Southern Ocean freshwater initiative

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Important role for ocean warming and increased ice-shelf melt in Antarctic sea-ice expansion

R. Bintanja*, G. J. van Oldenborgh, S. S. Drijfhout, B. Wouters and C. A. Katsman

"Here we show that **accelerated basal melting** of Antarctic ice shelves is likely to have **contributed significantly to sea-ice expansion**"

GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 4328–4332, doi:10.1002/grl.50820, 2013

The influence of recent Antarctic ice sheet retreat on simulated sea ice area trends

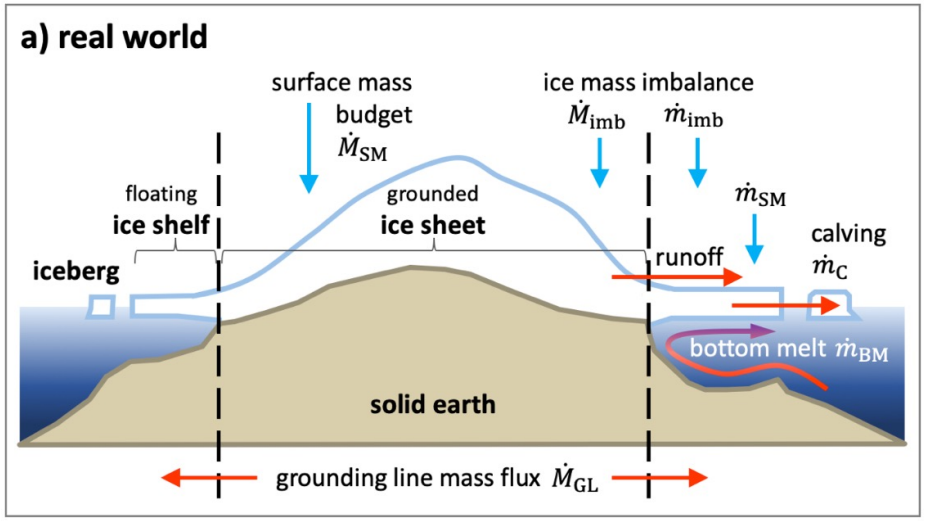
N. C. Swart[1] and J. C. Fyfe[2]

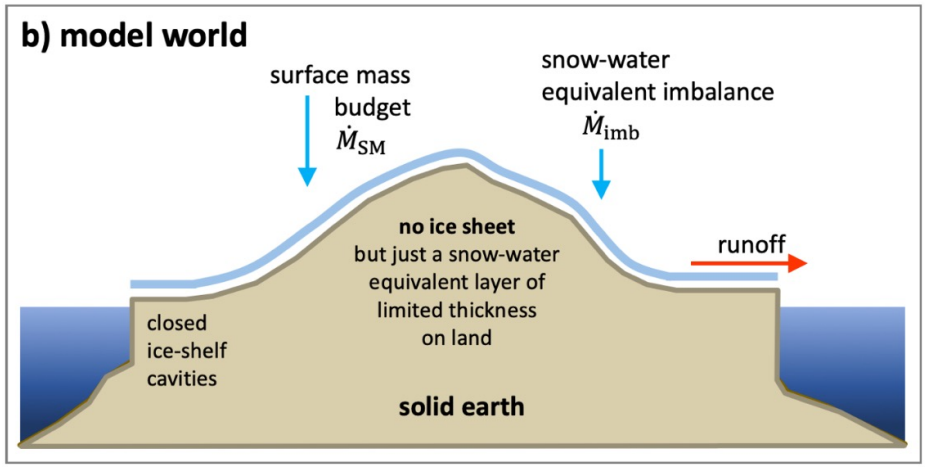
"Our simulations show that the **freshwater effect on sea ice** trends over the historical period **is small** and fails to reproduce the observed regional pattern of trends"

We propose a standardised Southern Ocean freshwater forcing protocol to quantify the impact of missing Antarctic meltwater on climate simulations across multiple models

Photo: Richard Jones

Coupled climate models do not represent ice sheets or shelves, neglecting important climate impacts





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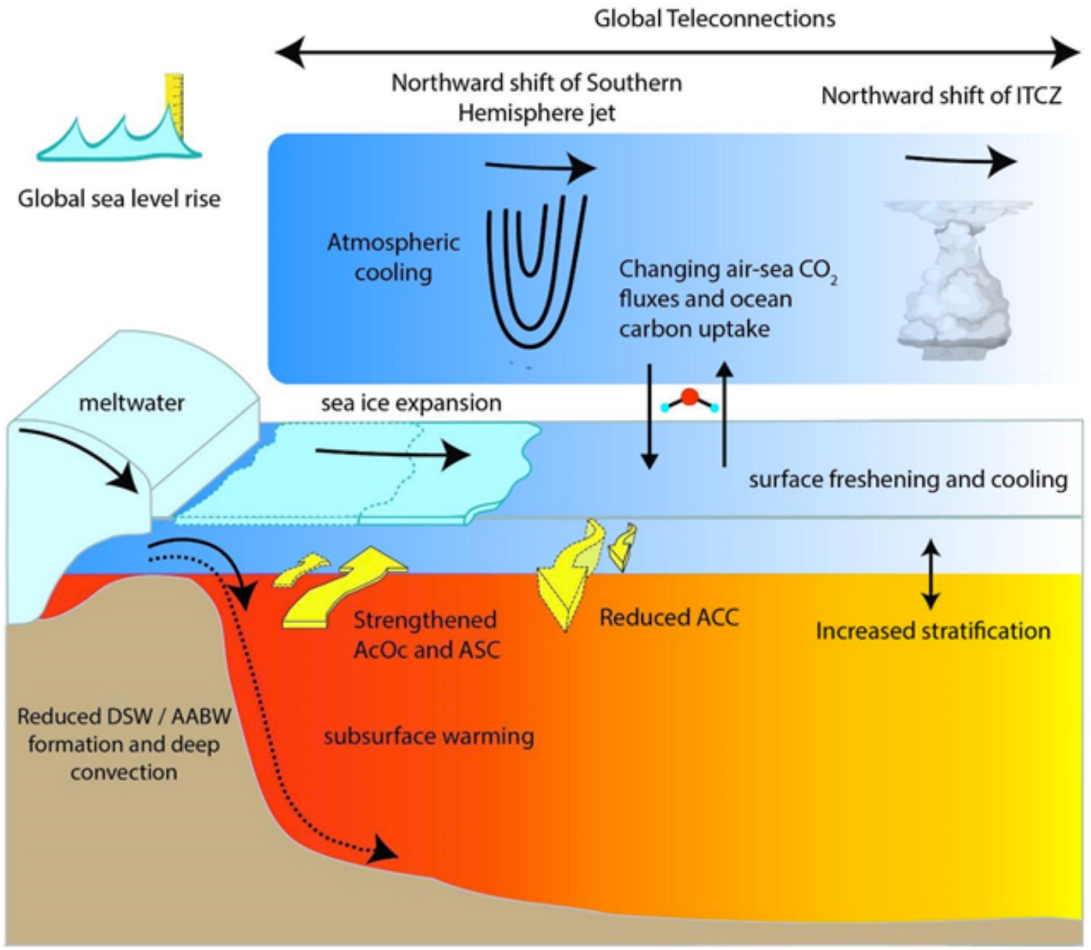
- P–E over Antarctica in CMIP models is essentially equal to runoff to the Southern Ocean (Pauling et al. 2016)
  - In control and historical simulations, runoff entering Southern Ocean is close to estimated ice shelf loss
  - In future warming simulations, meltwater amounts entering Southern Ocean are underestimated

Meltwater influences on climate

- High meltwater simulations produce anomalous surface cooling, reduced sea ice loss, hemispheric differences in precipitation, and ocean warming at depth
- Low meltwater simulations show the magnitude of climate responses are strongly dependent on applied meltwater amount (Purich and England 2023)



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Meltwater studies

- Studies examining the role of Southern Ocean surface freshening in contributing to climate trends reached conflicting conclusions due to different experimental designs and models used
- A **standardised meltwater intercomparison** is needed to better understand the global climate response to Antarctic meltwater additions

Study	Model	Function	Depth	Max input	Max input
			m	$\times 10^3$ Gt yr^{-1}	Sv
Hansen et al. (2016)	C	E	S	9.46 to 255.47	0.30 to 8.10*
Sadai et al. (2020)	C	V	S	25.23, 78.85	0.80, 2.50*
Ma et al. (2013)	C	C	S	31.54	1.00*
Stouffer et al. (2007)	C	C	S	31.54	1.00*
Bronselaer et al. (2018)	C	V	S	18.92	0.60*
Mackie et al. (2020)	C	E	R	17.71*	0.56
Purich and England (2023)	C	L	S	4.81 to 16.65	0.15 to 0.53
Golledge et al. (2019)	C	V	S	5.05*	0.16
van den Berk and Drijfhout (2014)	C	E	S	5.05*	0.16
Li et al. (2023b)	C	C	U	0.50, 2.0, 5.0*	0.02, 0.06, 0.16
Fogwill et al. (2015)	C	C	S	2.18 to 6.59	0.07 to 0.21*
Pauling et al. (2017)	C	L	R	4.10*	0.13
Beadling et al. (2022)	C	C	S	3.15	0.10*
Bronselaer et al. (2020)	C	C	S	3.15	0.10*
Park and Latif (2019)	C	C	S	1.58, 3.15	0.05, 0.10*
Rye et al. (2020)	C	V	U	0.74*	0.02
Bintanja et al. (2013)	C	C	S	0.25*	0.01
Pauling et al. (2016)	C	C	R	0.17 to 3.00*	0.01 to 0.10
Bintanja et al. (2015)	C	C	S	0.01 to 0.12*	<0.01
Swingedouw et al. (2009)	I	C	S	3.15 to 63.08	0.1 to 2.00*
Weaver et al. (2003)	I	L	S	6.31	0.20*
Aiken and England (2008)	I	C	S	0.13, 12.62	<0.01, 0.40*
Menviel et al. (2010)	I	C, L	S	5.68, 11.04	0.18, 0.35*
Swart and Fyfe (2013)	I	L	S	0.09 to 0.95	<0.01 to 0.03*
Lago and England (2019)	O	E	S	3.15	1.00
Moorman et al. (2020)	O	C	S	1.32, 5.05	0.04, 0.16*
Li et al. (2023a)	O	L	S	2.52	0.08*
Merino et al. (2018)	O	C	R	0.28*	<0.01
Seidov et al. (2001)	O	C	S	0.38 to 1.89	0.01 to 0.06*
Haumann et al. (2020)	O	C	U	0.84	0.03*

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The Southern Ocean Freshwater release model experiments Initiative (SOFIA)

- We propose a standardised Southern Ocean freshwater forcing protocol to quantify the impact of missing Antarctic meltwater on climate simulations across multiple models
- Swart et al. 2023, submitted to *GMD*
- SOFIA will address gaps in our understanding of:
  - Climate response to Antarctic meltwater
  - Forcing uncertainty
  - Model uncertainty

Experimental protocol

- We describe protocols for coupled models to maximise participation and to provide distinct pieces of information:

Tier	Experiment	Freshwater forcing
1	antwater	constant 0.1 Sv
2	hist-antwater	0.1, 0.3, 0.5, 1.1 x 10^{-3} Sv y^{-1} ramps
	ssp126-ismip6	ISMIP6 SSP126 basal melt
	ssp585-ismip6	ISMIP6 SSP585 basal melt
3	60Swater	constant 0.1 Sv south of 60°S
	antwater-lh	constant 0.1 Sv with latent heat

Freshwater anomalies are applied at the ocean surface in the grid cell adjacent to the Antarctic coast

Tier 1 output

- Tier 1 output is available for eight coupled models, including **ACCESS-ESM1.5**, and **ACCESS-CM2** runs are planned

Type	Model	Resolution (ocn/atm, lat×lon, °)	Contact	Reference
Coupled	ACCESS-ESM1-5	1/1.875×1.25	Ariaan Purich	Ziehn et al. (2020)
	CanESM5	1/3	Neil Swart	Swart et al. (2019)
	FOCI	0.5/1.9	Torge Martin	Matthes et al. (2020)
	GFDL-CM4	0.25/1	Stephen Griffies	Held et al. (2019)
	GFDL-ESM4	0.50/1	Stephen Griffies	Dunne et al. (2020)
	GISS-E2-1-G	1×1.25/2×2.5	Qian Li	Kelley et al. (2020)
	HadGEM3-GC3.1-LL	1/1	Max Thomas	Kuhlbrodt et al. (2018)
	NorESM2-MM	1/1	Tore Hattermann	Seland et al. (2020)
Ocean	MOM5	1	Riccardo Farneti	Griffies (2012)

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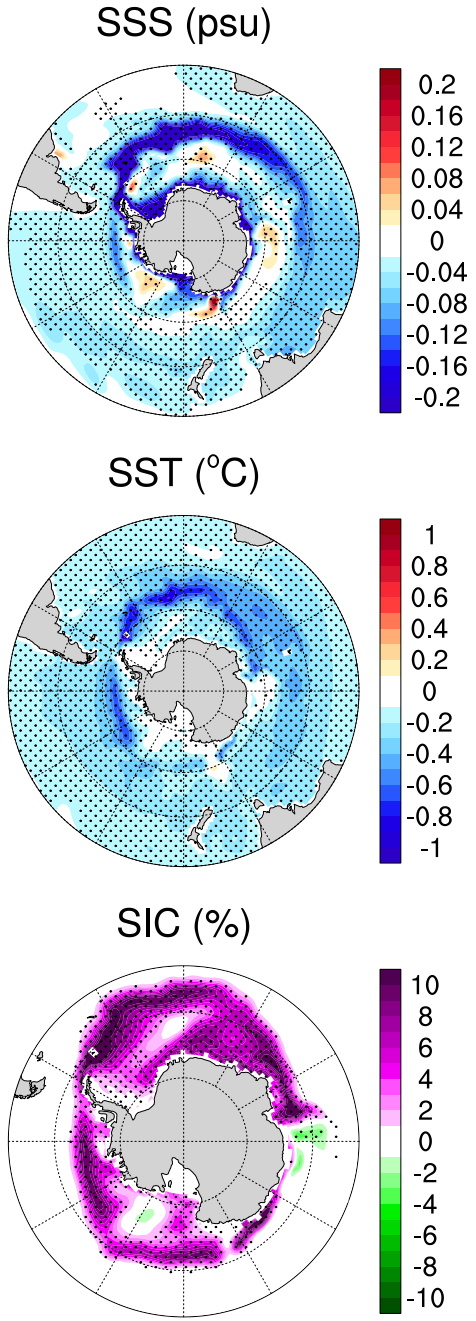
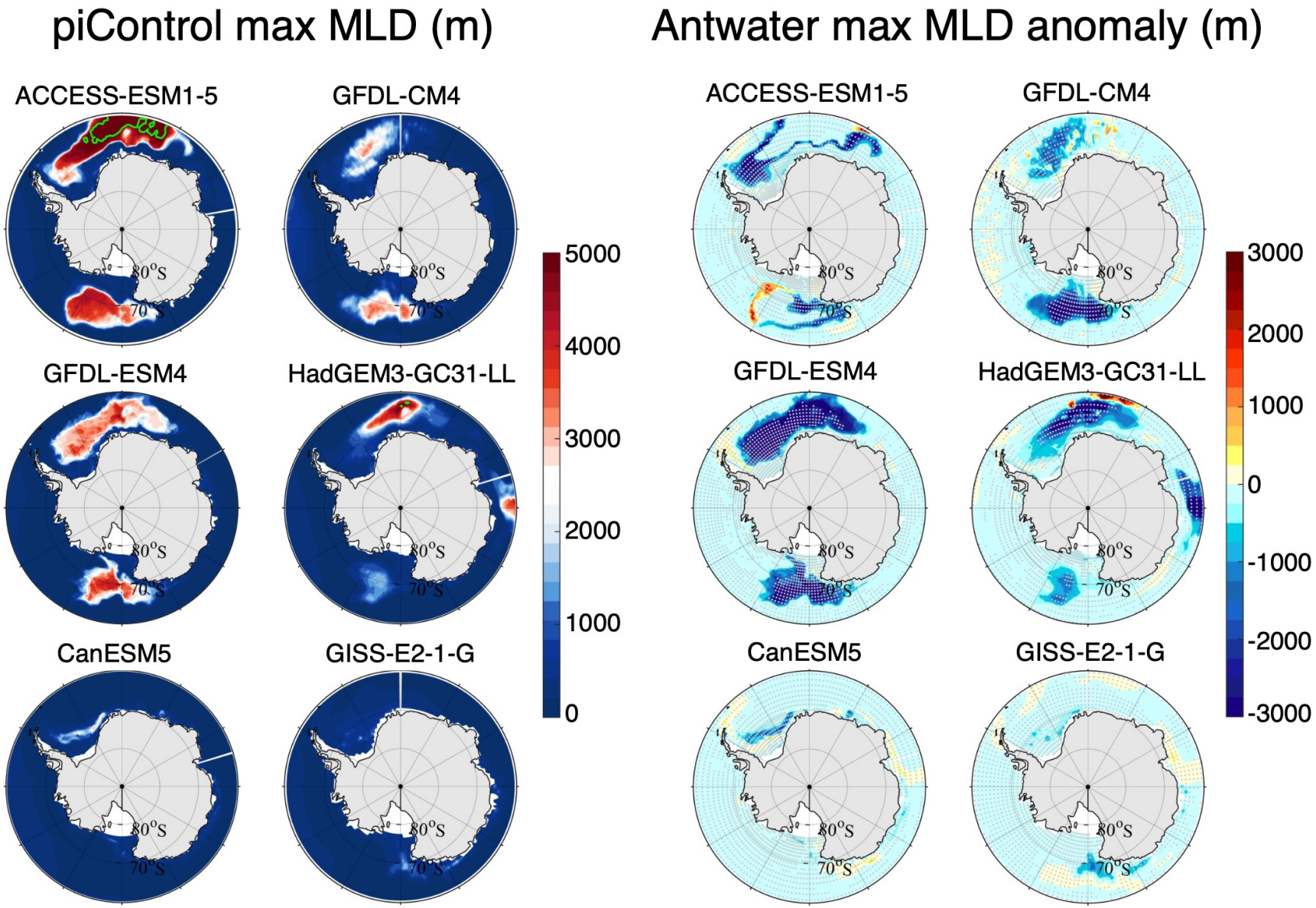
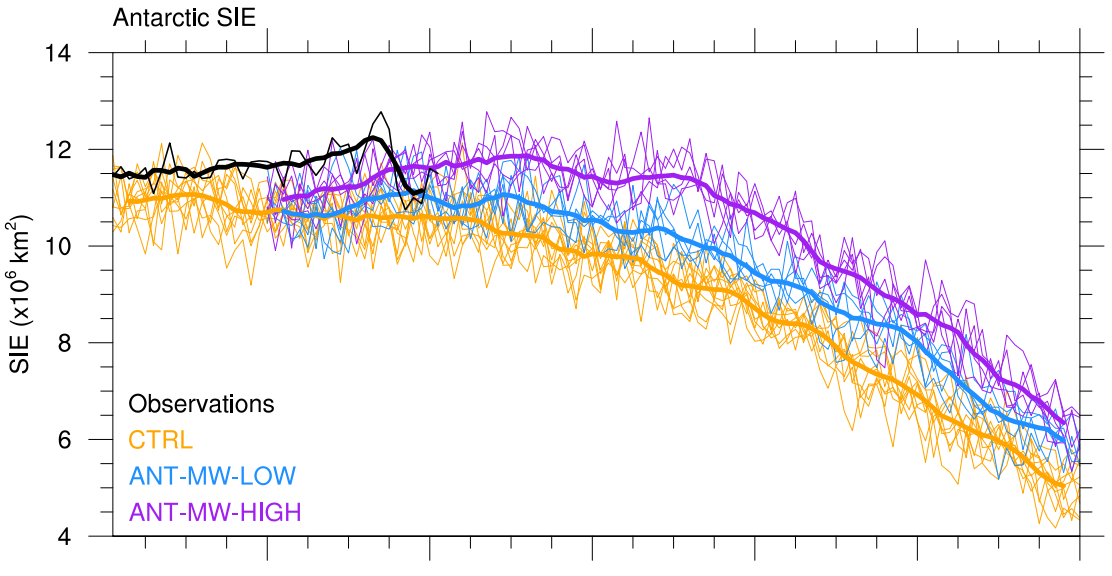




Figures from Jia-Jia Chen

SOFIA goals

- Encourage participation of a wide and diverse group of models
- Analysis papers: general climate response to freshwater forcing, effect on deep convection and bottom water formation, and circulation
- Detection and attribution of climate changes to freshwater forcing, such as for Antarctic sea ice
- Provide information on the relative importance of including ice-ocean interactions in future generations of coupled climate models



Purich and England 2023

SOFIA preprint

- Swart et al. 2023, *The Southern Ocean Freshwater release model experiments Initiative (SOFIA): Scientific objectives and experimental design*
- https://egusphere.copernicus.org/preprints/2023/egusphere-2023-198/