Ocean Heat Uptake in Eddy-Resolved and Eddy-Parameterized Transient Climate Change Simulations

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The Rate of Ocean Heat Uptake is a Key Element of the Climate Change Projections

$$d\Delta H / dt = \Delta R - \lambda \Delta T$$

- The large heat capacity of the ocean causes climate change to lag behind the changes in external forcing and damps the temperature response relative to the radiative equilibrium temperature
- The amount of heat stored in the ocean manifest itself as steric sea level rise through thermal expansion
- The same physics moderating the exchange of heat between the surface and deep ocean also play a role in the sequestration of greenhouse gases, nutrients, etc

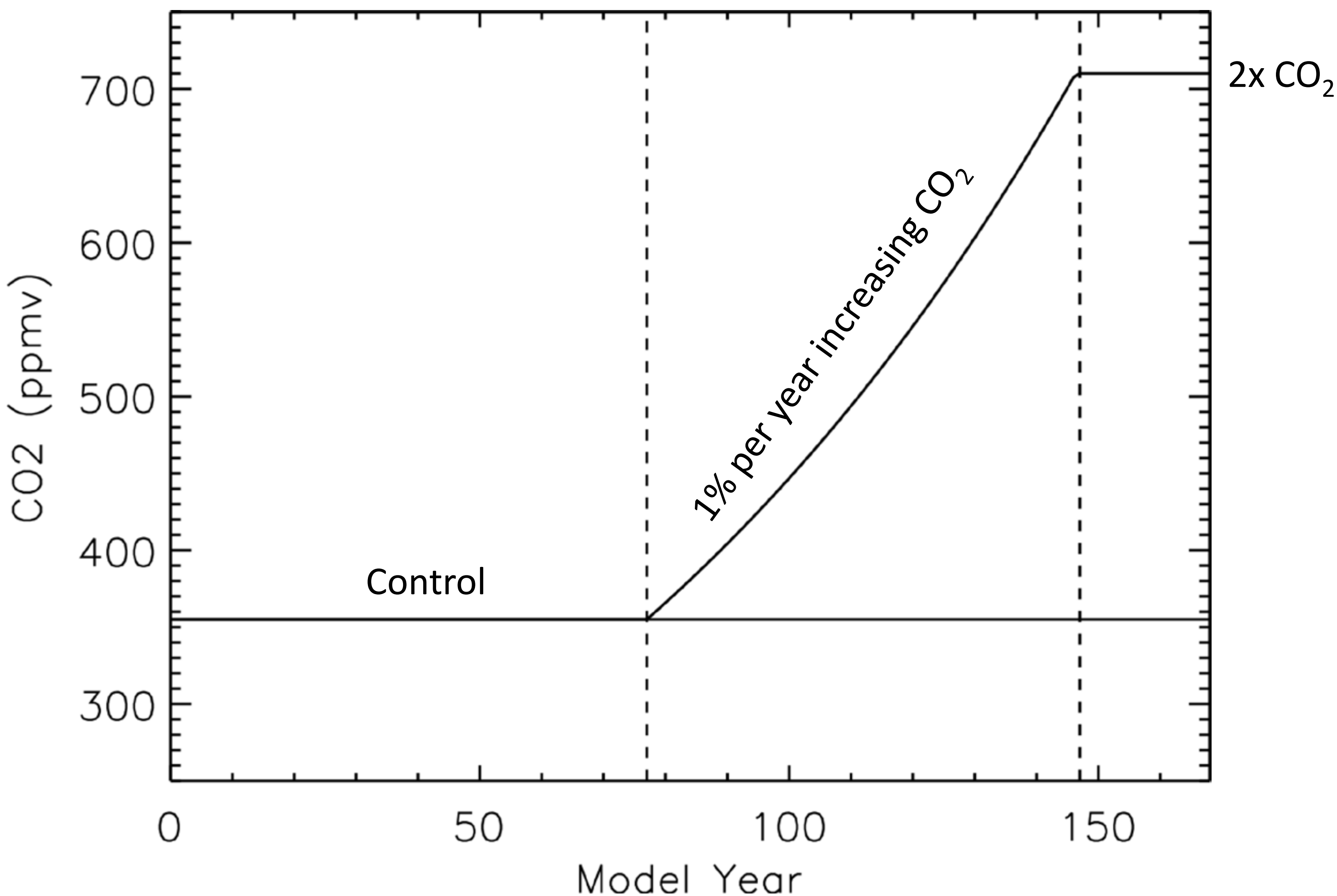
Objectives

- What are the dominant processes involved in the exchange of heat (and gases, nutrients, etc) between the surface and deep ocean?
- What role do mesoscale eddies play?
- How do simulations of climate change differ when eddies are explicitly resolved vs. parameterized?

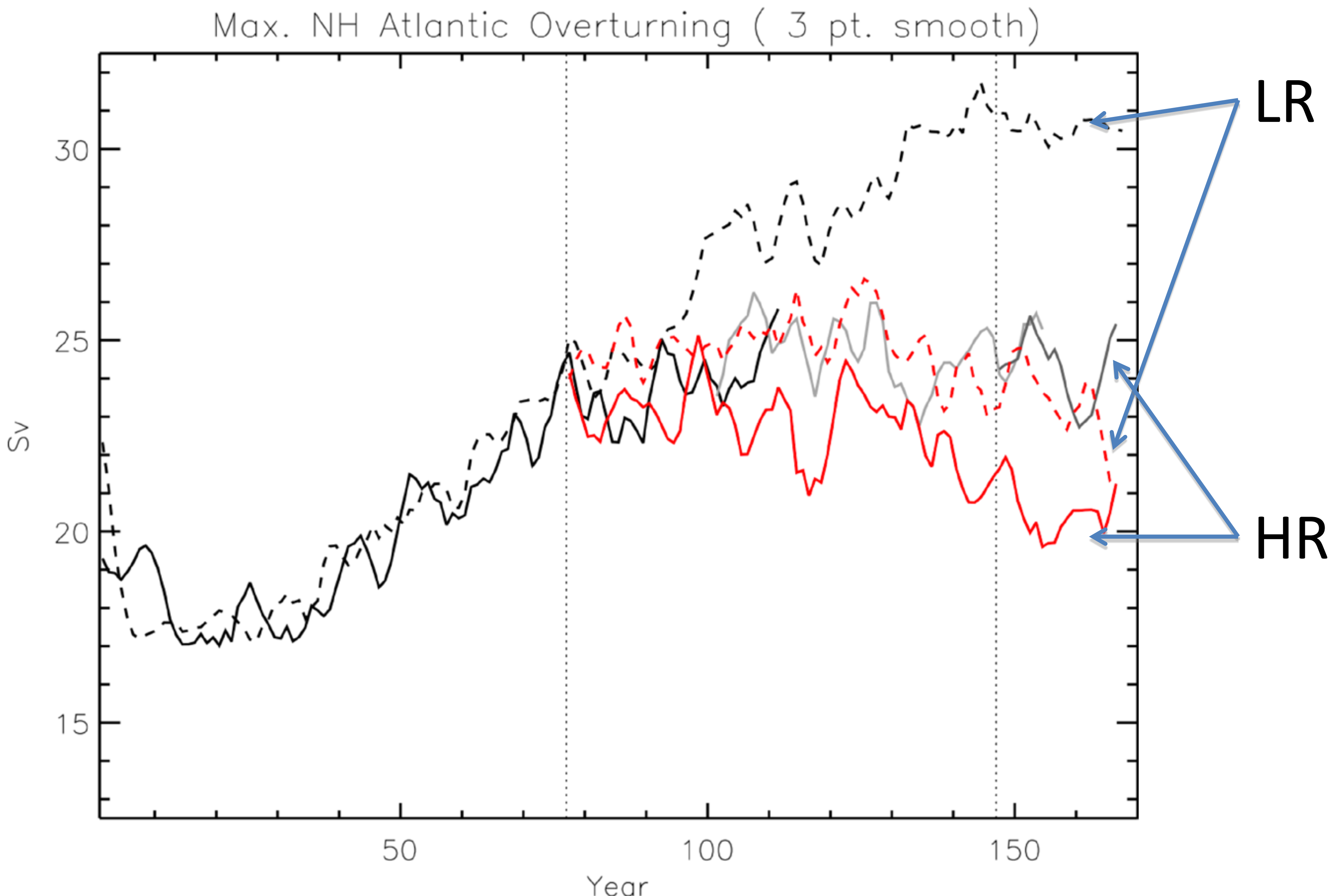
Methodology

- Compare present day control and 1% per year transient CO_2 experiments using two versions of CCSM3.5
- Low-resolution model
  - 0.5° atmosphere coupled to 1° ocean
  - Gent-McWilliams eddy mixing parameterization with state dependent isopycnal diffusivity
- High-resolution model
  - 0.5° atmosphere coupled to 0.1° ocean
  - Mesoscale eddies are explicitly resolved

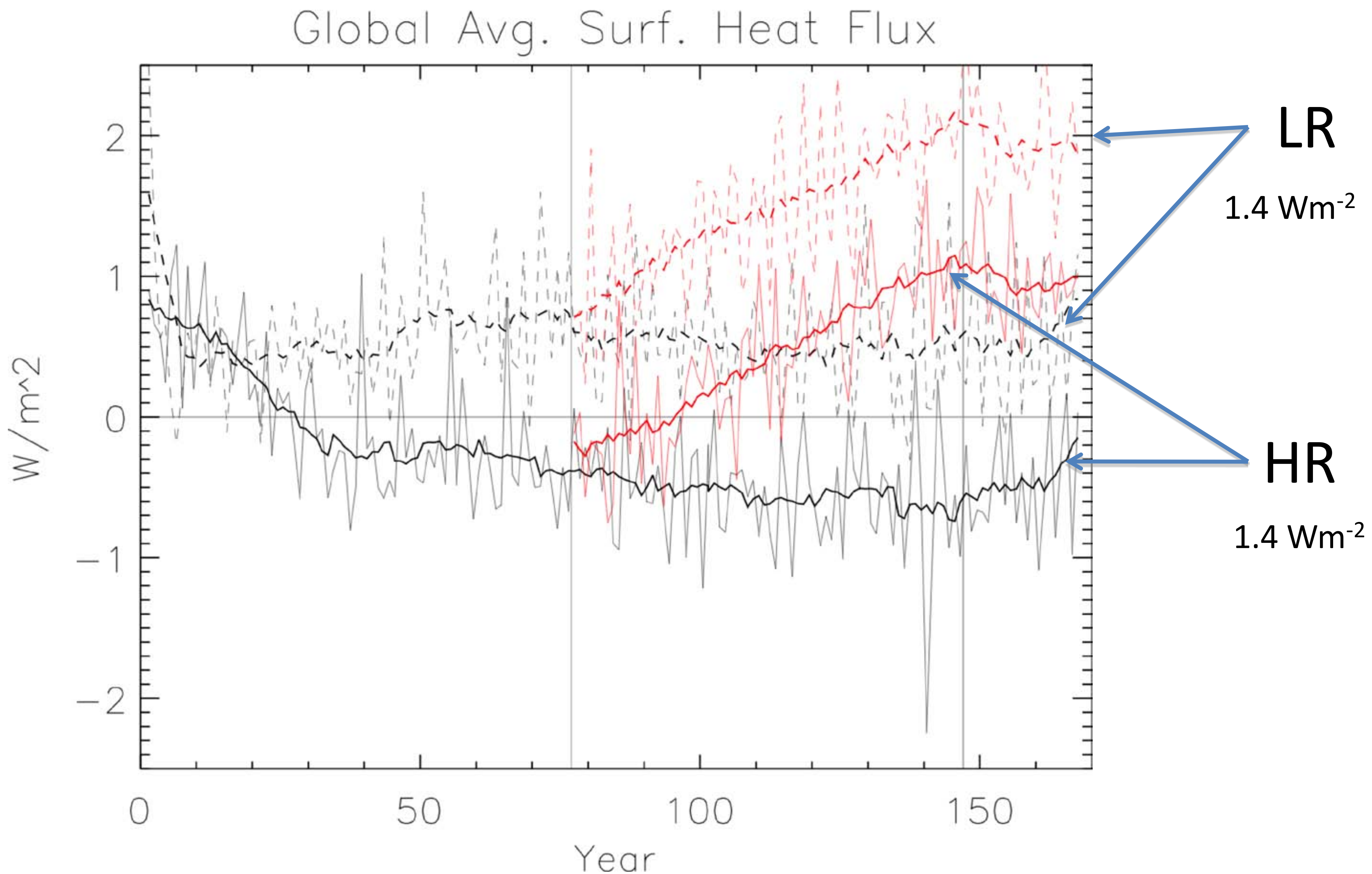
Experimental Design



AMOC Response



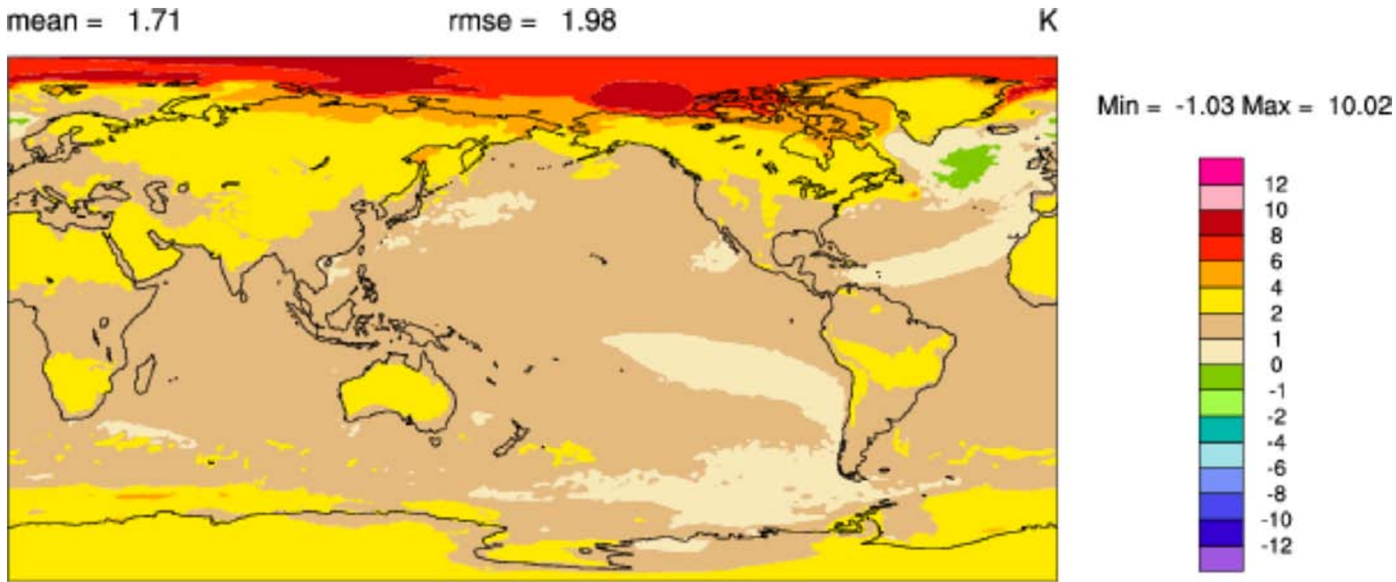
Ocean Surface Heat Flux



Surface Temperature Response

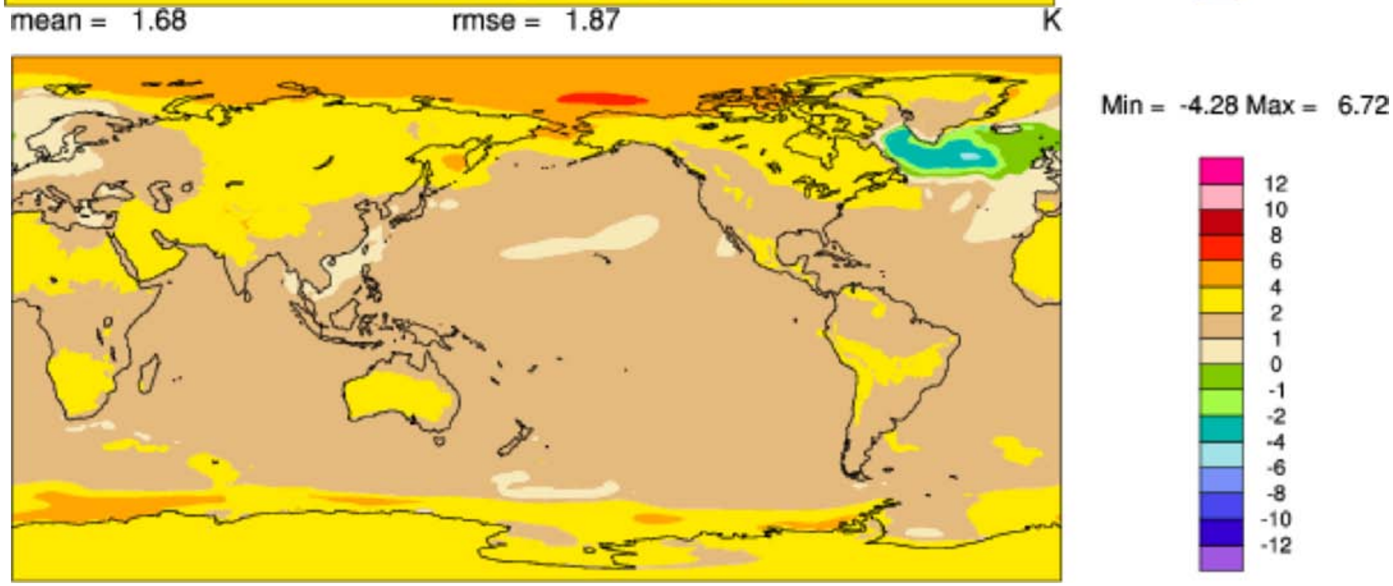
HR

1.7° C



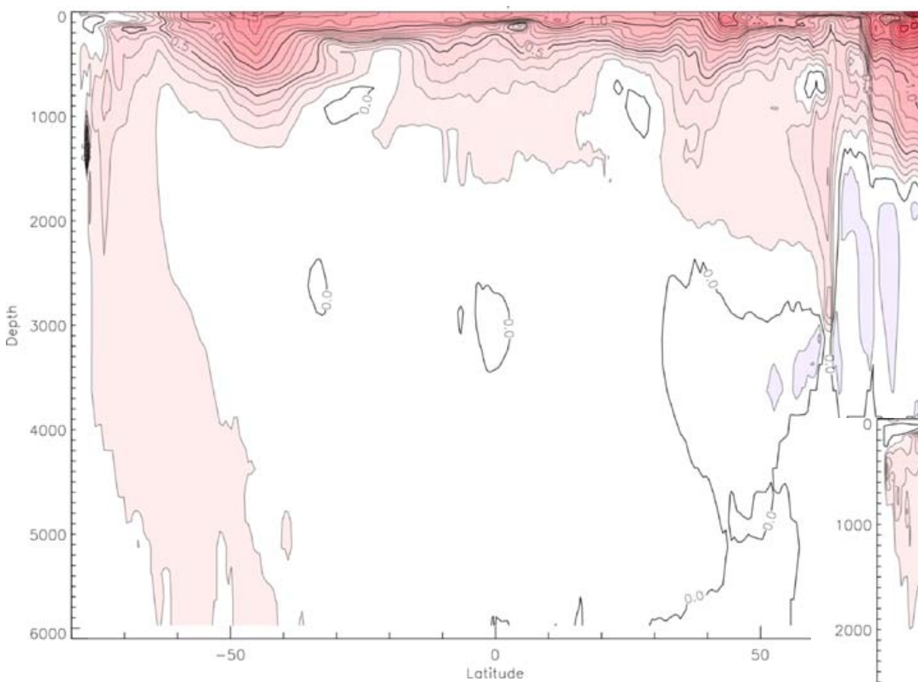
LR

1.7° C

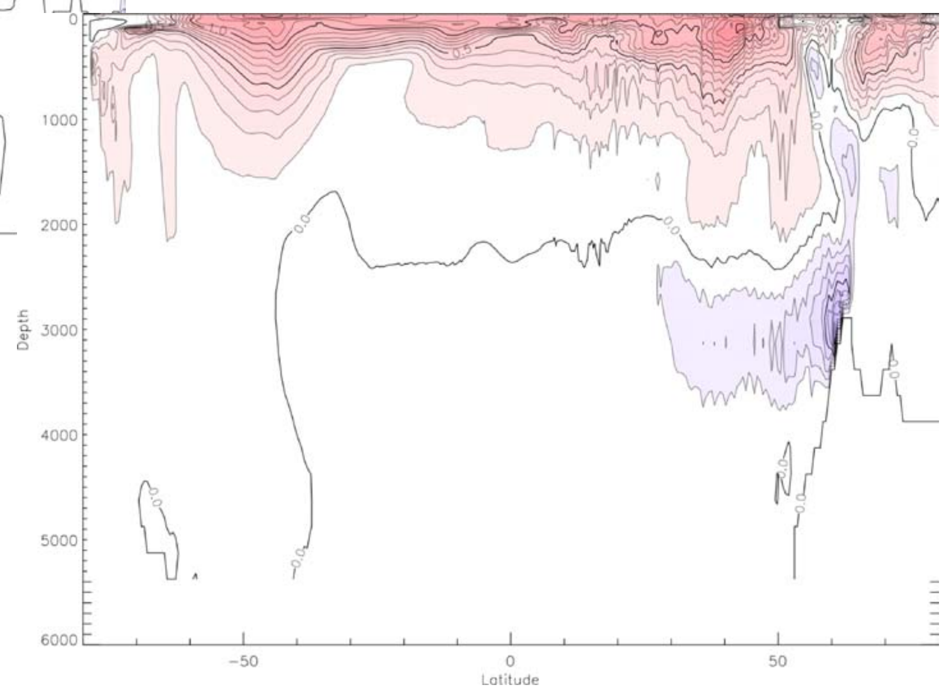


Zonal Avg. Temp. Response

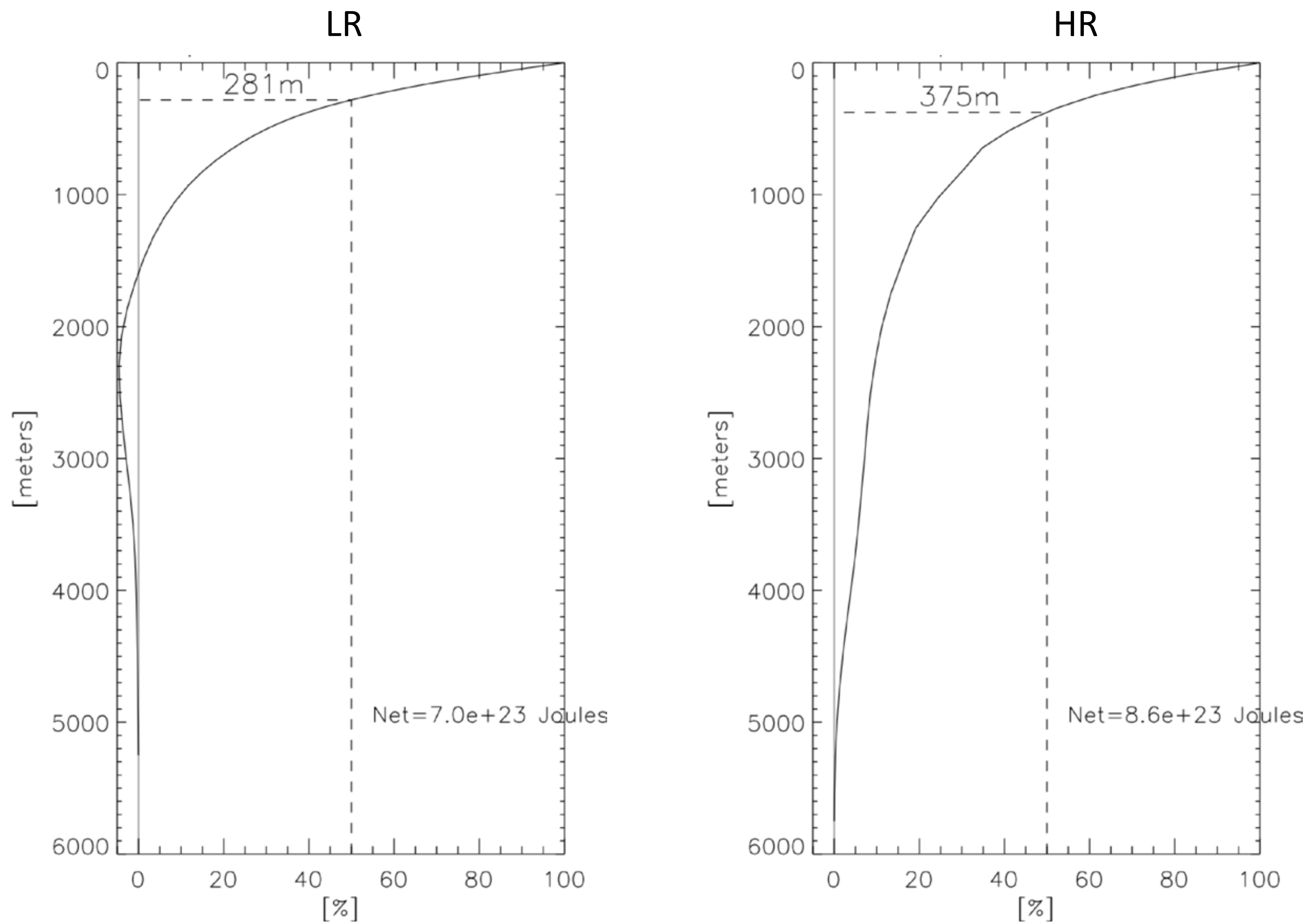
HR



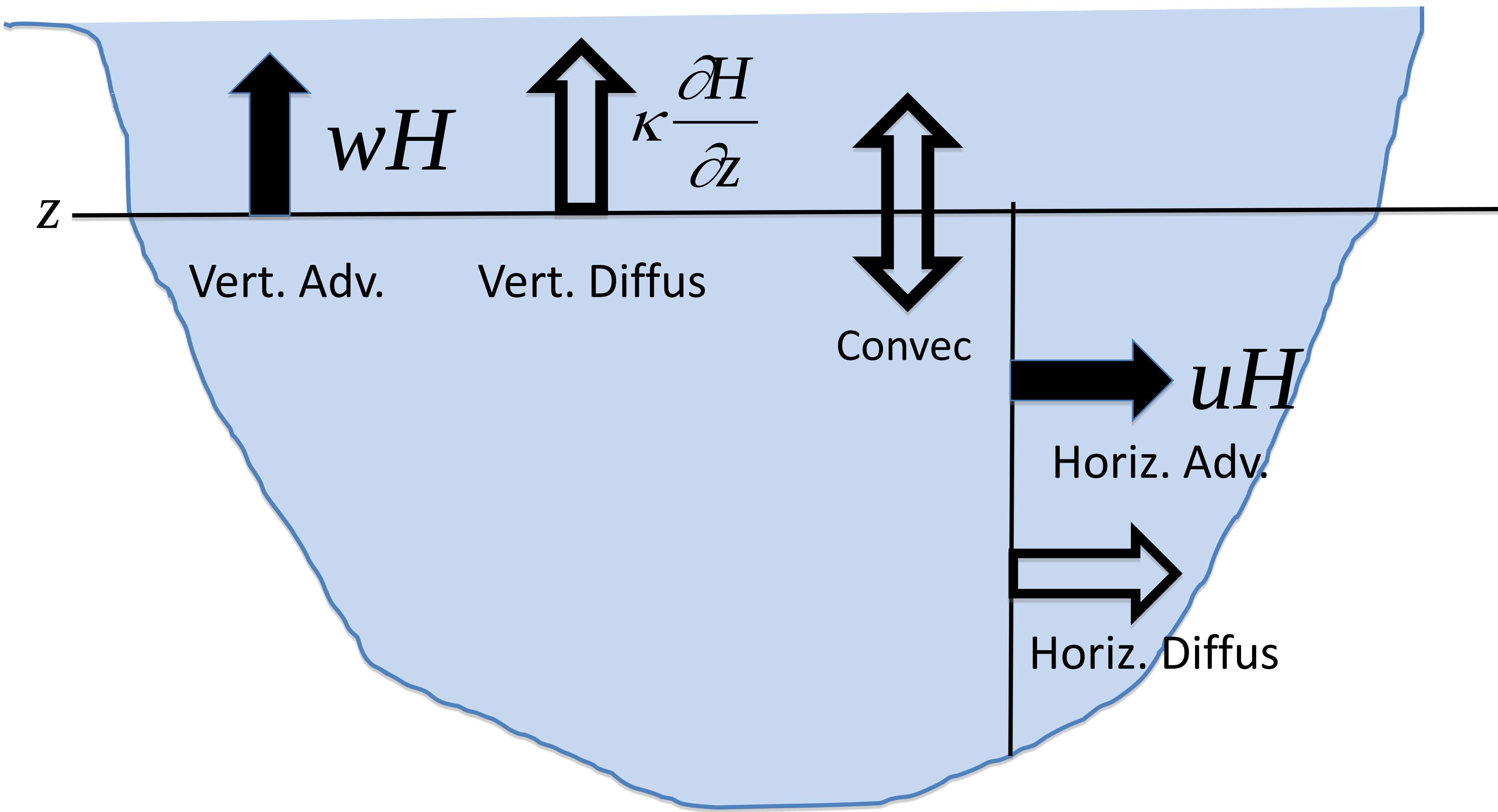
LR



Vertical Distribution of Heat Uptake



The Ocean Energy Budget



The Ocean Energy Budget

$$\int_{-D}^{z}\iint_{A}\frac{\Delta H}{\Delta t}dAdz+$$

Storage

$$\int_{-D}^{z}\iint_{A}\nabla\bullet\overline{u}\overline{H}dAdz+\iint_{A}\overline{w}\overline{H}dA+$$

Advection by Mean Flow

$$\int_{-D}^{z}\iint_{A}\nabla\bullet\overline{u'H'}dAdz+\iint_{A}\overline{w'H'}dA+$$

Advection by Eddies

$$\iint_{A}\kappa\frac{\partial H}{\partial z}dA+$$

(Background) Vert. Diffusion

$$\int_{-D}^{z}\iint_{A}SMSdAdz=0$$

Convection, Other Mixing

Vertical Advective-Diffusive Balance

$$\int_{-H}^{z}\iint_{A}\frac{\Delta H}{\Delta t}\,dAdz\;+$$

Storage

$$\int_{-H}^{z}\iint_{A}\nabla\bullet\overline{u}\,\overline{H}\,dAdz+\iint_{A}\overline{w}\,\overline{H}\,dA+$$

Advec. by Vertical Mean Flow
(POSITIVE)

$$\int_{-H}^{z}\iint_{A}\nabla\bullet\overline{u'H'}\,dAdz+\iint_{A}\overline{w'H'}\,dA+$$

Advection by Eddies

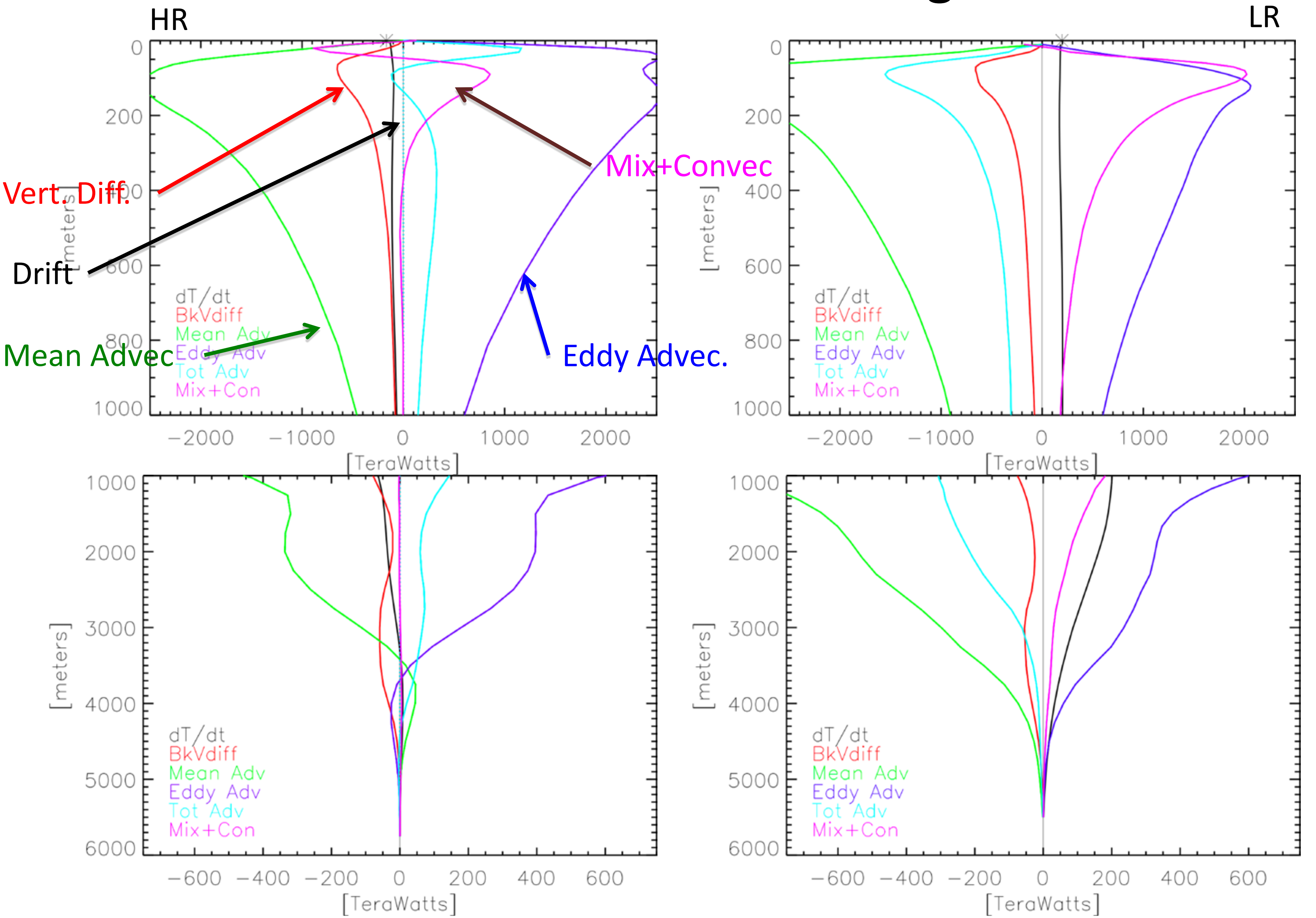
$$\iint_{A}\kappa\frac{\partial H}{\partial z}\,dA+$$

Vertical Diffusion
(NEGATIVE)

$$\int_{-H}^{z}\iint_{A}SMS\,dAdz=0$$

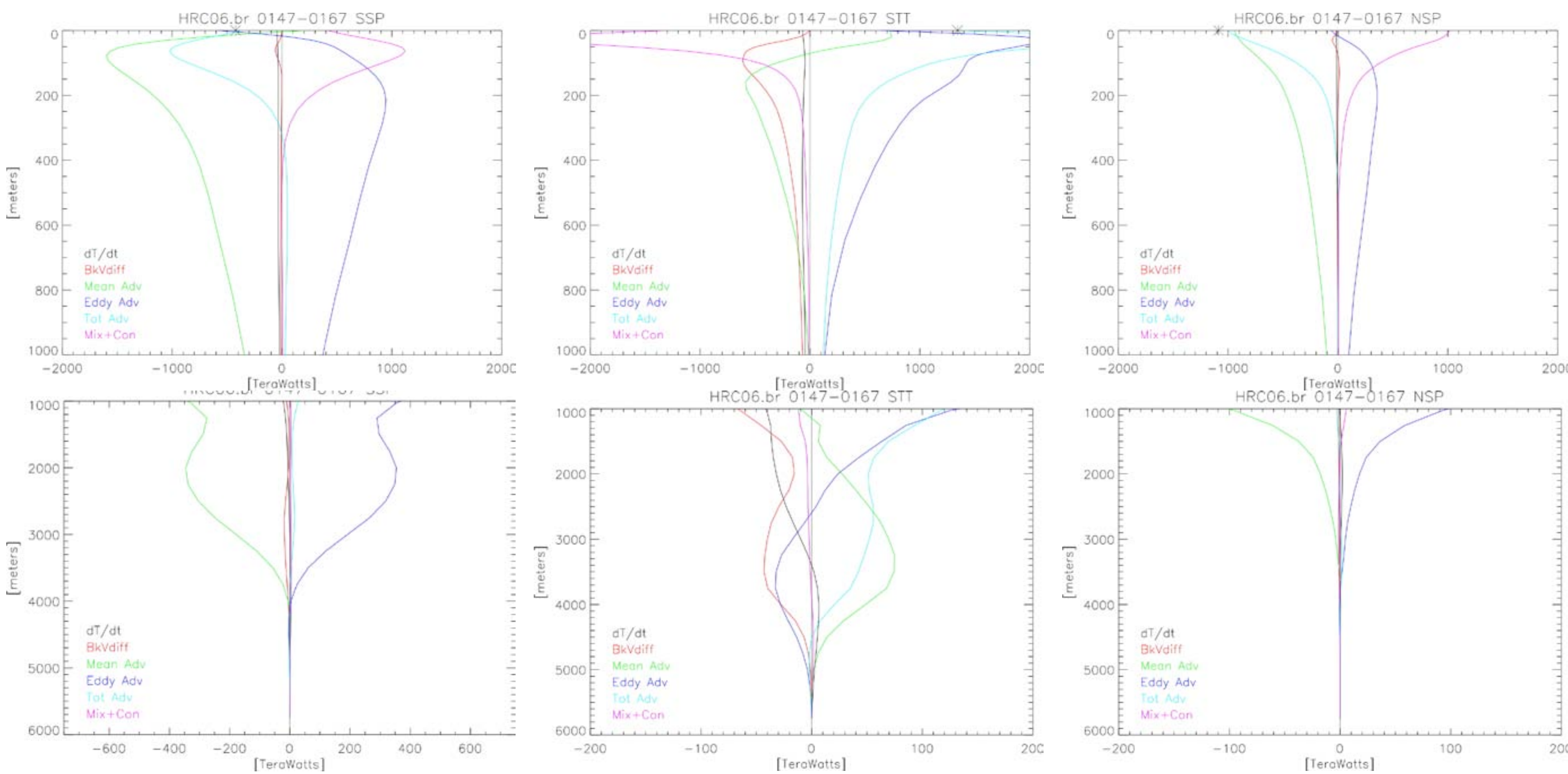
Convection, Other Mixing

Control Global Heat Budget

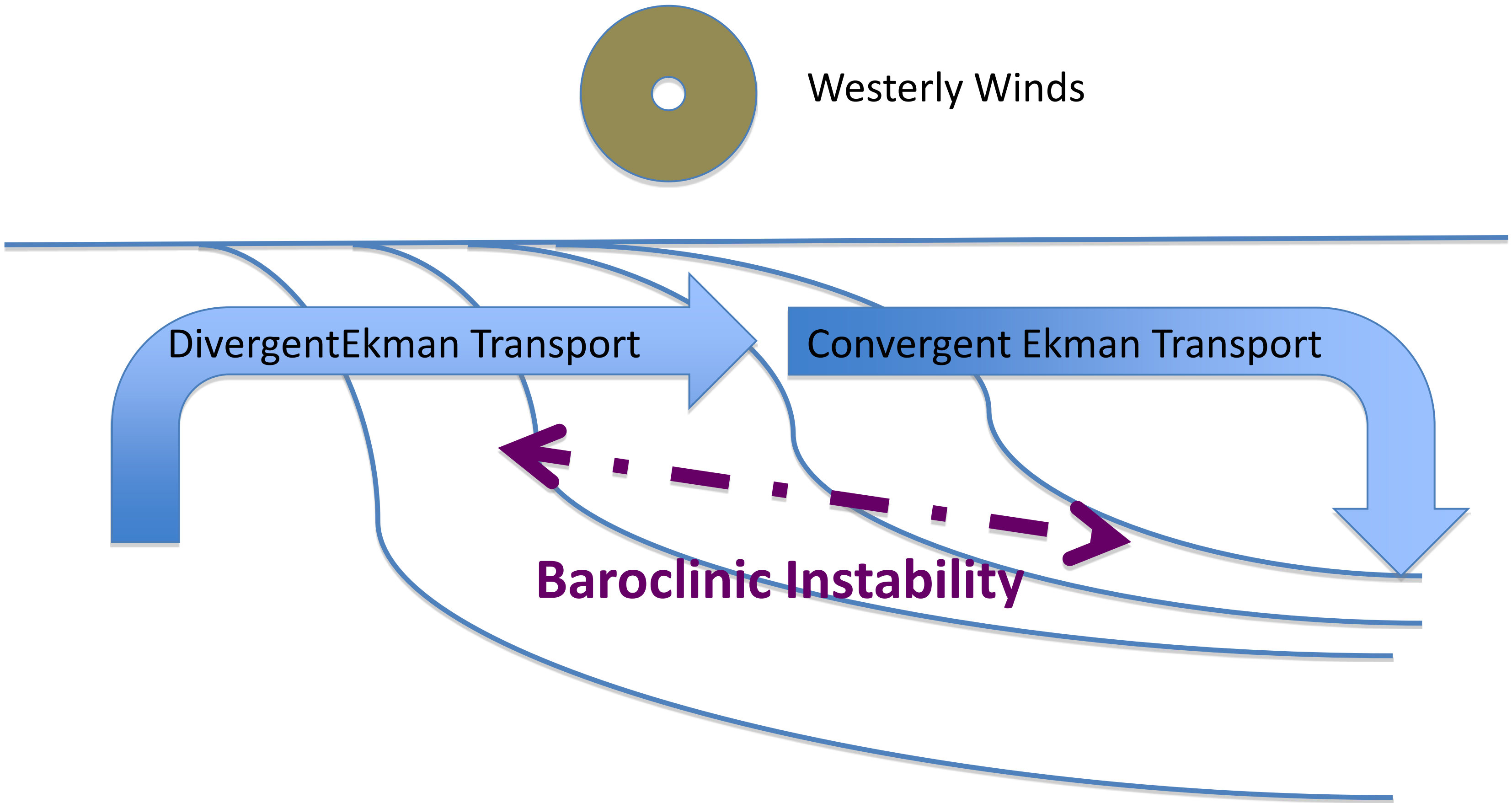


High Res. Control Regional Balances

Southern Subpolar | Tropics/Subtropics | Northern Subpolar

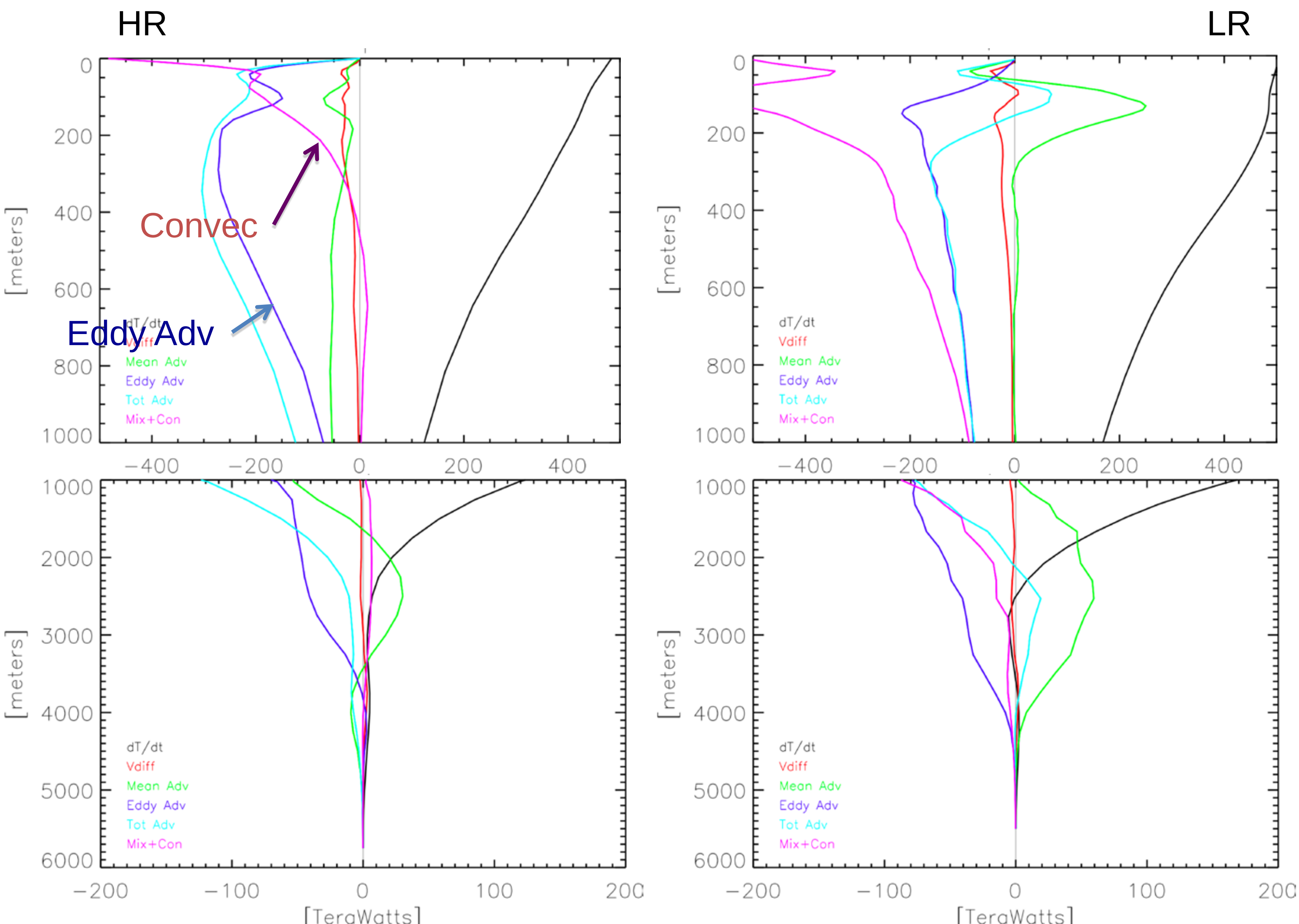


The Southern Ocean Balance



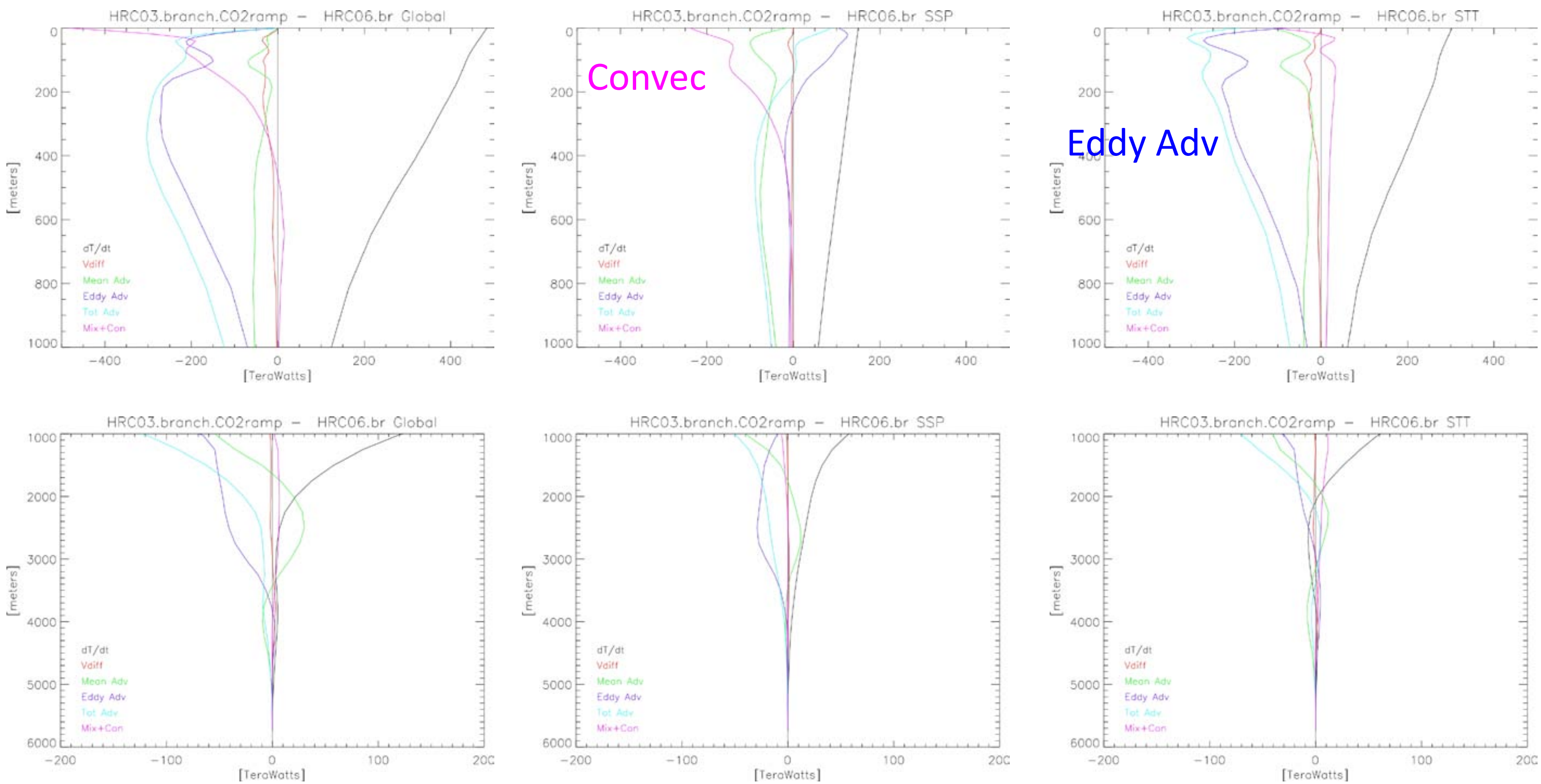
- Mean (Ekman) flow: warm water down / cold water up (positive)
- Eddy flow: warm water up / cold water down (negative)

Changes with Global Warming



Regional Changes in High-Res

Global | Southern Subpolar | Tropics/Subtropics



Conclusions

- Most of the ocean is not in advective-diffusive balance
- The interior ocean is overwhelmingly adiabatic – eddies and mean are in balance
- The warming of the deep ocean results from a weakening of processes that cool, rather than a strengthening of processes that heat
- Modern parameterizations of ocean mesoscale eddies produce the right qualitative balance, with some remaining quantitative discrepancies