Deep winter mixed layer anchored by the meandering Antarctic Circumpolar Current: Cross-basin variations

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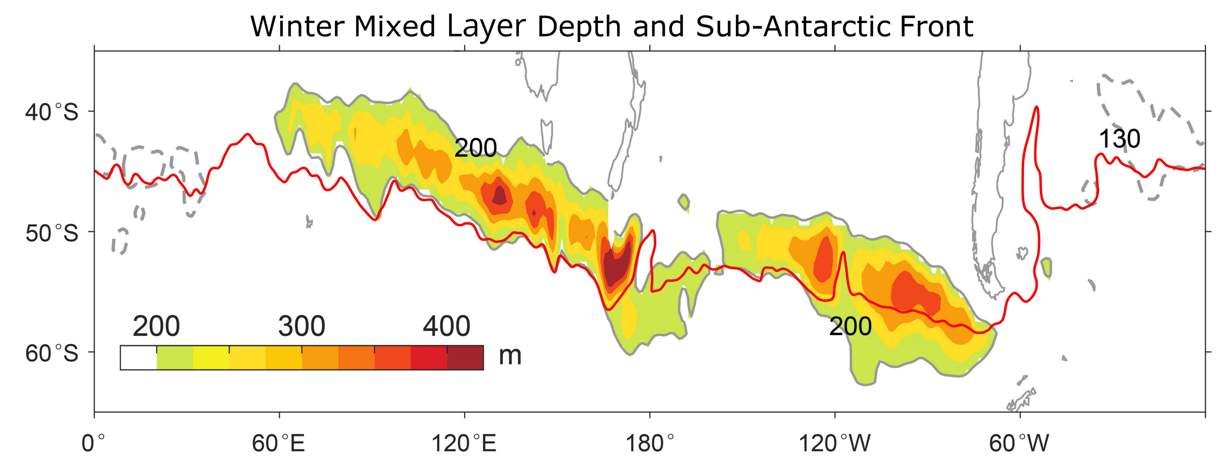
1 Motivation: What drives cross-basin variations in winter mixed layer depth in the Southern Ocean ?

- Climate models simulate a **overly broad distribution in winter mixed layer depth (MLD)** in the Southern Ocean[1].

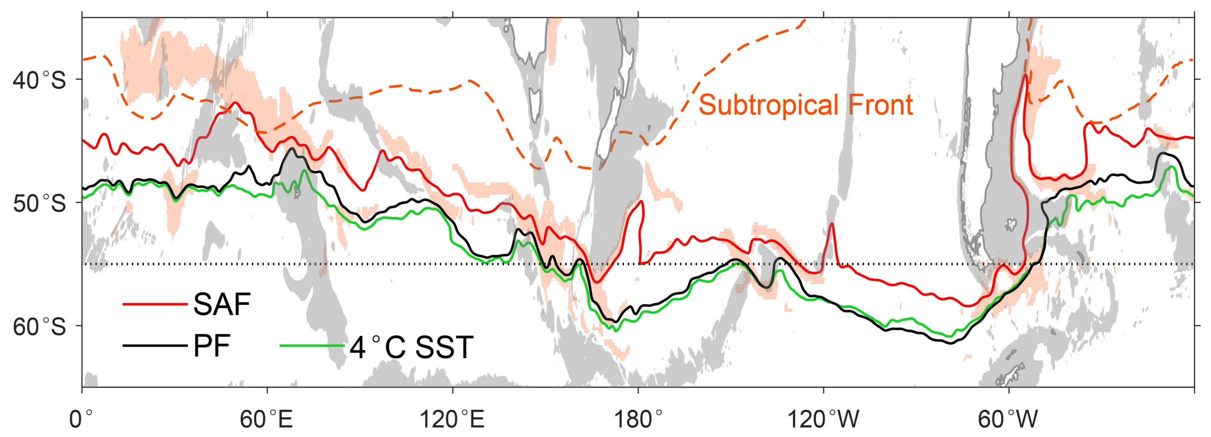


- In observations, **cross-basin variations** are pronounced:

1) Larger MLD in the Indo-Pacific (>300 m) than Atlantic (<150 m) sector.

2) Deep mixed layers in the Indian sector is bounded by the Subantarctic Front (SAF), compared to the broad distribution southeast Pacific.

2 Hypothesis: Zonal variations in ACC differentiate ocean heat loss and background stratification among basins



Zonal variations in ACC's latitudinal position and frontal intensity. Sub-Antarctic Front (SAF, -0.01 dyn m), Polar Fronts (PF, -0.42 dyn m); Large horizontal gradients in dynamic height (> 0.3 dyn m/100 km) are shaded in orange

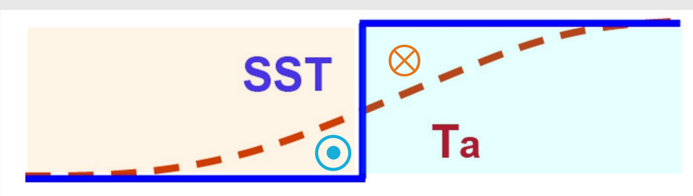
2.1 Meandering ACC (fronts) paths

southward / northward shifts from Indian to Pacific / Atlantic
↓
Warm / cold advection
↓
Warmer Pacific / colder Atlantic sectors
↓
Patterns of air-sea temperature difference (ΔT = SST - Ta) and ocean heat loss ?

equatorward (~ 45°S) / poleward (~56°S) position in Indian and Atlantic / Pacific
↓ Eddies from subtropical gyres & latitudinal solar radiation
strong / weak background stratification

2.2 Varying frontal intensity

- Stronger ACC fronts are found in the Indian and Atlantic sectors
- Oceanic fronts could amplify the air-sea heat exchange rate



[2]Adapted from *Xie 2023*

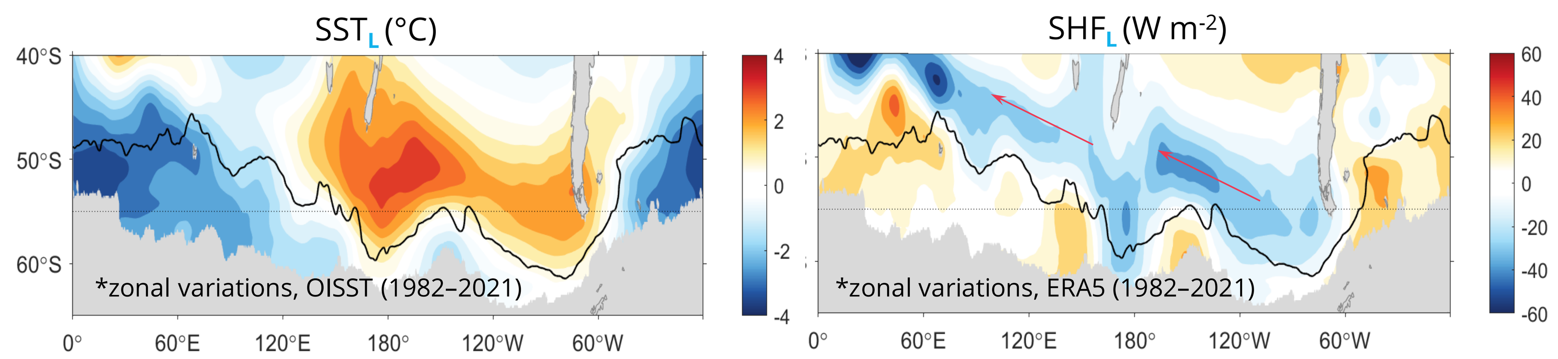
3 Surface ocean heat loss patterns at two scales

$$\mathrm{SST(SHF)} \xrightarrow{\text{spatial mean filter}} \mathrm{SST_L(SHF_L)} + \mathrm{SST_F(SHF_F)}$$

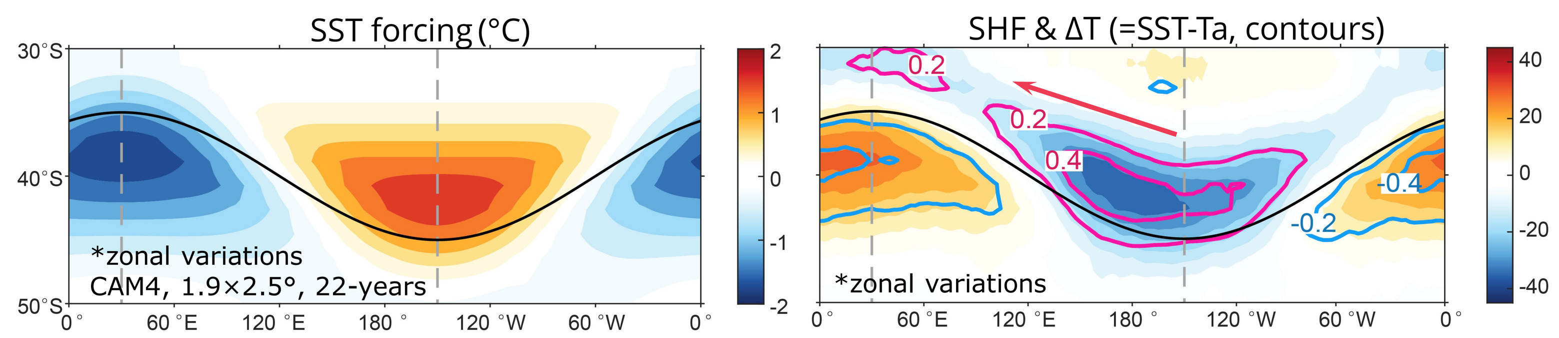
Large scale — Frontal scale

3.1 Large-scale SHF from observation

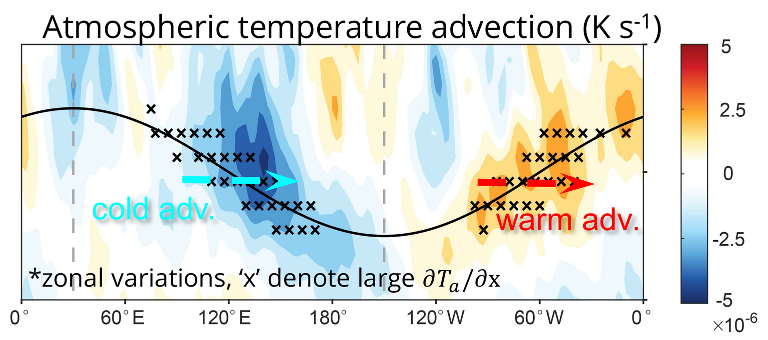
- Broad ocean heat loss (gain) in the Pacific (Atlantic) basin
- Peak heat loss **shifts westwards** along ACC from the peak SST



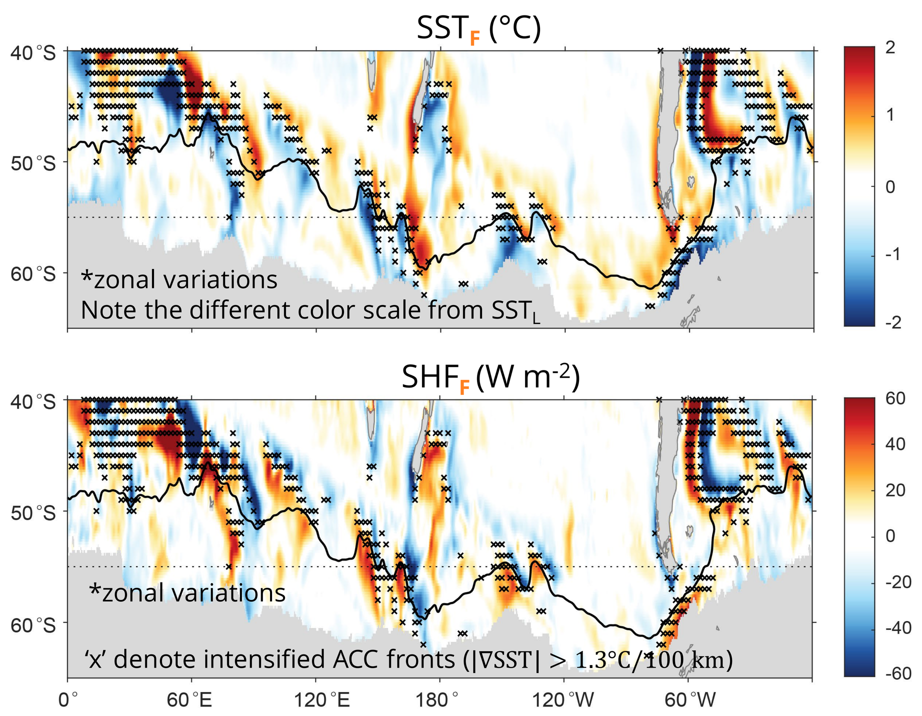
3.2 Large-scale SHF from AGCM simulation

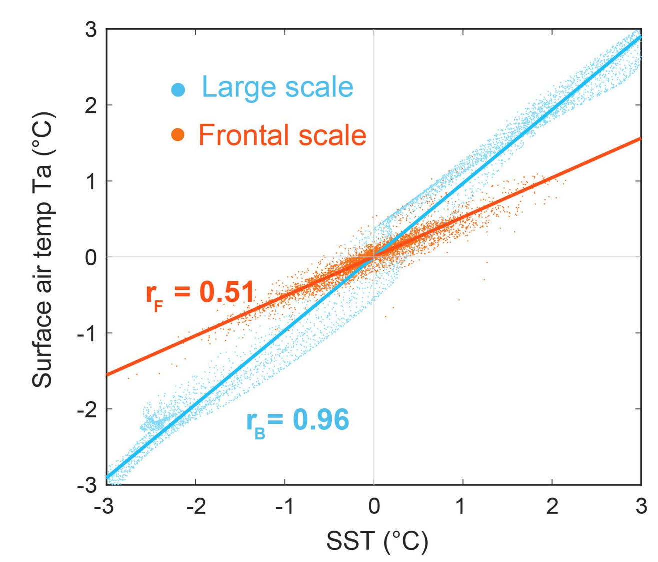


- **Asymmetric** SHF pattern emerges from a symmetric SST forcing
- **Heat advection by westerlies** contribute to the westward shift pattern and large ocean heat loss in southeast Indian sector



3.3 Frontal-scale pattern





SHF ~ ΔT (= SST – Ta)

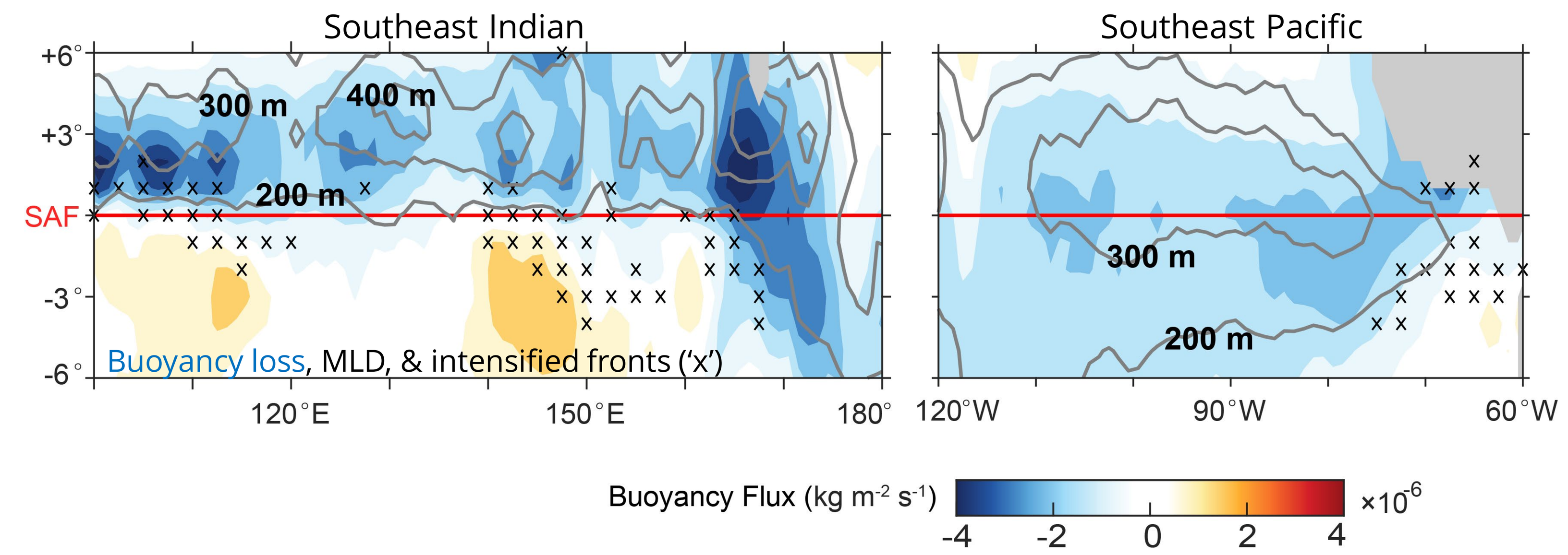
For a **+1 °C** SST anomaly of

Large-scale
~ + 0.96°C Ta ~ **+ 0.04 °C ΔT**

Frontal-scale
~ + 0.51°C Ta ~ **+ 0.49 °C ΔT**

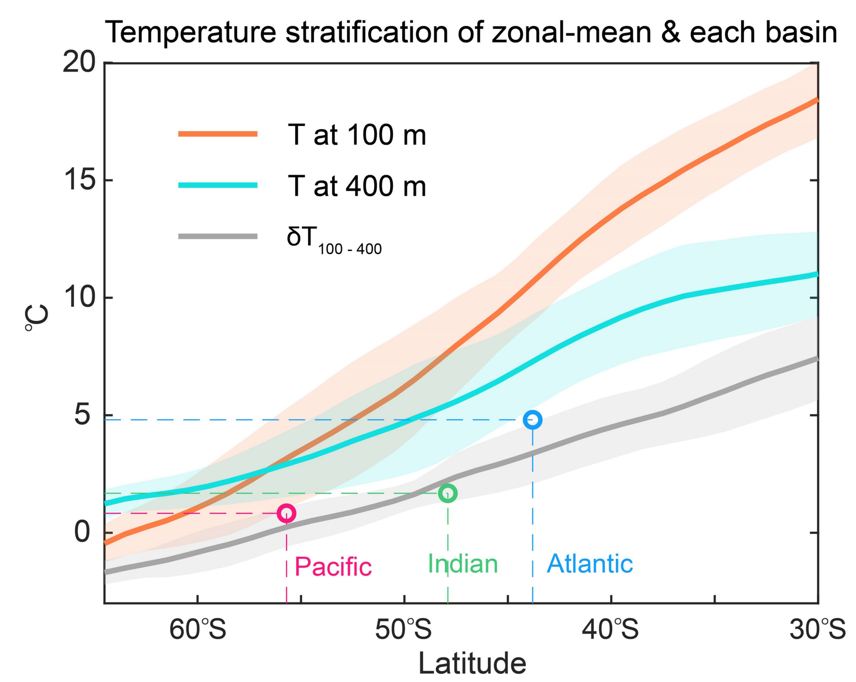
- Intense ocean heat loss (gain) on the warm (cold) flank of fronts
- Vanishingly small in southeast Pacific.
- SST_F variations are **more efficiently** (**~12 times larger** than SST_L) to induce surface heat flux

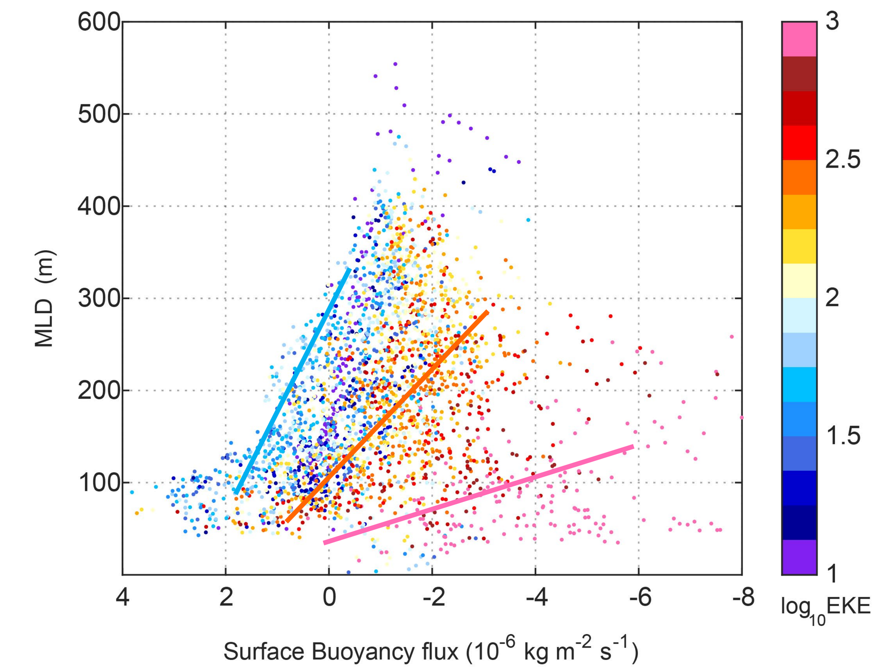
4 Deep MLDs driven by Ocean heat loss: Indian vs. Pacific



- **Large-scale** (~25 W m-2) ocean heat loss superimposed by **frontal-scale (40-50 W m-2)** heat loss
- Dominated by large-scale.

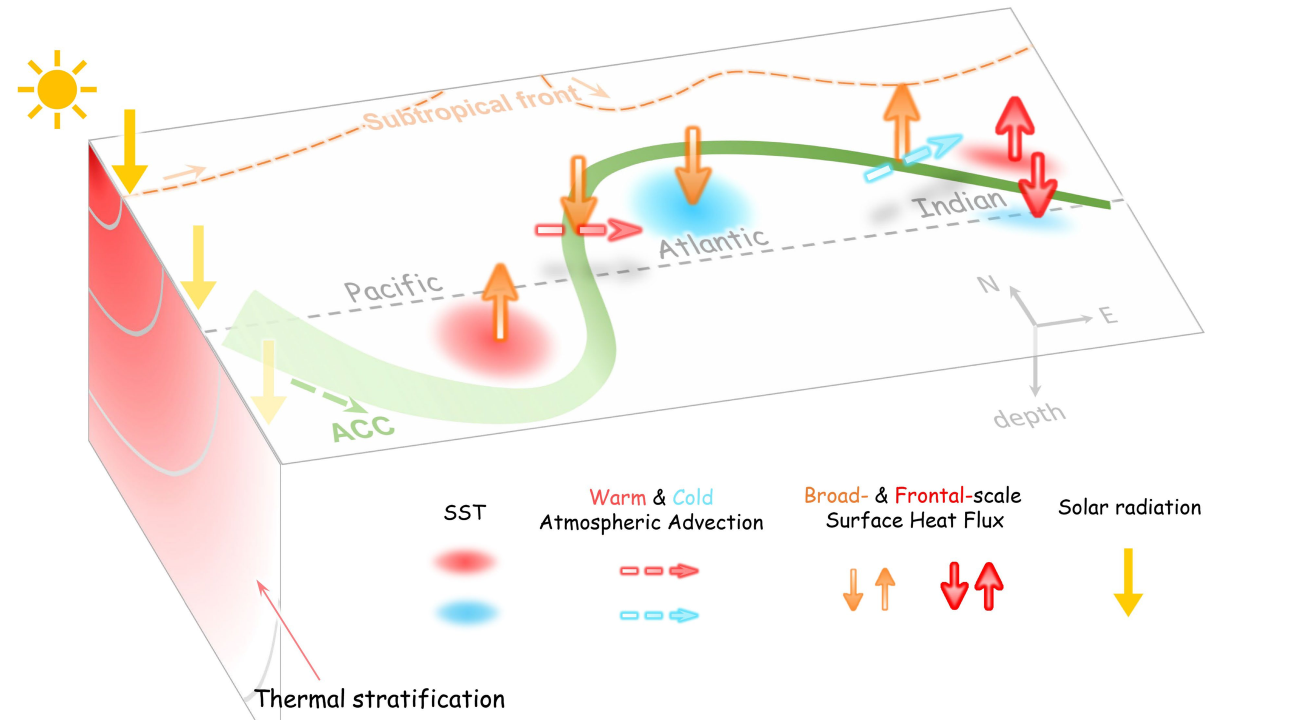
5 MLDs modulated by background stratification: Solar radiation & Mesoscale eddies





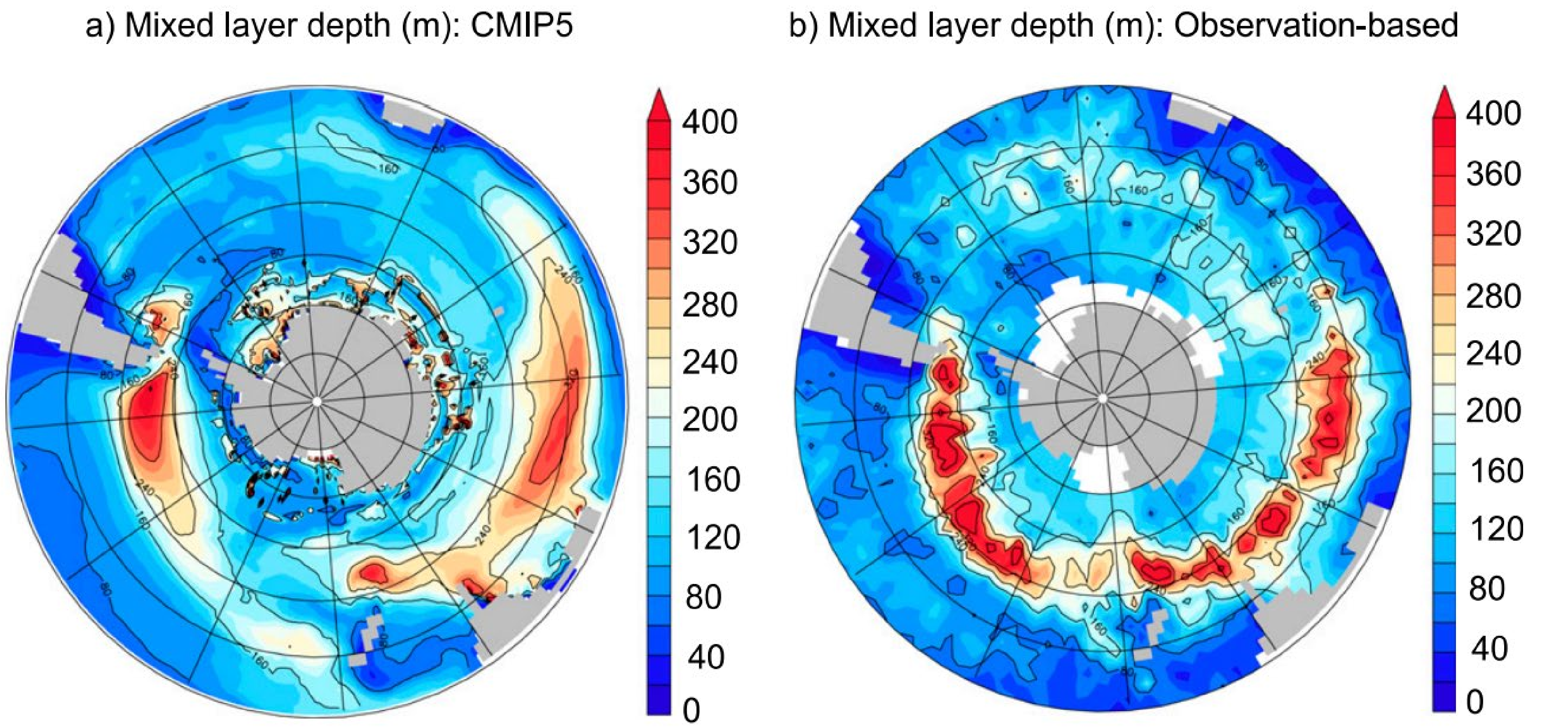
- Poleward decrease of temperature stratification
- Higher eddy kinetic energy (EKE), shallower MLD

6 Conclusion



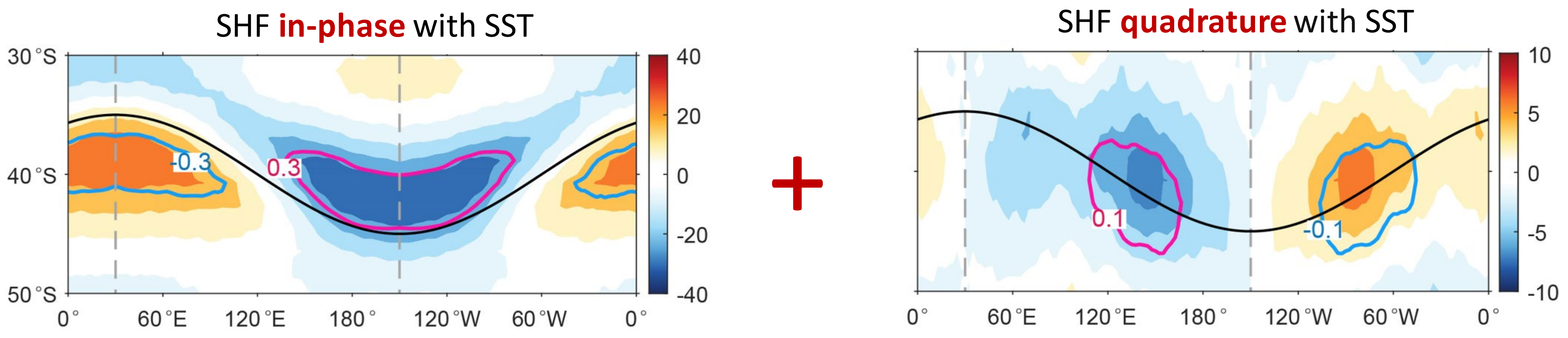
More details at:
Song, Z., S. Xie, L. Xu, X. Zheng, X. Lin, and Y. Geng, 2024: Deep winter mixed layer anchored by the meandering Antarctic Circumpolar Current: Cross-basin variations. *J. Climate*, https://doi.org/10.1175/JCLI-D-23-0174.1.

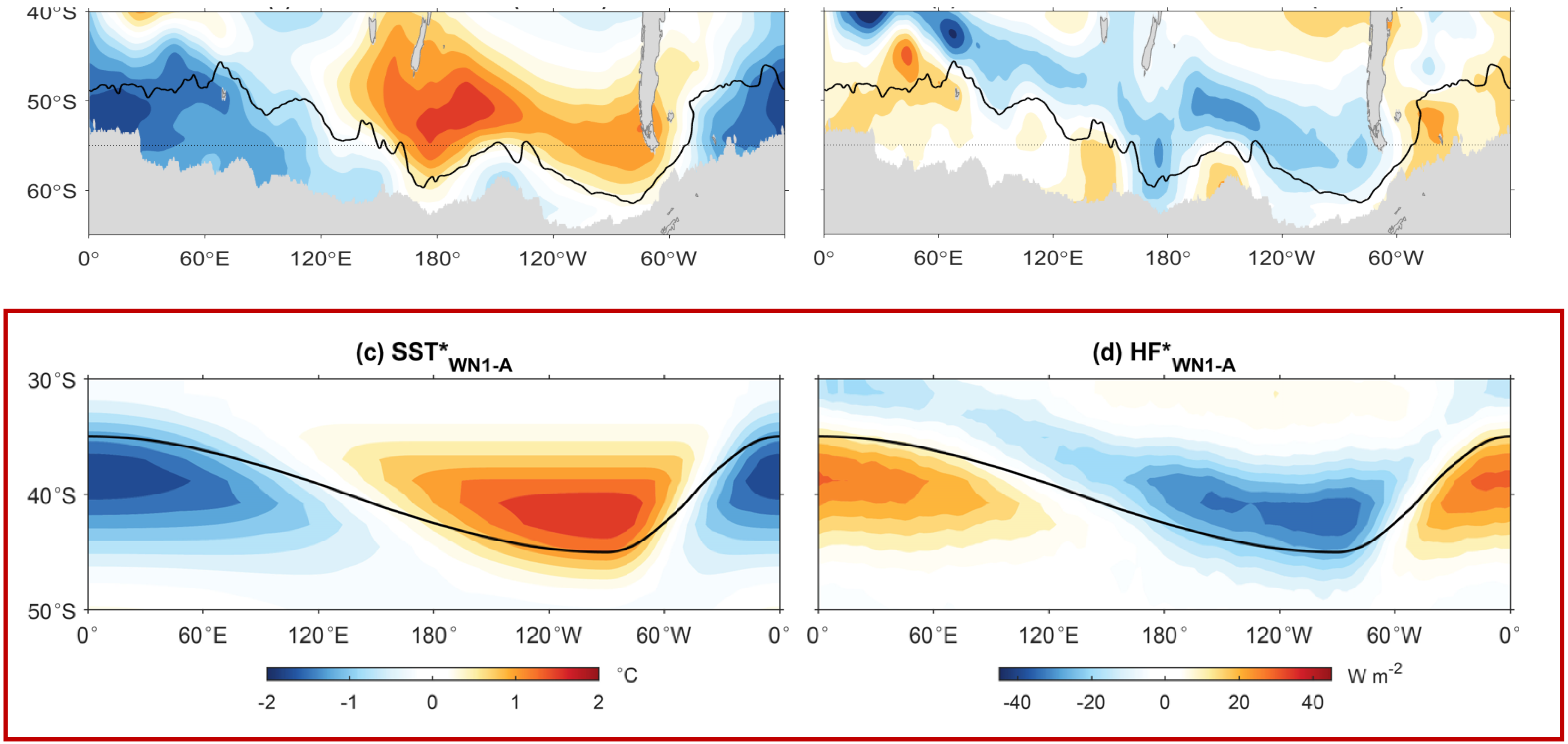
- Overly broad distribution of the deep winter mixed layers in climate models



Frölicher et al. (2015)

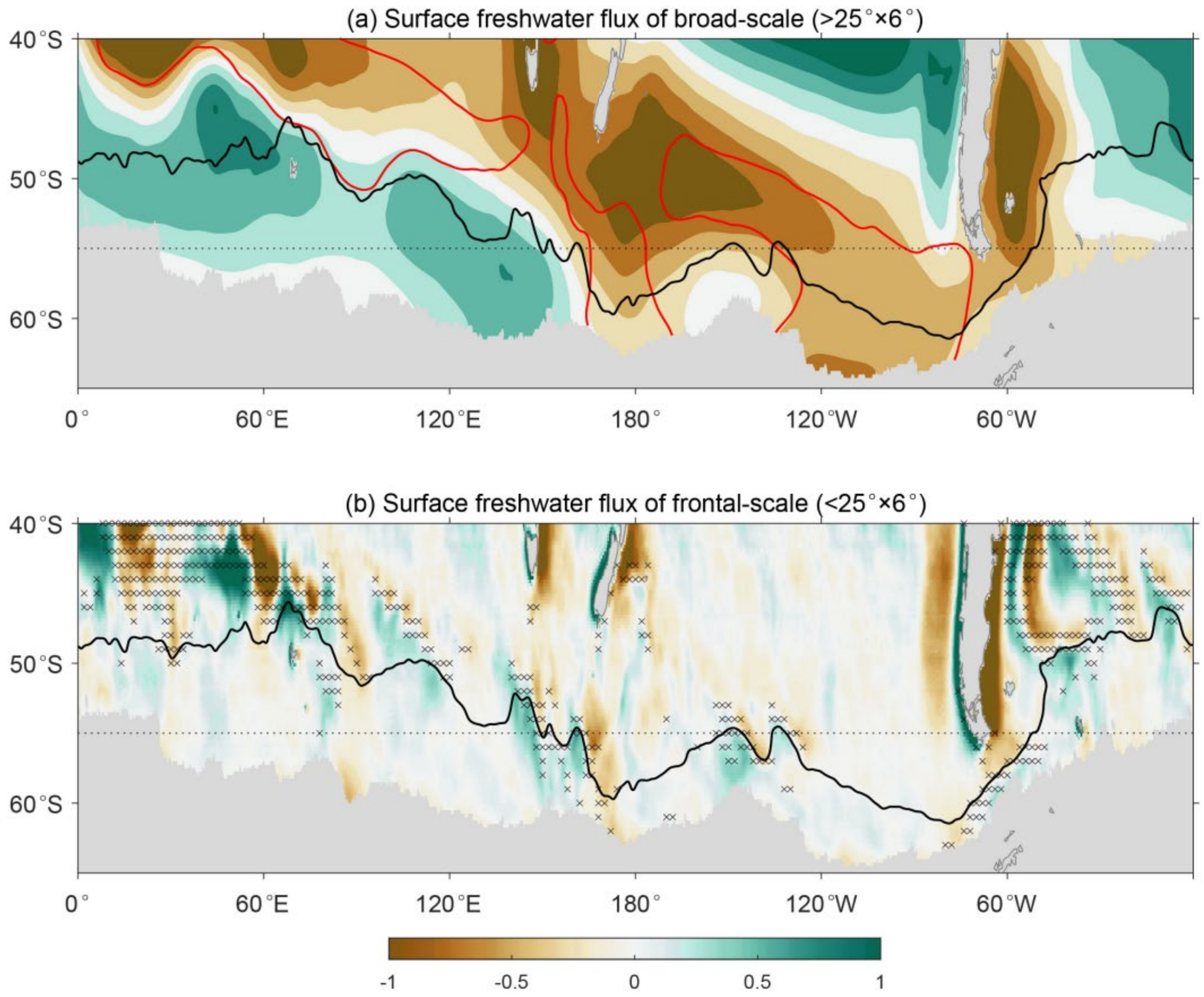
- The SHF pattern is further decomposed to an **in-phase** and a quadrature pattern relative to the SST.

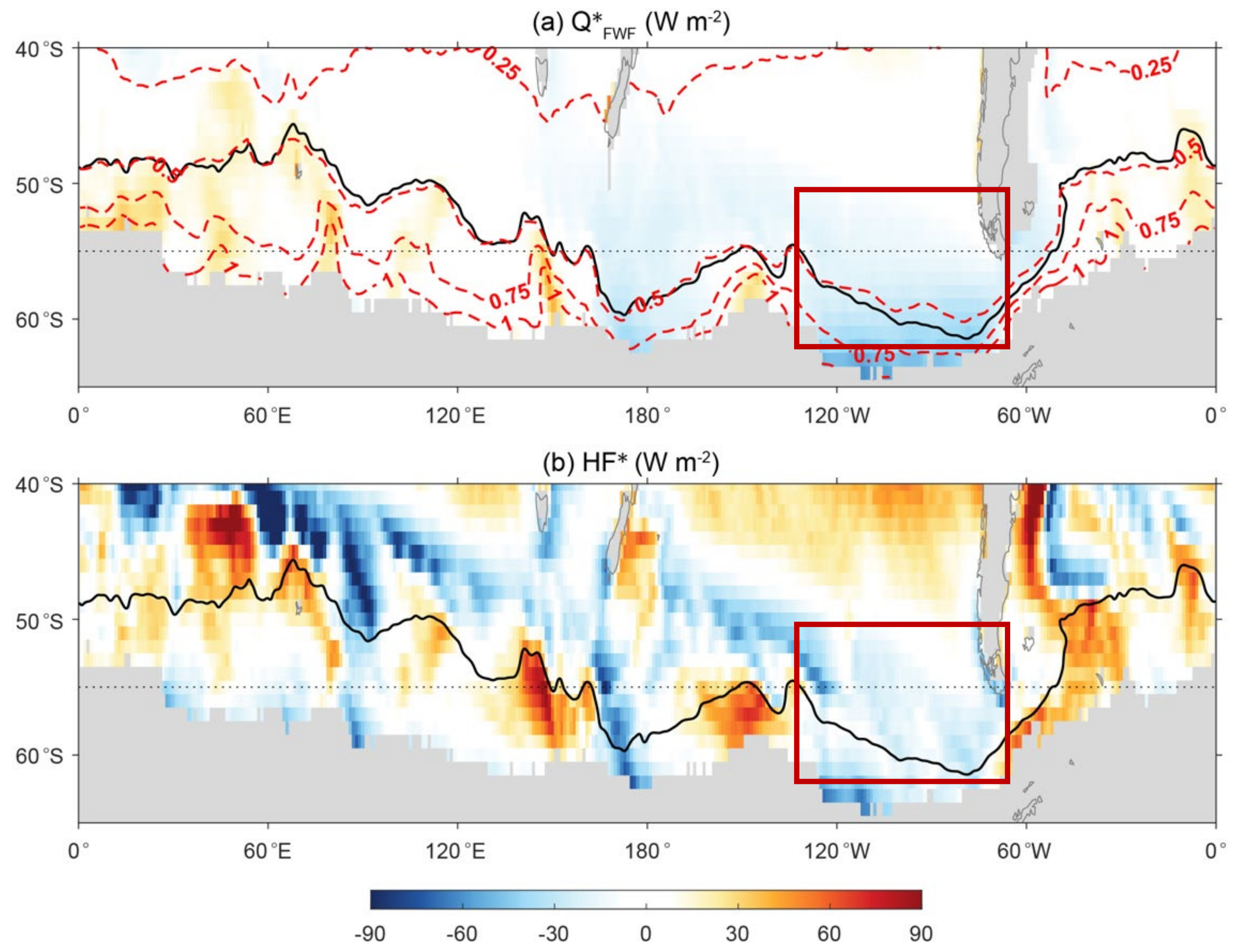




- A “more realistic” Aqua-planet SST forcing

- The freshwater flux (P-E) pattern generally follows the SST due to the dominance of the evaporation effects.





heat-equivalent freshwater flux (W m-2)

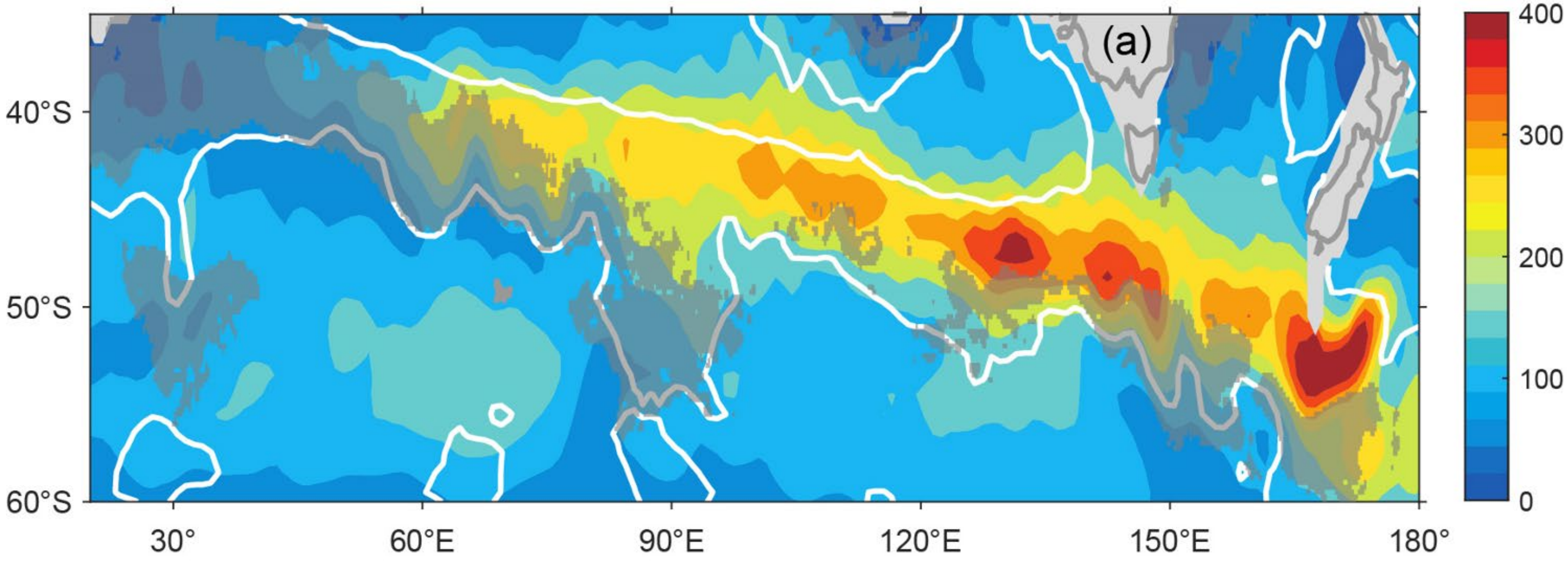
$$Q_{FWF} = \rho_0 c_p S \cdot \frac{\beta}{\alpha} \cdot FWF$$

α: thermal expansion coefficient

β: haline contraction coefficient

- **β/α (red dashed lines)** is a measure of relative importance of heat flux and freshwater flux effects on buoyancy flux.
- Low SST can amplify the effects of freshwater flux on buoyancy flux.
- In **southeast Pacific**, freshwater flux plays a comparable role compared to heat flux

- Eddy re-stratification in the southwest Indian Ocean



MLD (color), surface heart loss (white contour), and **EKE>300 cm^2s^{-2} (grey shaded)**