Ocean heat uptake and redistribution in ACCESS-OM

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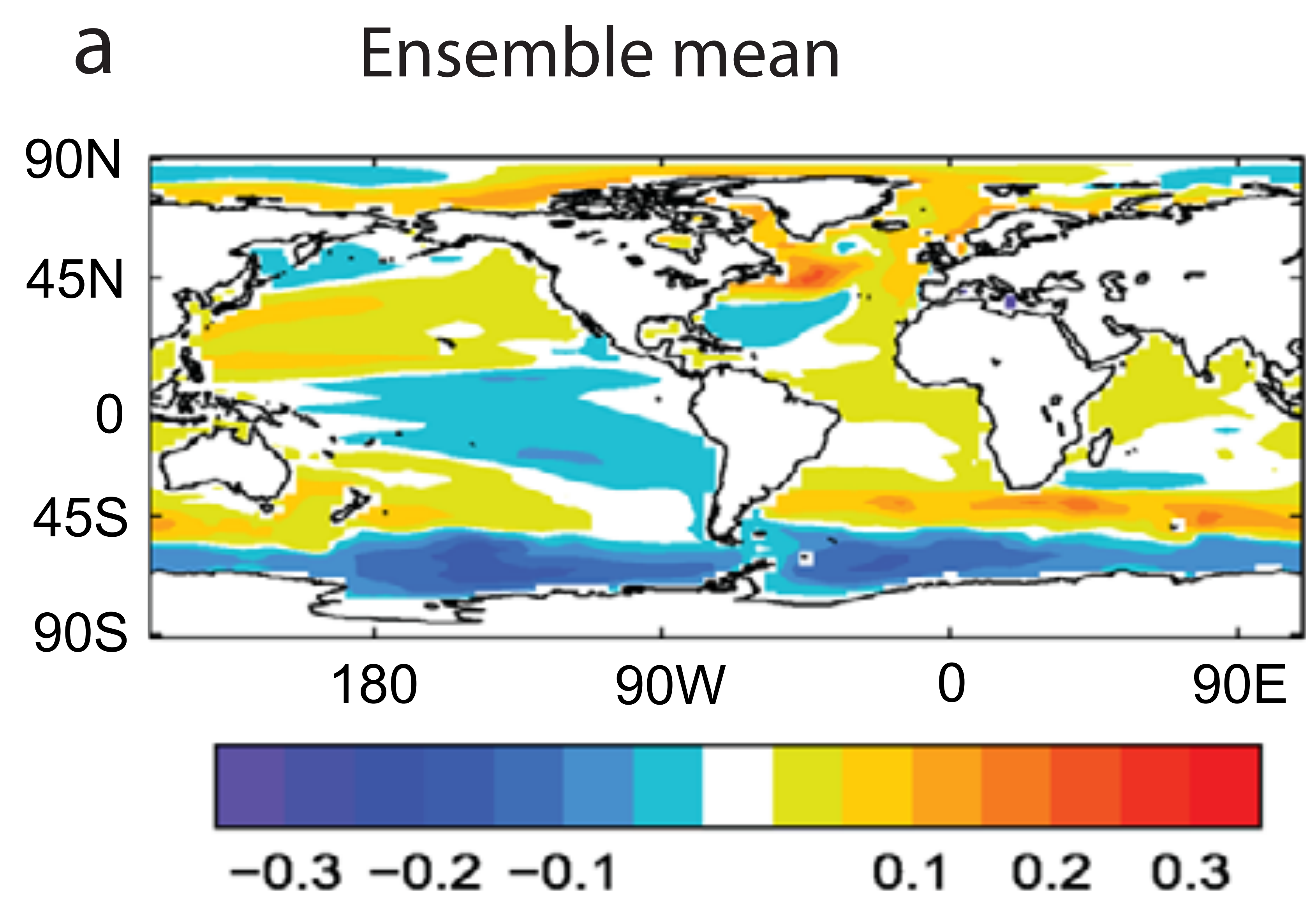
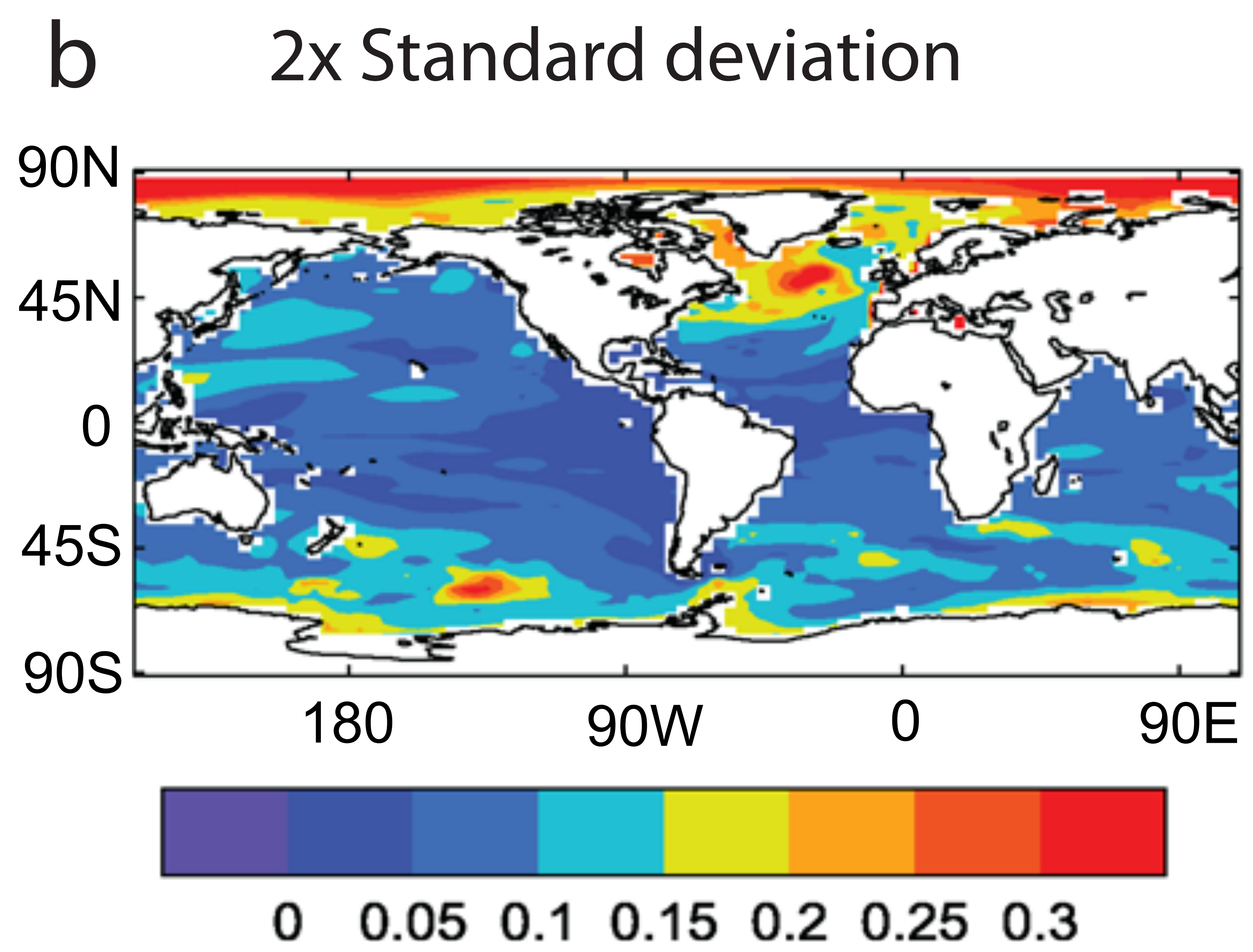
DP project: Understanding spread in regional sea level rise projections: the role of changing ocean properties and circulation processes

Motivation





Bouttes & Gregory (2014)

- Large uncertainty in **sea level rise projections** from AOGCMS - **Ocean heat uptake** and vertical/lateral **transport**

- Long standing scientific question of great societal importance (WCRP Grand Challenge Regional Sea Level and Coastal Impacts)

- Lack **mechanistic view** of the **physical processes** (diagnostics & international coordination) => CMIP6/FAFMIP (Flux-Anomaly-Forced MIP) and OMIP

OGCMs: inter model spreading under CORE-II forcings

Global mean ocean temperature

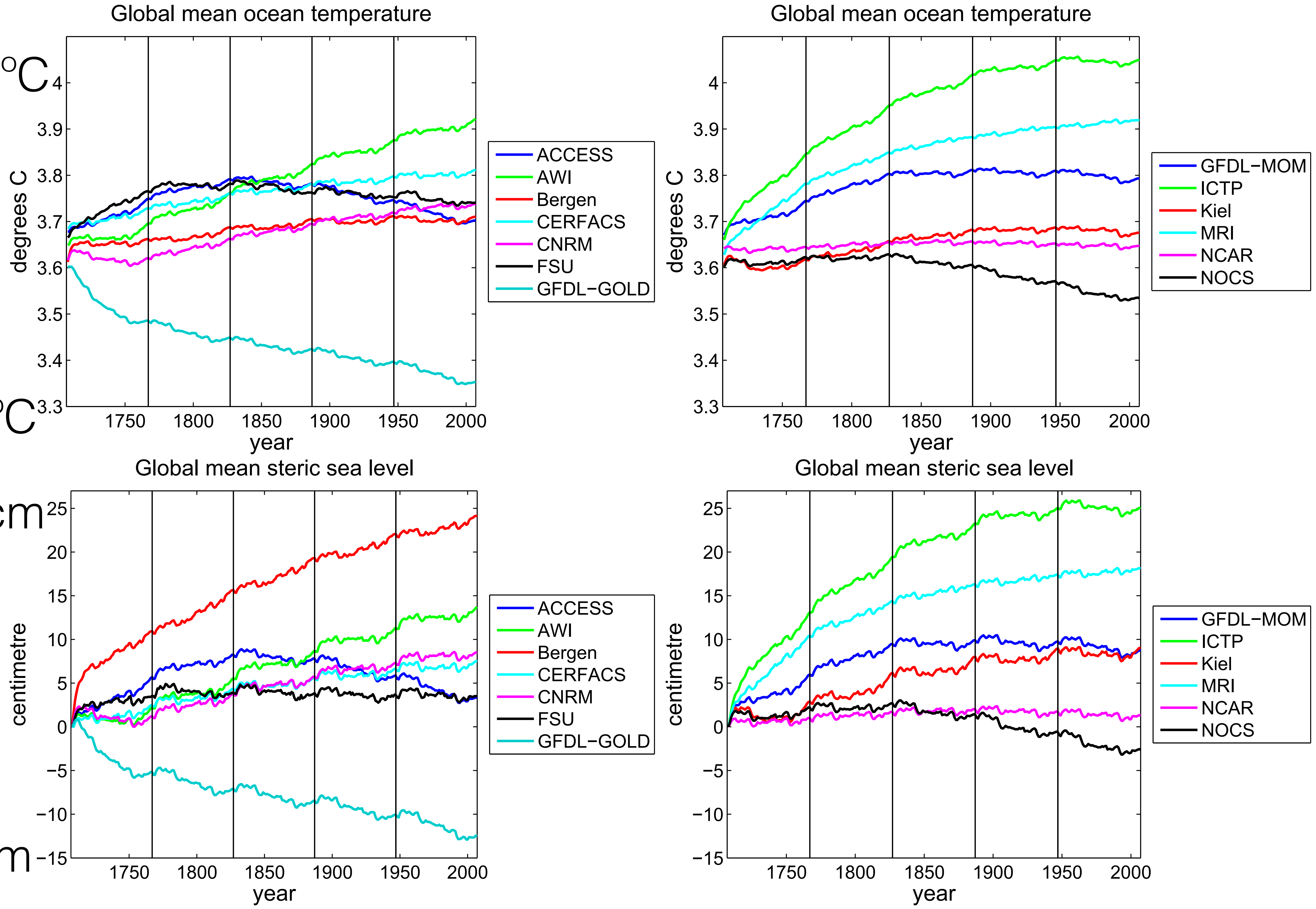
4°C

3.3°C

Global mean steric sea level

25 cm

-15 cm



Griffies et al (2014)

Objectives

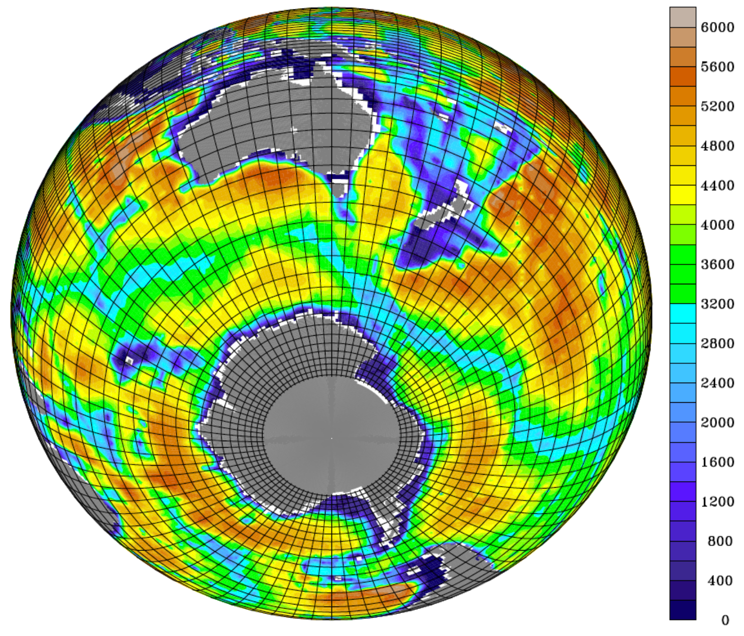
Aim to investigate the role of physical processes in the ocean heat uptake and redistribution in ACCESS ocean-sea ice model

- identify the **global heat balance** over **interannual to decadal** timescales and its regional mechanisms of heat transport

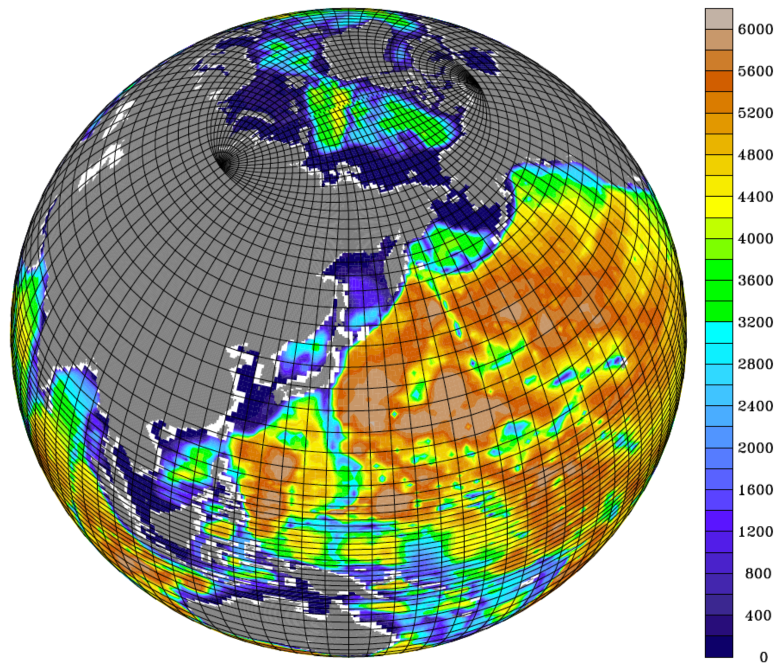
- **process-based view** of ocean response to different prescribed surface forcing (CORE-II/JRA-55)

Model configuration

Mercator grid in south



Tripolar grid in north



ACCESS Ocean Model

- Ocean/sea-ice component of the Australian Community Climate and Earth System Simulator (ACCESS)
- NOAA/GFDL MOM5 ocean
- LANL CICE5 sea ice model
- CERFACS OASIS-MCT coupling sytem
- Nominal 1 degree resolution with refinements at equator and high latitudes
- 50 vertical levels
- Sea Surface Salinity restoring 300 days/50 m

Experiments

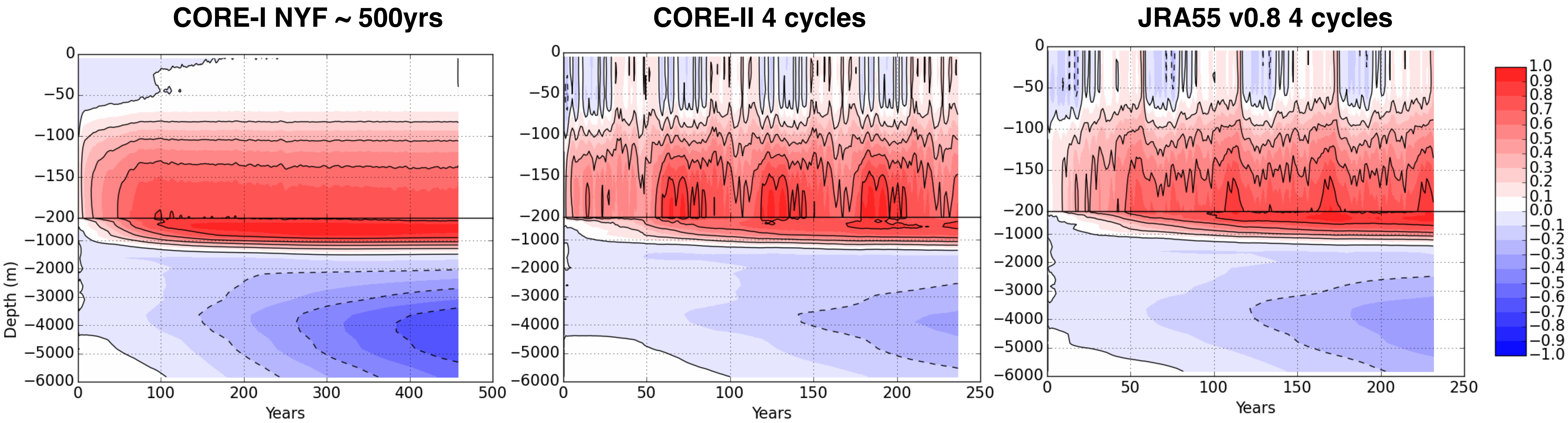
Following CORE-protocol

- Griffies et al 2009: CORE-I NYF
- Danabasoglu et al 2014: CORE-II/JRA-55
    - CORE-II (Large & Yeager 2009): 9 papers Special Issue in *Ocean Modelling*
    - JRA-55: Japanese reanalyse (+ resolution, + updated)

Experiment	Forcing	Period	Length of simulation
CORE-I NYF	CORE-II Normal Year Forcing	Climatology	500 years
CORE-II IAF	CORE-II Inter annual Year Forcing	1948 - 2007	300 years (5 cycles)
JRA-55	JRA-55 v0.8	1958 - 2015	290 years (5 cycles)

Results

Globally-integrated temperature

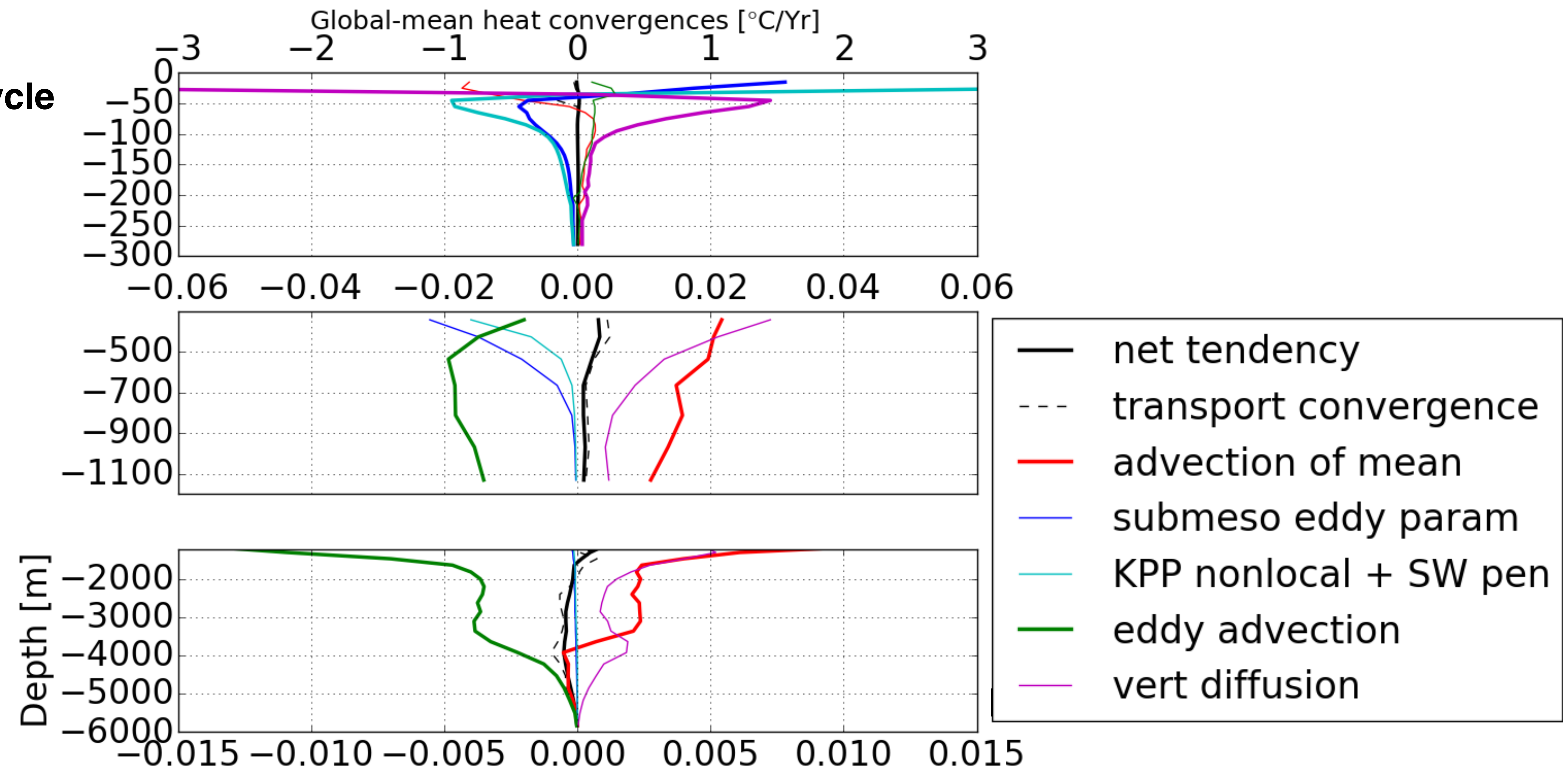


- **Ocean Heat Budget** - temperature evolution diagnosed online by several processes:
    - Advection
    - Diffusion
    - Vertical mixing
    - Surface fluxes

$$\rho_0 C_p \frac{\partial \Theta}{\partial t} = \nabla . (F_{ADV} + F_{DIFF} + F_{VM} + F_{SF})$$

Globally integrated heat budget

CORE-II IAF   4th cycle

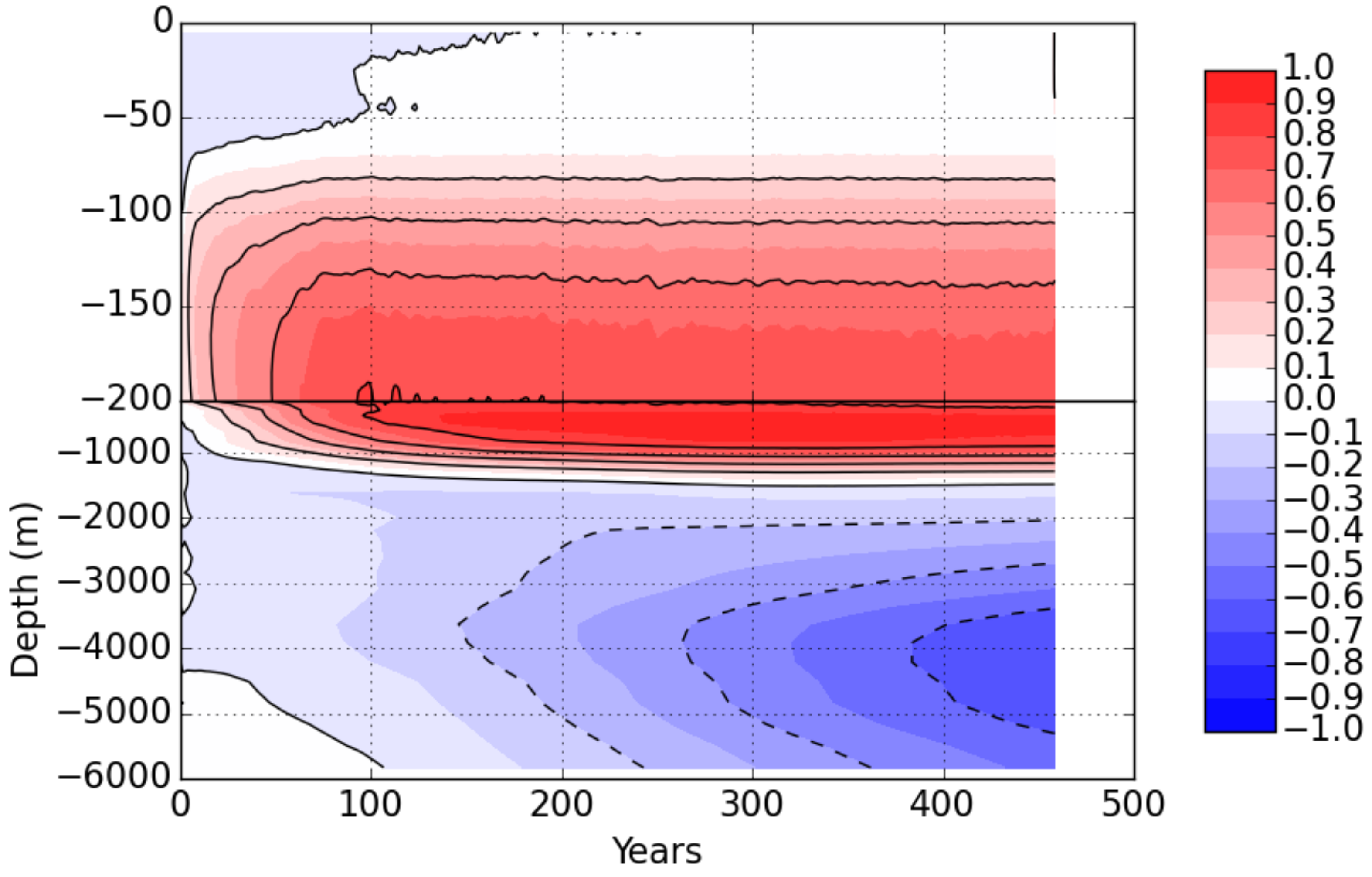


(-) Cooling (+) Warming

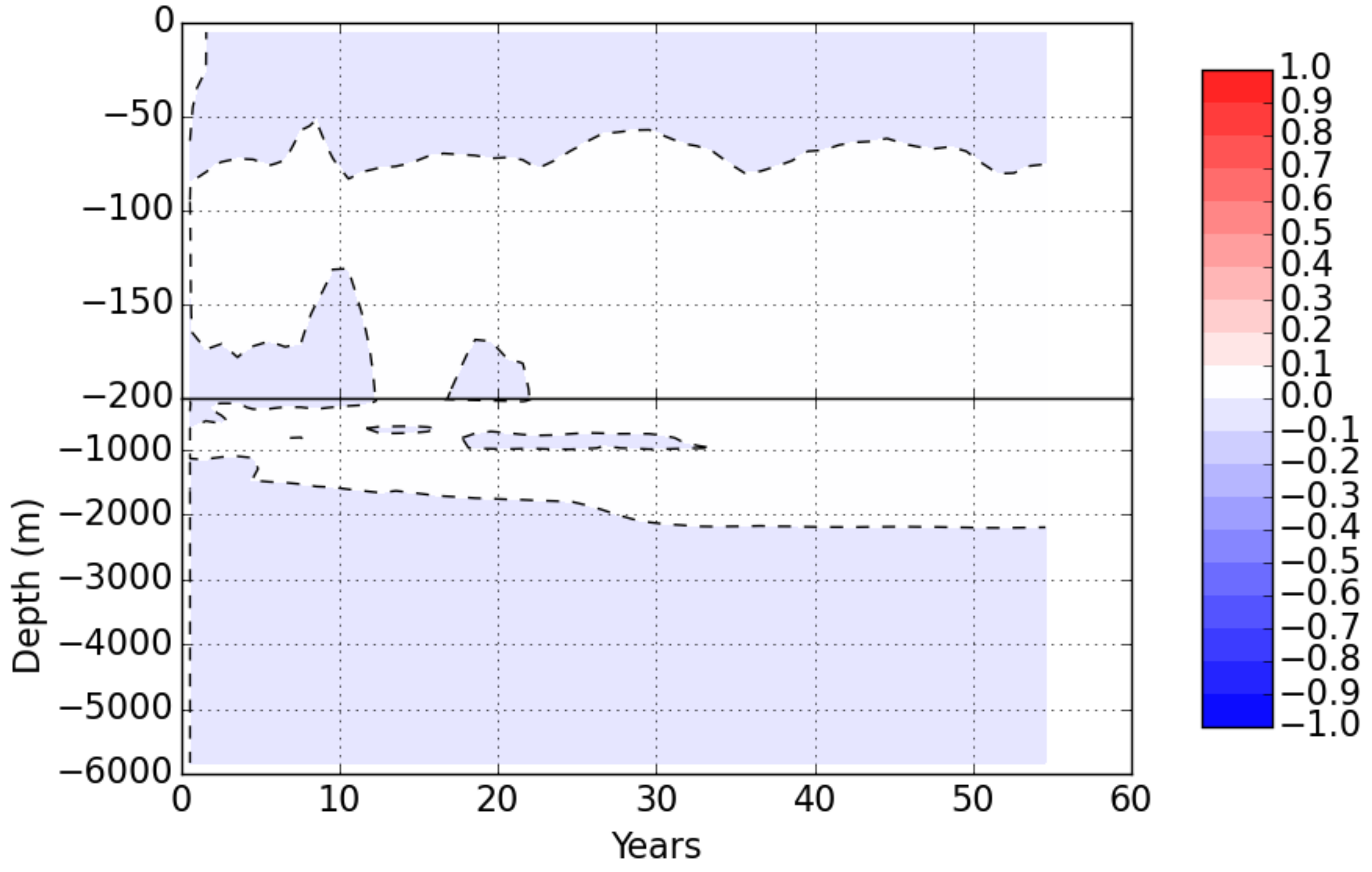
- Top 300 m: **ML physics** **X** **VERTICAL DIFFUSION**
- Ocean interior: **EDDY ADVECTION** **X** **MEAN ADVECTION** + **VERT. DIFFUSION**

De-trending experiment

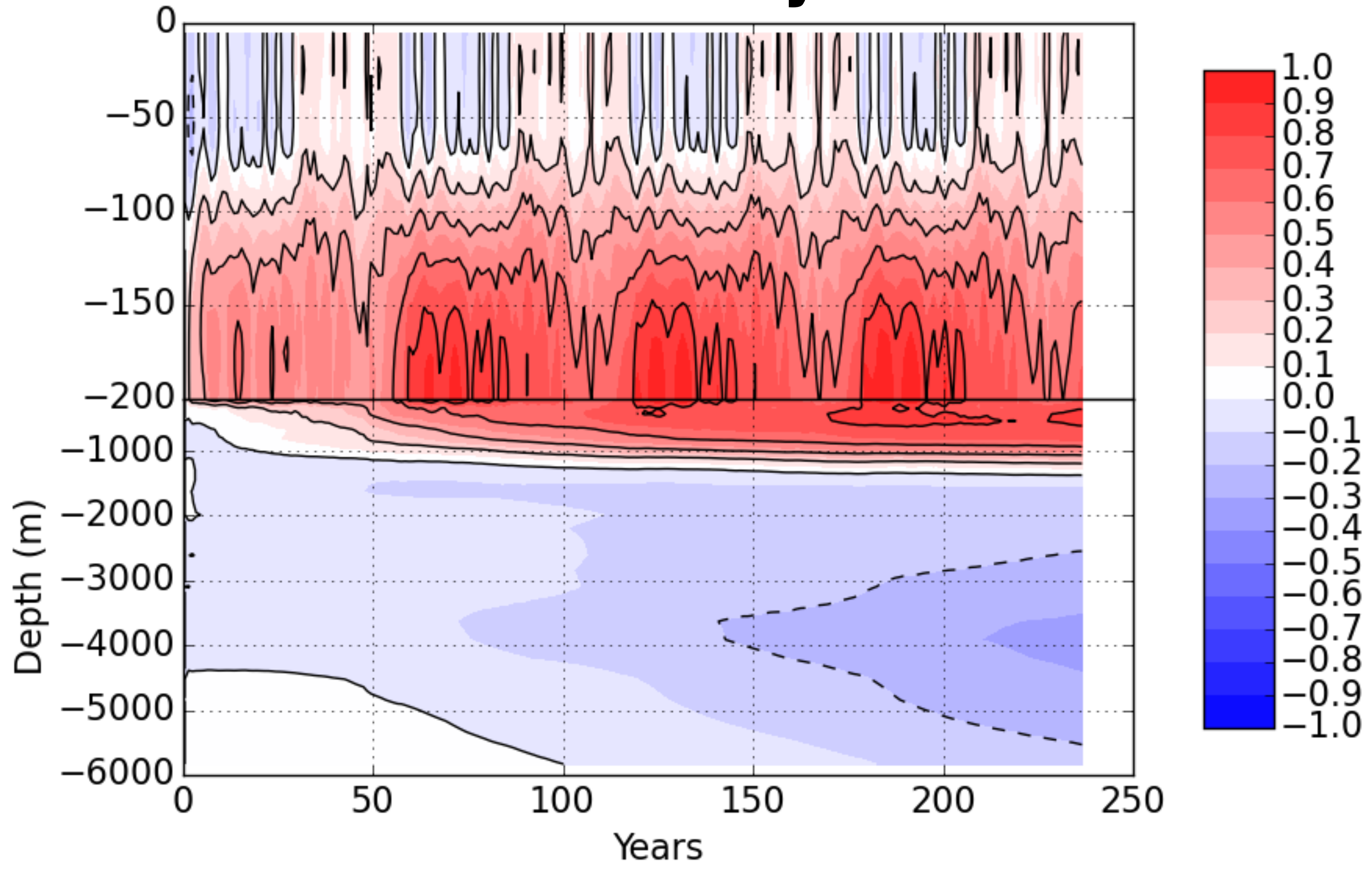
CORE-I NYF 500yrs run



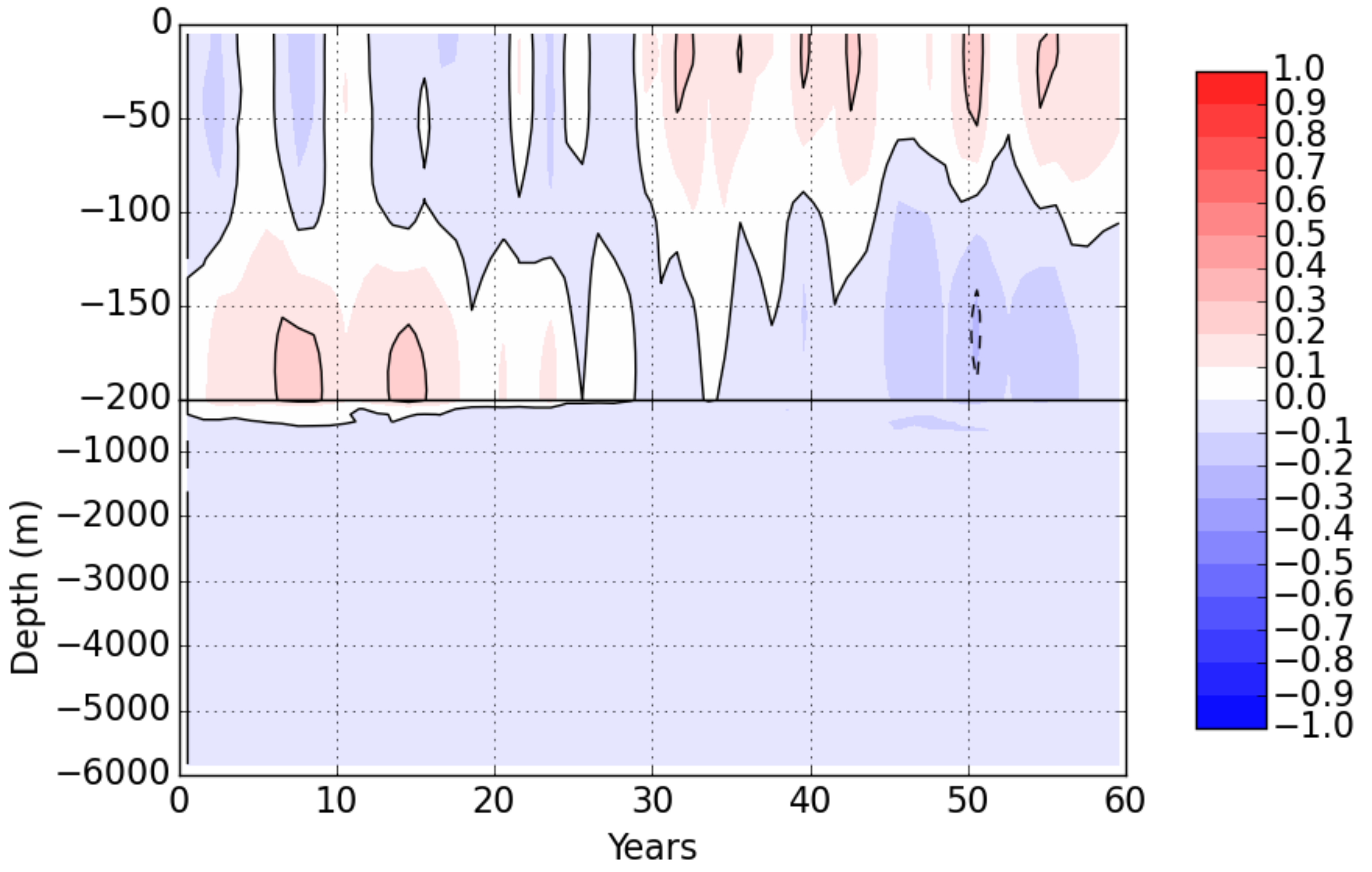
Control run started from NYF 500yrs run



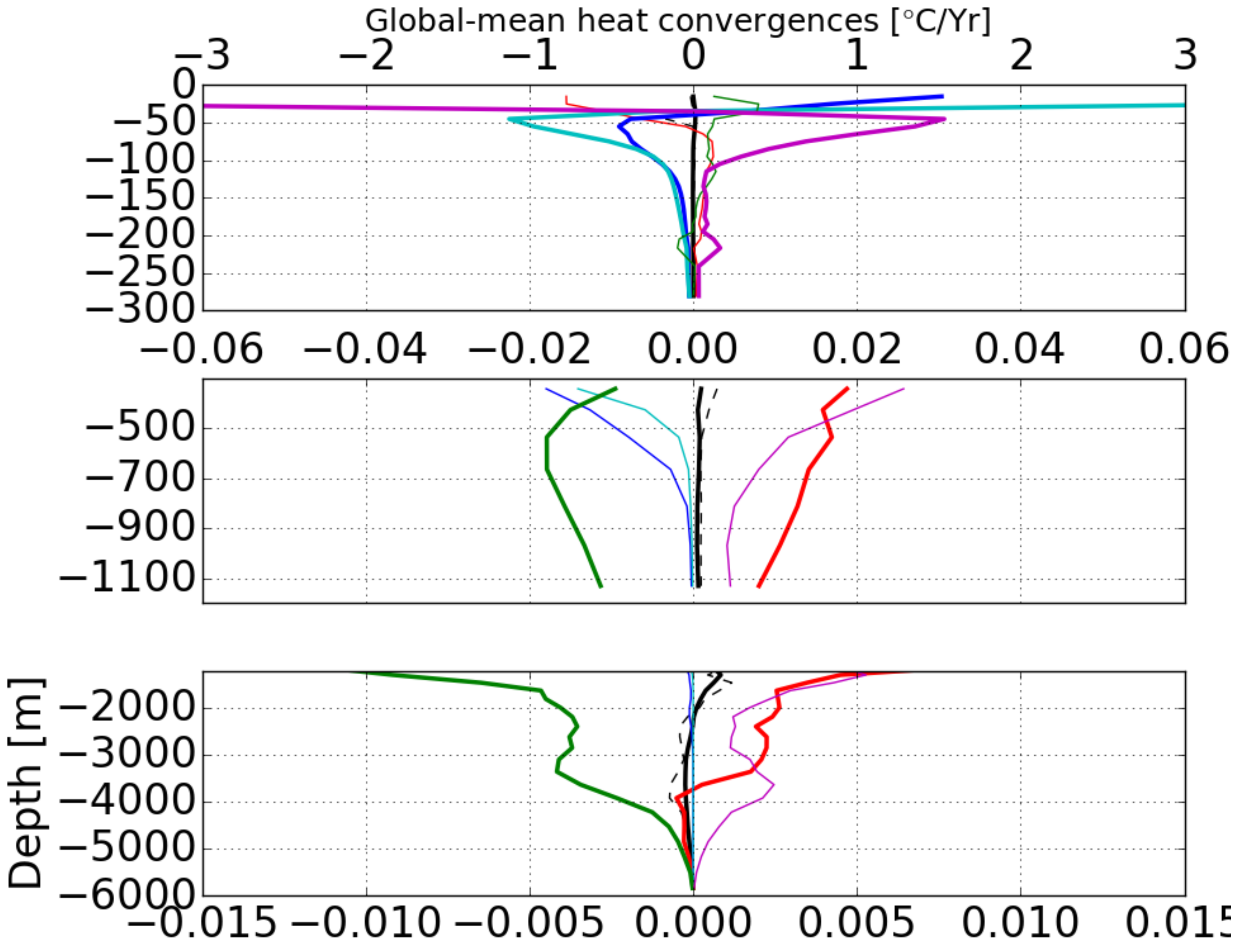
CORE-II 4 cycles



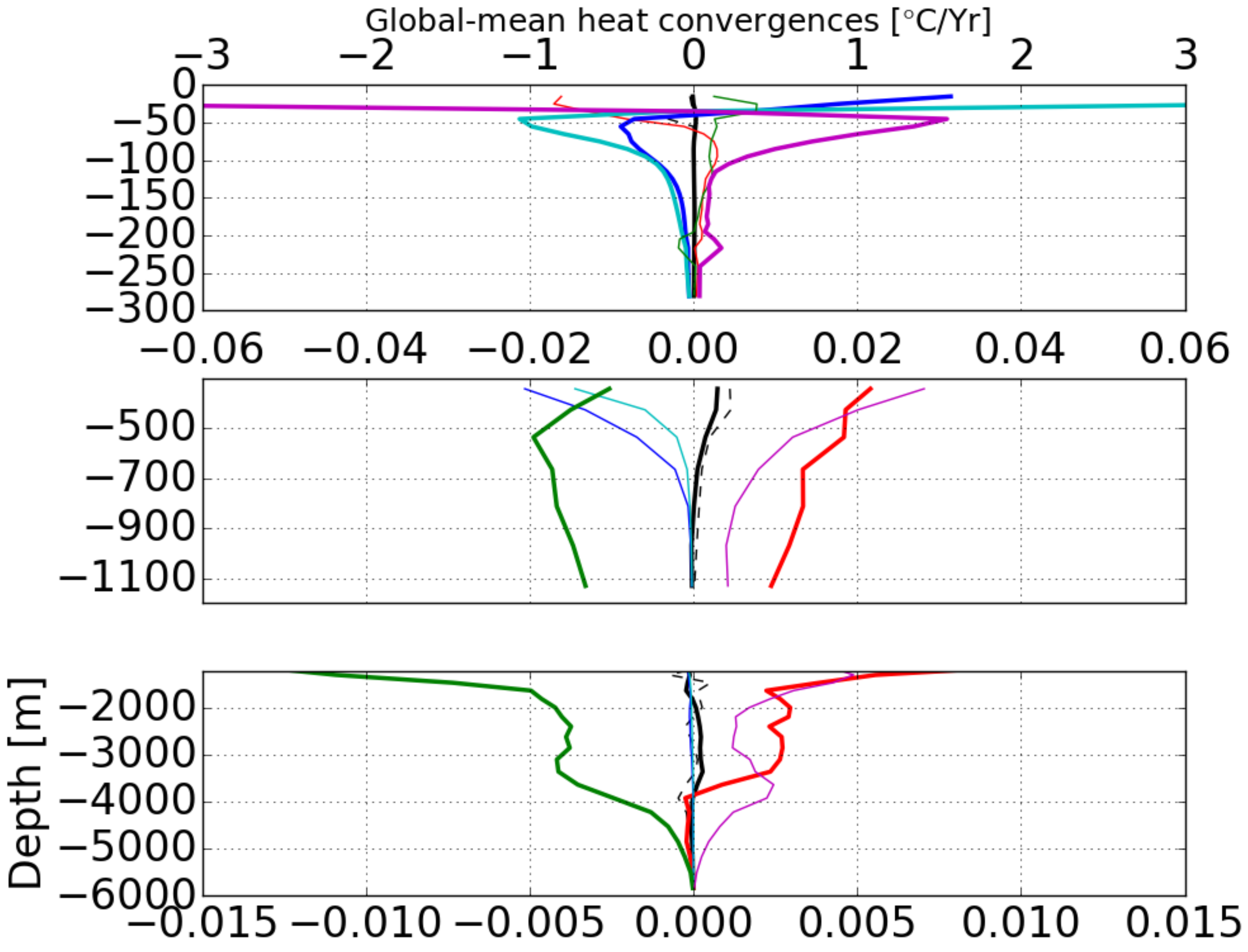
CORE-II IAF started from NYF 500yrs run



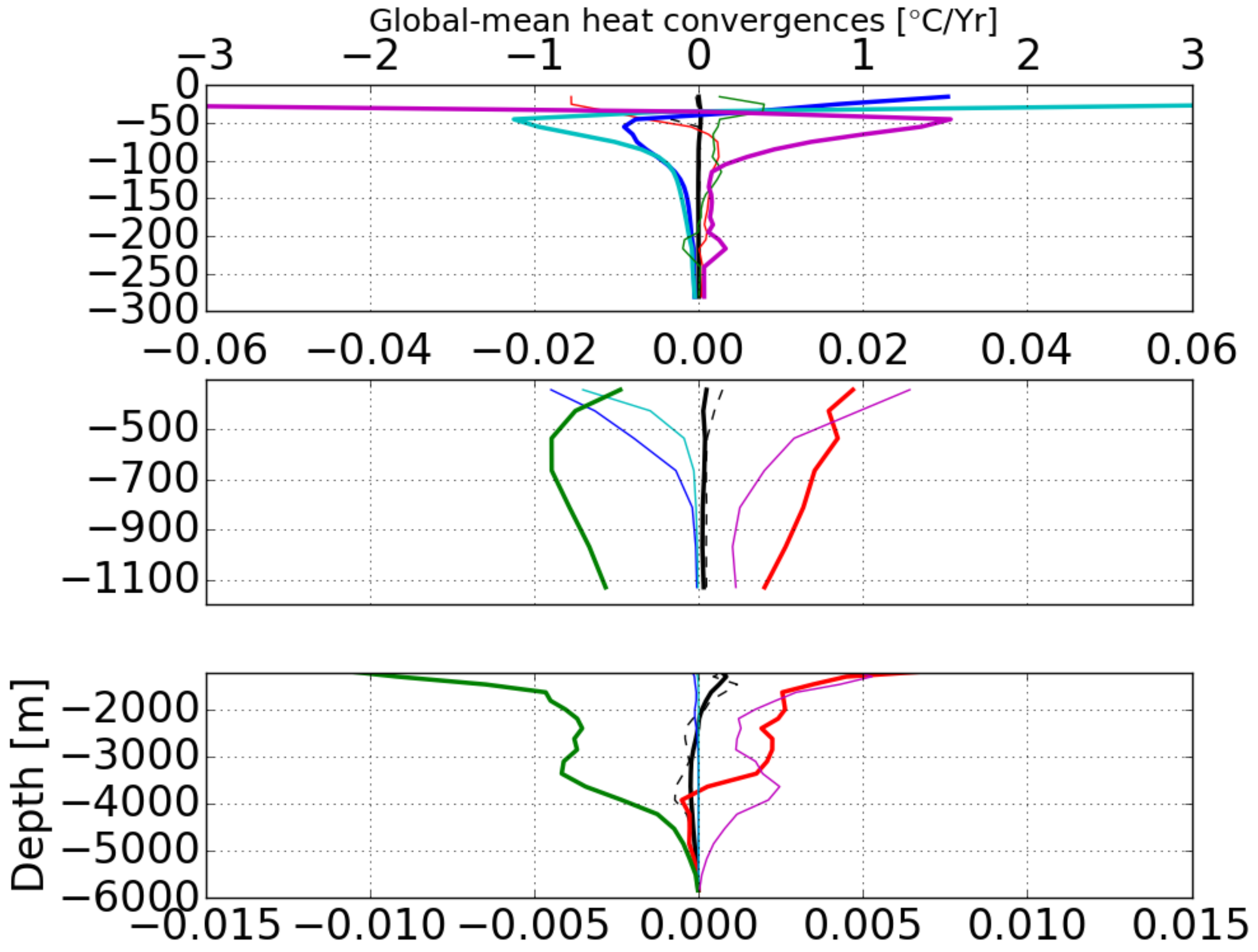
Control run started from NYF 500yrs run



CORE-II IAF started from NYF 500yrs run



Control run
started from
NYF 500yrs run



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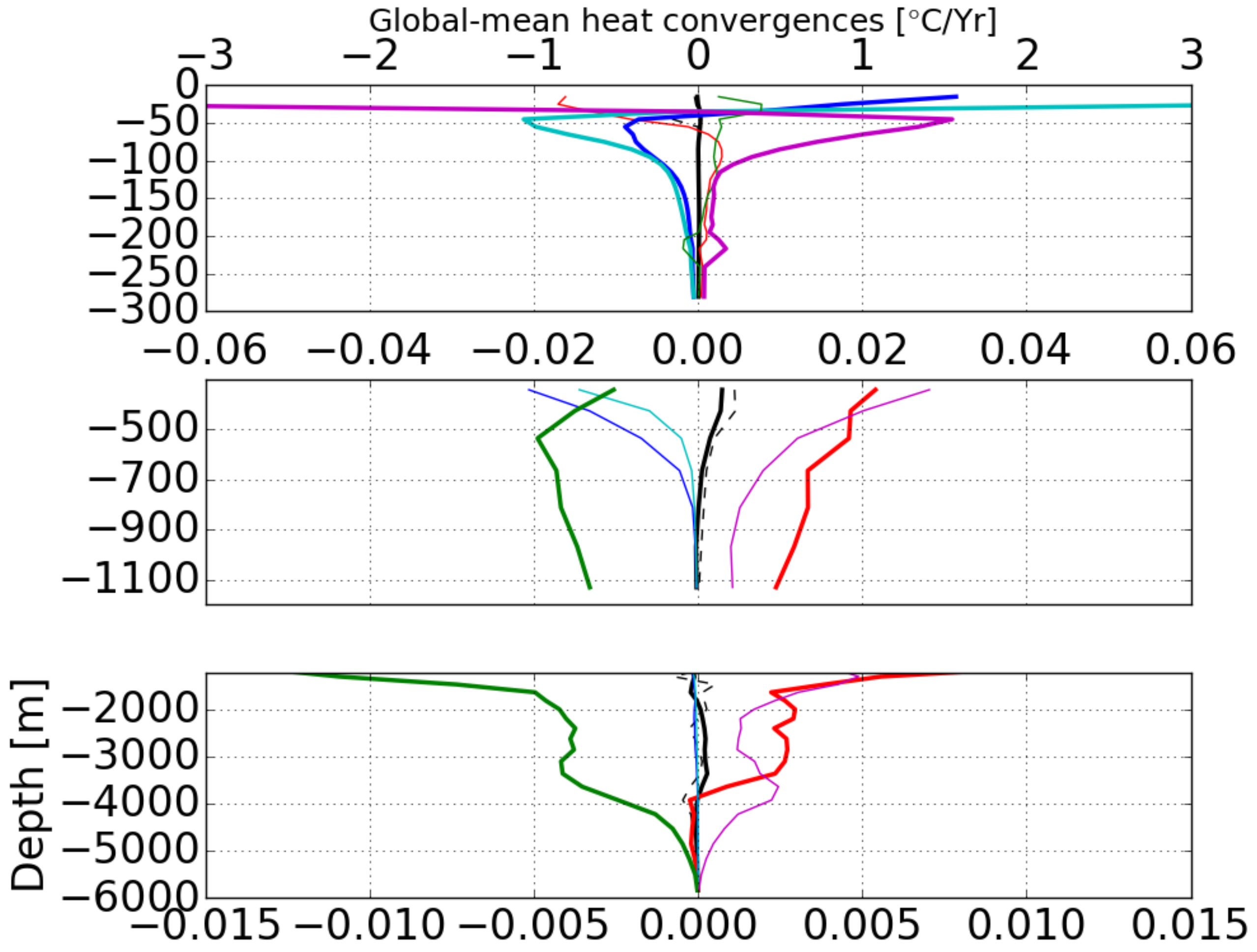
CORE-II IAF
started from
NYF 500yrs run



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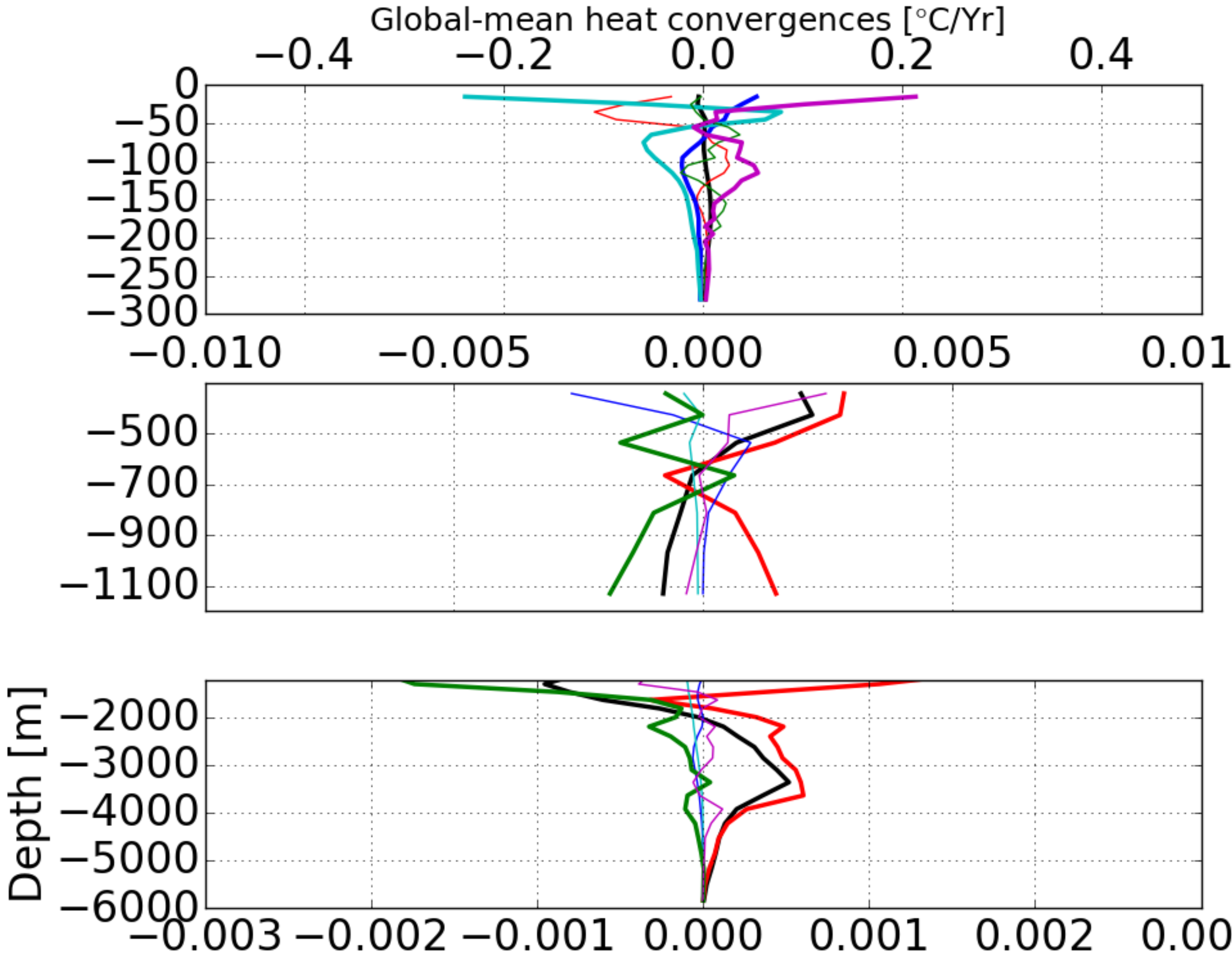
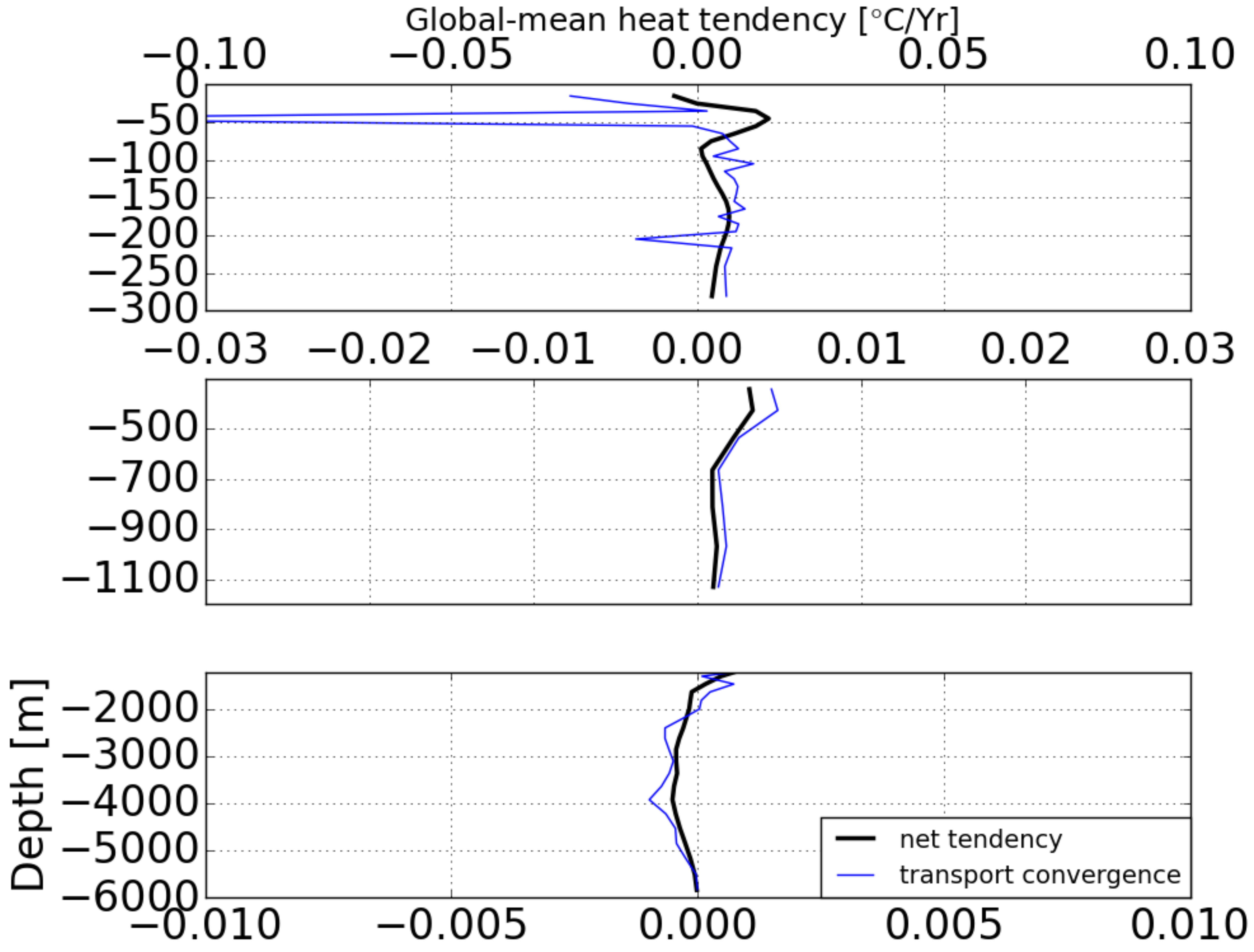
CORE-II de-drifted



But there is something going wrong with the heat budget:

$$\rho_0 C_p \frac{\partial \Theta}{\partial t} = \boxed{\nabla . (F_{ADV} + F_{DIFF} + F_{VM} + F_{SF})}$$



But there is something going wrong with the heat budget:

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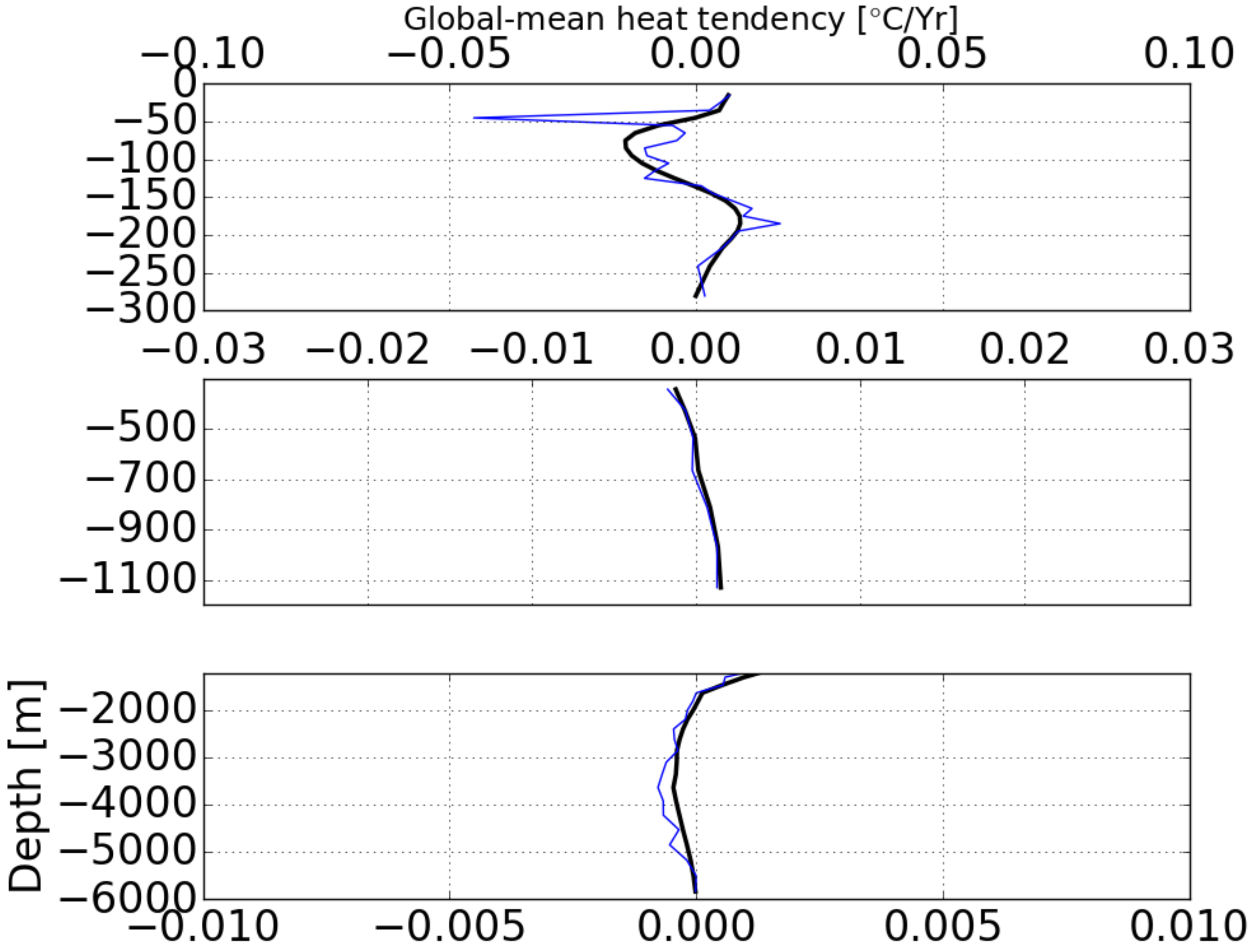
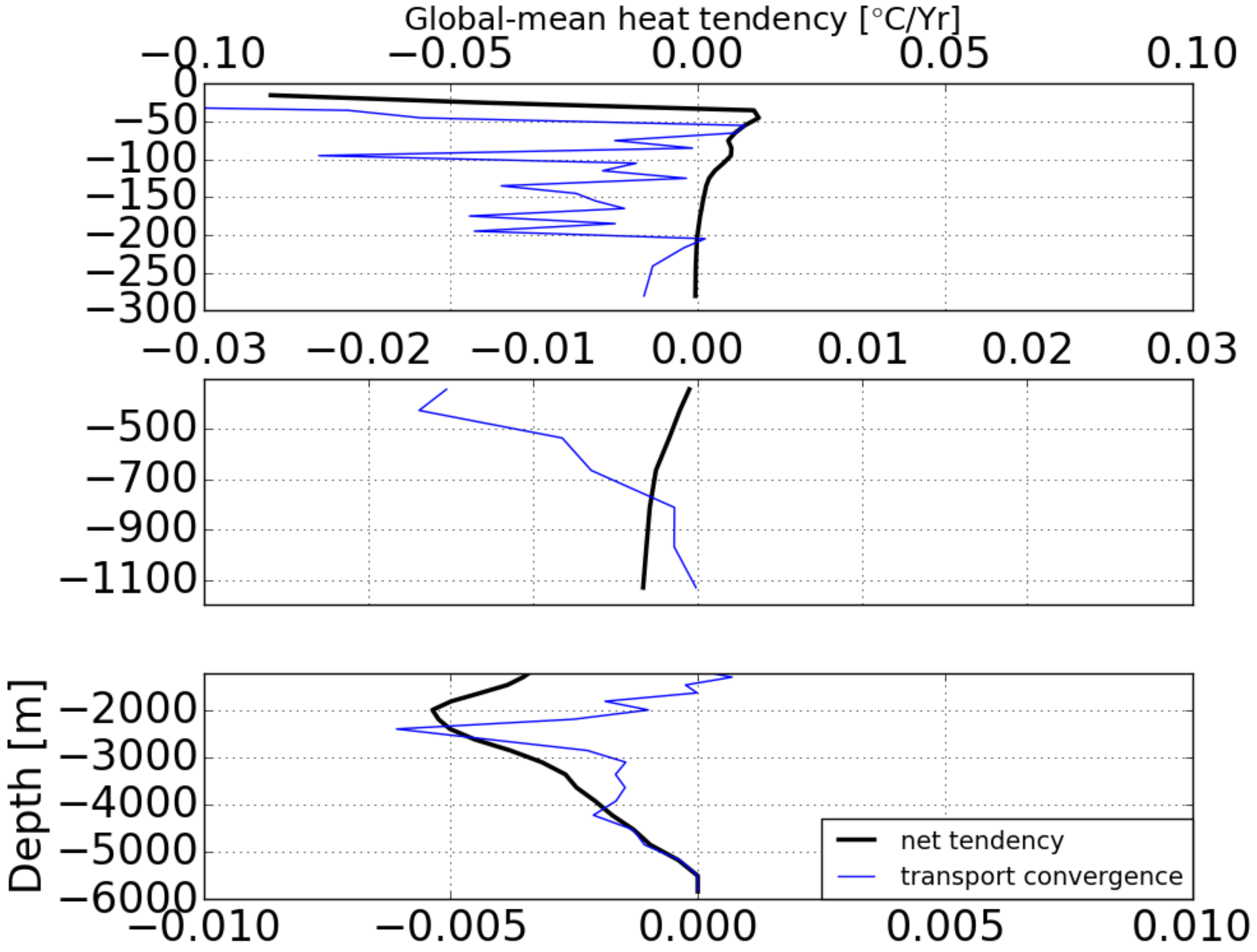
20°S - 20°N

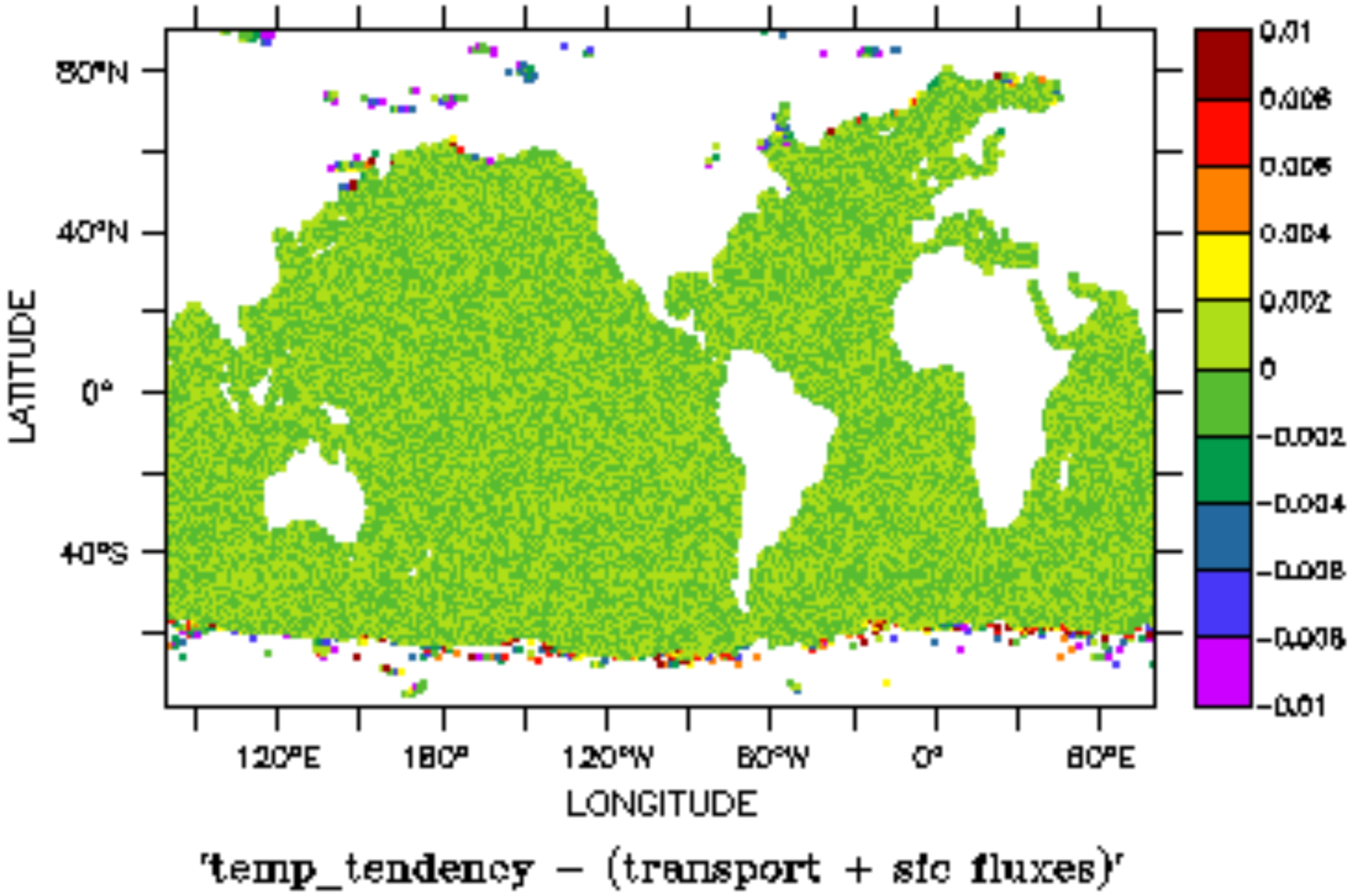


60°S - 75°S

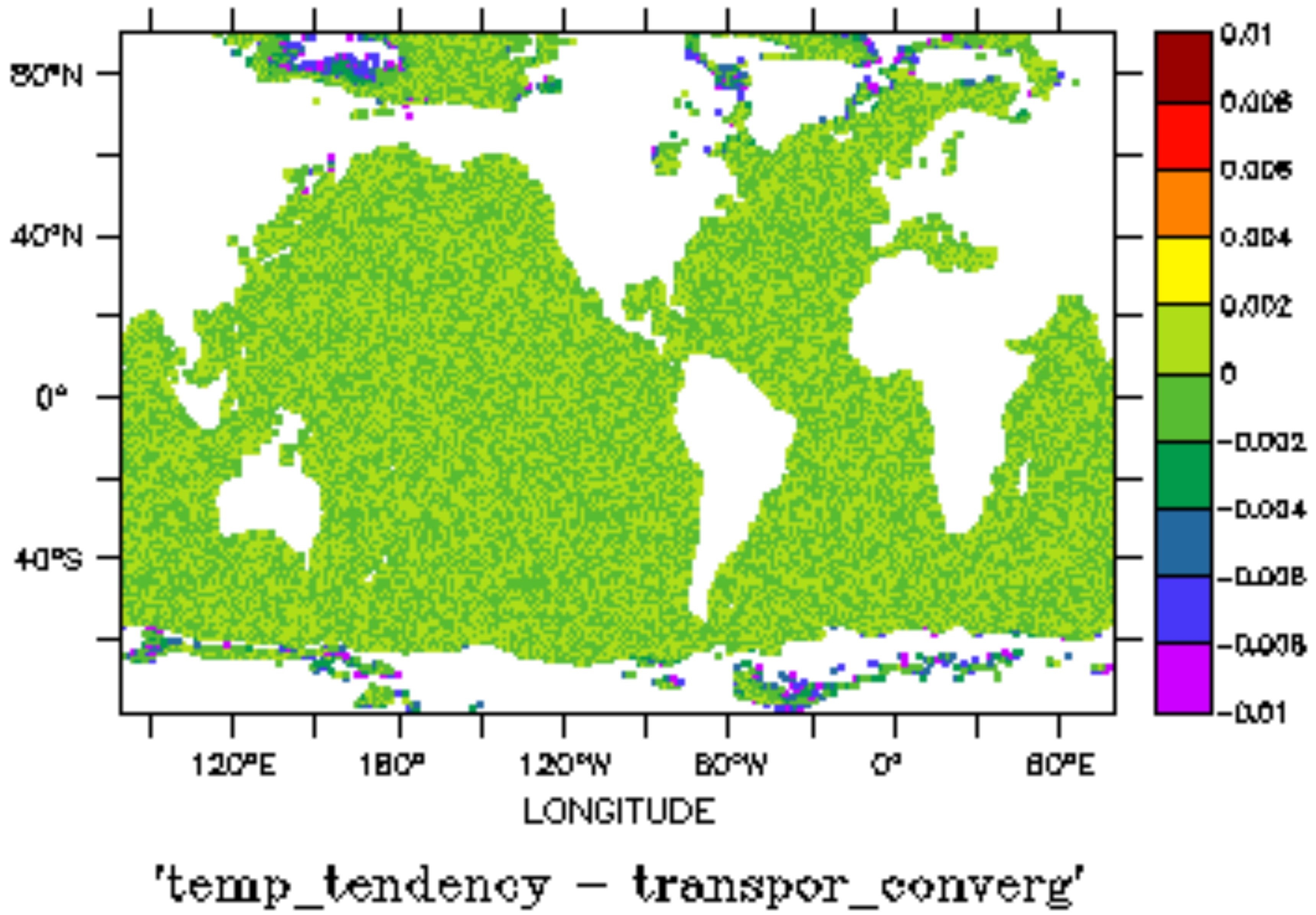


$$\rho_0 C_p \frac{\partial \Theta}{\partial t} = \nabla . (F_{ADV} + F_{DIFF} + F_{VM} + F_{SF})$$

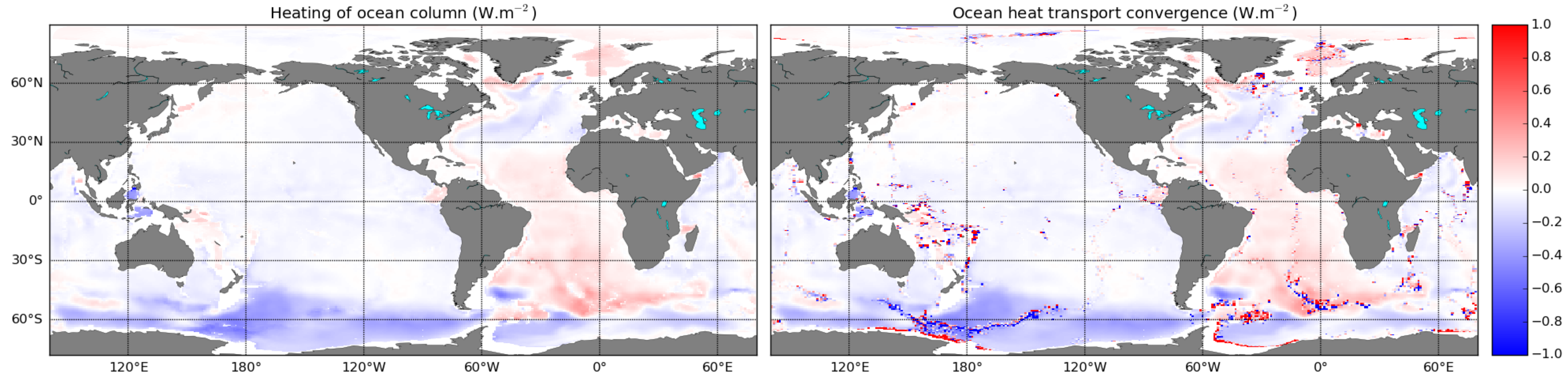
K=2



K=5



$$\int_{2000\ \mathrm{m}}^{3000\ \mathrm{m}} \rho_0 C_p \frac{\partial \Theta}{\partial t} = \nabla.\left(F_{ADV} + F_{DIFF} + F_{VM} + F_{SF}\right)\ \mathrm{dz}$$



Net sfc heat flux x area = dOHC/dt

What error should be:

Error in heat content change = -1.27185524720000000E+11 J.

Error in rate of heat content change = -1.35515319100958589E-10 W/m^2.

What error actually is:

Change in ocean heat content over time interval = 5.21455393906360320E+18 J.

Error in heat content change = 2.220E+15 J.

Error in rate of heat content change = 7.420E-05 W/m^2.

Next steps…

- Switch to GFDL-MOM for a conserving heat model
- Spin up + control + historical runs with JRA-55: using Repeat Year Forcing
- Use de-trending runs to investigate interannual to decadal variability with the OHB
- Implement the Water Mass Transformation framework
    - links between ocean circulation processes and water masses changes
- Idealised experiments to study climate change - using FAFMIP perturbations

Thanks!

Thermodynamic Framework

1st paper

Ocean Heat Budget Analysis

2nd paper

3D Water Mass Framework

3rd paper

FAFMIP experiments: momentum, heat

- Investigate the the link between ocean circulation processes, its driving mechanisms and water masses changes using a Water Mass Transformation (WMT) framework (e.g. Zika et al., 2012, 2013; Groeskamp et al., 2014) - historical runs

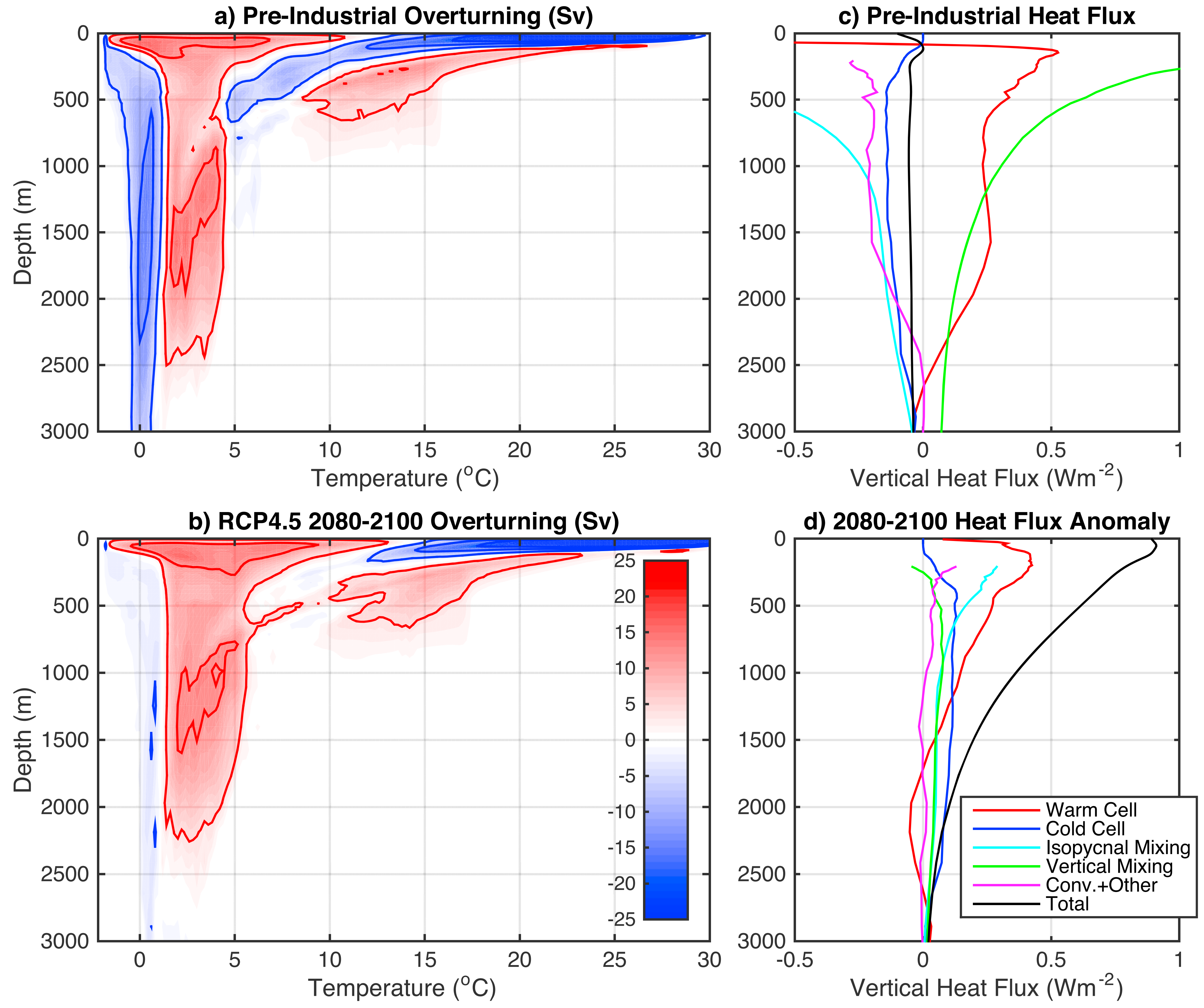
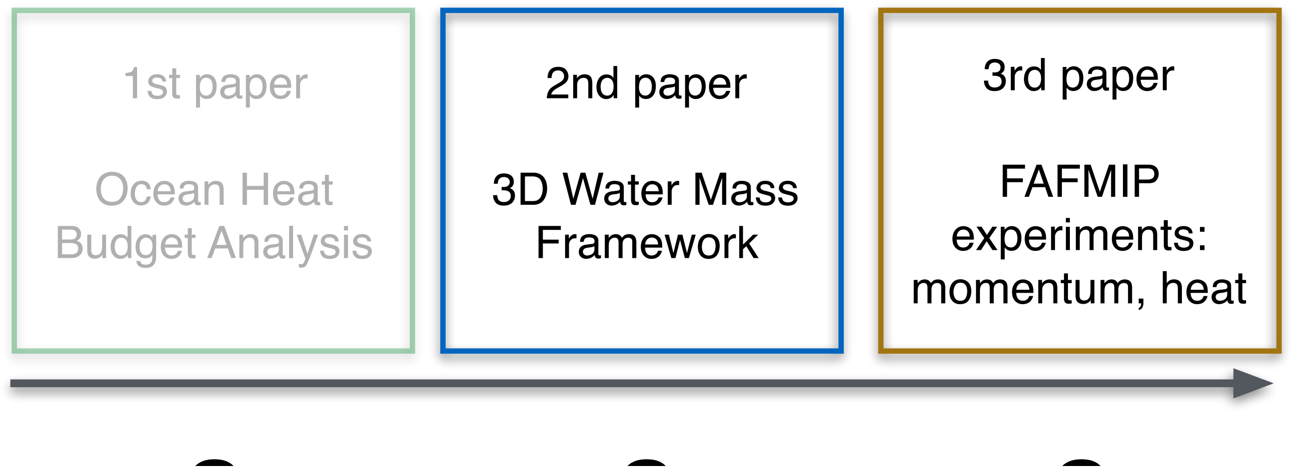


Figure 2. (a and b) Accumulated vertical volume transport in temperature coordinates at each depth level of CCSM4 including both the Eulerian and eddy-induced velocities in Sverdrup (Sv). Negative (blue) components circulate in an anticlockwise direction. Positive (red) components circulate in a clockwise direction. The cold cell, discussed in the text, is the blue anticlockwise cell that occupies water colder than 1°C. The warm cell is the red clockwise cell (we define the vertical heat transport due to the warm cell as including the anticlockwise cell at temperatures warmer than 4°C and shallower than 800 m). (c and d) Vertical heat flux due to the warm cell (red), the cold cell (blue), background vertical mixing (green), isopycnal mixing (magenta), the sum of all other contributions including parameterized convection (cyan), and the total (black). Shown are averages for years 845 to 875 of the preindustrial simulation (Figures 2a and 2c), the average for years 2080 to 2100 of the RCP4.5 scenario simulation (Figure 2b) and the difference between years 2080 and 2100 of the RCP4.5 scenario simulation and the preindustrial period (Figure 2d).

Zika et al (2015)

FAFMIP/CMIP6 experiments



- FAFMIP experiments: perturbation fluxes of momentum, heat and freshwater extracted from 1xCO2 projections (CMIP5) - applied to both AOGCMs and OGCM

    - Joint OHB + WMT = complete view of heat uptake/transport processes, surface forcing link with ocean circulation and water masses proprieties changes

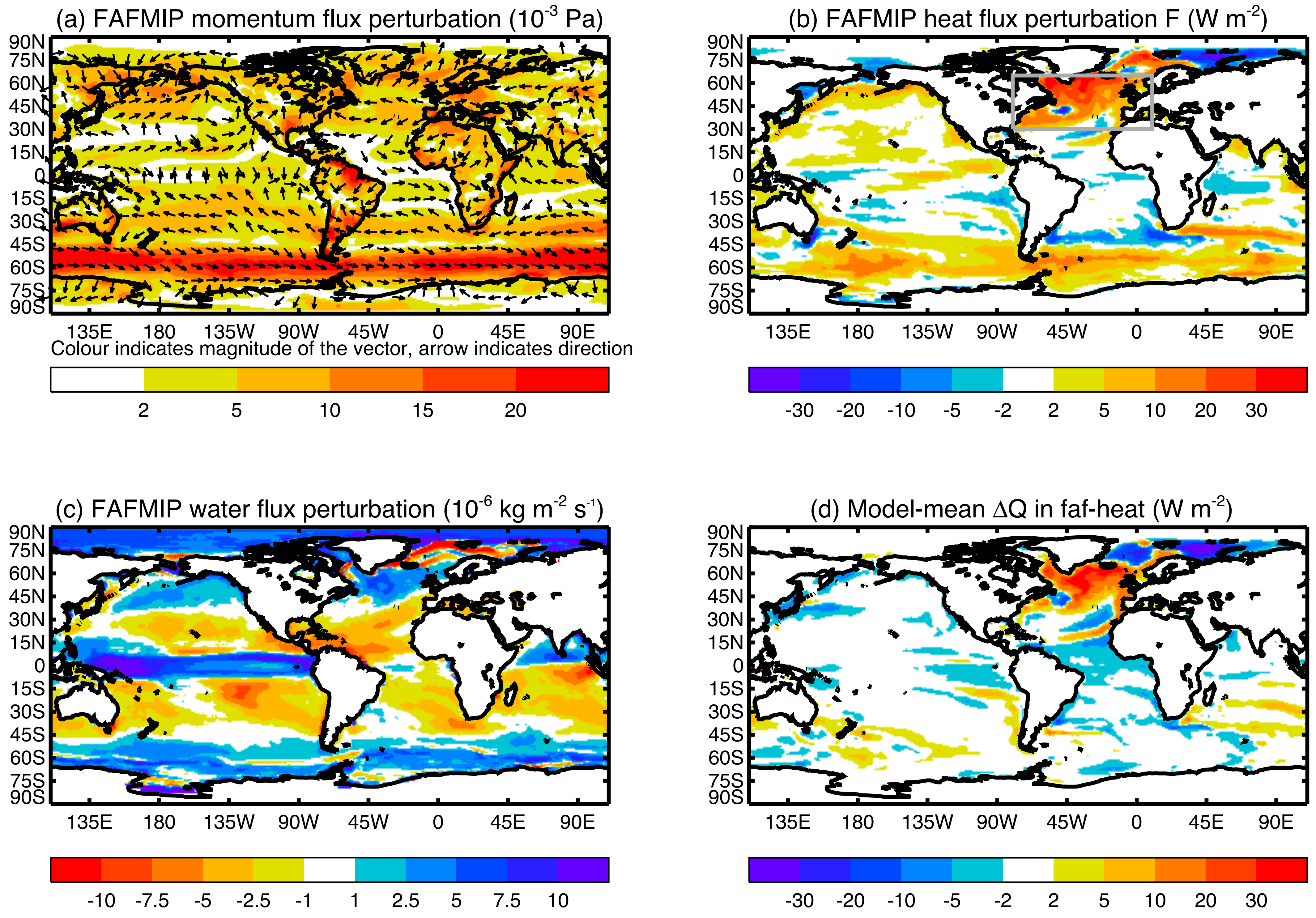
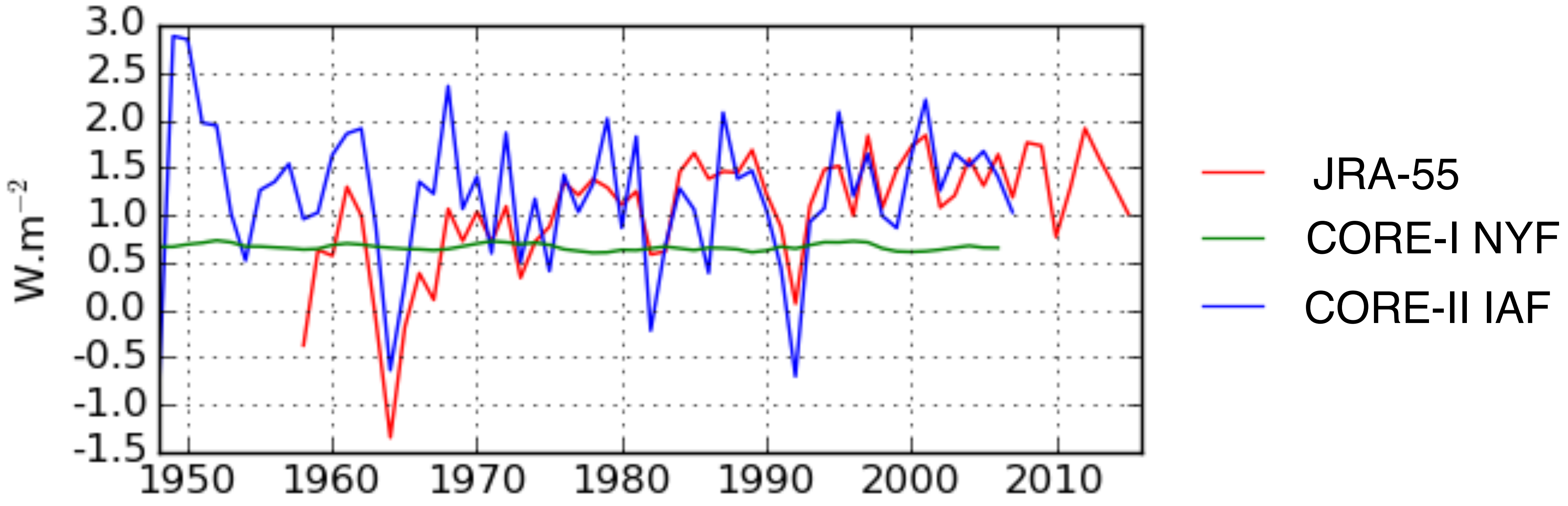


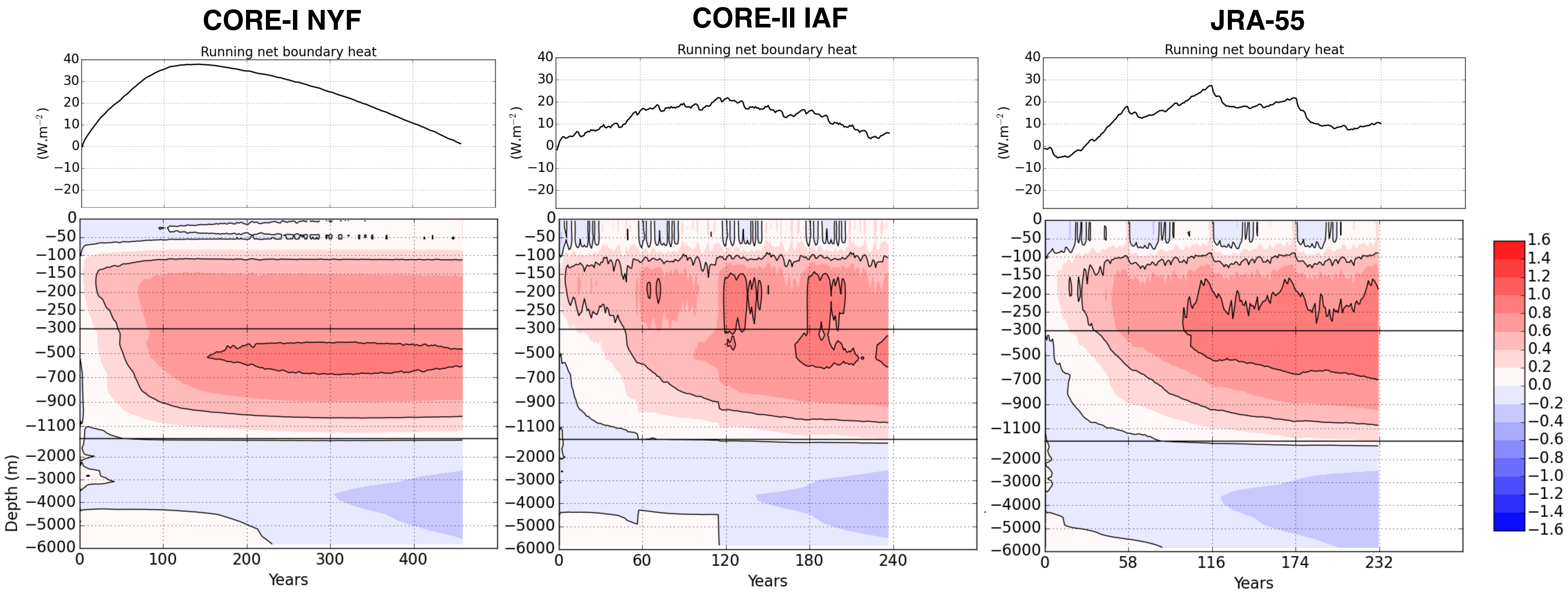
Figure 2. Annual-mean FAFMIP surface flux perturbations of (a) momentum, (b) heat, (c) water; (d) shows the model-mean change in the surface heat flux Q into the sea-water in the time-mean of the final decade of the faf-heat experiment relative to the control, not including the imposed heat flux perturbation F. The ocean area-average of (b) is 1.86 W m^{-2}, of (c) 0.072×10^{-6} kg m^{-2} s^{-1} and of (d) -0.09 W m^{-2}. The grey box in (b) is the North Atlantic region to which we refer in Sect. 3.1.

Gregory et al (2016)

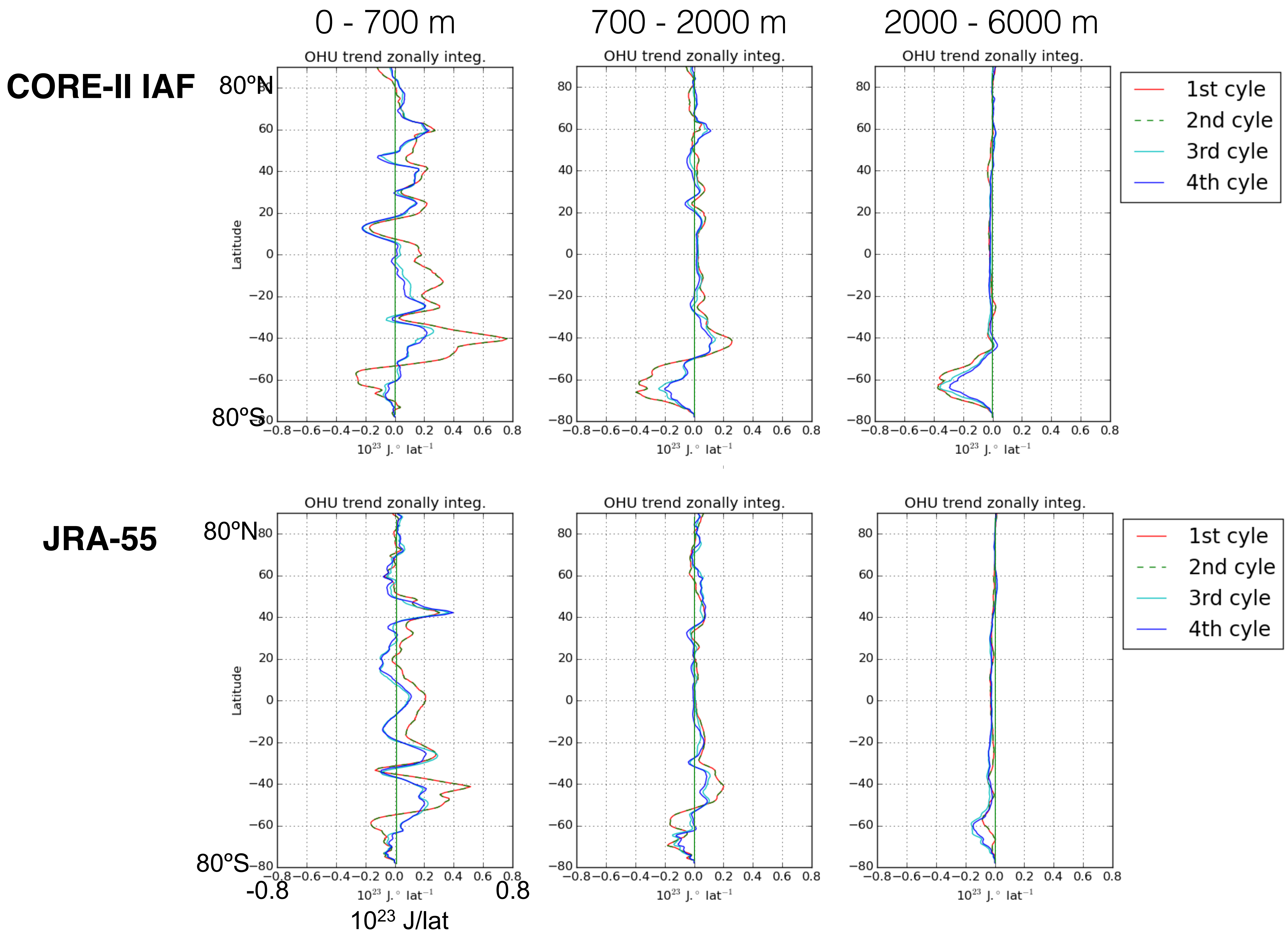
Results

Global averaged temperature evolution



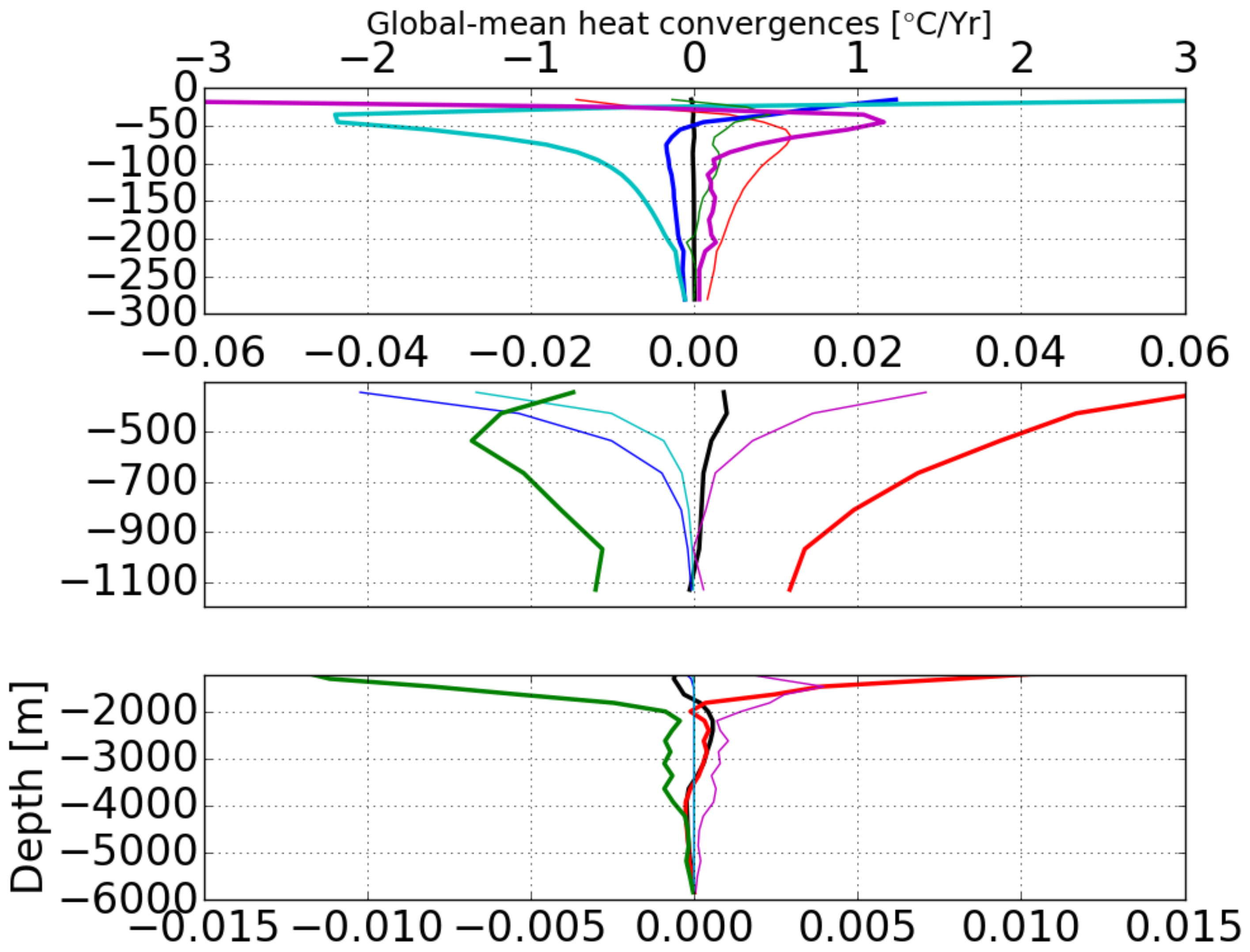


Linear trend 1993-2007 - zonally integrated Ocean Heat Content

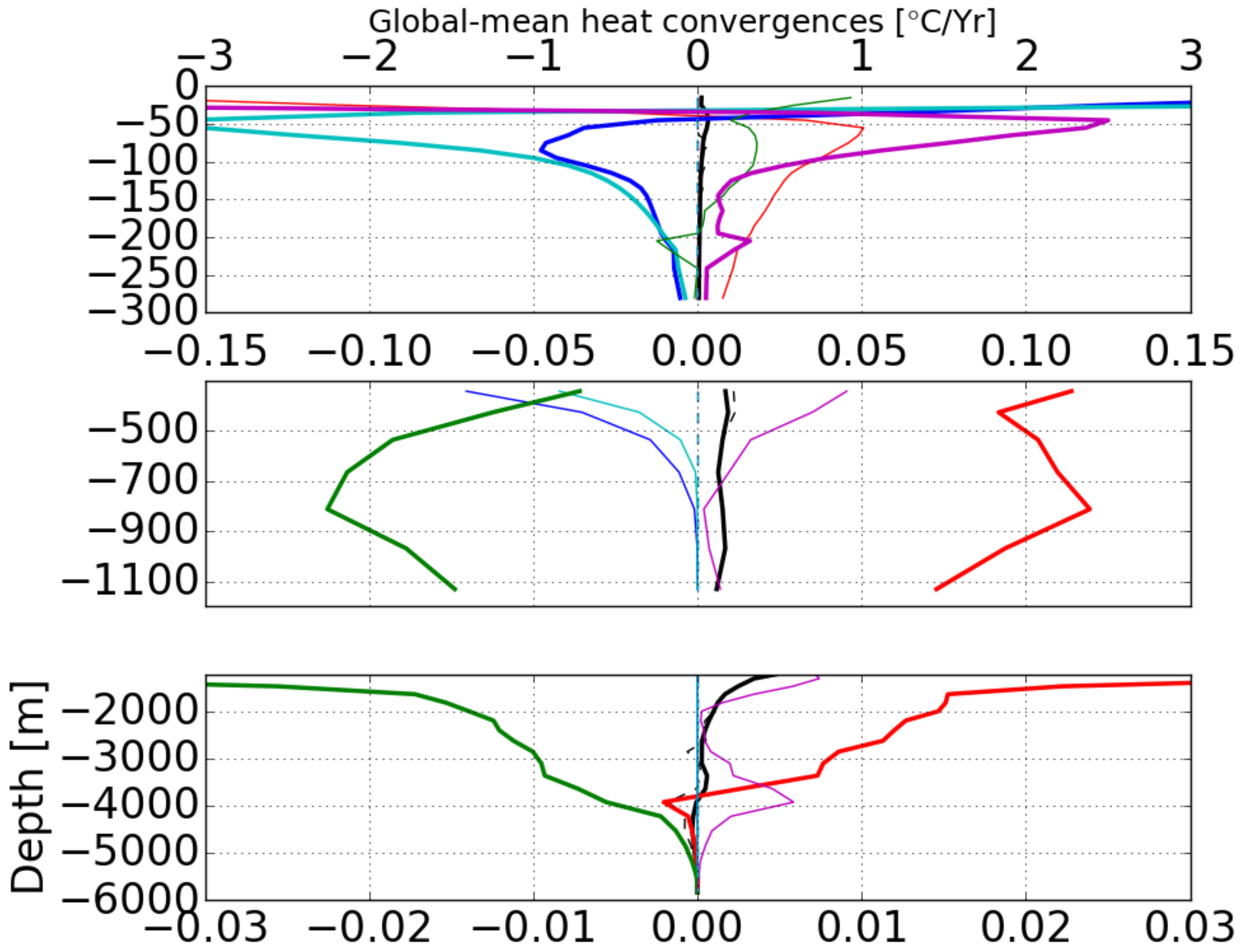


Global heat balance dominated by mid- and high latitude processes

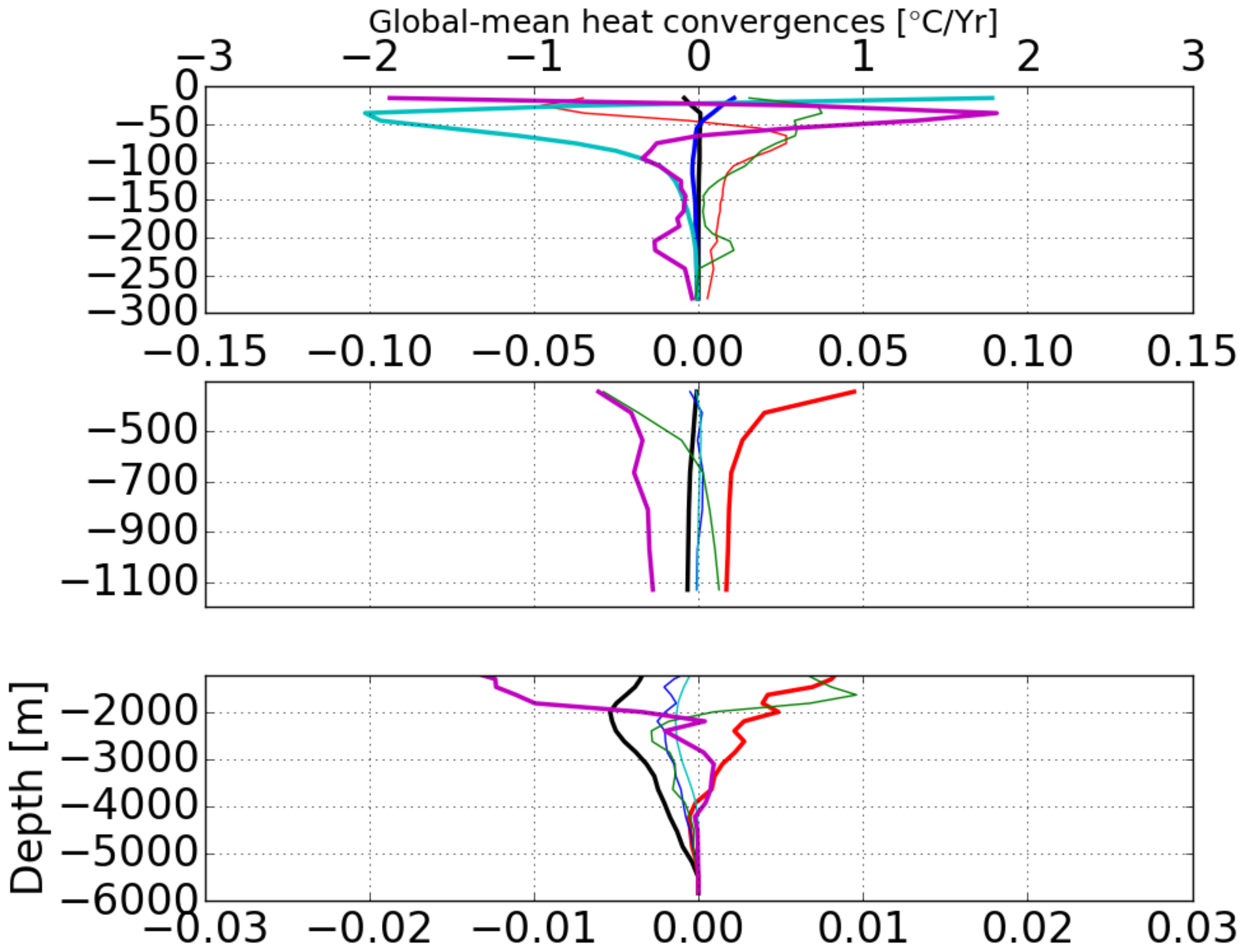
35°- 60°N



35°- 45°S

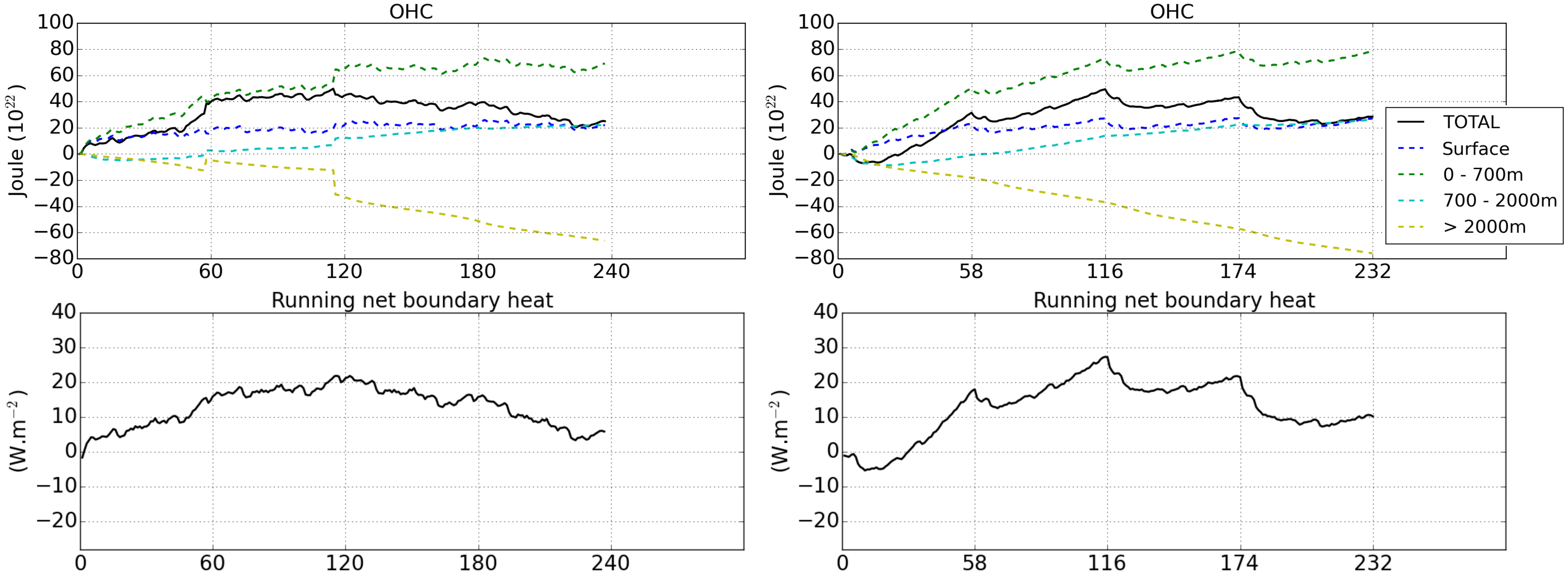


60° - 75°S



Global (horizontally averaged) Ocean Heat Content/Net Surface Heat Flux

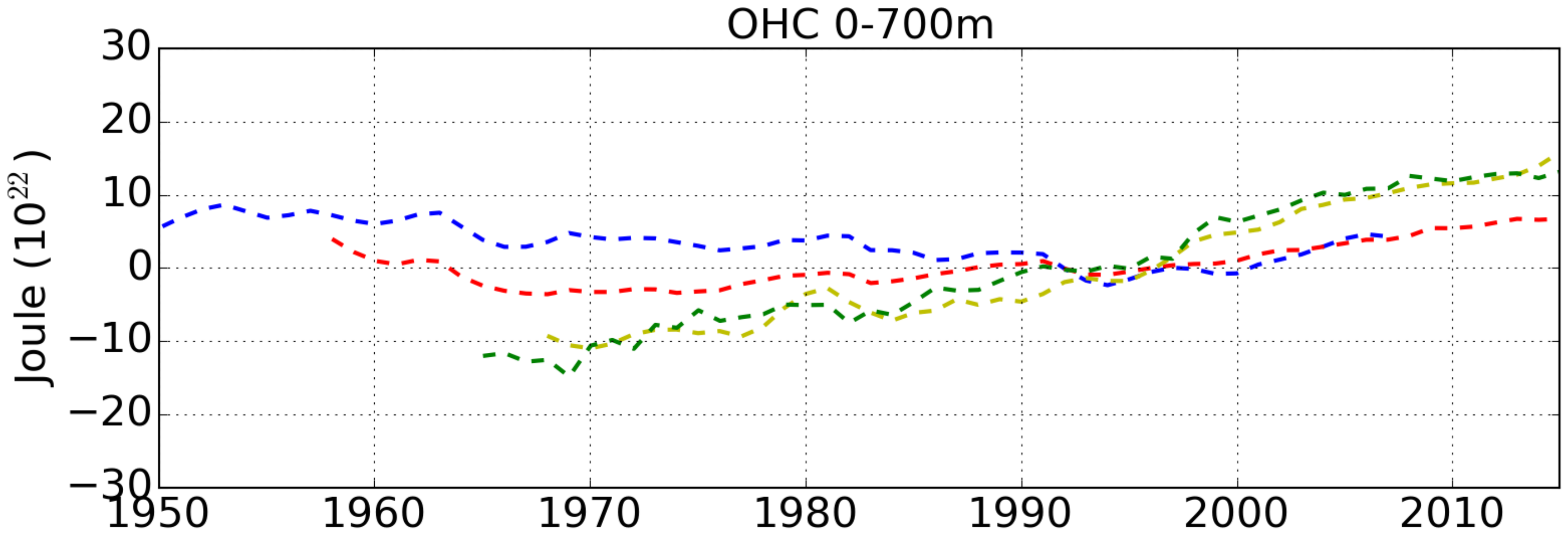
CORE-II IAF **JRA-55**



- OHC **increases** in the **upper 700 m** and largely **decreases below 2000 m**
- Total **depth-integrated OHC**: increasing in the first 2 cycles and decreases after
- Net surface heat flux - follow same pattern inter-cycle as OHC

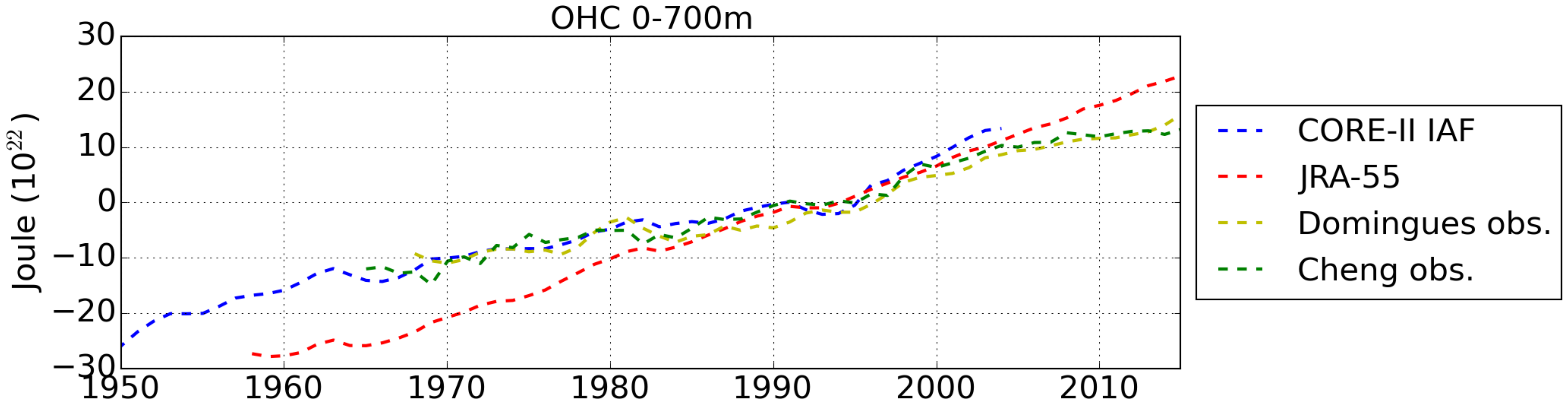
Global Ocean Heat Content (0-700m) compared with observations

4th cycle

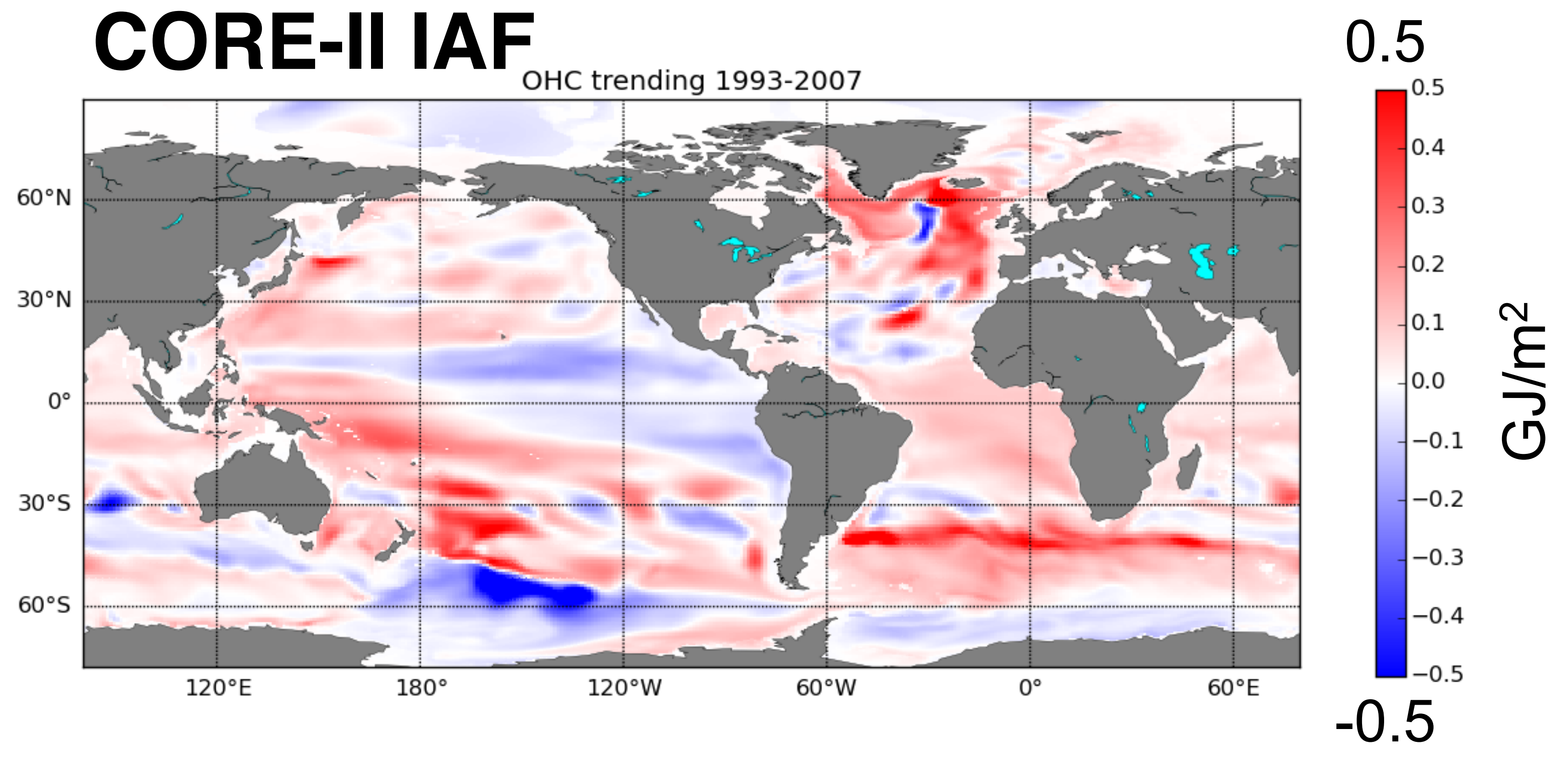


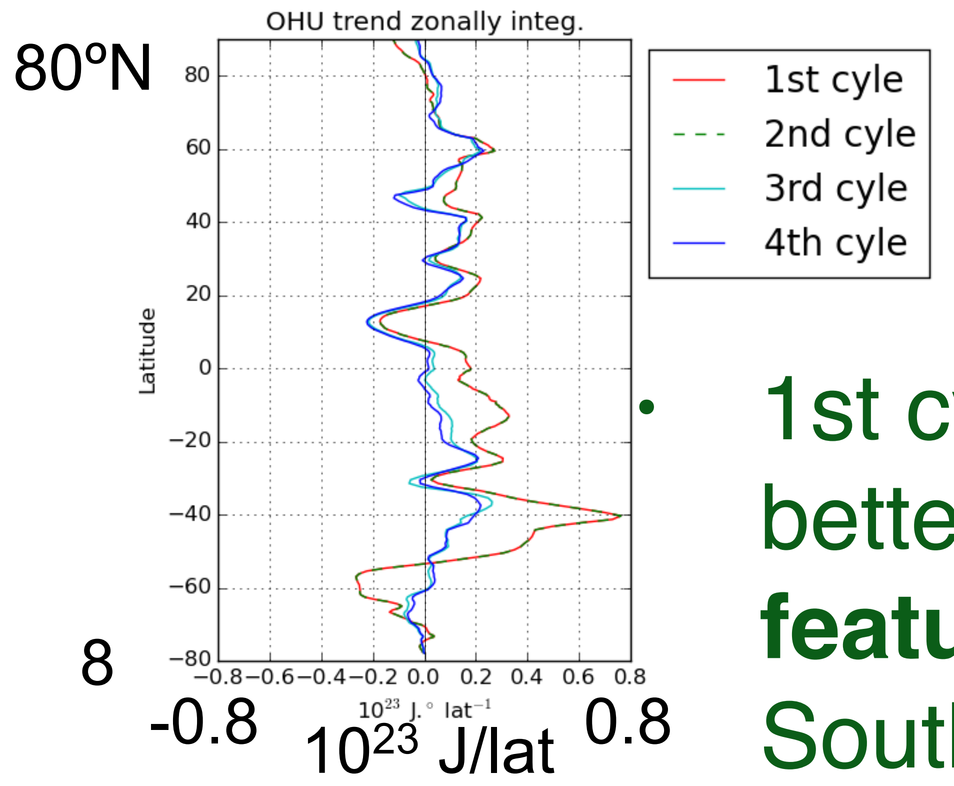
- Low trend in OHC_{700m} in the 4th cycle
- 1st cycle - OHC_{700m} increasing w/ similar rate as the observations

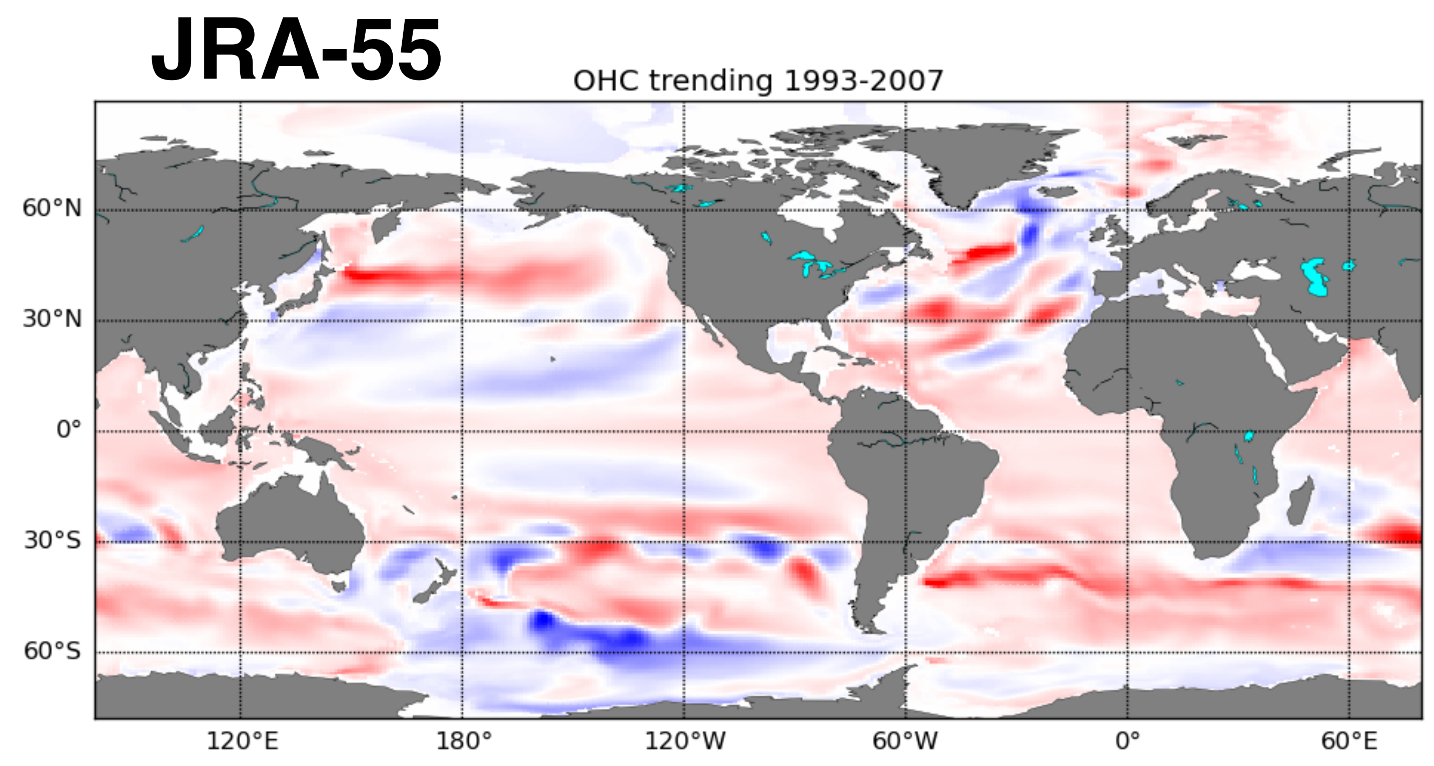
1st cycle

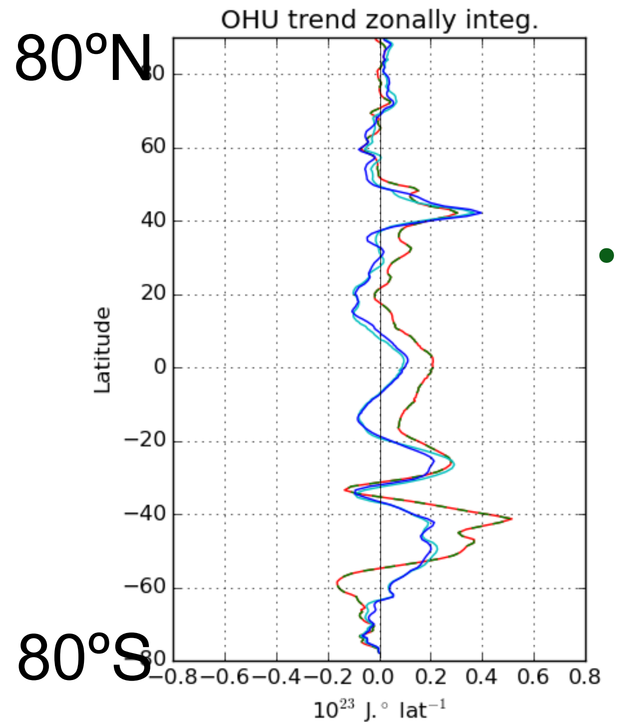


Linear trend 1993-2007 Ocean Heat Content 0-700m



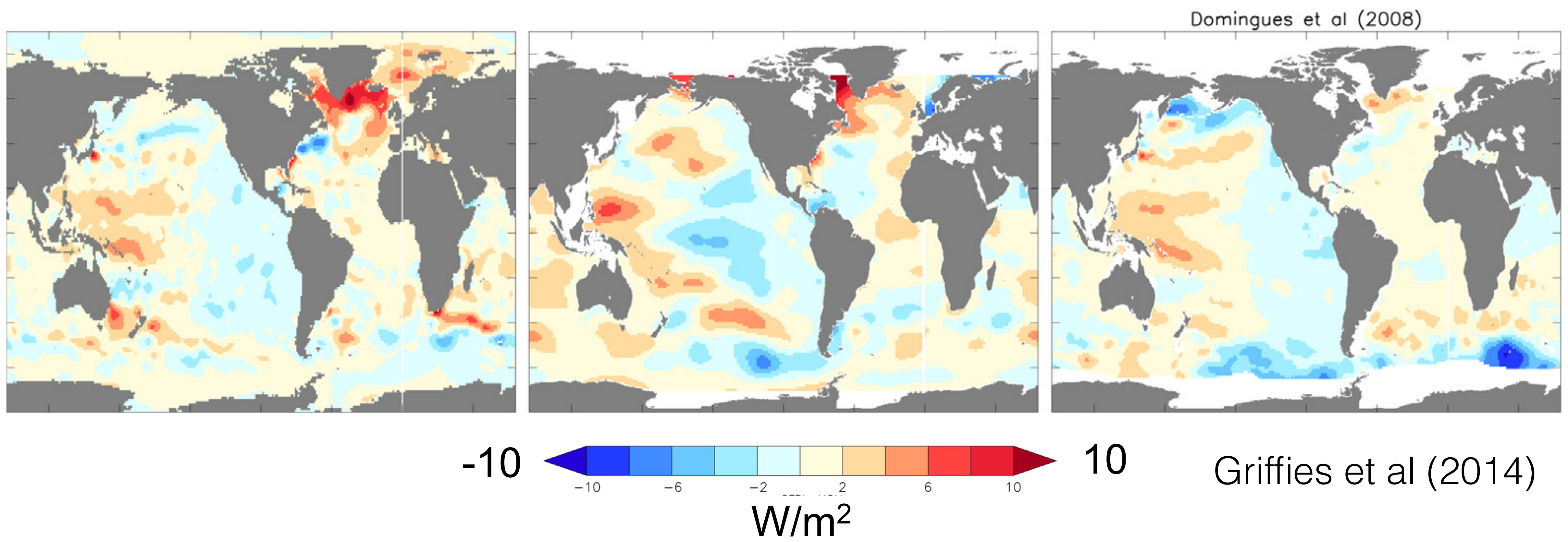






- 1st cycle also compares better in the **regional features**: Tropical Pacific, Southern Ocean and North Atlantic

- Zonally-integrated: decreased in heat uptake in last cycles



Griffies et al (2014)