The resolution dependent role of the AMOC in simulated Southern Ocean heat uptake

US AMOC Team Meeting, 2014

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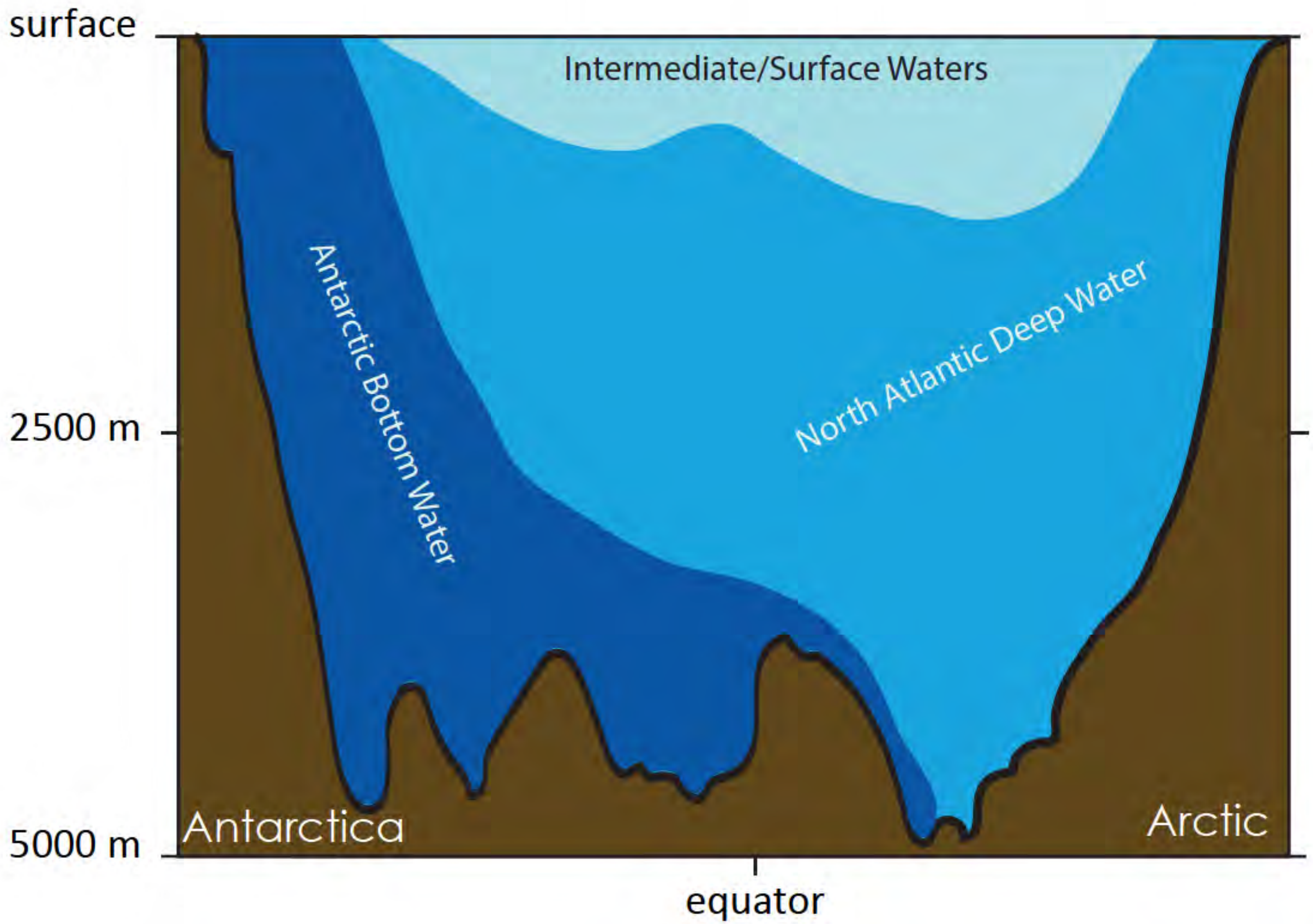
Deep ocean heat uptake

The efficacy of the ocean to buffer atmospheric warming depends on the processes by which heat is moved from the surface to the deeper layers of the ocean.

This, along with the strength of radiative feedbacks, determines the rate of transient surface warming.

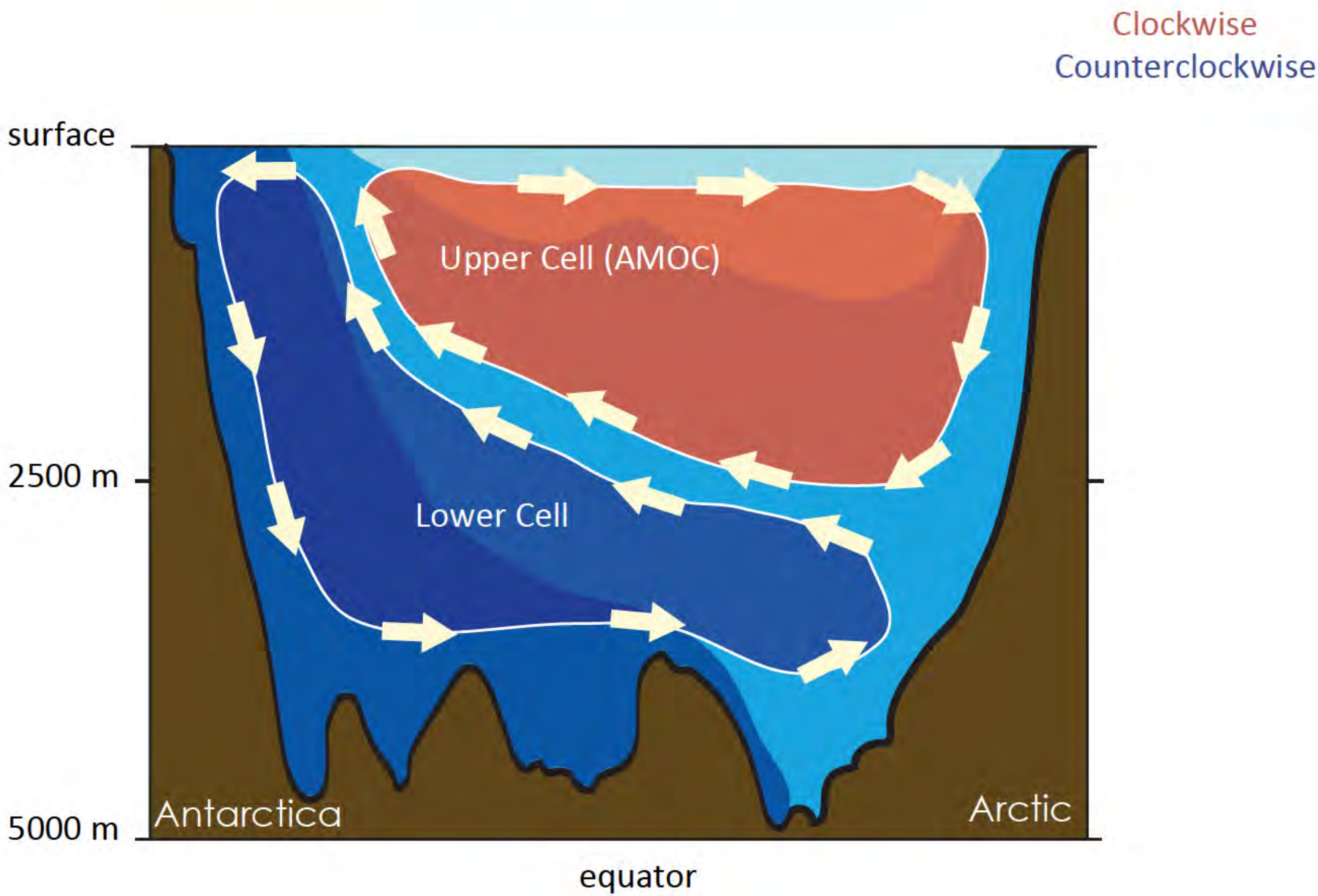
Deep Water Masses

The deep ocean is accessed through water formed at the poles



Adapted from Rhein et al., 2013

Background circulation



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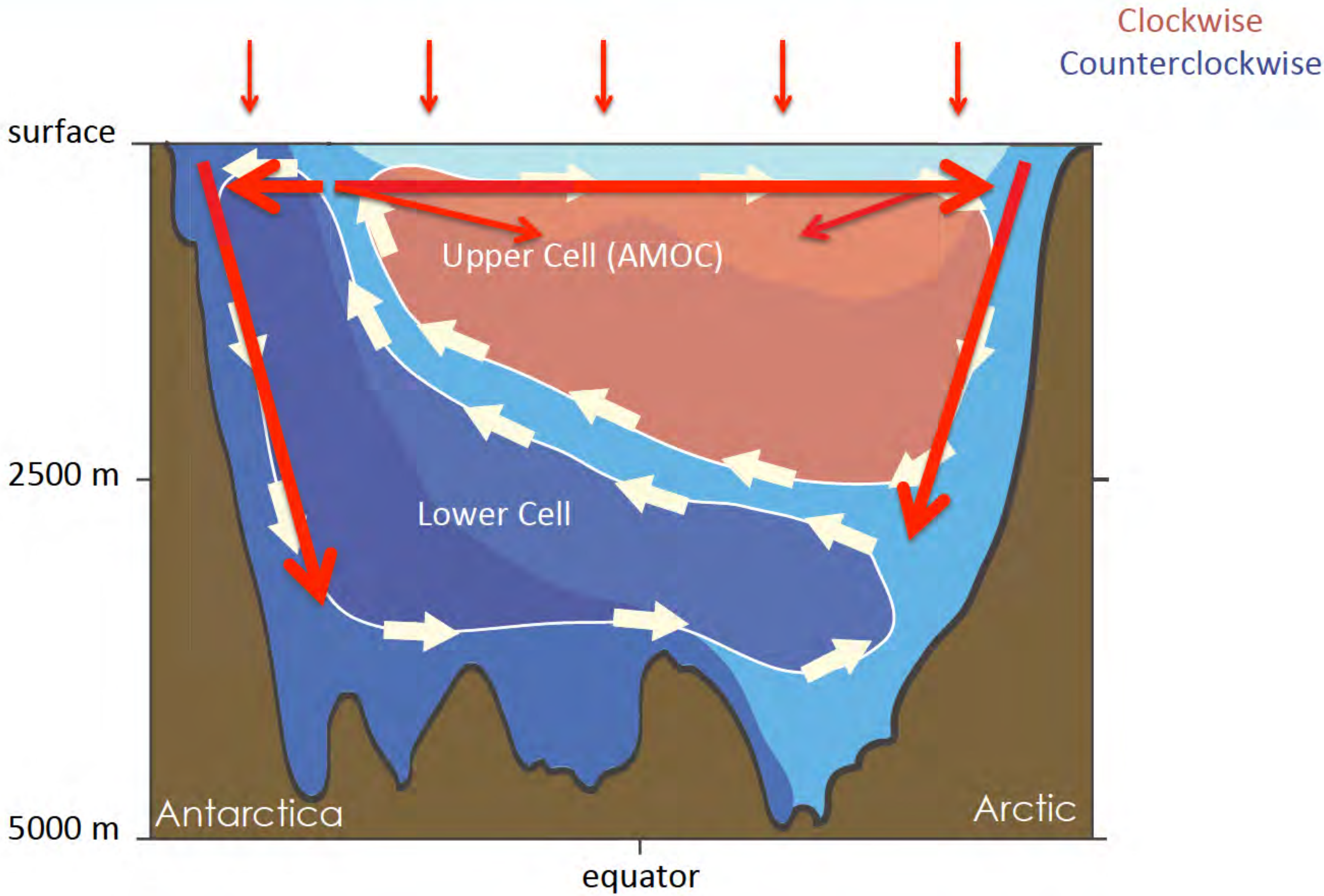
Background circulation



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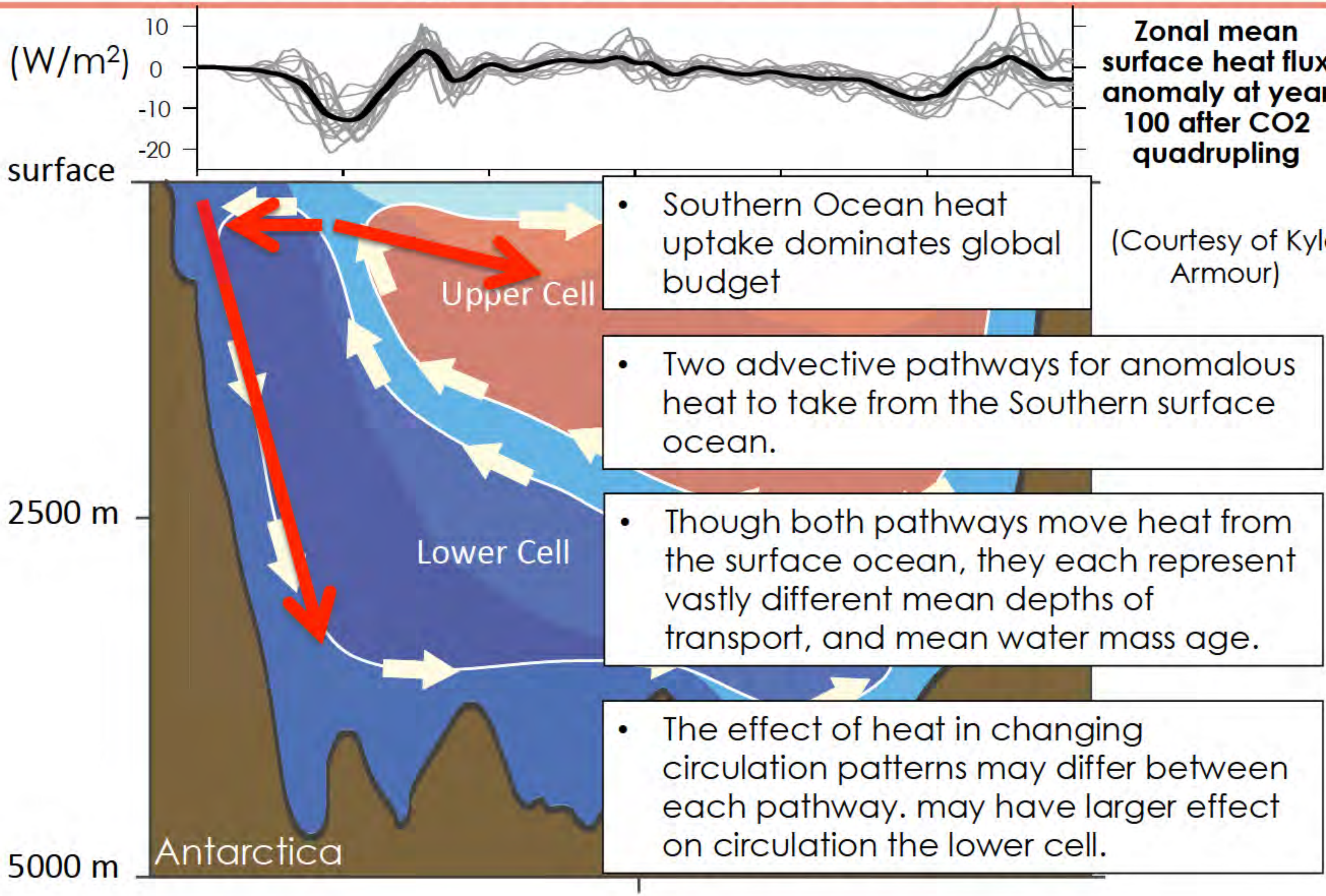
Background circulation

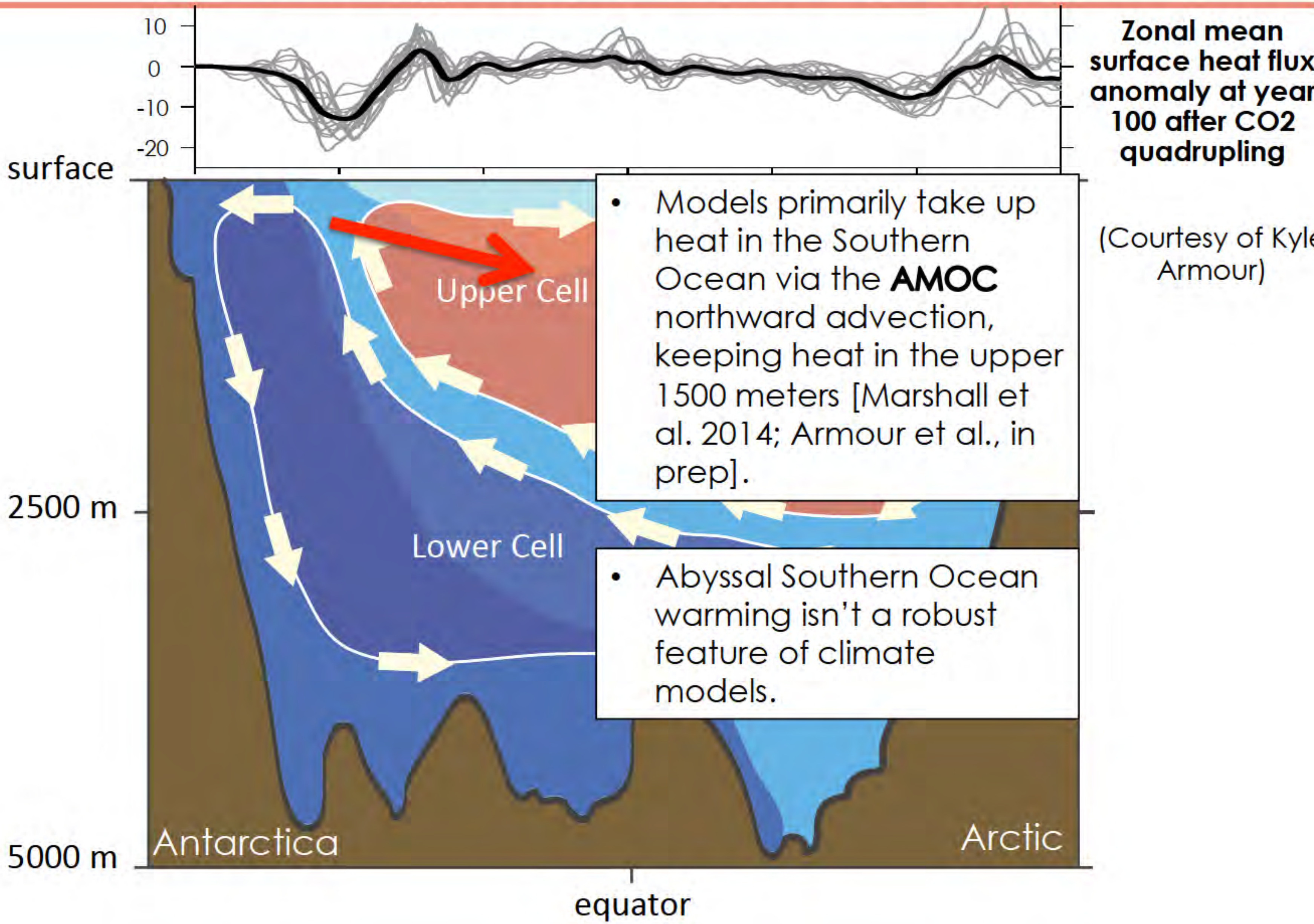


(Courtesy of Kyle Armour)

- Southern Ocean heat uptake dominates global budget
- Two advective pathways for anomalous heat to take from the Southern surface ocean.
- Though both pathways move heat from the surface ocean, they each represent vastly different mean depths of transport, and mean water mass age.
- The effect of heat in changing circulation patterns may differ between each pathway. may have larger effect on circulation the lower cell.

Adapted from Rhein et al., 2013

Background circulation

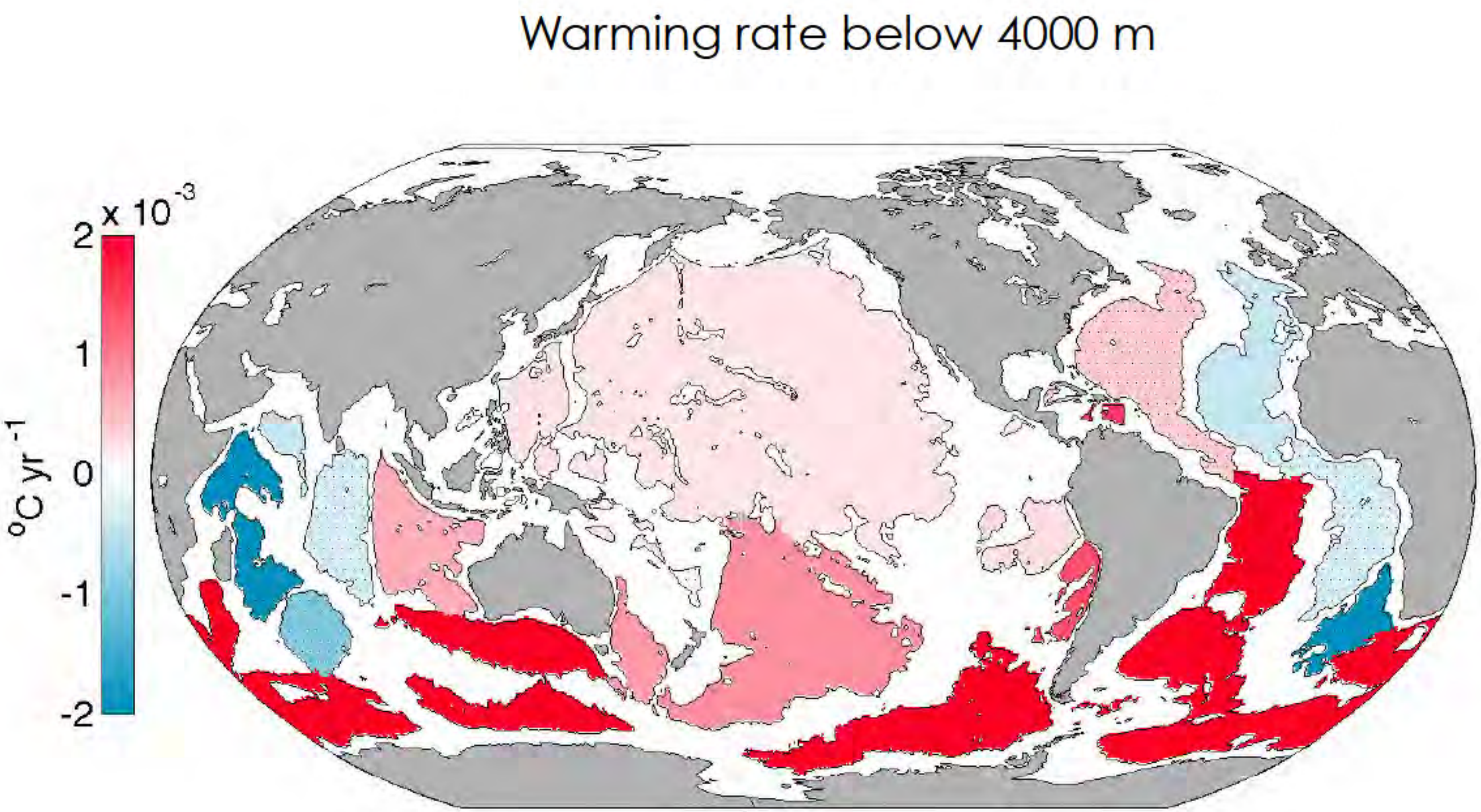


(Courtesy of Kyle Armour)

- Models primarily take up heat in the Southern Ocean via the **AMOC** northward advection, keeping heat in the upper 1500 meters [Marshall et al. 2014; Armour et al., in prep].
- Abyssal Southern Ocean warming isn't a robust feature of climate models.

Adapted from Rhein et al., 2013

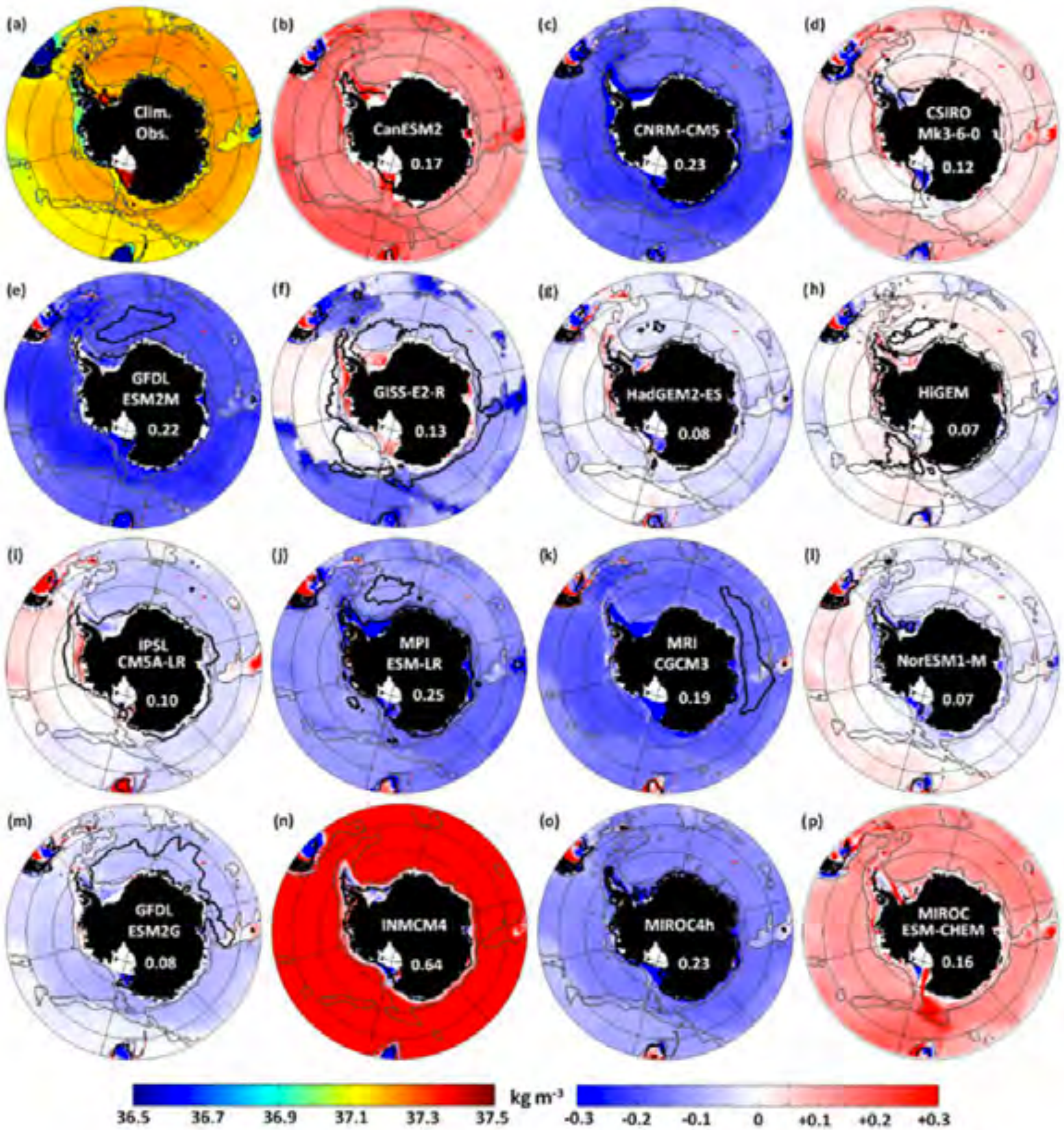
Observed abyssal ocean warming



Purkey and Johnson, 2013

Modeled abyssal ocean biases

CMIP 5 abyssal density biases compared to observations



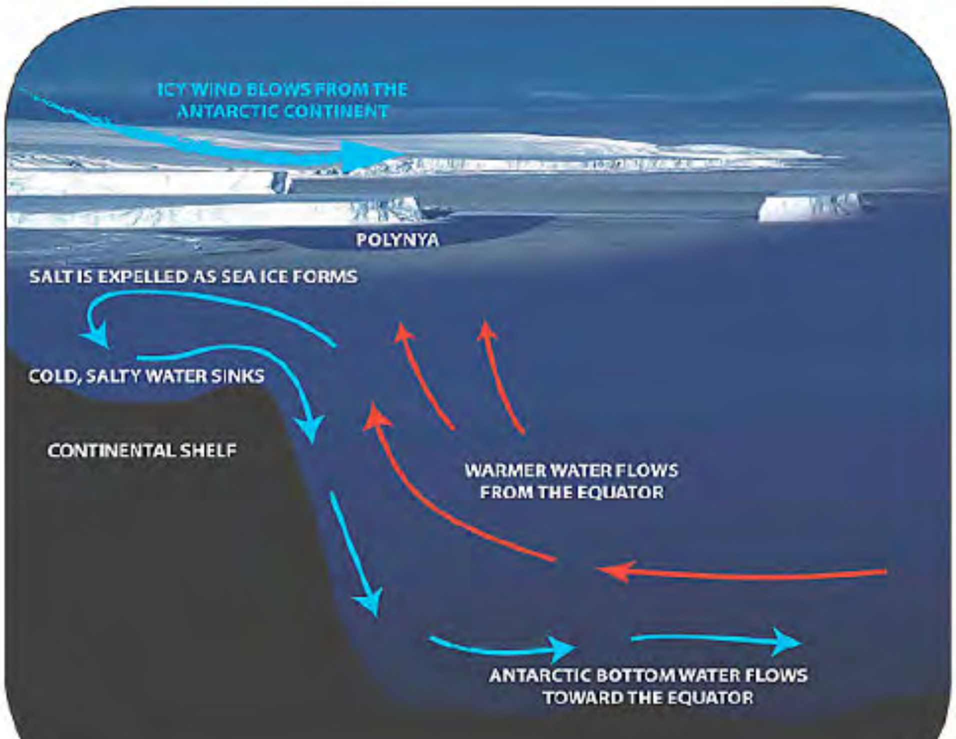
GCM's have large biases in AABW formation and abyssal ocean properties

No CMIP5 model forms shelf water that sinks to the ocean bottom (Heurzé et al., 2013)

Models that warm in the abyssal Southern Ocean due so because open ocean convective behavior (de Lavergne et al, 2014)

Heurzé et al., 2013

Antarctic bottom Water (AABW) formation



(http://web.maths.unsw.edu.au/~matthew/)

- AABW is formed around the Antarctic continental shelf through complex ocean/sea ice/ ice shelf interactions
- Export off continental shelf is in small scale plumes. Other important processes are: eddies, interaction with topography, easterly winds.

Motivating Questions

- Southern Ocean, and global ocean, heat uptake in models is dominated by uptake and advection via the upwelling branch of the AMOC. Is simulation of this mechanism biased by model resolution?
- Is the role of the lower cell minimized in models that don't resolve its dynamics?
- Is this impacting how we simulate transient climate change by keeping heat too close to the ocean surface?

Model and Experiments

Model: CCSM 3.5 run at two resolutions.

1 degree horizontal resolution in ocean and sea ice components. Eddies are parameterized.

0.1 degree horizontal resolution. Eddies are "resolved." Sea ice polyñyas are better captured.

Atmospheric resolution was 0.5 degrees for both simulations

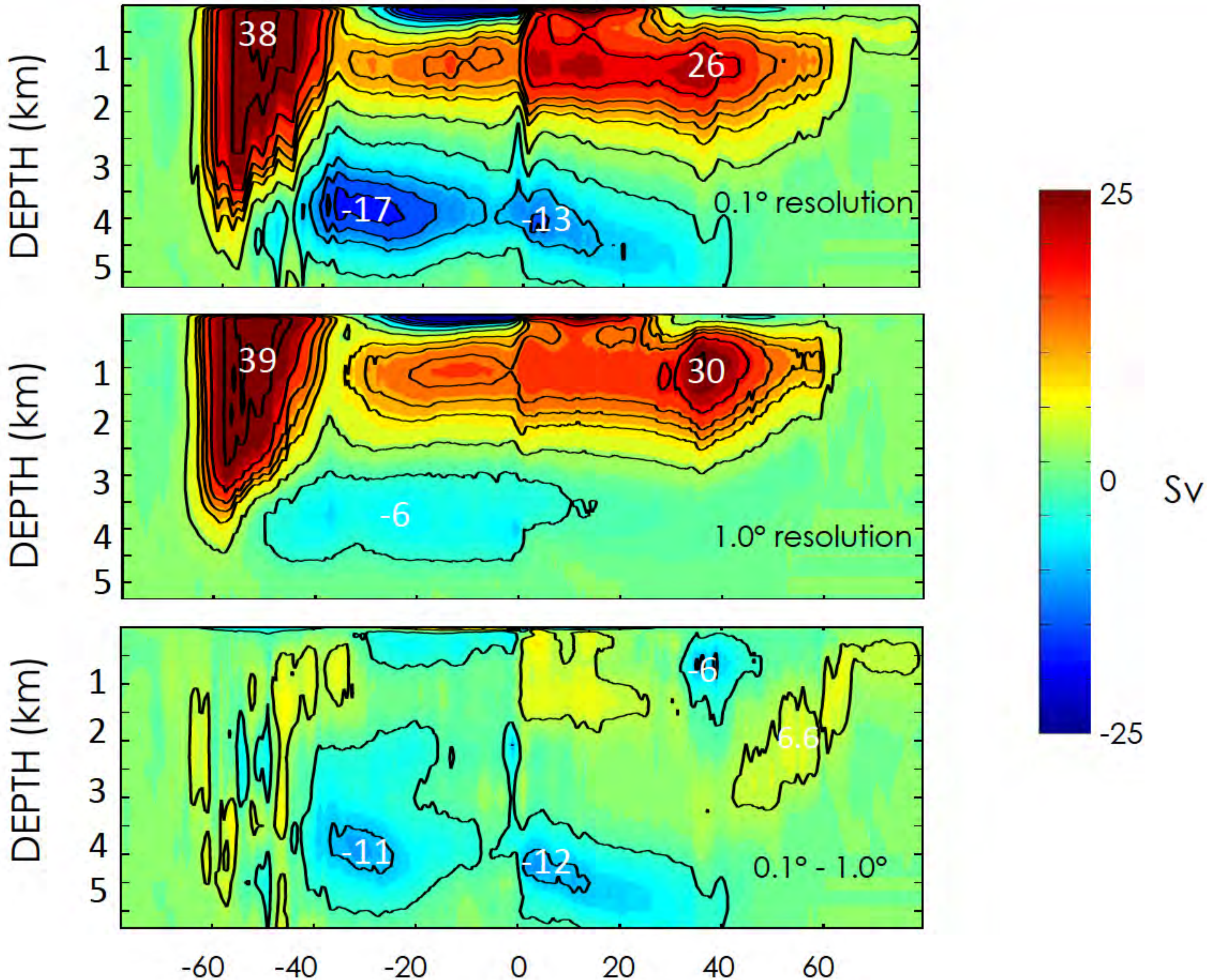
Experiment:

Ramped **atmospheric CO_2 at 1% per year until doubling** at each model resolution. We compared the behavior in the 20 years following doubling to corresponding years in control runs at each resolution.

Control Overturning

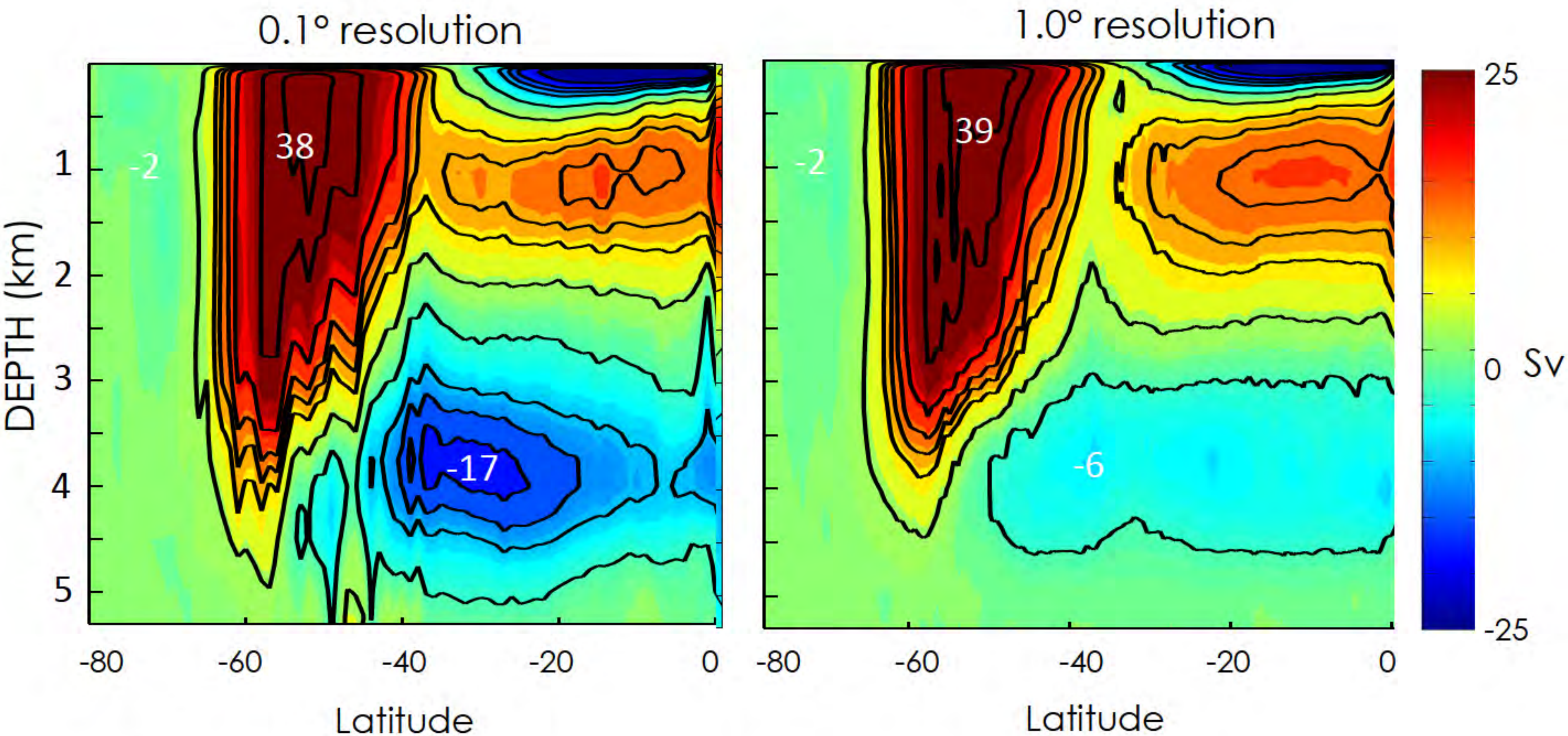
Meridional Overturning Circulation

(calculated on depth surfaces)



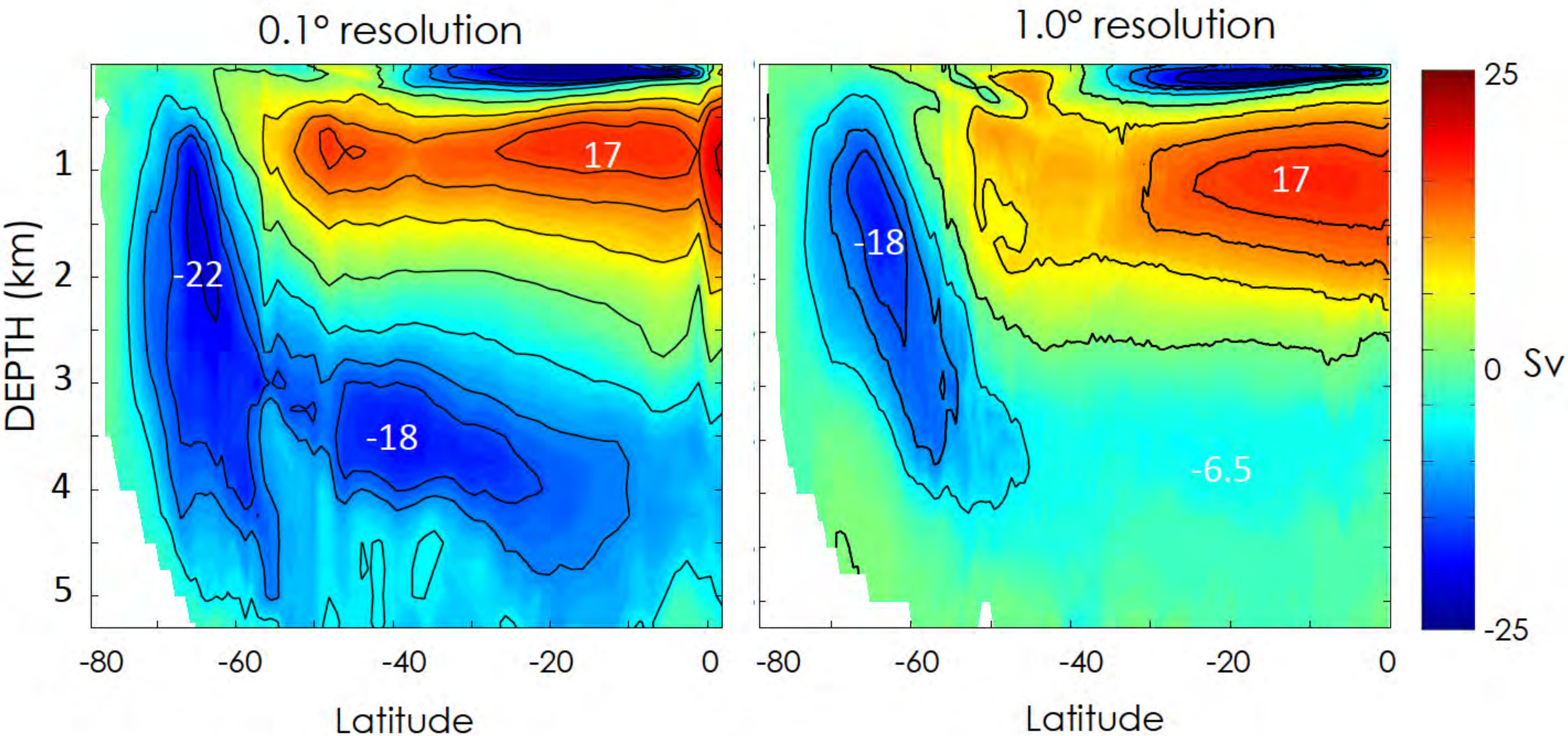
Control Circulation: MOC

(calculated on depth surfaces)



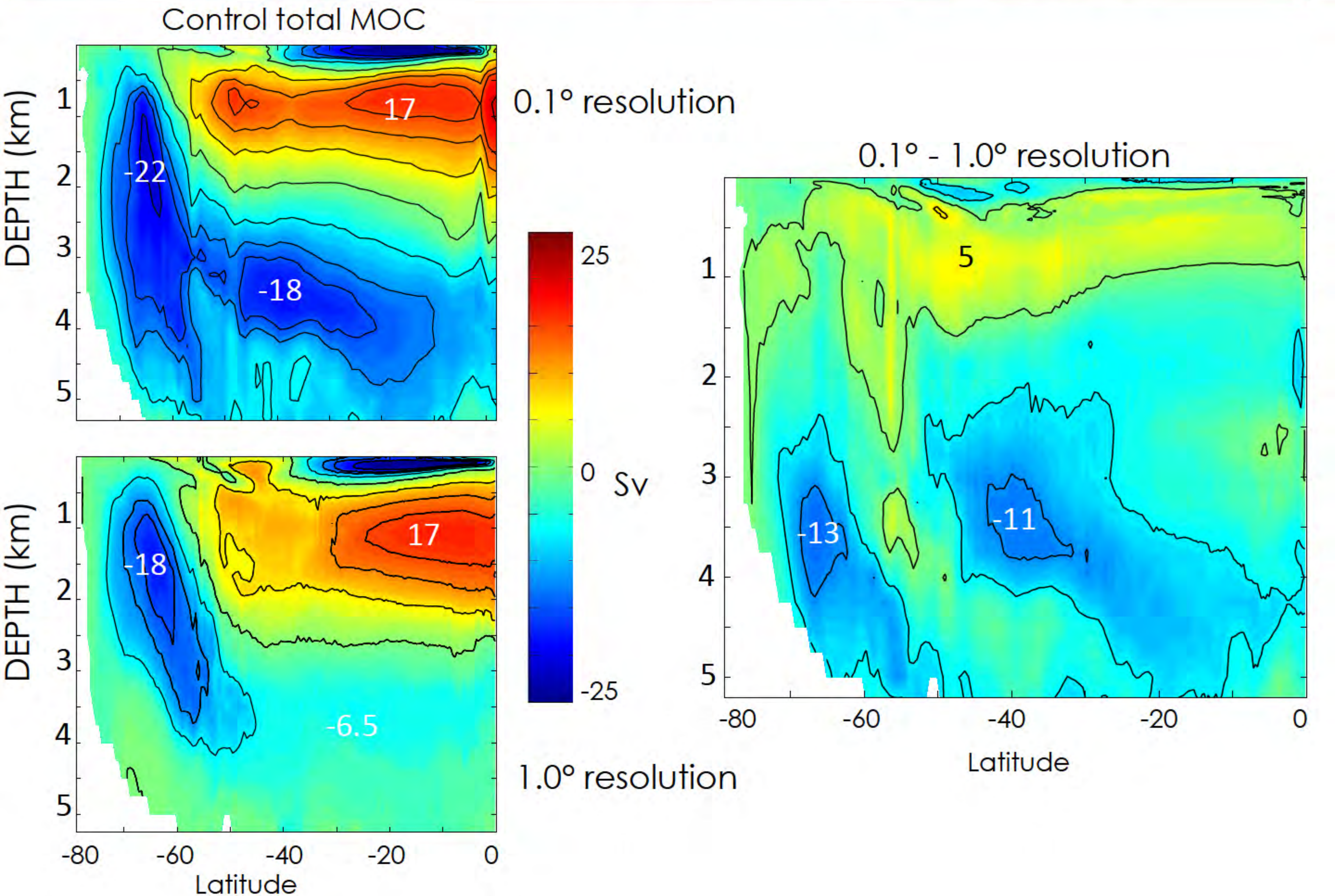
Control Circulation: Isopycnal MOC

(Streamfunction remapped onto average isopycnal depth)



High resolution simulates a deeper, more vigorous, and more extensive deep cell

Control Circulation: Isopycnal MOC



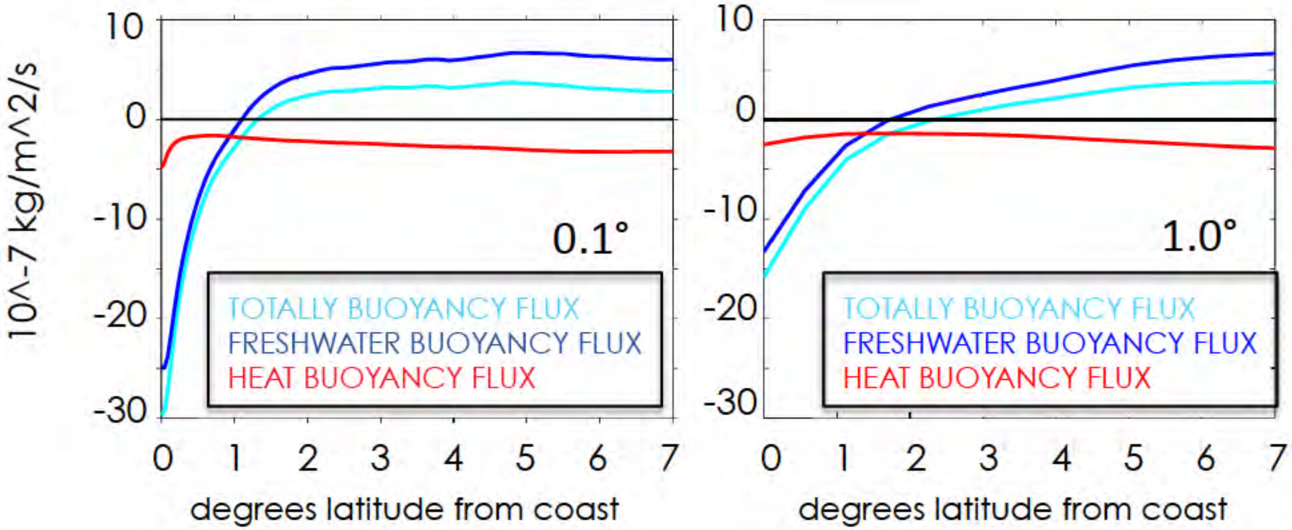
Surface buoyancy loss fluxes

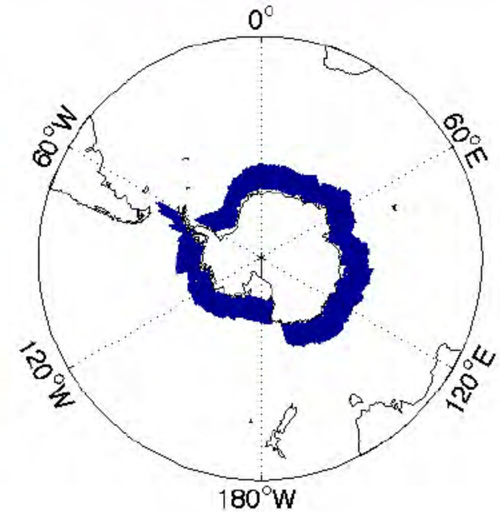
Buoyancy fluxes are how we compare the effect of heat loss and freshwater fluxes on seawater density

SENSE OF SURFACE FLUXES AROUND ANTARCTIC COAST (in our model)

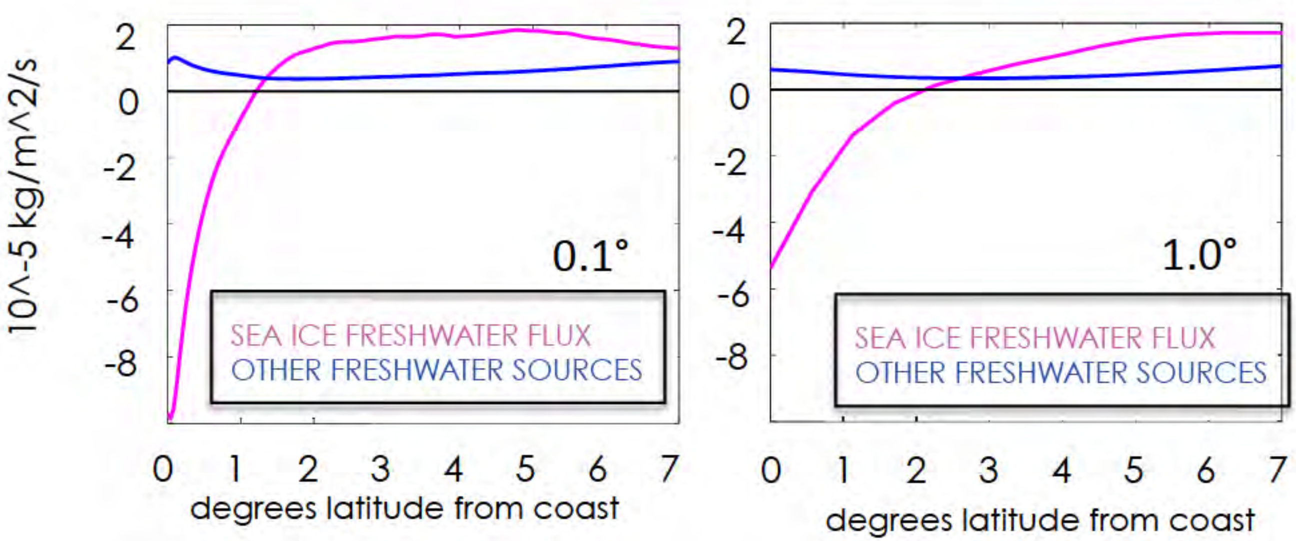
Surface buoyancy loss fluxes

Heat and freshwater buoyancy fluxes





Freshwater buoyancy flux components

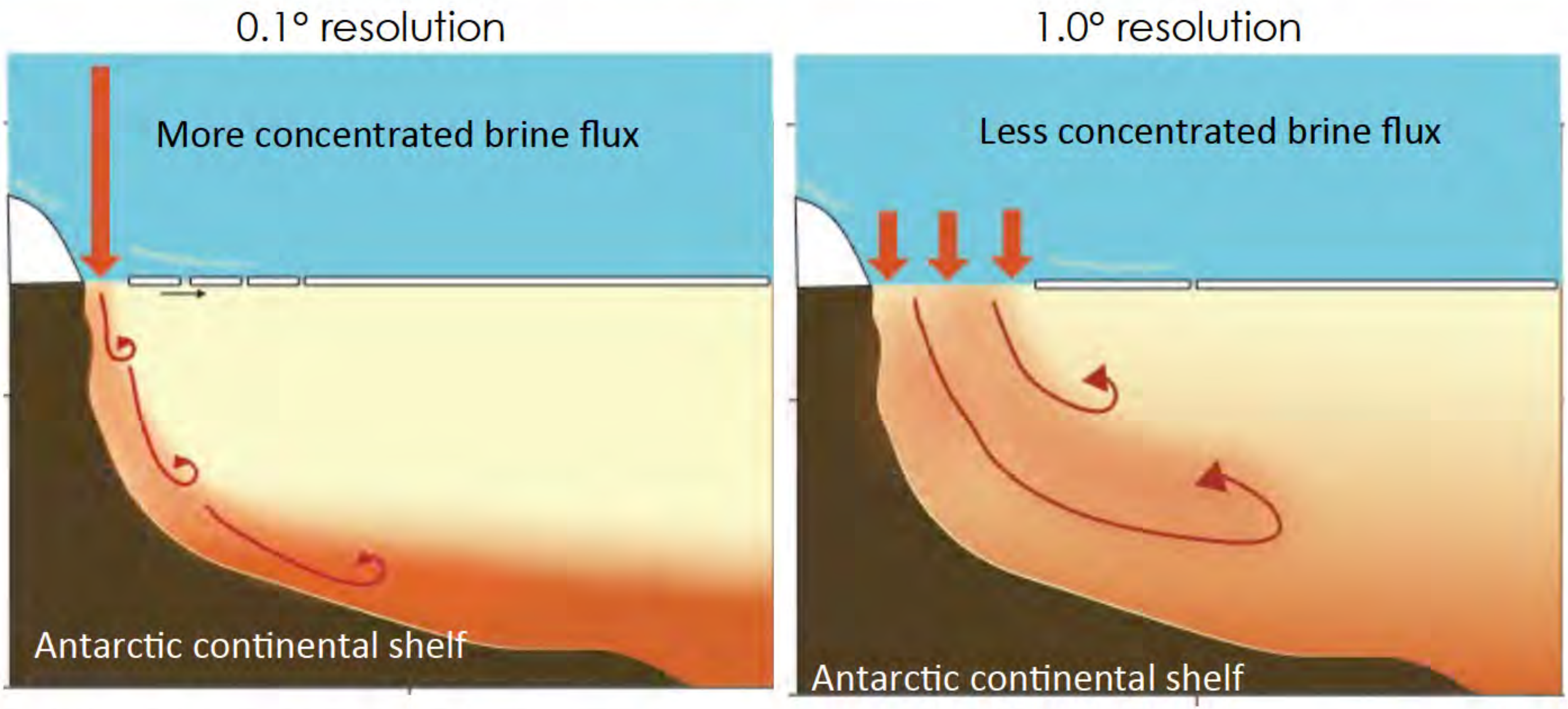


Freshwater fluxes dominate buoyancy loss.

Sea ice formation dominates freshwater related buoyancy loss

Fluxes are more concentrated at 0.1° resolution

Buoyancy loss from sea ice formation

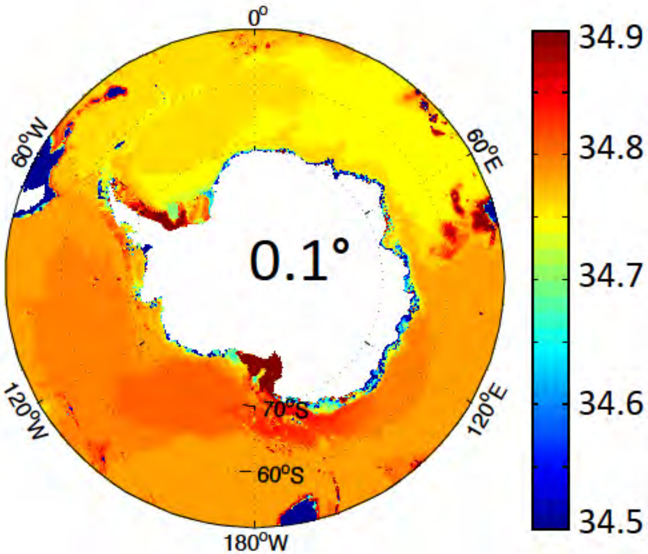


More concentrated brine flux leads to a more stratified shelf water column and denser shelf water, driving more AABW formation

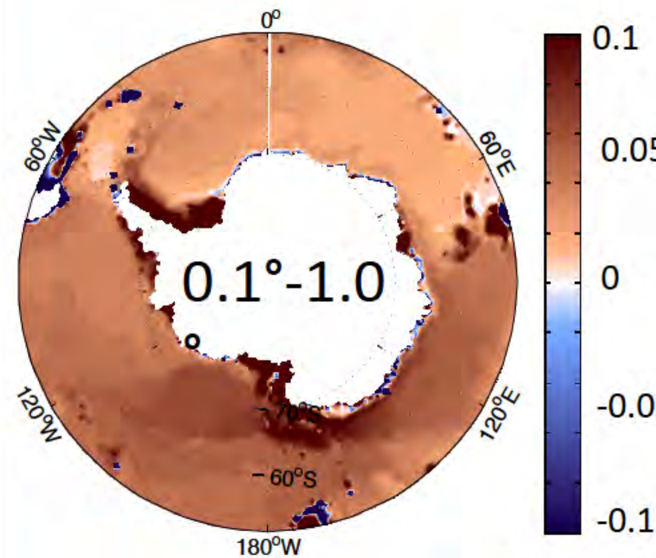
Additional possible effects due to resolution: topography, resolution of plumes, eddy behavior across shelf

Control Results: Abyssal salinity and temp

Salinity



Salinity difference



The localized formation of sea ice drives denser shelf water formation, a key precursor to AABW formation.

This contributes to a deeper and more vigorous lower cell overturning.

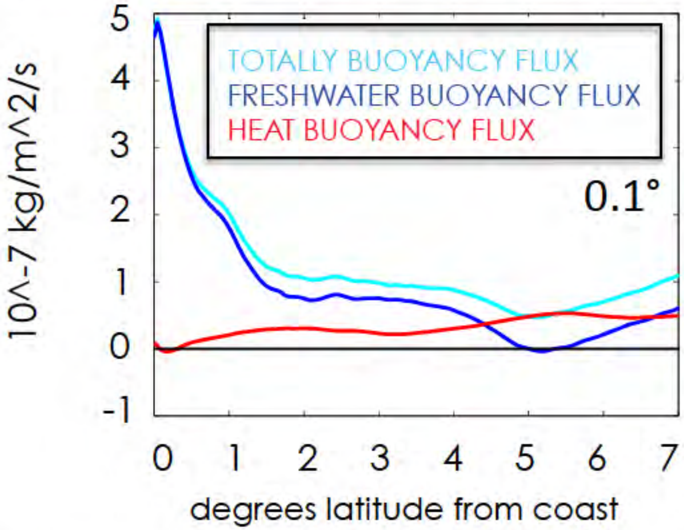
The strength of the AMOC is less sensitive to resolution.

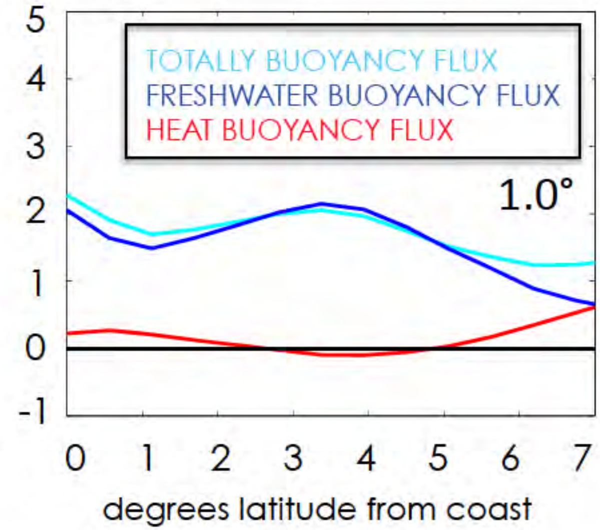
CO2 doubling response

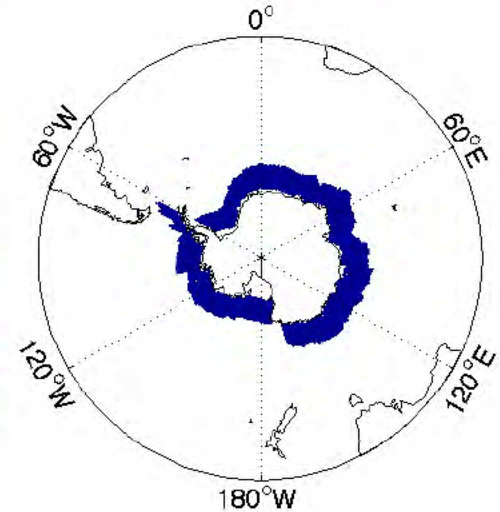
“Anomaly” = (2xCO2 – control)

2x CO2 : Reductions in buoyancy loss

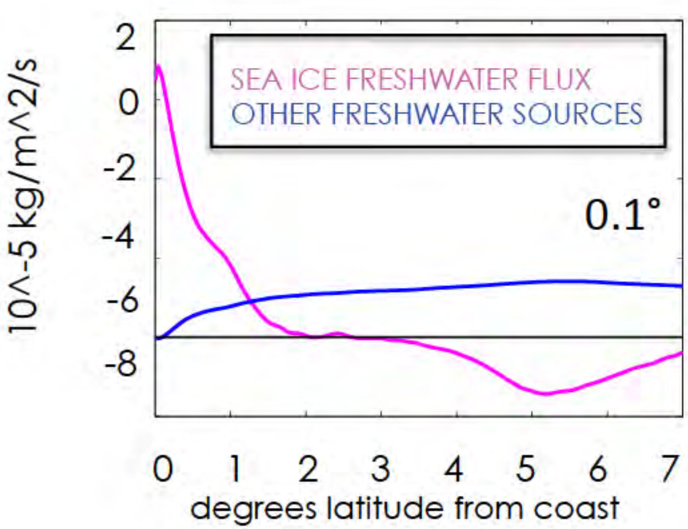
Anomalous heat and freshwater buoyancy fluxes

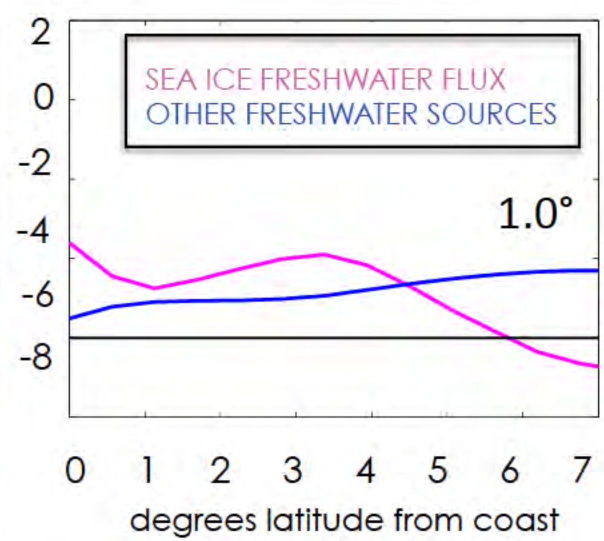






Anomalous freshwater buoyancy flux components





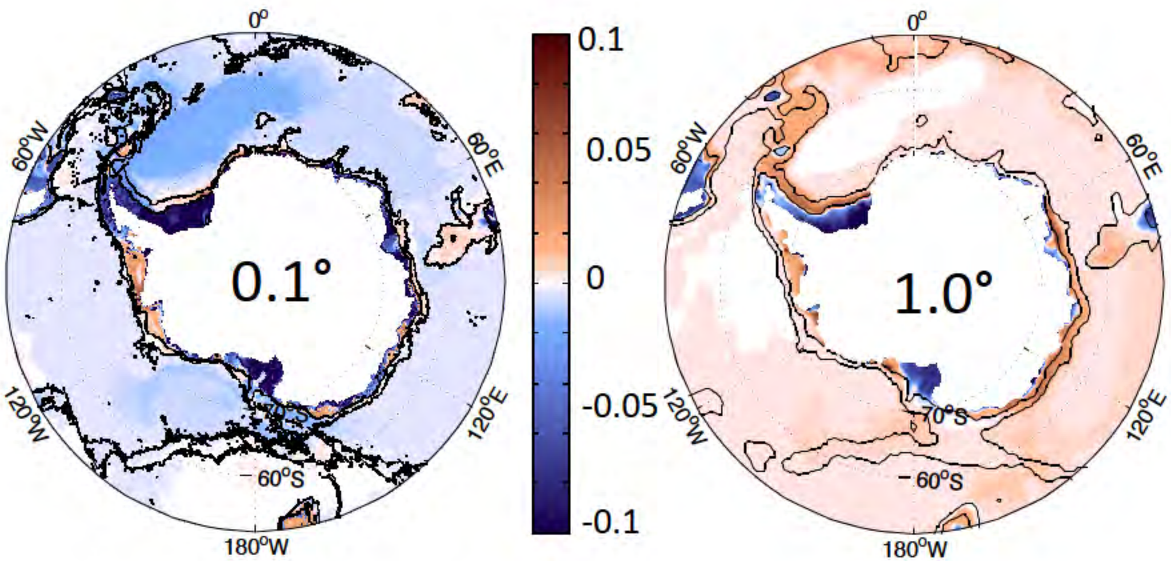
Reductions in buoyancy loss are due to changes in freshwater fluxes

These changes are dominated by reduction in sea ice formation.

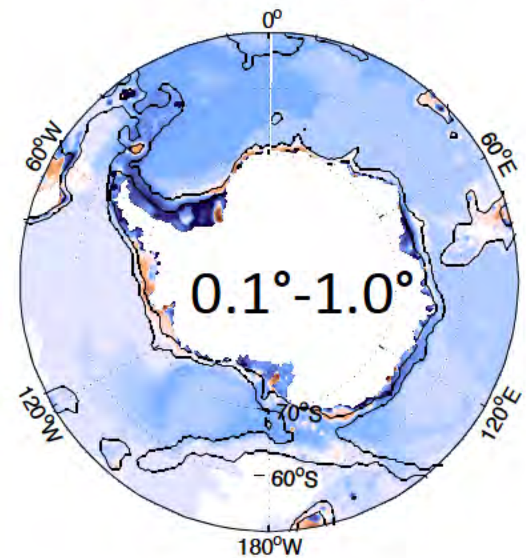
The reduction is more concentrated at 0.1° resolution.

2x CO2 : Abyssal temp and salinity changes

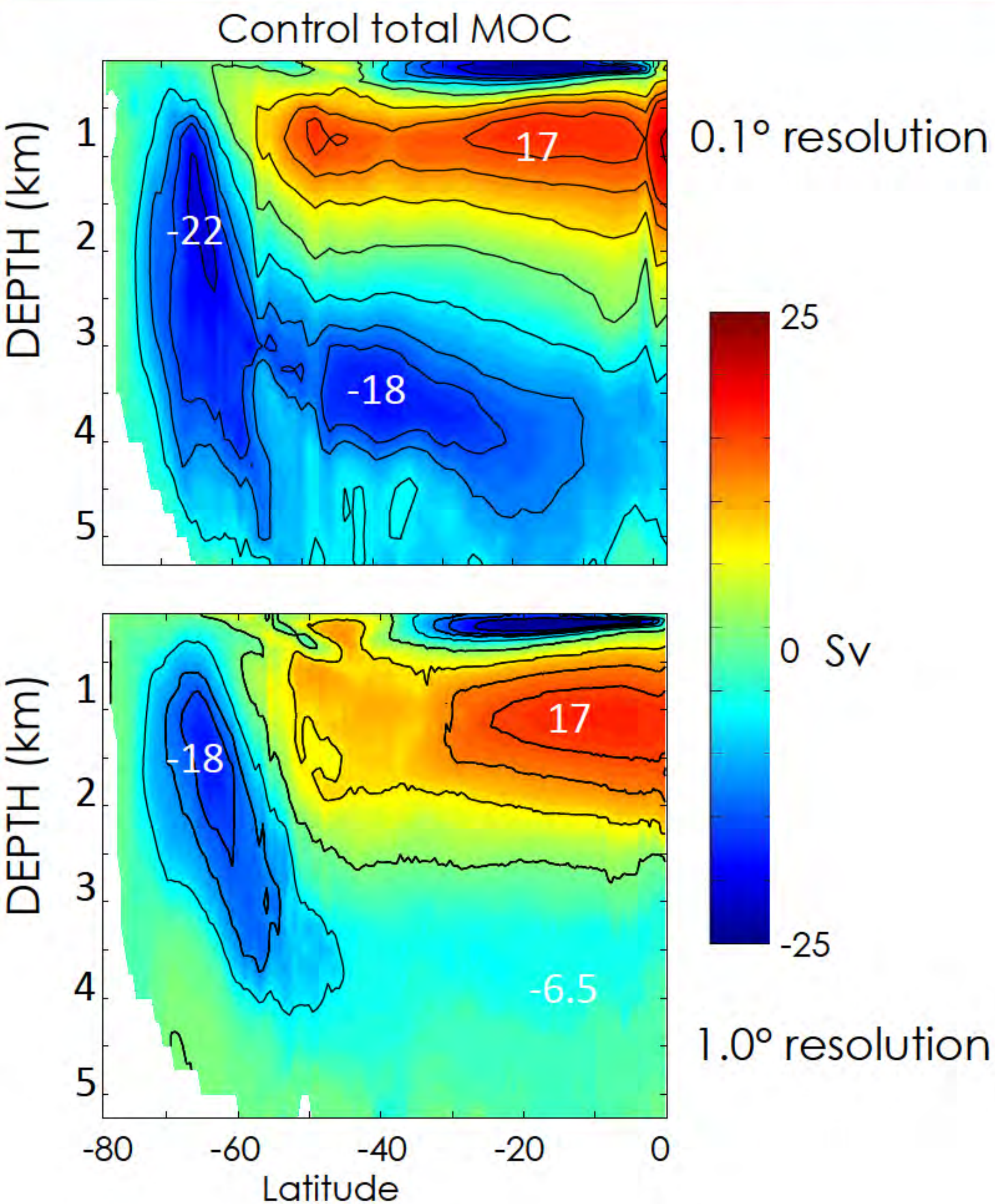
Abyssal salinity anomaly



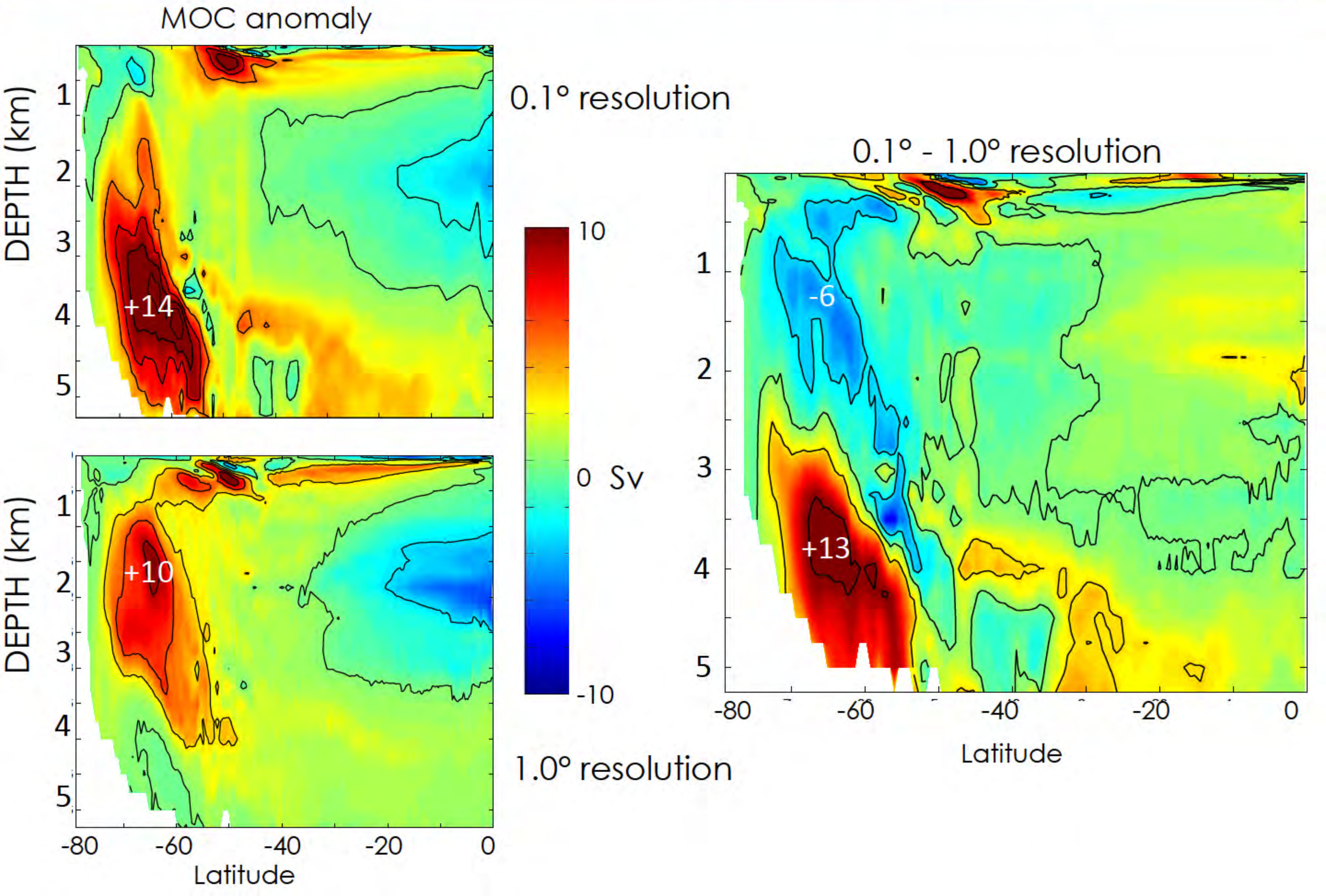
Difference in abyssal salinity anomaly



2X CO2 results: Circulation changes

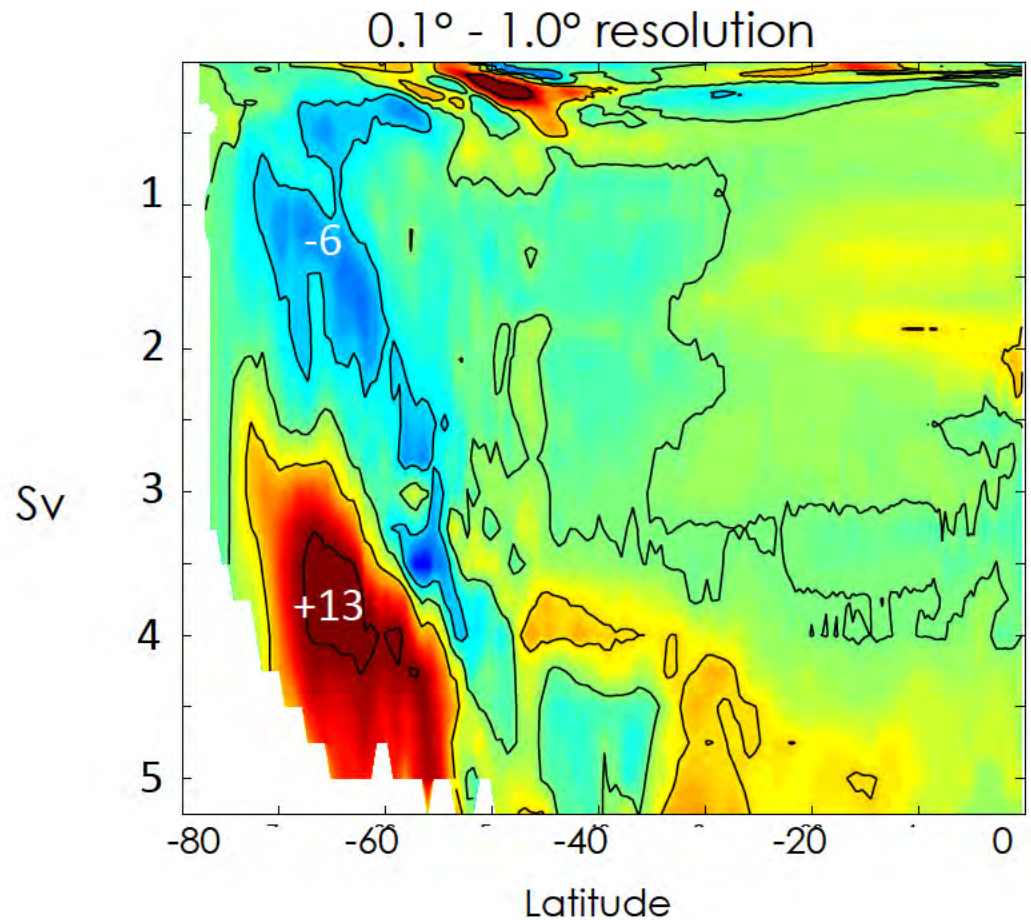


2X CO2 results: Circulation changes



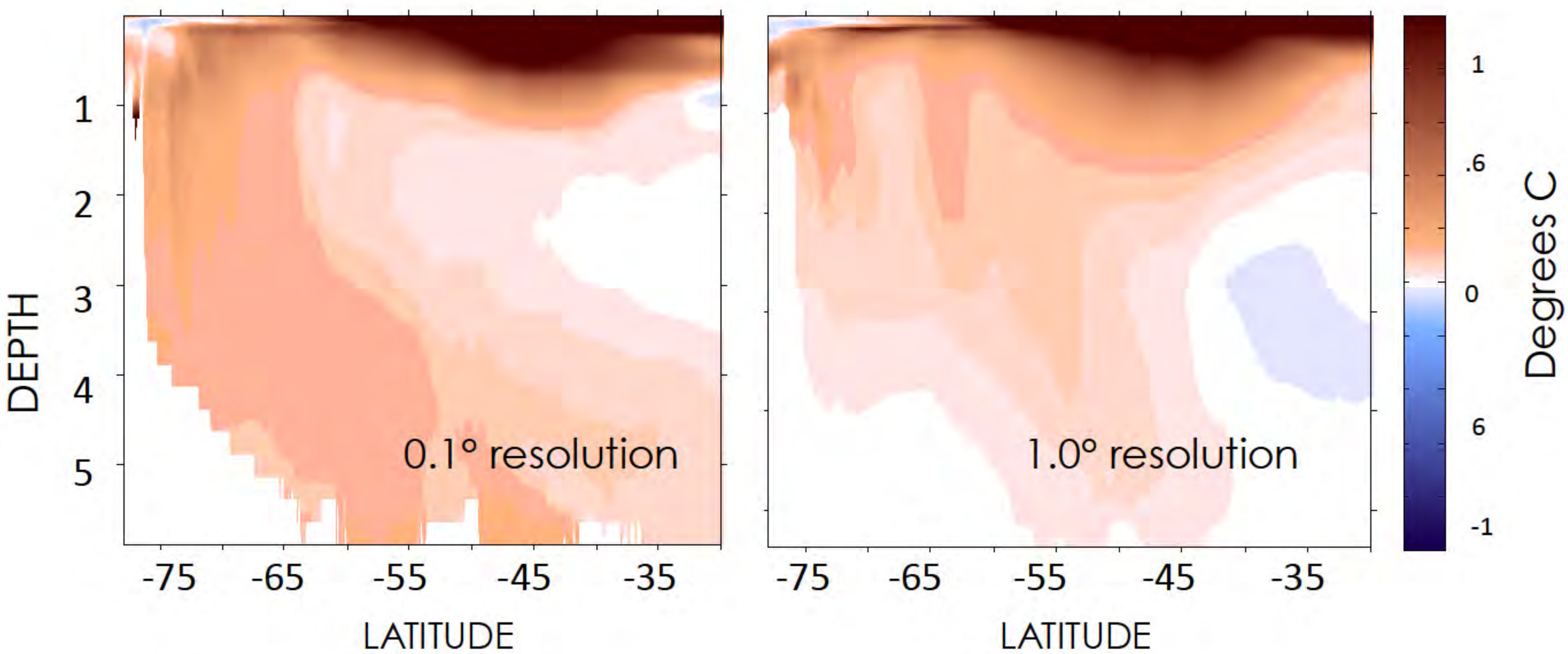
2X CO2 results: Circulation changes

The lower MOC slows more at 0.1° resolution, and affects a deeper region of the ocean.



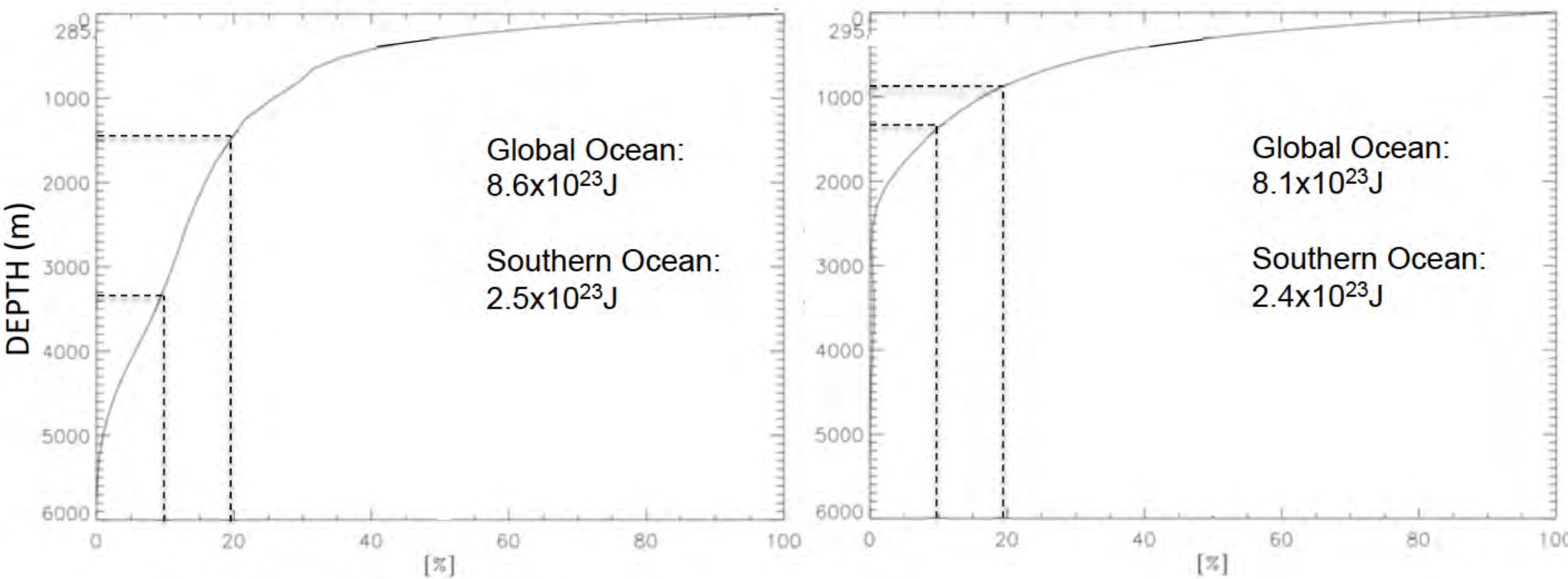
2x CO2 : Zonally average temperature change

Temperature anomaly



2X CO2 results: Heat storage depths

GLOBAL OCEAN HEAT UPTAKE

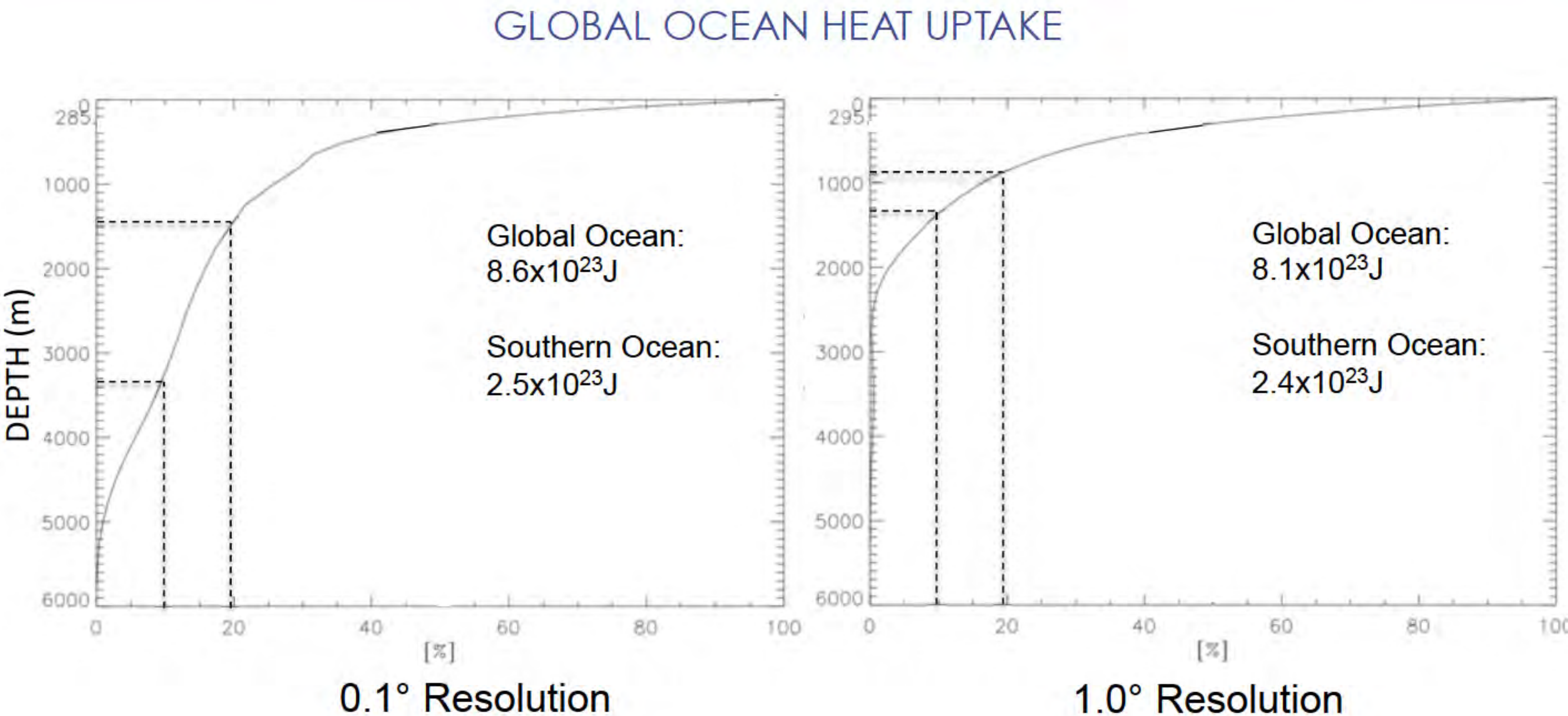


0.1° Resolution

1.0° Resolution

Difference in heat uptake below 3200 meters would instantaneously warm the atmosphere 17 degrees C.

2X CO2 results: Heat storage depths



Deep warming at 0.1° resolution is due to a combination of the larger deep reduction in the lower MOC (Δv), as well as the greater advective capacity of the control lower MOC to advect heat into the deep ocean (ΔT).

Conclusions

- The movement of heat from the surface ocean to depth is a key process in postponing atmospheric warming over long timescales.
- In the SO, the AMOC acts to advect heat northward, allowing the SO surface to absorb anomalous heat over long timescales. This mechanism dominates the Southern Ocean heat uptake in CMIP 5 models.
- In our model which better resolves the processes driving the overturning of the lower cell, advection and warming of the deep ocean becomes more important.
- This could be important to the simulation of transient climate change.

THANK YOU