Wind Anomalies Drive 2023 Antarctic Sea Ice Deficit

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BRIEFING NOTE 487

August 08, 2023

The current Antarctic sea ice deficit is one of many record-breaking events dominating climate news in 2023. The present situation is alarming (Figure 1), even more so considering that until quite recently Antarctic sea ice extent has been increasing. Media reporting implies that scientists have been left scratching their heads, at a loss to understand the current unprecedented deficit (e.g. Alvaro, 2023; Redfearn 2023). While there is still good reason for concern about potential climate change impacts, decades of existing research into Antarctic sea ice variability and Southern Ocean climate provides a robust context through which current changes can be interpreted.

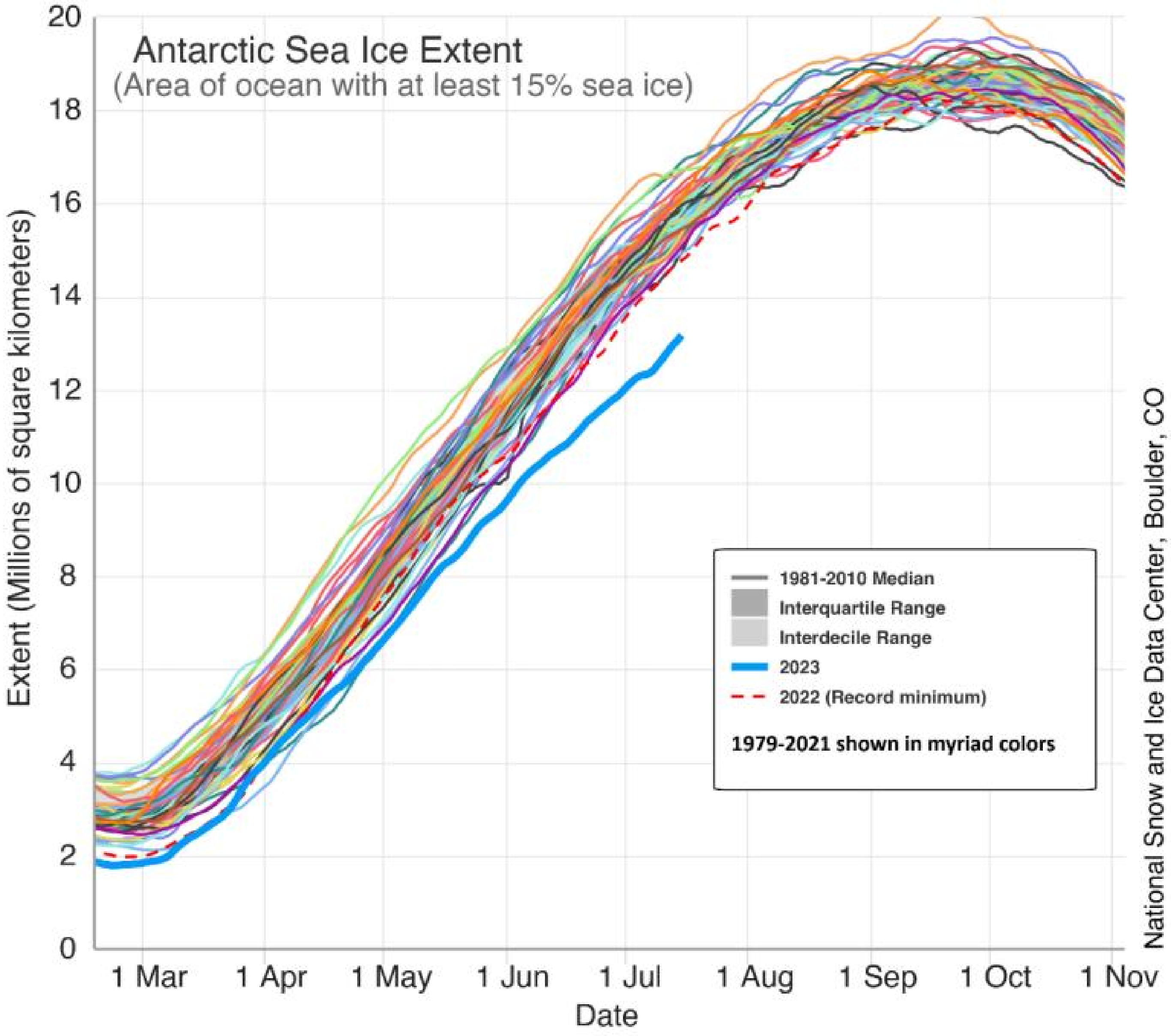

Figure 1 *Extent of Antarctic Sea Ice in 2022 and 2023 compared with previous years from March to November. Source: https://nsidc.org/arcticseaicenews/*

The National Snow and Ice Data Centre (NSIDC) at the University of Colorado helps to collate and present data from US satellites that have been recording the Arctic and Antarctic sea ice daily since November 1978. While sea ice extent in the Arctic has steadily decreased in recent decades, as expected in a warming world, Antarctica's sea ice extent has steadily increased, up until 2016, at which point the positive trend abruptly reversed (Figure 2), culminating in 2022 having the lowest sea ice extent on record…until 2023.

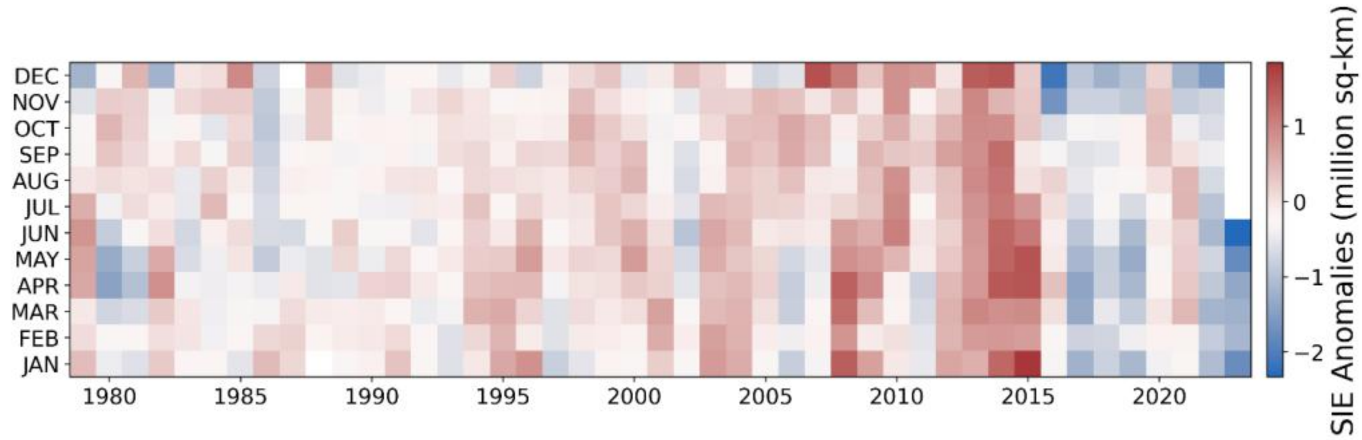

***Figure 2** Monthly Antarctic sea ice extent anomaly (difference relative to the 1981 to 2010 average) for January 1979 to June 2023. Red shades indicate higher than average extent, while blue shades indicate lower than average extent, with darker shades corresponding to larger differences. Source: https://nsidc.org/arcticseaicenews/*

Primary Driver of Sea Ice Variability

Sea ice extent around Antarctic has a pronounced seasonal cycle: it grows continuously from March to its annual maximum in September, after which it rapidly declines (Figure 1). While there are many facets to Antarctic sea ice formation, the primary drivers of year-to-year variability in sea ice extent are atmospheric circulation and wind (see Stammerjohn et al., 2008 and reference therein).

Sea ice sits on top of the ocean so near surface winds play a critical role in its formation and transport. In general, sea ice extent increases when cold southerly winds blow existing sea ice northward, away from Antarctica, opening leads (areas of open ocean) and allowing new sea ice to form in the colder waters close to the continent. Conversely, when warm northerly winds blow, sea ice production is reduced, and any sea ice that does form is stacked back up against the coastline, so overall sea ice extent decreases.

This relationship is clearly seen for June 2023 when sea ice extent anomalies (Figure 3a) are plotted alongside the near surface wind anomalies for May and June 2023 (Figure 3b): the main regions of sea ice decline, the eastern Bellingshausen sea, the Weddell sea, the Davis sea, and the western Ross sea all correspond to locations of anomalously strong northerly winds; whereas the region of anomalous sea ice growth in the eastern Ross/Amundsen seas corresponds to anomalous southerly winds.

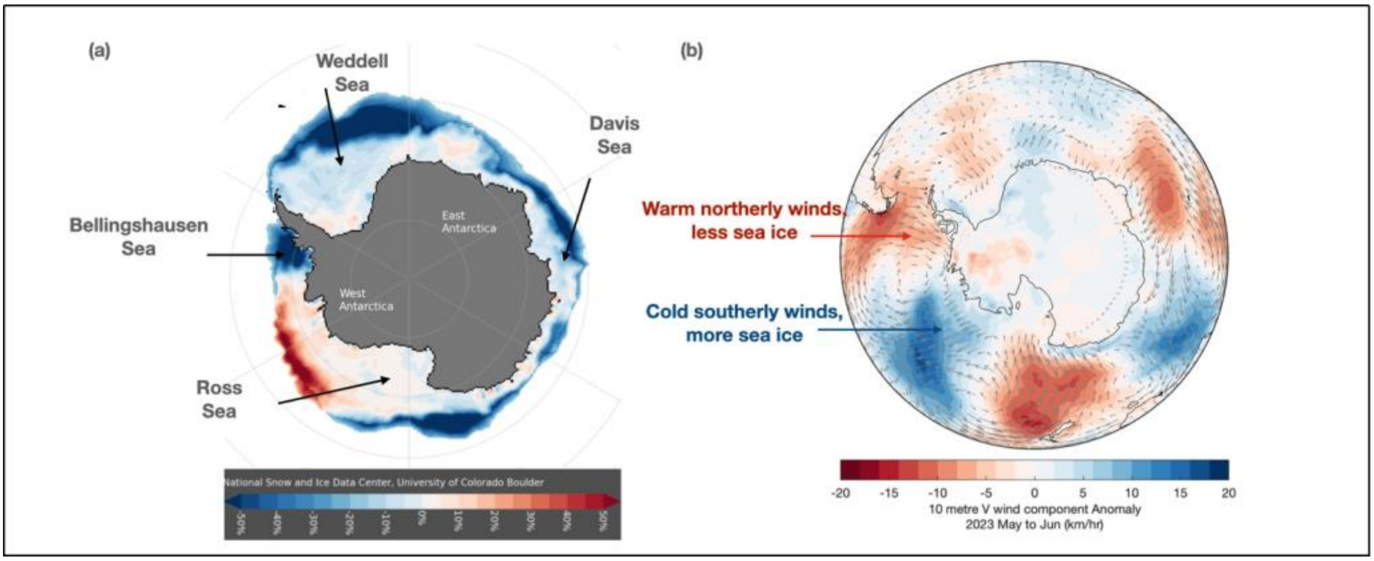

Figure 3 *(a) Sea ice anomaly around Antarctic for June 2023 from the NSIDC (Source: https://nsidc.org/arcticseaicenews/), and (b) anomalous near surface winds over the Southern Ocean for May and June 2023 from the ECWMF ERA5 reanalysis: colors indicate the meridional wind anomaly (v-wind) in km/hr where negative values (reds) represent winds form the north and positive values (blues) represent winds from the south; arrows indicate the magnitude and direction of corresponding winds anomalies. Anomalies are calculated relative to the 1991-2020 mean (data obtained from the Copernicus Climate Change Service, 2023). Corresponding temperature anomalies are shown in Figure 6.*

Atmospheric Circulation and Wind Anomalies

Atmospheric circulation around Antarctic is often described in terms of the zonal (north-south) expansion and contraction of westerly winds associated with the Southern Annular Mode (SAM). However, the wind and mean sea level pressure patterns during May and June 2023 (Figure 4) bear little resemblance to the annular structure of the SAM and are instead characterized by a meridional 3-wave pattern of alternating high- and low-pressure anomalies, particularly the high-pressure systems over the southern Indian Ocean and the south Pacific, and the low-pressure system over the southeast Pacific (known as the Amundsen Sea Low).

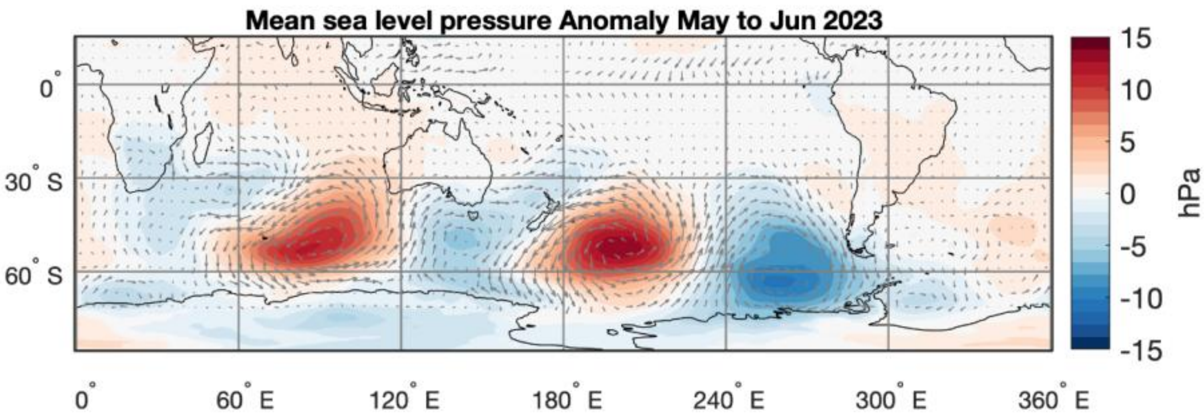

Figure 4 *Mean sea level pressure anomalies over the Southern Ocean for May and June 2023 with corresponding wind anomaly vectors. Anomalies are calculated from the ECWMF ERA5 reanalysis relative to the 1991-2020 mean. Positive values indicate areas of persistent high pressure where air circulates anti-clockwise; negative values indicate areas of persistent low pressure where air circulates clockwise (data obtained from the Copernicus Climate Change Service, 2023).*

Wave number 3 circulation has been shown to reduce sea ice extent, especially in spring, through increased advection of warm air and its role in driving warm ocean currents (Schlosser et al 2018; Schroeter et al., 2023), and is probably responsible for much of the observed sea ice decline since 2016 (Eayrs et al., 2021).

The Amundsen Sea Low also has a strong influence on regional sea ice extent, whereby a deeper Amundsen Sea Low decreases sea ice in the Bellinghausen sea and increases sea ice in the eastern Ross/Amundsen Sea (Liu et al., 2004; Turner et al., 2014; Holland et al., 2018)—as seen in 2023 (Figure 3). The Amundsen Sea Low deepens during SAM positive, and this is likely a contributing factor in the previous record low sea ice during 2022.

Atmospheric circulation over the Southern Ocean including the Amundsen Sea Low is influenced by large scale teleconnections to tropical climate drivers including the El Niño Southern Oscillation (ENSO); for example, during La Niña (El Niño) the SAM is usually positive (negative) and the Amundsen Sea Low deepens (weakens) (Turner et al., 2012).

While most research and discussion are focused on the SAM, as the leading mode of atmospheric variability in the southern hemisphere, the lesser known (and more interesting) Pacific South American modes (PSA1 and PSA2) better describe tropical teleconnection patterns.

PSA modes arise from the midlatitude response to tropical convective activity, where strong convection in the tropics, such as during thunderstorms and cyclones, generates large scale Rossby waves which propagate poleward and perturb the otherwise zonal westerly circulation. Both PSA patterns respond to ENSO: PSA1 is more sensitive to convection in the eastern Pacific (eg, Karoly 1989), and PSA2 is more sensitive to convection in the Indo-Pacific (eg, Mo and Higgins 1998; Yang et al., 2018). Similar Rossby wave trains can also emanate from the African continent and impact circulation over the southern Indian Ocean (Cai et al., 2011).

The mean sea level pressure pattern for May and June 2023 (Figure 4) represents a strong PSA2 positive teleconnection from the tropics to the midlatitudes. The PSA2 index for June 2023 (Figure 5) has the highest winter values on record (since 1980)—more than 2 standard deviations above the mean. The magnitude of the PSA2 index is now greater than that of the SAM, meaning it is currently the dominant driver of atmospheric circulation in the midlatitudes.

PSA2 is highly correlated to ENSO, whereby PSA2 is positive during La Niña. Interestingly the PSA2 index is not historically correlated to sea ice extent, but then it has never (at least since 1980) been this strong during winter and has never occurred in conjunction with such high global temperature anomalies.

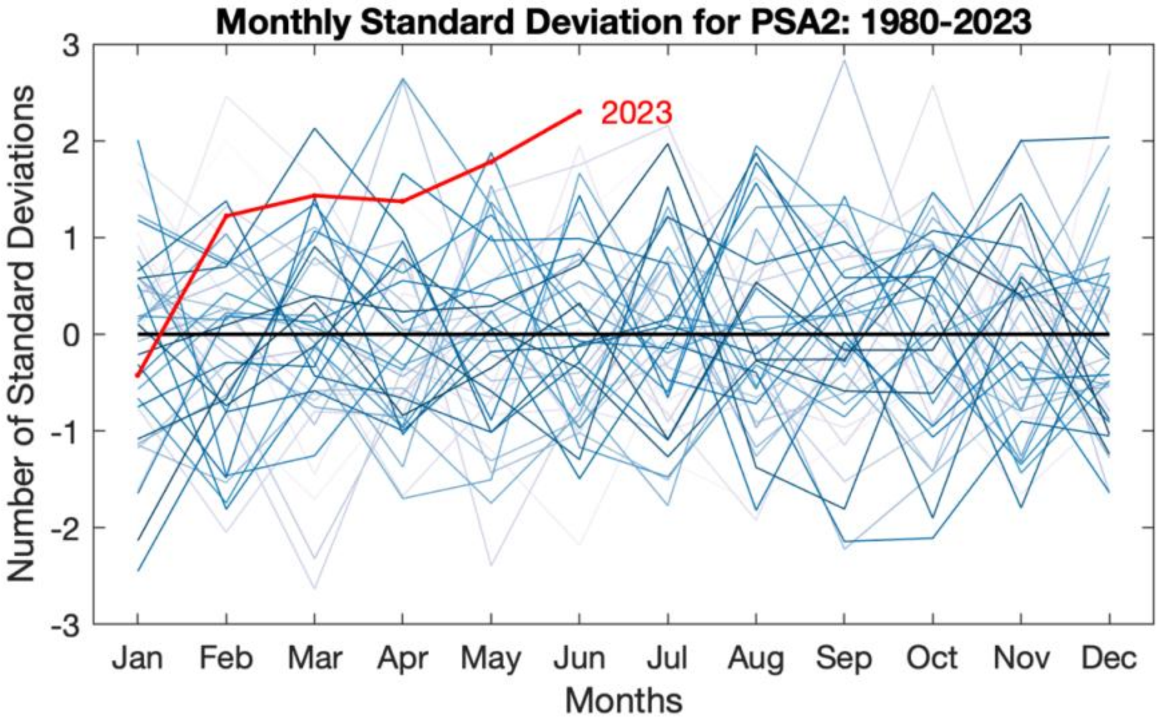

Figure 5 *Standardized monthly PSA2 index for each year from 1980-2023; darker blues indicate more recent years, with 2023 shown in red. PSA2 index is calculated according to Visbeck and Hall (2004) as the 3rd EOF of monthly mean sea level pressure anomalies over the southern hemisphere between 20S and 80S (data obtained from the Copernicus Climate Change Service, 2023).*

Global near surface temperature anomalies (Figure 6) illustrate the extraordinarily high temperatures across most of the planet, especially the northern hemisphere and parts of Antarctic experiencing the greatest sea ice deficit.

Sea surface temperature anomalies in the eastern Pacific are high enough for the World Meteorological Organization (WMO) to declare El Niño, but there are no corresponding cool anomalies in the western Pacific, or anywhere else across the tropics. Maximum convection in the tropics usually shifts to the eastern Pacific during El Niño, but Figure 7 shows that for May and June 2023 the strongest convection was over the west Pacific and maritime continent—the source region for PSA2 Rossby wave trains (Mo and Higgins 1998).

This is consistent with the Australian Bureau of Meteorology holding off on declaring El Niño because the atmospheric response has not yet developed. Meanwhile in the southern midlatitudes, the atmospheric response (PSA2 positive) still resembles La Niña.

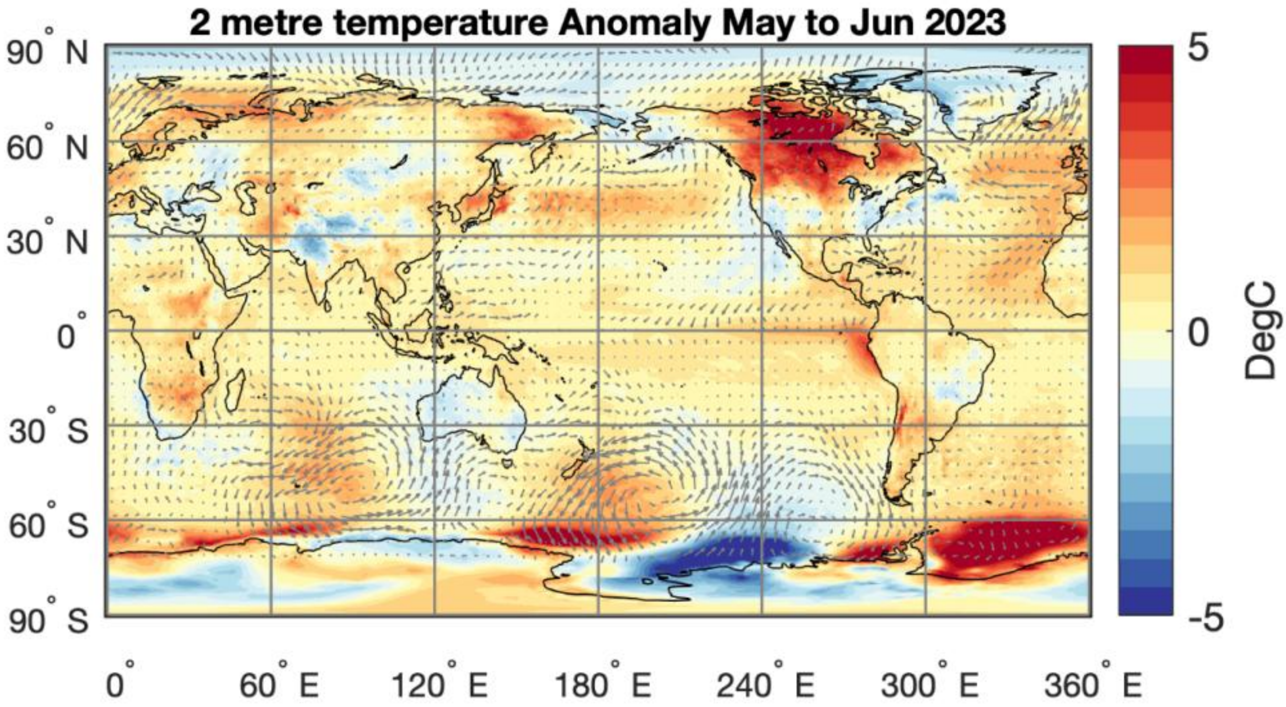

__Figure 6__ 2-meter air temperature anomalies for May and June 2023. Temperature data are monthly means from the ECWMF ERA5 reanalysis with anomalies calculated relative to the 1991-2020 mean. Wind vectors are anomalies calculated over the same time period (data obtained from the Copernicus Climate Change Service, 2023).

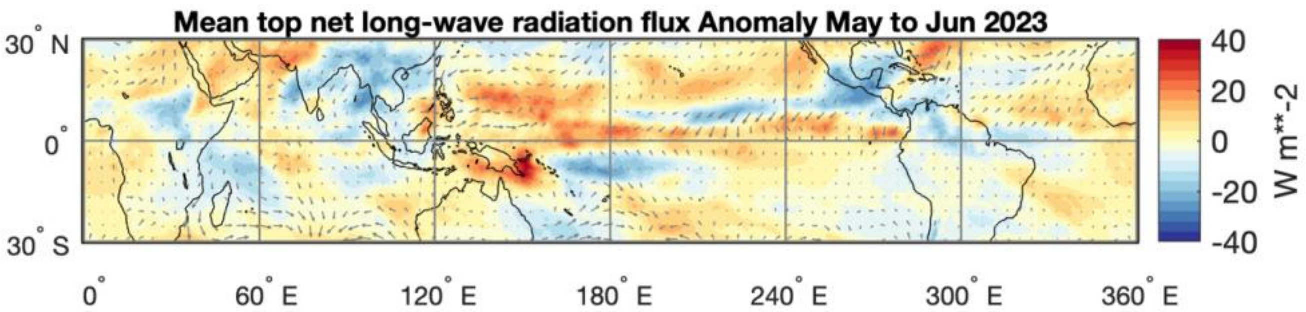

__Figure 7__ Mean long-wave radiation flux anomalies for May and June 2023 as an indicator of convection. Data are monthly means from the ECWMF ERA5 reanalysis with anomalies calculated relative to the 1991-2020 mean. Following ECWMF conventions for fluxes, positive is down and negative is up. Positive values occur due to decreased outgoing long-wave radiation fluxes from cloud tops and are thus indicative of increased cloudiness and convection (data obtained from the Copernicus Climate Change Service, 2023).

Implications

If the current decline continues, impacts could be profound. Although melting sea ice does not itself raise sea levels because it is already floating, it does perform critical climate and ecosystem functions.

Loss of ice reduces the amount of the sun's energy that is reflected back to space, causing more warming of the ocean. Antarctic sea ice also influences the way in which the ocean circulates oxygen, nutrients, and energy around the globe.

By buffering waves, Antarctic sea ice protects the ice shelves that are attached to the land. Without the sea ice, the rate at which the ice shelves break up could accelerate, which would increase global sea levels and have much more pronounced impacts on the climate system. Furthermore, for many years the strong zonal circulation of SAM positive had thermally isolated East Antarctic from rising global temperatures (Thompson and Solomon 2002; Nicolas and Bromwich 2014).

If a strong wave number 3 circulation becomes more frequent, then East Antarctica could warm rapidly, with cascading impacts on ecosystems, climate, and sea level (Stokes et al., 2022).

Summary

The current sea ice extent deficit around Antarctic is at least in part being driven by anomalously strong warm northerly winds which limit the production of new sea ice and push existing sea ice back towards the continent.

These wind anomalies are embedded in a high amplitude 3-wave circulation pattern consistent with the strongest positive winter PSA2 on record and driven by anomalous convection in the tropical Indo-Pacific.

PSA2 positive is produced by La Niña like convective anomalies so its current strength indicates that the atmospheric response to the east Pacific El Niño, especially in the west Pacific and mid-latitudes, has not yet materialised. Although the PSA2 circulation pattern is not typically associated with low sea ice extent, the unusual strength of the circulation pattern and associated winds, coupled to unprecedented global warmth available for advection to Antarctica, is probably the primary cause of extreme sea ice deficits in 2023.

While there is still good reason for alarm about potential climate change impacts, decades of existing research into Antarctic sea ice variability and Southern Ocean climate provides a robust context through which current changes can be interpreted.

References

Alvaro, Alexandra (2023). 'Antarctic sea ice levels dive in 'five-sigma event', as experts flag worsening consequences for planet'. https://www.abc.net.au/news/2023-07-24/antarctic-sea-ice-levels-nosedive-five-sigma-event/102635204

Cai, W., P. van Rensch, T. Cowan, and H. H. Hendon, 2011: Teleconnection pathways of ENSO and the IOD and the mechanisms for impacts on Australian rainfall. J. Climate, 24, 3910–3923, https://doi.org/10.1175/2011jcli4129.1.

Copernicus Climate Change Service (C3S) (2023): ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate. Copernicus Climate Change Service Climate Data Store (CDS) (Accessed on July-2023). https://cds.climate.copernicus.eu/cdsapp#!/home

Eayrs, C., X. Li, M. N. Raphael, and D. M. Holland, 2021: Rapid decline in Antarctic sea ice in recent years hints at future change. Nat. Geosci., 14, 460–464, https://doi.org/10.1038/s41561-021-00768-3.

Holland, M. M., Landrum, L., Raphael, M. N., & Kwok, R. (2018). The regional, seasonal, and lagged influence of the Amundsen Sea Low on Antarctic sea ice. Geophysical Research Letters, 45, 11,227–11,234. https://doi.org/10.1029/2018GL080140

Karoly, D. J., 1989: Southern Hemisphere Circulation Features Associated with El Niño-Southern Oscillation Events. J. Clim., 2, 1239–1252, https://doi.org/10.1175/1520-0442(1989)002<1239:shcfaw>2.0.co;2.

Liu, J., J. A. Curry, and D. G. Martinson, 2004: Interpretation of recent Antarctic sea ice variability: RECENT ANTARCTIC SEA ICE VARIABILITY. Geophys. Res. Lett., 31, https://doi.org/10.1029/2003gl018732.

Mo, K. C., and R. W. Higgins, 1998: The Pacific-South American modes and tropical convection during the Southern Hemisphere winter. Mon. Weather Rev., 126, 1581–1596, https://doi.org/10.1175/1520-0493(1998)126<1581:tpsama>2.0.co;2

National Snow and Ice Data Centre at the University of Colorado at Boulder (NSIDC). https://nsidc.org/arcticseaicenews/

Nicolas, J. P., and D. H. Bromwich, 2014: New Reconstruction of Antarctic Near-Surface Temperatures: Multidecadal Trends and Reliability of Global Reanalyses*,+. J. Clim., 27, 8070–8093, https://doi.org/10.1175/JCLI-D-13-00733.1.

Redfearn, Graham (2023). 'Something weird is going on': search for answers as Antarctic sea ice stays at historic lows. https://www.theguardian.com/world/2023/jul/29/something-weird-is-going-on-search-for-answers-as-antarctic-sea-ice-stays-at-historic-lows

Schlosser, E., F. A. Haumann, and M. N. Raphael, 2018: Atmospheric influences on the anomalous 2016 Antarctic sea ice decay. Cryosphere, 12, 1103–1119, https://doi.org/10.5194/tc-12-1103-2018.

Schroeter, S., T. J. O'Kane, and P. A. Sandery, 2023: Antarctic sea ice regime shift associated with decreasing zonal symmetry in the Southern Annular Mode. Cryosphere, 17, 701–717, https://doi.org/10.5194/tc-17-701-2023.

Stammerjohn, S. E., D. G. Martinson, R. C. Smith, X. Yuan, and D. Rind, 2008: Trends in Antarctic annual sea ice retreat and advance and their relation to El Niño–Southern Oscillation and Southern Annular Mode variability. J. Geophys. Res-Atmos, 113, C03S90, https://doi.org/10.1029/2007jc004269.

Stokes, C. R. et al. 2022: Response of the East Antarctic Ice Sheet to past and future climate change. Nature 608, 275–286.

Thompson, D. W., and S. Solomon, 2002: Interpretation of recent Southern Hemisphere climate change. Science, 296, 895–899, https://doi.org/10.1126/science.1069270.

Turner, J., J. S. Hosking, T. J. Bracegirdle, G. J. Marshall, and T. Phillips, 2015: Recent changes in Antarctic Sea Ice. Philos. Trans. R. Soc. A: Math., Phys. Eng. Sci., 373, 20140163, https://doi.org/10.1098/rsta.2014.0163.

Turner, J., T. Phillips, J. S. Hosking, G. J. Marshall, and A. Orr, 2012: The Amundsen Sea low: The Amundsen Sea low. Int. J. Clim., 33, 1818–1829, https://doi.org/10.1002/joc.3558.

Visbeck, M., and A. Hall, 2004: Reply*. J. Climate, 17, 2255–2258, https://doi.org/10.1175/1520-0442(2004)017<2255:r>2.0.co;2.

Yang, S., Z. Li, J.-Y. Yu, X. Hu, W. Dong, and S. He, 2018: El Niño–Southern Oscillation and its impact in the changing climate. Natl. Sci. Rev., 5, 840–857, https://doi.org/10.1093/nsr/nwy046.

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Stuart is Risk Frontiers' Climate Risk Scientist, with extensive experience studying the weather and climate in Australian and the Asia-Pacific region. His focus is to understand the large-scale climatic drivers of extreme weather events to better quantify risk over seasonal to multi-decadal timescales, using reanalysis data, model simulations, and paleoclimate records.