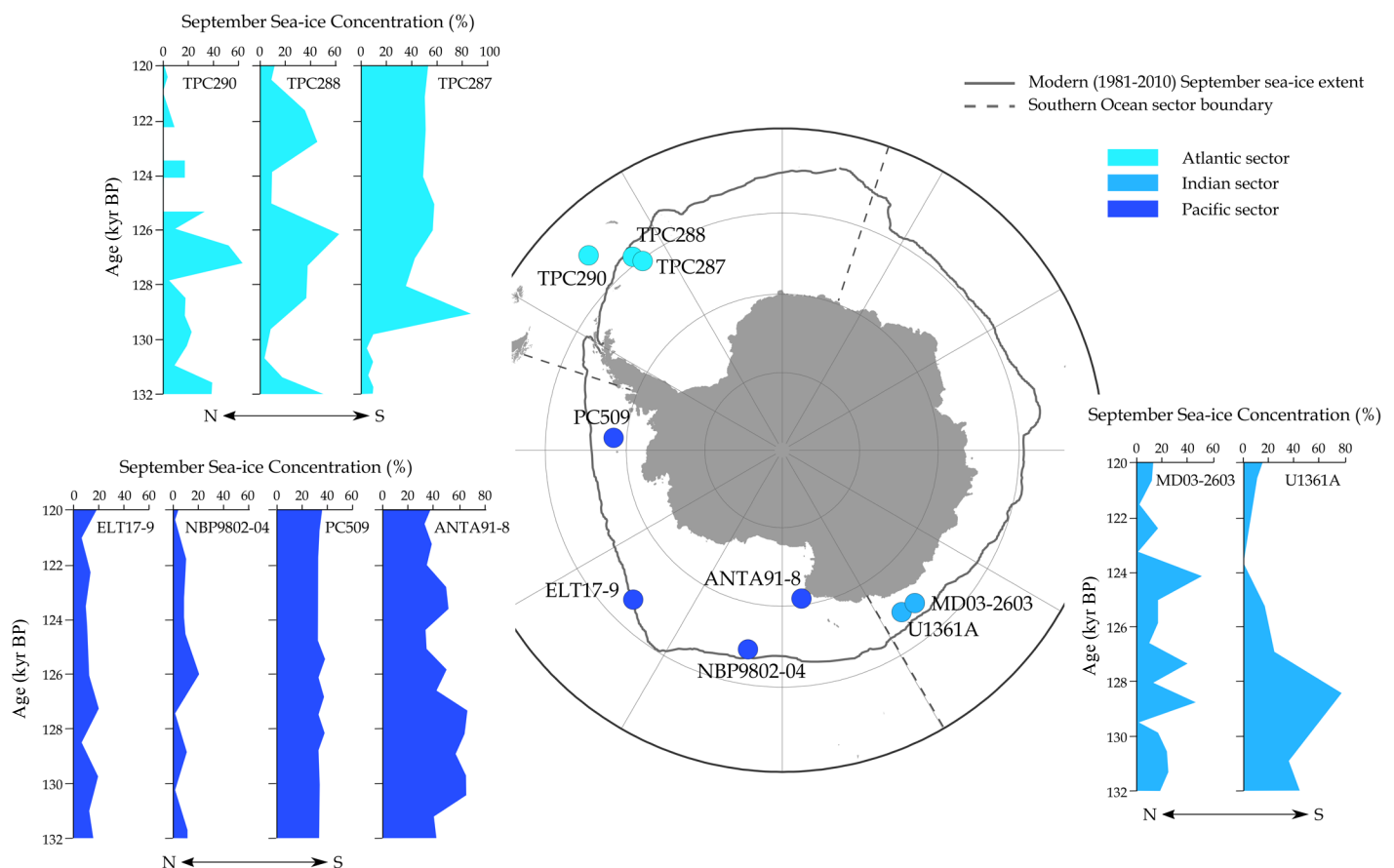


Figure 1: September sea-ice concentrations for the end of Termination II and early to mid MIS 5e from nine marine sediment cores. Figure modified from Chadwick et al. (2022a).

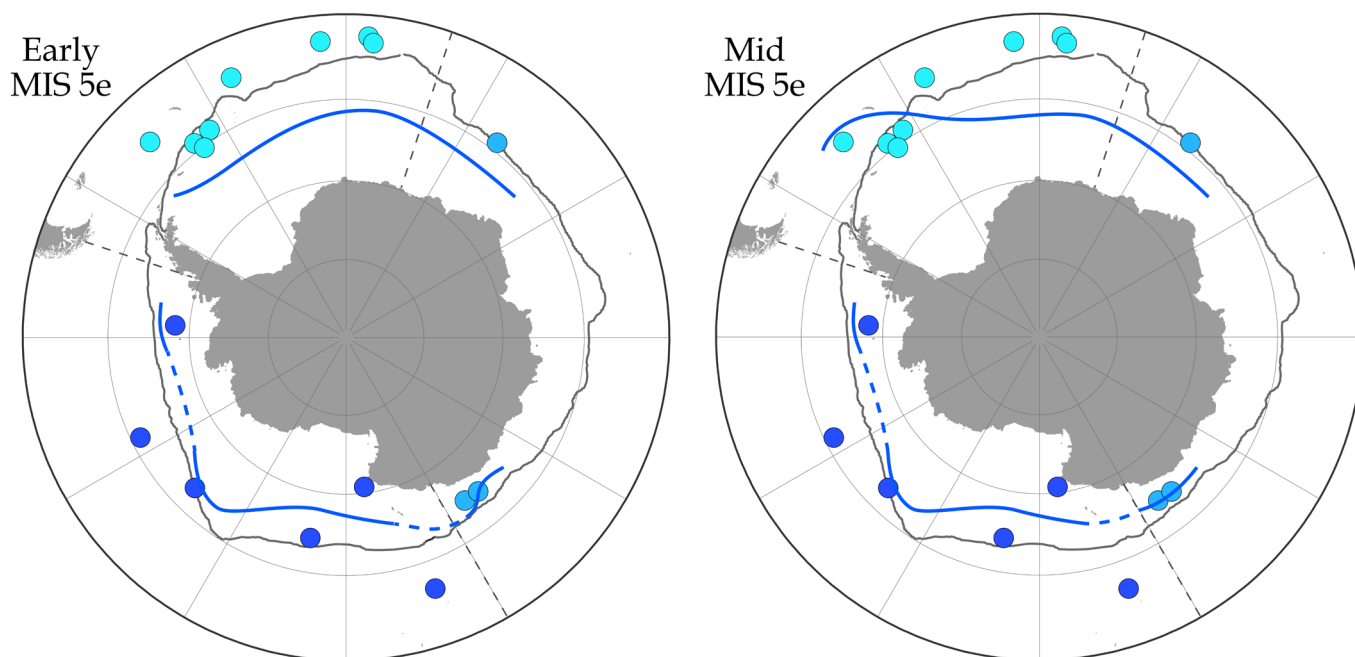


Figure 2: September winter sea-ice extent during early and mid-MIS 5e (blue lines) compared to the modern (1981–2010) September sea-ice extent (solid grey line). For the MIS 5e September winter sea-ice extent, the dashed line marks the areas that are less robustly constrained. MIS 5e sea-ice extent is estimated using data from marine sediment cores presented in Chadwick et al. (2020; 2022a).

years ago), followed by a substantial increase to a maximum around 127,000–126,000 years ago. In contrast to the prominent minimum and maximum in Atlantic-sector sea-ice concentrations, the Pacific-sector records (darkest blue shading in Fig. 1) show very little variability in sea-ice concentrations. All the Pacific-sector records show largely consistent sea-ice concentrations throughout MIS 5e, and the two more southerly cores are the first records where the core site was located beneath winter sea ice throughout MIS 5e. The Indian-sector records (mid-blue shading in Fig. 1) show more variability in sea-ice concentration than in the Pacific sector, but at a higher frequency than the variability in the Atlantic sector. Millennial-scale sea-ice variability in the Indian sector during MIS 5e results in a series of sea-ice concentration maxima and minima, with a greater proportion of high sea-ice periods during earlier MIS 5e followed by a transition to more intervals of low sea ice (Fig. 1) after 125,000 years ago.

How did MIS 5e Antarctic sea-ice extent compare to today?

The sea-ice concentrations reconstructed for MIS 5e (Chadwick et al. 2020; Chadwick et al. 2022a) can be used to estimate where the winter sea-ice edge reached, which can then be compared to its modern position (Fig. 2). During early MIS 5e, the Antarctic winter sea-ice extent reached a minimum of roughly 62% of its modern area, with this increasing slightly, to roughly 71%, by mid MIS 5e. During early MIS 5e, the largest reduction in sea-ice extent, to 58% of its modern extent, was in the Atlantic sector, where the winter sea-ice edge was located roughly 5° latitude south of its modern position (Fig. 2). During mid-MIS 5e, the winter sea-ice edge in the western Atlantic sector expanded by approximately 5–8° latitude, placing it to the north of its modern position (Fig. 2). Chadwick et al. (2022b) hypothesized that this expansion

in the western Atlantic sector is a result of the release of large amounts of meltwater and icebergs from the Antarctic ice sheets that outflow into this region of the Southern Ocean. This high outflow of meltwater and icebergs from the Antarctic continent was likely influenced by the sea-ice minimum in early MIS 5e allowing the greater penetration of warmer waters into embayments and under floating ice shelves, promoting their melting and breakup.

Unlike the Atlantic sector, the Indian and Pacific sectors show a greater consistency between early and late MIS 5e, with minimal change in the position of the winter sea-ice edge (Fig. 2). In the Pacific sector, the reduction in MIS 5e winter sea ice relative to today is greatest in the western part of the sector, where it was located roughly 3–4° latitude south of its modern position (Fig. 2). This contrasts to the eastern Pacific sector where the winter sea-ice edge was located <2° latitude south of its modern position (Fig. 2). In the Indian sector, although the average position of the winter sea-ice edge is largely consistent between early and mid-MIS 5e (Fig. 2), the millennial-scale variability previously discussed means that the position of the winter sea-ice edge will have varied a lot around this average (Fig. 1). Chadwick et al. (2022a) hypothesized that the millennial-scale variability in the Indian-sector winter sea-ice extent is due to the influence of Southern Ocean fronts and surface water masses migrating north and south.

What does this mean for the future?

Although the warmer climate during MIS 5e was driven by different forcings than current anthropogenic warming, it still presents an excellent analog for how the climate system is likely to respond to increasing global temperatures. The reconstructions of Antarctic sea ice during MIS 5e indicate that in the future we could see a substantial reduction

in Antarctic winter sea-ice extent, to 62% of its modern extent, but that this reduction will not be uniform across the Southern Ocean. The greatest sea-ice losses are expected in the Atlantic sector, with the Pacific-sector sea-ice extent seemingly more resilient to a warming climate. The retreat of Antarctic sea ice in the future has many knock-on consequences for the global climate system, one of which is the likely loss of a substantial volume of the Antarctic Ice Sheet, as evidenced during MIS 5e by the release of meltwater and icebergs into the Atlantic sector (Chadwick et al. 2022a, b).

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