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Overview of *China Polar Climate Change Annual Report (2022)*

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Abstract The China Meteorological Administration recently released *China Polar Climate Change Annual Report (2022)* in Chinese, with the following main conclusions. Using the China Reanalysis-40 dataset (CRA-40), rapid warming has been observed in the Antarctic Peninsula and West Antarctica since 1979, with some parts of East Antarctica also experiencing warming. In 2022, the regional average temperature in Antarctica based on observational data was close to the long-term average (1991–2020). The Arctic, on the other hand, has experienced a warming trend at a rate of 0.63 °C per decade from 1979 to 2022 based on CRA-40, which is 3.7 times the global mean during the same period (0.17 °C per decade). In 2022, the overall temperature in the Arctic, using station data, was 1.10 °C above the long-term average (1991–2020). In recent years, both the Antarctic and Arctic regions have witnessed an increase in the frequency and intensity of extreme weather events. In 2022, based on the sea ice extent from National Snow and Ice Data Center, USA, Antarctic sea ice reached its lowest extent on record since 1979, and on 18 March, the most rapid surface warming event ever recorded on Earth occurred in the Antarctic, with a temperature increase of 49 °C within 3 d. This report has been integrated into China's National Climate Change Bulletin system, to contribute to raising public awareness of polar climate change and providing valuable scientific references to address climate change.

Keywords **polar extreme weather and climate events, air temperature, sea ice, greenhouse gases, ozone**

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1 Introduction

The Antarctic and the Arctic play privotal roles in the Earth's climate system, influencing global atmospheric circulation, weather and climate, and the redistribution of heat and moisture between the Northern and Southern Hemispheres. In recent years, global warming has led to the rapid melting of Arctic sea ice, the thawing of the Greenland Ice Sheet, and an increase in extreme events in Antarctica. Polar ecosystems have undergone significant changes, such as the concentration of krill, a key species, shifting towards the Antarctic continental shelves due to changes in Antarctic sea ice (Atkinson et al., 2019). The impacts of polar changes have also extended beyond the polar regions to affect the global climate, leading to the intensification of extreme weather events at mid-latitudes (Cohen et al., 2021)，For instance, the 2020/21 NH winter saw the emergence of a powerful Arctic cold wave, known as the "Beast from the East", which significantly impacted agriculture, infrastructure, transportation, environmental health, and ecosystems in East Asia. These extreme weather events have garnered worldwide attention. Recently, the China Meteorological Administration released *China Polar Climate Change Annual Report (2022)* in Chinese for the

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first time, providing a comprehensive overview of the climate in the Antarctic and Arctic since 1979. This report extensively analyzes the climate system monitoring conditions in 2022, including temperature, sea ice, major greenhouse gases, and total ozone (hole). It provides a comprehensive assessment of polar extreme weather and climate events and their impacts. To facilitate a better understanding and interpretation of its findings and to provide information to English-speaking readers, we summarize the relevant information in the following.

2 Air temperature

The air temperature from the China Reanalysis-40 dataset (CRA-40) reveals pronounced warming trends in the West Antarctic and the Antarctic Peninsula. Using station observation data, South Orkney Islands, Faraday Station and Marie Byrd Land exhibited warming rates of 0.20 °C per decade (1904–2022), 0.45 °C per decade (1946–2022), and 0.22 °C per decade (1957–2022), respectively. The Arctic has experienced accelerated warming over the past four decades, with an overall temperature increase rate of 0.63 °C per decade during the period of 1979–2022, which is 3.7 times the global warming rate (0.17 °C per decade) over the same period.

CRA-40 also indicates that in 2022, Vostok Station in East Antarctica, the Antarctic Peninsula, and its surrounding ocean areas exhibited significant warm anomalies, consistent with observational results. Conversely, the Ross Sea region experienced a cold anomaly, resulting in minimal overall temperature change in Antarctica for 2022, with a slight deviation of –0.05 °C from the long-term average (Figure 1). As shown in Figure 2, Global Historical Climatology Network-Daily (GHCN-D) (Menne et al., 2012) and Global Summary of the Day (GSOD) station data (Kilibarda et al., 2015) show that in 2022, the Arctic overall average temperature was 1.10 °C above the long-term average, with the most substantial warming occurring in the Barents-Kara Sea region, exceeding 2 °C.

3 Sea ice

Data from the Fengyun-3 polar-orbiting meteorological satellite's Microwave Radiation Imager indicates that between 2012 and 2022, the monthly average sea ice extent in February and September for Antarctica were 3.69×10^6 km^2 and 18.94×10^6 km^2, respectively. In 2022, the maximum and minimum sea ice extents in Antarctica deviated below the long-term average (2012–2022) by 23.84% and 2.96%, respectively, with the minimum extent at 1.92×10^6 km^2 marking the lowest record since 1979 based on sea ice extent index from the National Snow and Ice Data Center (NSIDC), USA. When compared to the sea ice concentration in February for the years 2012–2021, a notable decrease of sea ice concentration occurred in various regions of Antarctica in February 2022, particularly in the northwest portion of the Weddell Sea Ice Shelf, where it reduced by 25% to 75%. The regions along the western Ross Sea, the coastlines of Marie Byrd Land, the northeastern coast of Wilkes Land, and the coastal areas of Queen Mary Land saw a decrease in sea ice concentration ranging from 20% to 50%. In September, significant reductions of sea ice concentration, ranging from 25% to 75%, were observed in the Bellingshausen Sea, the western portion of the Weddell Sea, and at the outer peripheries of sea ice in East Antarctica (Figure 3). The similar seasonal variation characteristics can be found in the State of the Climate in 2022 (Clem et al., 2023).

In the Arctic, based on the sea ice concentration and extent indices from NSIDC for the years 1979 to 2022, there was an overall reduction in sea ice extent in 2022, with a minimum extent of 4.67×10^6 km^2 during the summer and autumn seasons, slightly larger than the minimum observed in 2007, while during the winter and spring seasons, the sea ice extent remained comparable to that of 2007 (Figure 4). The areas experiencing reduced sea ice concentration during the summer season in 2022 were mainly in the Bering Sea, the Chukchi Sea, the East Siberian Sea, the Laptev Sea, and the Kara Sea. Conversely, the winter season saw reductions in sea ice concentration in more southern regions, such as the Barents Sea, the Sea of Okhotsk , the Greenland Sea, and Baffin Bay.

4 Atmospheric composition

Using data from the World Data Centre for Greenhouse Gases at polar monitoring stations, it was observed that from 1984 to 2021, the concentration of greenhouse gases in the Antarctic atmosphere exhibited a consistent upward trend, aligning closely with the global trend. In 2021, at Zhongshan Station, the annual average concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and sulfur hexafluoride (SF_6) were 412.01 mg·m^{-3}, 1839.28 μg·m^{-3}, 333.27 μg·m^{-3}, and 10.40 ng·m^{-3}, respectively (WMO, 2023). These concentrations have increased compared to 2020, with sulfur hexafluoride showing the most significant increase of 0.36 ng·m^{-3}, reaching the highest annual increment in recent years. Over the period of 1984 to 2021, the concentrations of greenhouse gases in the Arctic atmosphere steadily increased. In 2021, the annual average concentrations of carbon dioxide, methane, nitrous oxide, and sulfur hexafluoride in the Arctic were 417.78 mg·m^{-3}, 1988.36 μg·m^{-3}, 334.75 μg·m^{-3}, and 10.86 ng·m^{-3}, respectively, showing a noticeable rise compared to the 2020 averages (WMO, 2023).

In 2022, the Antarctic ozone hole exhibited a slightly smaller area than the previous year, continuing the overall trend of reduction observed in recent years. However, the end date of the ozone hole was later than most of the past 40 years, ranking as the 12th largest ozone hole since 1979

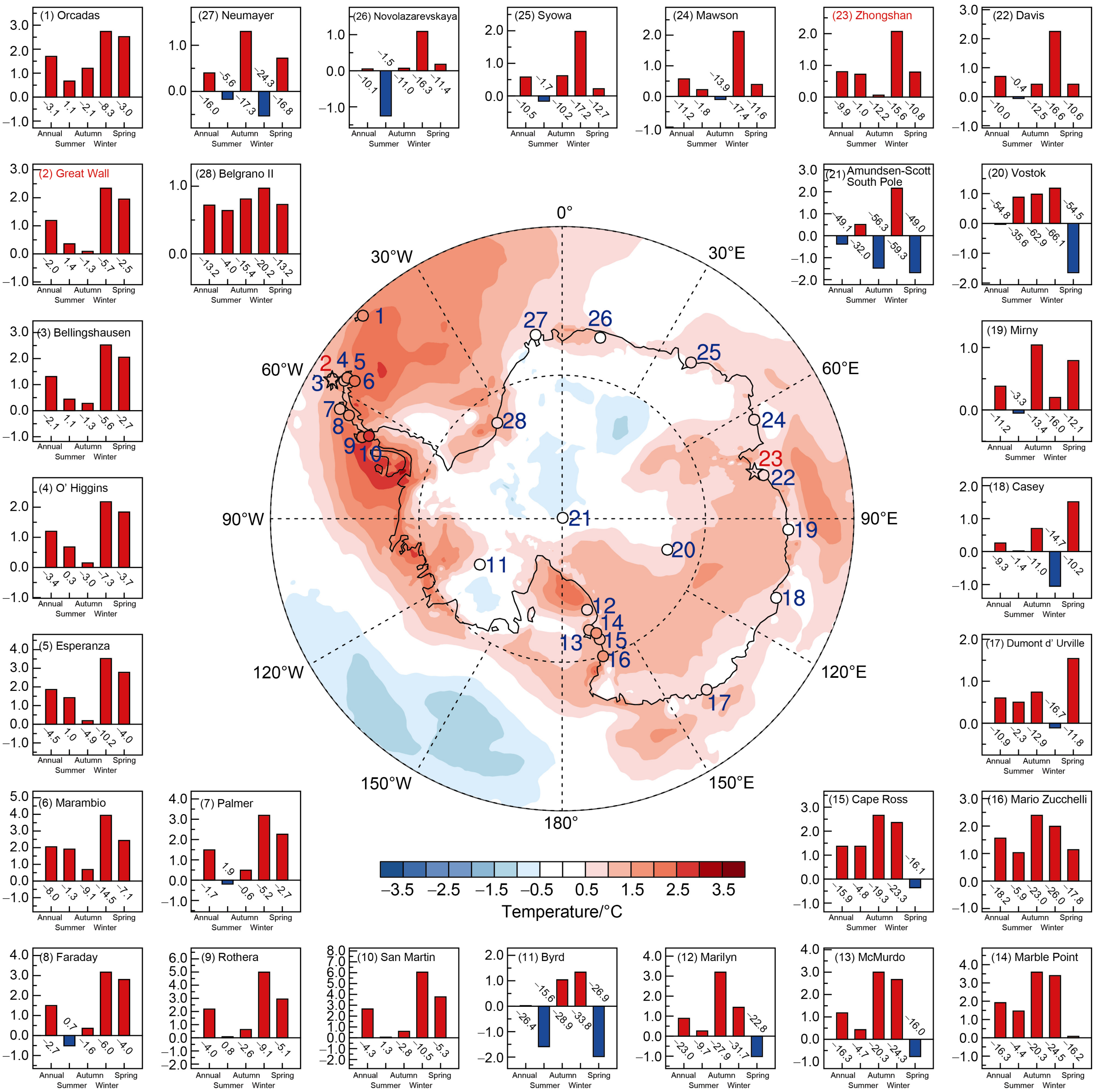

Figure 1 The spatial distribution of 2022 annual mean temperature anomaly in Antarctica, bar charts depicting annual and seasonal mean temperature anomalies at monitoring stations (relative to the 1991–2020 average), shading representing the CRA-40 reanalysis dataset, circular markers showing station-specific data, numerical values at the zero line in the bar charts corresponding to the 1991–2020 average (in degrees Celsius, °C)

if comparing the area with a total ozone amount below 220 DU (Dobson Unit). During the spring of 2020, a significant portion of the Arctic region experienced record-low total ozone column values. From late December 2022 to March 2023, the average total ozone in the Arctic was exceptionally high relative to historical levels, in contrast to the situation in 2021–2022. Recent research by Friedel et al. (2022) suggests that reductions in springtime Arctic ozone can lead to climate anomalies in the Northern Hemisphere.

5 Extreme events

The occurrence of extreme weather events in the Arctic and Antarctic regions is showing a trend of increased frequency and intensity. In March 2022, the

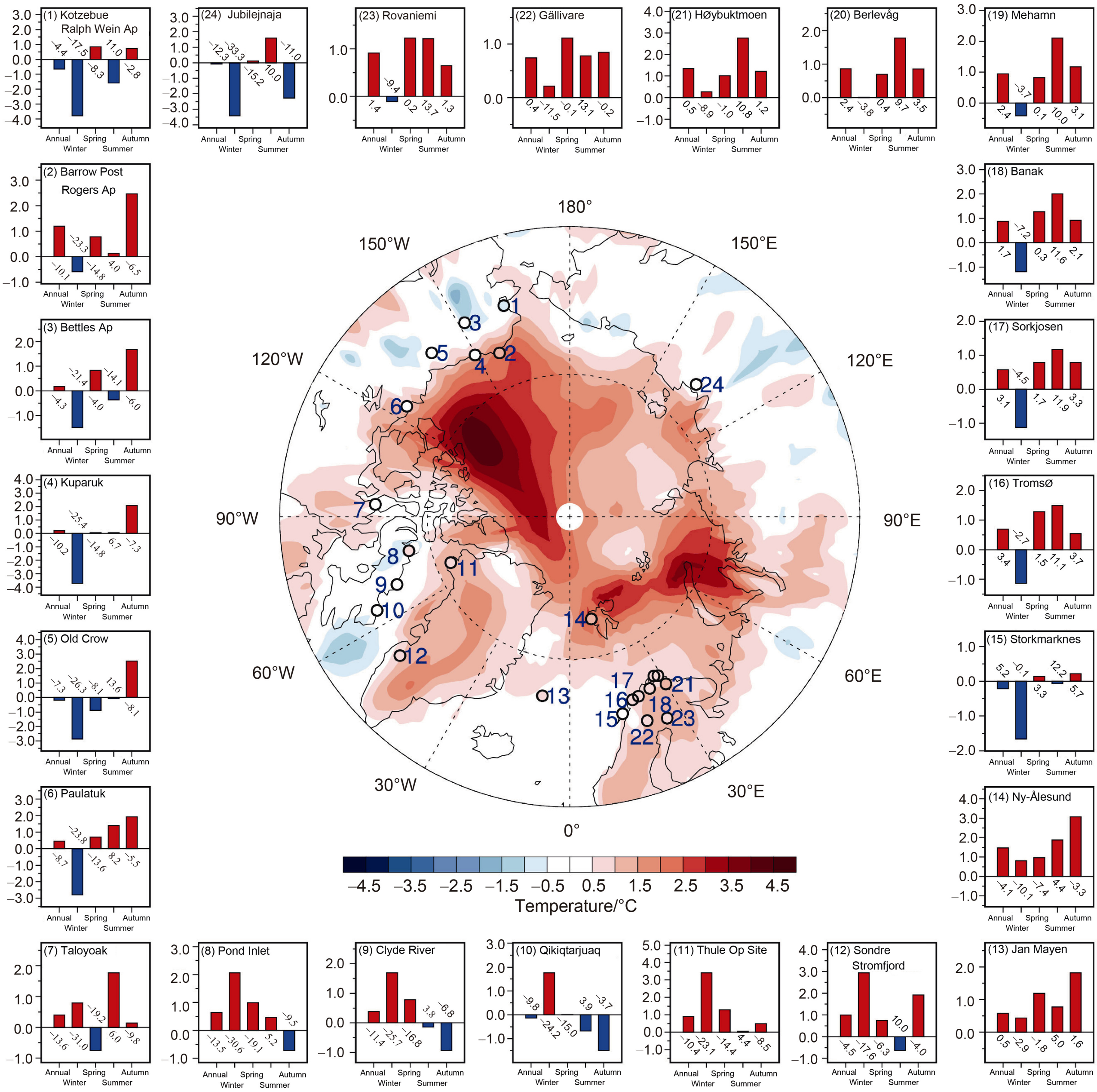

Figure 2 As in Figure 1, but in Arctic.

Antarctic witnessed the largest short-term warming event ever recorded. At Concordia Station, Vostok Station, and Kunlun Station, all located in the interior of the East Antarctic Ice Sheet, the average surface air temperatures on 18 March were 44.5 °C, 39.0 °C, and 26.2 °C higher, respectively, than their long-term averages (Figure 5). The magnitude of warming and the anomalies in surface air temperatures set new records in the history of Antarctic observations (Wang et al., 2023a). At near the same time, sea ice in the Antarctic reached a record-low extent. On 25 February 2022, the Antarctic sea ice extent was at an all-time low of 1.92×10^6 km^2, 0.19×10^6 km^2 lower than the previous record of 2.11×10^6 km^2 recorded on 3 March 2017.

Compared with the Antarctic, climate change in the Arctic has been more rapid, especially in regions such as Greenland and the Arctic Ocean. In summer 2012, warming in Greenland led to melt over 96% of the ice sheet surface, setting a record for the lowest surface albedo. In 2019, a similar extreme warming event resulted in the melting of about 90% of its surface. On 14 August, 2021, Summit Station in central Greenland recorded its first-ever rainfall with temperatures above freezing for about 9 h, marking the third instance of above-freezing temperatures in the region after 2012 and 2019. This warm event and rainfall led to extreme surface melting, with the second-largest melt since satellite records began, exceeding 8.00×10^6 km^2. From 15 to 17 July, 2022, the

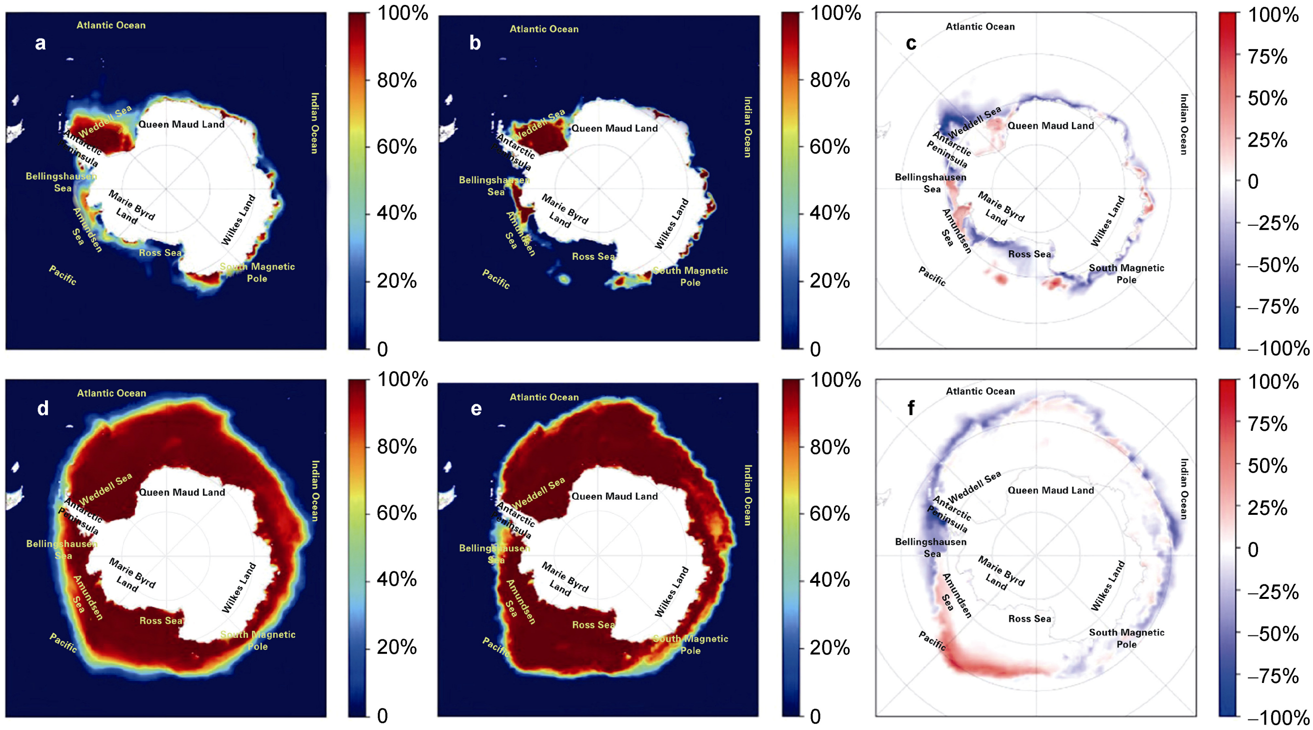

Figure 3 The monthly mean sea ice concentration (%) in Antarctica, as observed by the China Fengyun series of meteorological satellites: sea ice concentration average (2012–2021) in February (**a**) and September (**d**), sea ice concentration (2022) in February (**b**) and September (**e**), sea ice concentration anomalies (2022 vs. 2012–2021 average) in February (**c**) and September (**f**).

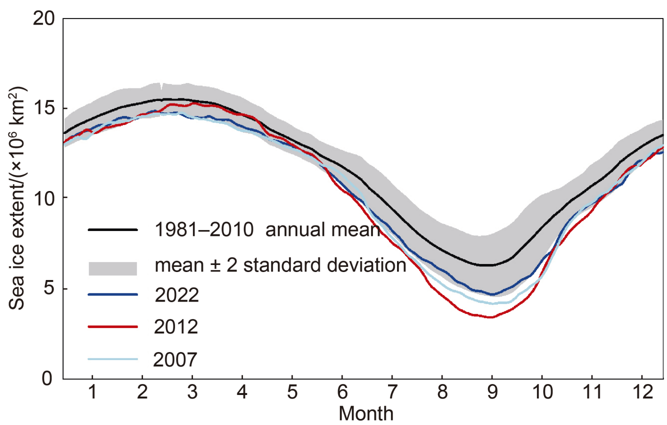

Figure 4 The seasonal variations in Arctic sea ice extent from NSIDC for the years 1981–2010, 2007, 2012, and 2022.

Greenland Ice Sheet lost up to 6×10^9 t of mass daily. On 17 September, 2012, Arctic sea ice extent reached a historical minimum since 1979, measuring 3.387×10^6 km^2. In the summer of 2022, the Arctic sea ice extent continued to remain at low levels, with a measurement of 4.674×10^6 km^2 on 18 September, ranking as the 12th lowest extent on record.

6 Discussion and perspective

This report highlights two key findings that have garnered significant attention: firstly, it appears that the climate in Antarctic has been undergoing rapid changes since 2016, and secondly, there has been an increase in both the frequency and intensity of polar extreme events (Ding et al., 2023). Wang et al. (2023a) recently discovered a close correlation between the very rapid warming event in Antarctica in 2022 and an active blocking high-pressure anomaly in the Ross Sea region. The Ross Sea blocking led to an influx of coastal air into the interior in Antarctica, disrupted the inversion structure, and rapid energy exchange near the ice surface.

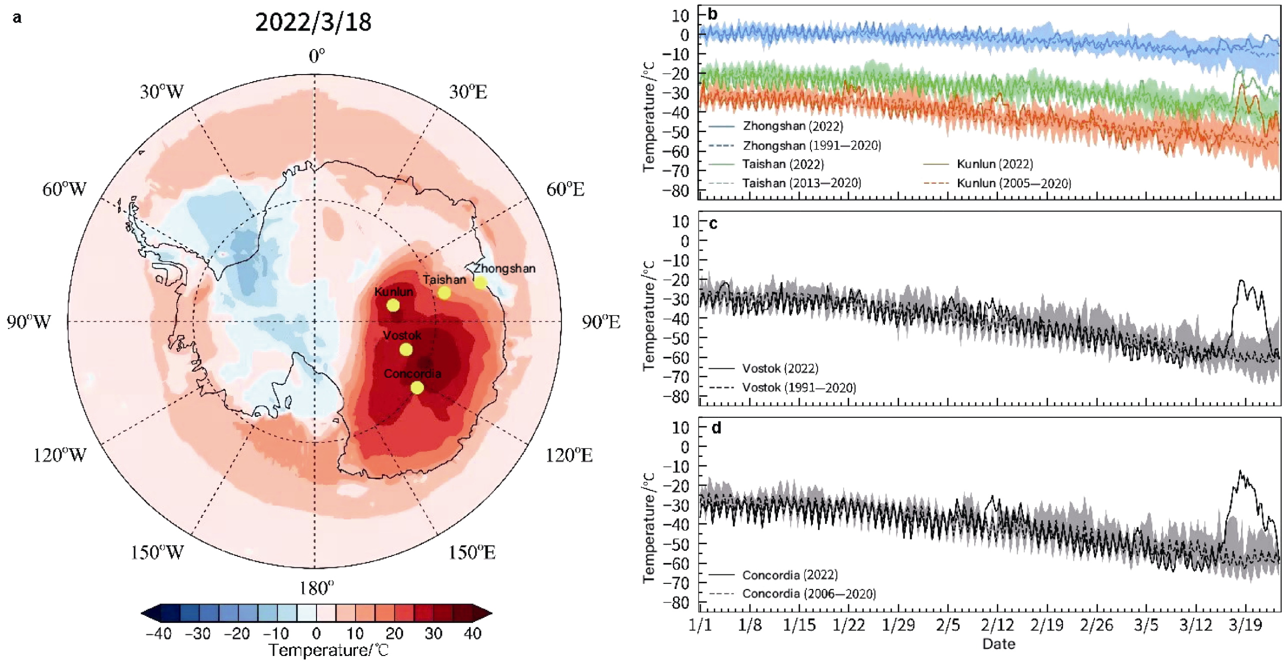

Figure 5 **a**, On 18 March, 2022, the surface air temperature in Antarctica (based on CRA-40 reanalysis data) and the distribution of stations; **b–d**, Daily average surface air temperature variations at Kunlun, Taishan, Zhongshan, Vostok, and Concordia stations in Antarctica from 1 January to 23 March, 2022. The shaded area represents the daily average surface air temperature range from maximum to minimum.

Simultaneously, the warm and moist air mass transported by the blocking high-pressure system, when encountering colder air, produced precipitation and released a substantial amount of latent heat, intensifying the temperature increase and contributing to the very rapid warming event. The extreme reduction in the Antarctic sea ice extent can be attributed to three primary factors. Firstly, an early onset of sea ice melting, coupled with an extended melting season, has increased the probability of achieving record-low sea ice extents (Raphael and Handcock, 2022). Additionally, the global ocean reached a record-high temperature in 2021, with abnormally high subsurface temperature in the Southern Ocean, which favored ice thinning, making it more susceptible to fracturing and melting (Raphael and Handcock, 2022; Zhang and Li, 2023). Concurrently, the surface level atmospheric pressure in the Antarctic continent remained low, and the Amundsen Sea Low persisted in 2022, with warm air advection by north winds on the eastern side of the Low promoting ice melt and restricting ice expansion, while southerly winds on the western side facilitated ice dispersion, accelerating ice melt towards the warm Southern Ocean (Wang et al., 2023b).

A wealth of studies (e.g. Liang and Zhou, 2023) have indicated that the September 2012 Arctic sea ice minimum event was attributable not only to the exceedingly fragile and thin ice under the backdrop of global warming but also to the intense cyclonic storms near the ice edge in August. The September 2007 Arctic sea ice minimum event was primarily associated with ice thinning and atmospheric conditions that led to increased air temperatures, decreased relative humidity, reduced cloud cover, and increased downward shortwave radiation over the Arctic Ocean (Cui et al., 2015). Furthermore, the atmospheric state of springtime ice growth and decay has been recognized as a critical factor influencing the late summer and autumn sea ice extents (Kapsch et al., 2019). The extreme melting events on the surface of Greenland are primarily caused by the control exerted by an anomalous ridge of warm air, which obstructs the flow of air over Greenland (Nghiem et al., 2012), and factors such as increased snow grain metamorphism rates, increased downward shortwave flux at the surface, and decreased snowfall rates leading to reduced albedo (Box et al., 2012). Slater and Straneo (2022) believed that it is atmospheric warming that has amplified the impact of the ocean on the Greenland Ice Sheet.

Antarctica is still undergoing abnormal conditions with the sea ice extent continuing at a record low in every month this year (2023). Could this induce chain reactions in the polar climate system? The answer seems to be yes, for ecosystems and weather have also been abnormal recently. When will its global impact show? This is still a mystery to investigate. To date more attention has been paid to the Arctic, and we suggest that further efforts should be made in Antarctica.

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