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Supplement of

Signature of the stratosphere–troposphere coupling on recent record-breaking Antarctic sea-ice anomalies

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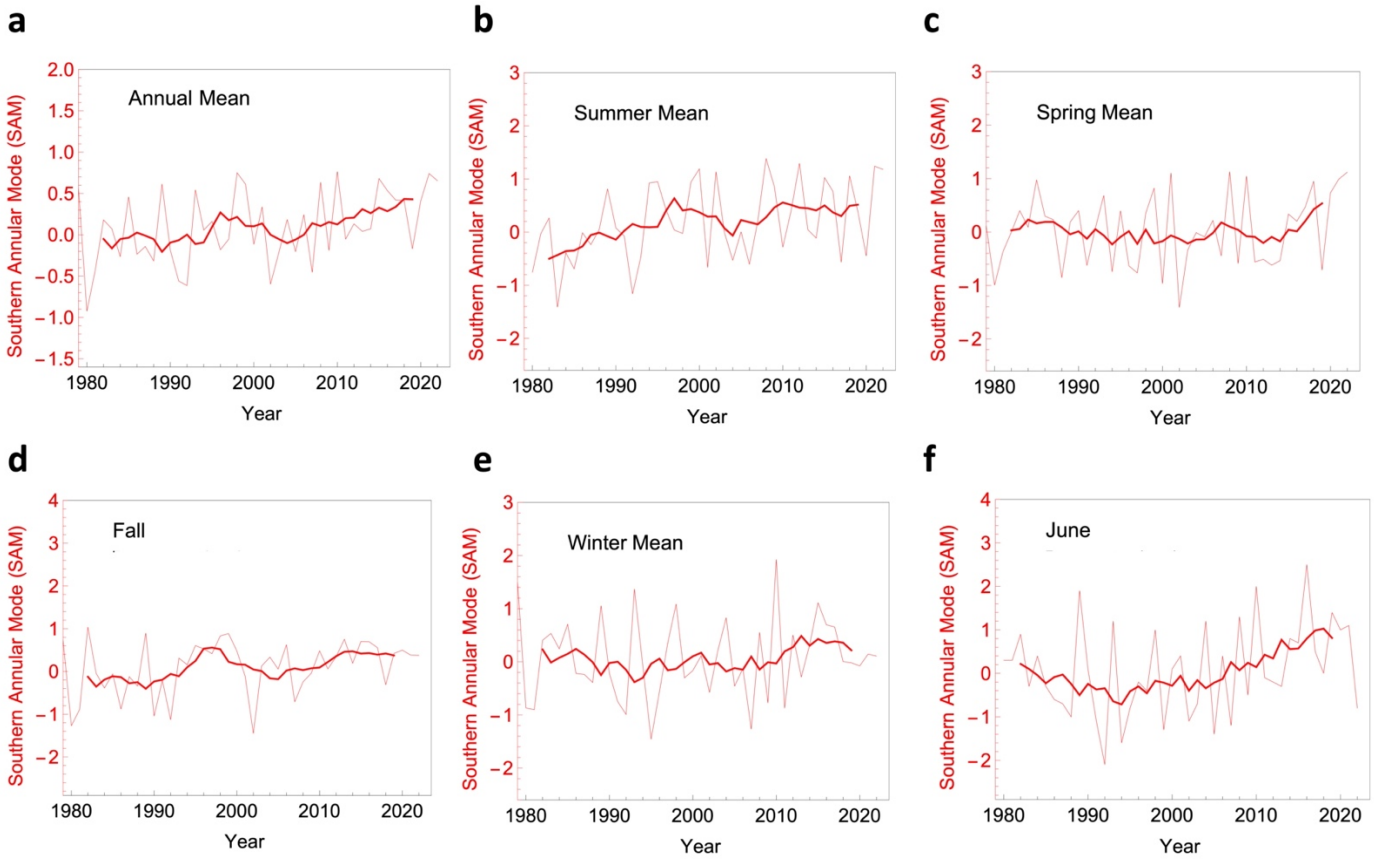

Figure S1

(a) Annual mean of the Southern Annular Mode (SAM) index. There is a long-term trend toward positive values of the SAM index. In 2022, the annual mean of the SAM index ended in positive values for the third year in a row.

(b) Mean SAM index for summer (DJF). Attributable to the success of the Montreal Protocol, there has been a pause in the long-term strengthening of the summertime SAM.

(c) Mean SAM index for spring (SON). The highest spring SAM average since 2008 occurred in 2022.

(d) Mean SAM index for fall (MAM).

(e) Mean SAM index for winter (JJA).

(f) Mean SAM index for early winter (June). The lowest SAM average for June since 2007 occurred in 2022.

Bold lines show 7-year centered moving averages.

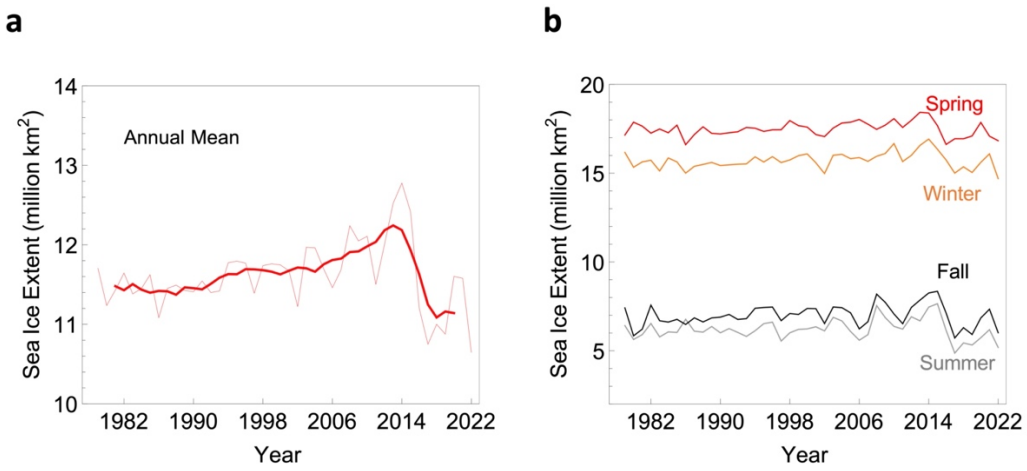

Figure S2

(a) Annual mean of the sea ice extent (SIE) around Antarctica. In 2022, the SIE reached its lowest annual mean since the start of satellite observations, surpassing the previous record of 2017. Bold lines show 5-year centered moving averages.

(b) SIE for each season.

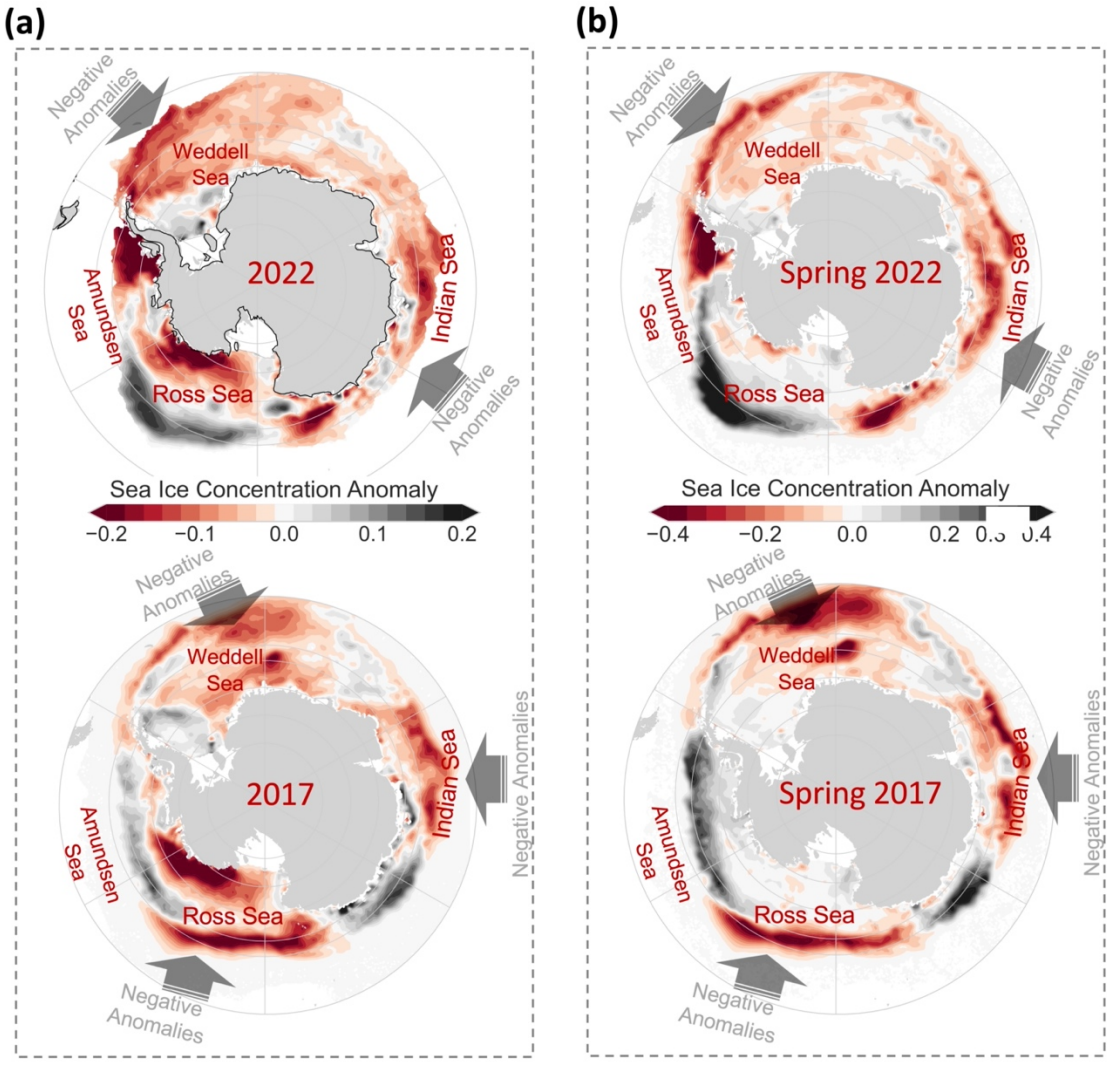

Figure S3

Sea ice concentration (SIC) anomalies for 2022 (upper panel) and for 2017 (lower panel), relative to the 1981–2010 mean.

a) Annual anomalies.
b) Spring anomalies.

Although SIC losses in 2017 and 2022 were of comparable magnitude, they exhibited different regional patterns.

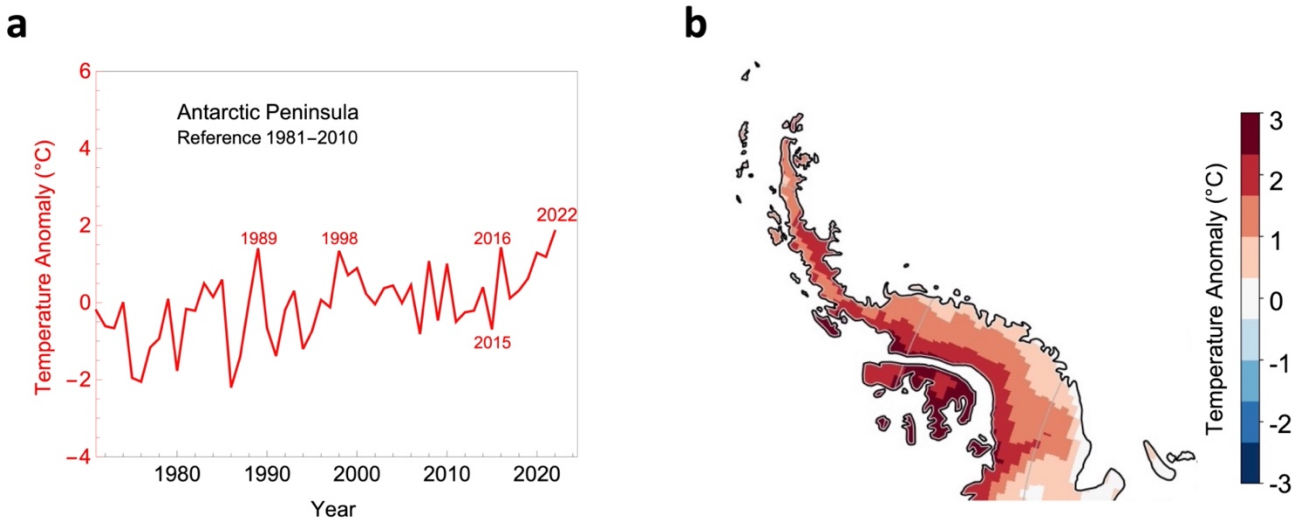

Figure S4

Annual temperature anomalies in the Antarctic Peninsula region relative to the 1981-2010 mean.

(a) Time series of the annual mean temperature. The Antarctic Peninsula experienced its warmest year on record in 2022.

(b) Regional pattern of the annual temperature anomalies for 2022.

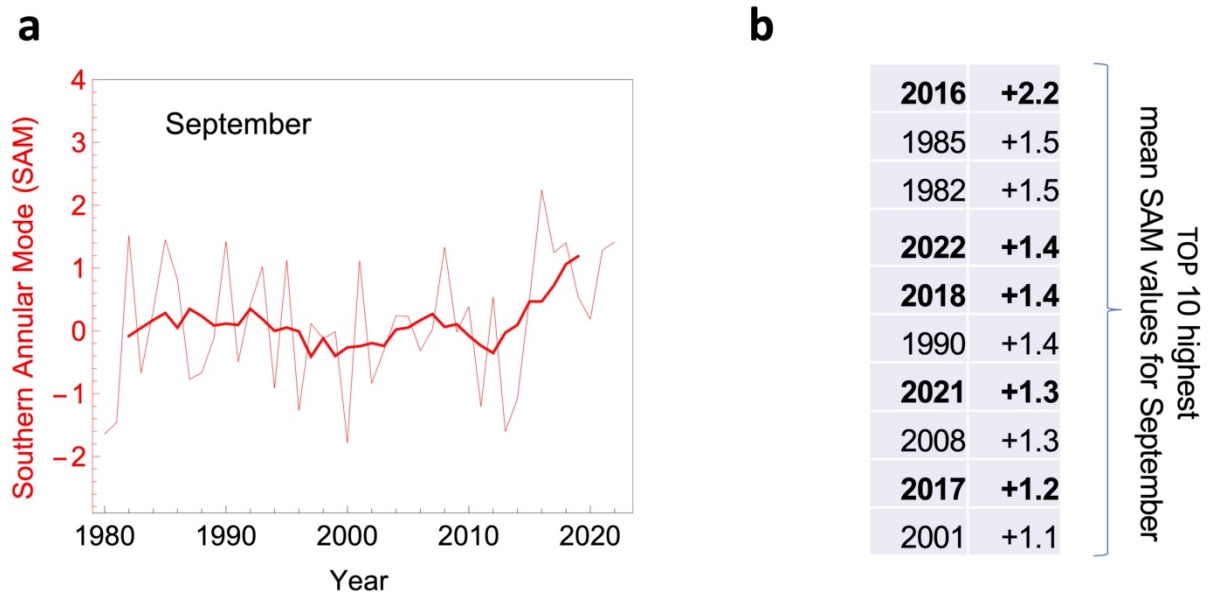

Figure S5

(a) Mean SAM index for September. Bold line shows 7-year centered moving averages.

(b) Top 10 highest mean SAM values for September. Five of the ten largest positive SAM anomalies occurred since 2016 (bold).

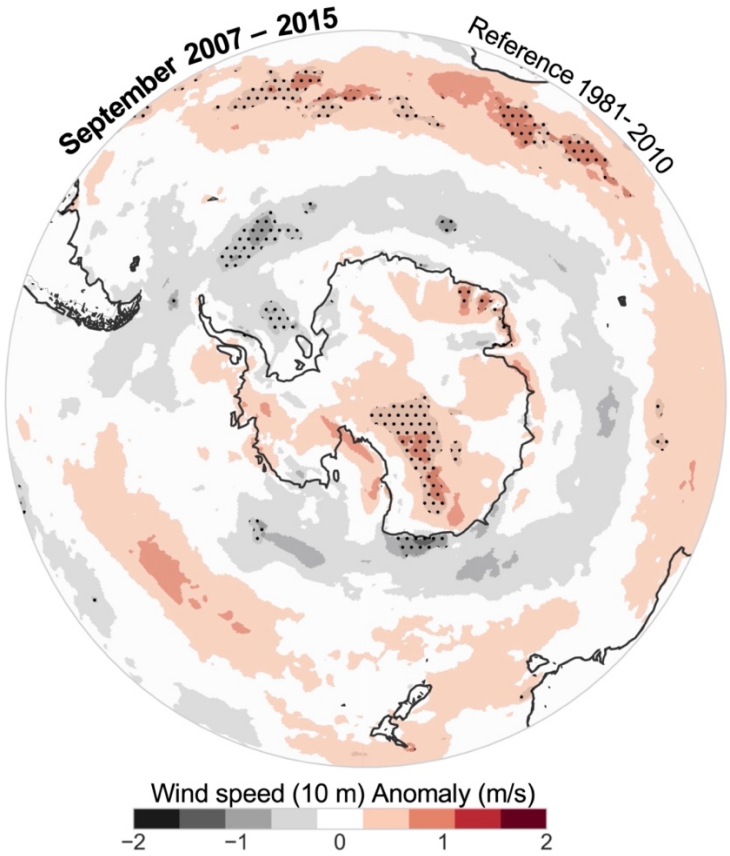

Figure S6

Average near-surface wind speed for September 2007-2015 relative to the 1981–2010 mean. Over the period 2007-2015, westerly winds around Antarctica were in early spring (September) slightly below the 1981–2010 climatology. Stippling indicates regions where the wind speed anomalies are considered to be significant according to the Welch's t-test.

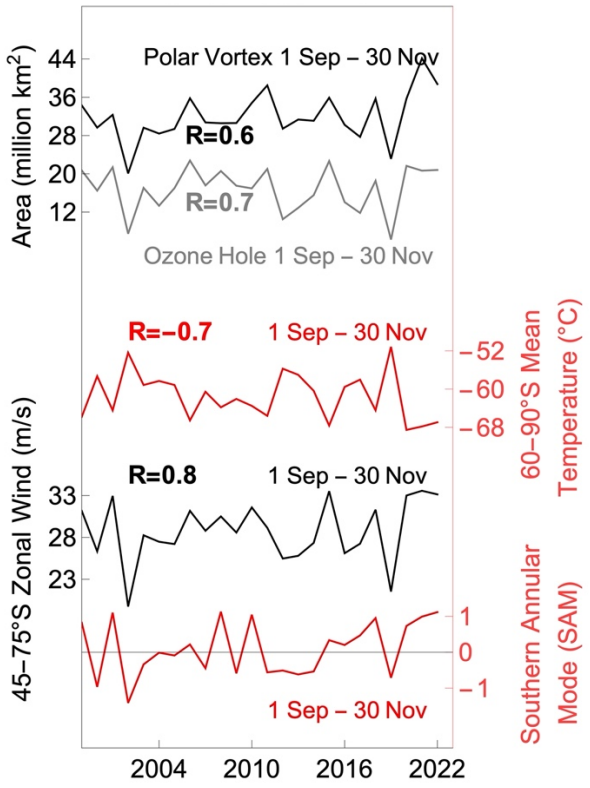

Figure S7

Spring averages of the SAM index (red line, lower panel), the 45-75° zonal mean zonal wind speed on the 100-hPa surface (black line, middle panel), the 60-90° zonal mean zonal temperature on the 50-hPa surface (red line, middle panel), the ozone hole area (gray line, upper panel), and the polar vortex (PV) area on the 460-K isentropic surface (black line, upper panel). In every case, daily estimates were averaged from 1 September to 30 November. The correlation coefficients (R) between the SAM index and the stratospheric temperature, the stratospheric wind speed, the ozone hole area, and the PV area are shown in the plot.

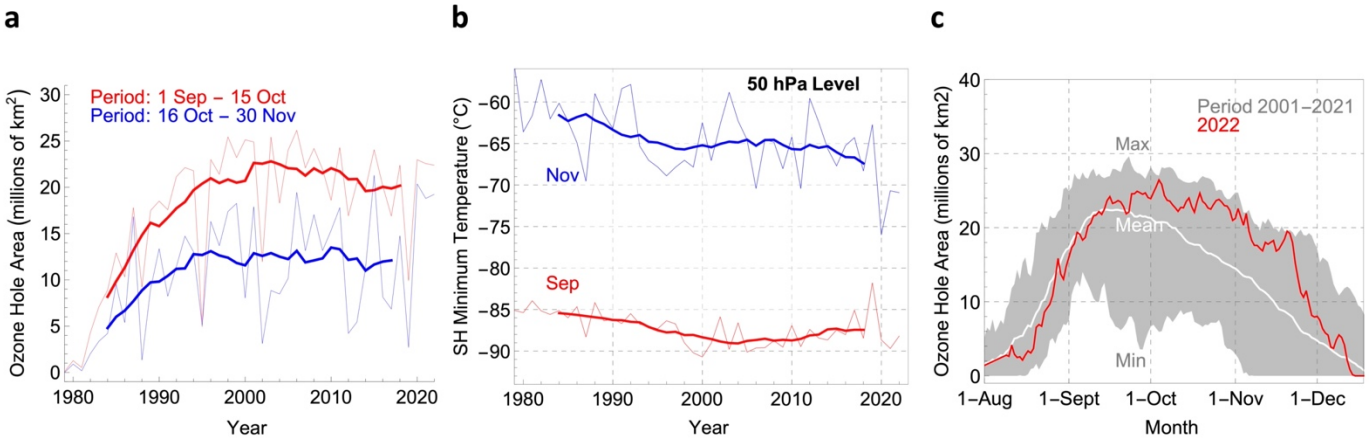

Figure S8

(a) Progress of ozone hole area averaged from 1 September to 15 October (red line) and from 16 October to 30 November (blue line). Bold lines show 11-year centered moving averages.

(b) Mean Southern Hemisphere (SH) minimum temperature for November (blue) and for September (red) at the 50 hPa Level. Bold lines show 11-year centered moving averages.

(c) Progress of the total ozone column for 2022 (red line). The gray shading indicates the highest and lowest values measured over the period 2001–2021, while the white line indicates the mean over the same period.

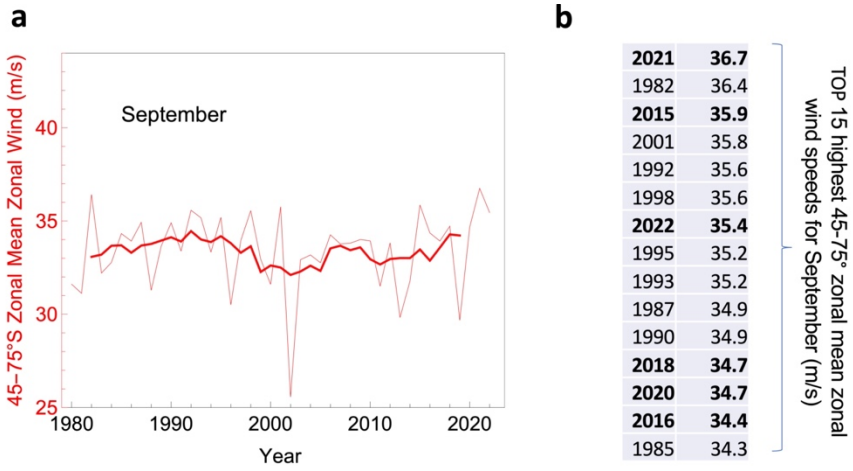

Figure S9

(a) 45-75° zonal mean zonal wind speed on the 100-hPa surface for September. The average east-west (zonal) wind speed for 45°S to 75°S is near the peak of the polar jet maximum. Bold line shows 7-year centered moving averages.

(b) Top 15 highest 45-75° zonal mean zonal wind speed on the 100-hPa surface for September. Six of the TOP 15 highest mean 45-75° zonal mean zonal wind speeds for September occurred during the last decade.

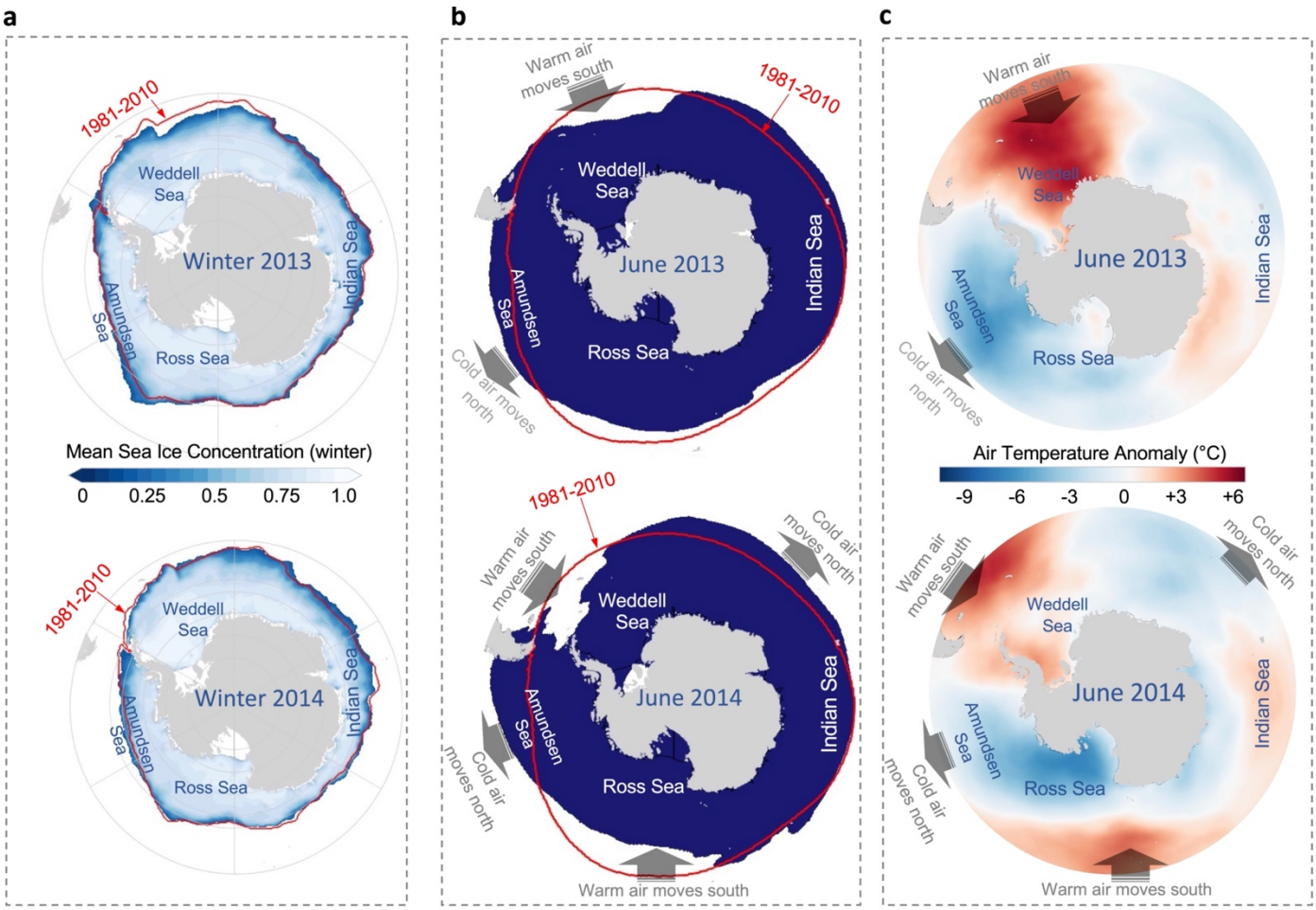

Figure S10

(a) Sea ice concentration (SIC) for winter 2014 (lower panel) and for winter 2013 (upper panel). The spring ice edge averaged over the period 1981–2010 is also shown (red line). The ice edge was defined by applying a 0.15 threshold. Relative to 1981-2010 climatology, there are several apparent anomalies. In winter 2013, slightly negative anomalies occurred in the Weddell Sea while positive anomalies were present in the Amundsen-Ross Seas. In winter 2014, slightly negative anomalies occurred in the Weddell and Ross Seas while positive anomalies were present in the Amundsen Sea and in the Atlantic sector.

(b) Polar vortex (100 hPa) for June 2014 (lower panel) and for June 2013 (upper panel). Here, the June vortex edge averaged over the period 1981–2010 is also shown (red line). The vortex edge was defined by applying a 1.2 x 10^{-5} K kg^{-1} m^2 s^{-1} threshold to the potential vorticity on the 100 hPa pressure surface.

(c) Average air temperature (800 hPa) for June 2014 (lower panel) and for June 2013 (upper panel), relative to the 1981–2010 mean. PV anomalies (see (b)) likely played a role in the heat advection seen in the Weddell Sea in early winter 2013, as well as in the heat advection seen in the Weddell and Ross Seas in early winter 2014.