

1 **Supplementary Information for**

2 **Opposite changes in Arctic and Antarctic sea-ice internal variability under**
3 **anthropogenic global warming**

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5 Siou-Min Tsao¹, Yu-Chiao Liang^{1*}, Clara Deser², and Jin-Yi Yu³

6
7 ¹Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan

8 ²National Center for Atmospheric Research Climate and Global Dynamics, Boulder,
9 Colorado

10 ³Department of Earth System Science, University of California-Irvine, Irvine, CA, USA

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12 *Corresponding author to Yu-Chiao Liang (yuchiaoliang@ntu.edu.tw;
13 pamip.yuchiaio@gmail.com)

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18 Supplementary Figures 1-15.

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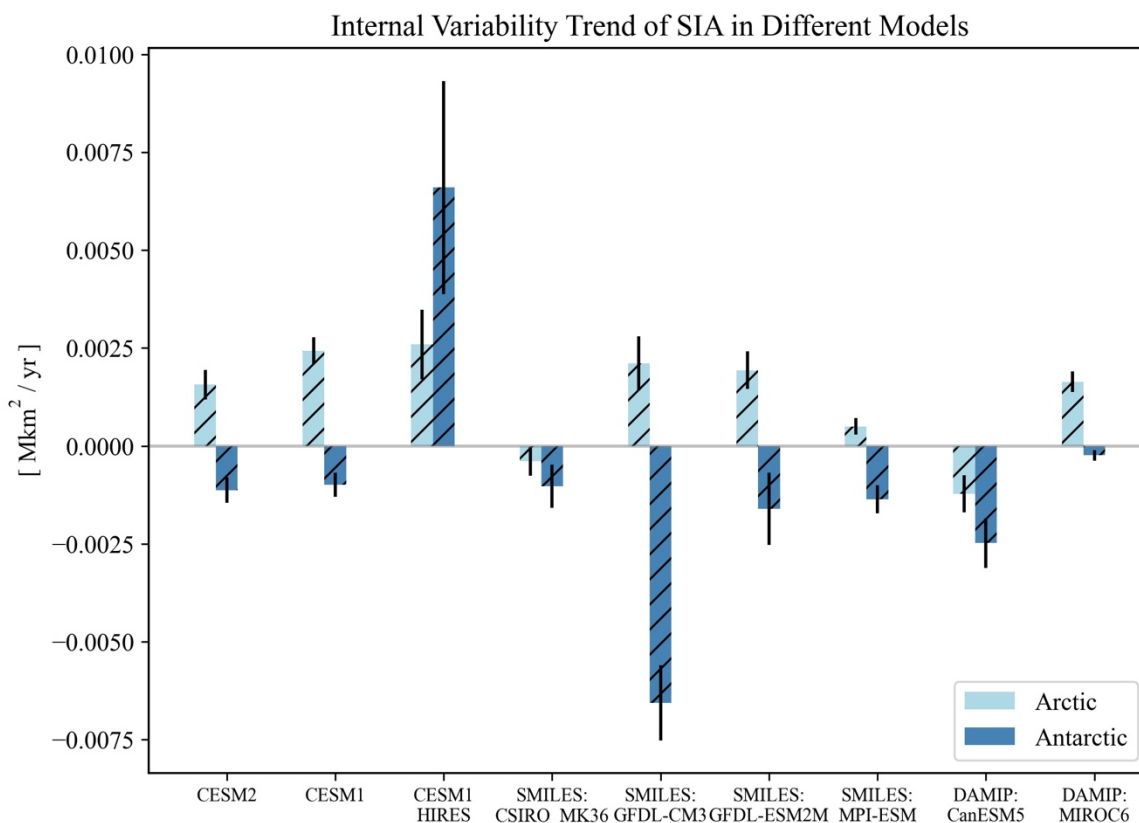
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30 **Supplementary Fig. 1: Long-term (1970-2050) trends of internal variability of**
 31 **Arctic and Antarctic annual sea-ice area (SIA) across different climate models.**

32 Hatched bars indicate statistically significant trends, and the 5–95% confidence intervals
 33 are shown by vertical lines. Full model names corresponding to the abbreviations, along
 34 with their simulation timespans, are listed below. CESM1_LE: Community Earth System
 35 Model Version 1 Large Ensemble (40 members; 1920–2100). CESM1_HIRES: High-
 36 resolution configuration of CESM Version 1.3 (10 members; 1850–2100). SMILES: Single-
 37 Model Initial-condition Large Ensembles (1850–2100), including CSIRO-Mk3.6 (30
 38 members), GFDL-CM3 (20 members), and MPI-ESM (100 members). DAMIP: Detection
 39 and Attribution Model Intercomparison Project (1850–2100), including CanESM5 (25
 40 members) and MIROC6 (50 members).

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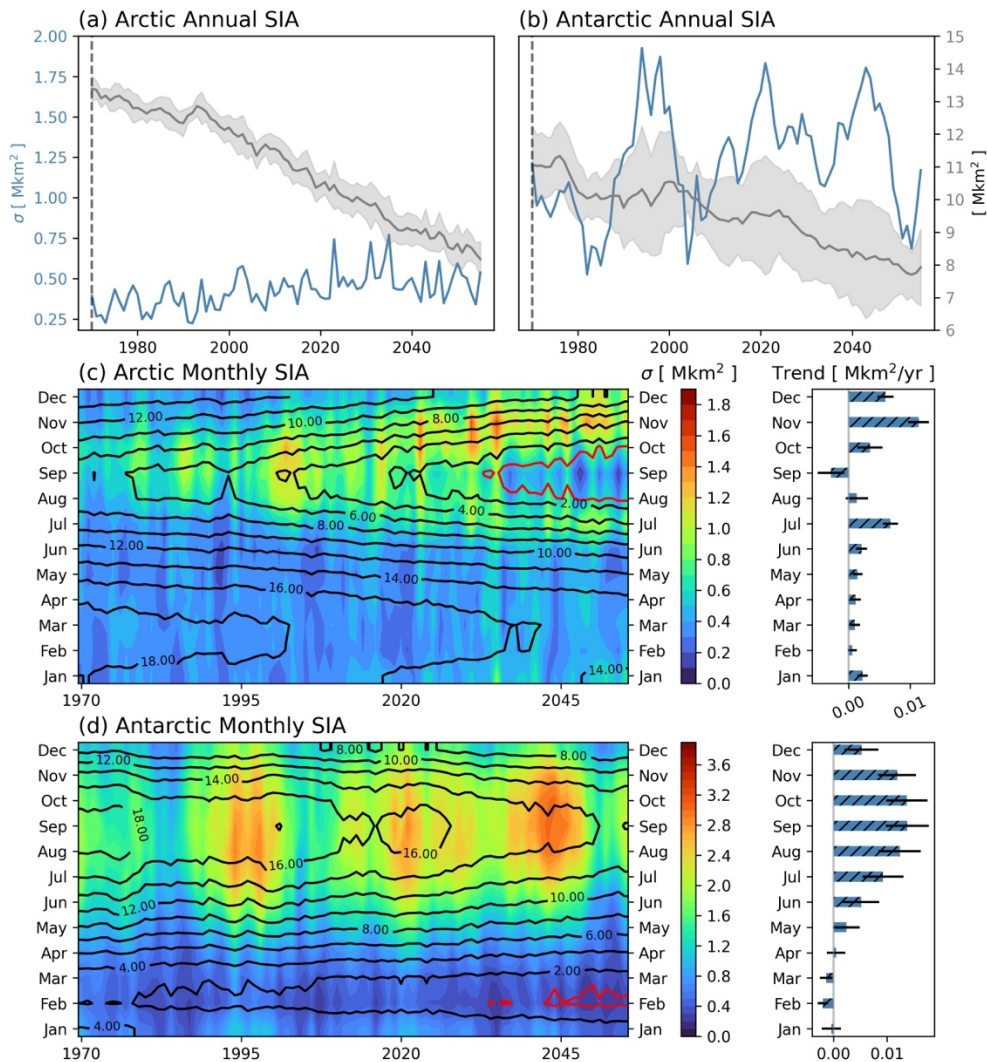
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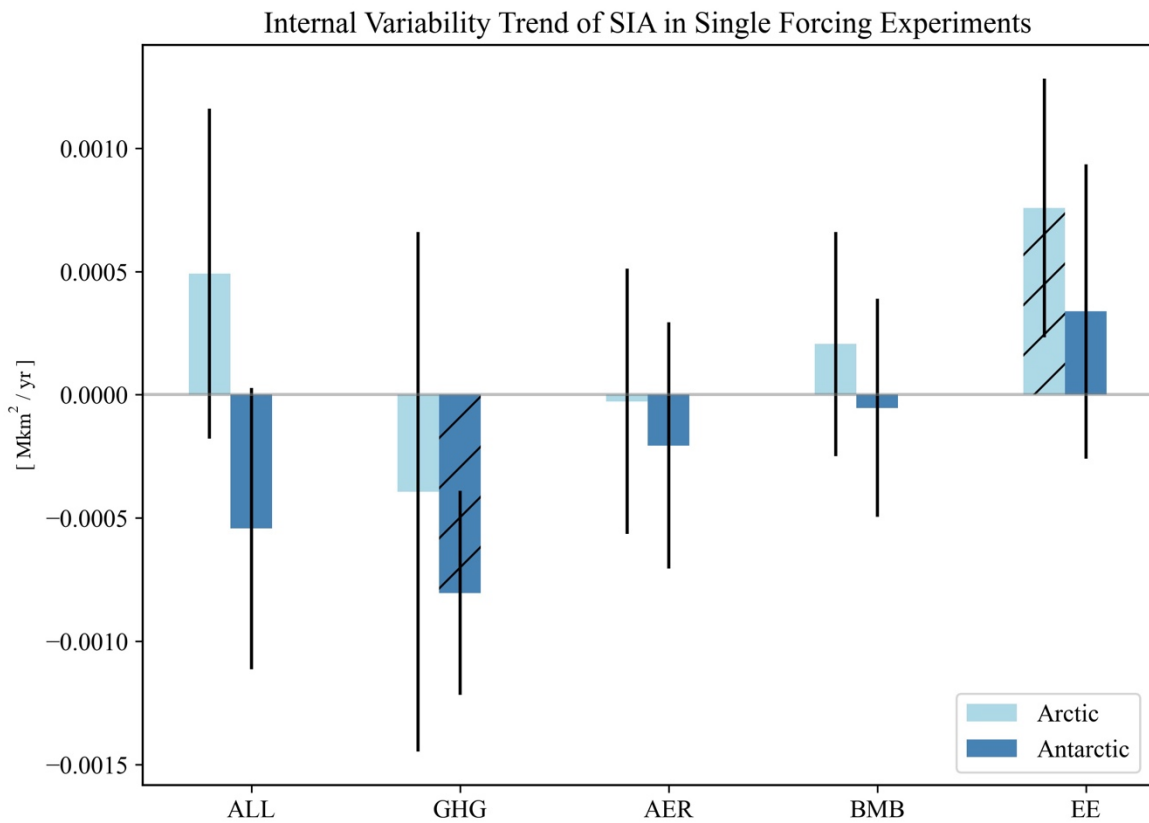
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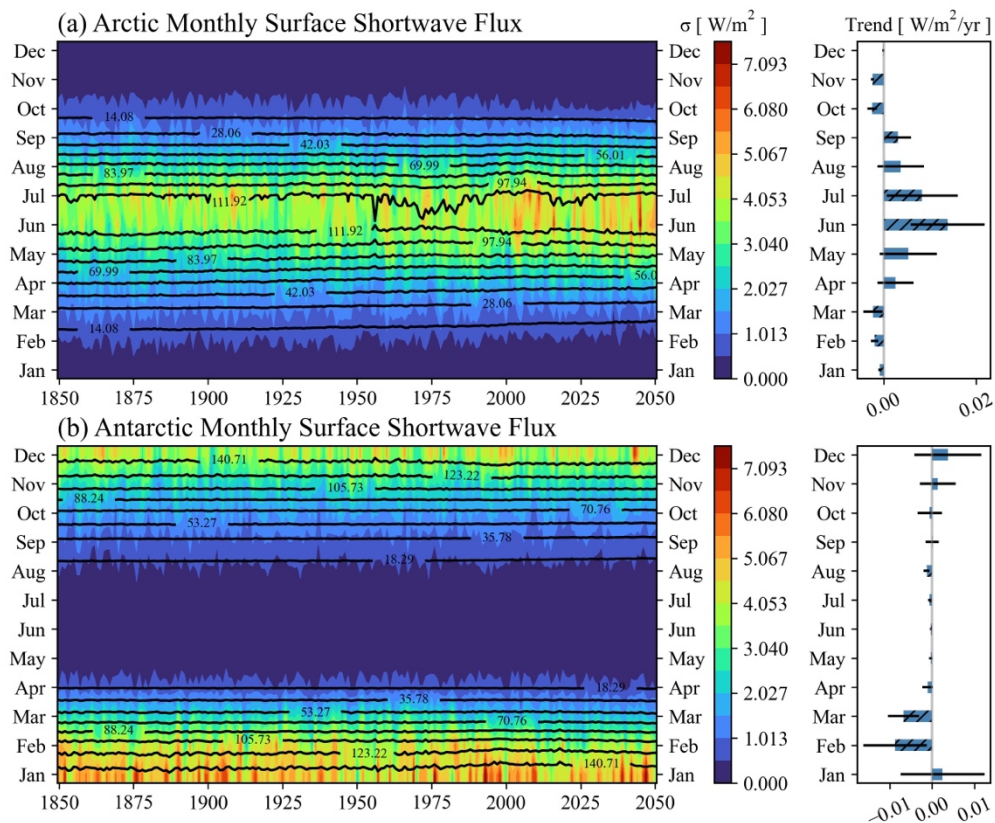
49 **Supplementary Fig. 2: Time series and trends of Arctic and Antarctic sea-ice**
 50 **internal variability from 1850 to 2050 simulated in CESM1-HIRES Large**
 51 **Ensembles. a** Time series of annual Arctic sea-ice area (SIA) internal variability (blue
 52 line), estimated as one standard deviation across ensemble members. The grey line
 53 indicates the ensemble-mean SIA, and the light grey shading represents the ensemble
 54 spread (± 1 standard deviation). **b** Same as **a**, but for Antarctic SIA internal variability. **c**
 55 Monthly Arctic SIA internal variability (color shading), overlaid with ensemble-mean SIA
 56 values (black contours) and the ice-free condition ($SIA < 1$ million km^2) is indicated by
 57 the red contour (left panel). The right panel shows the linear trend from 1970 to 2050 for
 58 each month (bars). Hatched bars indicate statistically significant trends, and the 5–95%
 59 confidence intervals are shown by horizontal lines. **d** Same as **c**, but for Antarctic monthly
 60 SIA internal variability.



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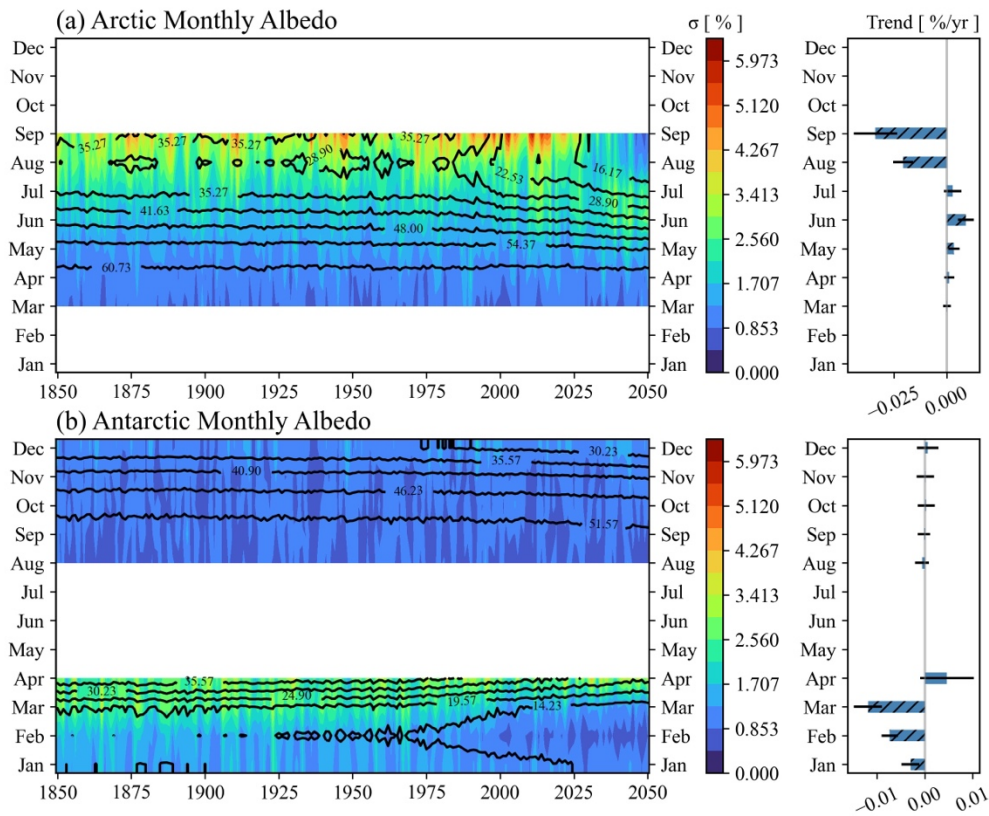
62 **Supplementary Fig. 3: Trends in internal variability of Arctic and Antarctic annual**
 63 **sea ice area (SIA) from 1970 to 2050 in CESM2 single-forcing experiments.** Hatched
 64 bars indicate that the trends are statistical significant at 5% significant level, and the 5–
 65 95% confidence intervals are shown by the vertical lines. The single-forcing experiments
 66 include well-mixed greenhouse gases (GHGs; 15 members), anthropogenic aerosols
 67 (AER; 20 members), biomass burning aerosols (BMB; 15 members), and “everything else”
 68 (EE; i.e., all forcings other than GHG, AAER, and BMB; 15 members).

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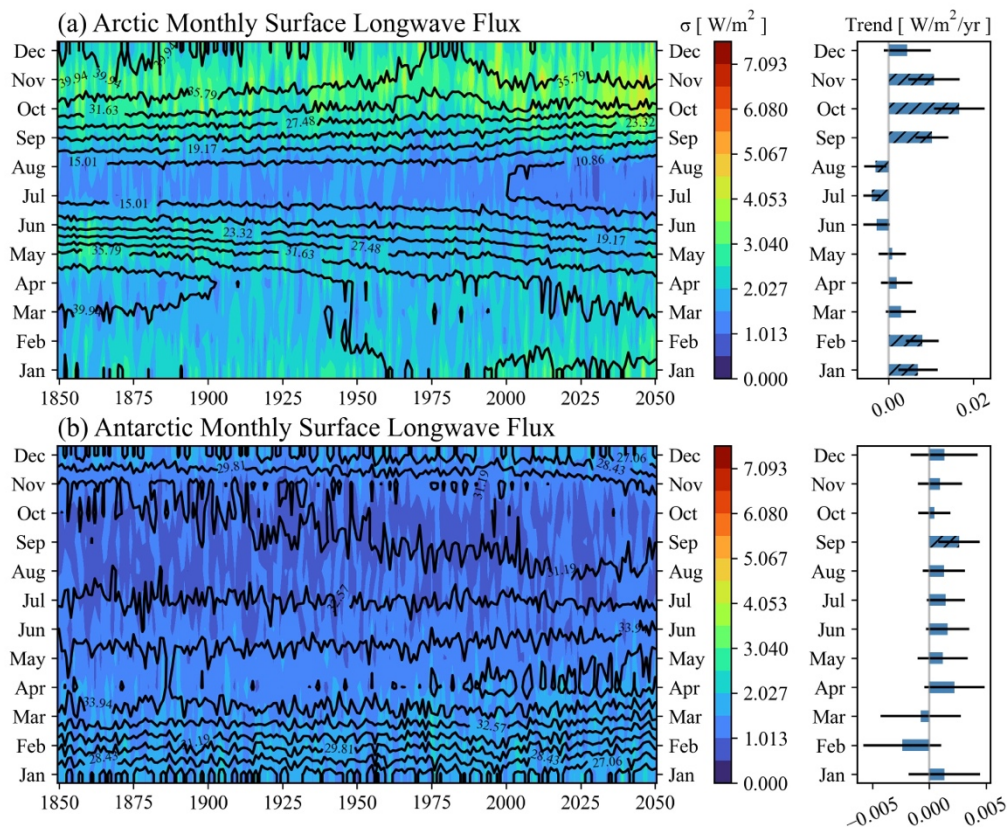
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71 **Supplementary Fig. 4: Monthly time series and trends of Arctic and Antarctic**
 72 **surface shortwave radiation internal variability from 1850 to 2050 simulated in**
 73 **CESM2 Large Ensembles.** Same as Fig. 1c, and d in the main text, but showing the
 74 internal variability of monthly surface shortwave radiation over the Arctic and Antarctic
 75 from 1970 to 2050.



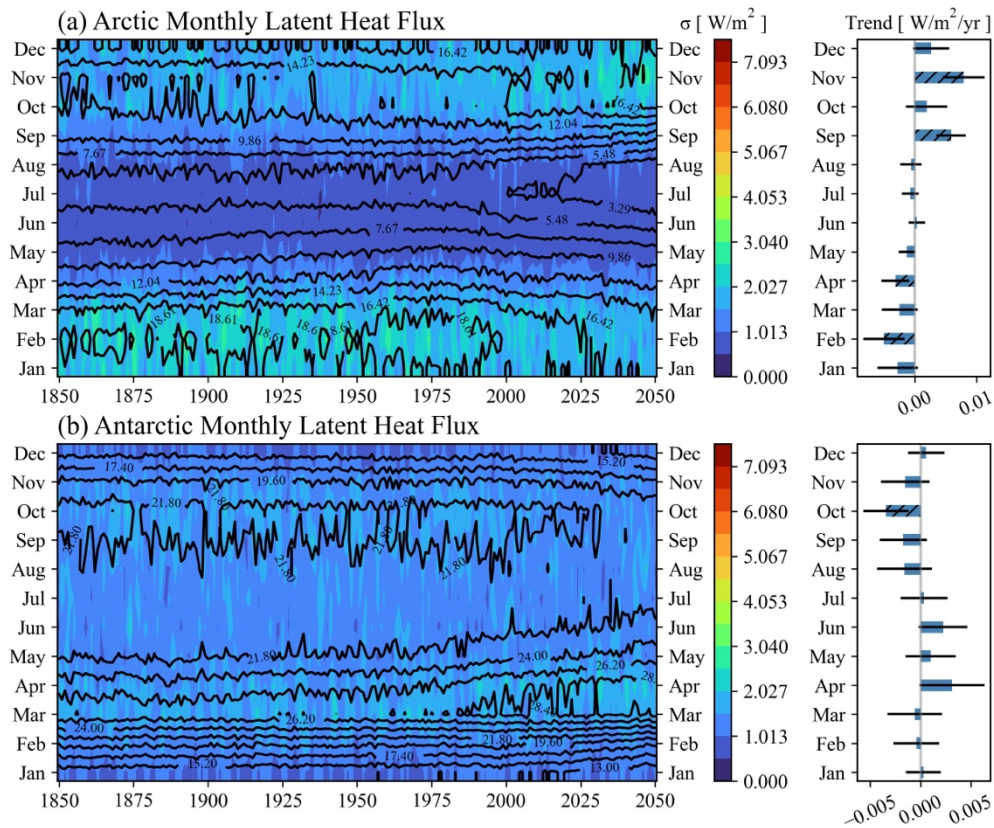
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77 **Supplementary Fig. 5: Monthly time series and trends of Arctic and Antarctic**
 78 **albedo internal variability from 1850 to 2050 simulated in CESM2 Large**
 79 **Ensembles.** Same as Fig. 1c, and d in the main text, but showing the internal variability
 80 of monthly surface albedo over the Arctic and Antarctic from 1970 to 2050.



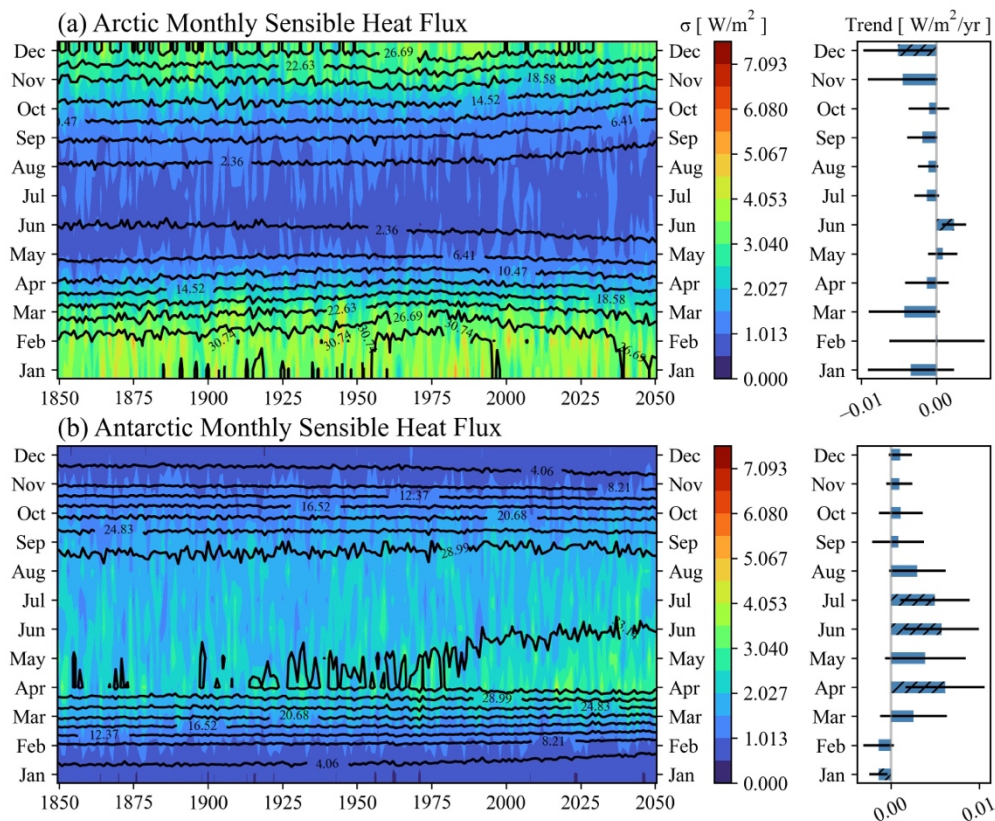
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82 **Supplementary Fig. 6: Monthly time series and trends of Arctic and Antarctic**
 83 **surface longwave radiation internal variability from 1850 to 2050 simulated in**
 84 **CESM2 Large Ensembles.** Same as Fig. 1c, and d in the main text, but showing the
 85 internal variability of monthly surface longwave radiation over the Arctic and Antarctic
 86 from 1970 to 2050.



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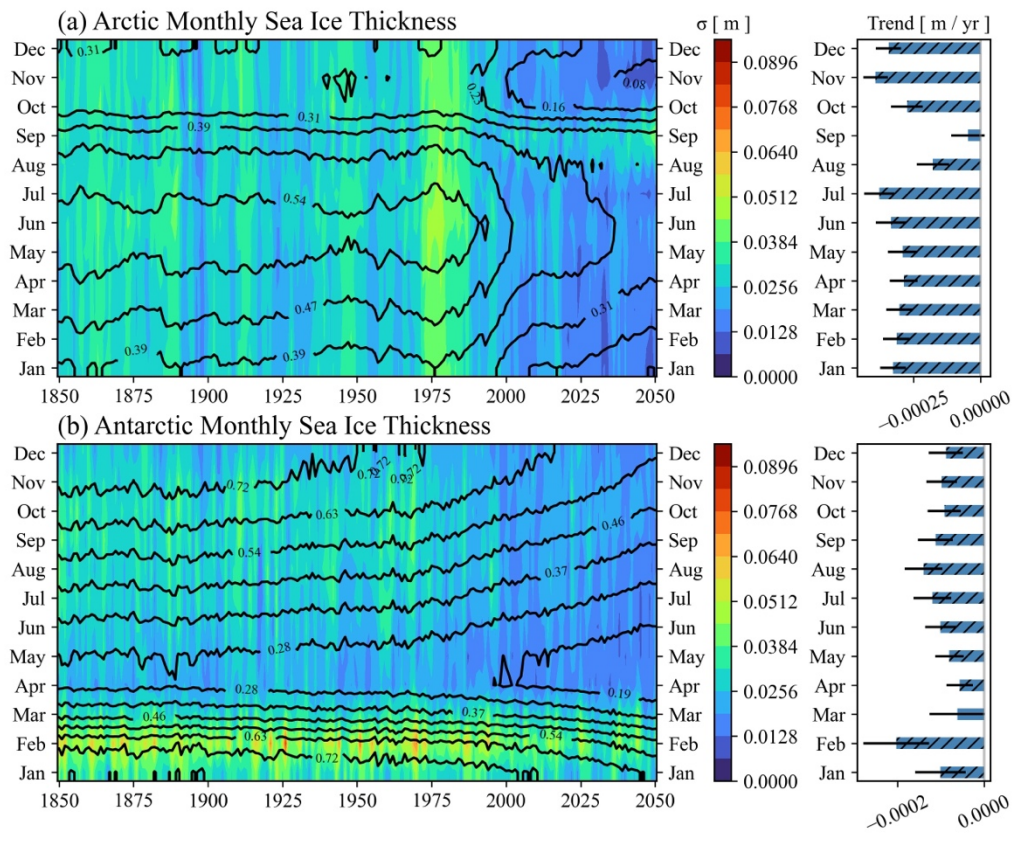
88 **Supplementary Fig. 7: Monthly time series and trends of Arctic and Antarctic**
 89 **surface latent heat flux internal variability from 1850 to 2050 simulated in CESM2**
 90 **Large Ensembles.** Same as Fig. 1c, and d in the main text, but showing the internal
 91 variability of monthly surface latent heat flux over the Arctic and Antarctic from 1970 to
 92 2050.



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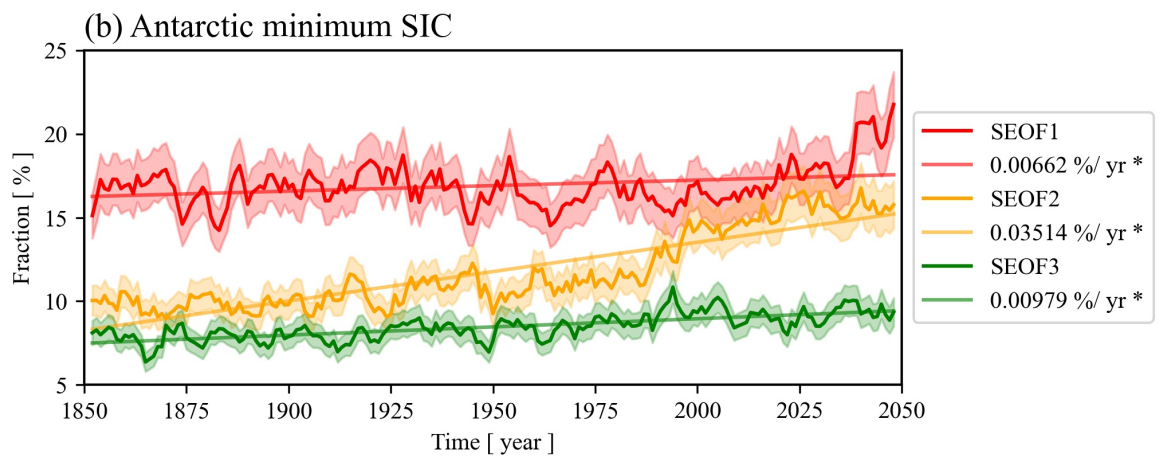
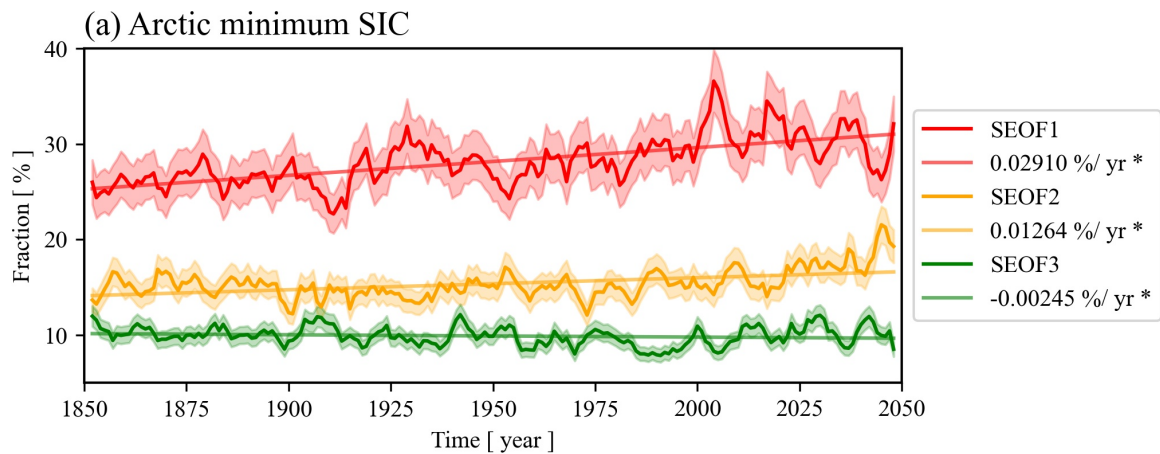
94 **Supplementary Fig. 8: Monthly time series and trends of Arctic and Antarctic**
 95 **surface sensible heat flux internal variability from 1850 to 2050 simulated in**
 96 **CESM2 Large Ensembles.** Same as Fig. 1c, and d in the main text, but showing the
 97 internal variability of monthly surface sensible heat flux over the Arctic and Antarctic
 98 from 1970 to 2050.

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101 **Supplementary Fig. 9: Monthly time series and trends of Arctic and Antarctic sea-**
 102 **ice thickness internal variability from 1850 to 2050 simulated in CESM2 Large**
 103 **Ensembles.** Same as Fig. 1c, and d in the main text, but showing the internal variability
 104 of monthly sea-ice thickness over the Arctic and Antarctic from 1970 to 2050.



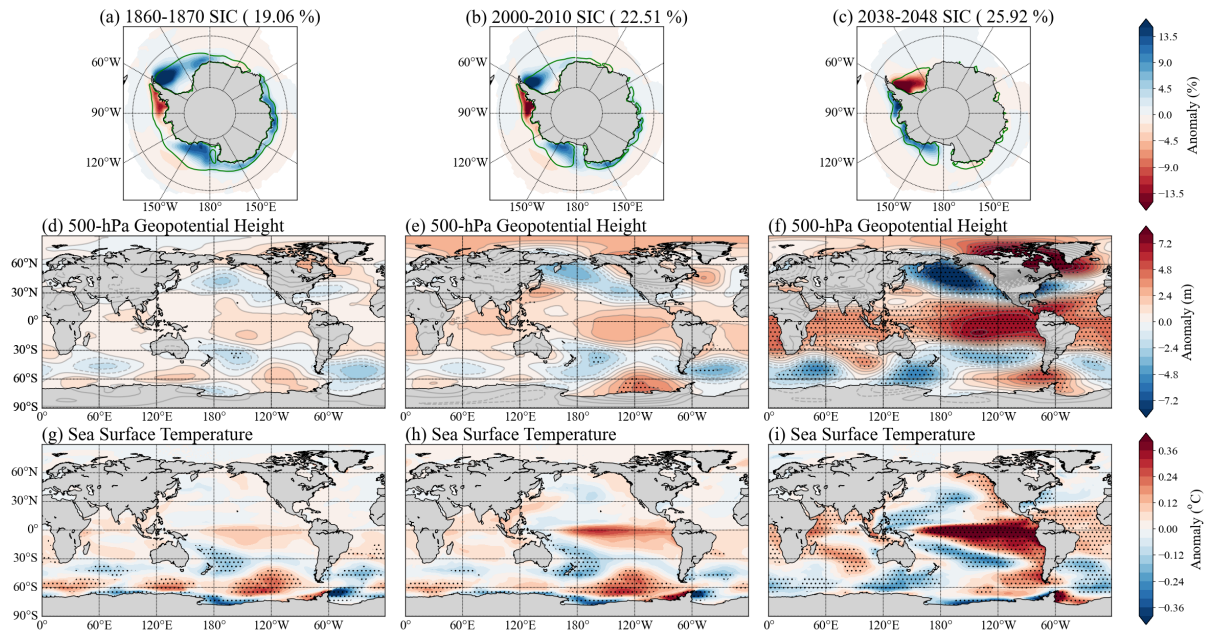
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106 **Supplementary Fig: 10. The time series of the explained variance of the three**
 107 **leading SEOFs of Arctic and Antarctic sea-ice internal variability. a** August–
 108 **September-October mean Arctic sea-ice concentration (SIC) and their long-term trends.**
 109 **(b)** January-February-March mean Antarctic sea-ice concentration (SIC) and their long-
 110 term trends.

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116 **Supplementary Fig. 11: Leading mode of snapshot empirical orthogonal function**
 117 **(SEOF) analysis of Antarctic sea-ice concentration (SIC) averaged over January–**
 118 **March, and its associated 500-hPa geopotential height and sea-surface**
 119 **temperature (SST) anomaly patterns. a** The regressed spatial pattern of the leading
 120 SIC SEOF mode during 1860–1870. The green contour indicates the sea-ice edge, defined
 121 as the ensemble-mean SIC of 15%. **d** The regression map of geopotential height onto the
 122 principal component of the leading SIC SEOF mode. Stippling indicates regions where the
 123 regression coefficient is statistically significant (p value < 0.05) in at least 7 of the 10
 124 years. **g** Same as **d**, but for SST. **b**, **e**, **h** and **c**, **f**, **i** are the same as **a**, **d**, **g**, but for the 2000–
 125 2010 and 2038–2048 periods, respectively.

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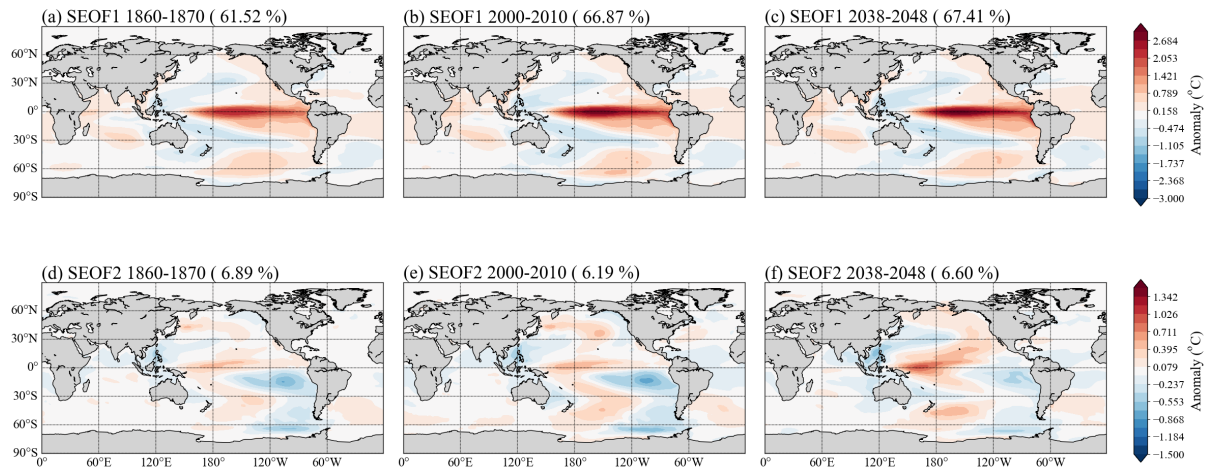
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137 **Supplementary Fig. 12: The two leading modes of snapshot empirical orthogonal function**
 138 **(SEOF) analysis of sea-surface temperature (SST) averaged over December–February**
 139 **over the tropical Pacific (30°S–30°N, 140°–295°E; TPac). The time period chosen is the**
 140 **same as the time periods in the SEOF analysis of SIC (Fig. 4 and Fig.5 in the main text).**

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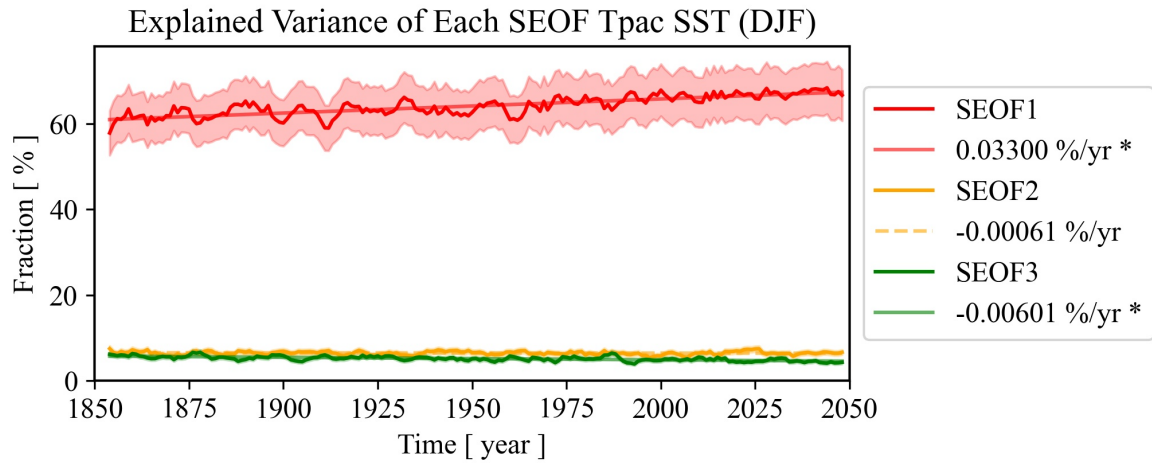
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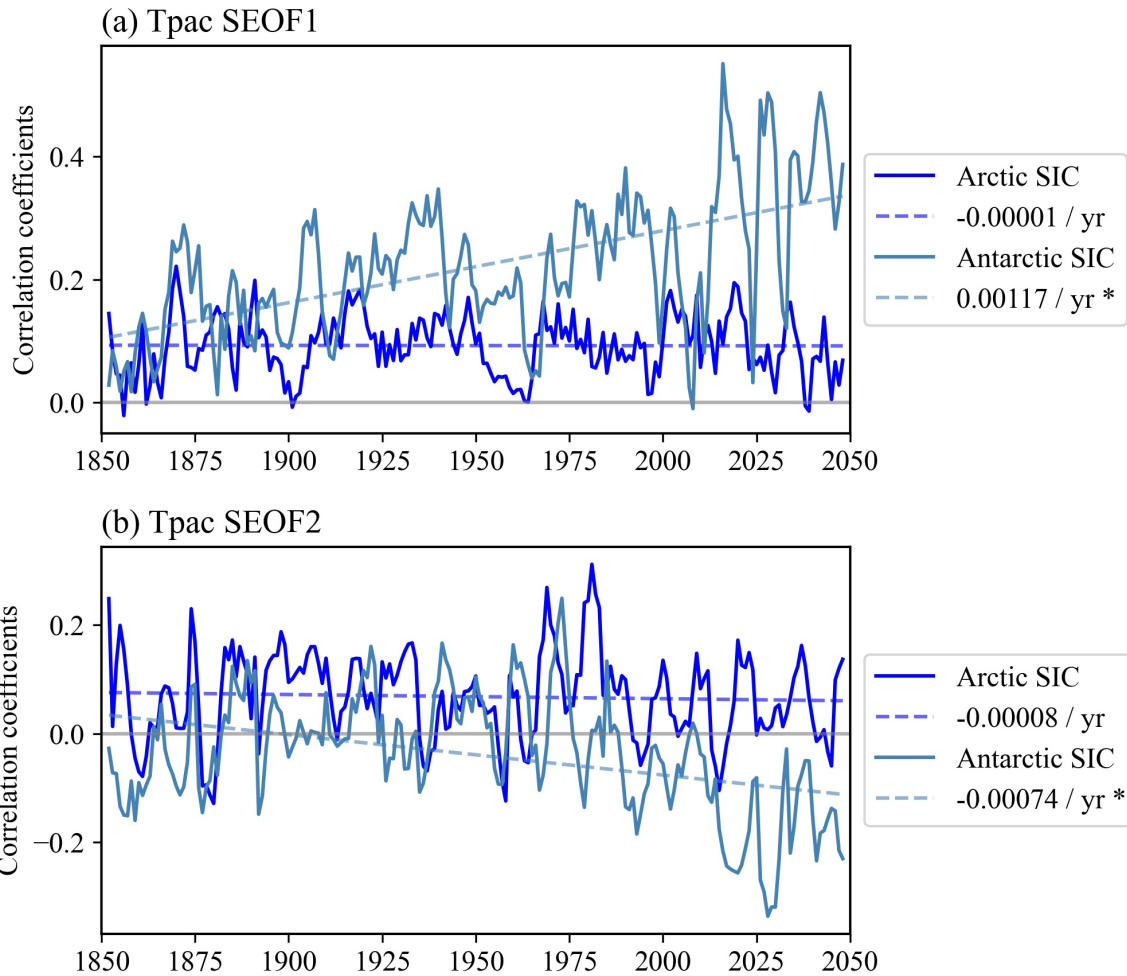
154 **Supplementary Fig. 13: Time series of the explained variance of the three leading**
 155 **SEOFs of SST averaged over December–February in the tropical Pacific domain (30°S–**
 156 **30°N, 140°–295°E; TPac) and their long-term trends.** Solid lines indicate statistically
 157 significant linear trends with p value less than 0.05, whereas dashed lines indicate
 158 statistically insignificant trends.

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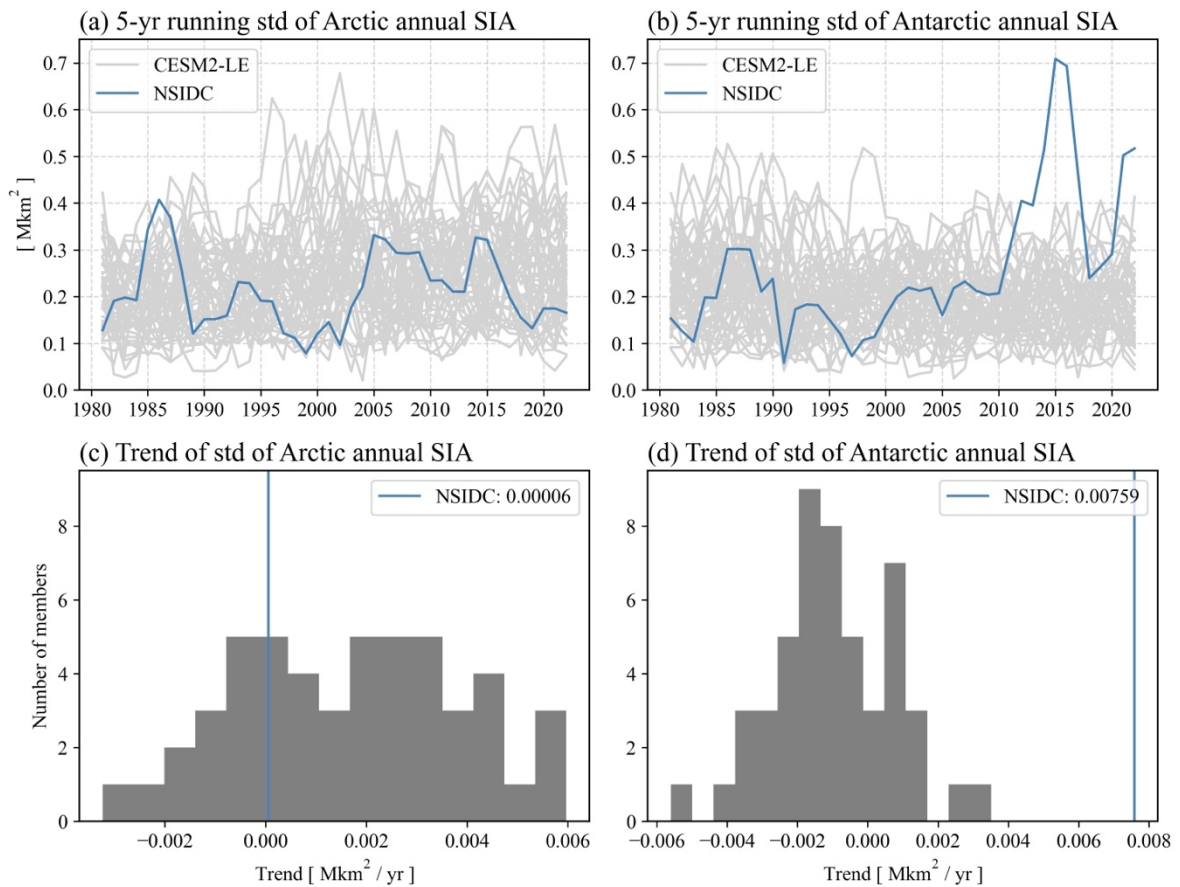
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164 **Supplementary Fig. 14: The temporal evolution of correlation coefficients between**
 165 **the principal component of the SEOF modes (SPC) of the leading SEOF mode of**
 166 **Arctic and Antarctic sea ice concentration (SIC) and the SPC of tropical sea-surface**
 167 **temperature (SST).** The correlation coefficients for (a) first and (b) second SEOF modes
 168 of DJF tropical Pacific SST, along with their long-term trends. The best-fit linear trend
 169 lines are shown as dashed lines, and asterisks indicate statistically significant trends.



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171 **Supplementary Fig. 15: The time series of sea-ice internal variability in**
 172 **observations during the 1979-2025 period.** The time series of the 5-year running
 173 standard deviation of annual sea-ice area (SIA) for the Arctic (a) and Antarctic (b),
 174 derived from the National Snow and Ice Data Center. The grey lines indicate the results
 175 from the individual 50 members of CESM2-LE. c, The trend of observed Arctic sea-ice
 176 internal variability trend. d, The trend of observed Antarctic sea-ice internal variability
 177 trend. The grey bar indicate the distribution of trends from 50 members of CESM2-LE.

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