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# Intensification of the Antarctic slope current due to freshwater forcing in a warmer climate

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## Research Questions

- How does the Antarctic slope current (ASC) respond to the global warming?
- How does the freshening in the future climate affect changes in the ASC?
- What factor plays a major role in the freshening?

## Ultra-high-resolution climate simulation

- Fully-coupled Community Earth System Model (CESM) version 1.2.2.
- Vertical resolution: 62 levels / Horizontal resolution: 10 km and 25 km resolutions for the atmosphere and ocean components, respectively.
- Present-day (PD) control simulation (367 ppm) with two ideal simulations with 2×CO2 (734 ppm) and 4×CO2 (1468 ppm).

## Intensification of the ASC

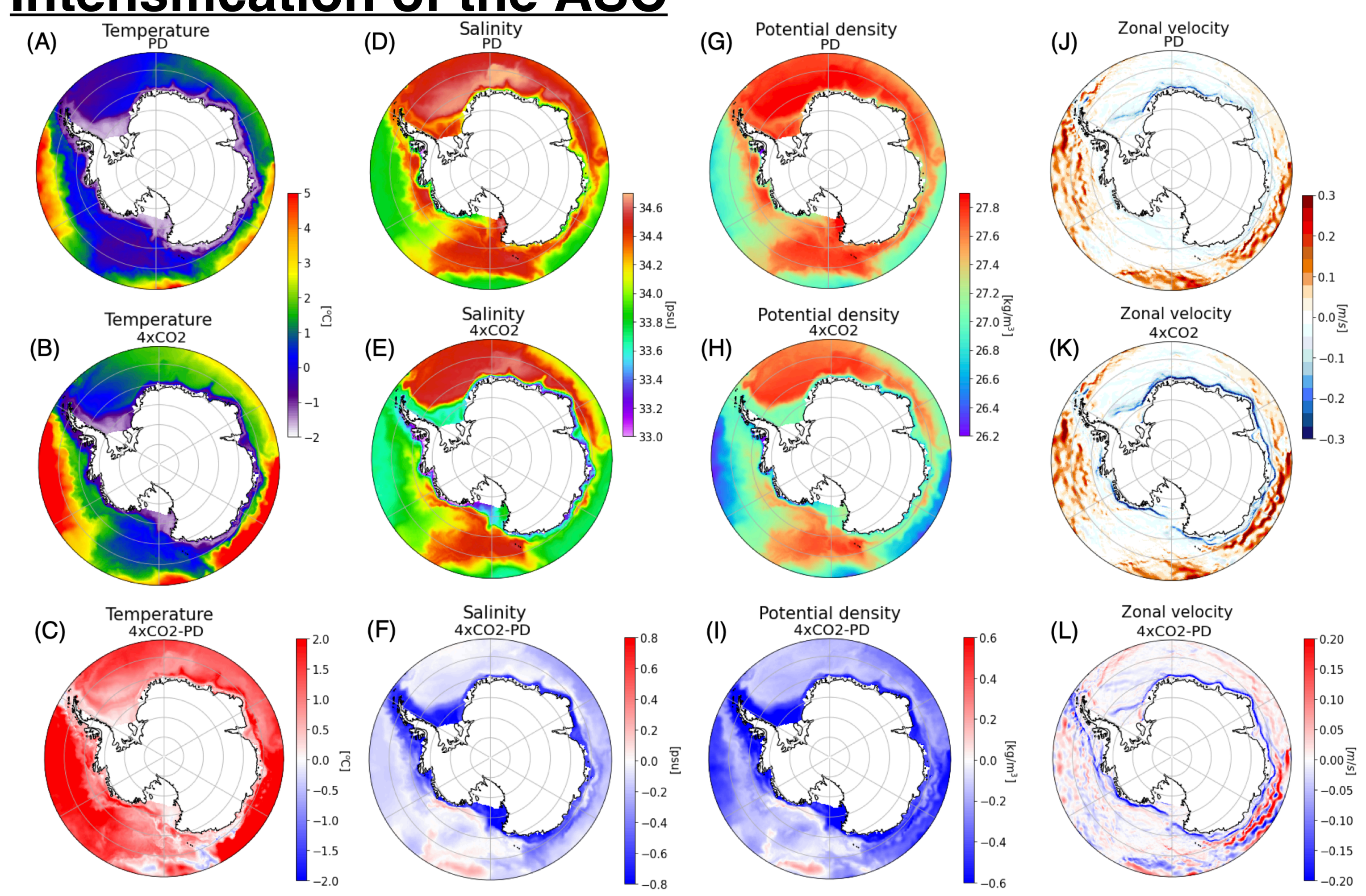

**Fig. 1** The spatial distributions of (A, B) temperature, (D, E) salinity, (G, H) potential density, and (J, K) zonal velocity of the PD and 4×$CO_2$ simulations from the CESM. The differences of each simulation are shown in panels (C, F, I, and L), respectively. The temperature, salinity, potential density, and zonal velocity of PD and 4×$CO_2$ conditions were averaged from the surface to 200 m depth.

## Salinity contribution

Linear equation of seawater: $\rho - \rho_0 = a(T - T_0) + b(S - S_0) + kp$

$$\underbrace{\frac{\partial}{\partial y}\,\rho_{4xCO2} - \rho_{PD}}_{\Delta\rho} = \underbrace{\frac{\partial}{\partial y}\,a(T_{4xCO2} - T_{PD})}_{\Delta\rho_T} + \underbrace{\frac{\partial}{\partial y}\,b(S_{4xCO2} - S_{PD})}_{\Delta\rho_S}$$

(a= −0.15 kg/m °C, b= 0.78kg/m³ psu)

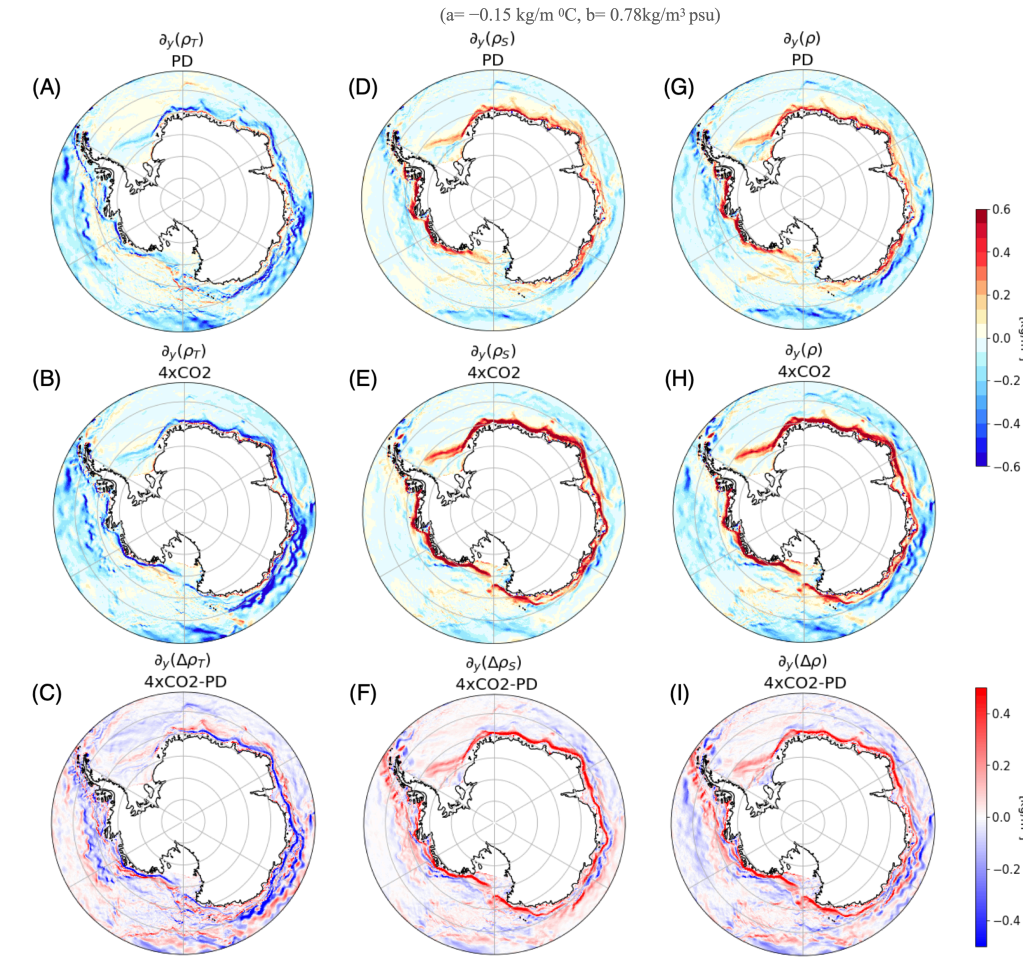

**Fig. 2** Contributions of (A, B) temperature and (D, E) salinity to (G, H) meridional gradient of potential density from PD and 4×$CO_2$ conditions. The differences of each simulation are shown in panels (C, F, and I), respectively. Thermal and haline contributions to the density were obtained from a linear equation of state of seawater. The pressure effect in the equation of state was ignored, and all parameters were averaged from the surface to 200 m depth.

## Geostrophic balance

- Freshening → Increase of SSH gradient and potential density change → Intensification of ASC by geostrophic balance
- Deepening and strengthening of ASC.

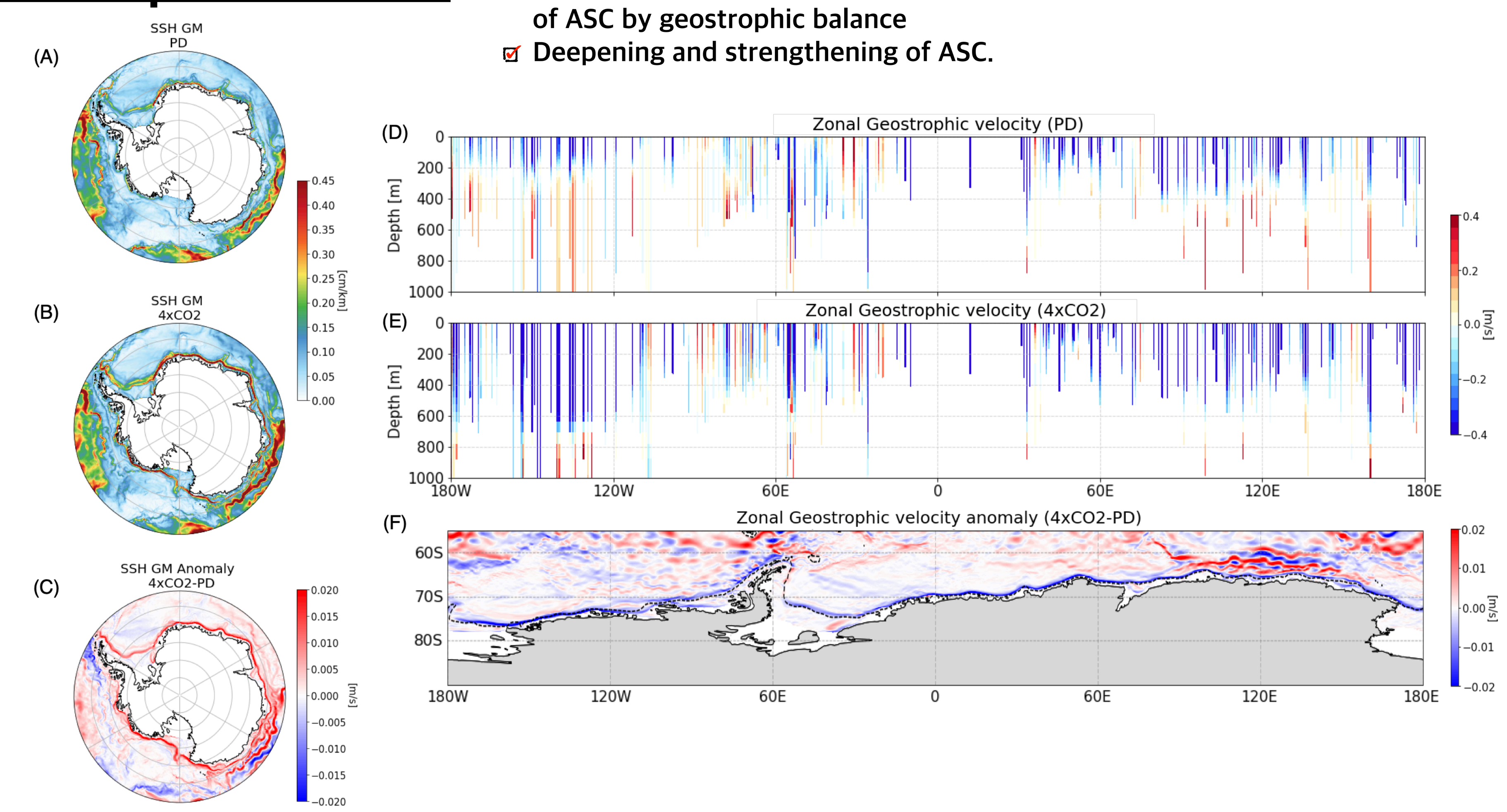

**Fig. 3** The spatial distributions of gradient magnitude (GM) of SSH of (A) PD, (B) 4×$CO_2$, and the (C) differences between two conditions. Vertical structure of the zonal geostrophic velocity at 1000 m isobath from (D) PD and (E) 4×$CO_2$ conditions. Difference of zonal geostrophic velocity from surface to 200 m depth of each simulation is shown in panel (F). Dotted line in panel (F) indicates the 1000 m isobath. The geostrophic velocity was calculated with the potential density and SSH of the CESM.

## Freshwater forcing

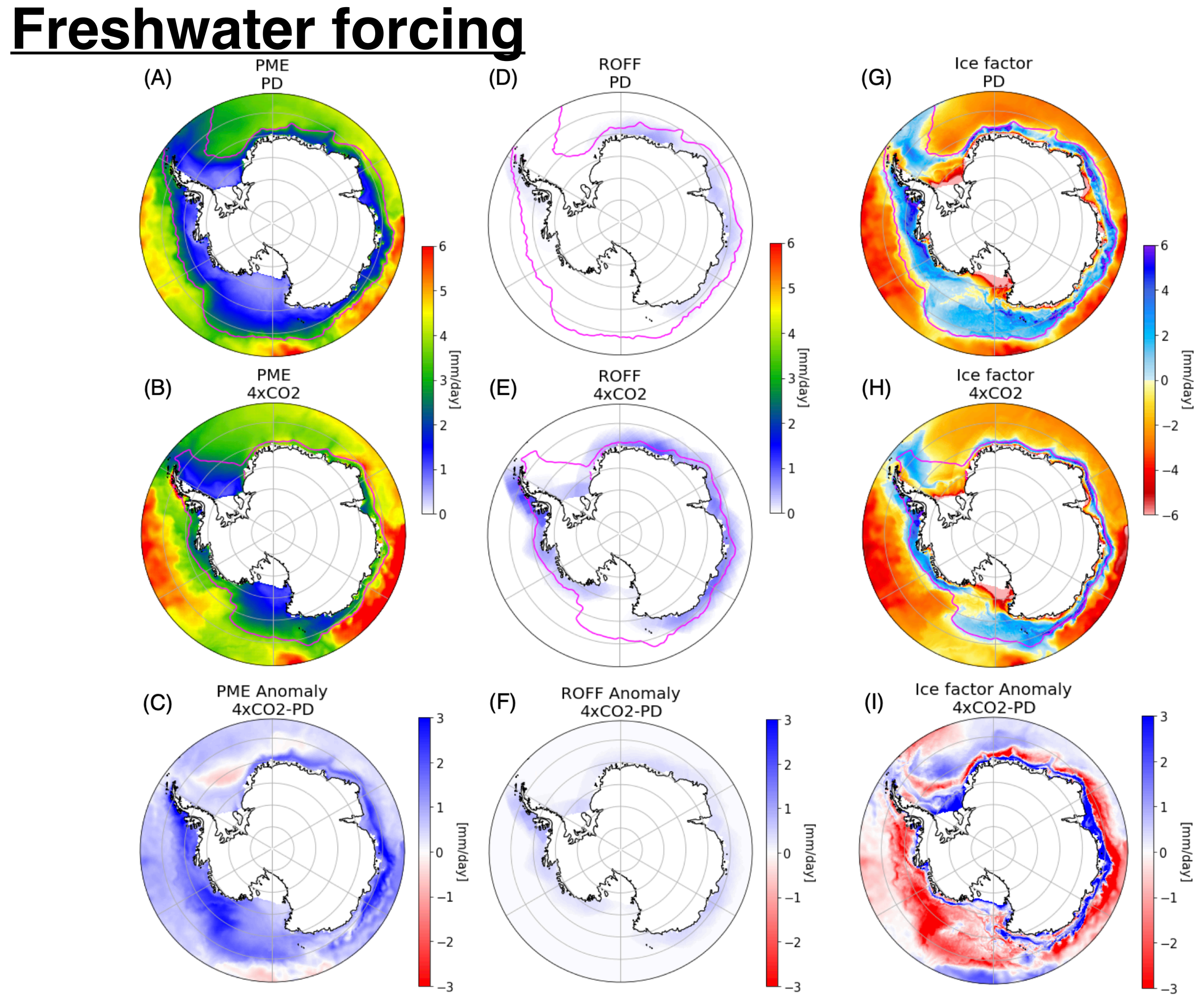

**Fig. 4** The spatial distributions of (A, B) precipitation minus evaporation (PME), (D, E) river runoff (ROFF), and (G, H) ice related factors (meltwater from sea ice plus ice runoff, ICE factor) from the Antarctica of PD and 4×$CO_2$ simulations from CESM. The differences of each simulation are shown in (C, F, and I), respectively. The ICE factor was calculated by subtracting the runoff and PME from freshwater flux. The contour lines indicate the 15 % ice concentration of each simulation.

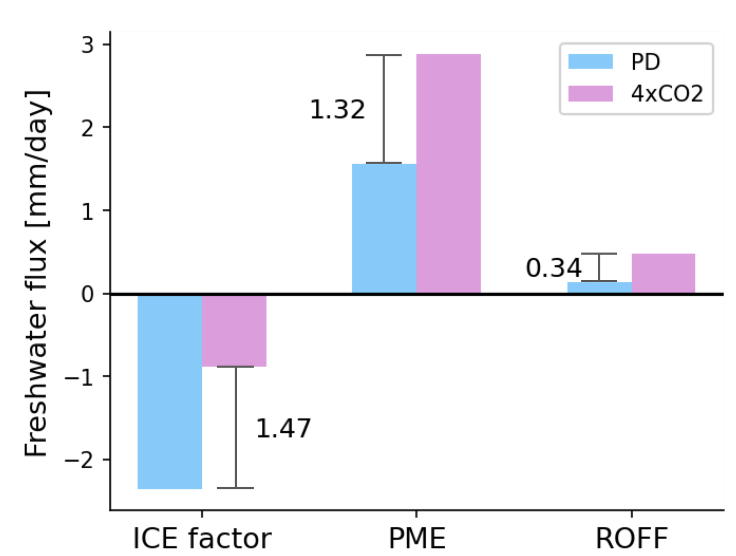


**Fig. 5** The changes of ICE factor, PME and ICE factor in the future simulation. Blue and pink colored bars indicate the PD and 4×$CO_2$ conditions, respectively. The values were calculated by averaging the values in the area one degree latitude away from the coastline.

- **Increase in all the freshwater factors (ICE factor, PME, and ROFF) in the future simulation.**
- **The ASC velocity of PD and 4×$CO_2$ simulations were -0.04 m/s and -0.08 m/s, respectively.**
- **The ASC was strengthened as the freshwater flux increased.**
- **The change in the ICE factor (1.47 mm/day) was greater than the changes in PME (1.32 mm/day) and ROFF (0.34 mm/day).**

## Wind forcing

- **The change of easterlies near the Antarctica was not significant.**

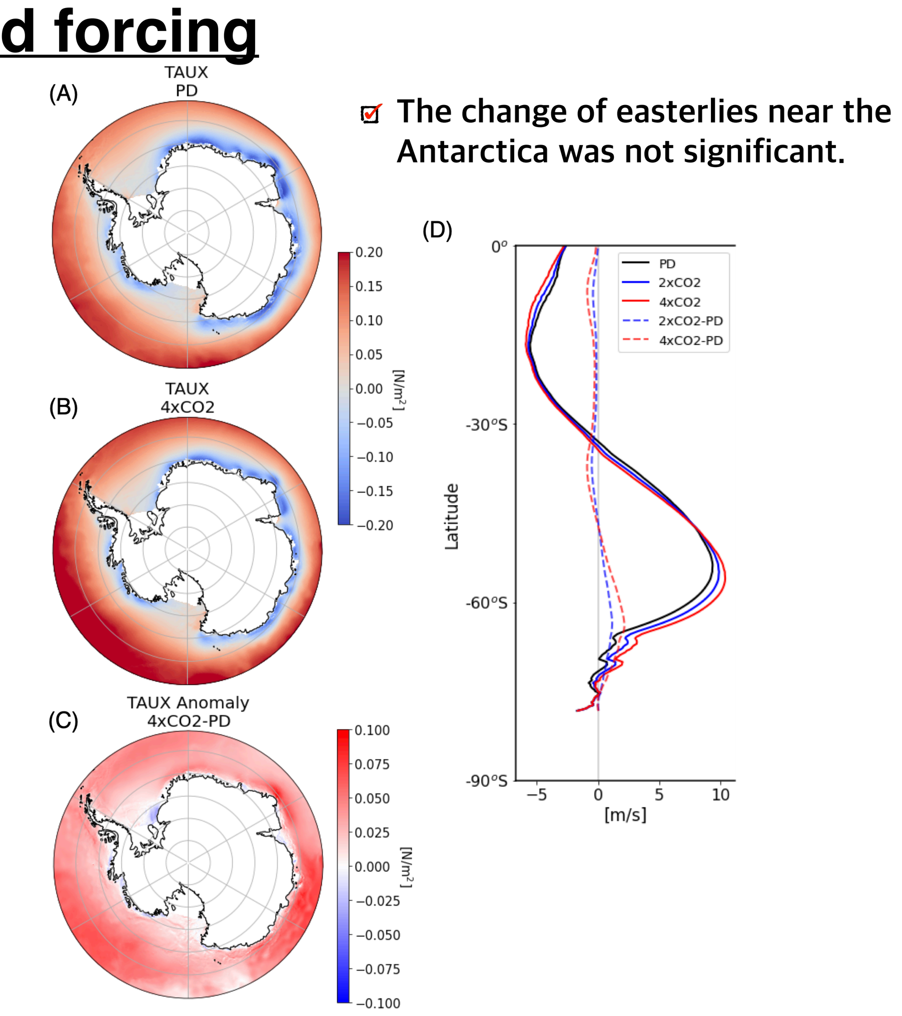

**Fig. 6** The spatial distributions of zonal wind stress (TAUX) of (A) PD and (B) 4×$CO_2$ simulations. The difference of each simulation is shown in (C). (D) The zonal mean of the zonal wind over the ocean region.

## Conclusions

- In the Antarctic ocean, there was a decrease of salinity and intensification of the ASC in the 4×$CO_2$ simulation compared to the PD simulation (Fig. 1).
- The freshening in a warmer climate can increase the SSH gradient and strengthen the ASC through geostrophic balance (Fig. 2 and Fig. 3).
- The freshwater from ice had more impact on the change of the ASC than the precipitation minus evaporation and runoff (Fig. 5).
- It is known that poleward wind shift in the future can reduce the Ekman pumping near the Antarctica, which can induce weakening of the ASC as the gradient of isopycnal decreases, but there was no relationship between wind and ASC changes in the CESM (Fig. 6).

### References


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