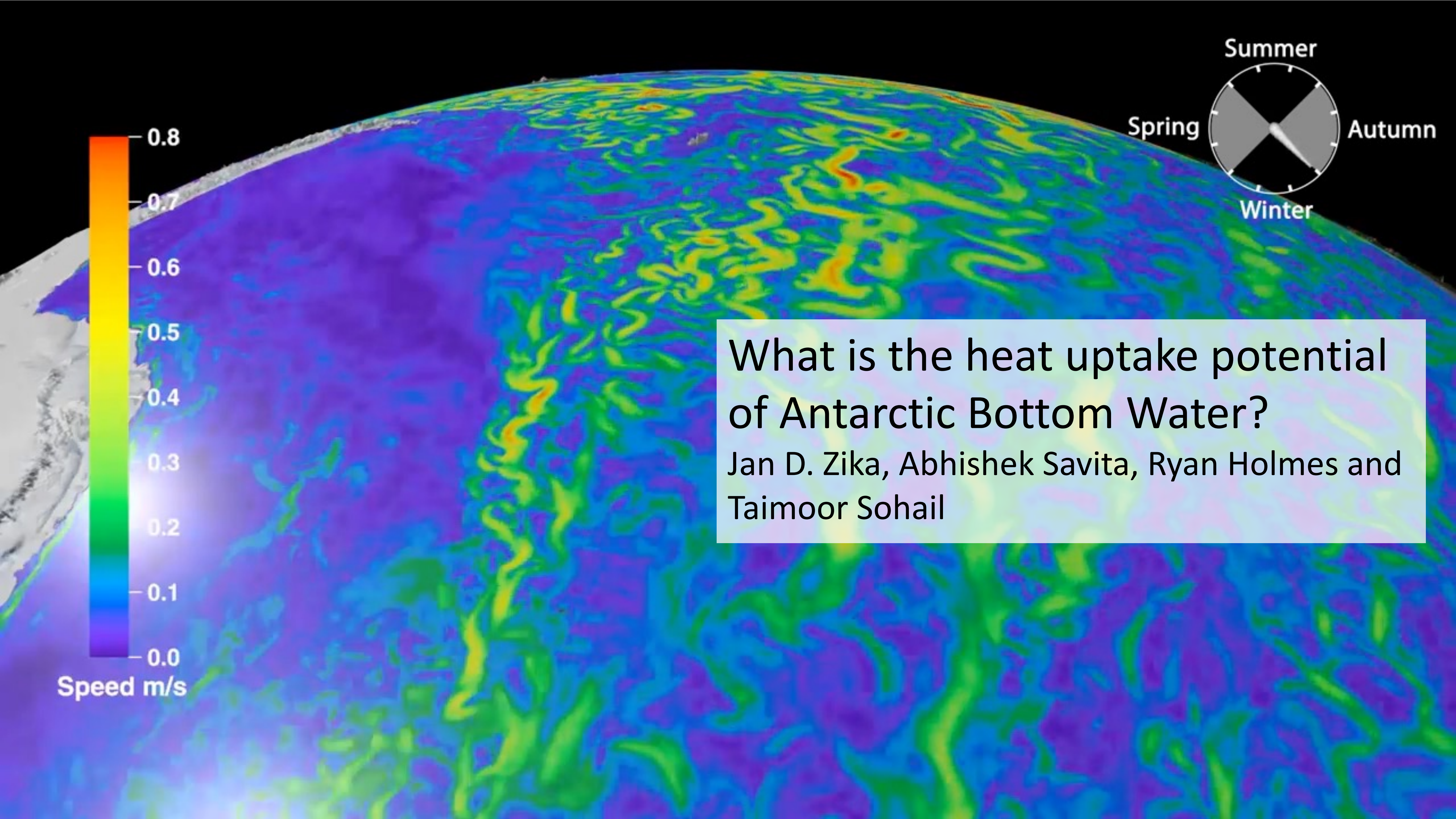


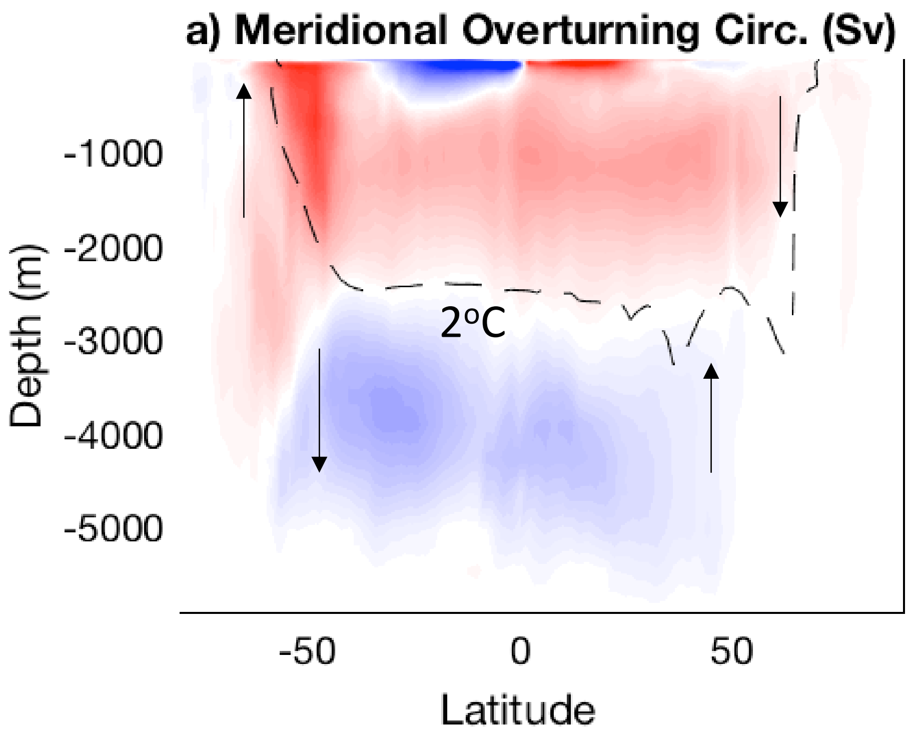
What is the heat uptake potential of Antarctic Bottom Water?

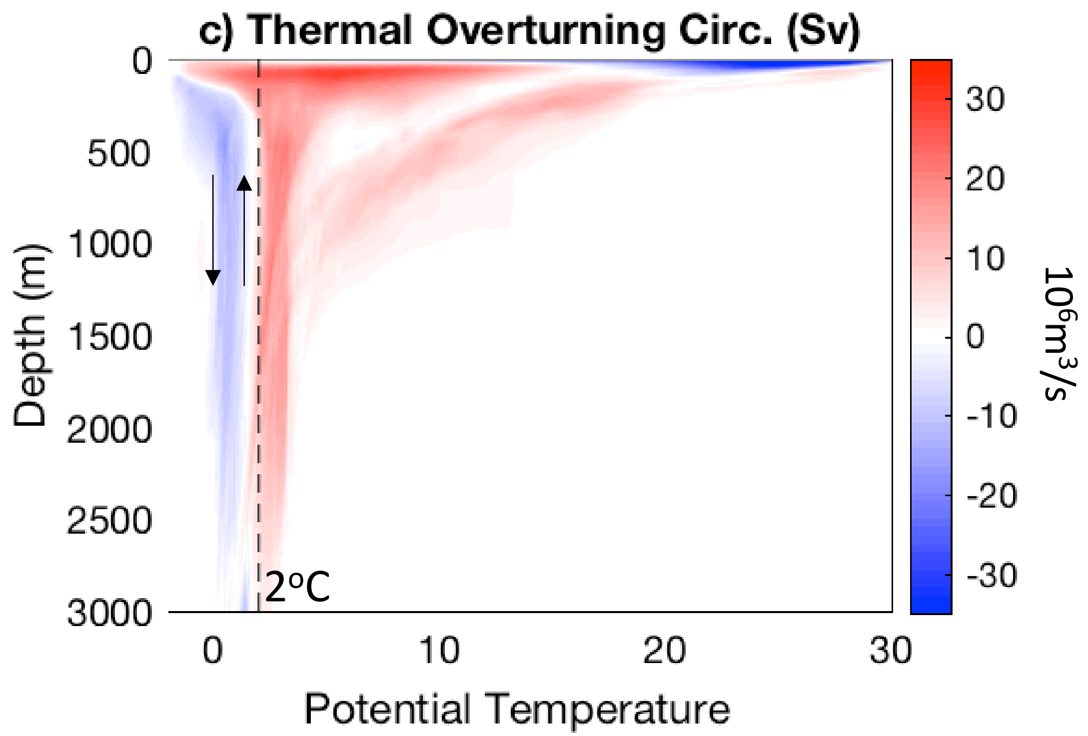
Jan D. Zika, Abhishek Savita, Ryan Holmes and Taimoor Sohail

Key points

- Extinguishing Antarctic Bottom Water (AABW) could upset the heat balance of the deep ocean - causing it to warm.
- The long term mean heat flux due to AABW may be an upper bound on this deep ocean heat uptake – we call it the ‘ocean heat uptake capacity’.
- Climate models with stronger ocean heat uptake capacity warm more in the deepest/coldest parts of the ocean.
- Observational constraints on AABW would help constrain the potential influence of AABW’s future temperature and sea-level.

What is the AABW circulation and what is its role in the ocean's vertical heat balance?





Latitude vs depth streamfunction:

- 'Abyssal Cell' evident in deep
- No connection to Antarctic Margin

Temperature vs depth streamfunction:

- 'Bottom' cell links sinking cold surface water to deep
- Cold water sinks implying thermally direct/cooling

Data:
ECCOv4,
monthly w and θ
(Forget & Ponte, 2015)

lat vs z streamfunction:

$$\psi(lat', z') = \iint_{\substack{lat<lat' \\ z=z'}} w dA$$

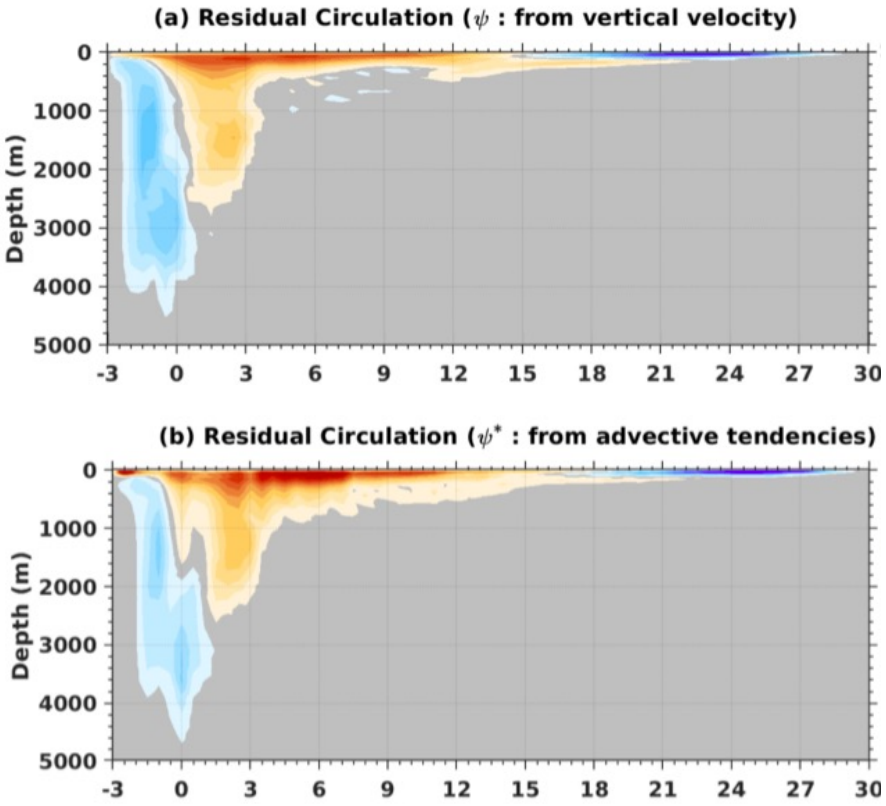
θ vs z streamfunction:

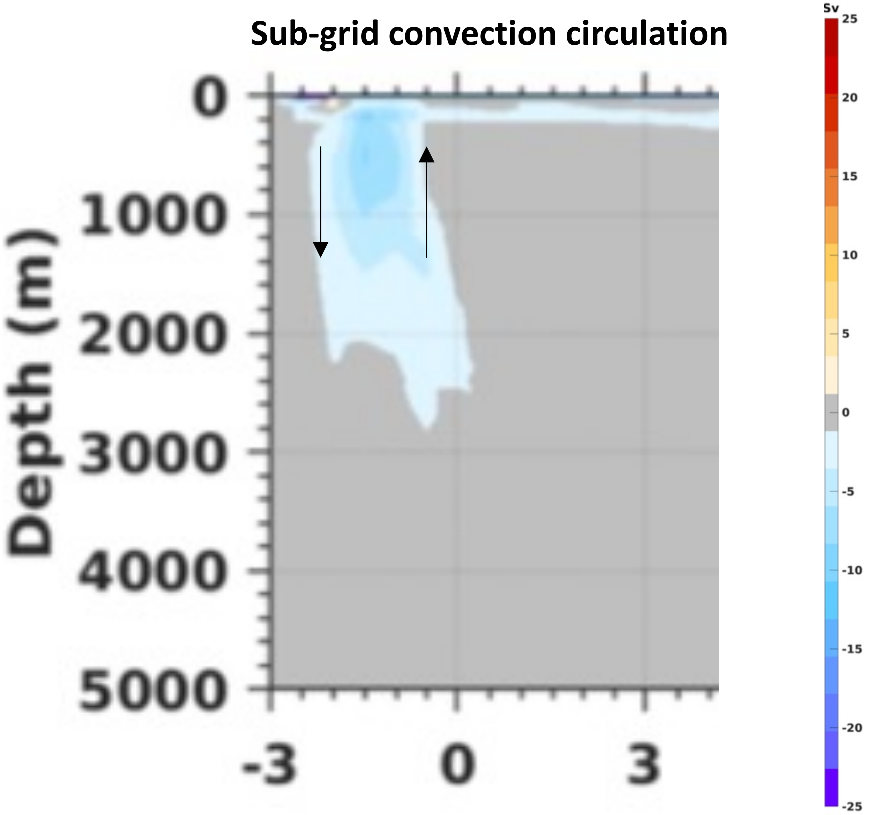
$$\psi(\theta', z') = \iint_{\substack{\theta<\theta' \\ z=z'}} w dA$$

w includes both Eulerian and eddy induced (e.g. GM) velocities.

(Zika et al. 2013)

What about parameterized convection?





We can compute the streamfunction from the advective tendency (grid cell by grid cell) rather than *w*

Using the same approach, we can compute a circulation representing any sub-grid term in a model.

Data:
ACCESS-OM2, 1 degree.

θ vs z streamfunction from advective tendency:

$$\psi(\theta', z') = \iint_{\substack{\theta<\theta' \\ z=z'}} w dA$$

$$= \frac{\partial}{\partial \theta} \iint_{\substack{\theta<\theta' \\ z<z'}} \boldsymbol{u} \cdot \nabla\, \theta dV$$

Circulation representing sub-grid convection ($\dot{\theta}_{conv}$):

$$\psi_{conv} = \frac{\partial}{\partial \theta} \iint_{\substack{\theta<\theta' \\ z<z'}} \dot{\theta}_{conv} dV$$

(Savita et al. JPO in rev.)

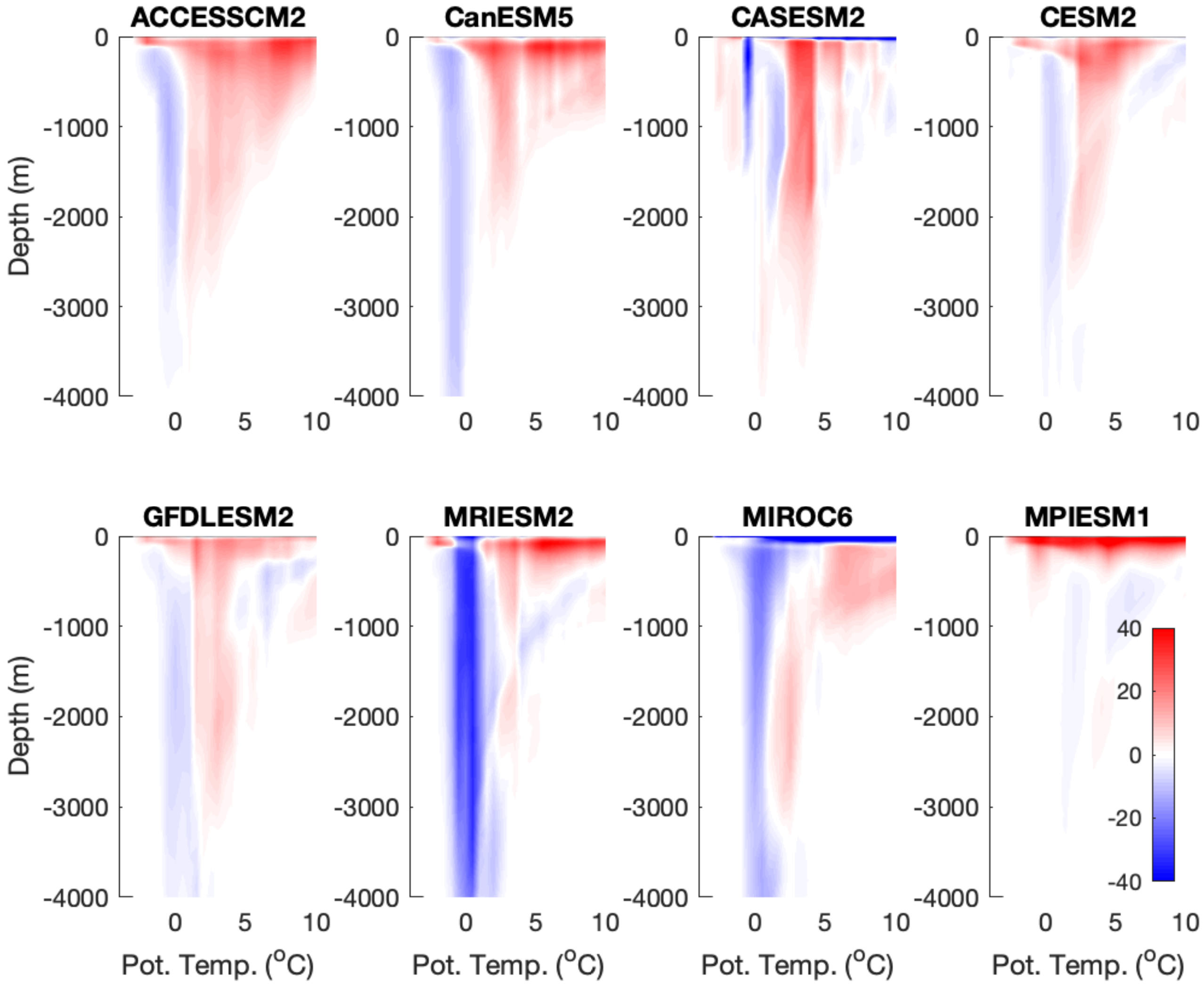
8 Models for the “Flux Anomaly Forced Model Intercomparison Project” (FAFMIP)

ψ (advective tendency)

Large diversity of model overturning circulations.

Most show deep reaching ‘Bottom cell’ but all differ in terms of strength.

Some are weird (this is preliminary analysis - there may be bugs)



FAFMIP control:

Pre-industrial coupled climate simulation.

Models:

ACCESS-CM2 (Australia)
CanESM5 (Canada)
CAS-ESM2 (China)
CESM2, GFDL-ESM2 (US)
MRI-ESM2, MIROC6 (Japan)
MPI-ESM1 (Germany)

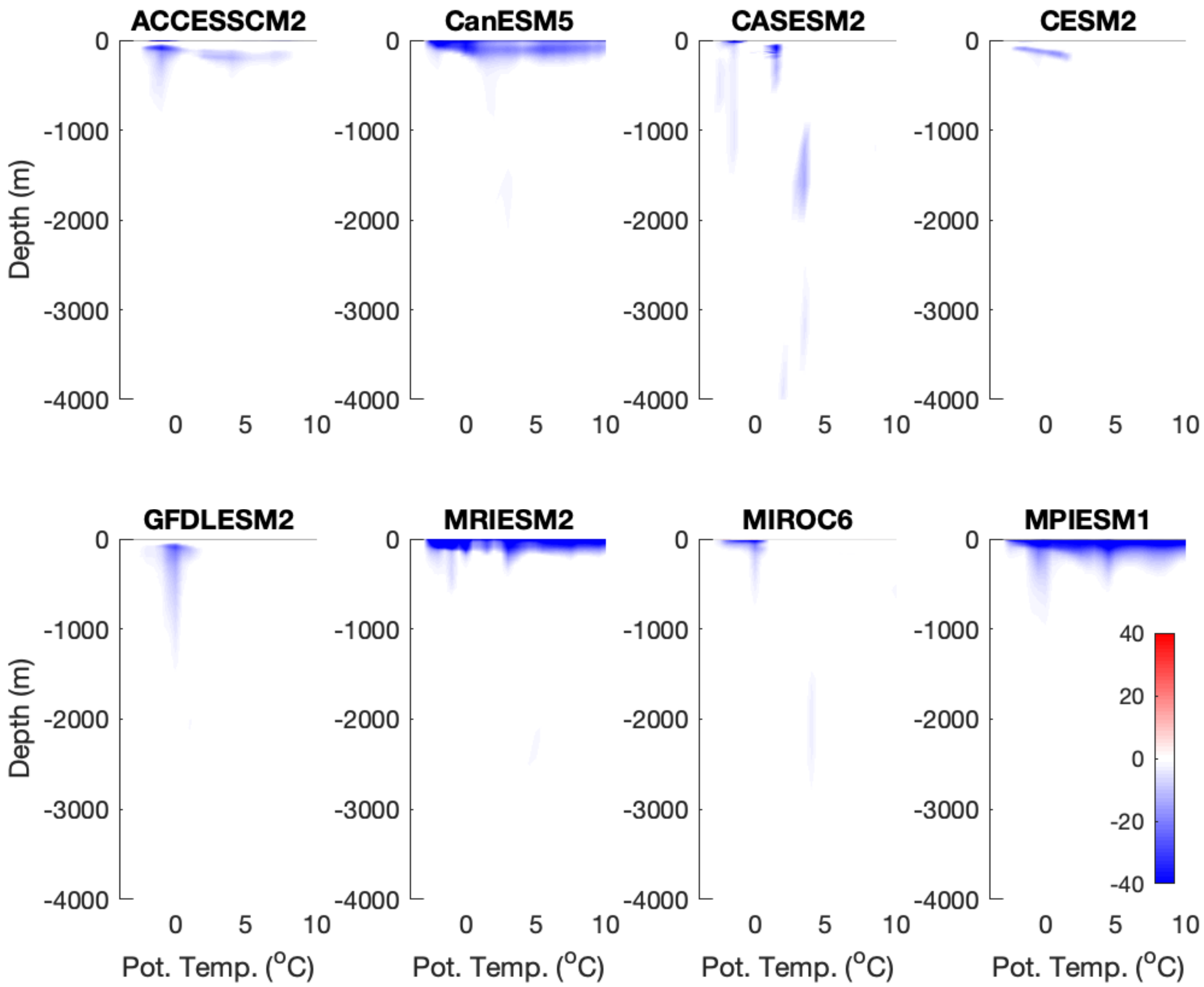
Annually averaged tendencies binned in 0.5C temperature ranges and accumulated vertically then averaged over 70 year simulation.

8 Models for the “Flux Anomaly Forced Model Intercomparison Project” (FAFMIP)

ψ_{conv} (subgrid convection)

Again, diverse range of mean cycles.

In some cases (such as MIP-ESM1) the deep(ish) cooling at low temperatures is driven purely by sub-grid mixing (and balanced by advection).



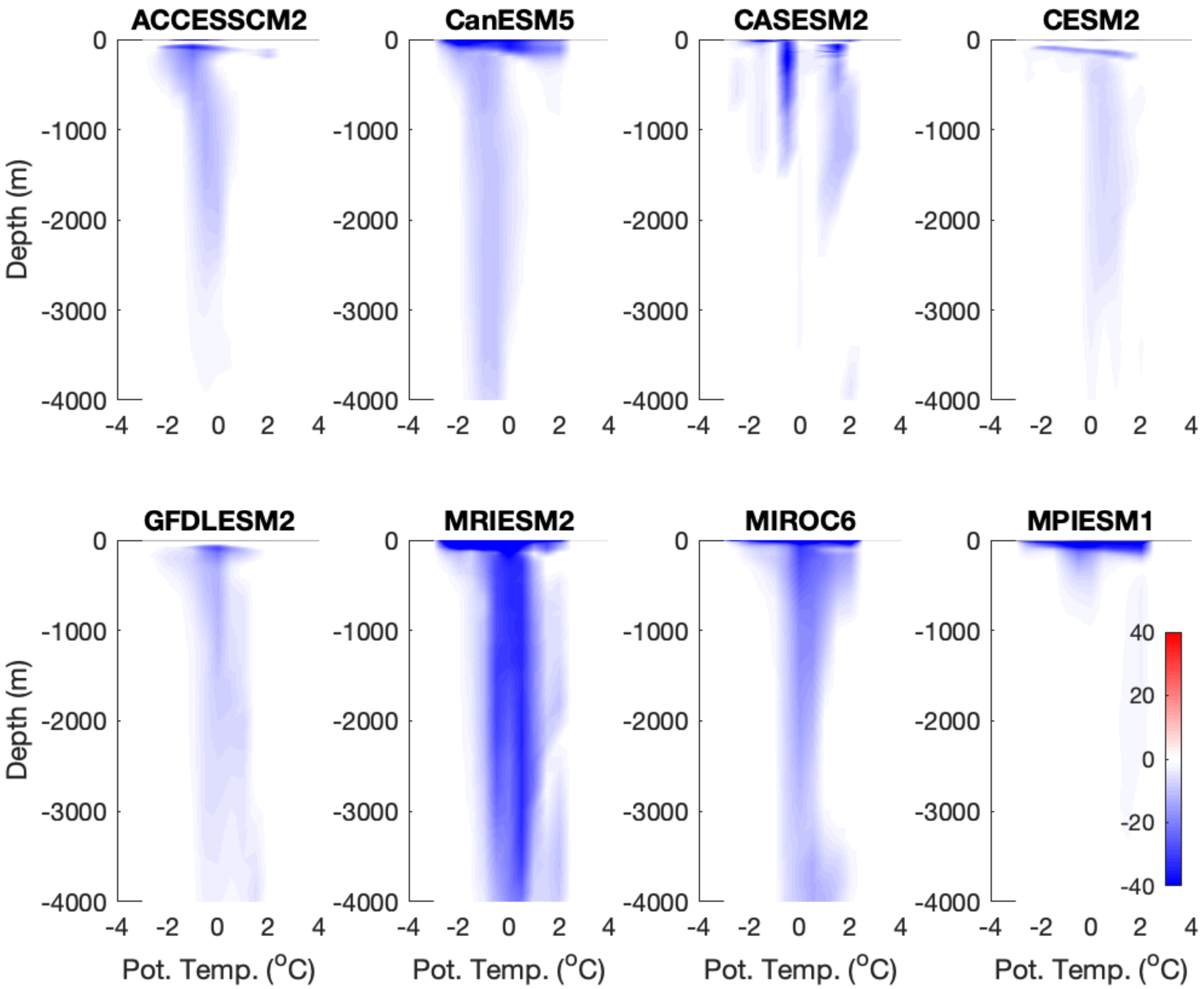
FAFMIP control:

Annually averaged mixing tendencies were binned in 0.5C temperature ranges and accumulated vertically then averaged over 70 year simulation.

We do not currently have the explicit convection term in each model. We computed a circulation from the total vertical mixing and extracted only the thermally direct component ($\psi < 0$).

Mean AABW circulation

Let's see what happens when we hit warm the surface of the ocean!



To make the streamfucntion describing the AABW circulation we add the thermally direct part of the advective ($\boldsymbol{\psi}$) and sub-grid convective ($\boldsymbol{\psi}_{\text{conv}}$) circulations together:

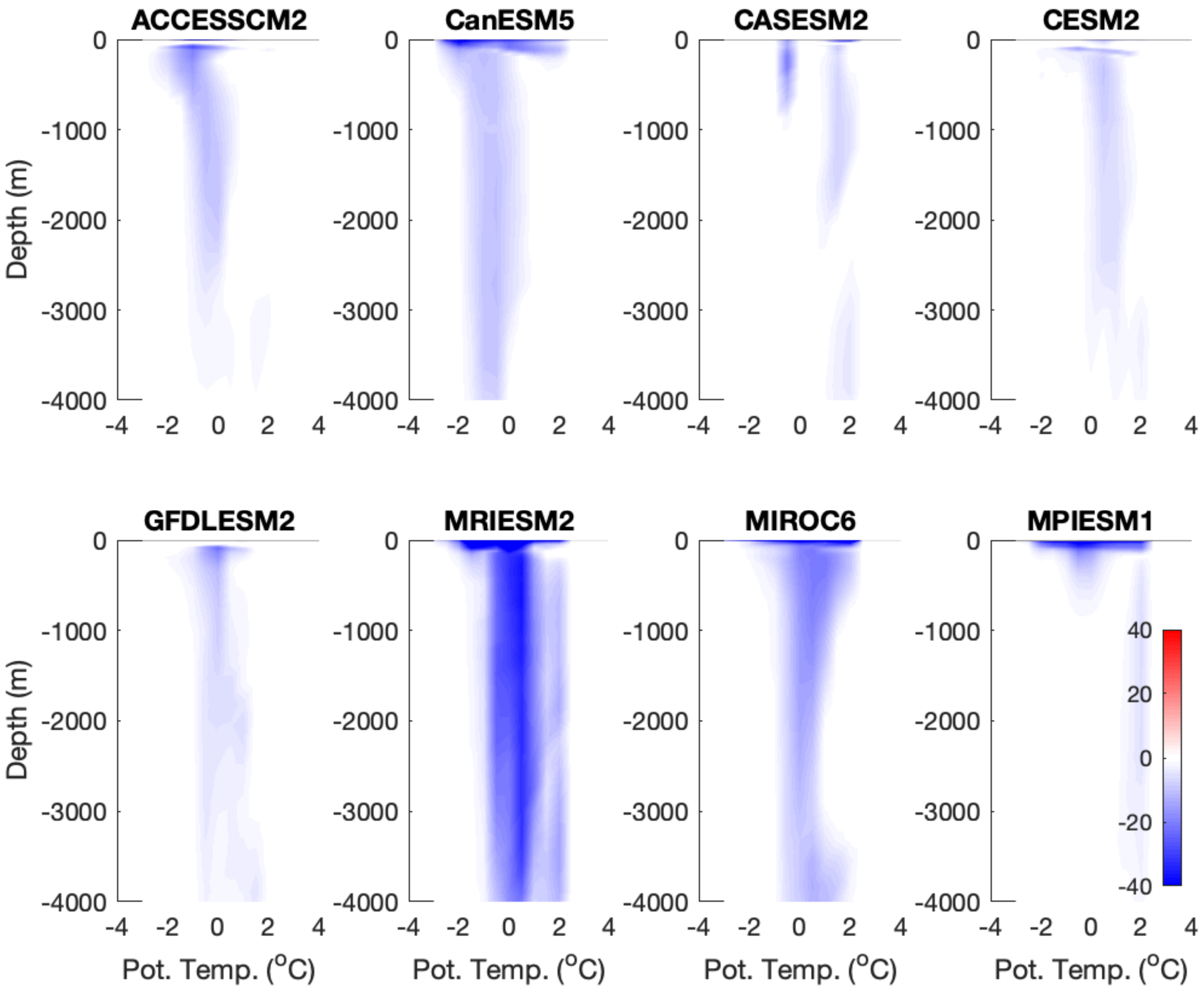
$$\boldsymbol{\psi}_{\mathbf{AABW}} = \boldsymbol{\psi}^{-} + \boldsymbol{\psi}_{\text{conv}}$$

$$\boldsymbol{\psi}^{-} = \begin{cases} \boldsymbol{\psi} & \boldsymbol{\psi} < \mathbf{0} \\ \mathbf{0} & \boldsymbol{\psi} \geq \mathbf{0} \end{cases}$$

Warming experiments are 'fafheat'. All models are given the same air-sea heat flux anomaly based on the CMIP5 ensemble mean response to 1%/year CO_2 increases (Gregory et al 2016).

Mean AABW circulation and with CO_2 doubling

Let's see what happens when we hit warm the surface of the ocean!



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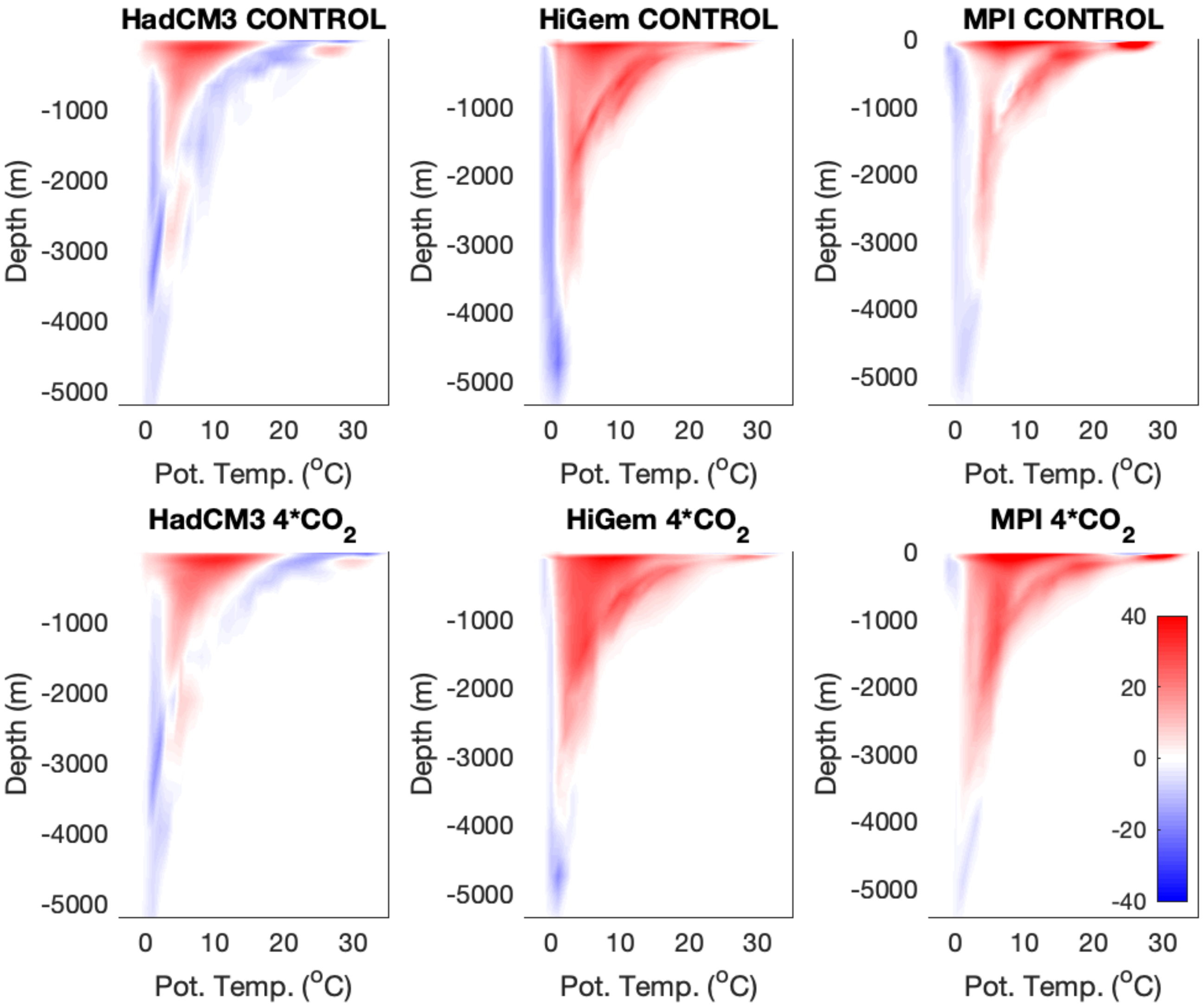
Warming experiments are 'fafheat'. All models are given the same air-sea heat flux anomaly based on the CMIP5 ensemble mean response to 1%/year CO_2 increases (Gregory et al 2016).

What about larger forcing anomaly ($4*CO_2$)

Models hit with a larger climate forcing can completely extinguish.

Though responses still vary.

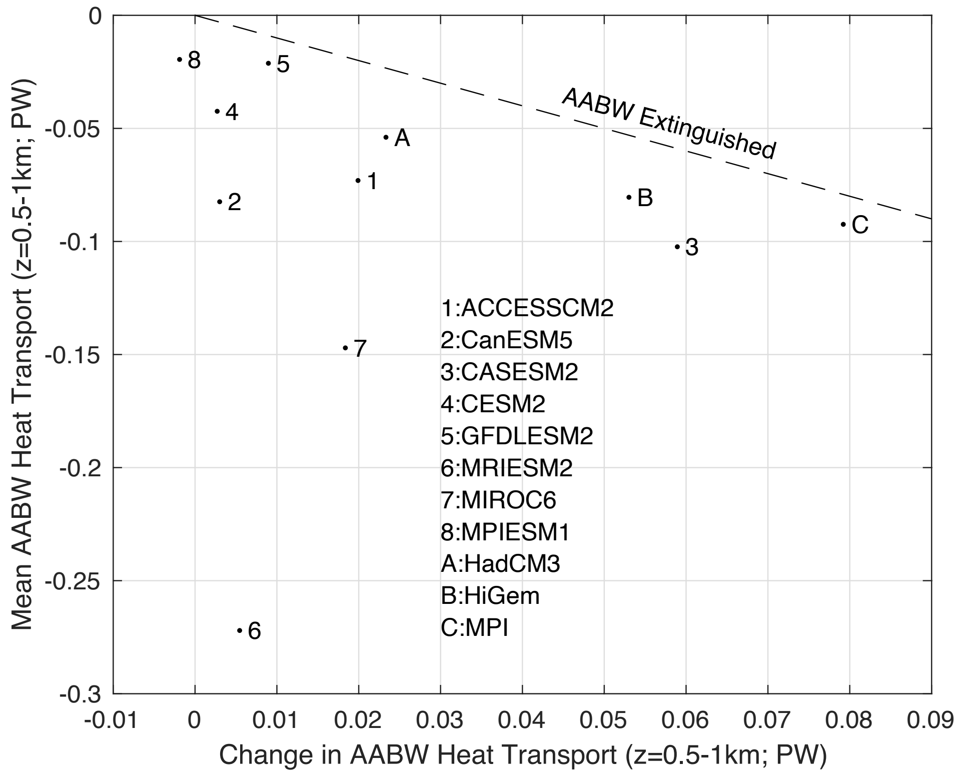


Climate models are subjected to abrupt CO_2 quadrupling as described in Exarchou (2016).

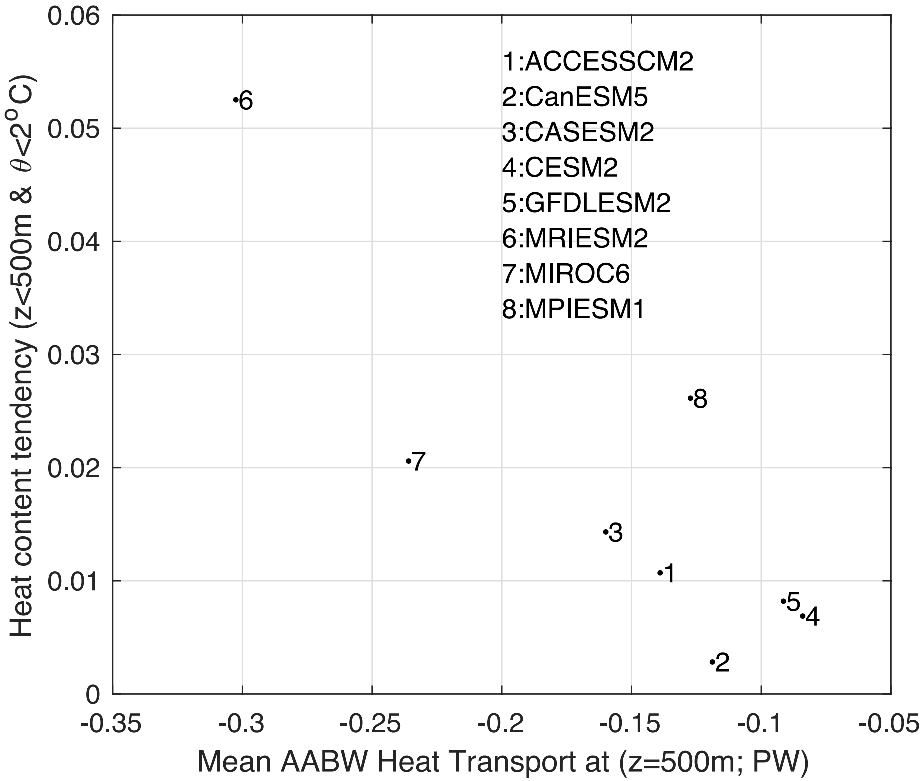
HiGem is relatively high resolution (1/3°).

Only advective ($\boldsymbol{\psi}$) component known.

What does all this mean?



The total heat flux change is bounded by the mean.



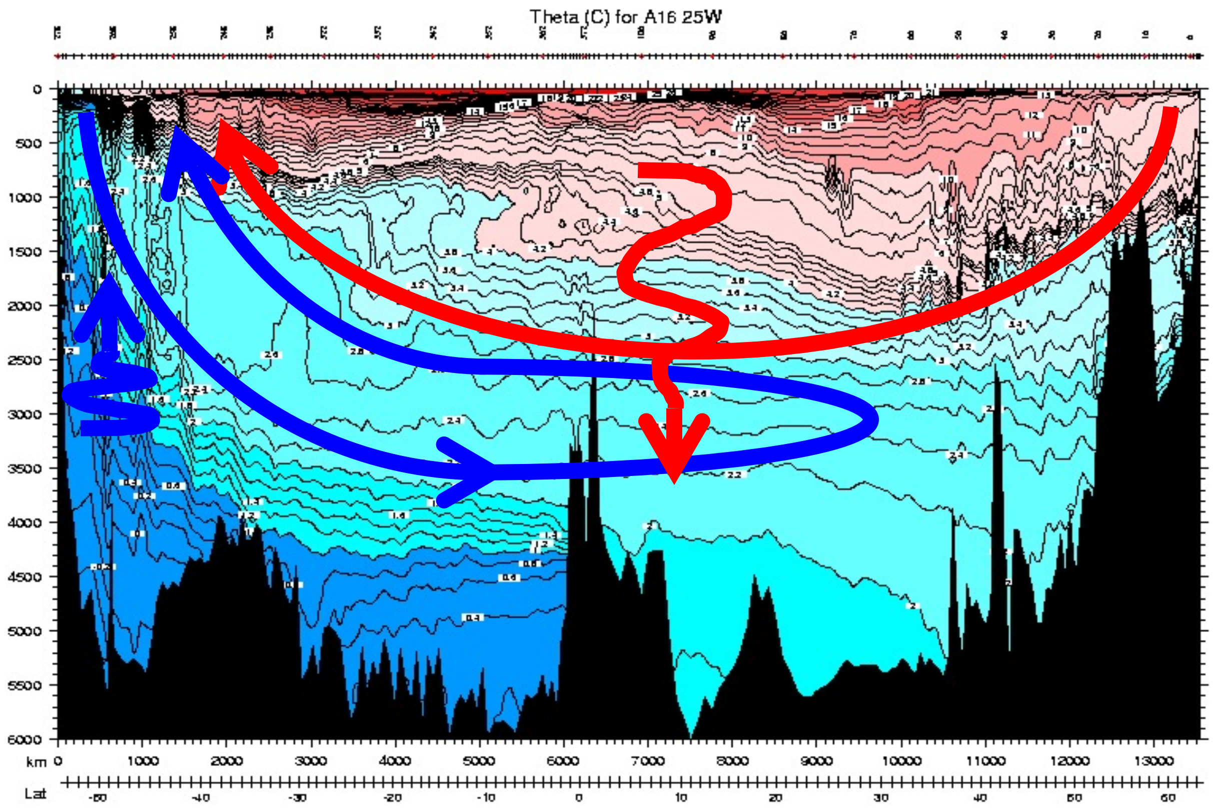
Models with stronger AABW circulations warm more in the deep ocean relative to the upper ocean.

In the FAFMIP models (1-8) we compare years 40-50 of the fafheat and fafcontrol experiment.

In the 4*CO_2 experiments we compare years 50-70 of the perturbation and control.

Final remarks and questions

- Switching off the usual cooling by AABW could cause the deep ocean to warm. We think AABW heat transport places an upper bound on how much the deep ocean can warm.
- In models we looked at, a more vigorous mean AABW circulation meant more deep-ocean warming.
- How could we constrain the 'actual' AABW circulation based on observations?



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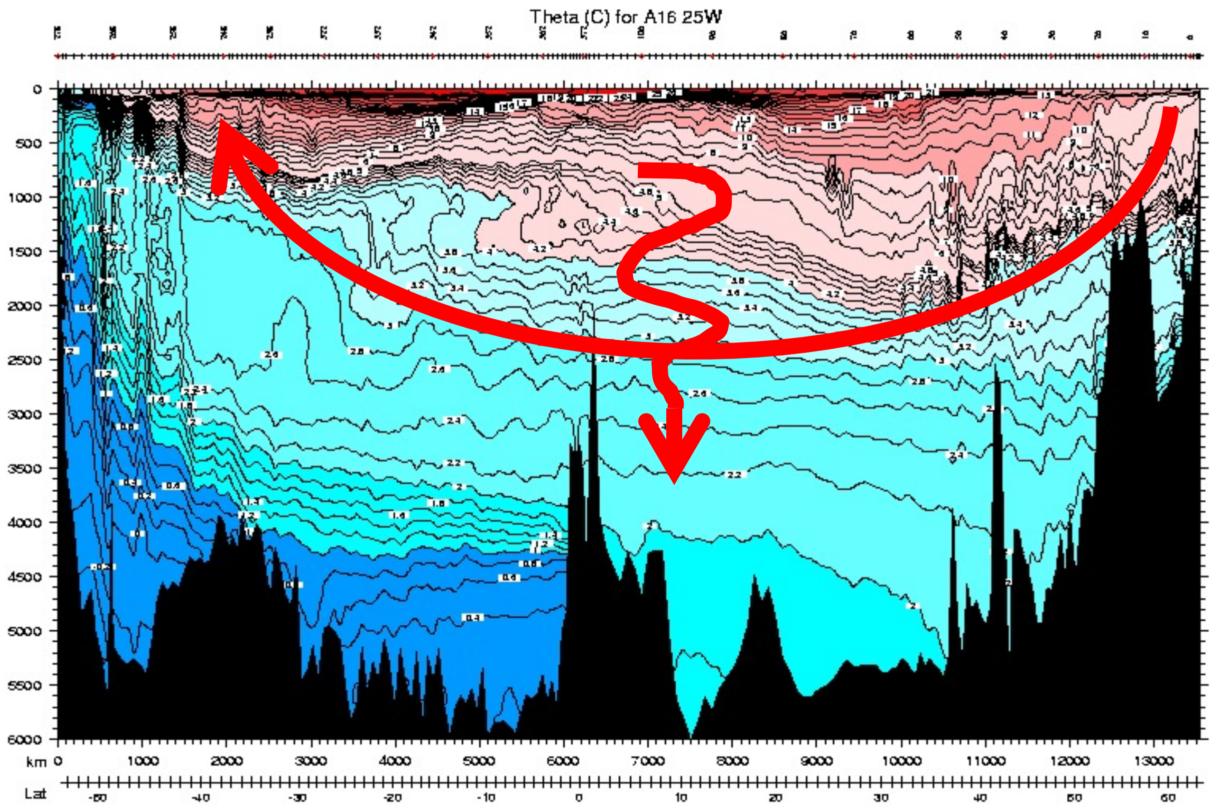

Credits

Opening animation: NCI, ANU: youtube.com/watch?v=8VMSF28J9H4

Papers on the θ-z circulation:

Zika et al. 2013, doi.org/10.1175/JPO-D-12-0179.1

Zika et al. 2015, doi.org/10.1002/2015GL064156

Paper on projection of sub-grid terms into θ-z :

Savita, A., Zika, J.D. et al., Super Residual Circulation: a new perspective on ocean vertical heat transport, JPO, under review.

Papers on FAFMIP and 4*CO_2 experiments (respectively):

Gregory et al. 2016, doi.org/10.5194/gmd-9-3993-2016

Exarchou et al 2016, doi.org/10.1175/JCLI-D-14-00235.1