# Absorption of Ocean Heat Along and Across Isopycnals in HadCM3

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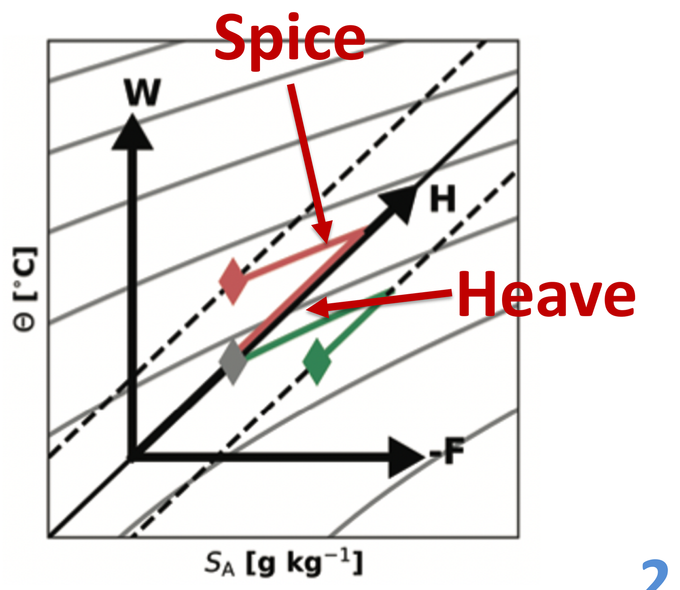
## Comparing two decompositions of temperature anomalies in T-S space reveals:

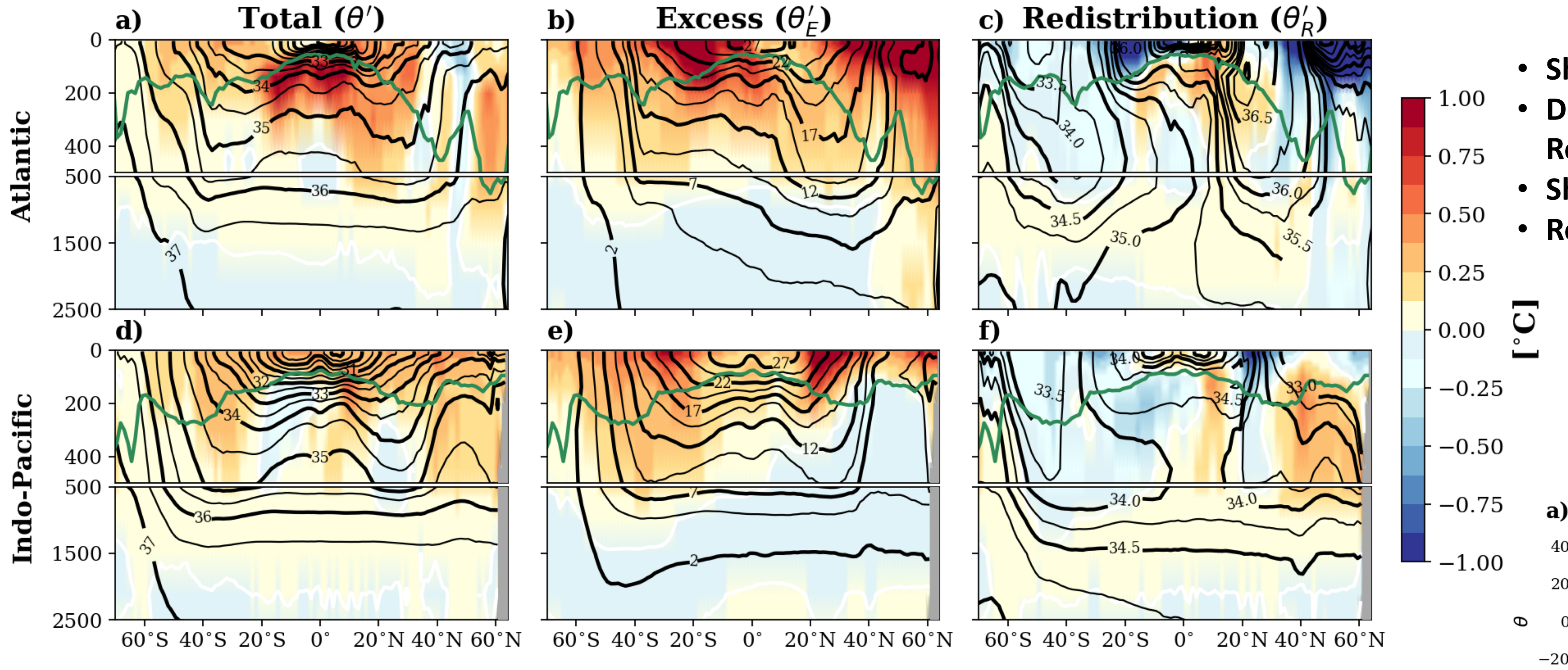
1) the mechanisms responsible for Spice (along-isopycnals) and Heave (along T-S curve) warming
2) and whether these warmings result from surface fluxes (Excess heat) or from a changing circulation (Redistributed heat).

## 1) Introduction

- Up to 93% of the anthropogenic warming is stored in the ocean. Despite the large role of oceanic warming in regional sea-level rise, distinguishing the Excess heat (due to perturbed surface heat fluxes) from the Redistributed heat (that arises from the changing circulation) remains challenging with observations.
- In this work, using a coupled climate model (HadCM3) with realistic historical forcing (anthropogenic and natural) over the past 50 years, we identify whether Excess warming mostly project onto Spice or Heave warming.

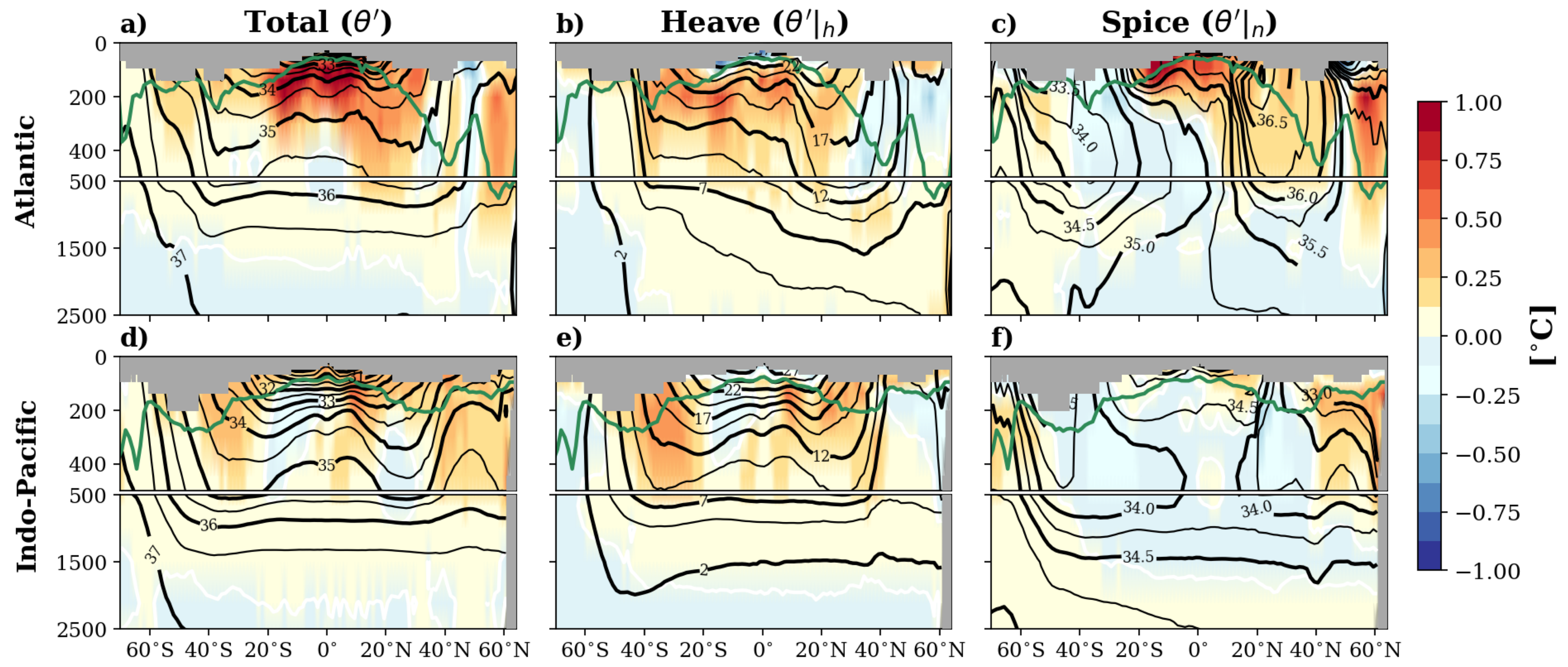



## 2.a) Temperature decomposition: - Excess and Redistribution



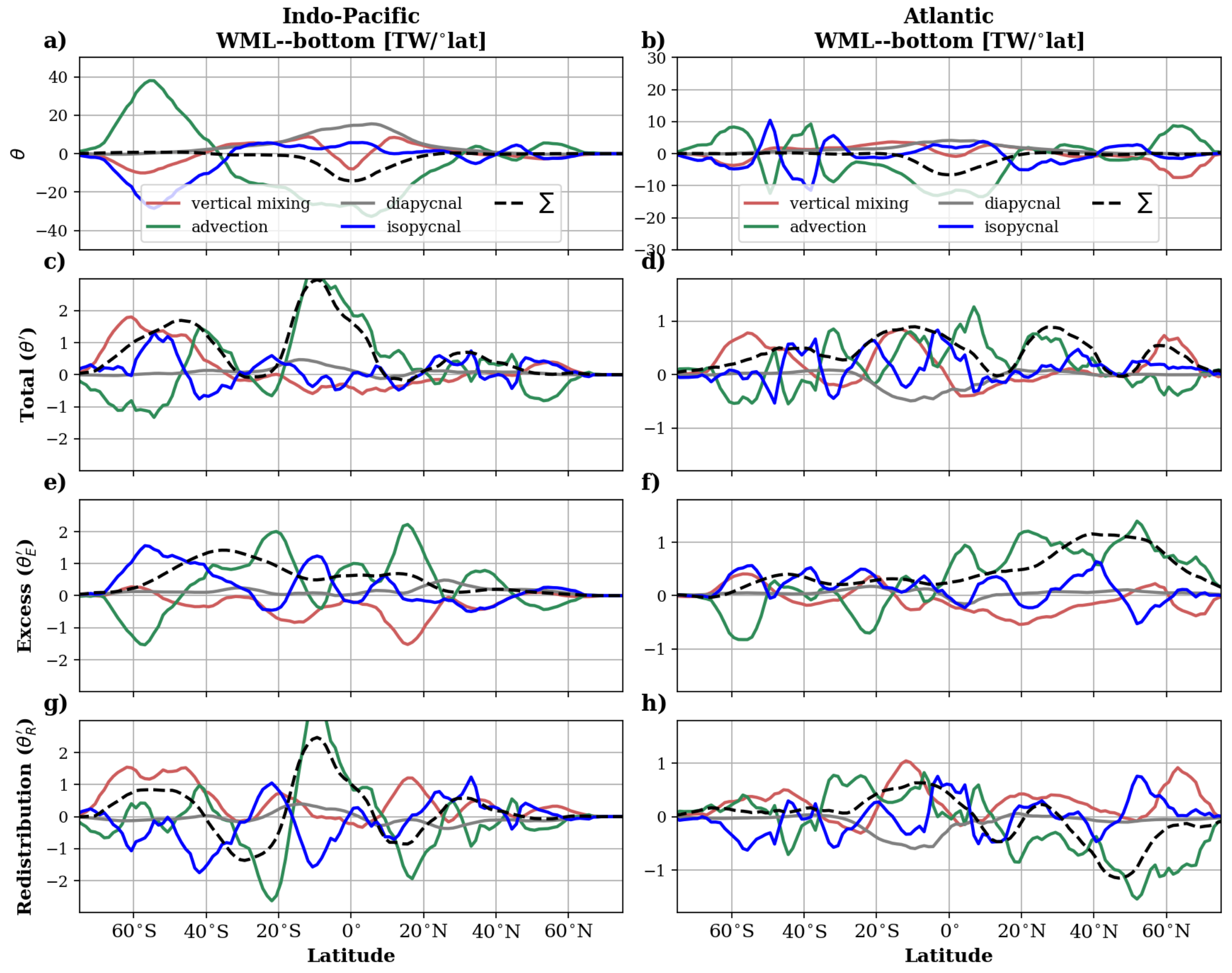

- Shallow global Excess warming in the top 500 m.
- Deeper Excess warming in North Atlantic partly compensated by Redistributed cooling.
- Shallow Excess and Deep Redistributed warming in the Southern Ocean.
- Reduction of MOC → Tropical Excess warming ~400 m.

## 2.b) Temperature decomposition: - Spice and Heave



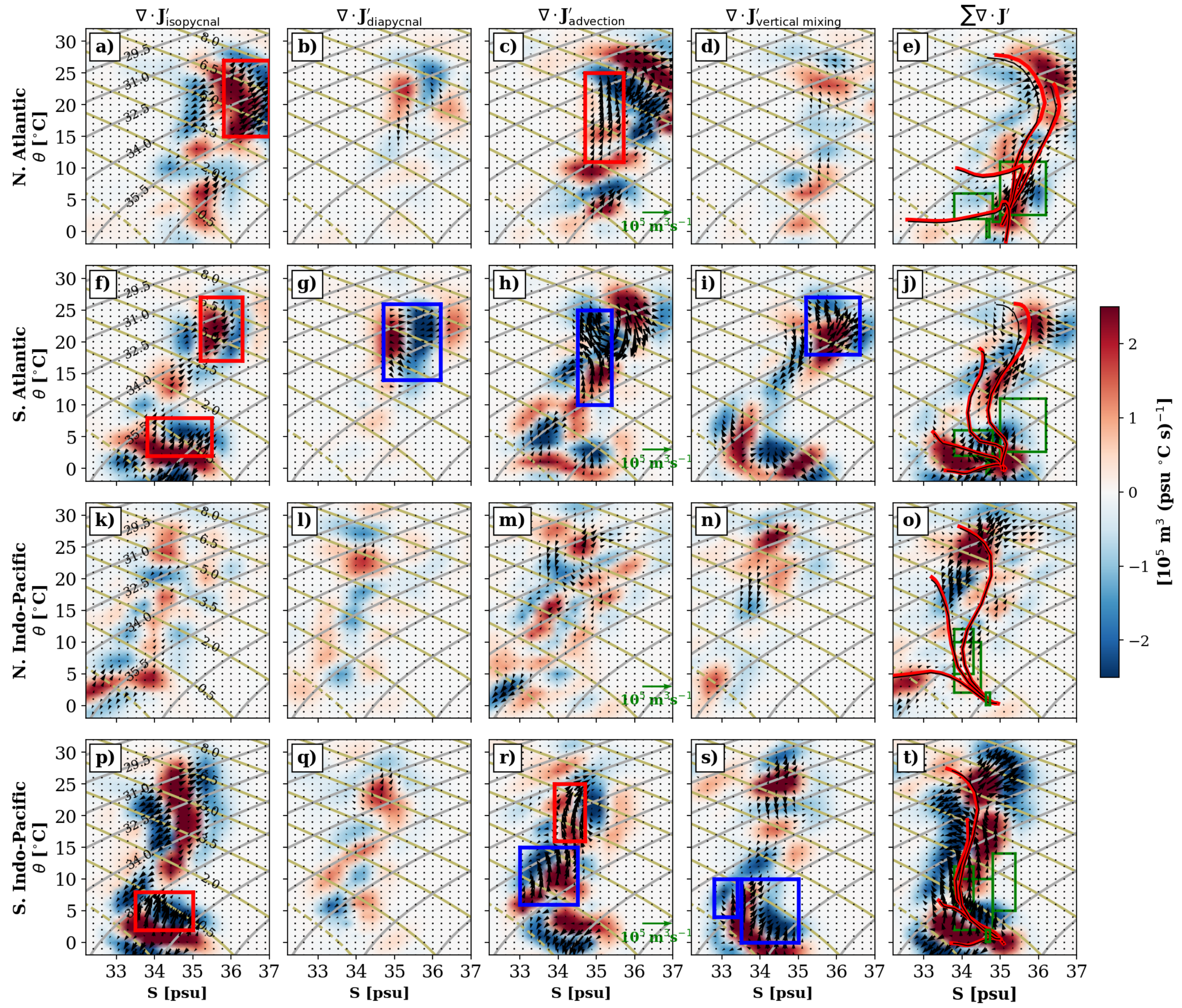

- Equatorward of 50°, Heave warms as in Excess and Redistribution (~400 m in the Tropics).
- North of 30°N in the Atlantic, most Excess warming is in Spice and most Redistribution cooling is in Heave.
- In the Southern Ocean (South of 45°S), most warming is in Spice.

## 3) Eulerian Heat Budget




- Redistributed convective warming at 60°N/S (red) due to reduced convection.
- Redistributed mixed layer warming at 45°S (red) due to shifting of westerlies.
- Excess warming through isopycnal mixing (blue) around 40-50°S
- Reduced overturning circulation → Redistributed advective (green) warming in tropical Pacific.
- Reduced AMOC: Redistributed Advective (Green) Cooling (Warming) in Subpolar (Subtropical) North Atlantic.

## 4) Heat and Salinity Budgets in thermohaline coordinates




Red box: Excess. Blue box: Redistribution

- In the subtropical Atlantic (subpanel e and j), Advection warms (i.e. Heave). Excess isopycnal mixing warms but also becomes more saline (i.e. Spice).
- In the subtropical Pacific (subpanel t), Heave mostly warms (Ekman downwelling) with a slight freshening.
- In the Southern Ocean, Excess isopycnal mixing and convective warmings are mostly along isopycnals (i.e. Spice).

## 5) Conclusions

- Most shallow Excess subtropical warming and deep equatorial Redistributed warming project onto Heave through advection.
- Spice warming captures most of the North Atlantic Excess warming (due to advection and isopycnal mixing) and most of the shallow Excess warming of the Southern Ocean (due to isopycnal mixing).
- Because Spice and Heave depend only on T and S, our study suggests a method to detect Excess warming in observations.

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