Mechanisms of global and large-scale ocean heat uptake on multidecadal timescales

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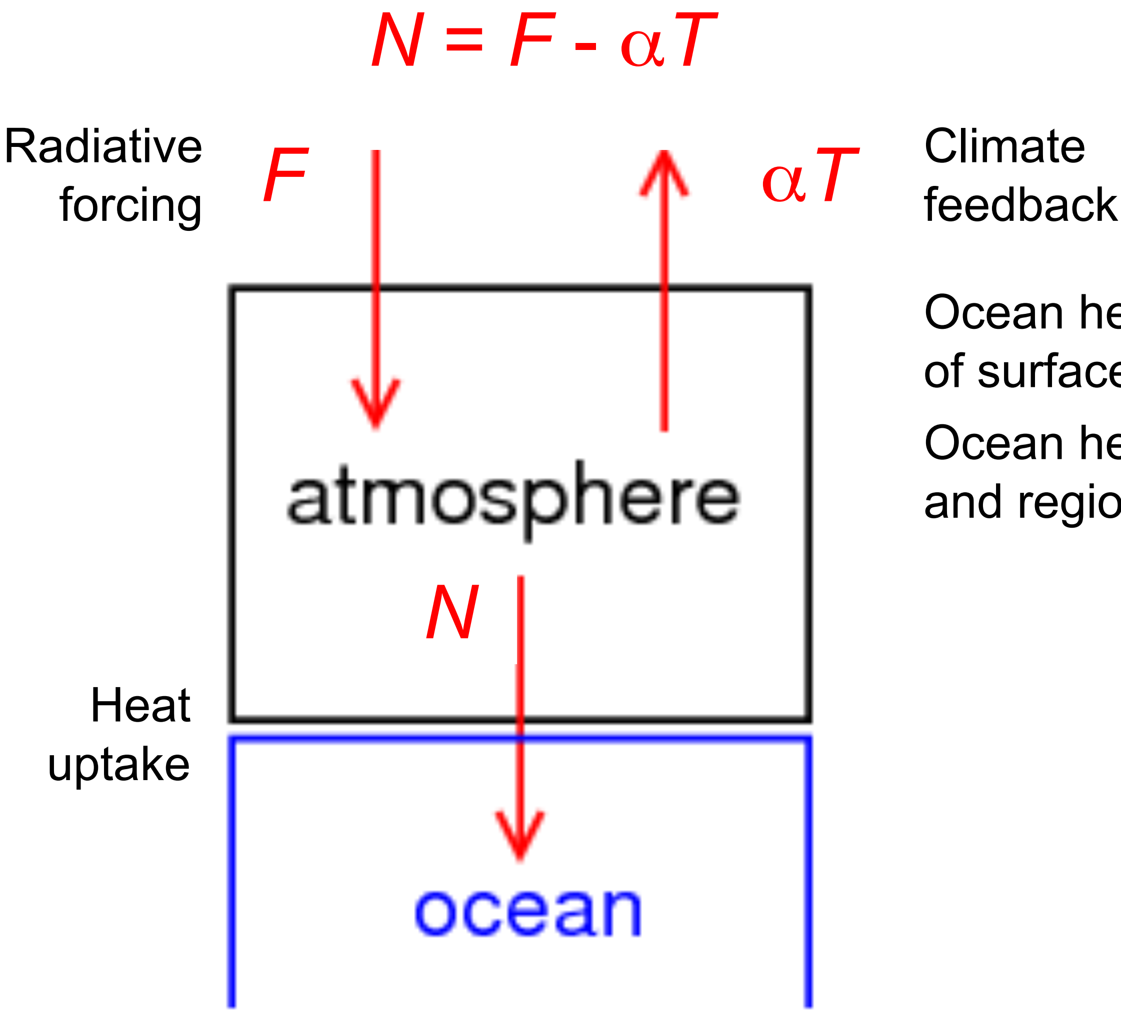
Ocean heat uptake in the Earth energy budget

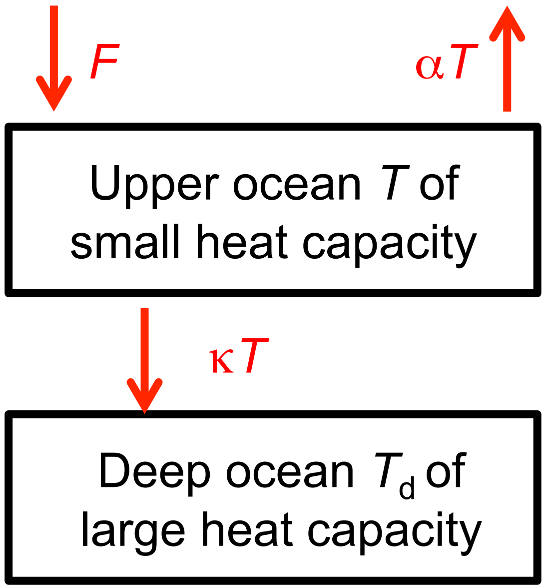


Ocean heat uptake mitigates the rate of surface climate change.

Ocean heat storage causes global and regional sea level change.

Two-layer model for transient climate response

$$N = F - \alpha T$$
$$N = C_u \, dT/dt + \kappa(T - T_d)$$



For a few years after switching on *F*, the upper-ocean heat capacity C_u determines the rate of climate change.

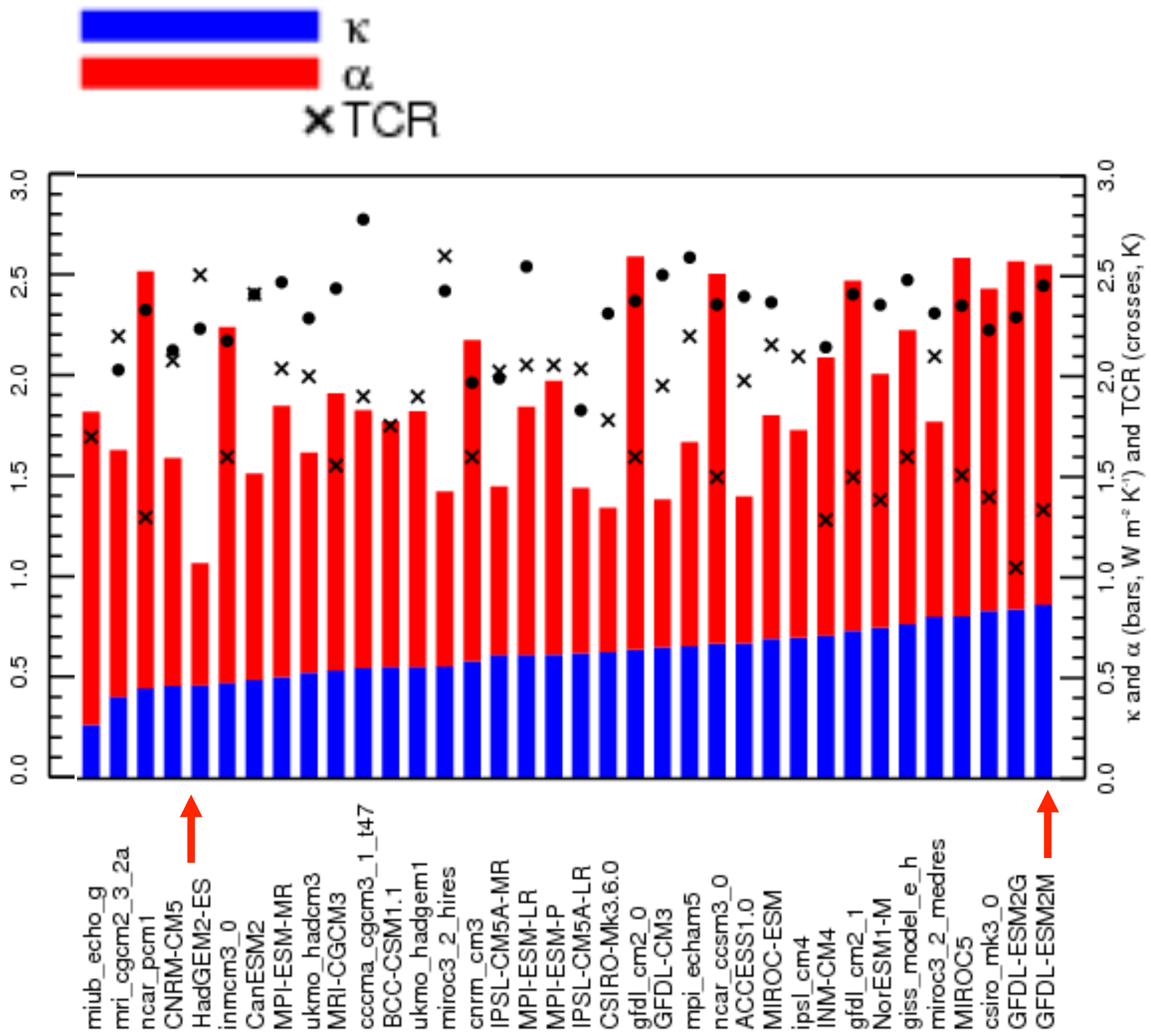
On longer timescales, most of the heat goes into the deep ocean.

For many decades, $T_d << T$, so $N \approx \kappa T$ and $T \approx F/(\alpha + \kappa)$.

The ocean heat uptake efficiency κ reduces the surface warming by removing heat into the deep ocean.

Transient climate response in K
TCR = $F(2\times CO_2)/(\alpha + \kappa)$

Ocean heat uptake is ~1/3 of CO_2 radiative forcing



$$F = \alpha T + \kappa T$$

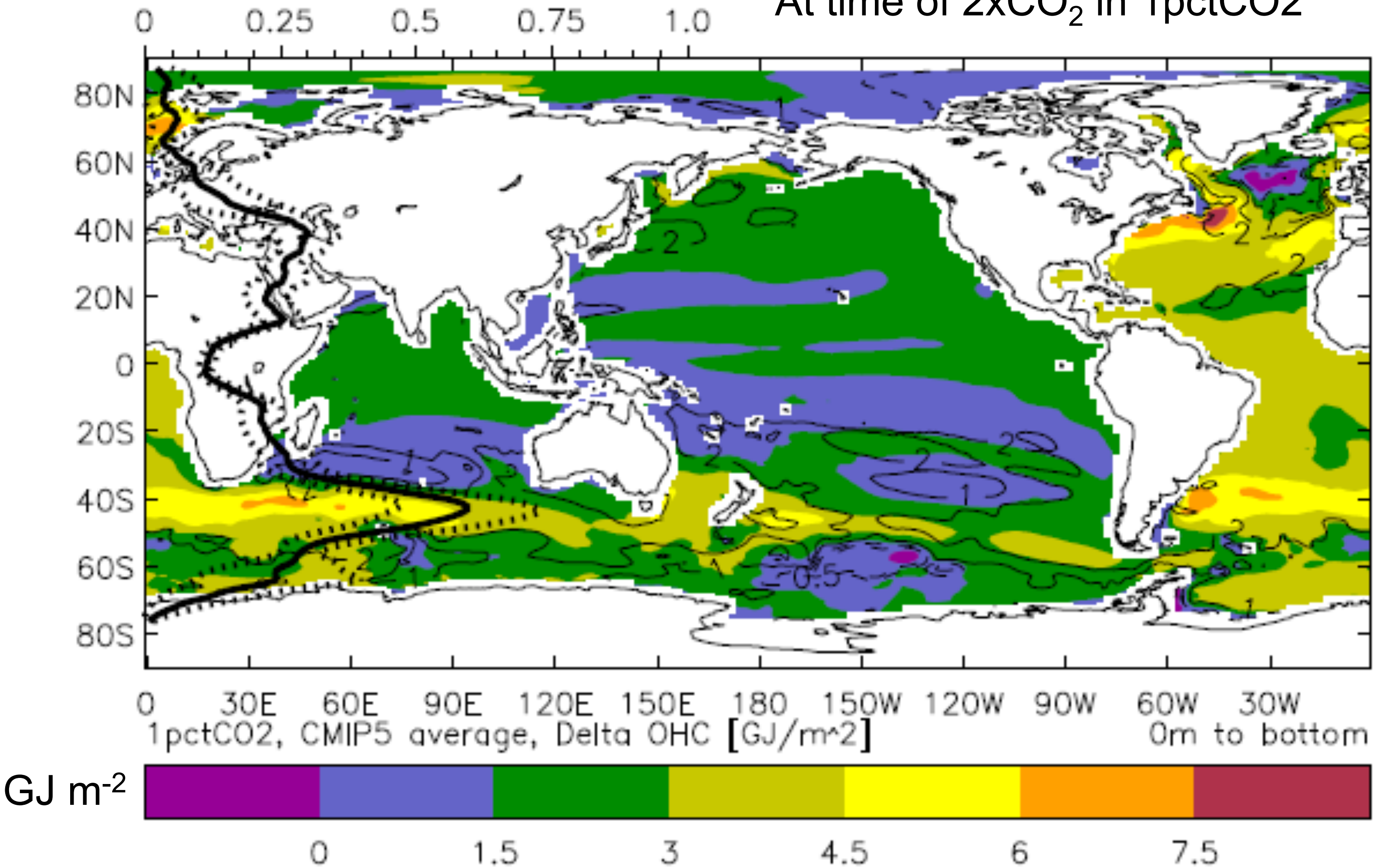
Ocean heat uptake efficiency κ has a spread of a factor of ~2 across CMIP3+5 AOCGMs.

A lot is known about the spread in α, much less about the spread in κ.

Kuhlbrodt and Gregory (2012)

Geographical distribution of ocean heat uptake

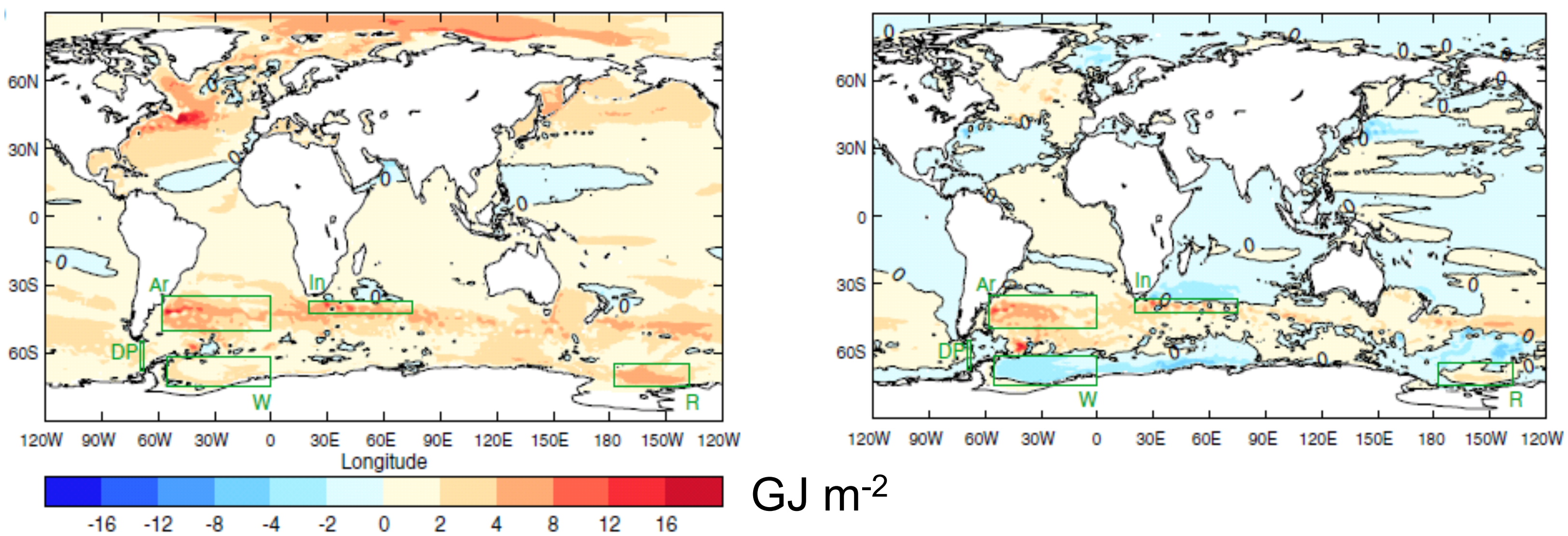
At time of $2xCO_2$ in 1pctCO2



Kuhlbrodt and Gregory (2012)

Effect of surface flux changes on ocean heat content (OHC)

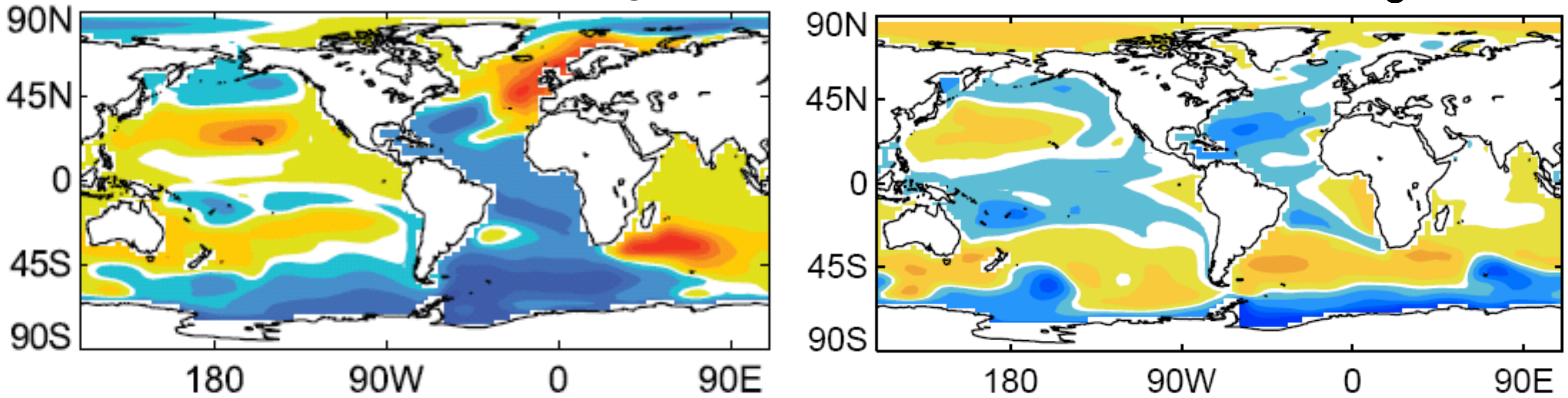
OHC change under elevated CO_2 | OHC change due to windstress change



Kuhlbrodt et al. (2015)

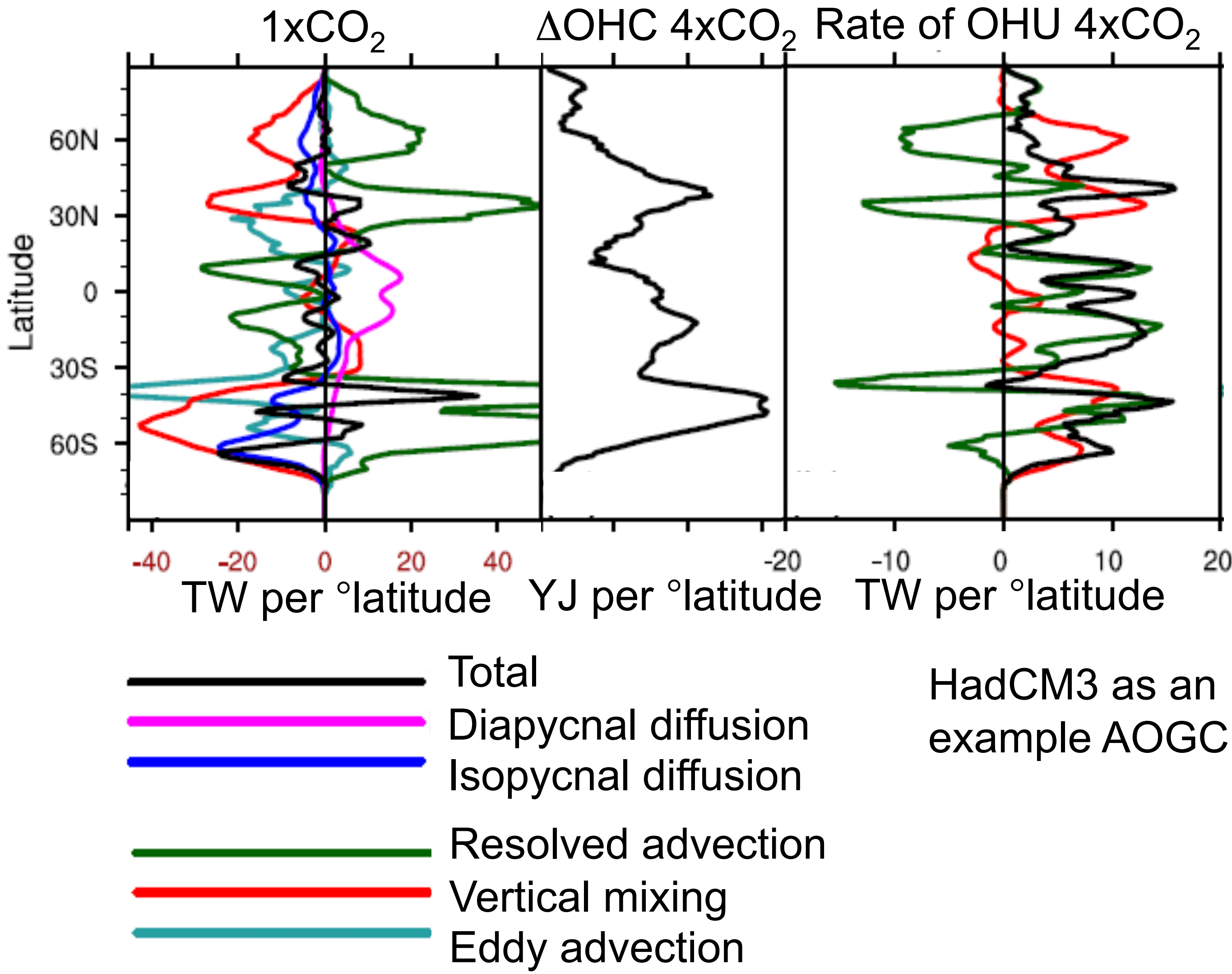
Change in ocean dynamic topography in FAMOUS forced by CMIP5 …

surface heat flux change | windstress change



Bouttes and Gregory (2014)

Processes of interior ocean heat transport below ~100 m

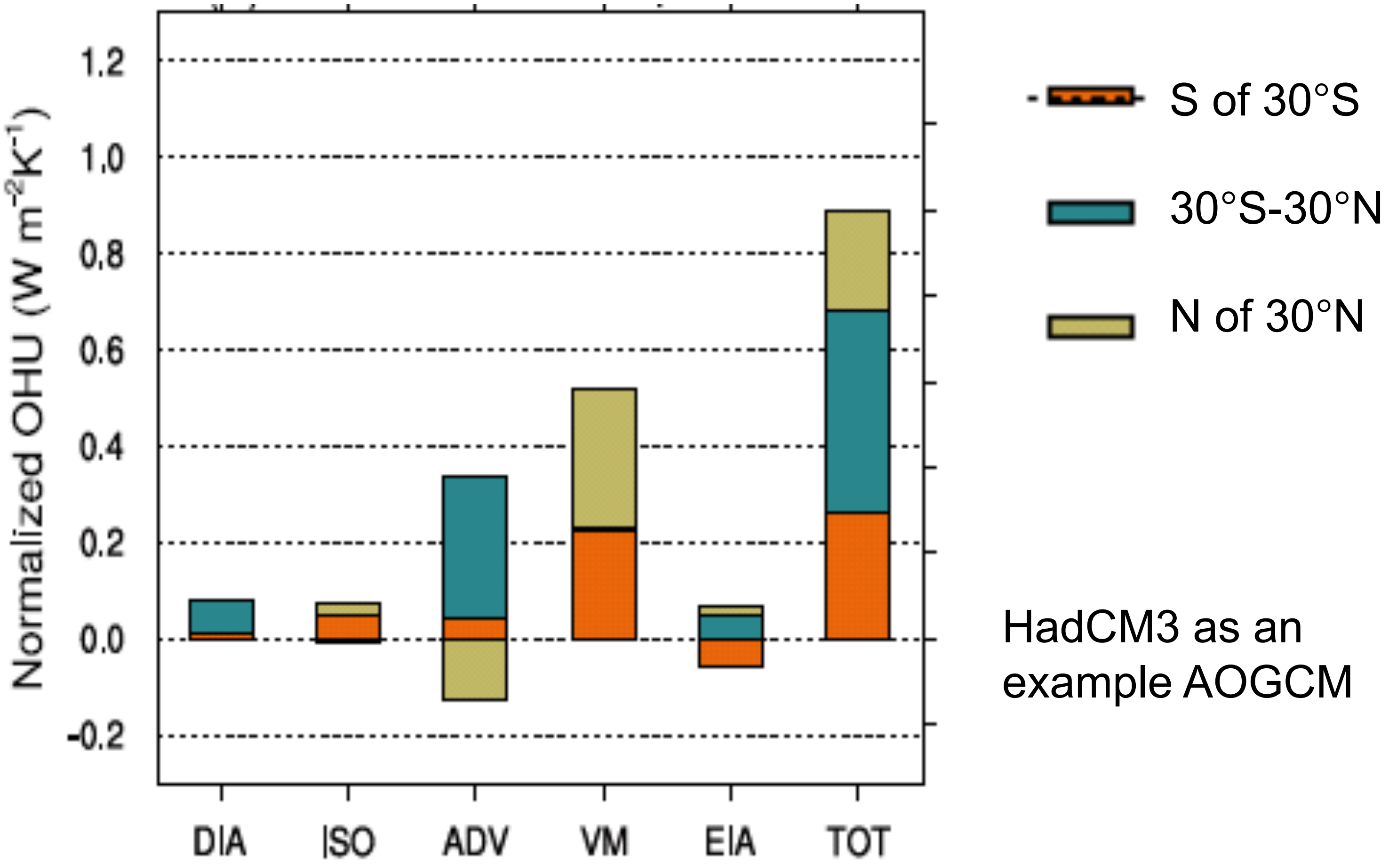


HadCM3 as an example AOGCM

Exarchou et al. (2015)

Processes of interior ocean heat transport below ~100 m

Ocean heat uptake efficiency

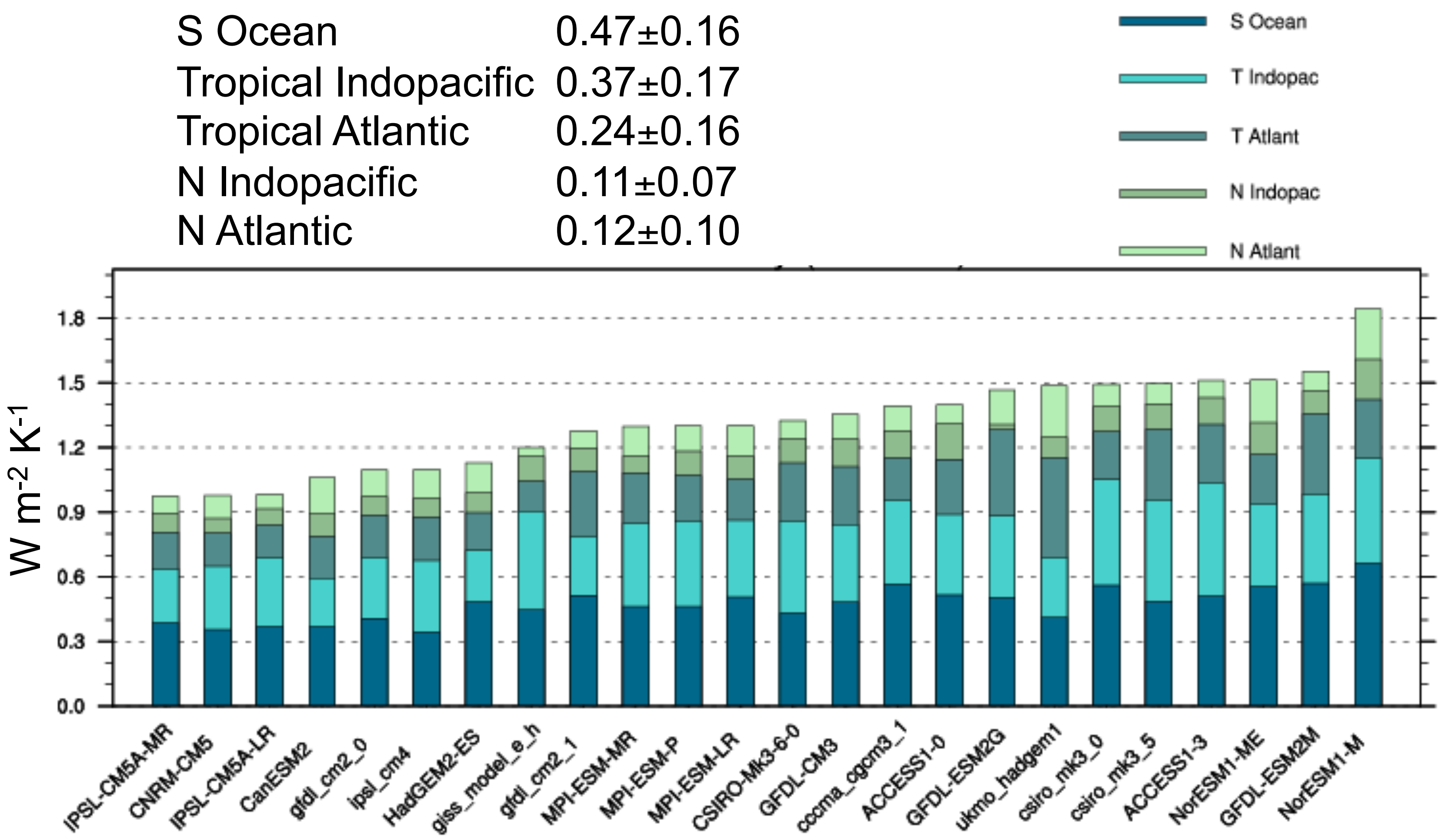


HadCM3 as an example AOGCM

Exarchou et al. (2015)

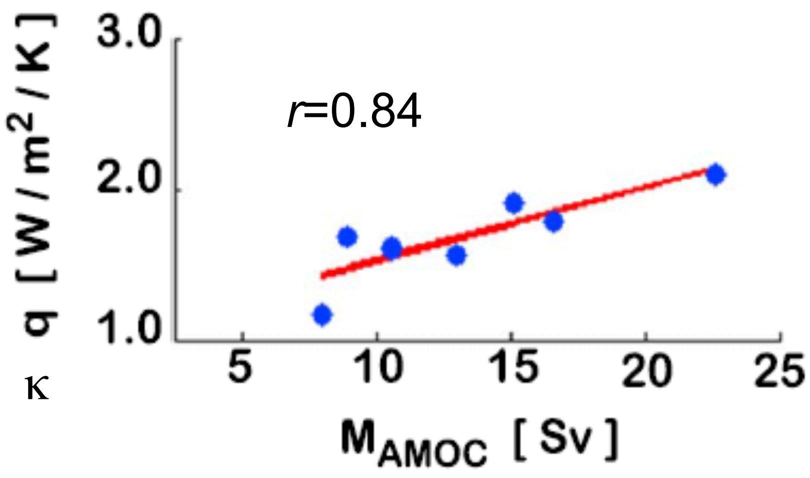
OHU in basins ÷ time-mean (global) ΔSST

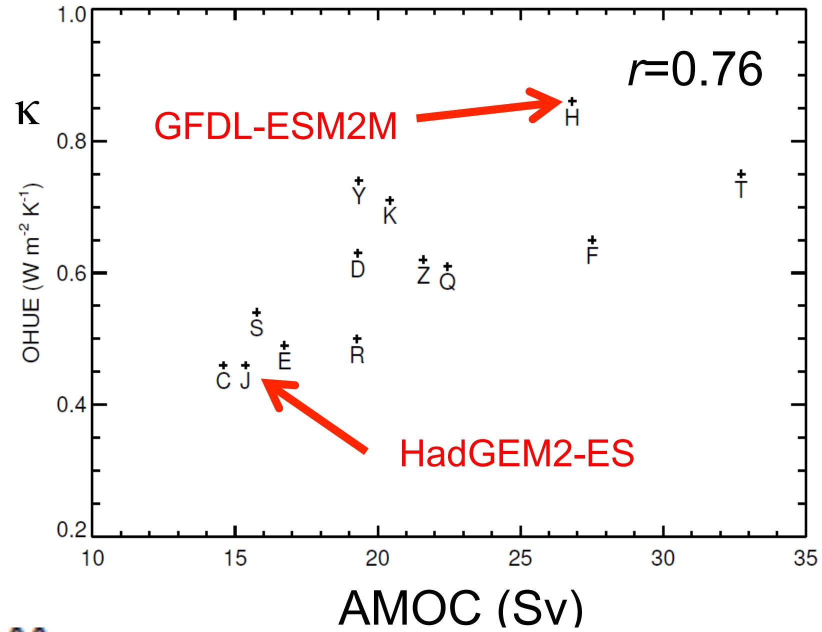
S Ocean	0.47±0.16
Tropical Indopacific	0.37±0.17
Tropical Atlantic	0.24±0.16
N Indopacific	0.11±0.07
N Atlantic	0.12±0.10



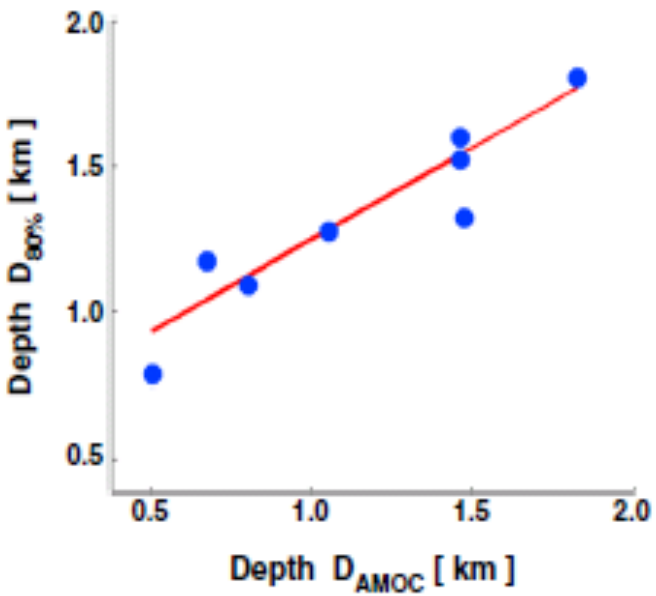
Global total correlates most strongly (~0.85) with its S Ocean contribution

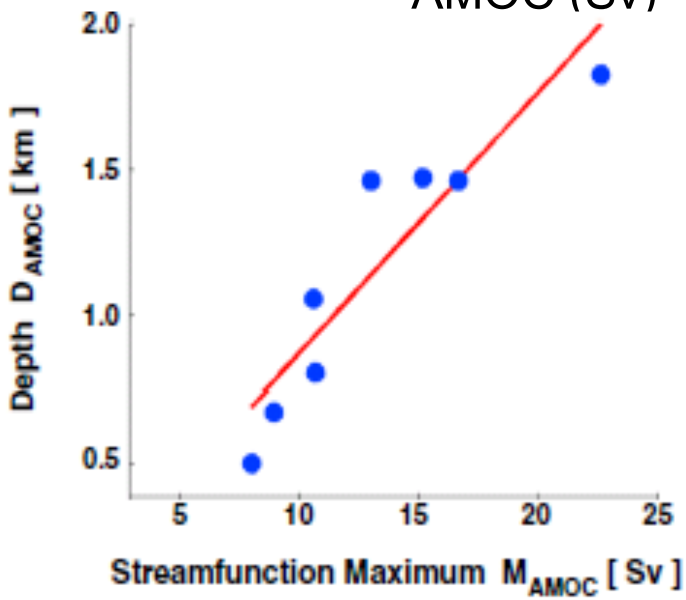
Relationship of OHUE (≈OHU ÷ *T*) and AMOC strength



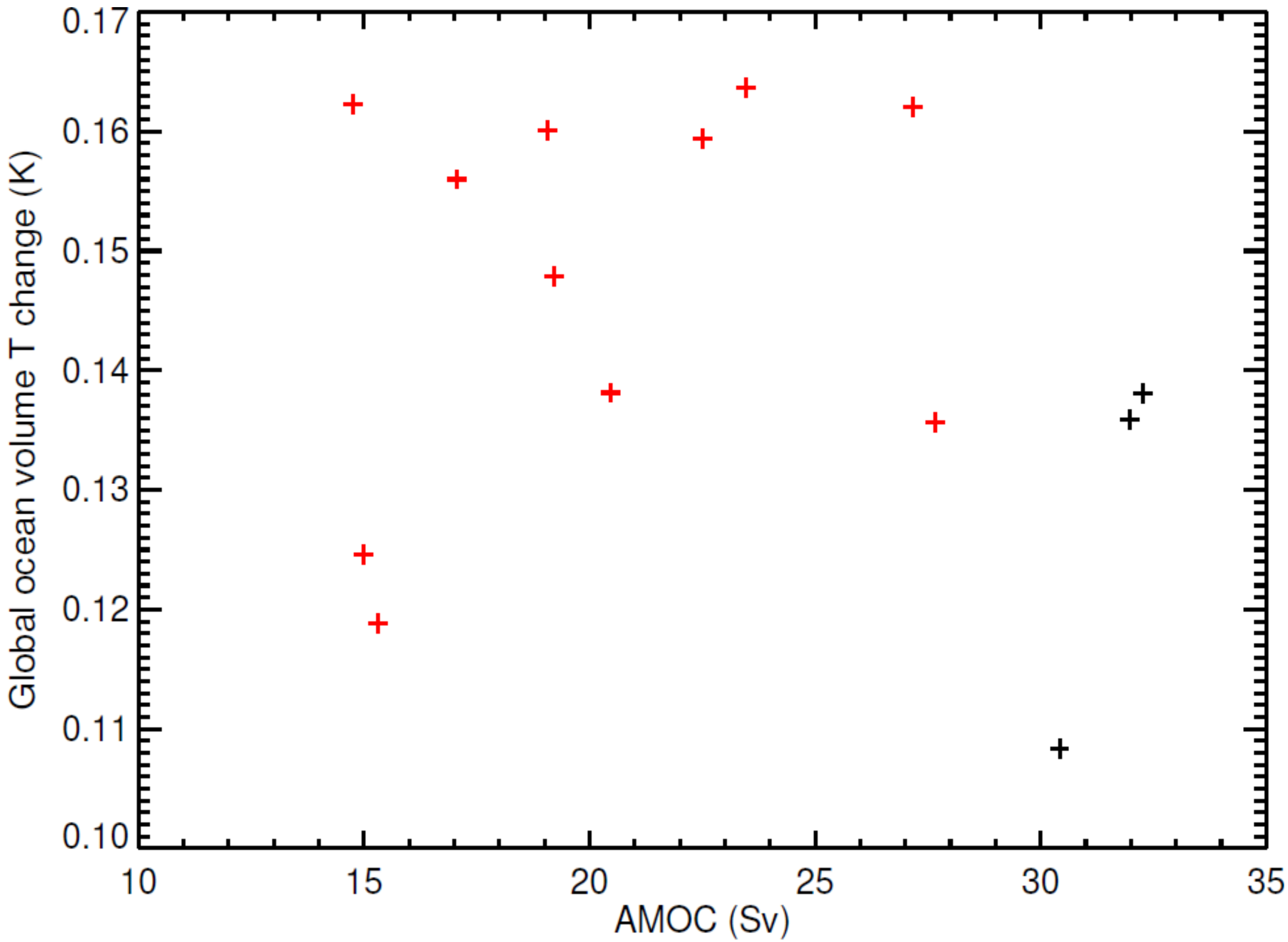


Kostov et al. (2014)

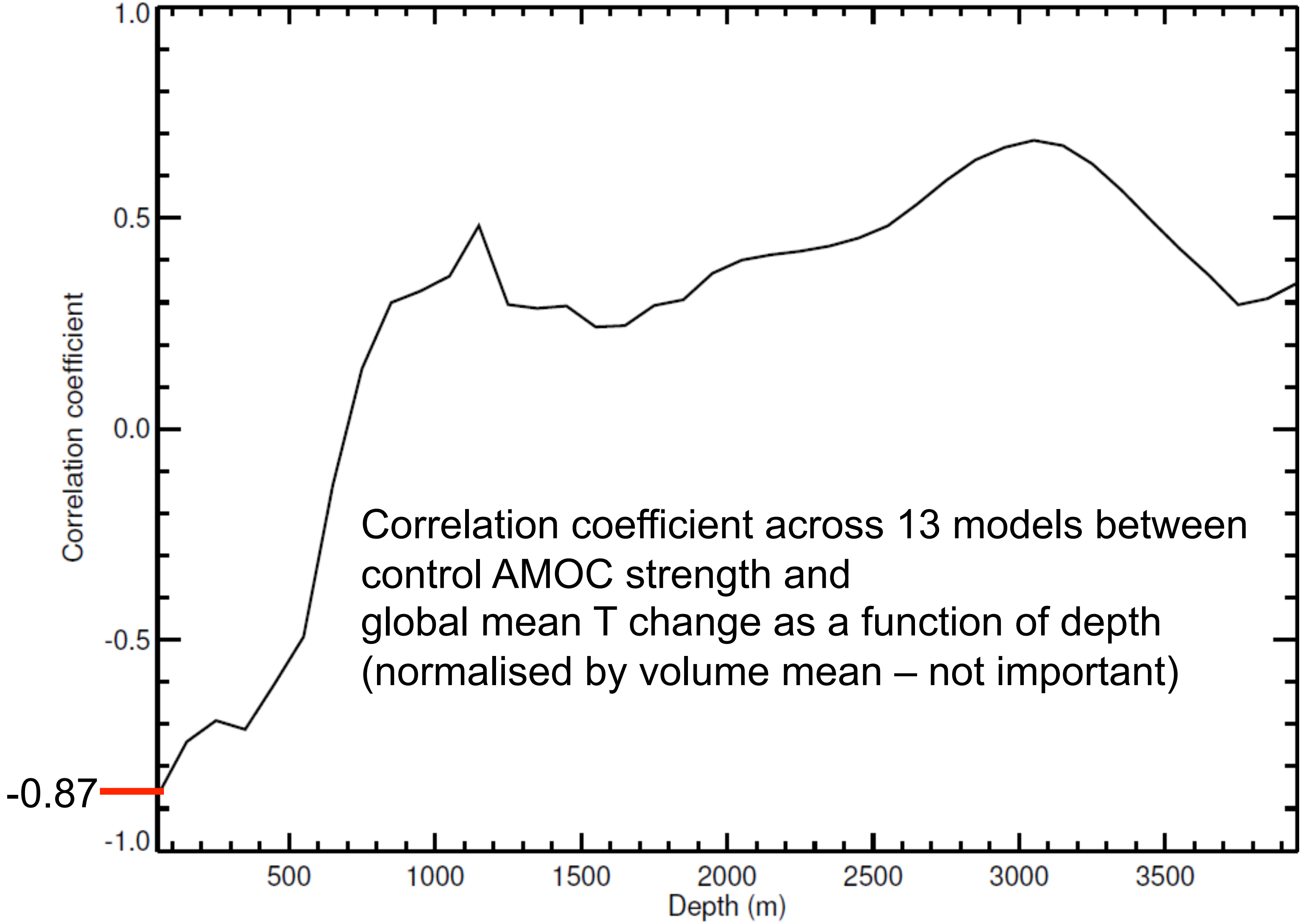




OHU is not strongly influenced by AMOC

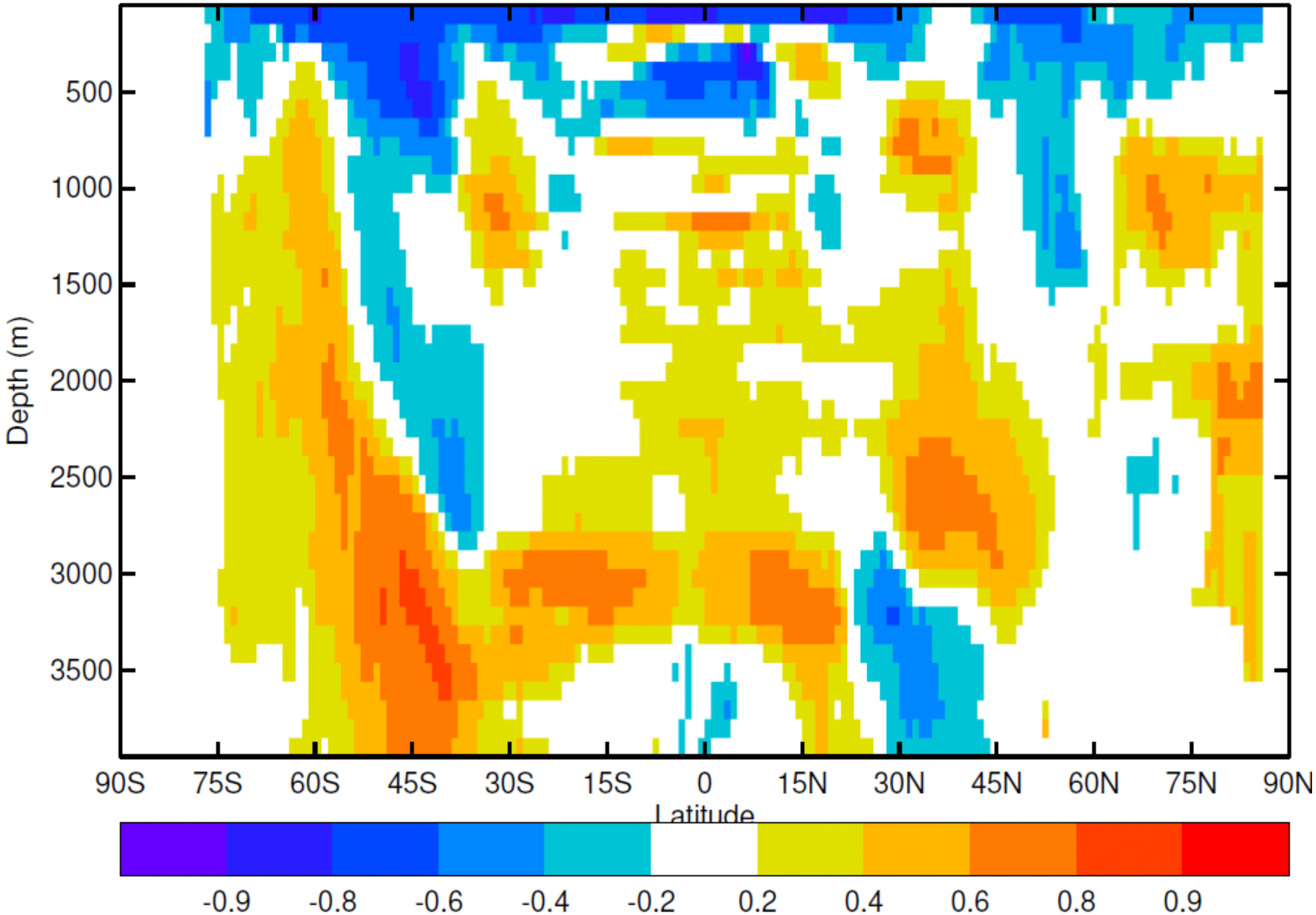


AMOC affects the vertical distribution of ocean warming



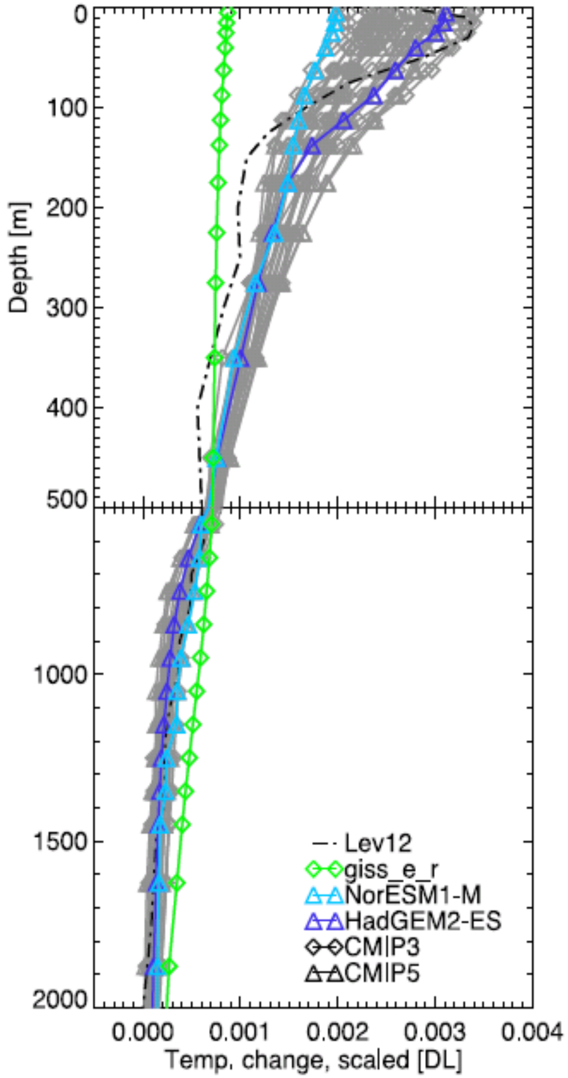
Stronger AMOC → Smaller T (warming at surface) → larger κ = OHU ÷ T

AMOC affects the vertical distribution of ocean warming

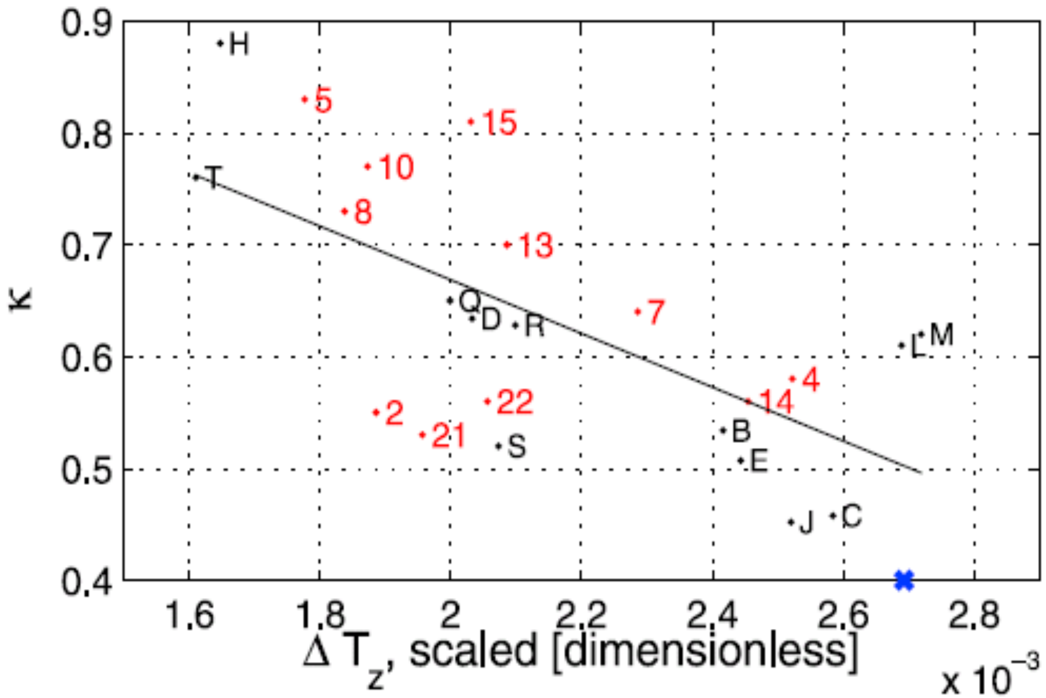


Stronger AMOC → Smaller *T* (warming at surface) → larger κ = OHU ÷ *T*

Ocean warming may penetrate too deeply in models



Comparison with CMIP3+5 at 2xCO2 in 1pctCO2 with observed change from Levitus et al. (2012)



ΔT_z is a measure of the vertical distribution, and correlates with OHUE κ

Kuhlbrodt and Gregory (2012)

Conclusions

There is a large spread in ocean heat uptake efficiency (OHUE) across CMIP3+5 models under increasing CO_2.

This represents an uncertainty in projections of ocean heat uptake (OHU), sea level rise and surface warming.

The largest contribution to OHUE is from the Southern Ocean.

There is a maximum in Southern Ocean heat uptake around 45°S, partly caused by Ekman pumping. There is a dipole in North Atlantic heat content change.

In models, vertical mixing (convection) is the most important heat uptake process in the Southern Ocean and the North Atlantic, and advection at low latitudes.

OHUE (=OHU ÷ T) correlates strongly with control AMOC strength because models with a strong AMOC simulate a deeper penetration of warming and consequently a smaller T; AMOC does not strongly influence OHU.

Models project a deeper penetration of warming than suggested by observations, which may suggest an excessive OHUE.

FAFMIP (a CMIP6 project) will give new information about the response of AOGCMs to ocean surface flux forcing and about simulated OHU processes. Any observational constraints will be valuable for reducing uncertainty.