Ocean Circulation & Heat Uptake: Processes & Uncertainty

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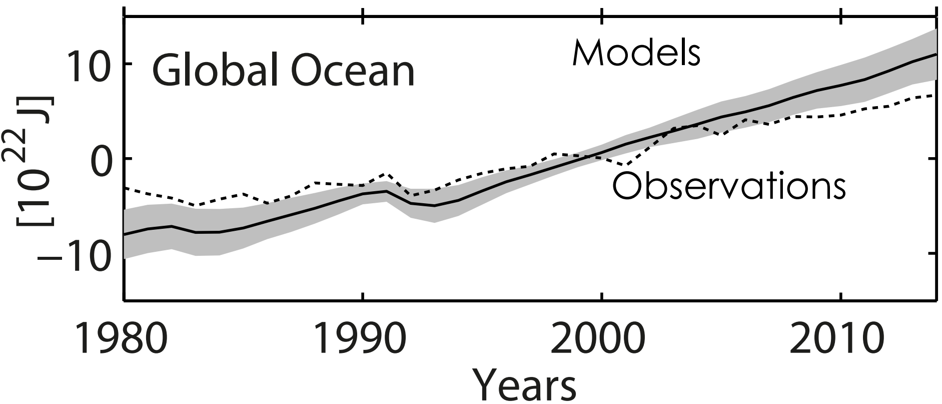
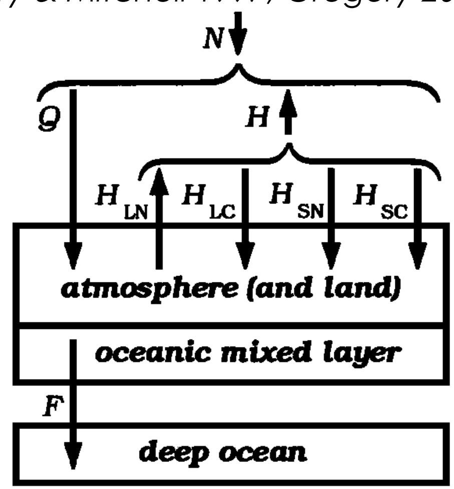
Thanks to M. Huber, J. Ison, D. Marshall

Motivation

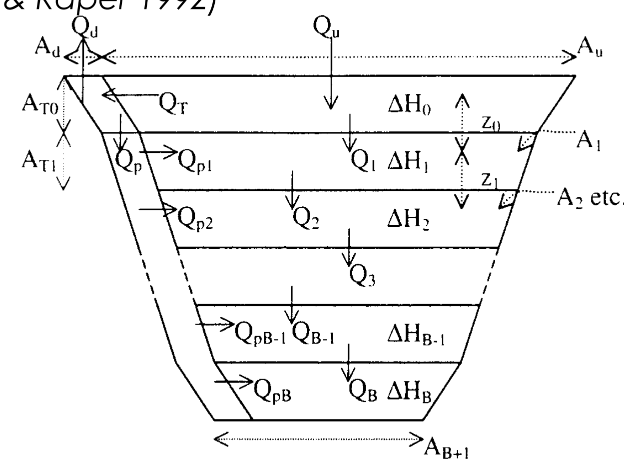


- Ocean Heat Uptake (OHU) is key in setting the surface response to climate change
- Increase in OHU in Obs & CMIP5 (in all basins)

"Box models" with vertical advective flux *(Gregory & Mitchell 1997; Gregory 2000; Held et al 2011)*

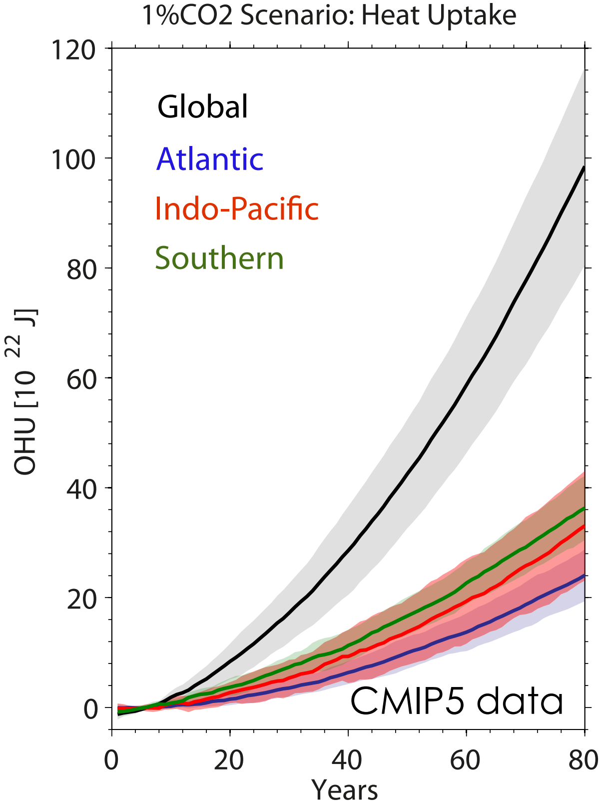


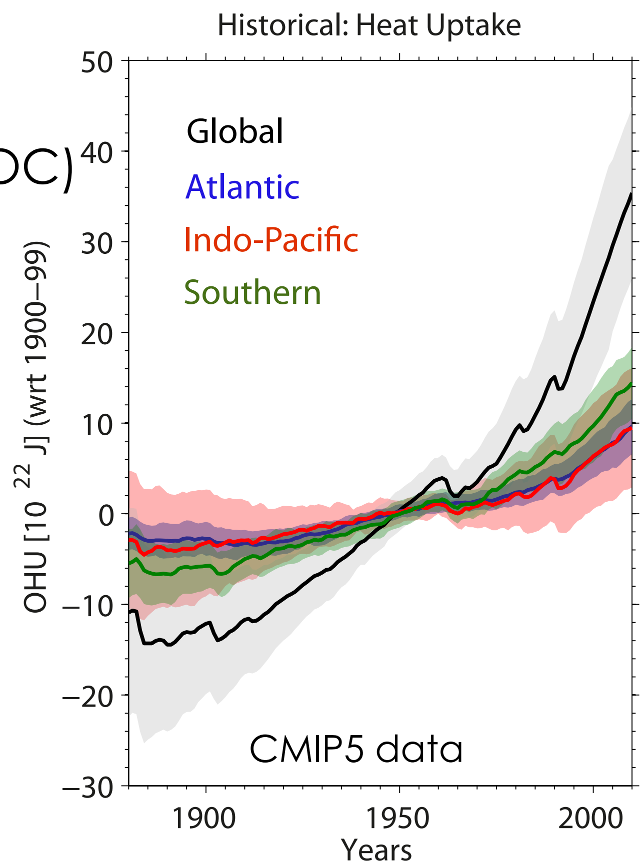
Upwelling-diffusion based on *Munk 1966 (e.g., Hoffert et al 1980, Schlesinger & Jiang 1990, Wigley & Raper 1992)*



Aim: Ocean Heat Uptake Processes

- OHU: surface forcing + ocean stratification & consequently by different thermodynamical & dynamical processes (such as Southern Ocean, MOC)





➡ Hypothesis: Transient ocean heat uptake is dominated by Southern Ocean Ekman pumping

Heat Uptake/ Circulation/ Stratification

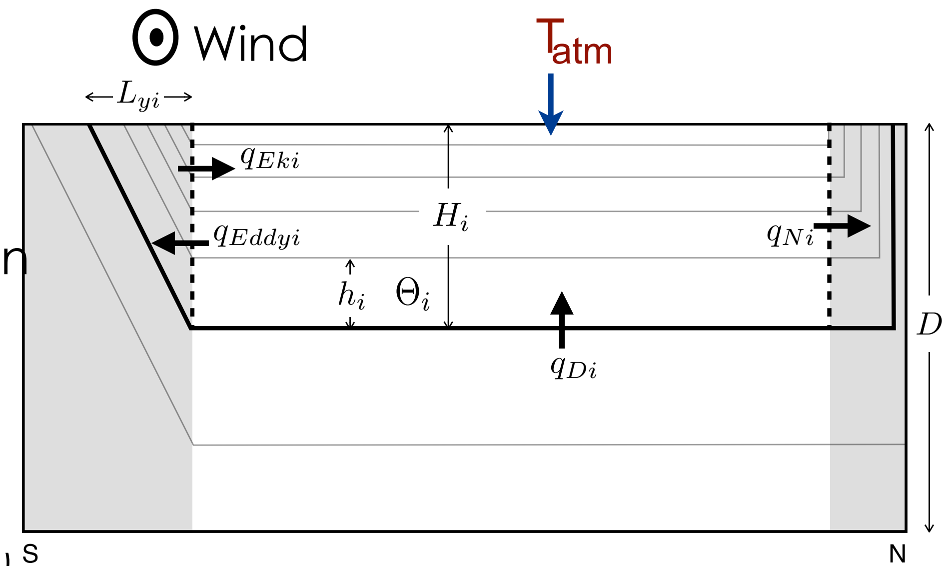
- Time-dependent evolution of heat content as an extension of Gnanadesikan 1999 nonlinear pycnocline model *(or Samelson 1999, Vallis 2000, Wolfe & Cessi 2010 Nikurashin & Vallis 2011, 2012)*

- Volume fluxes in & out of the layer = water mass transformations setting the **mid-latitude** stratification & ocean heat uptake

Volume budget for each layer
$$A\frac{\partial H_i}{\partial t} = q_{Eki} - q_{Eddyi} + q_{Di} - q_{Ni}$$

- Northward wind-driven Ekman circulation

- Eddy-induced transport *(Gent-McWilliams parametrization, 1990)*



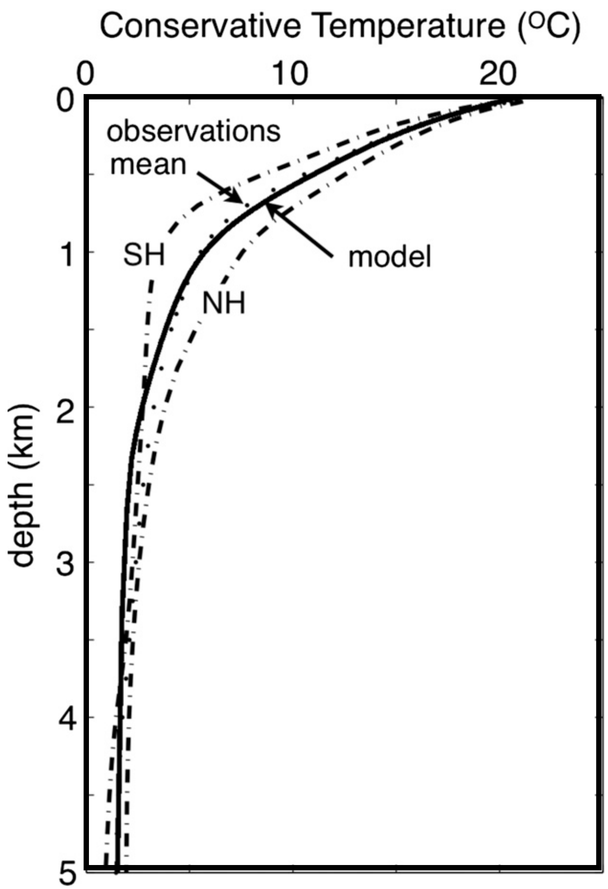
- North Atlantic Deep Water formation (NADW) = MOC& Sinking (prescribed)

- Upwelling balanced by downward diffusion *(Munk,1977)*

Ocean Heat Content/ Uptake
$$\mathcal{H} = \rho_0\, c_p^0 \sum_{i=1}^{n} \Delta\Theta\, A\, H_i$$

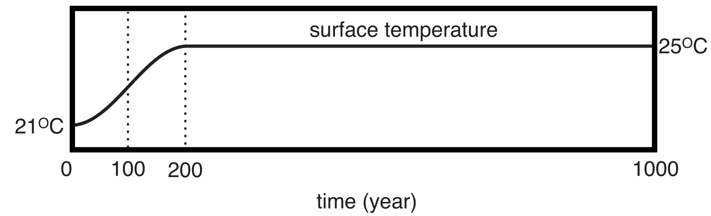
(Marshall & Zanna 2014)

Heat Uptake/ Circulation/ Stratification



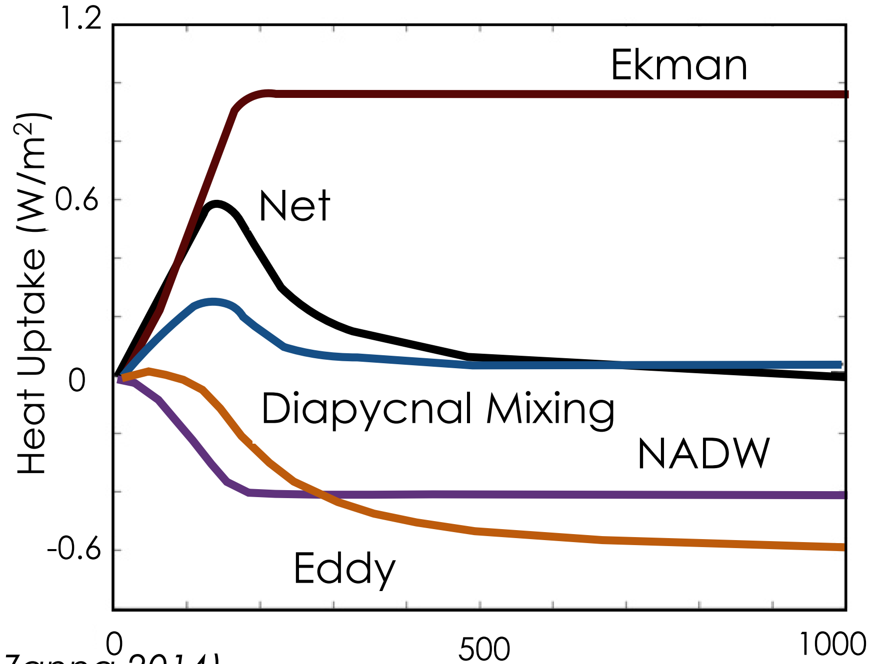
➡ "Realistic" stratification

➡ Forcing



➡ Ekman transport dominant = heat pumped into the interior, upper 2km *(e.g, Gregory 2000, Xie & Vallis 2012)*

➡ Diapycnal mixing is important initially but not dominant overall



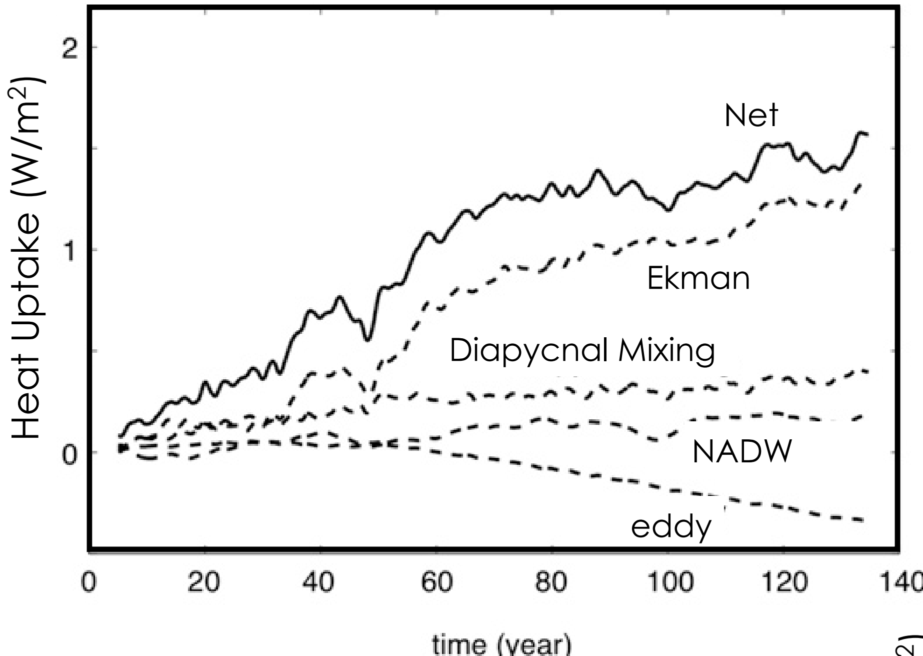
➡ Eddies set the adjustment time-scale

➡ NADW here is a transformation of water water into cold so reduces the heat uptake

(Marshall & Zanna 2014)

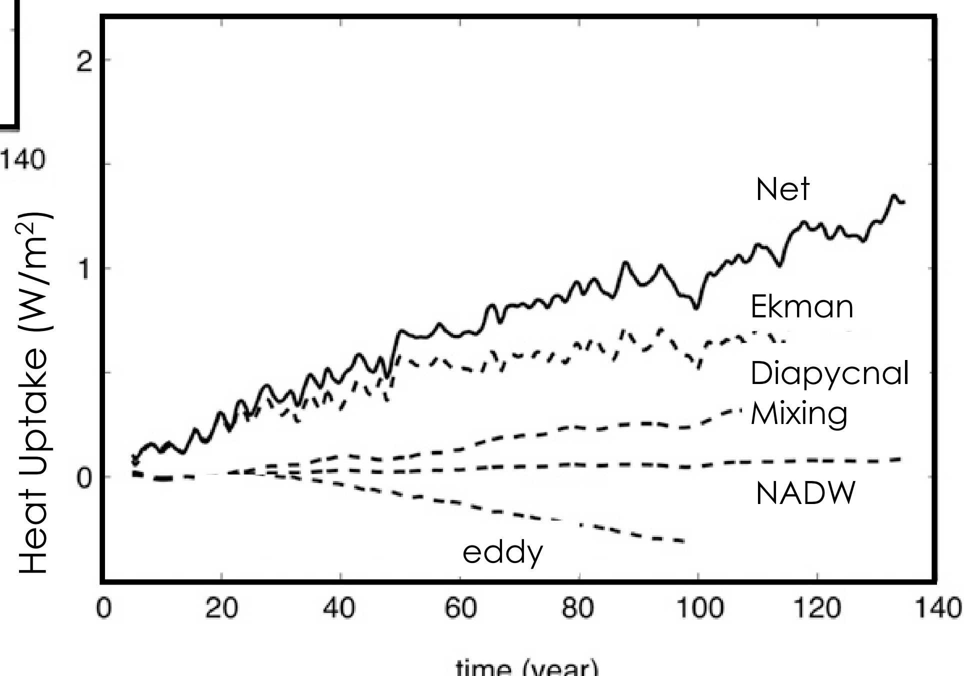
Processes in GCMs

➡ Using timeseries for MOC, Ekman transport, SST & eddy + diapycnal mixing coefficients, we can estimate processes/timescales of uptake in GCMs + obs



MITgcm idealized geometry (Eddy Resolving)

CanESM2 (1degree, parametrised eddies)

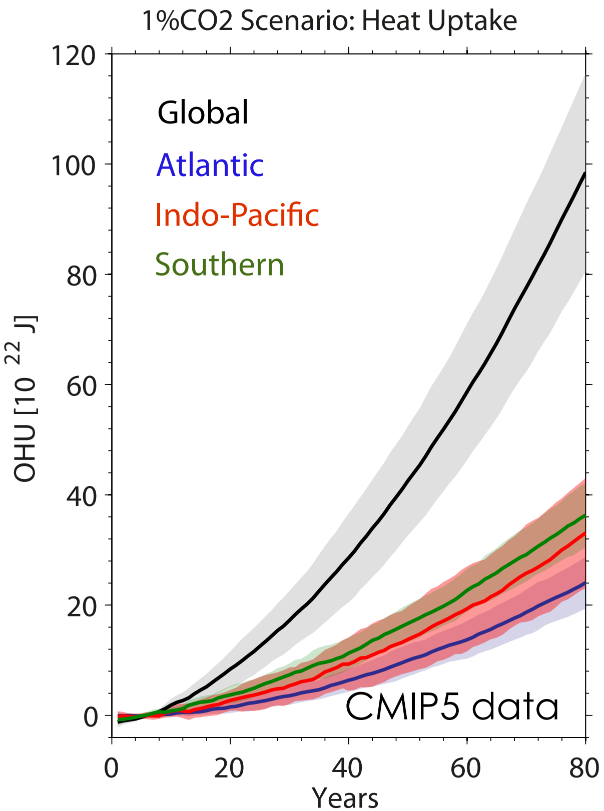


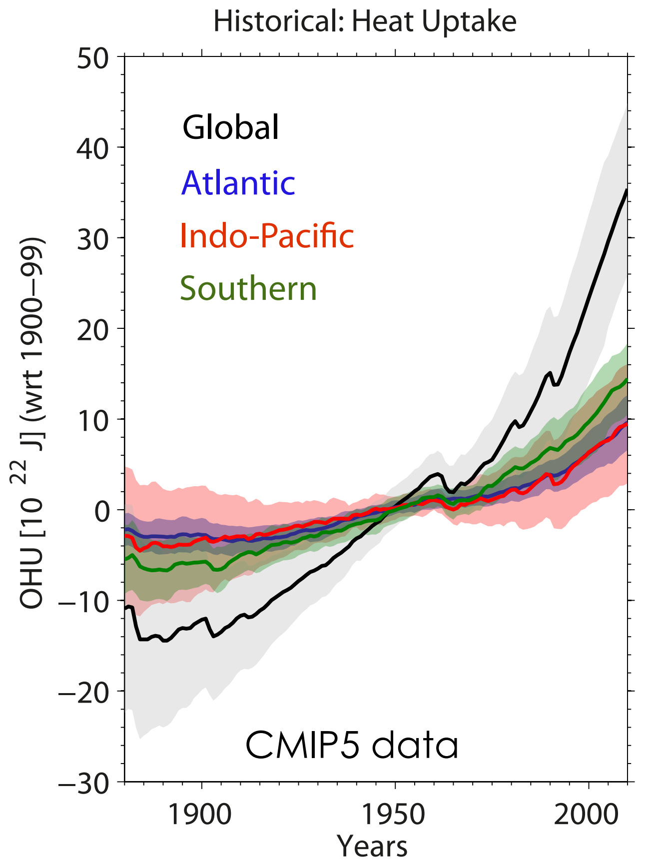
(Zanna, Ison, Huber, In Prep 2016)

Uncertainty in ocean heat uptake

➡ For a given warming & a given stratification the Southern Ocean is dominated by Ekman

▸ The stratification is set by surface atmospheric forcing & internal ocean processes …

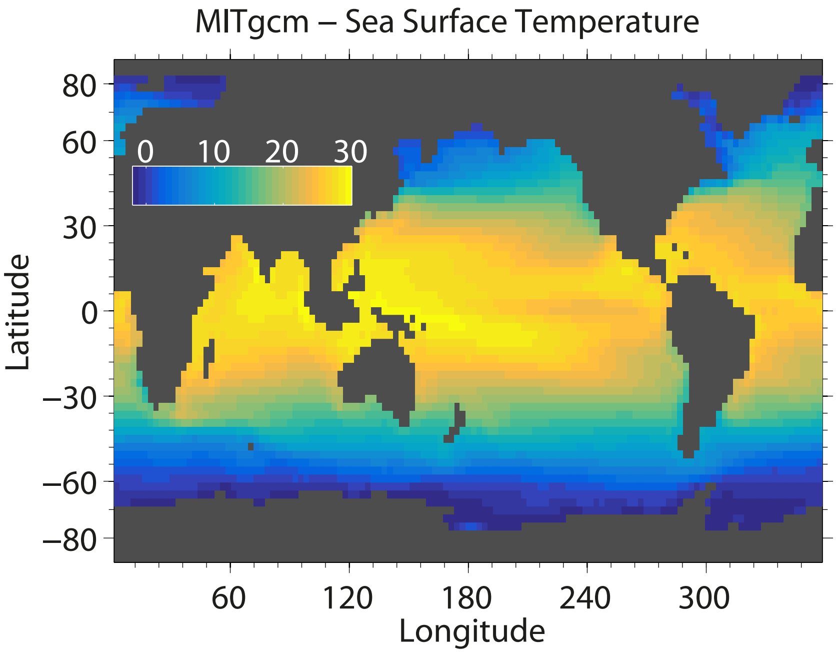




➡ Is the heat uptake uncertainty driven by the difference in atmospheric forcing/feedbacks or the different initial stratifications?

We should have stopped there

Ocean model forced with CMIP5 fluxes



- **Ocean-only model**
- **MITgcm** *(Marshall et al 1997)*
- 2.5 x 2.5 deg
- Monthly forcing
- Bryan-Lewis diffusivity & GM eddy parametrization

- **Surface boundary conditions** taken **from 28 CMIP5 runs**

$$F_u = \frac{\tau_x}{\rho_0 \Delta z_s} \qquad F_\theta = -\lambda_\theta(\theta - \theta^*) - \frac{1}{c_p \rho_0 \Delta z_s} Q$$

$$F_v = \frac{\tau_y}{\rho_0 \Delta z_s} \qquad F_s = -\lambda_s(S - S^*) + \frac{S_0}{\Delta z_s}(E - P - R)$$

= Ensemble with the same ocean model and 28 different surface forcing: control & 1%CO2 (time-evolving)

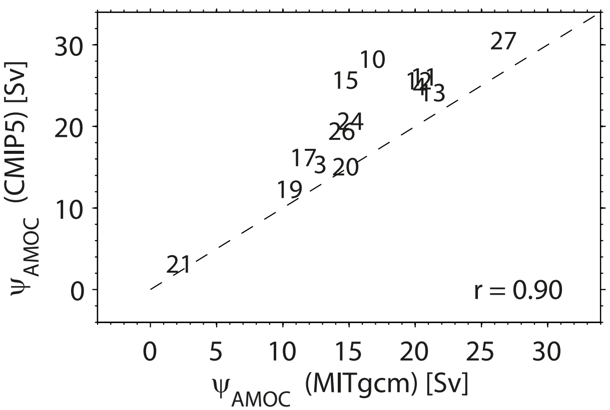
Diversity & Spread due to Surface Fluxes: Control

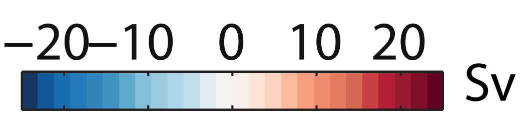
- **MITgcm residual circulation & stratification**

when forced with surface forcing from 28 CMIP5 control runs

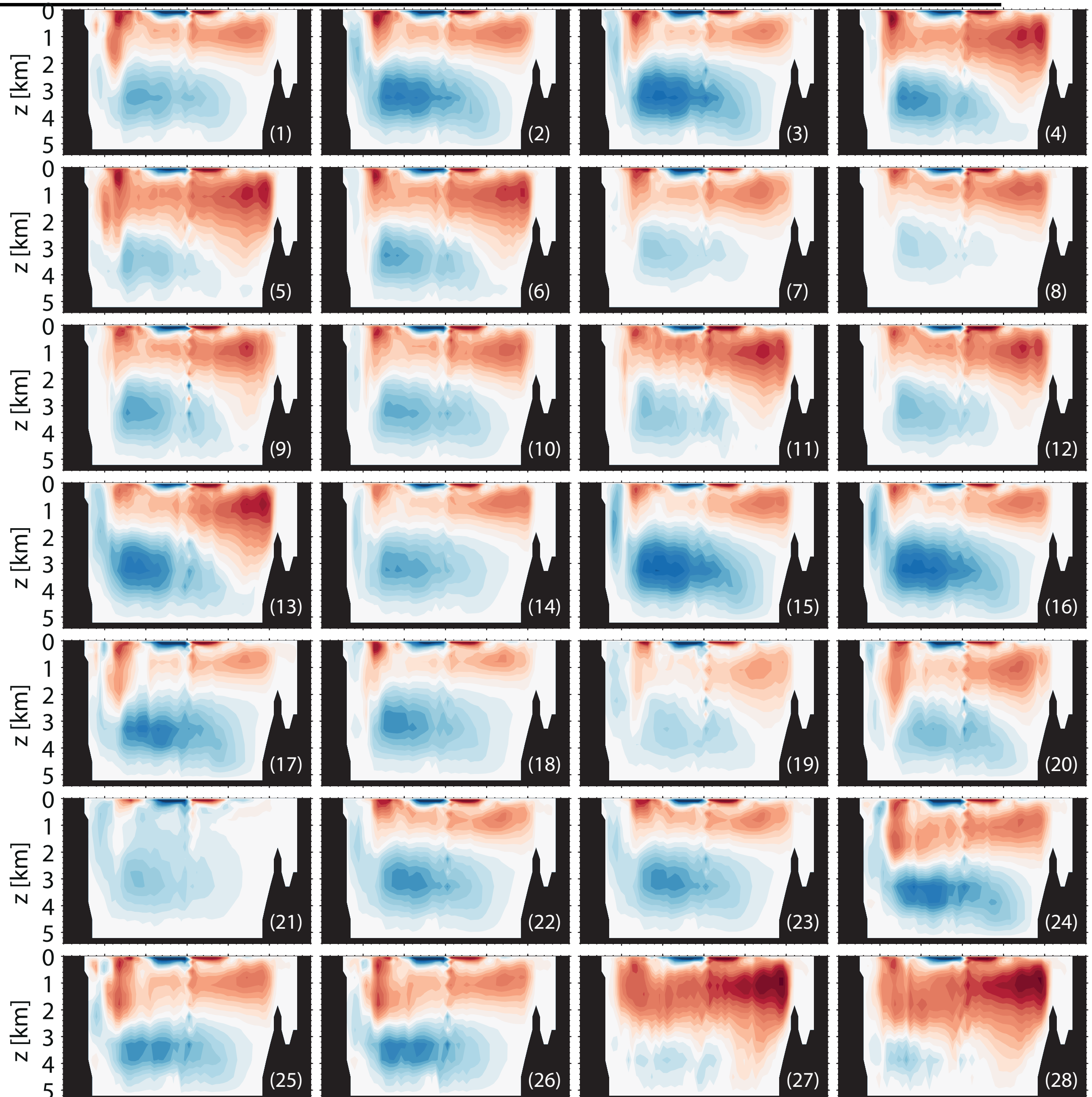
CMIP5 vs MITgcm

r= 0.80-0.90

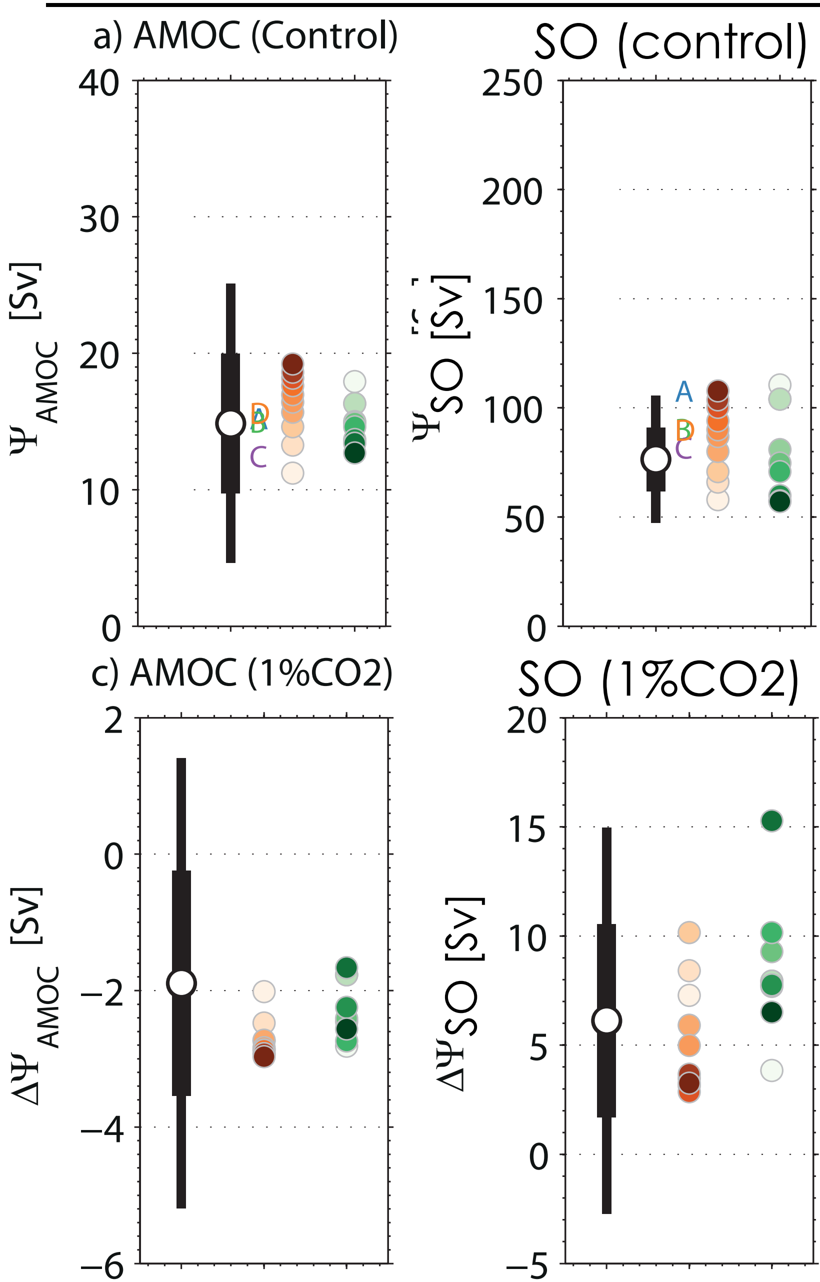




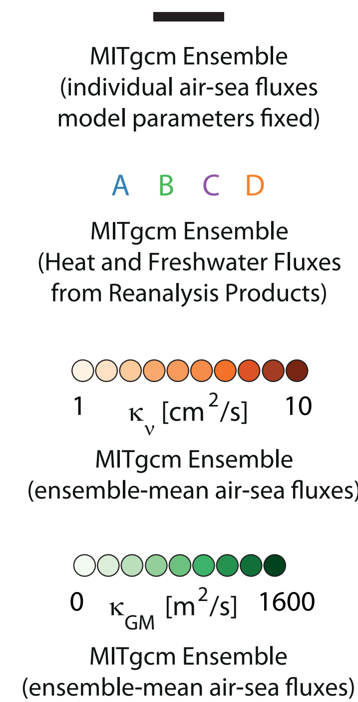
(*Huber & Zanna, submitted 2016*)



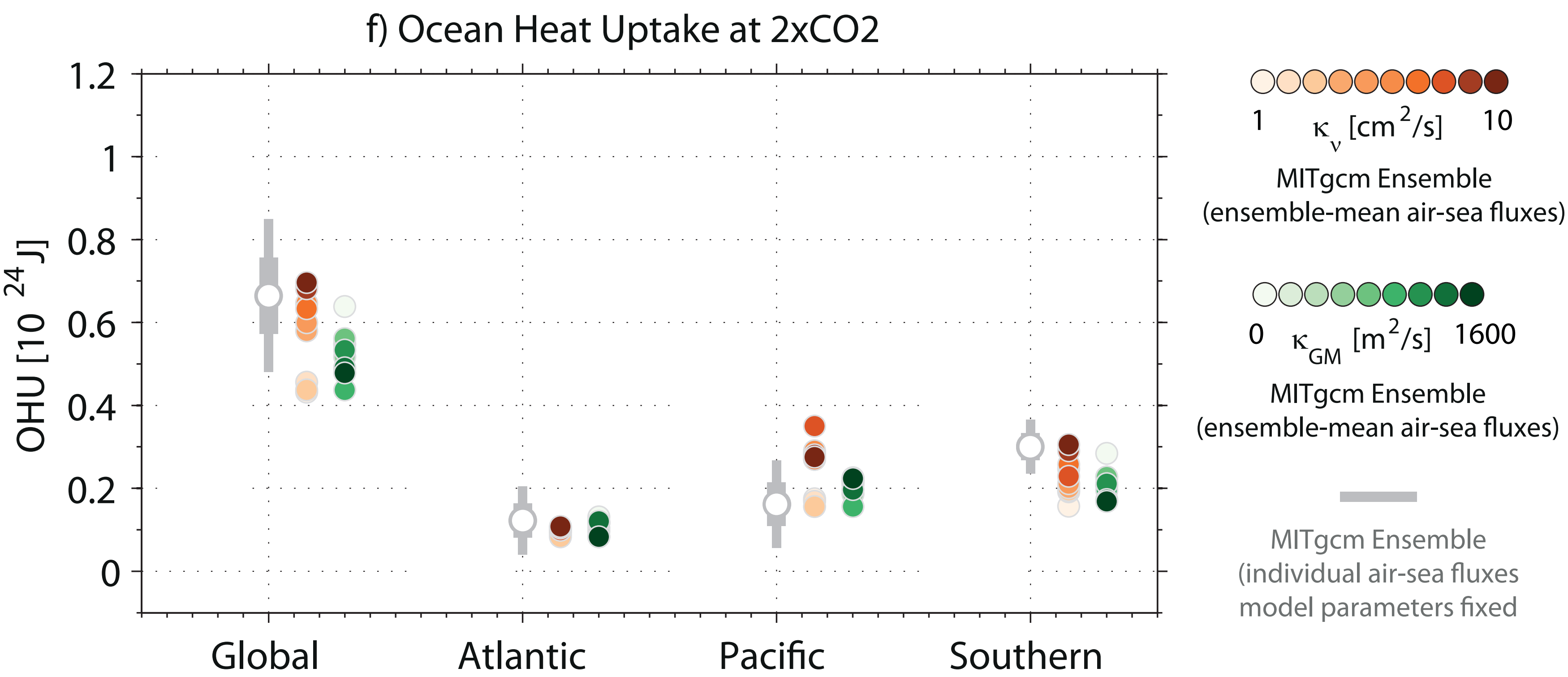
Fluxes vs. Paramaters Uncertainty: Circulation



- Control
  - AMOC: spread due air-sea fluxes dominates
  - SO residual circulation: Spread due to diapycnal mixing, eddy coefficient & air-sea fluxes are comparable
- 1%CO2
  - Same results hold …



Fluxes vs. Paramaters Uncertainty: Heat Uptake



- Global heat uptake spread: depends on all, internal physics & surface forcing
- Atlantic: air-sea flux (heat flux); Pacific: diapycnal mixing; Southern Ocean : eddy mixing and vertical mixing

(*Huber & Zanna, submitted 2016)*

Concluding remarks

- Ocean heat uptake controlled by Southern Ocean Ekman transport in observations, simple & complex models (with or without eddies)

- Idealized models can be used for diagnostic purposes to understand & identify the mechanisms & timescales for the rate of ocean heat uptake

- Global uptake: depends on the stratification & the forcing; with basin-scale dependence

- Needed: A better understanding of the transient response of the ocean - stratification/forcing/uptake & subsequent feedback with any good tools/ models