Seasonal impacts of Antarctic freshwater forcing on ITCZ based on SOFIA multi-model ensemble

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Motivation

Over 30% of global precipitation occurs in the Intertropical Convergence Zone (ITCZ), where variations in deep convection significantly influence global atmospheric circulation. However, CMIP6 coupled climate models exhibit substantial biases in ITCZ intensity and location trends compared to observations.

Recent studies suggest these biases may arise in part from the lack of representation of melting Antarctic ice sheets and shelves, which contribute to a warm SST bias in the Southern Ocean.

Research gaps

1. The seasonal responses of the ITCZ to Antarctic freshwater forcing remain unclear.
2. Previous studies based on single coupled climate models fail to reach a consensus on Antarctic freshwater forcing responses because of substantial inter-model spread.

SOFIA multi-model ensemble

The Southern Ocean Freshwater Input from Antarctica (SOFIA) Initiative aims to improve our understanding of the simulated response to Antarctic freshwater input.

The initiative was started by the CliC/CLIVAR/SCAR Southern Ocean Regional Panel, is endorsed as a CLIVAR task team, and is a registered CMIP7 community MIP.

More Information: https://sofiamip.github.io

Table 1 Tier1 simulations (Fixed 0.1 Sv freshwater forcing for 100 years) used in this study.

Model Name	Resolution (ocn/atm, lat × lon, °)	Variable		
		pr	SST	hfds
ACCESS-ESM1-5	1/1.875×1.25	√	√	√
AWI-ESM-1-REcoM	1/1.8	√	√	√
CanESM5	1/3	√	√	√
CESM2	1/0.9×1.25	√	√	
FOCI	0.5/1.9	√		√
GFDL-CM4	0.25/1	√	√	
GFDL-ESM4	0.50/1	√	√	
GISS-E2-1-G	1x1.25/2x2.5	√	√	
HadGEM3-GC3.1-LL	1/1	√	√	√

pr: precipitation flux hfds: surface downward heat flux in sea water

Seasonal responses of MME tropical rainfall and SST to freshwater forcing

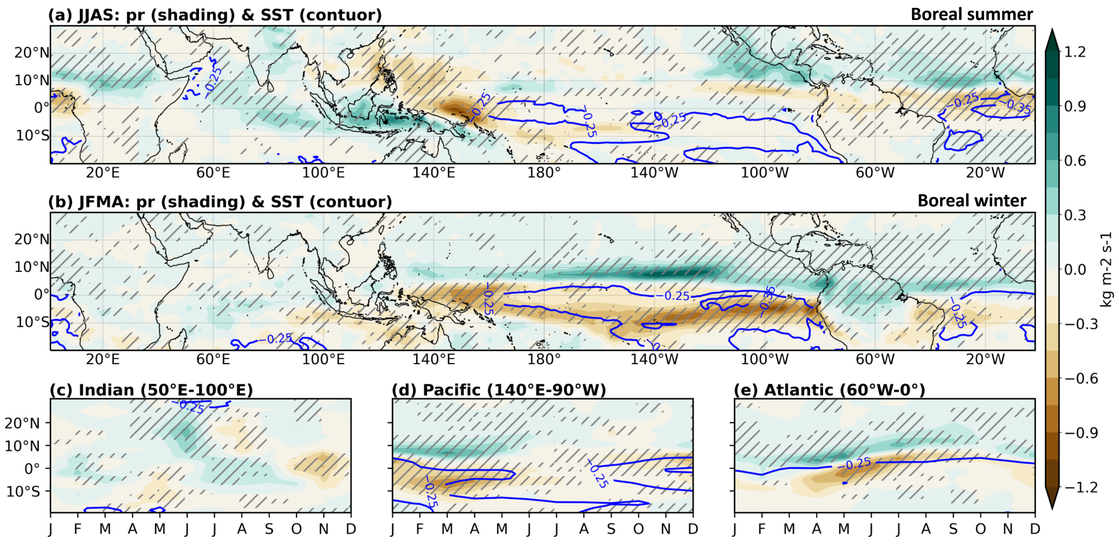

Fig. 1 (a and b) Seasonal responses of MME tropical rainfall (shading) and SST (contour) to Antarctic freshwater forcing. (c-e) Hovmöller plots of monthly responses along 20°S-30N° in the three tropical oceans.

Indian Ocean:
Increased rainfall along equatorial regions in boreal summer, indicative of an enhanced Indian summer monsoon.

Maritime continent:
East-west dipole pattern in precipitation changes.

Pacific:
Poleward migration over coaster regions in boreal summer, but across the tropics in boreal winter.
SST anomalies extend to the equator during boreal winter.

Atlantic:
Seasonal poleward migration of the ITCZ.
Uniform SST decreases across the Southern Hemisphere.

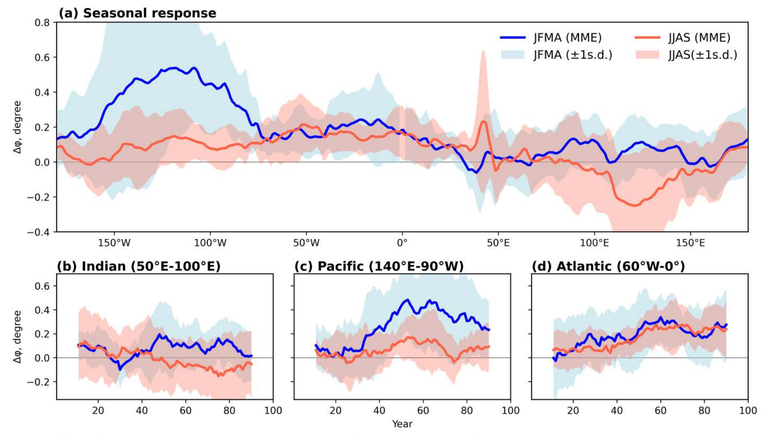

Fig. 2 Longitudinal responses of tropical rainfall centroid to freshwater forcing and the evolution in the three basins.

Indo-Pacific warm pool: Robust responses & southward migration of ITCZ in boreal summer.

Pacific: Robust responses & northward migration of ITCZ in boreal winter.

Atlantic: Steady responses & northward migration of ITCZ across seasons.

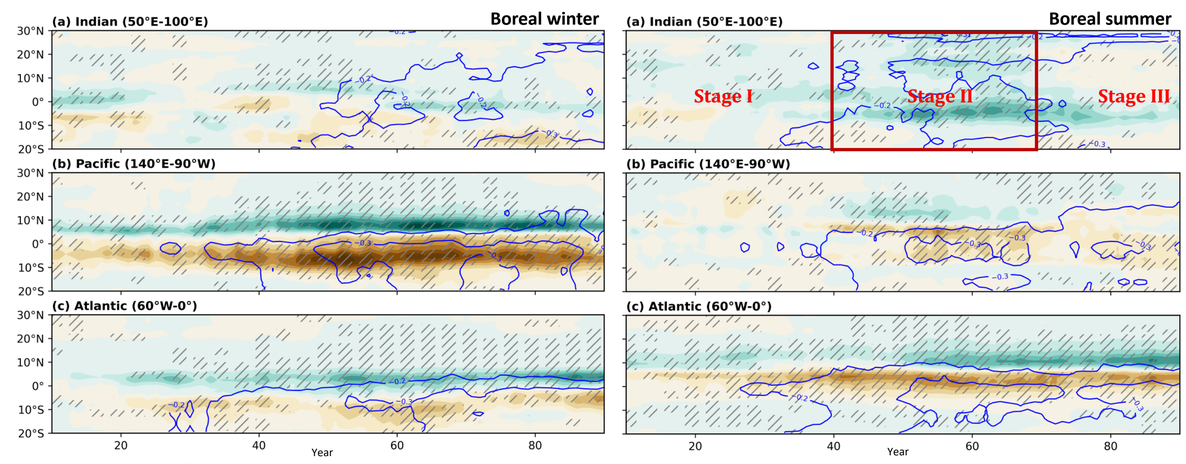

Fig. 3 Hovmöller plots of seasonal responses of MME rainfall and SST to freshwater forcing in the three basins.

Indian: No strong signal

Pacific: Quick responses in the first 20 years.

Atlantic: Northward migration (centered at 2°S)

Indian: Three stages

Pacific: Rainfall decrease after Year 40 associated with SST decrease.

Atlantic: Northward migration (centered at 8°N)

Heat flux theory and the role of SST

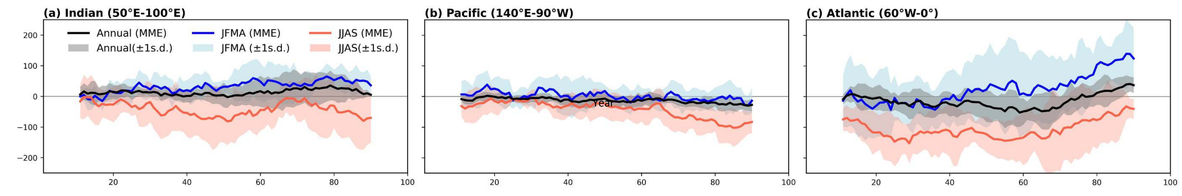

Fig. 4 Evolution of net surface heat flux to freshwater forcing in the three basins.

- **Seasonal variation of the net surface heat flux can not explain the seasonal responses of tropical rain belts migration (heat storage).**

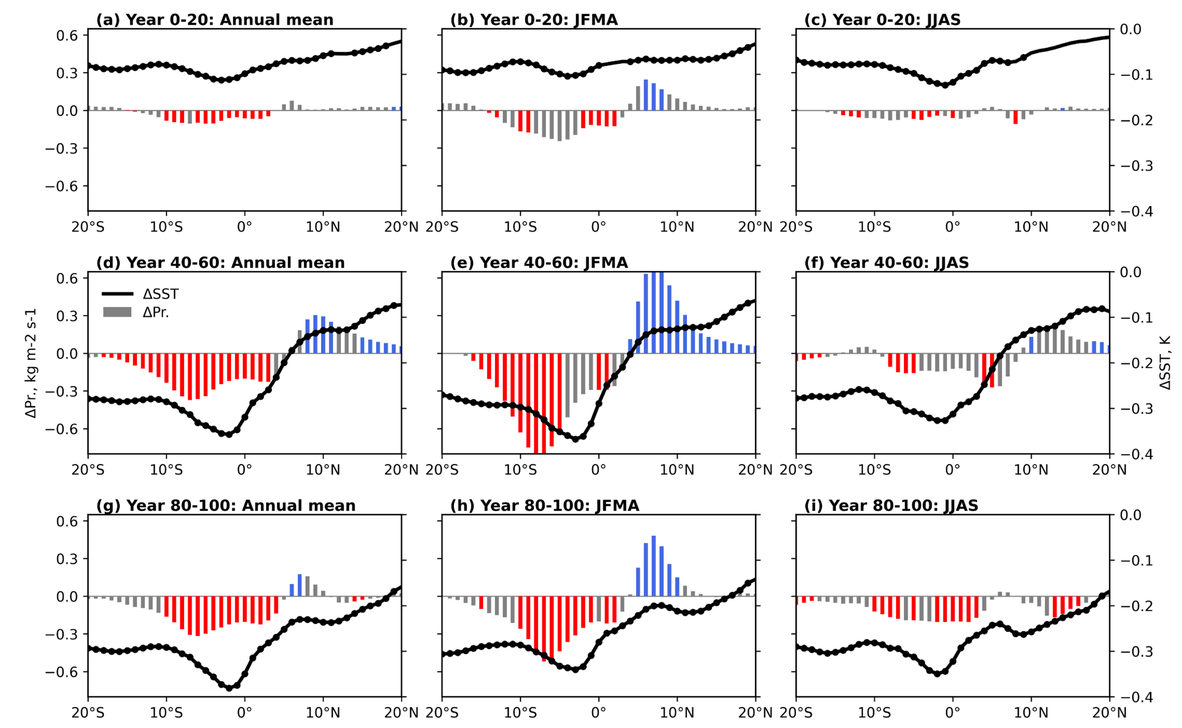

Fig. 5 Basin-wide evolution of SST and precipitation changes along 20°S-20°N in the Pacific

Year 0-20: Slight northward migration in boreal winter.

Year 40-60: Stronger responses with intensified meridional SST gradient.

Year 80-100: Rainfall decrease ~10°N due to enhanced SST cooling.

Summary

1. The ITCZ response to uniform and steady Antarctic freshwater forcing shows substantial seasonal variations and inter-basin differences.

2. Local SST variations could potentially explain the underlying mechanisms.

Acknowledgement

This work is supported by the National Natural Science Foundation of China (Grant No. 424B2036).

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