

Sea ice in 2023

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Antarctic sea ice extent was the lowest on record in 2023, with an annual mean of 9.81 million km², beating the previous minimum of 2022. Arctic sea ice extent was also low, with an annual mean of 10.49 million km², but did not break any records.

Sea ice cover in the polar oceans has a key role in climate, ecology and society. It influences global ocean circulation, the radiation budget, global climate sensitivity and ice sheet mass loss¹; it offers habitats for plankton and wildlife; and it provides a vital lifeline for native communities². Sea ice extent (SIE, the total surface area with at least 15% sea ice concentration) is strongly seasonal. In the Arctic, it typically varies from a maximum of 15 million km² in March to a minimum of 6 million km² in September, whereas in the Antarctic, it spans from a minimum of 3 million km² in February to a maximum of 19 million km² in September. Superimposed on these seasonal cycles is longer-term variability (Fig. 1a) driven by anthropogenic greenhouse emissions, ozone depletion and natural internal variability.

In the Arctic, sea ice decline has been evident over much of the satellite record: SIE reductions of approximately $-3\% \text{ dec}^{-1}$ in March, approximately $-13\% \text{ dec}^{-1}$ in September and $-5\% \text{ dec}^{-1}$ in the annual mean have been observed, with a record low September (3.57 million km²) and annual mean (10.42 million km²) SIE in 2012. Accompanying these SIE declines have been corresponding increases in open water season length and reductions in ice age³ and thickness. A different story has unfolded in the Antarctic. From 1979 to 2014, Antarctic SIE expanded slightly: SIE increases of $4\% \text{ dec}^{-1}$ in February, $1\% \text{ dec}^{-1}$ in September and $2\% \text{ dec}^{-1}$ in the annual mean have been apparent, reaching a record high annual mean (12.73 million km²) as well as record high September (19.76 million km²) SIE in 2014. Thereafter, SIE rapidly declined, reaching a then record-low annual mean SIE in 2017 (10.70 million km²) which was surpassed in 2022 (10.68 million km²)⁴.

Here, we present an overview of Antarctic and Arctic sea ice in 2023 based on satellite observations of sea ice extent⁵ and concentration⁶.

Antarctic sea ice

2023 saw many Antarctic sea ice records broken, exceeding previous lows set in 2022. For example, annual mean SIE was the lowest in the satellite record, reaching only 9.81 million km², 0.87 million km² lower than the previous 2022 record (Fig. 1a,b). Relatedly, monthly SIE was also low throughout much of the year (Fig. 1c), culminating in the lowest recorded monthly summer (February) minimum and winter (September) maximum, which reached only 1.91 million km² and 16.80 million km², respectively (Fig. 1d,e).

Low sea ice cover toward the end of 2022 (ref. 4) unsurprisingly led to record-breaking sea ice conditions in austral summer 2023. In January and February, SIE was, on average, 36% (or 2.6 standard deviations, SD)

below the 1979–2022 mean. Indeed, SIE during 1st January–8th March was the lowest recorded for those dates, encompassing the lowest daily Antarctic SIE ever recorded – 1.77 million km² on 19th Feb 2023. The timing of this minimum was similar to previous years. Sea ice retreated close to the coast in all sectors, with large negative anomalies particularly prominent in the Ross Sea (Fig. 1d).

Following the low summertime sea ice, seasonal autumn freeze-up regained SIE. Between 9th March and 1st May, sea ice cover exceeded previous record-low years. However, on the 1st May, SIE conclusively dropped below the previous observational record, and the ice advance slowed. Regionally, the slow autumn advance was dominated by the Weddell Sea.

Sea ice in austral winter and into spring was unprecedented in the satellite record (Fig. 1c,e). Although the relative anomalies in summer were larger, winter Antarctic SIE is typically more consistent year-to-year, and so the winter anomalies were more unusual. SIE in May through October was, on average, 14% or 4.5 SD below the 1979–2022 mean, but in late August and early September approached 6 SD (or -10%) below average. This period encompasses the annual daily maximum of 16.99 million km² on 7th September 2023, a record low that far exceeds the previous low of 18.03 million km² on 18th September 1986. The low September maximum was caused by large negative anomalies in the Weddell and Ross Seas and minor negative anomalies in the Indian and Pacific sectors (Fig. 1e); by contrast, the Amundsen and Bellingshausen Seas exhibited positive anomalies. Sea ice remained at these record low levels until 12th November, when it caught up with 2016 levels.

This anomalously negative SIE throughout much of 2023 has a substantial impact on the overall Antarctic SIE trend. In fact, 2023 reverses the sign of the annual mean SIE trend: from 1979 to 2022 the trend is $0.18 \pm 0.45\% \text{ dec}^{-1}$, but over 1979–2023 it is $-0.28 \pm 0.50\% \text{ dec}^{-1}$. Of course, linear trends poorly capture the large year-to-year variability in Antarctic SIE. Looking ahead, the early months of 2024 show continued low SIE, but the future evolution of Antarctic sea ice remains highly uncertain owing to poor model skill.

Key points

- Global sea ice extent (Antarctic and Arctic combined) reached a satellite era record daily minimum of 15.86 million km² on 31st January 2023.
- Antarctic sea ice extent exhibited record lows in many months of the year, including the lowest monthly summer minimum (1.91 million km² in February) and the lowest monthly winter maximum (16.80 million km² in September).
- Arctic sea ice anomalies were largest in boreal summer, including a September sea ice extent of 4.37 million km², the 5th lowest on record.

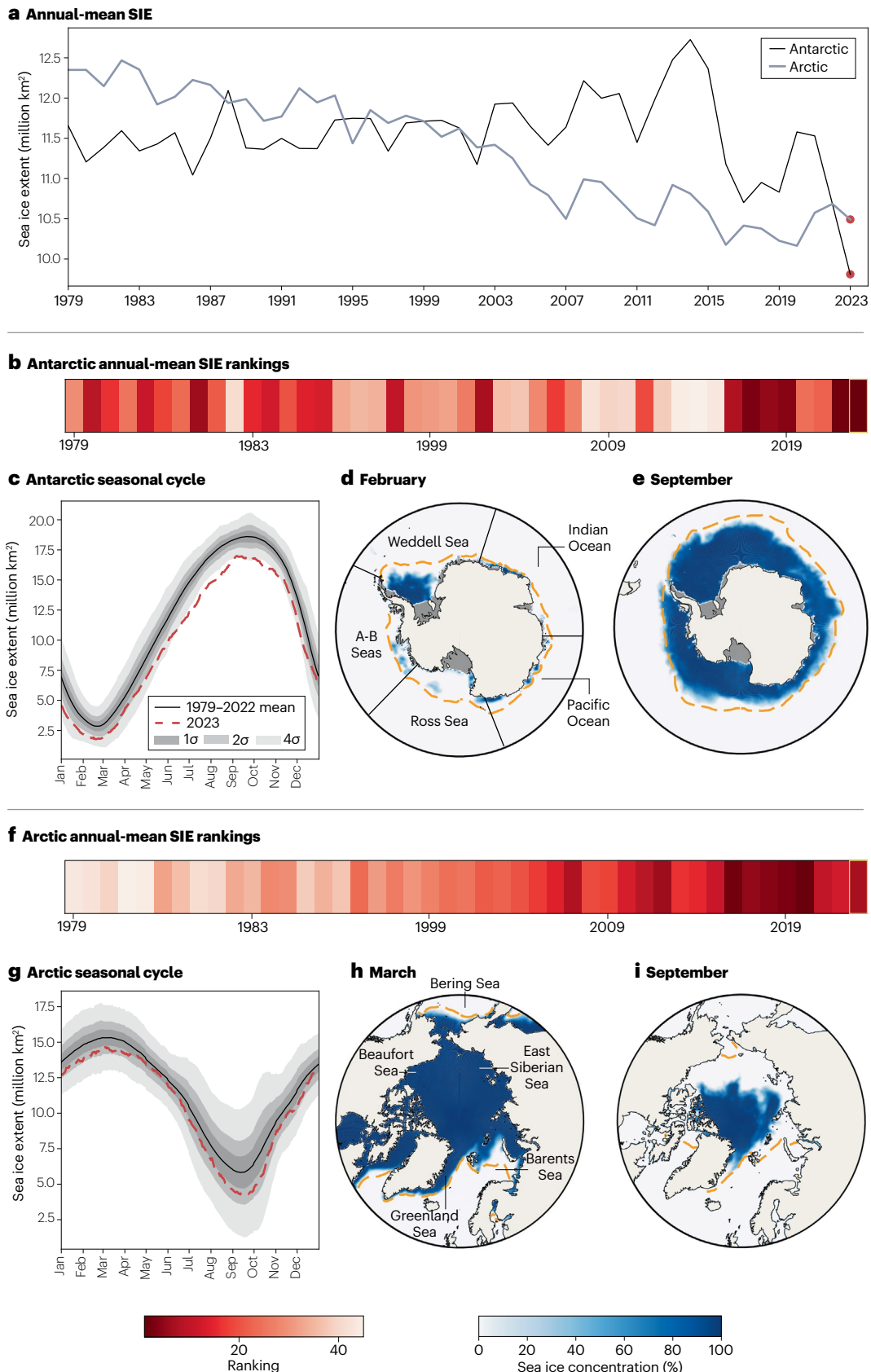


Fig. 1 | Arctic and Antarctic sea ice change. **a**, Time series^{5,6} of annual mean sea ice extent (SIE) for the Arctic and Antarctic. **b**, The ranking of annual mean Antarctic SIE, with 1 (darkest shade) representing the year with the lowest SIE on record and 45 (lightest shade) the year with the highest SIE on record. **c**, The seasonal cycle of daily Antarctic SIE, with the 1979–2022 mean in black, 2023 in red, and standard deviations in grey shading. **d**, February Antarctic sea ice concentration. The dashed

orange line represents the climatological (1979–2022) sea ice edge (the 15% sea ice concentration boundary). **e**, As in **d**, but for September. **f**, As in **b**, but for Arctic SIE. **g**, As in **c**, but for the Arctic. **h**, As in **d**, but for March sea ice concentration in the Arctic. **i**, As in **h**, but for September. Antarctic sea ice was the lowest on record in 2023, with anomalies in austral winter being particularly unusual, while Arctic sea ice remained low but did not break any records.

Arctic sea ice

In contrast to the record-breaking situation in Antarctica, Arctic sea ice exhibited less dramatic changes in 2023, but the long-term decline in sea ice continues. Annual mean Arctic SIE reached 10.49 million km² (Fig. 1a), the 7th lowest in the satellite record (Fig. 1f). Accordingly, no monthly records were broken: the summer (September) monthly minimum was 4.37 million km², the 5th lowest in the satellite record, while the winter (March) monthly maximum was 14.44 million km², the 6th lowest on record.

Reflecting on 2023 as a whole, wintertime SIE was anomalously negative, but not excessively so. Specifically, SIE from January to March was, on average, -6% or 1.5 SD below the 1979–2022 mean (Fig. 1g). This anomalous winter SIE was primarily driven by low sea ice in the Barents Sea (Fig. 1h). Despite the largely unremarkable winter season, high sea ice variability did contribute to four daily record lows in this season: on 31st January (13.64 million km²), 1st February (13.76 million km²), 14th March (14.33 million km²) and 15th March (14.35 million km²). In spring (April–June), total SIE moved closer to the long-term climatology (Fig. 1g), partly thanks to positive anomalies in the Greenland Sea.

However, as the melt began, total SIE dropped rapidly. For instance, SIE was only 5% or 0.9 SD below climatological values in mid-June but reached 30% or 1.4 SD by the end of September (Fig. 1g). The daily minimum occurred on 17th September, totalling 4.21 million km². Sea ice concentration anomalies were prominent in the Pacific sector, particularly in the Beaufort and East Siberian Seas (Fig. 1i). Indeed, 2023 represented the second-lowest extent on record for the Beaufort Sea, behind only 2012.

Transitioning into autumn, rapid freeze-up returned Arctic SIE closer to climatological levels by November. Total SIE was -6% or 1.0 SD below 1979–2022 levels in November and December, with some variability. Autumn recovery was most evident in the Beaufort and East Siberian Seas.

Unlike Antarctica, 2023 has no impact on the long-term Arctic sea ice trends. The annual mean trend is unchanged at $-4.6 \pm 0.2\%$ dec⁻¹ for 1979–2022 and 1979–2023. September SIE trends – where the largest reductions have been observed – also remain unchanged at $-13.2 \pm 1.1\%$ dec⁻¹ for both periods. Although Arctic sea ice loss has slowed since 2008 (Fig. 1a), it is anticipated to continue³, with a practically ice-free Arctic projected to occur sometime between 2030 and 2050 (irrespective of emissions in the next three decades)⁷.

Summary

Global sea ice continues to decline as a result of anthropogenic forcing and internal variability. Although the long-term global trend was once dominated by sea ice reductions in the Arctic, rapid changes in the Antarctic are now exerting a strong influence. Based on the satellite record, Antarctic SIE was at a record low for much of the year in 2023, including wintertime SIE 5 SD below average, shifting the previously positive trend to negative.

The record lows in global and Antarctic sea ice occurred concurrently with record highs in global mean surface air temperature, sea surface temperature⁸ and ocean heat content⁹. As greenhouse gas-induced

warming continues, it will undoubtedly continue to impact global sea ice, as unequivocally seen in the Arctic. However, much remains to be understood in terms of contemporary and future Antarctic sea ice behaviour, and the coupled ocean–atmosphere–cryosphere mechanisms at play. Although the sea ice satellite record now spans 45 years, it might not be sufficient to capture the large natural multi-decadal variability in Antarctic climate¹⁰. The continuation of current observations, development of proxy-based climate reconstructions to provide long-term context, and improved observations of sea ice thickness and the subsurface ocean will be crucial to advance understanding and prediction of sea ice.

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Competing interests

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