Mean and seasonal states of the ocean heat and salt budgets in ACCESS-OM2

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Ocean heat and salt budget analyses

$$\rho_0 c_p \frac{\partial \Theta}{\partial t} = -\nabla.(F_{ADV} + F_{DIA} + F_{KPP} + F_{SW} + F_{EIT} + F_{SUBMESO} + F_{CONV} + F_{PME} + F_{RUNOFF} + F_{FRAZIL})$$

$$\frac{\partial S}{\partial t} = -\nabla.(F_{ADV} + F_{DIA} + F_{KPP} + F_{EIT} + F_{SUBMESO} + F_{CONV} + F_{PME} + F_{RUNOFF} + F_{ICE} + F_{REST})$$

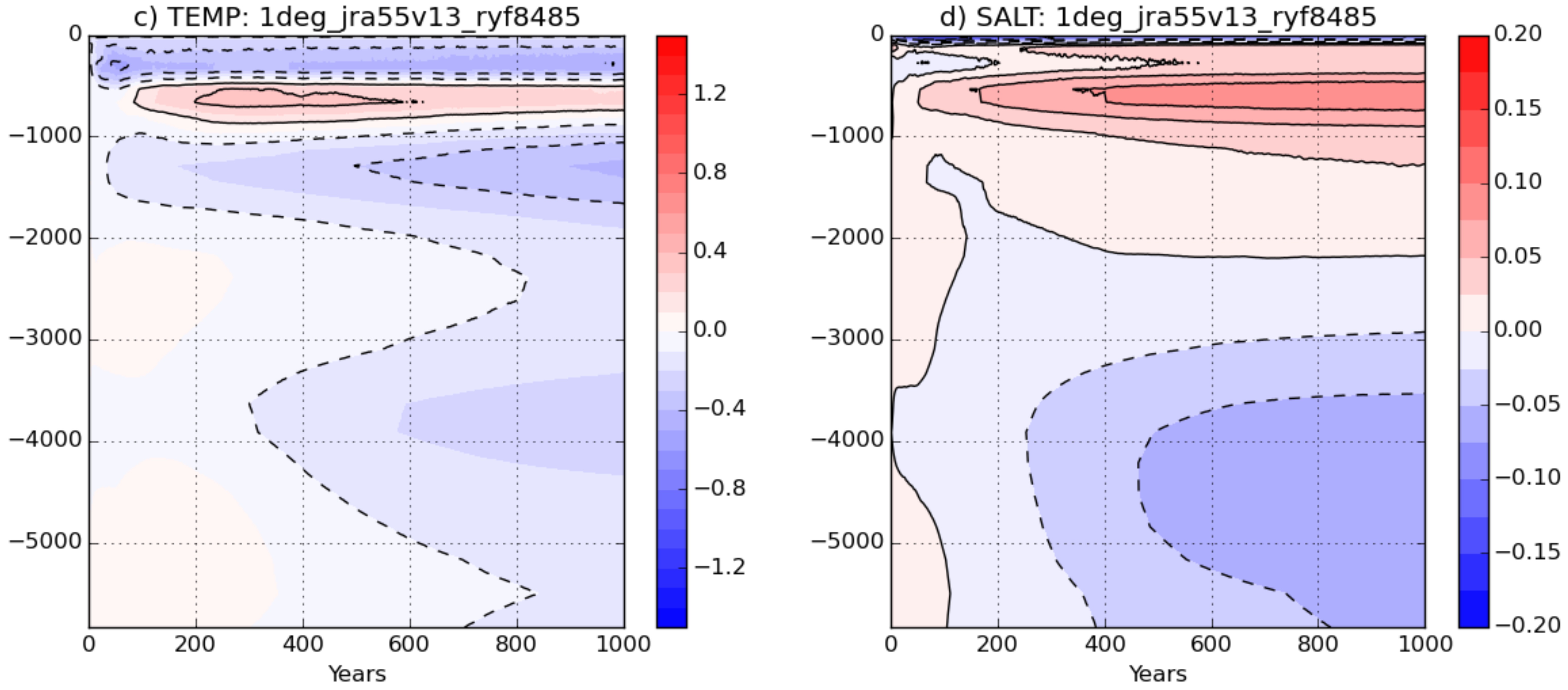
- Quantify heat/salt transport by each processes
- Potential to reduce steric sea-level projections spreading among climate models (CMIPs) through model inter comparison
  - differences in ocean heat uptake and vertical heat transport (Kuhlbrodt & Gregory, 2012)

Mean state - previous studies

- Munk abyssal recipe (1966): diapycnal diffusion downward balanced by large-scale advection upward
- Gregory (2000): global vertical transport dominated by Southern Ocean - downward advection (wind-driven) and upward mixing along isopycnals
  - later confirmed by other studies (e.g. Gnanadesikan et al. 2005, Hieronymus & Nycander 2013, Exarchou et al 2015)
  - parametrised eddy-advection (GM) also contributes to upward heat transport
  - Eddy-resolved models also agree with Gregory; e.g. Wolfe (2008), Griffies et al. (2015)
- Residual advection = mean + eddy-induced advection
  - comparison b/w coarse and eddy-resolved models
  - Kuhlbrodt et al (2015) suggested a new term:
    - **Super-residual advection** = Mean advection + Eddy-advection + Isoneutral diffusion
    - High-resol. models include or not parametrisation for isoneutral diffusion

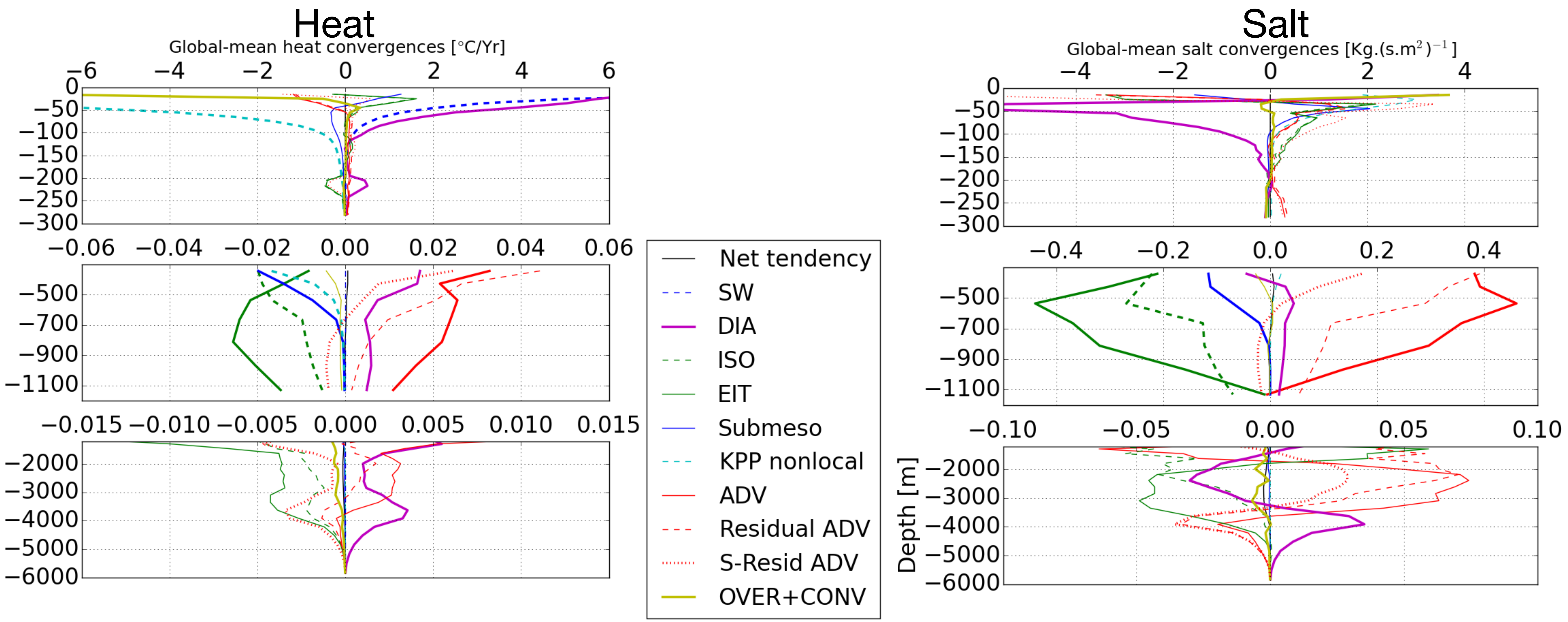
Ocean-Sea Ice coupled model

- ACCESS-OM2 1-degree, 50 z* levels
  - 1000-years spin-up forced with JRA55-DO Repeat Year Forcing (1984-85) (Tsujino et al, *submitted*)



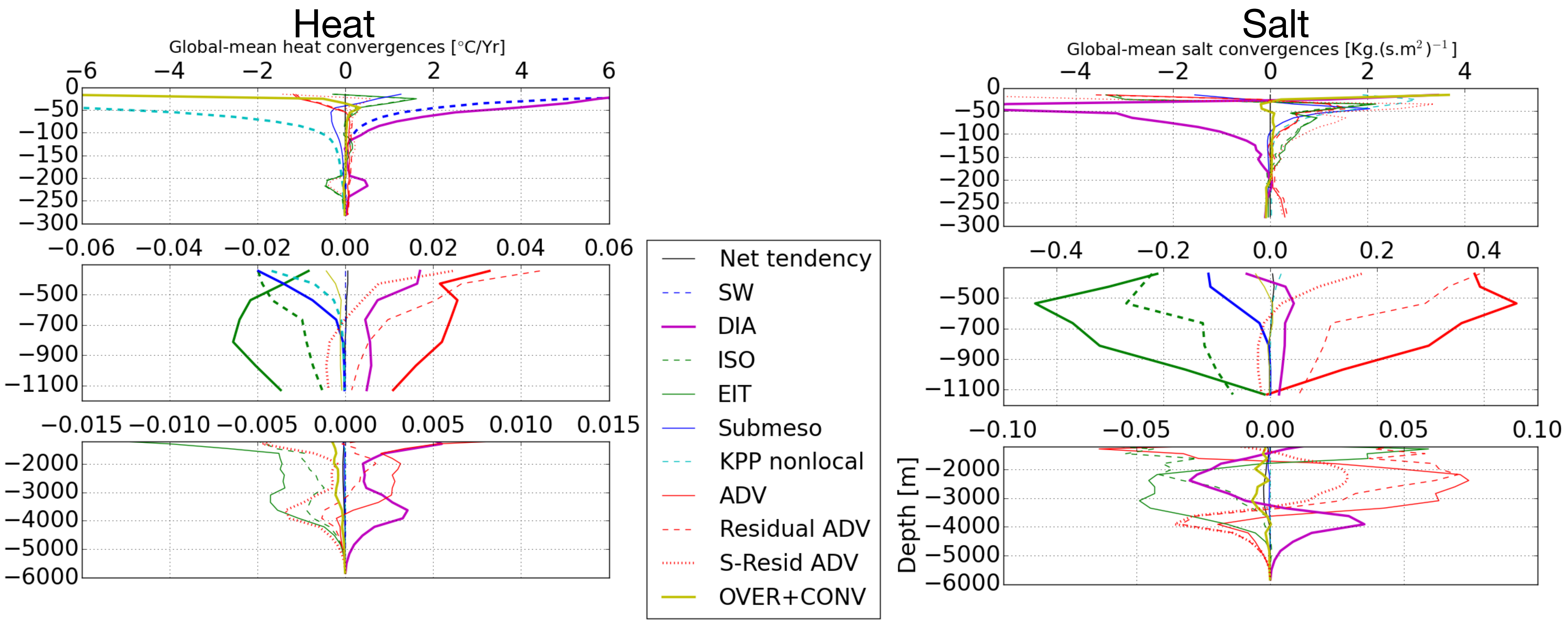
Global mean temperature and salinity by depth

Global vertical transport



- Upper-200 m dominated by:
  - **Heat**: SW penetration and surface heat fluxes (DIA) - warming
    - convection and vertical mixing (KPP) - cooling
  - **Salt**: Diapycnal diffusion of salt freshens, all other terms salinify

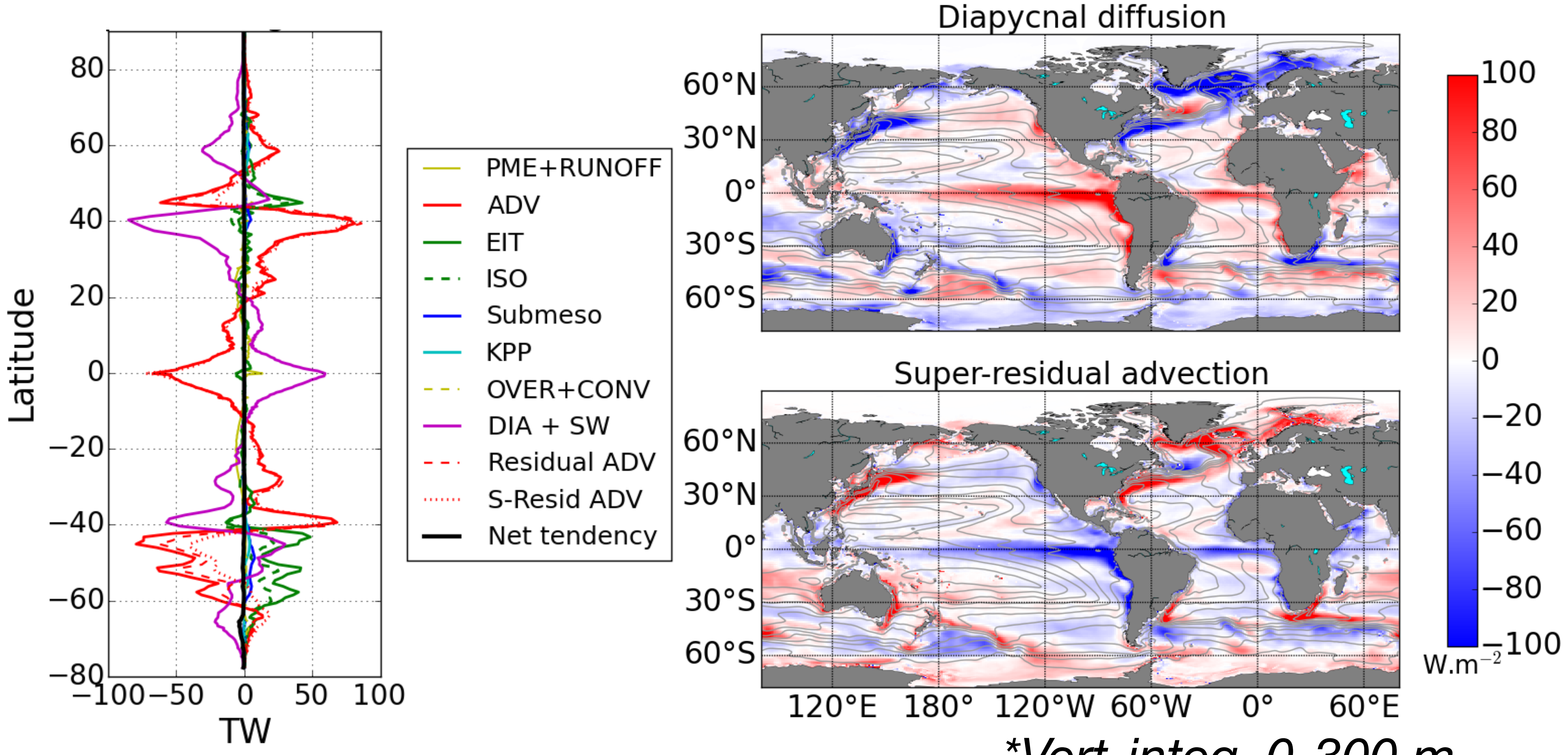
Global vertical transport



- Ocean interior dominated by similar processes (heat/salt)
  - **Upper-700 m**: Mixed layer processes are balanced by diapycnal diffusion and super-residual advection
  - **700 - 3500 m**: super-residual balance as found by previous works
    - Mean advection downward, eddy-induced transport upward
  - **Below 3500 m**: diapycnal diffusion downward, super-residual advection upward

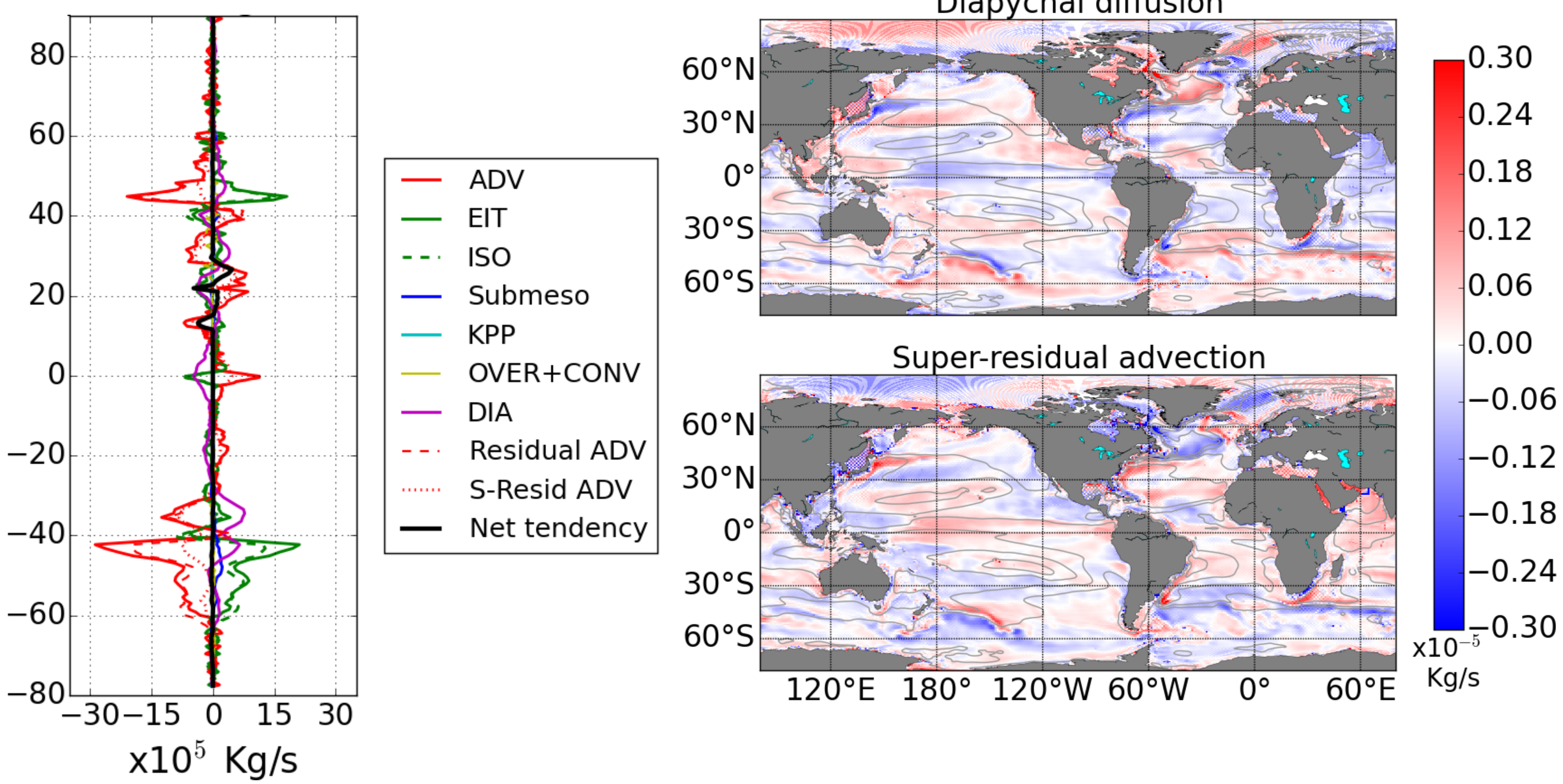
Regional contribution: upper-300 m

Heat



**Vert-integ. 0-300 m*

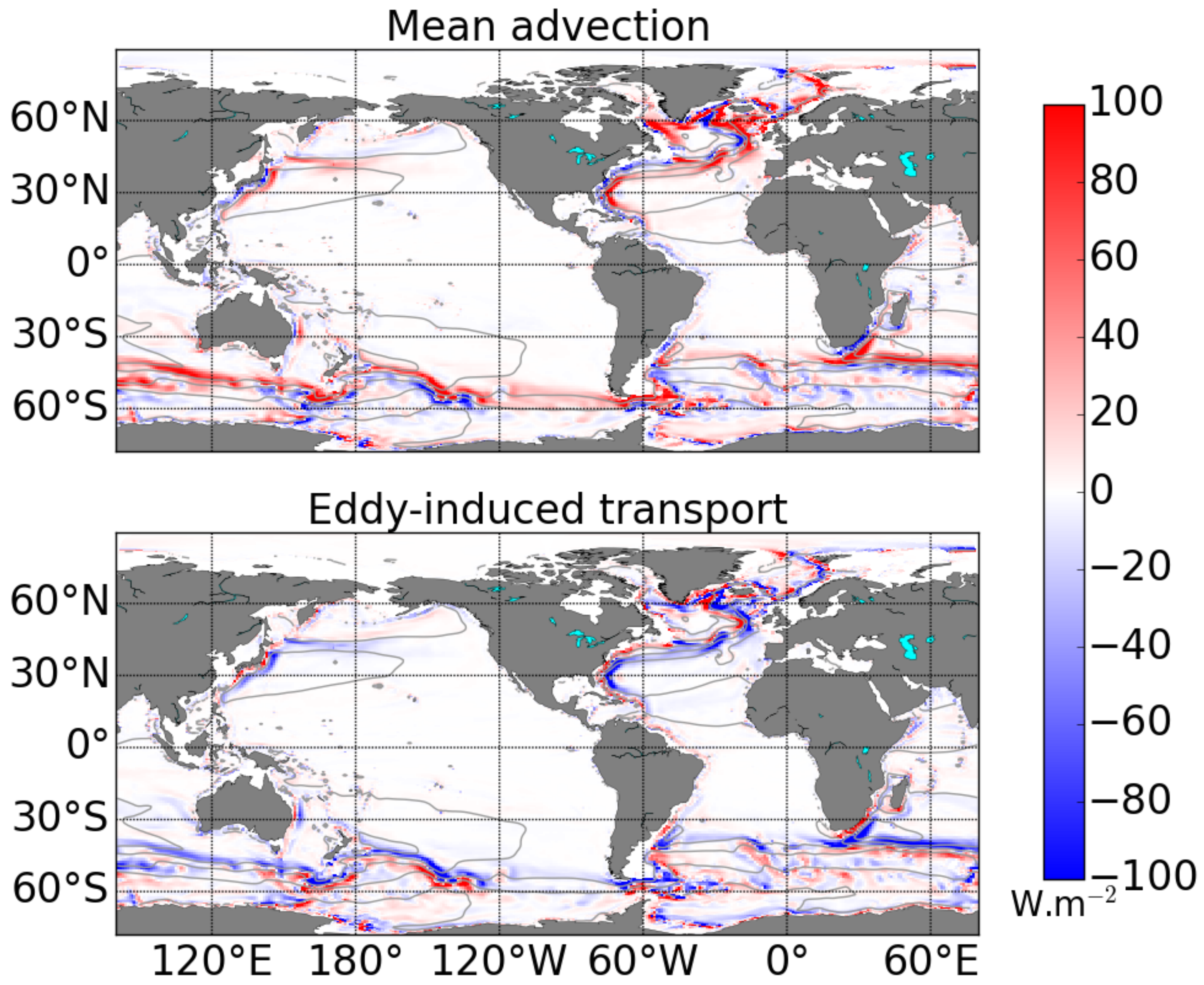
Salt



- Net surface heat flux (DIA) is mainly balanced by mean advection
  - Tropics and WBCs
- Net surface salt flux dominated by restoring term:
  - also counterbalanced by advection
  - less intuitive spatial variability

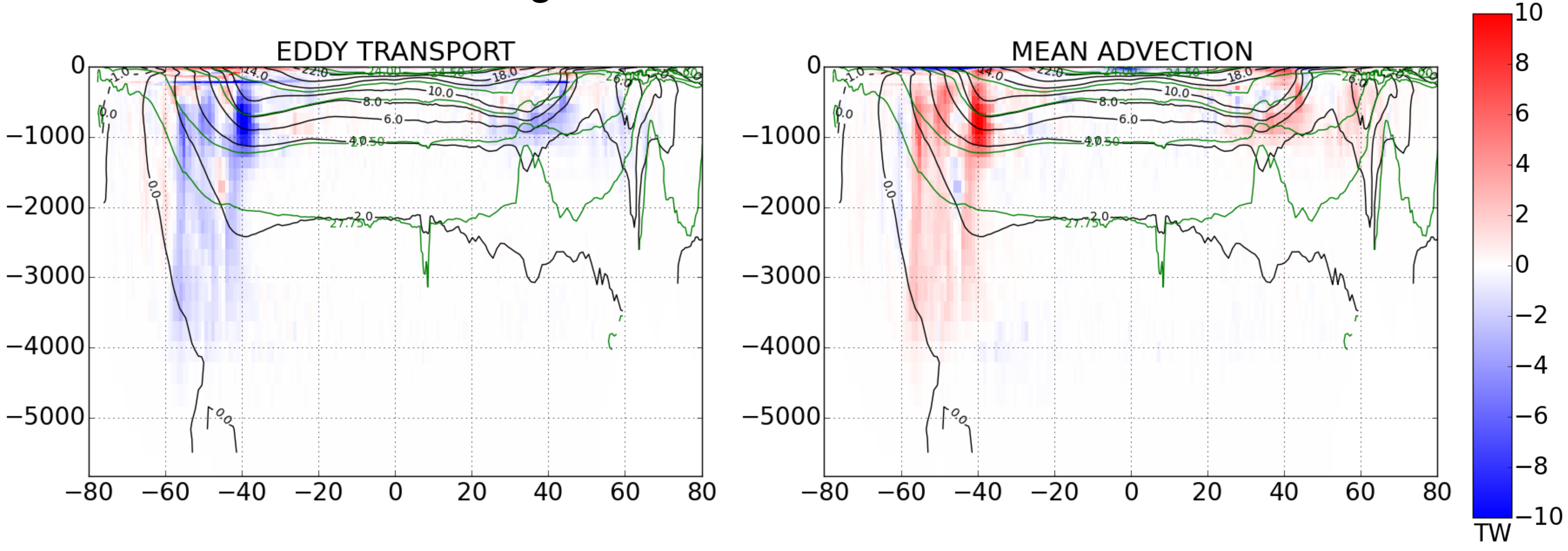
Mean advection and eddy-transport

Heat



Vert-integ. 300-1200 m

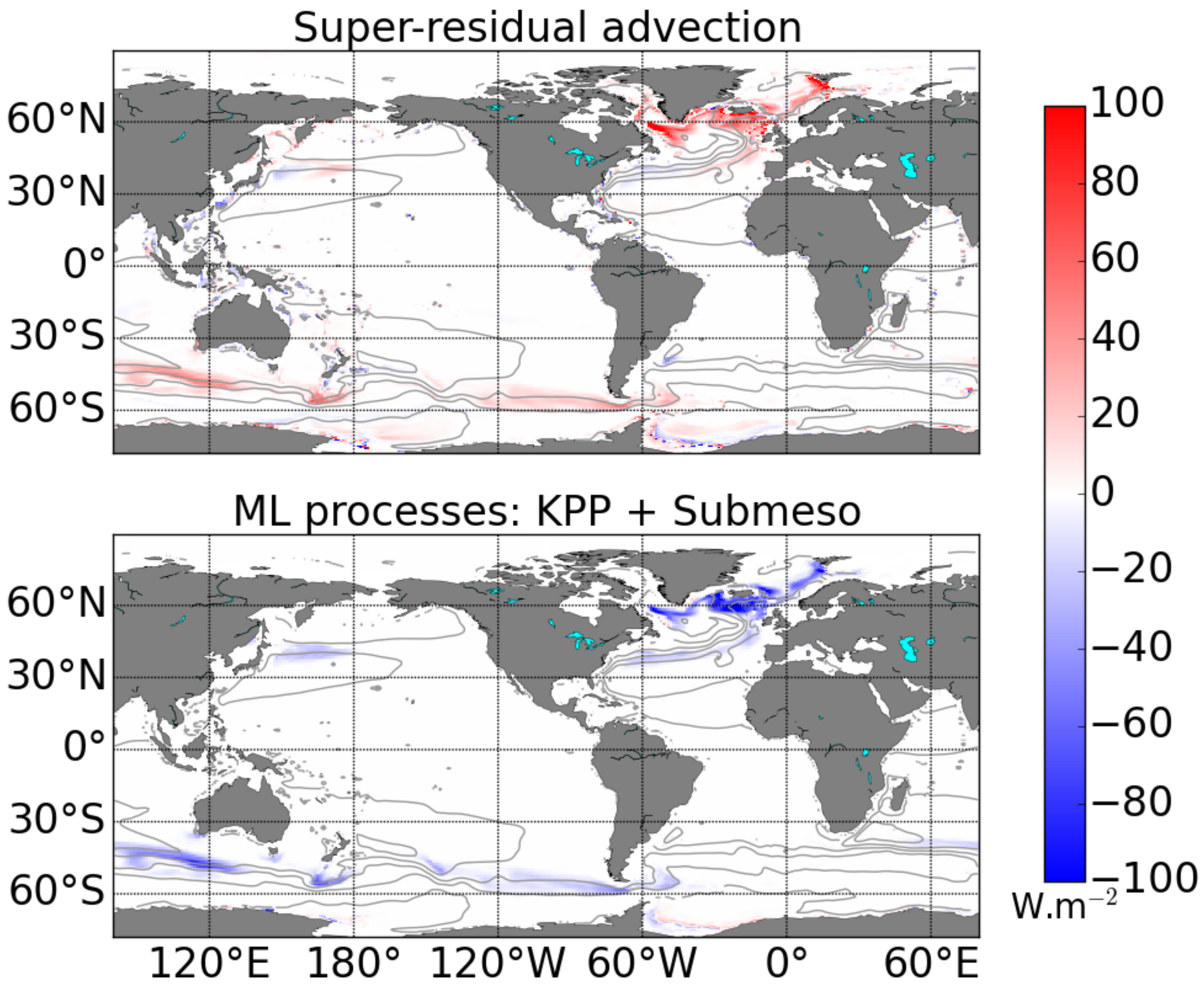
- Dominated along frontal regions - ACC and Gulf Stream
- Northern flank of ACC: downward of heat by large-scale advection and upward by mesoscale eddies



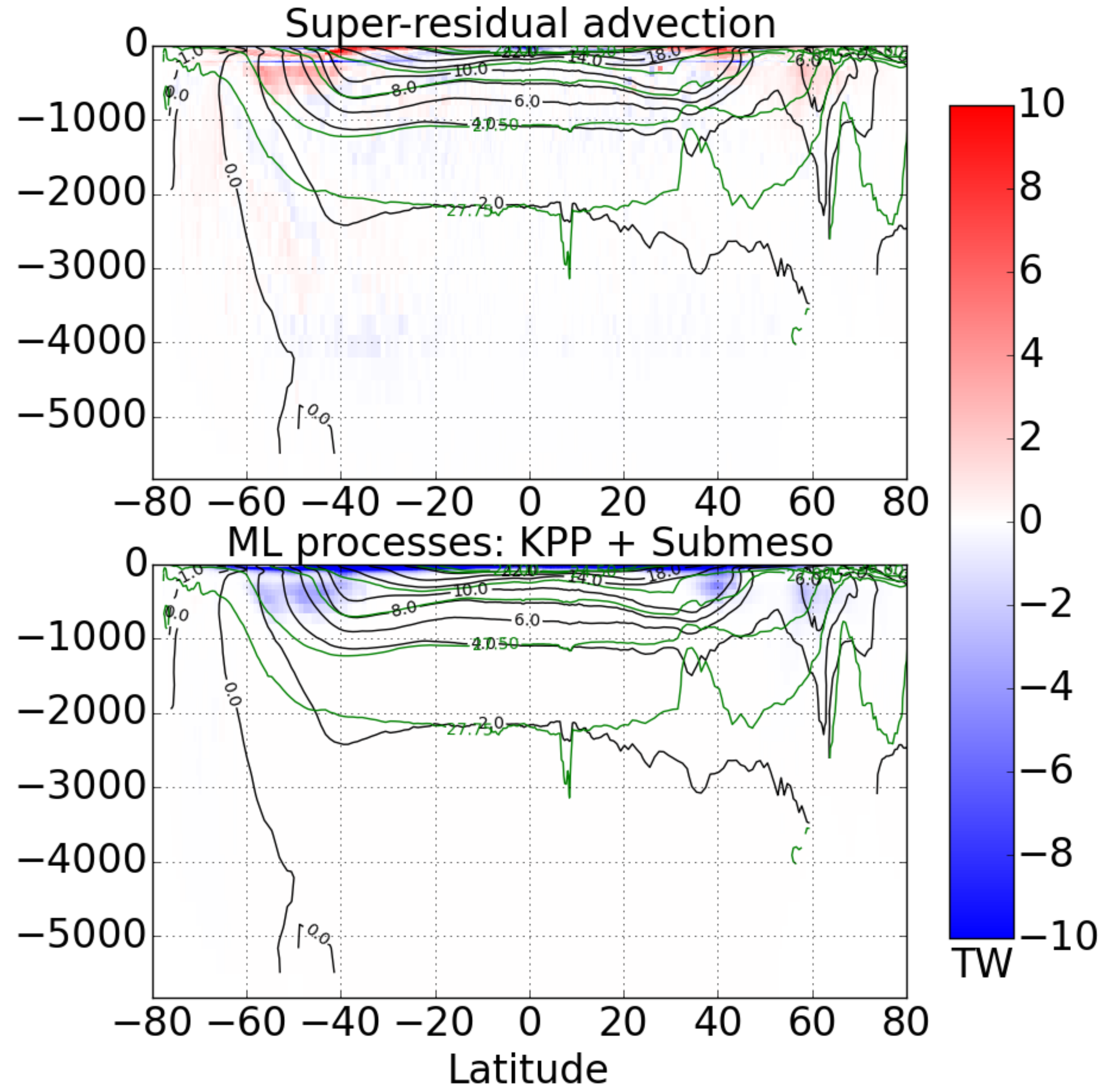
Water masses definition:

TW	$\sigma_\Theta < 24.5$
STMW	$24.5 < \sigma_\Theta < 26.6$
SPMW	$26.6 < \sigma_\Theta < 27.0$
IW	$27.0 < \sigma_\Theta < 27.5$
DP	$27.5 < \sigma_\Theta < 27.75$
BW	$\sigma_\Theta > 27.75$

Super-residual advection:

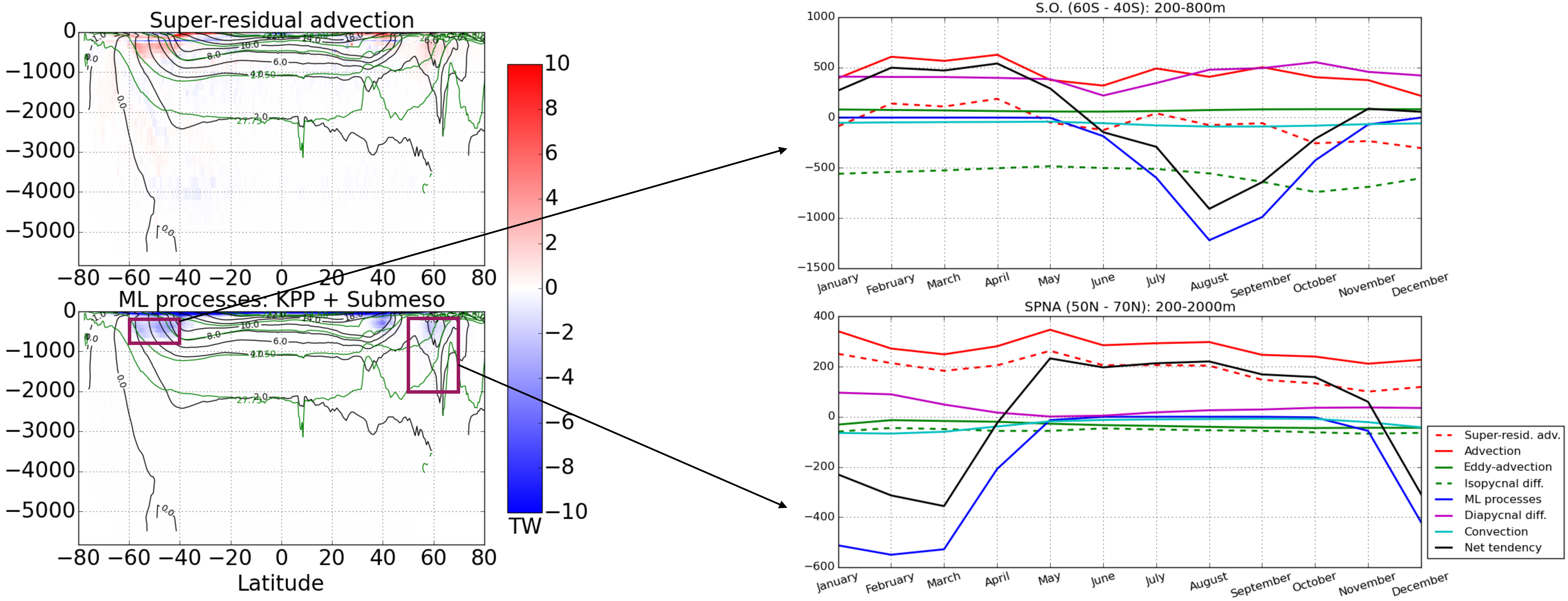


**Vert-integ. 300-1200 m*



- Net effect of SR advection balances Mixed Layer processes
  - Deep mixed layer regions: SAMW, AAIW and NADW

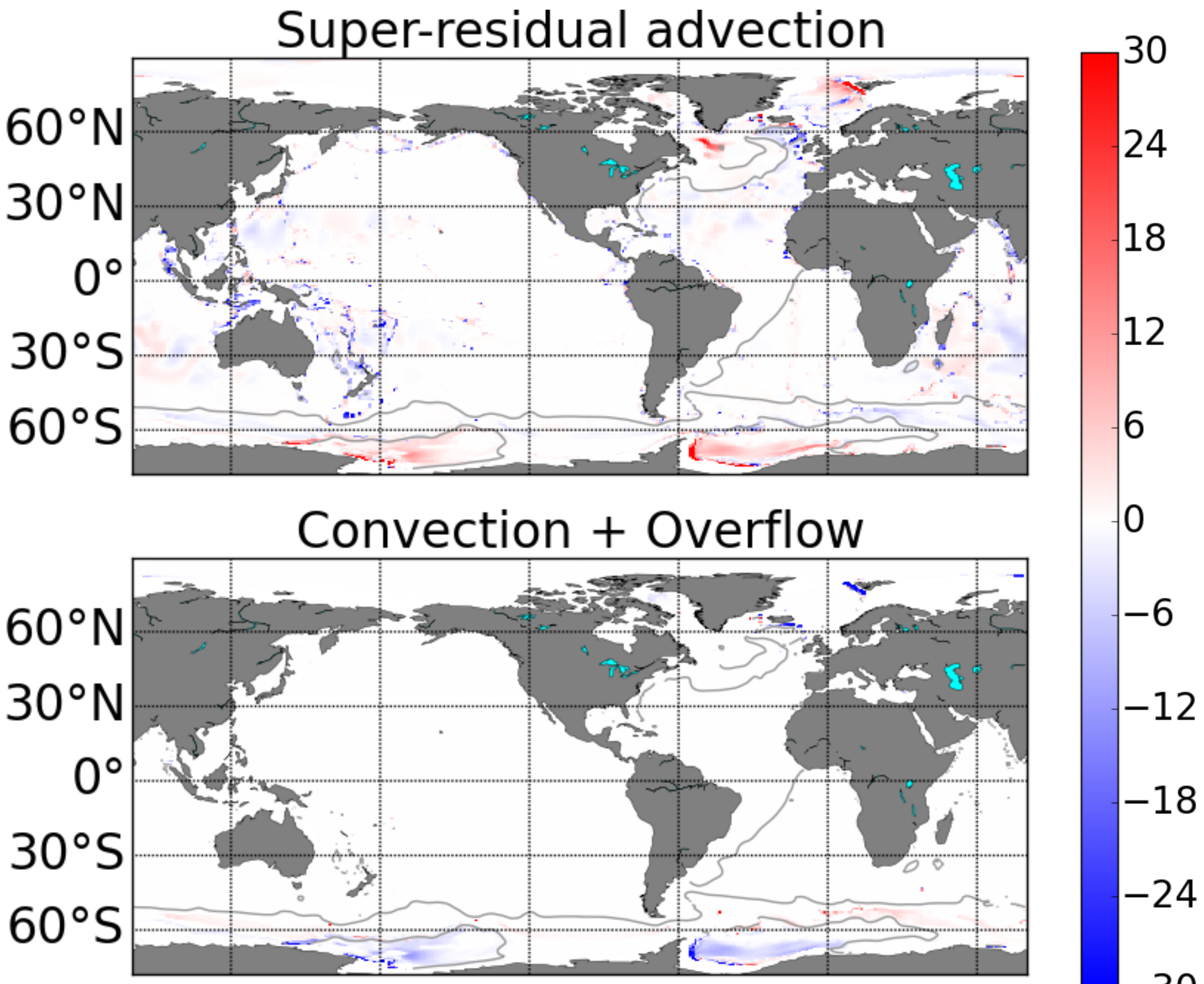
SR advection and ML processes: seasonal variability



- Mixed layer processes: strong seasonality as expected from water formation processes - hemispheric winter

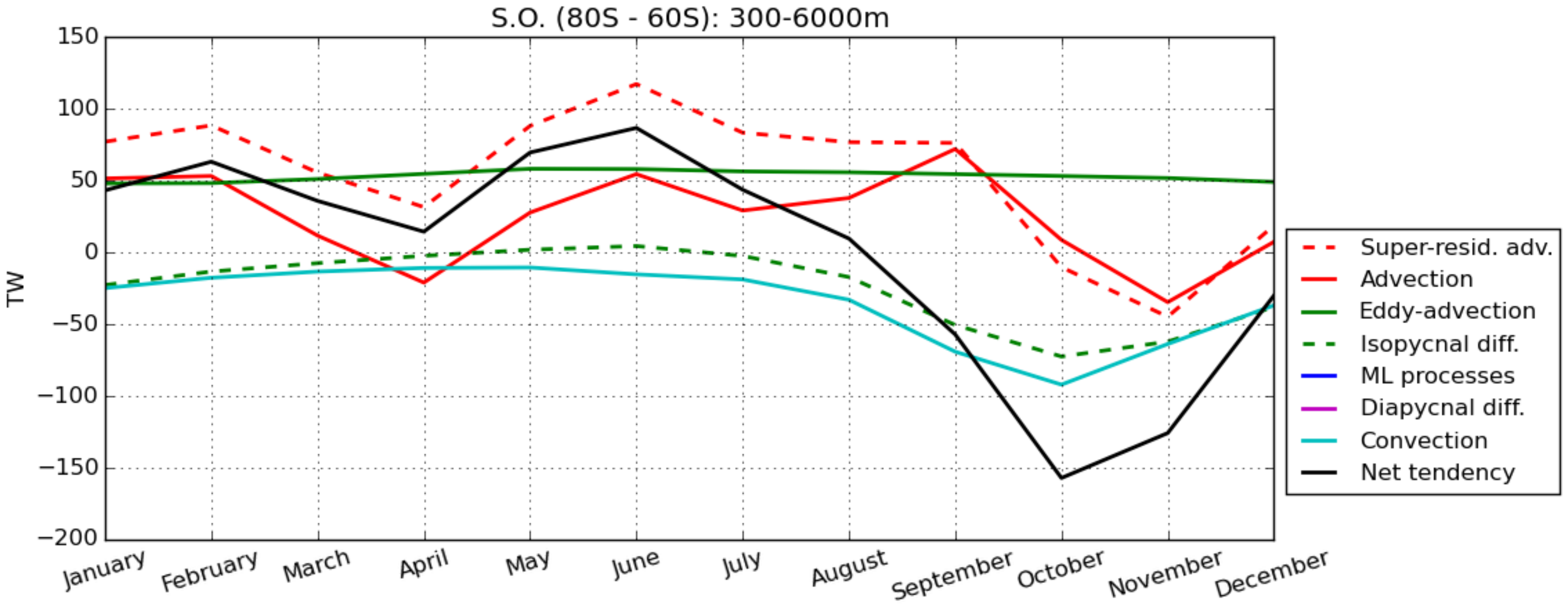
- Compensated along the year by SR advection - weak seasonality

Bottom water formation - convection



Vert-integ. 1100-1800m

- Balanced by super-residual advection
- Poleward of 60°S: transport of cold water downward as bottom water (AABW) is formed
  - Weddell and Ross Seas
- Both SR advection and convection experienced significant seasonal cycle



Global balance below 700 m - role of diapycnal diffusion

- Important role in downward transport by diapycnal diffusion
  - counterbalanced by super-residual advection: cooling at NADW and AABW
  - erosion of AABW by NADW layer
  - original Munk's balance

Conclusions

- Heat and salt budget in ACCESS-OM are dominated by downward transport from large-scale advection and upward transport from mesoscale eddies
    - Southern Ocean has stronger and deeper transport than its northern counterpart
- These processes combined as super-residual advection balance different processes depending on depth:
    - Mixed layer processes at SAMW/AAIW and NADW formation regions, dominating upper-700 m budgets
    - Diapycnal diffusion below 700 m: spreading and destruction of cold (NADW and AABW) water
        - suggest that Munk's balance, where mean advection can be interpreted as SR advection
- Strong dependence on parametrised processes:
    - vertical mixing (KPP, convection), submesoscale eddies, diapycnal diffusion
    - suggesting that particular choices on ocean models can play a large influence in vertical heat/salt transport and therefore steric sea-level