High-latitude Southern Ocean response to changes in surface momentum, heat and freshwater fluxes under 2xCO2 concentration

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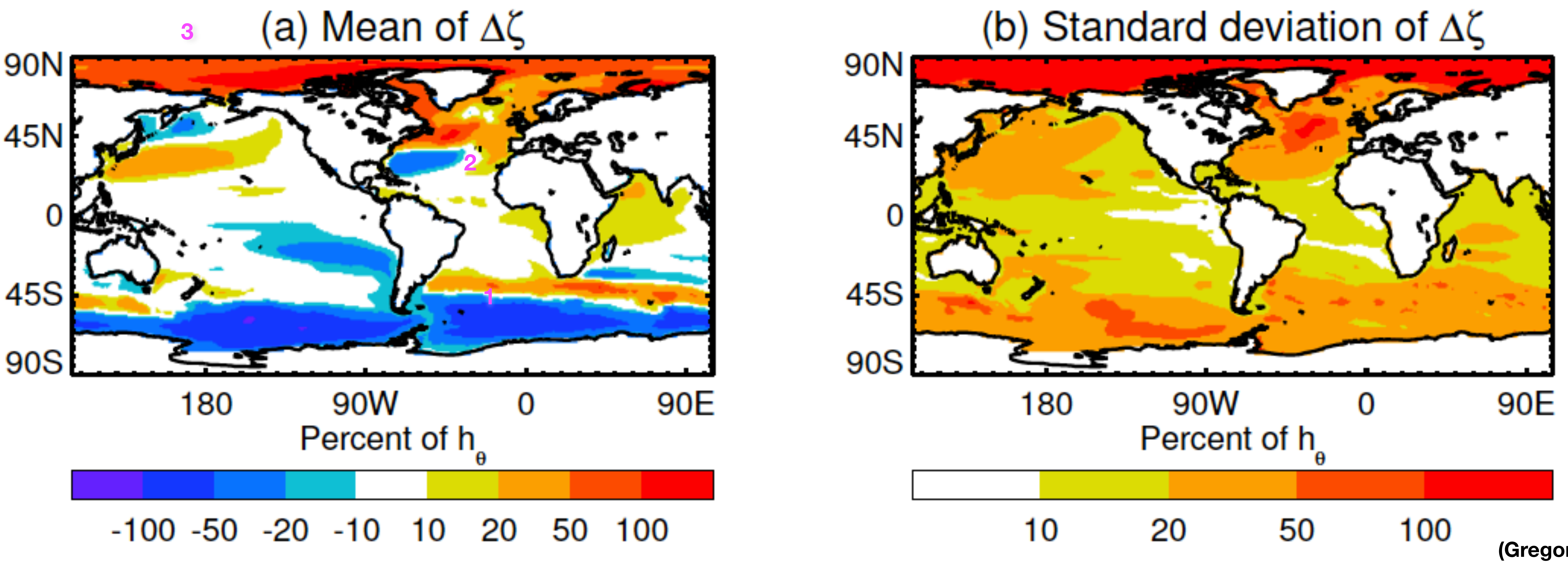
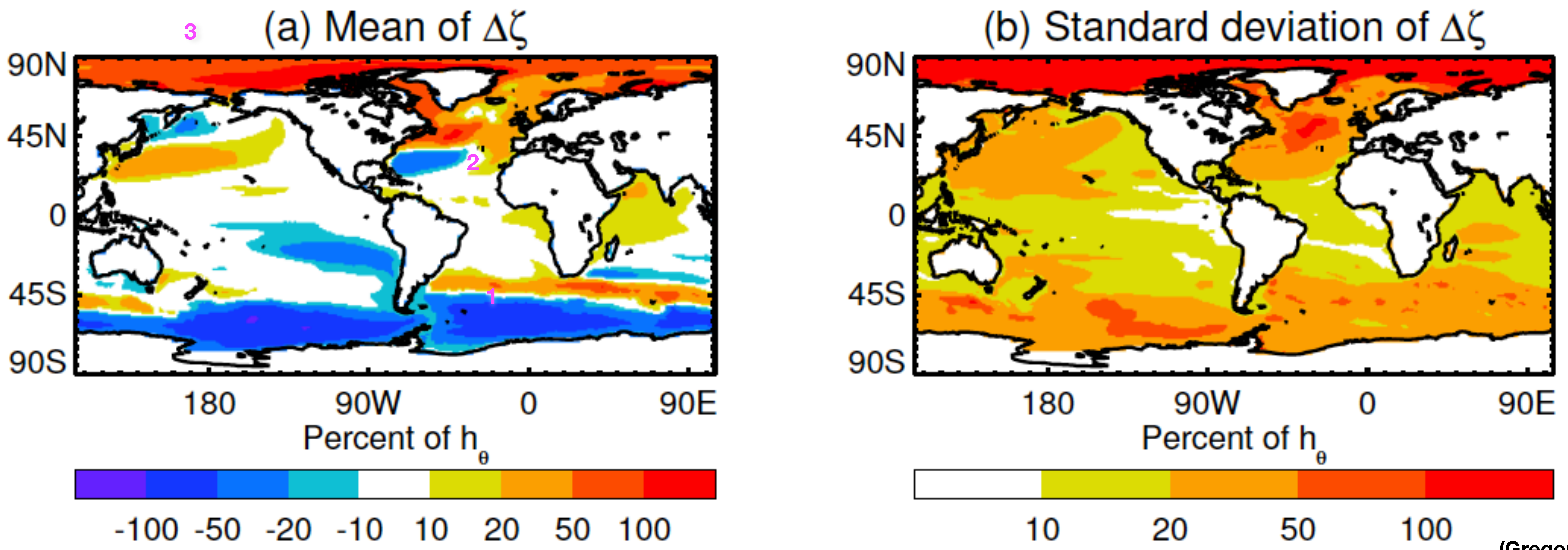
Understanding spread in sea-level projections



(Gregory et al. 2016)

- Spread among CMIP models caused by:
  - Atmosphere response
  - Ocean response

Understanding spread in sea-level projections



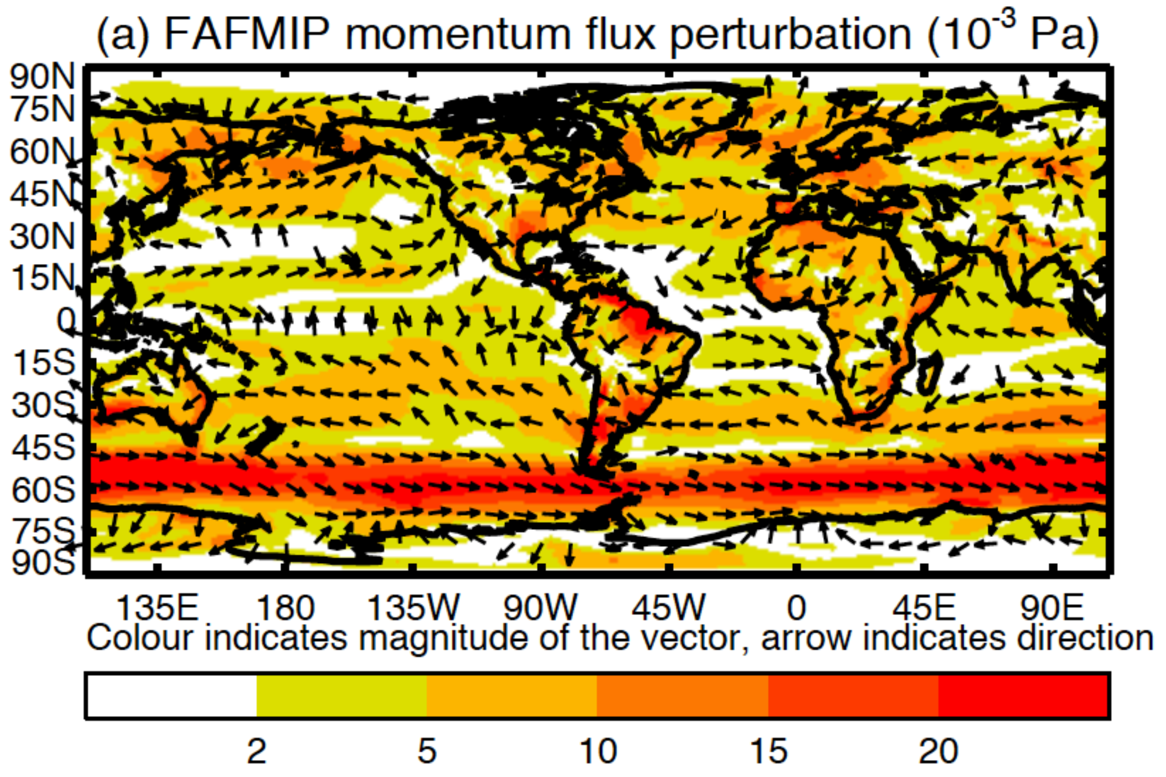
(Gregory et al. 2016)

- Spread among CMIP models caused by:
  - Atmosphere response
  - Ocean response

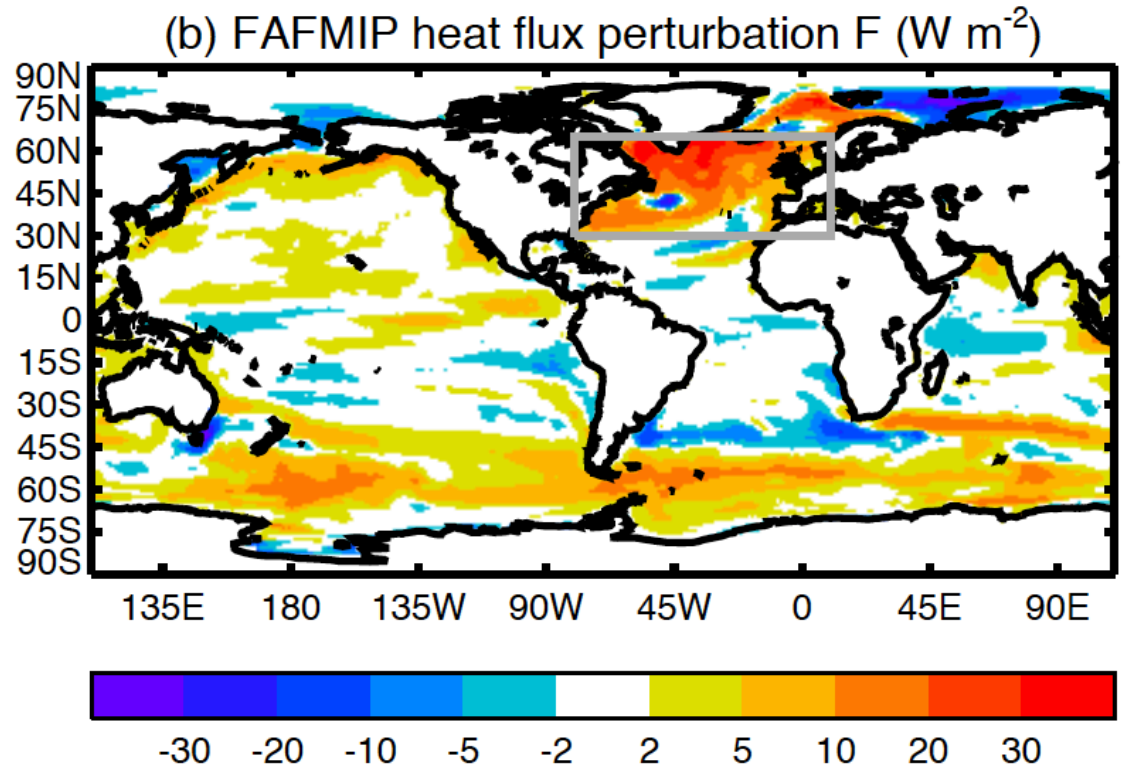
Ocean heat uptake efficiency
vertical transport
physical processes

Investigating the ocean response

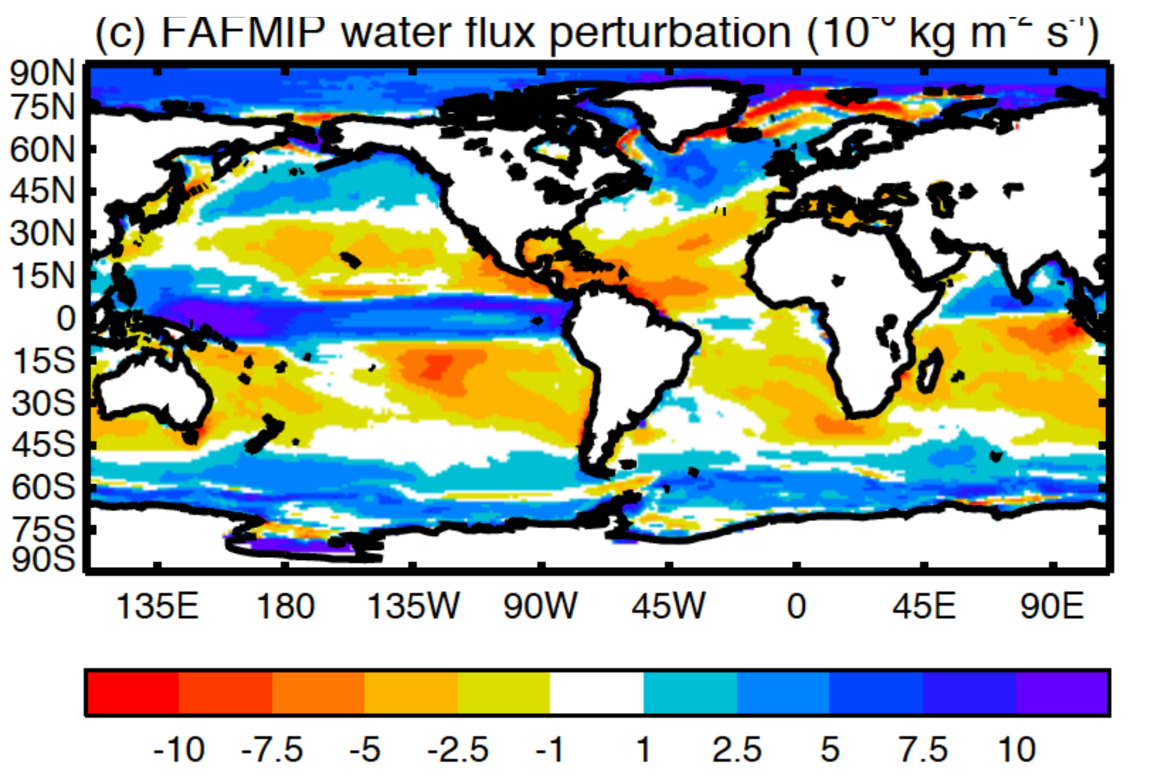
FAFSTRESS

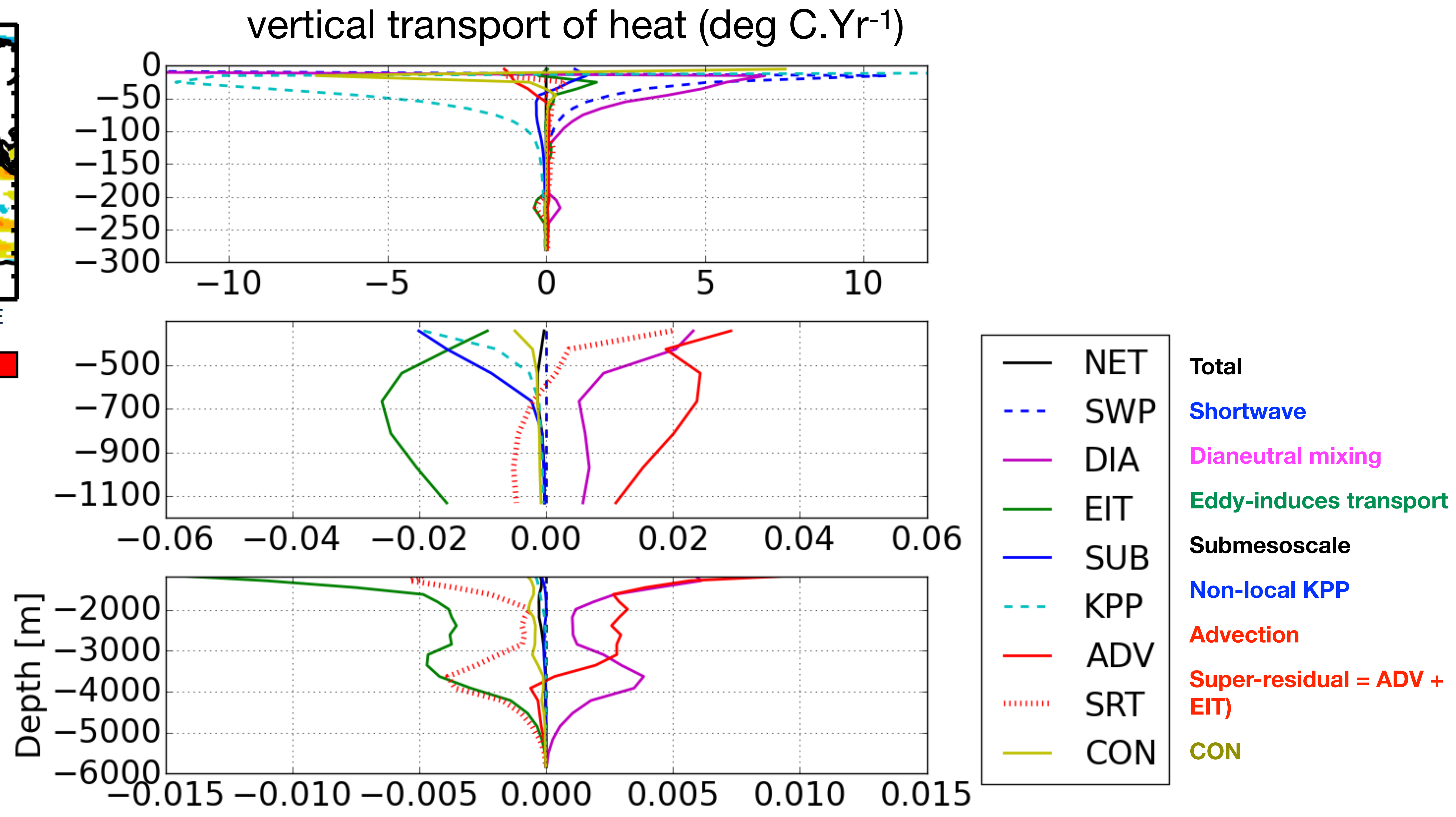


FAFHEAT



FAFWATER



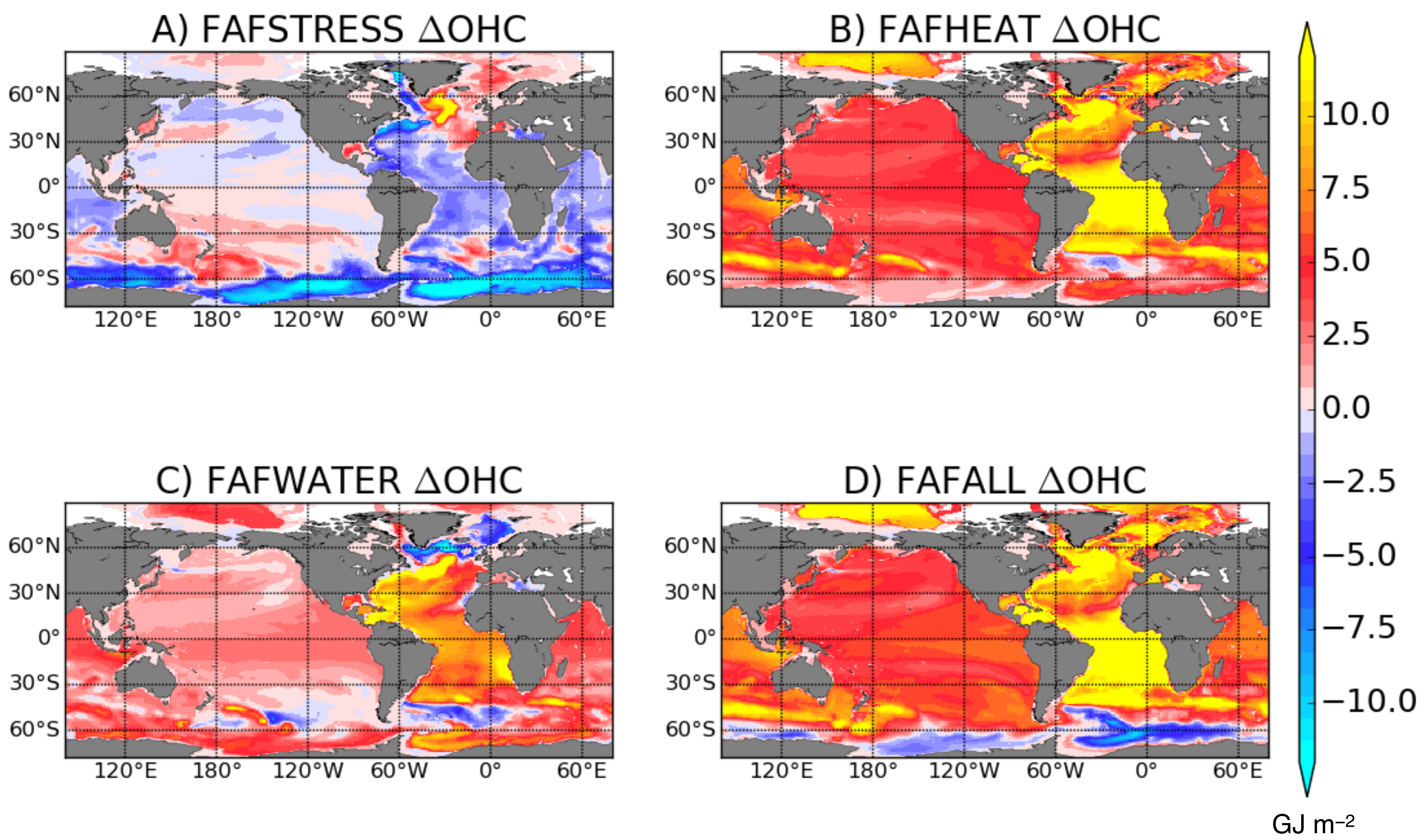


- Common surface flux perturbations: FAFMIP
- Process-based analyses: heat and salt budgets

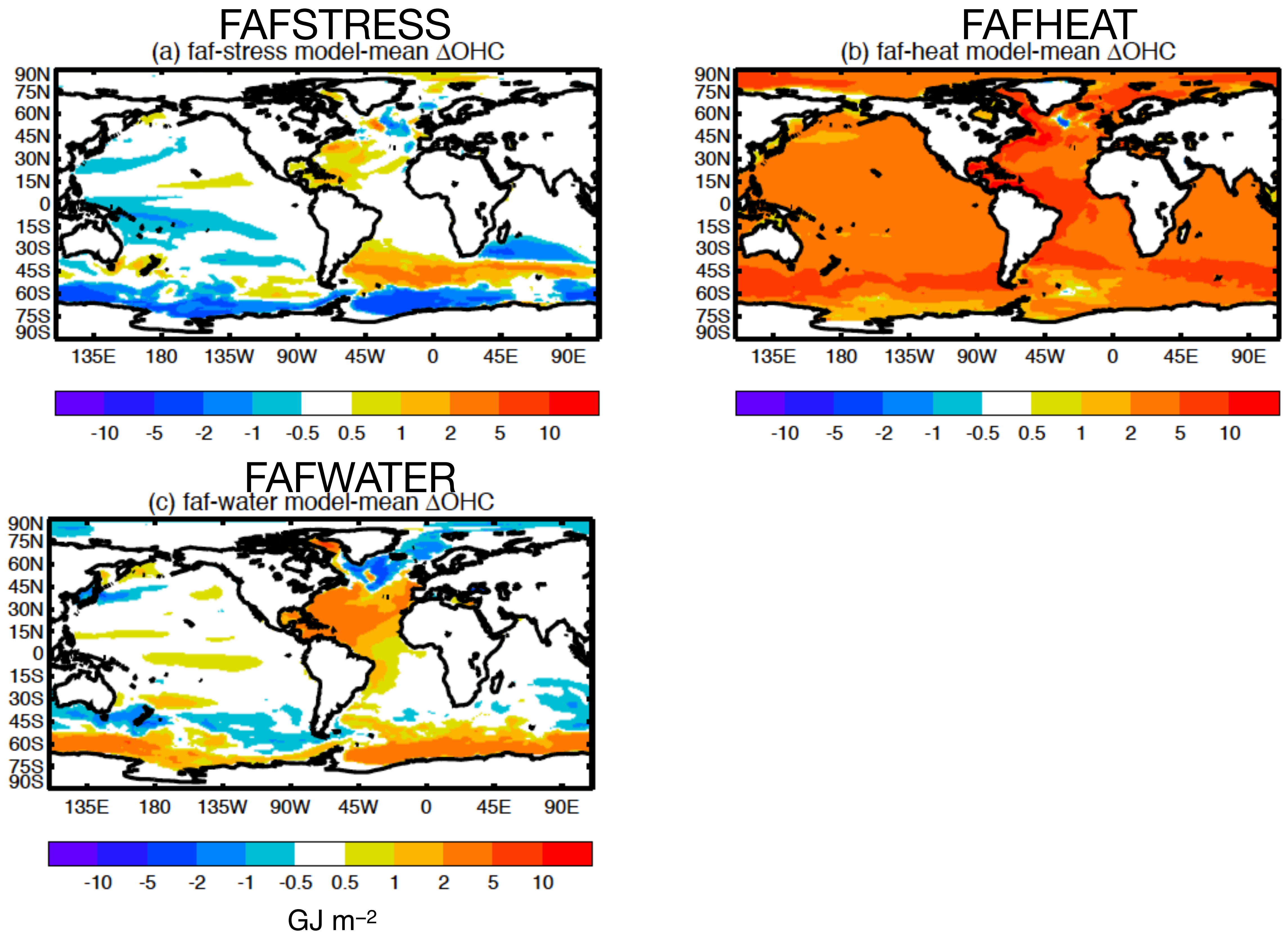
Ocean heat: ACCESS-OM2 results

Regional patterns comparison

ACCESS-OM2



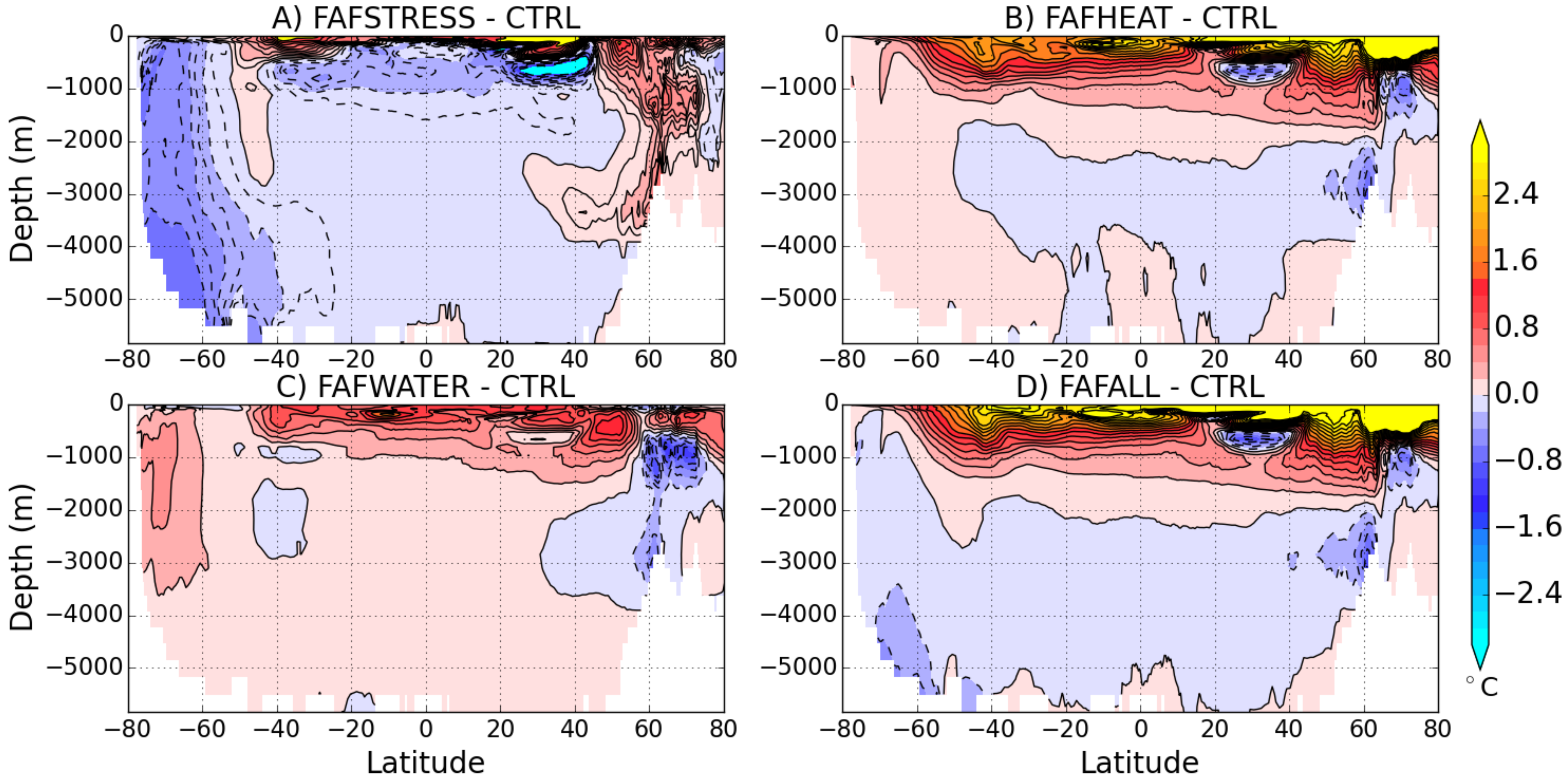
Ensemble-mean of 4 AOGCMs (Gregory et al. 2016)



- Similar results in terms of OHC change
  - Differences: North Atlantic (FAFHEAT) and low latitudes (FAFSTRESS/FAFEWATER)
  - Response in the high-latitude Southern Ocean: dominates by the wind-stress perturbation in FAF-ALL

Vertical structure comparison

ACCESS-OM2



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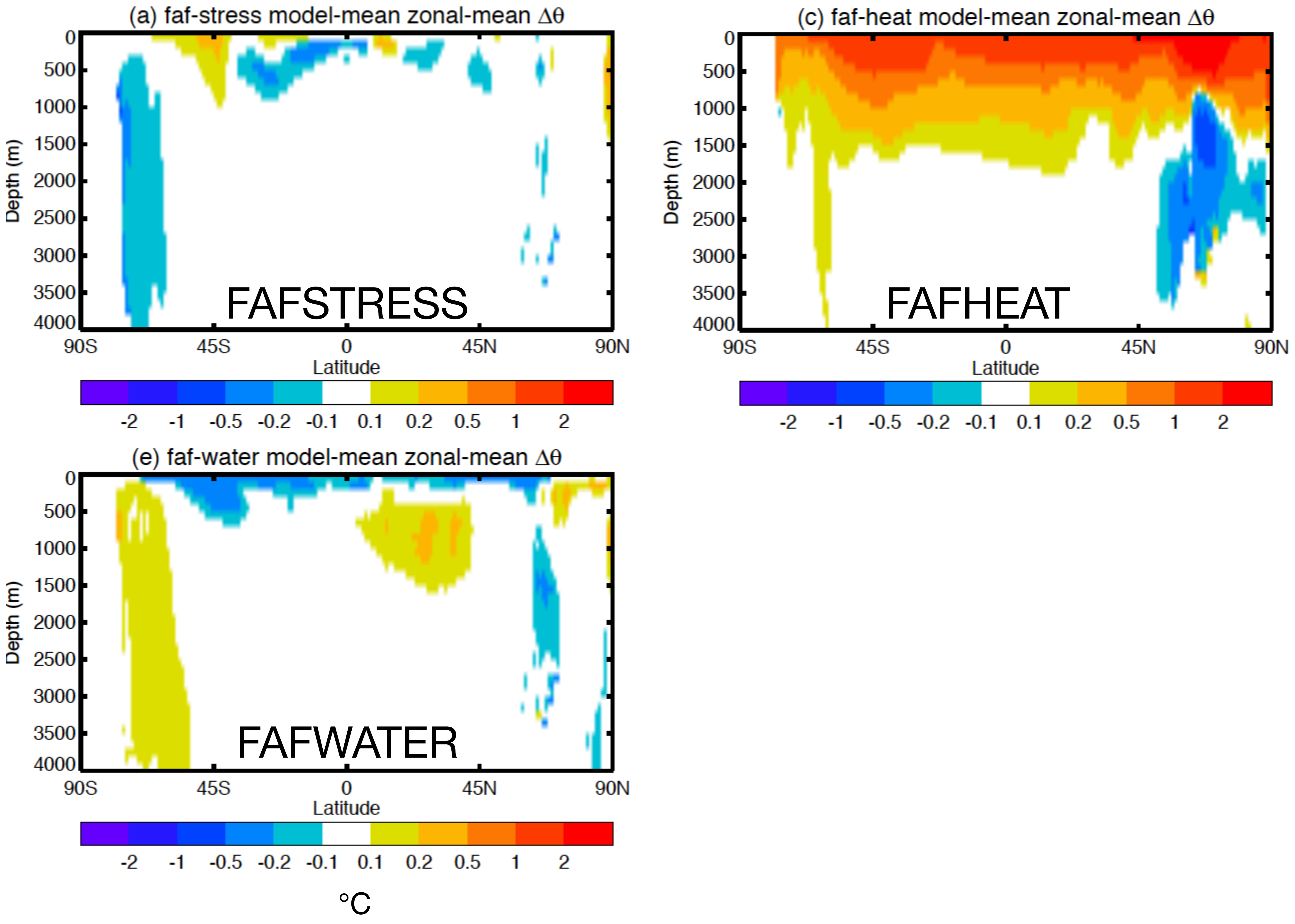
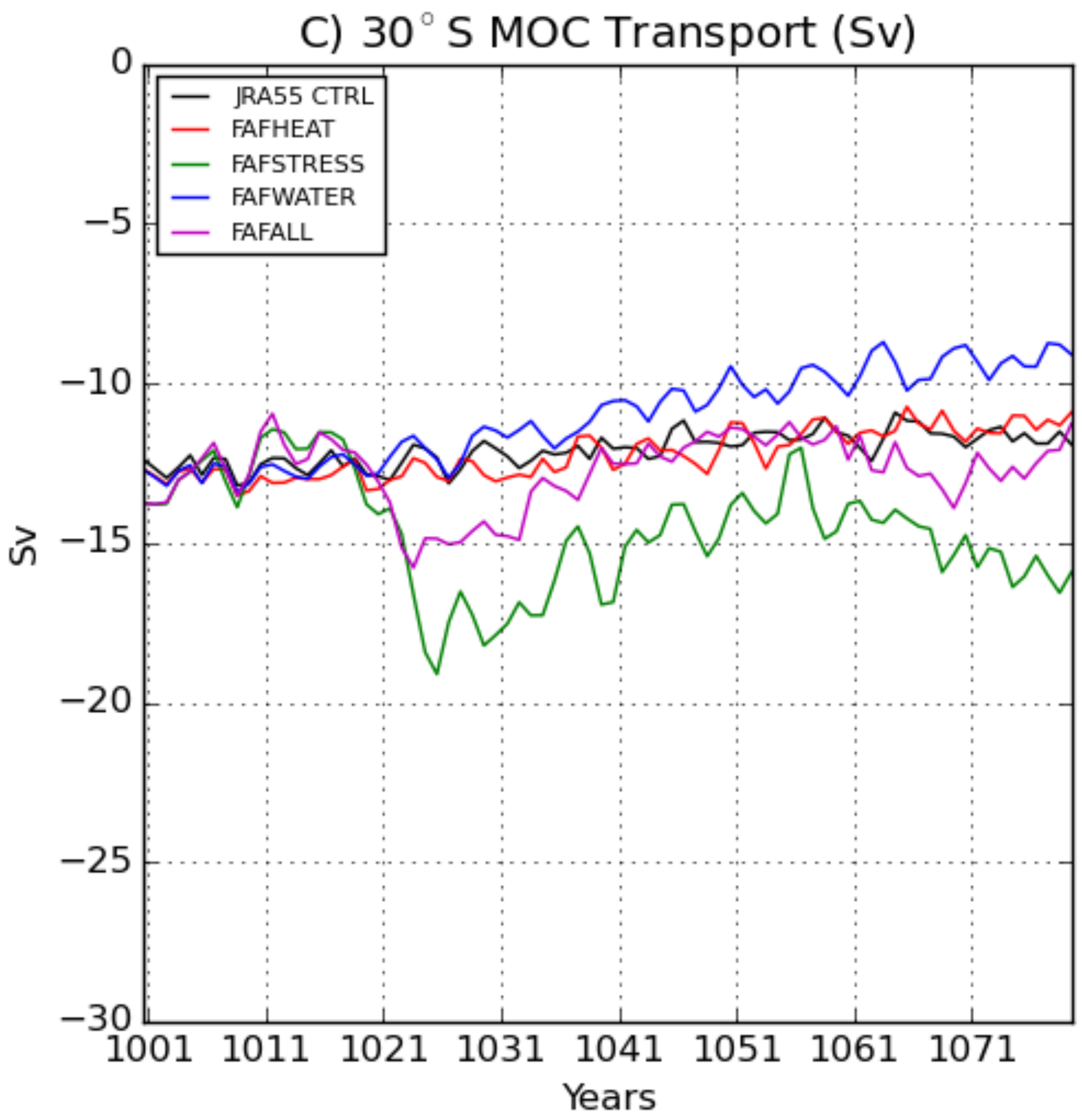


- intensification/shift of the Westerlies -> increase AABW formation
    - freshwater perturbations reduce MOC lower cell (heat secoondary)

Meridional Overturning Circulation response



Abyssal cell at 30°S: max negative transport >500m

- changes near linear due to increased freshwater - gradual slowdown (-3Sv/80yrs)
- heat perturbation does not affect MOC substantially
- changes in Westerlies accelerate MOC - oscillating b/w 0.5-7 Sv larger than control

Questions

1. What processes drive changes in high-latitude S.O. ocean heat content?

2. What is the impact in water mass (TS) properties?

Process-based analysis: Climatological state (control)

- **Climatological state (control)**
  - Convection drives cooling to depths below 1000m
  - Locally is balanced by the combination of ADV and EIT = Super-residual Transport

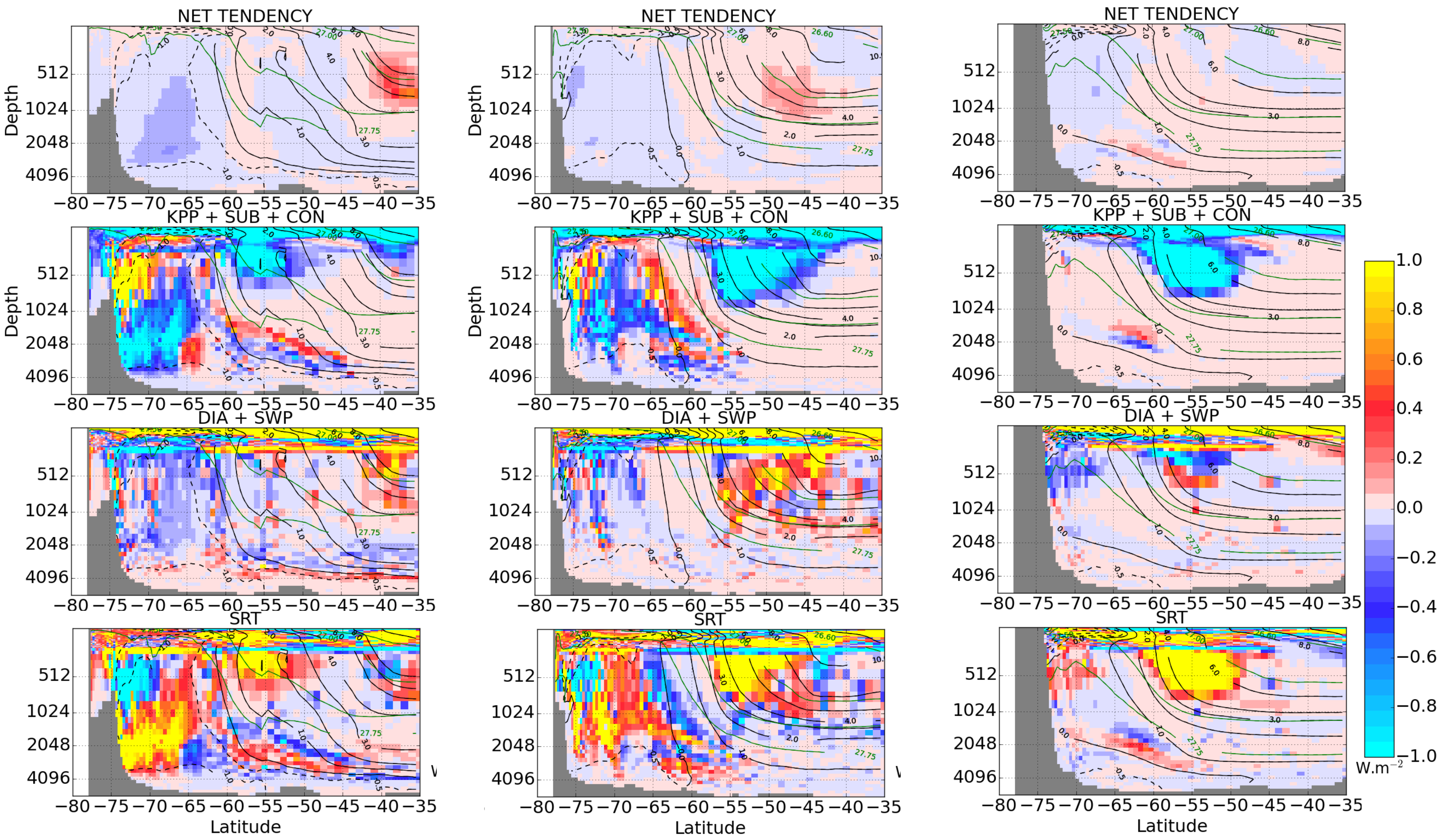
Atlantic sector | **West Pacific sector** | **East Pacific sector**

Heat tendency

Mixed Layer processes

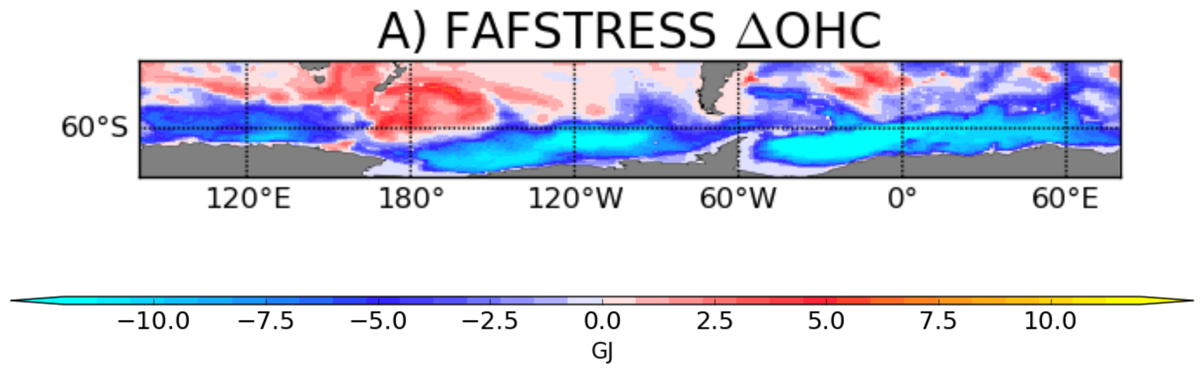
Dianeutral mixing

Super-residual transp.



On the superposition of the mean advective and eddy-induced transport for the heat and salt budget (Boeira Dias et al, submitted to Journal of Climate)

Process-based analysis: FAFSTRESS



- **Convection** and **dianeutral mixing** cooling increase
- **Super-residual transport** advects anomalies away

Heat tendency

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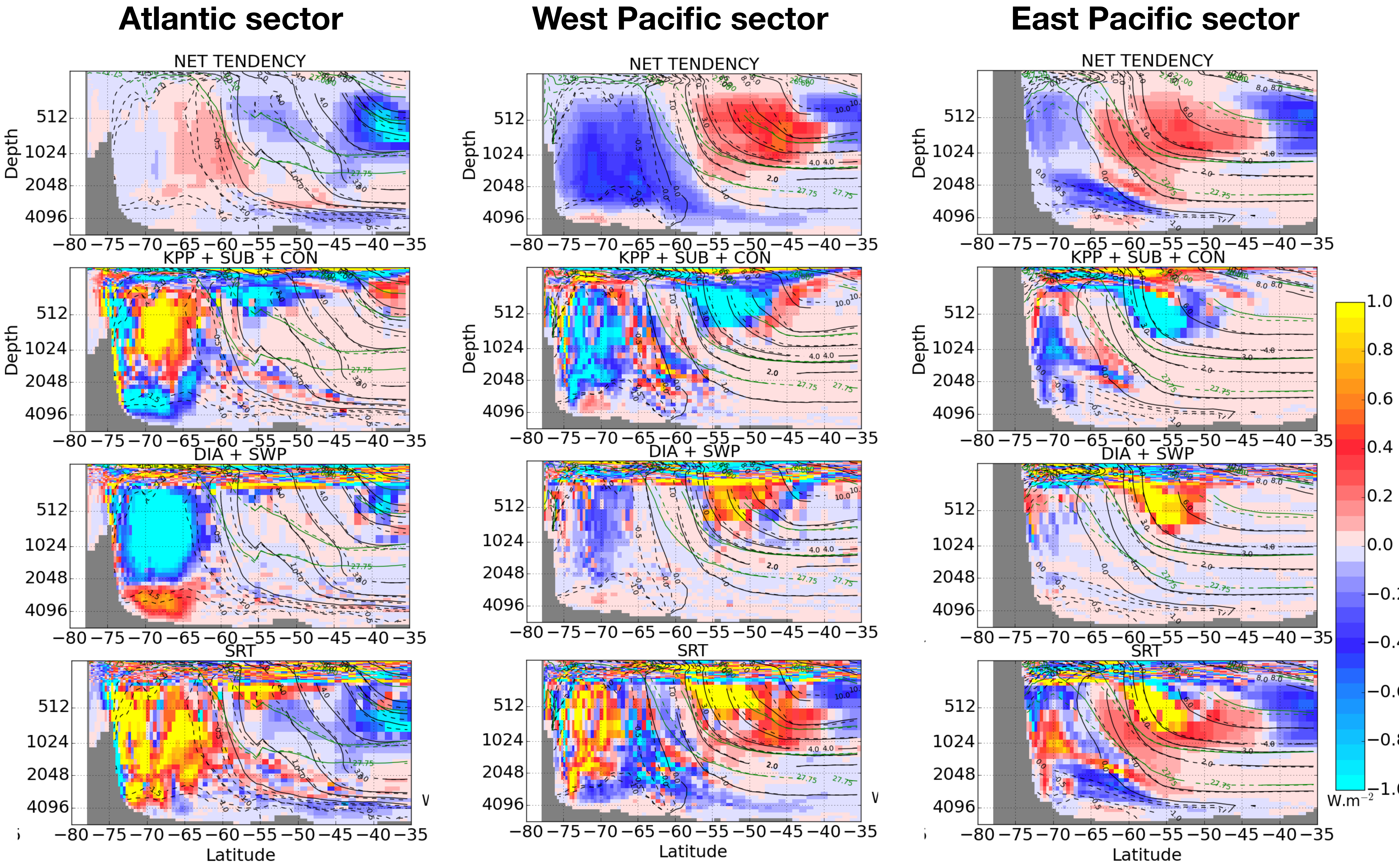
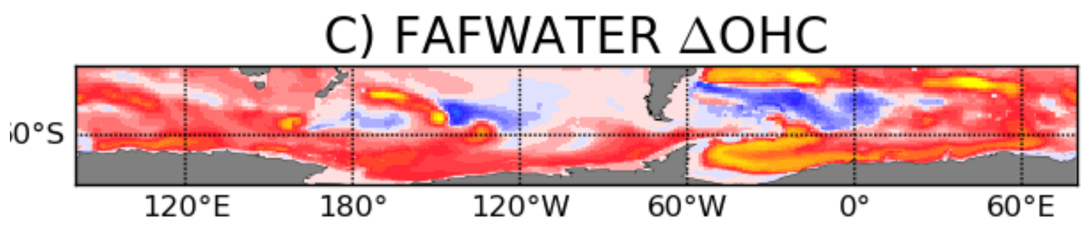


Process-based analysis: FAFWATER

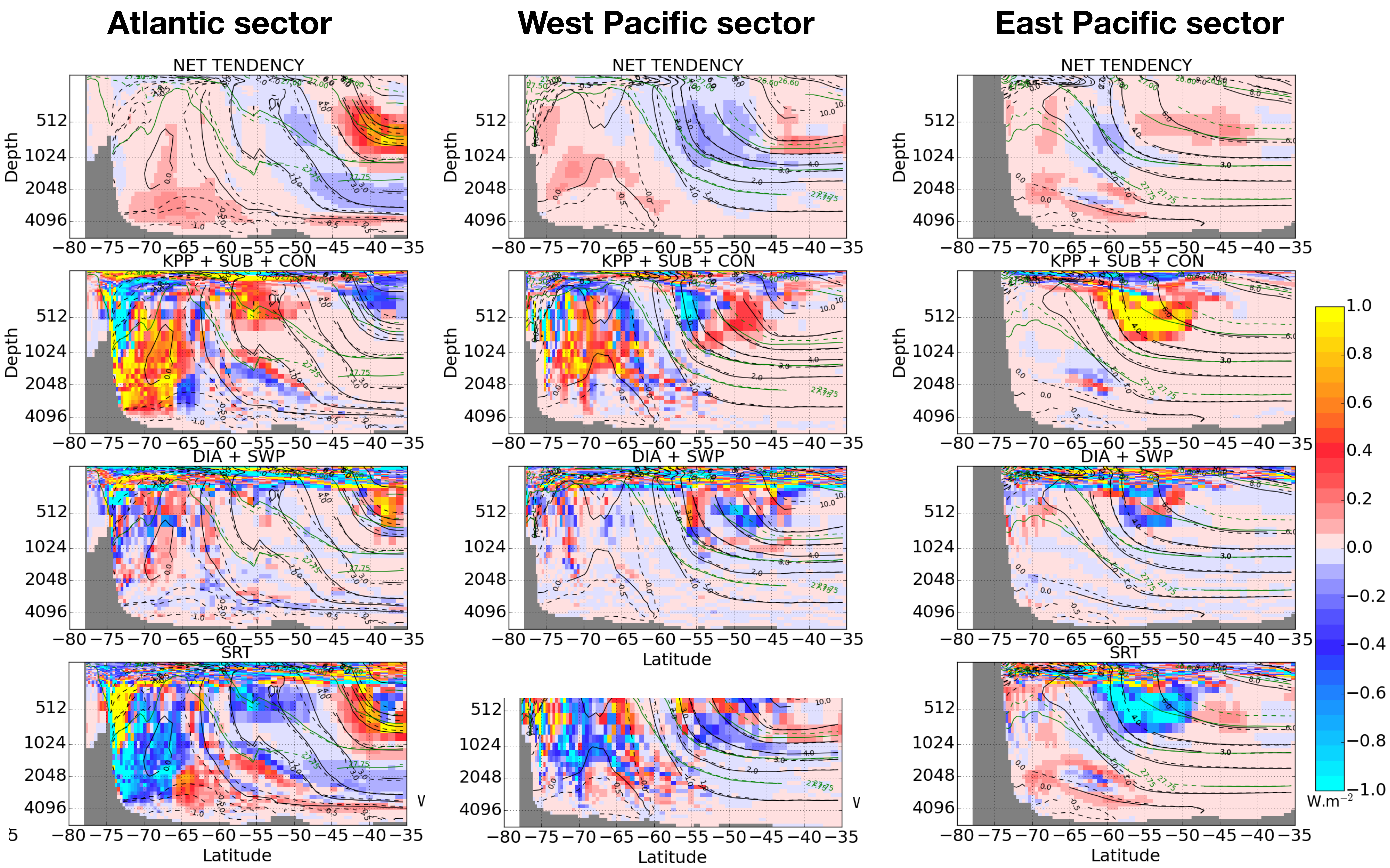


Heat tendency

Mixed Layer processes

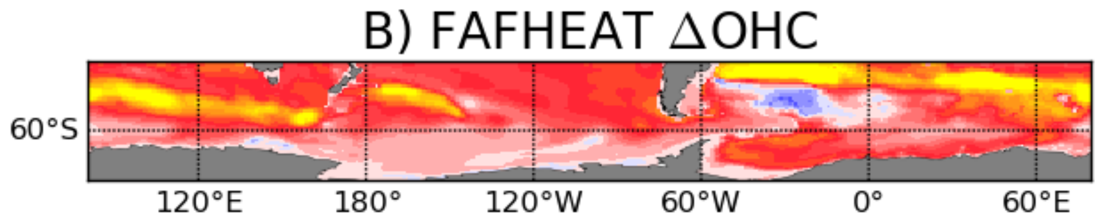
Dianeutral mixing

Super-residual transp.



- **Convection** cooling decrease
- **Super-residual transport** advects anomalies away

Process-based analysis: FAFHEAT



- **Convection** cooling decrease
- **Super-residual transport** advects anomalies away

Heat tendency

Mixed Layer processes

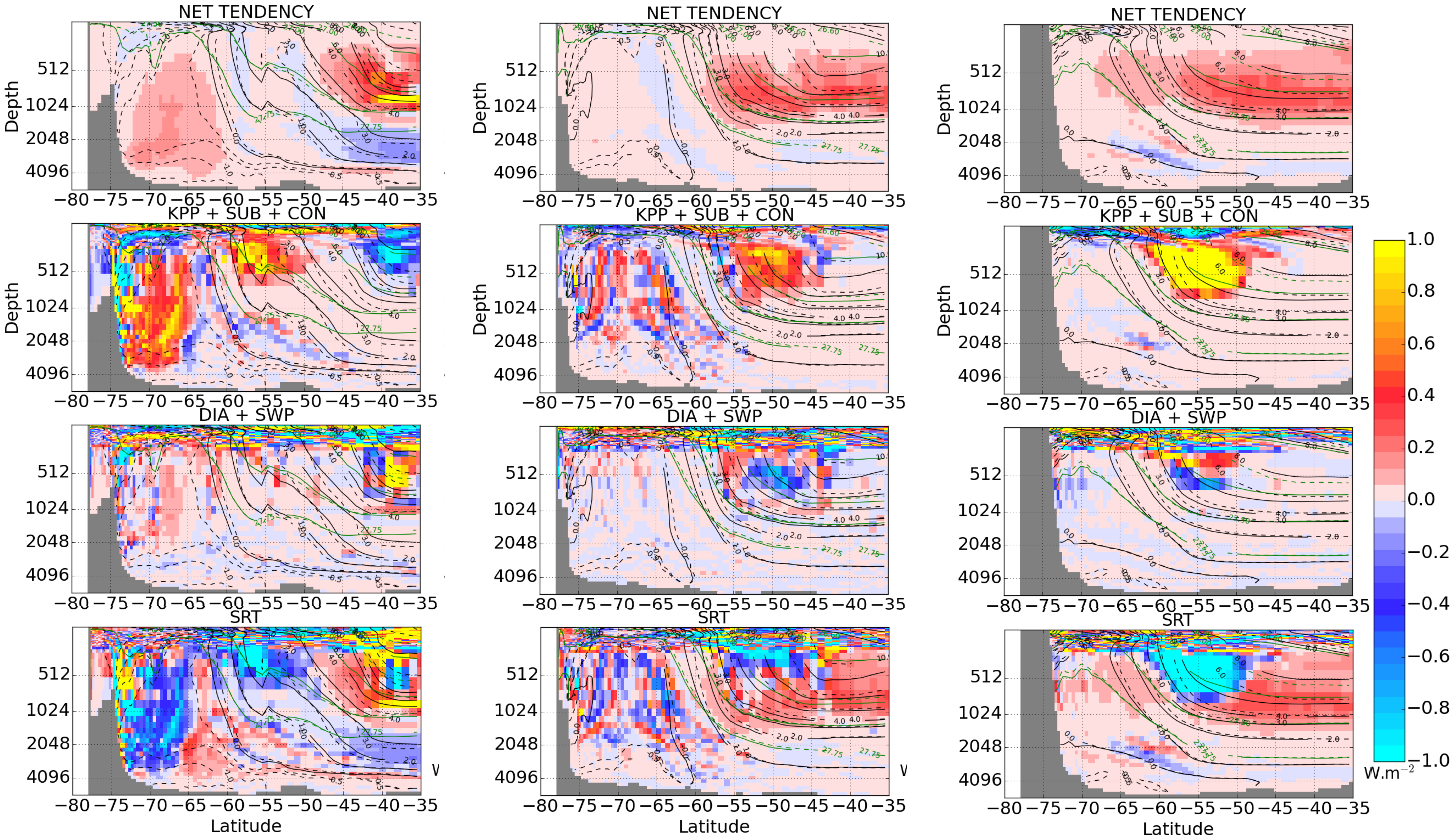
Dianeutral mixing

Super-residual transp.

Atlantic sector

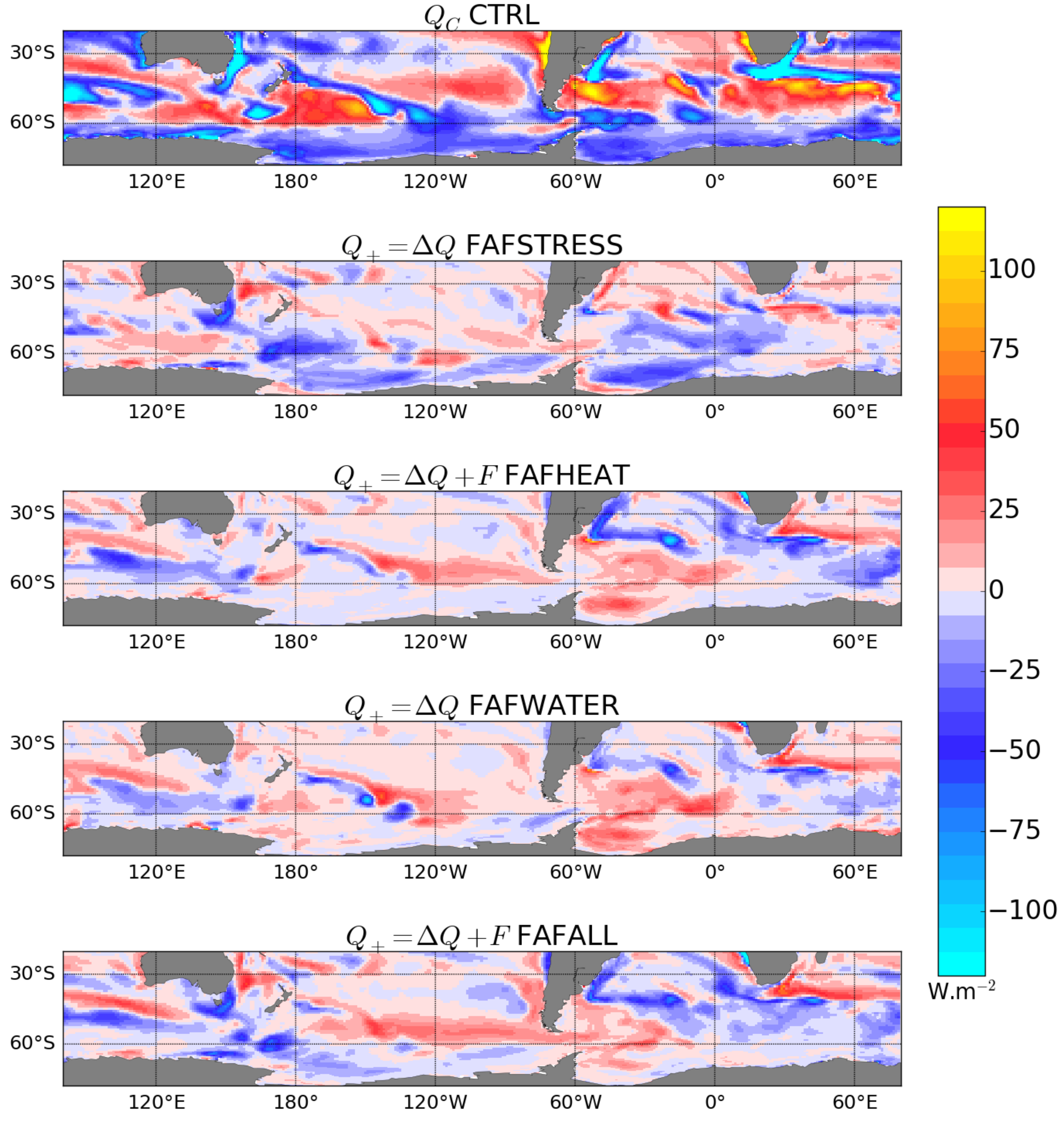
West Pacific sector

East Pacific sector

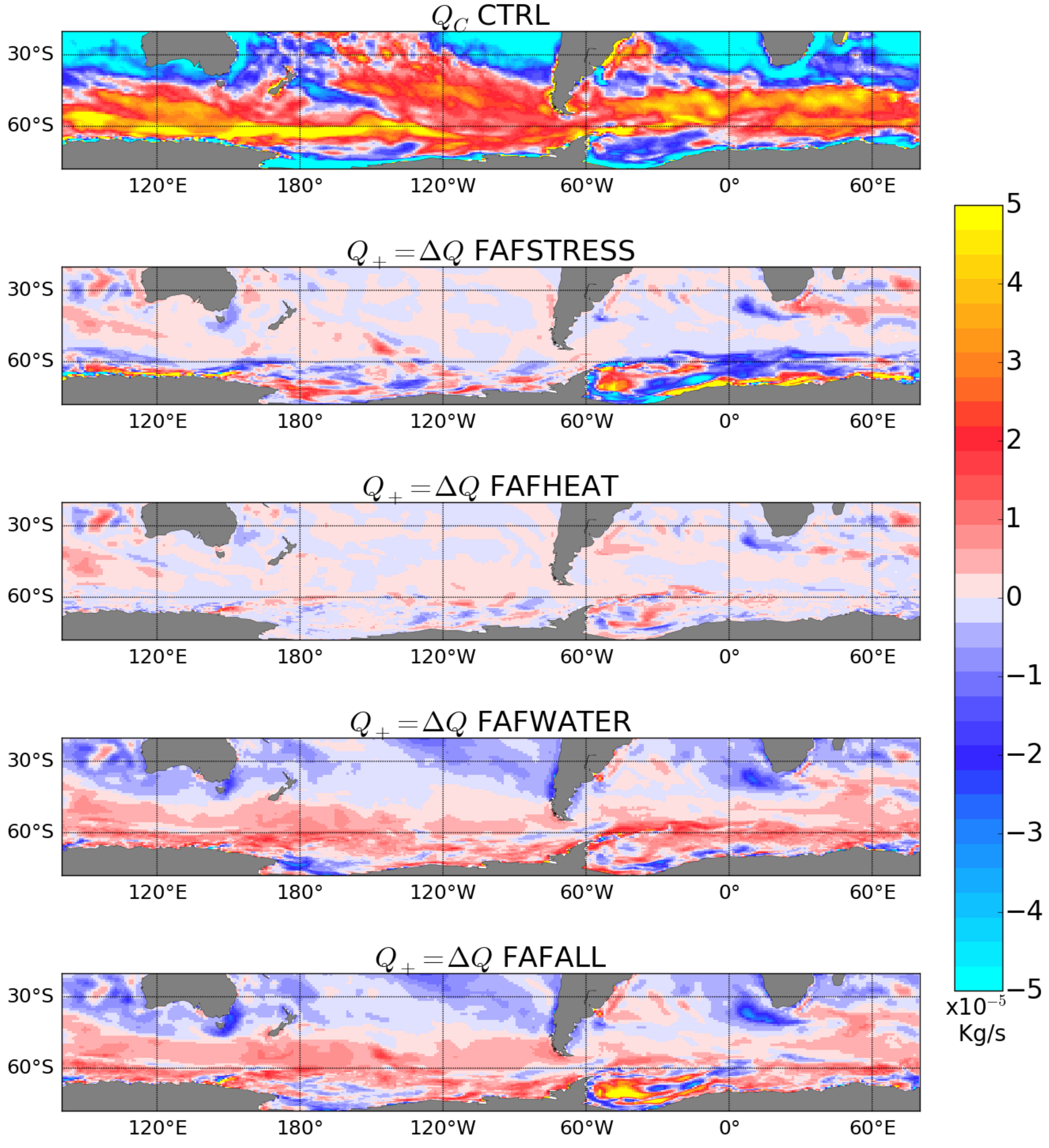


Changes in air-sea fluxes

Net surface heat flux



Net surface freshwater flux

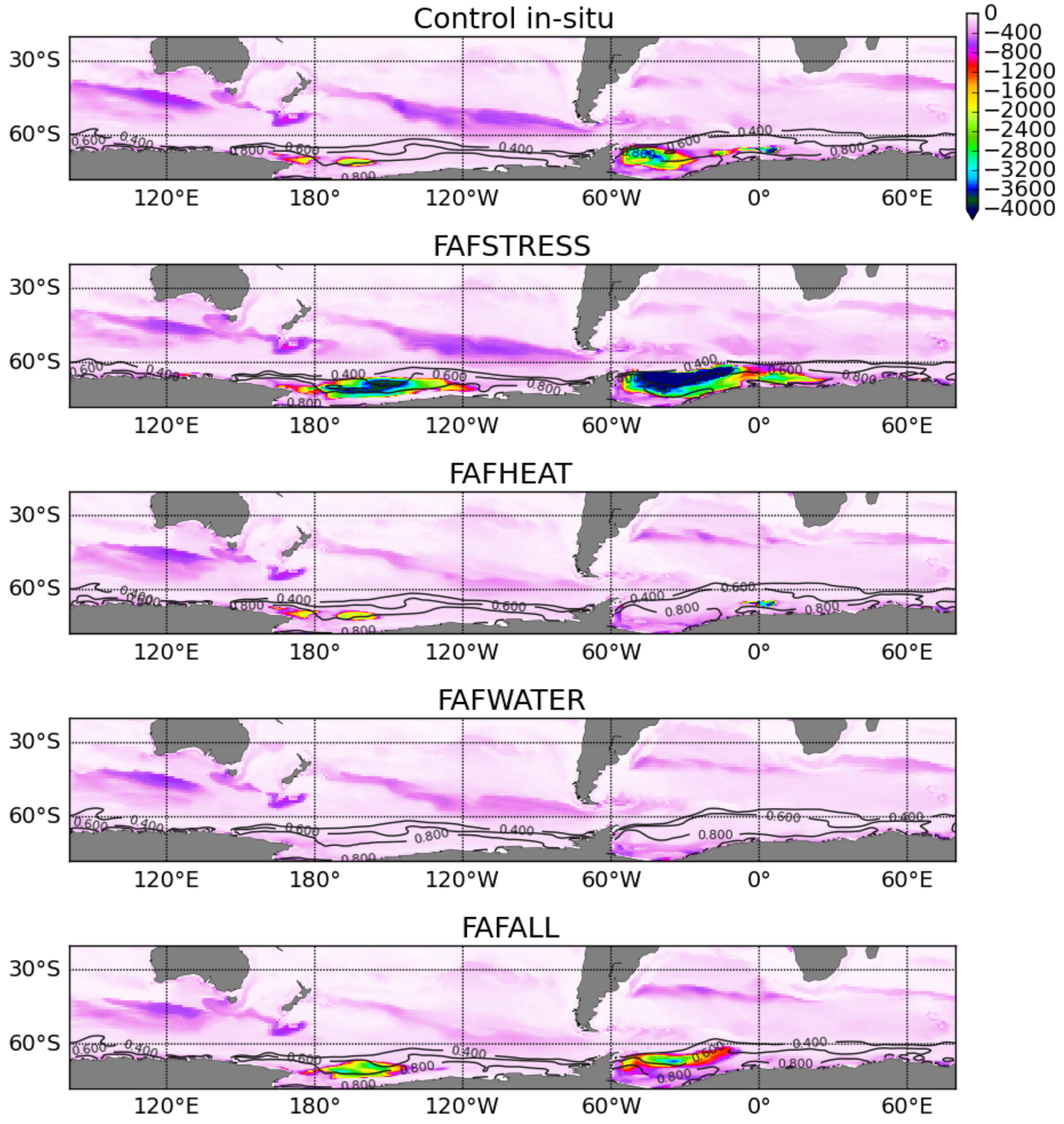


- **FAFSTRESS**: stronger surface heat loss
- **FAFHEAT/FAFWATER**: reduction of heat loss

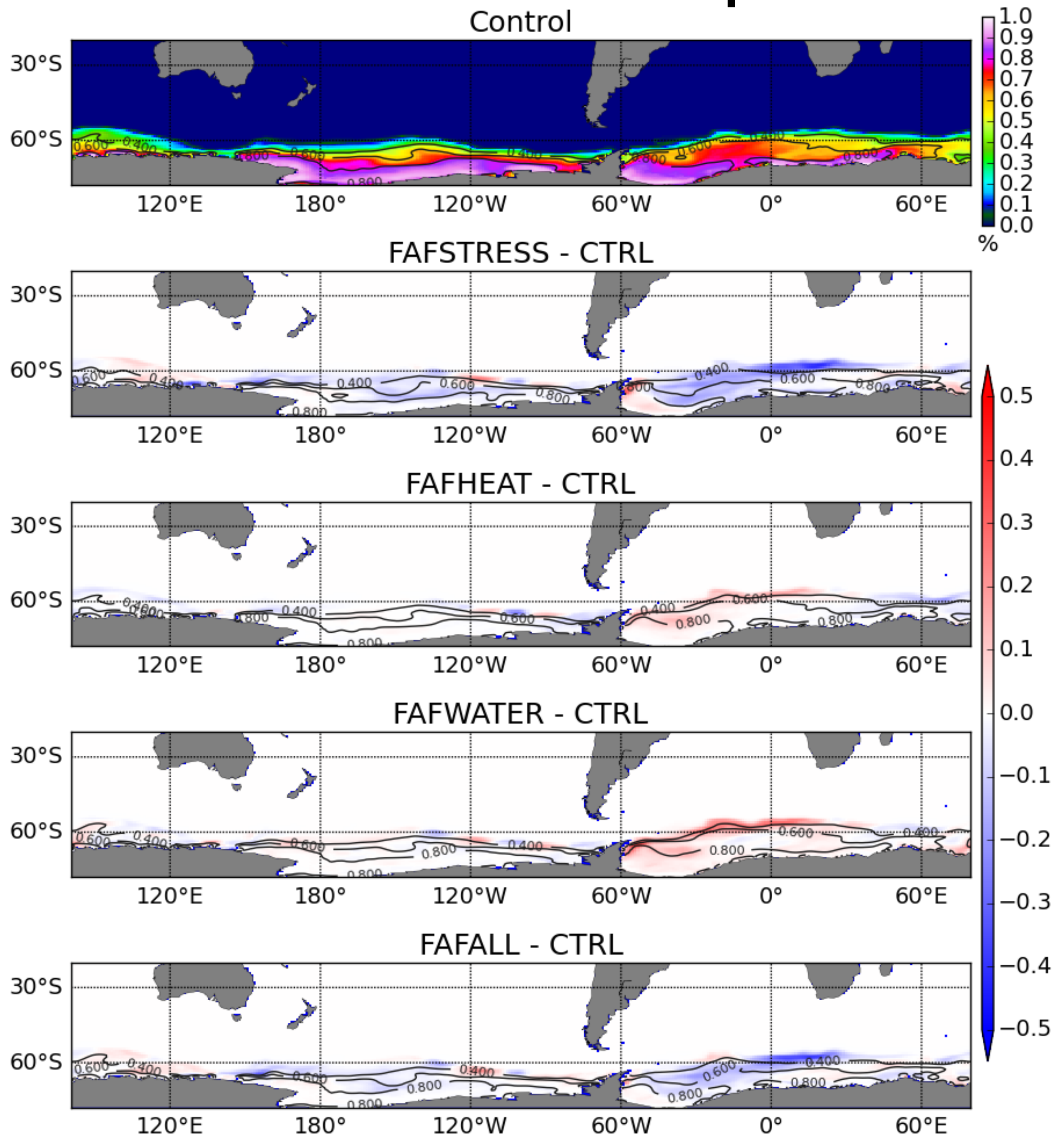
- **FAFSTRESS**: have anomalous freshwater and salt fluxes - spatially variable
- **FAFWATER**: overall freshening
- **FAFHEAT**: freshening over Weddell Sea

Open-ocean polynyas

MLD - September

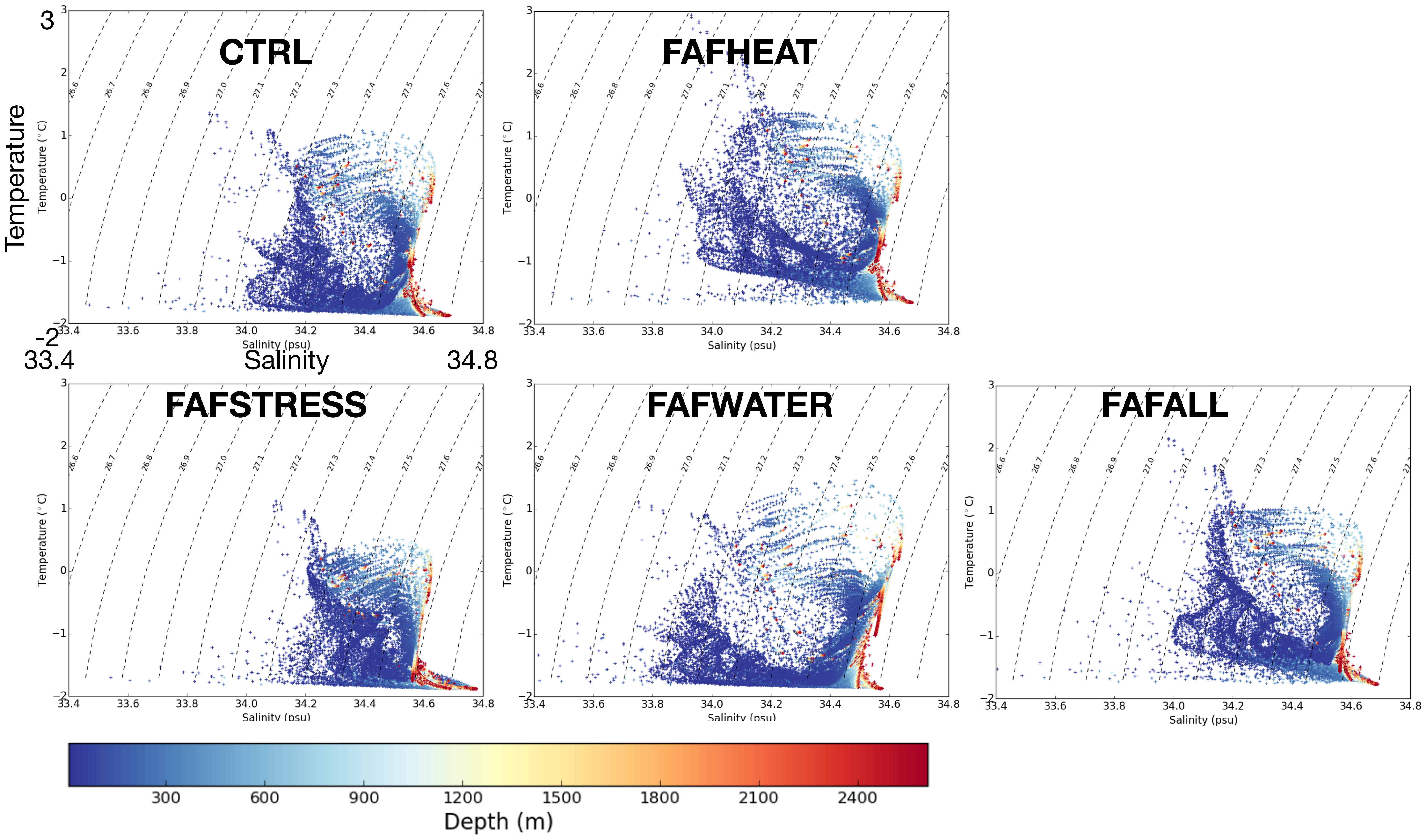


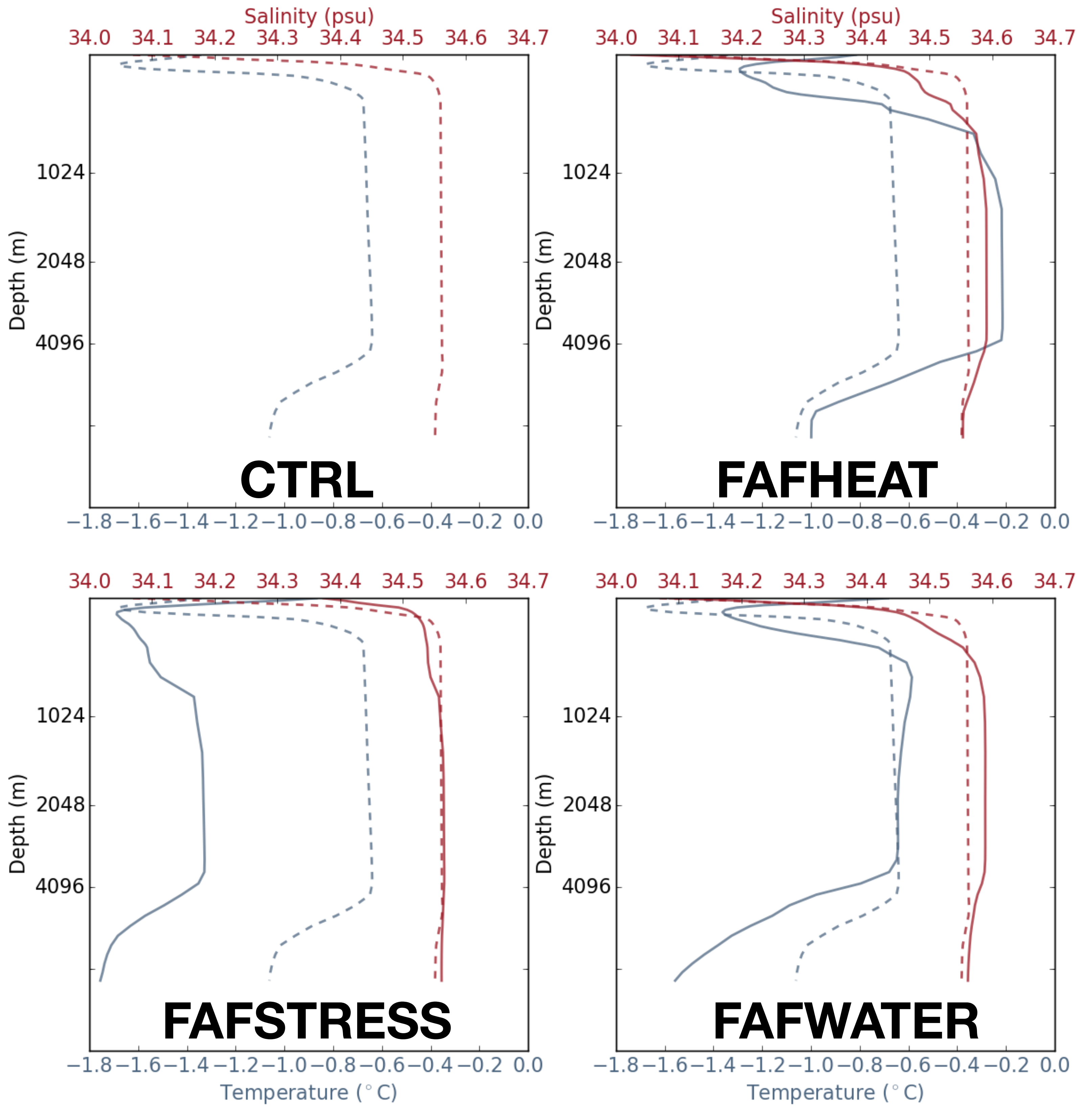
Sea-ice concentration - September



- Weddell & Ross Seas: areas of low sea-ice concentration and deep mixed layer
- **FAFSTRESS**: expansion of polynyas, deepening of MLs and decrease of sea-ice
- **FAFHEAT/FAFWATER**: shutdown of polynyas

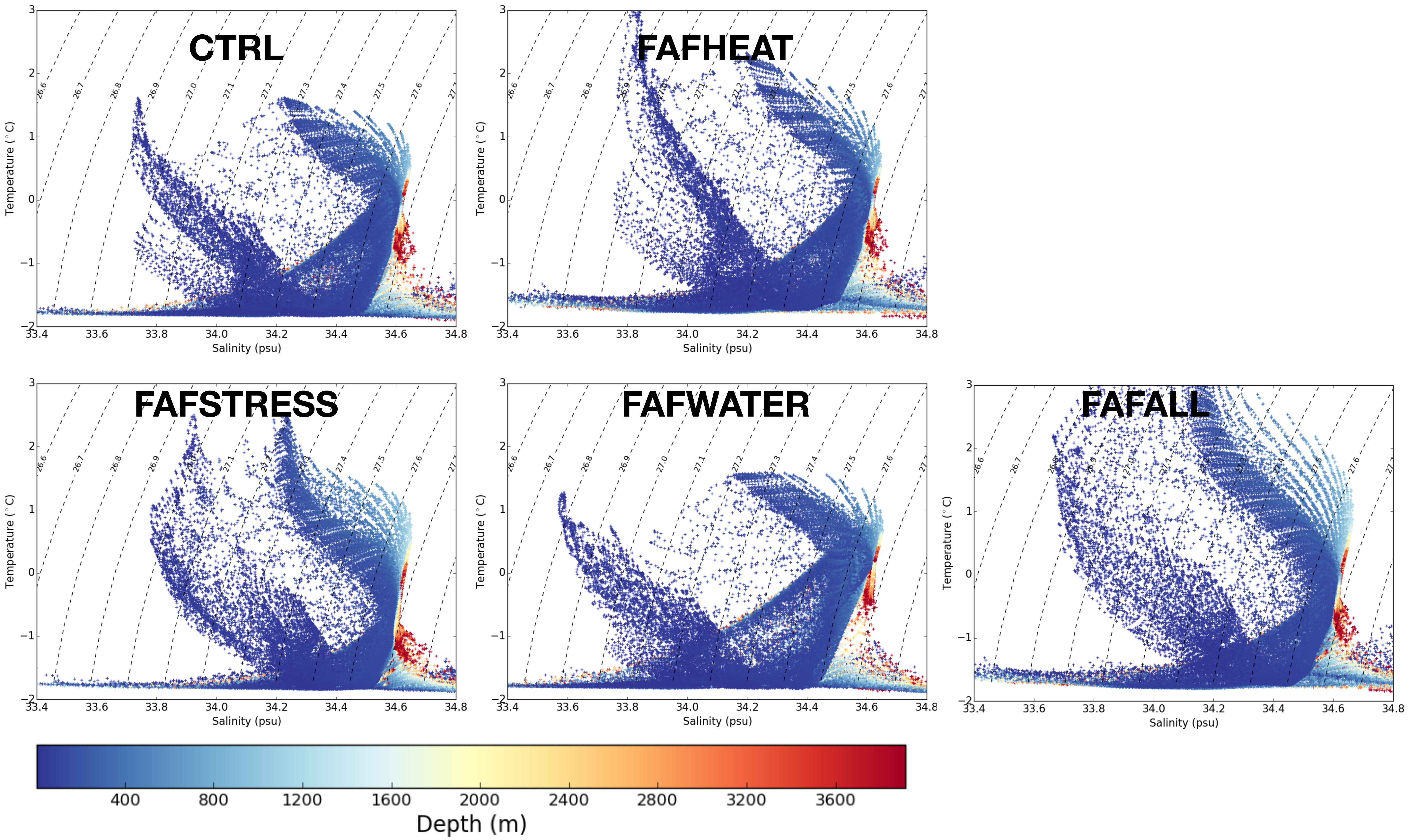
Changes in water masses: Weddell Sea

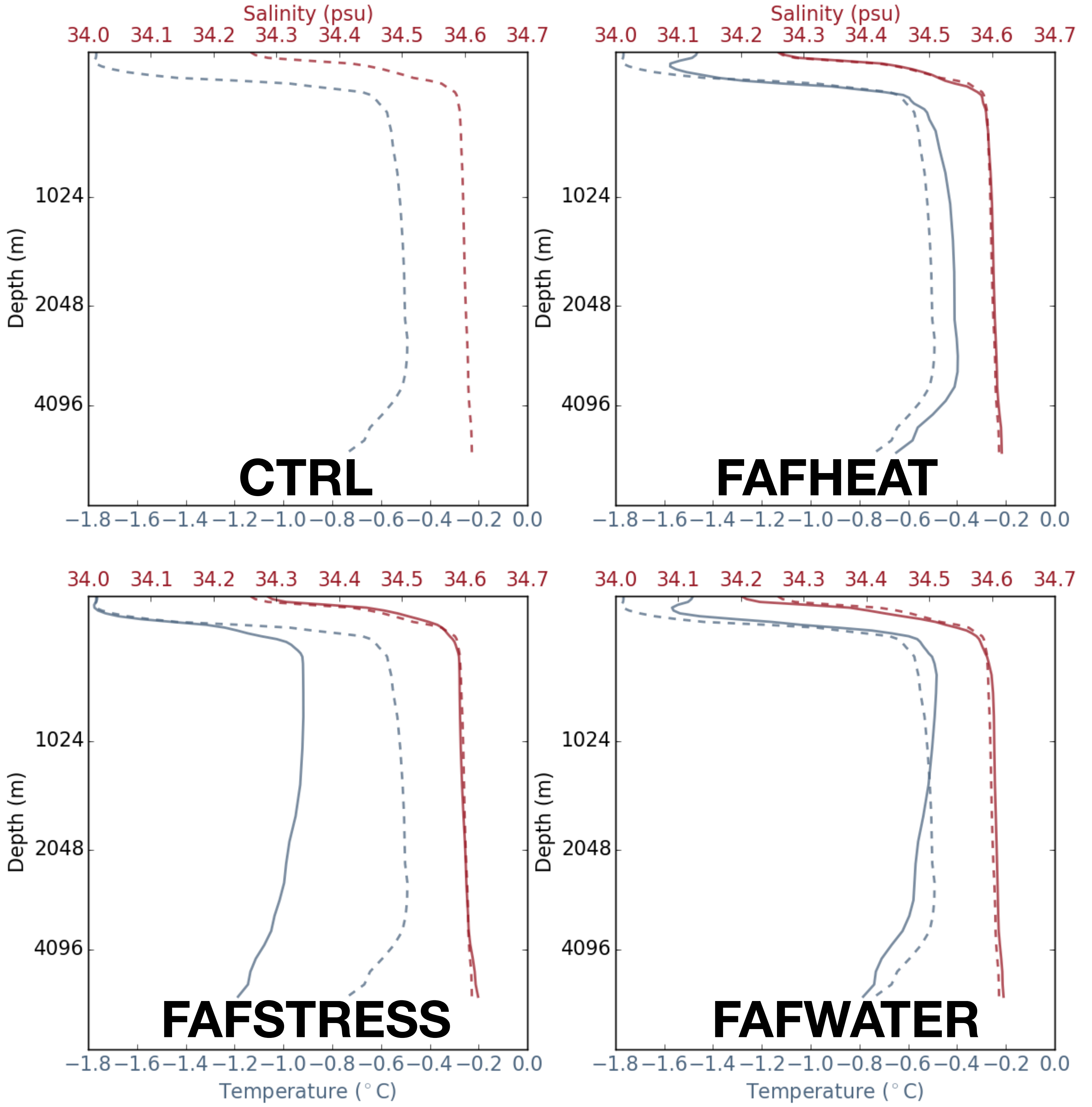




- **FAFSTRESS:** Larger polynyas create denser (colder & saltier) Weddell Sea Bottom Water (WSBW)
  - subsurface water gets colder while surface waters become warmer; convection carry cold water downward
- **FAFHEAT/FAFSTRESS/**Shutdown of polynyas induces lightening (warming/freshening) of interior waters
  - deepening thermo/halocline & increased salt deficit: freshwater content in the ML

Changes in water masses: Ross Sea





- **FAFWATER**: shutdown of polynyas
  - freshening & warming:
    - High-salinity Shelf Waters (HSSW)
    - Ross Sea Bottom Water (RSBW)

Summary

- High-latitude Southern Ocean responds differently to individual forcing:
  - Changes in Westerlies dominate -> increased AABW formation
  - Addition of freshwater/reduction of heat loss -> opposite response
- Increased convection under wind stress perturbation (Frankcombe et al 2013, Kuhlbrodt et al 2015, Saenko et al 2015)
- Shutdown of convection due to freshwater (*e.g.* Gregory 2000, Huang et al 2003, De Lavergne et al 2014)
  - FAFMIP/CMIP5 do not include ice-shelf/sheet melting - underestimate freshwater perturbation
- Compare AABW response in ACCESS-OM2 with AOGMCs from Gregory et al. (2016)

Process-based analysis: FAFALL