

Supporting Information for

**Distinct impacts of diverse forcing agents on Arctic sea ice
since the mid-twentieth century**

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Supplementary Tables

Table S1: CMIP5 and CMIP6 models and ensemble configurations. List of CMIP5 and CMIP6 models, simulations and ensemble members used in this study.

Model	CMIP5/6	Historical	GHG-only	AER-only
CCSM4	CMIP5	r[1-6]i1p1	r[1,4,6]i1p1	r[1,4,6]i1p10
CSIRO-Mk3-6-0	CMIP5	r[1-3,5-7,9-10]i1p1	r[1,3-5]i1p1	r[1-5]i1p4
CanESM2	CMIP5	r[1-5]i1p1	r[1-5]i1p1	r[1-5]i1p4
GFDL-CM3	CMIP5	r[1-5]i1p1	r[1,3,5]i1p1	r[1,3,5]i1p1
ACCESS-CM2	CMIP6	r[1-10]i1p1f1	r[1-3]i1p1f1	r[1-3]i1p1f1
ACCESS-ESM1-5	CMIP6	r[1-40]i1p1f1	r[1-3]i1p1f1	r[1-3]i1p1f1
CESM2	CMIP6	r[1-4, 6-7, 9-11]i1p1f1	r1i1p1f1	r[1,3]i1p1f1
CNRM-CM6-1	CMIP6	r[1-20, 29]i1p1f1	r[1-10]i1p1f1	r[1-10]i1p1f1
GFDL-ESM4	CMIP6	r1i1p1f1	r1i1p1f1	r1i1p1f1
IPSL-CM6A-LR	CMIP6	r[1-2, 4-33]i1p1f1	r[1-10]i1p1f1	r[1-10]i1p1f1
MIROC6	CMIP6	r[1-50]i1p1f1	r[1-3]i1p1f1	r[1-3]i1p1f1
MRI-ESM2-0	CMIP6	r[1-6]i1p1f1 & r1i2p1f1	r[1-5]i1p1f1	r[1-5]i1p1f1
NorESM2-LM	CMIP6	r[1-3]i1p1f1 & r1i1p4f1	r[2,3]i1p1f1	r[1-3]i1p1f1

Table S2: Trends in Arctic sea ice area. Annual and ensemble-averaged linear trends of Arctic sea ice area (SIA) for the periods 1956-1980 and 1981-2005.

($10^6 \text{ km}^2/\text{decade}$)	Historical	GHG	AAER	BMB
1956-1980				
Walsh et al. (2019)	-0.09	-	-	-
CESM1	-0.02	-0.17*	0.26*	0.04
CMIP5 & 6 MMM	0.02 (3*)	-0.15 (9*)	0.10 (6*)	-
1981-2005				
Walsh et al. (2019)	-0.42*	-	-	-
CESM1	-0.20*	-0.29*	-0.16*	0.14*
CMIP5 & 6 MMM	-0.25 (13*)	-0.17 (10*)	-0.06 (5*)	-

Note: Trend values marked with an asterisk (*) are significant at the 95% confidence level.

For trend values from CMIP5 & 6 MMM, the number in parentheses with an asterisk indicates how many CMIP5 & 6 models exhibit significant trends (at the 95% confidence) with the same sign.

Table S3: Trends in Arctic sea ice volume. Annual and ensemble-averaged linear trends of Arctic sea ice volume (SIV) for the periods 1956-1980 and 1981-2005.

(10 ³ km ³ /decade)	Historical	GHG	AAER	BMB
1956-1980				
CESM1	0.25	-1.30*	2.59*	0.39*
CMIP5 & 6 MMM	0.26 (6*)	-0.59 (10*)	1.26 (9*)	-
1981-2005				
CESM1	-2.37*	-3.25*	-1.54*	0.55*
CMIP5 & 6 MMM	-1.63 (13*)	-0.90 (8*)	-0.16 (3*)	-

Note: Trend values marked with an asterisk (*) are significant at the 95% confidence level.

For trend values from CMIP5 & 6 MMM, the number in parentheses with an asterisk indicates how many CMIP5 & 6 models exhibit significant trends (at the 95% confidence) with the same sign.

Supplementary Figures

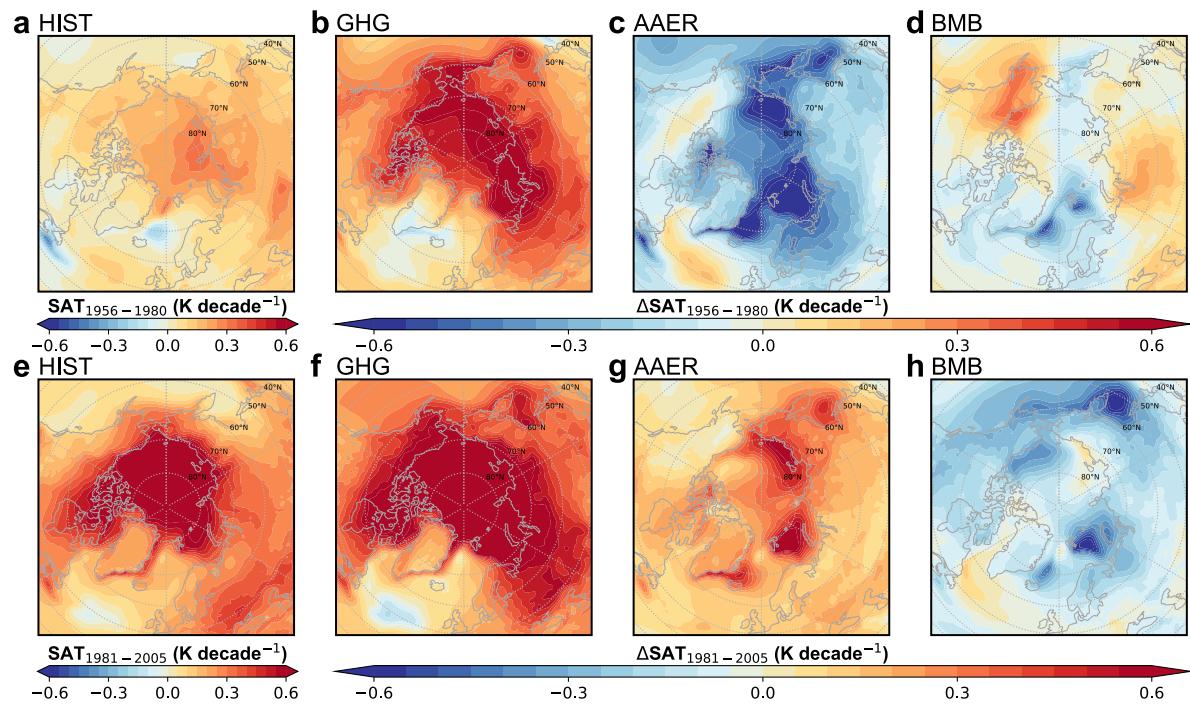


Fig. S1: Arctic surface air temperature trends during two periods (1956-1980 and 1981-2005). Linear trends of annual and ensemble mean surface air temperature (shading in K decade^{-1}) over the Arctic during (a-d) 1956-1980 and (e-h) 1981-2005. (a,e) for historical climate forcings (HIST), (b,f) for well-mixed greenhouse gases (GHG), (c,g) for anthropogenic aerosols (AAER), and (d,h) for biomass burning (BMB).

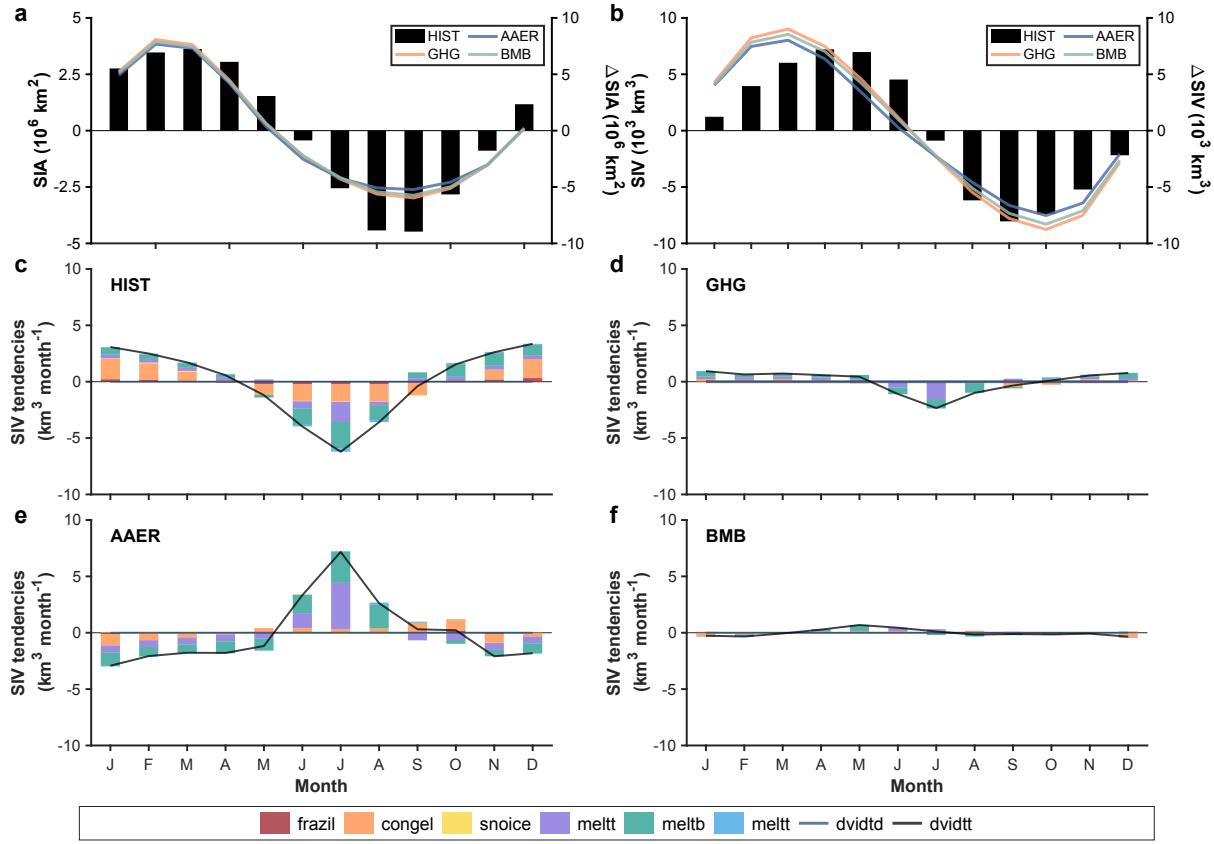


Fig. S2: Seasonal Arctic sea ice area, volume, and volume budgets over 1956-1980. Seasonal ensemble-mean Arctic sea ice (a) area and (b) volume as well as (c-f) sea ice volume budget over 1956-1980, with annual mean removed. The left y-axis in (a,b) refers to historical values (HIST: black bars) and the right y-axis refers to contributions from well-mixed greenhouse gases (GHG: orange lines), anthropogenic aerosols (AAER: blue lines), and biomass burning (BMB: green lines).

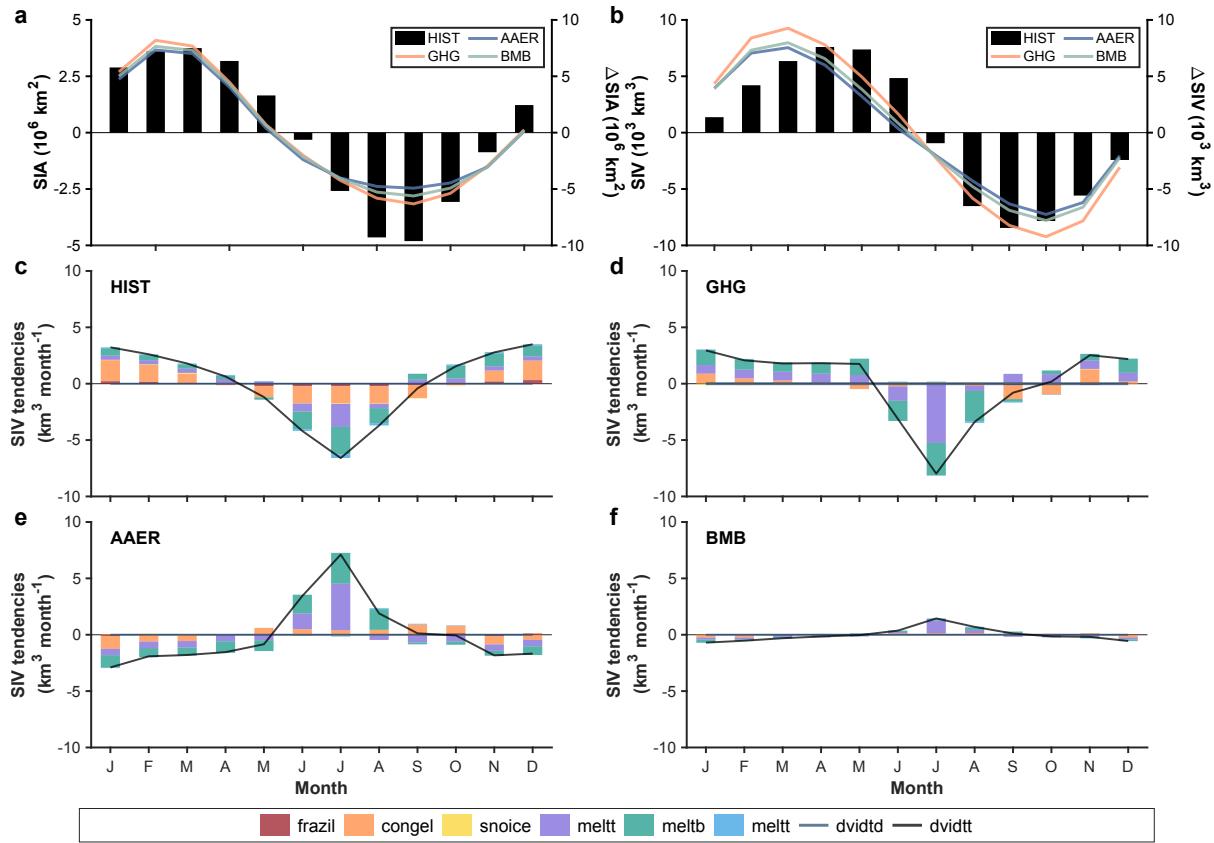


Fig. S3: Seasonal Arctic sea ice area, volume, and volume budgets over 1981-2005. Seasonal ensemble-mean Arctic sea ice (a) area and (b) volume as well as (c-f) sea ice volume budget over 1981-2005, with annual mean removed. The left y-axis in (a,b) refers to historical values (HIST: black bars) and the right y-axis refers to contributions from well-mixed greenhouse gases (GHG: orange lines), anthropogenic aerosols (AAER: blue lines), and biomass burning (BMB: green lines).

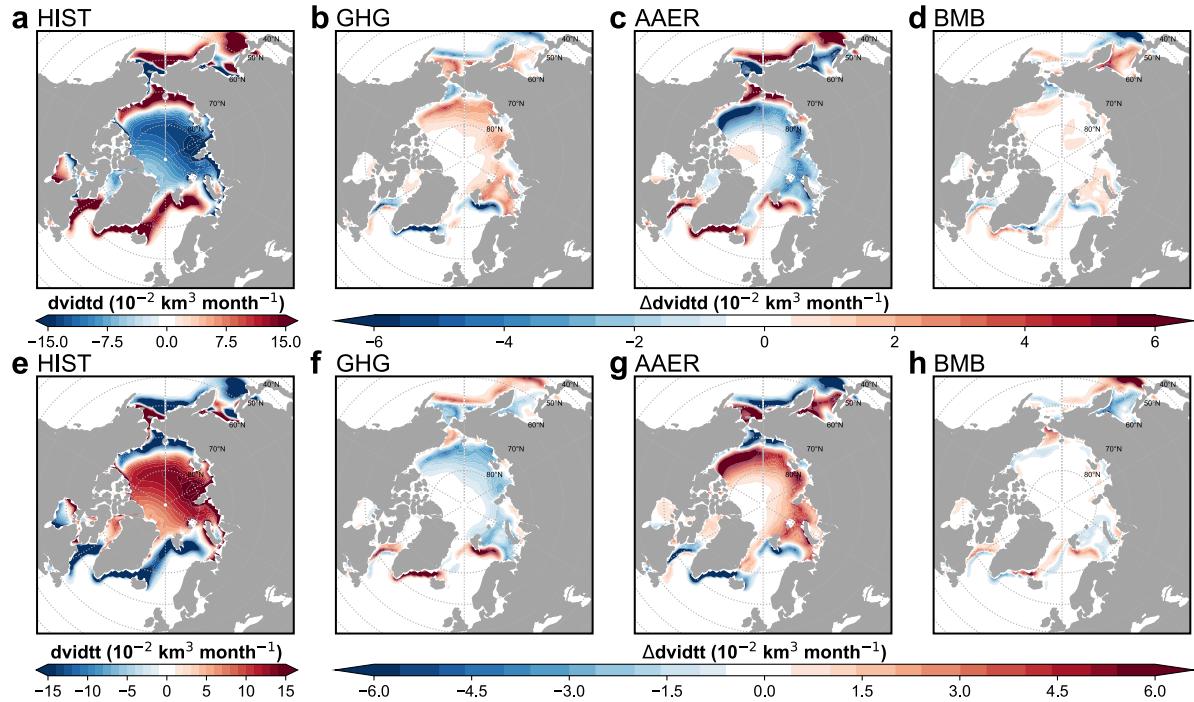


Fig S4: Annual mean Arctic sea ice volume tendencies (1956-1980) in CESM1.
 Annual ensemble mean of (a-d) dynamic sea ice volume tendencies (shading in $10^{-2} \text{ km}^3 \text{ month}^{-1}$) and (e-h) thermodynamic sea ice volume tendencies (shading in $10^{-2} \text{ km}^3 \text{ month}^{-1}$) for the period 1956-1980. (a,e) for historical climate forcings (HIST), (b,f) for well-mixed greenhouse gases (GHG), (c,g) for anthropogenic aerosols (AAER), and (d,h) for biomass burning (BMB).

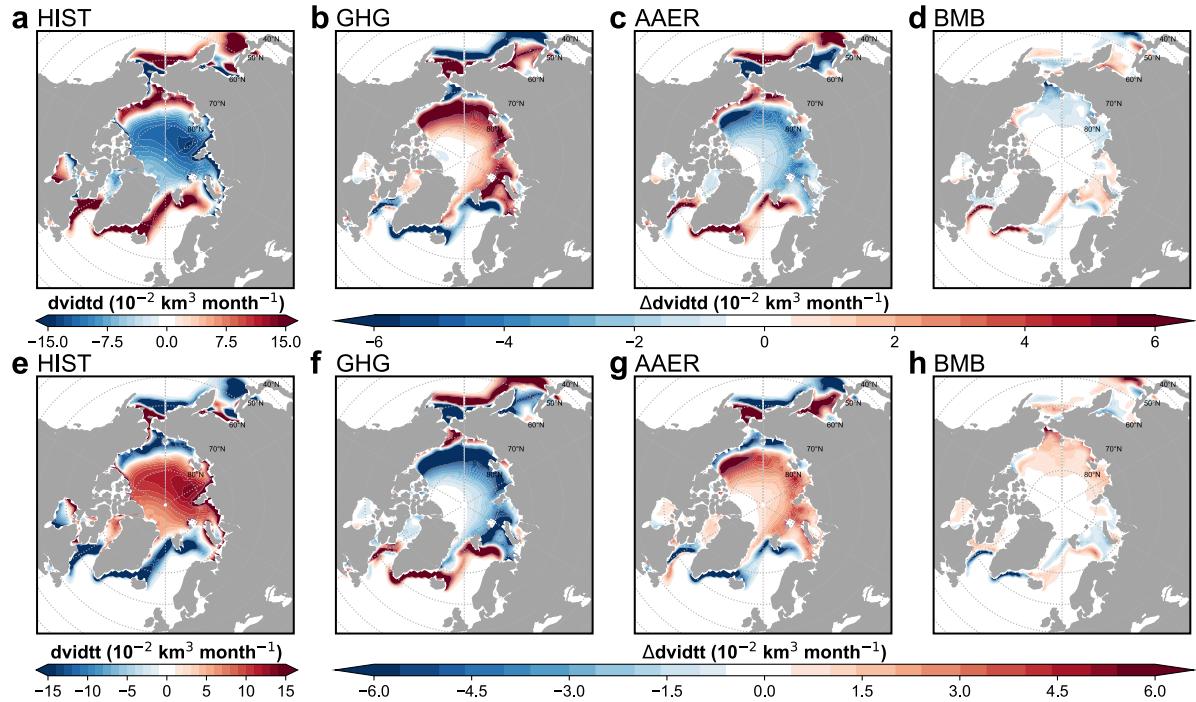


Fig S5: Annual mean Arctic sea ice volume tendencies (1981-2005) in CESM1.
 Annual ensemble mean of (a-d) dynamic sea ice volume tendencies (shading in $10^{-2} \text{ km}^3 \text{ month}^{-1}$) and (e-h) thermodynamic sea ice volume tendencies (shading in $10^{-2} \text{ km}^3 \text{ month}^{-1}$) for the period 1981-2005. (a,e) for historical climate forcings (HIST), (b,f) for well-mixed greenhouse gases (GHG), (c,g) for anthropogenic aerosols (AAER), and (d,h) for biomass burning (BMB).

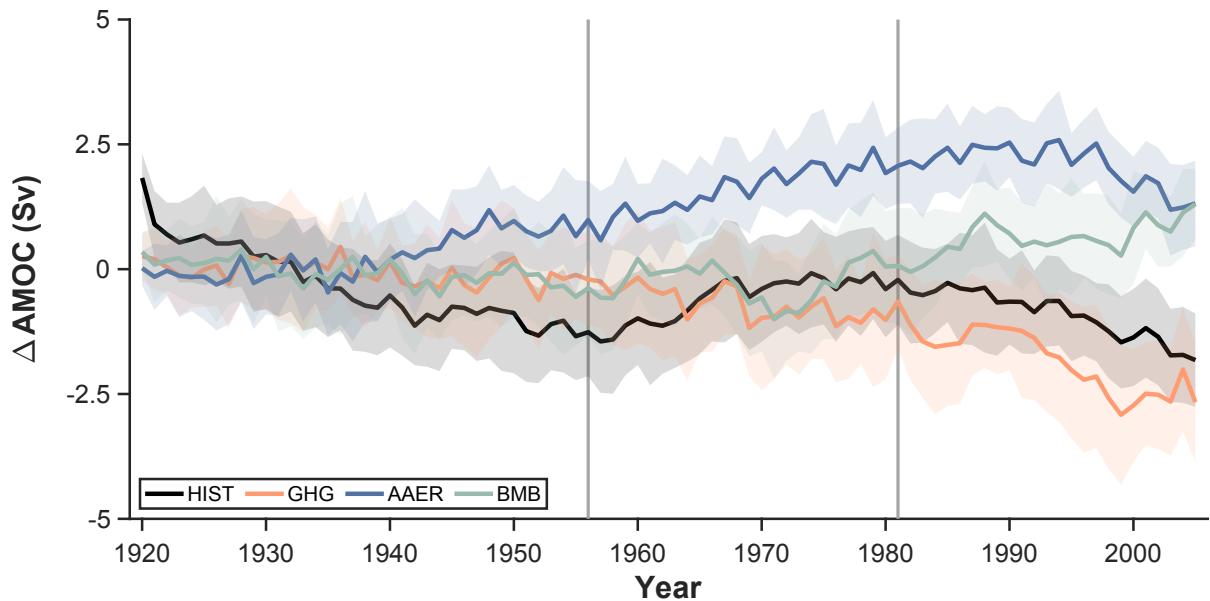


Fig S6: AMOC changes driven by different climate forcings. Changes in annual and ensemble mean AMOC strength (relative to 1920-1945) under different forcings: historical climate forcings (HIST: black), well-mixed greenhouse gases (GHG: orange), anthropogenic aerosols (AAER: blue), and biomass burning (BMB: green). Shadings represent one standard deviation across ensemble members. The AMOC strength is defined as the maximum of the annual mean stream-function below 500 meters across the North Atlantic.