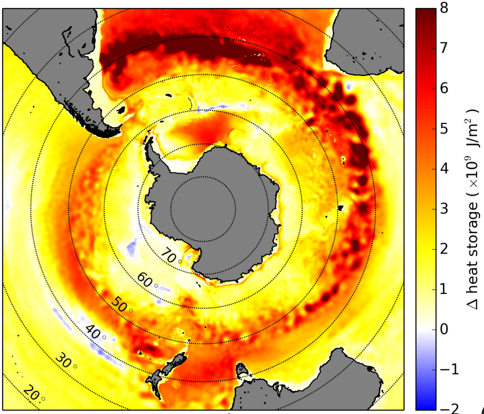
The Role of Circulation Change and Eddies in Southern Ocean Heat Uptake

Adele Morrison, Stephen Griffies, Michael Winton, Brendan Carter



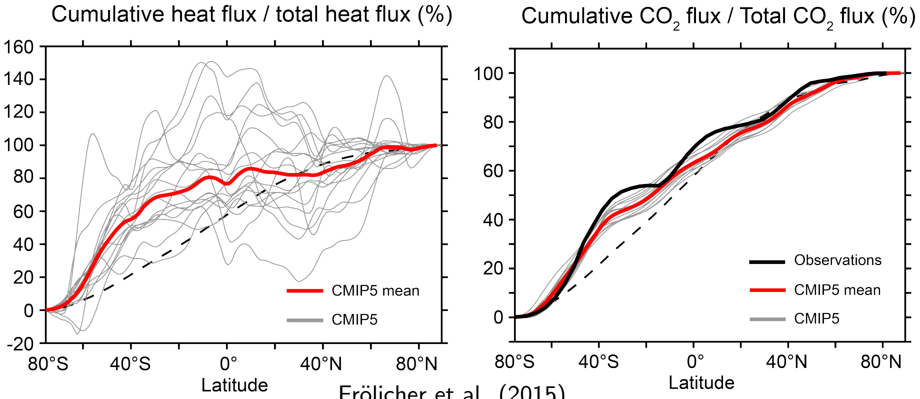
CM2.6: 1% yr^{-1} to $2xCO_2$

PRINCETON UNIVERSITY

GFDL Geophysical Fluid Dynamics Laboratory

Modelled Southern Ocean warming

- Southern Ocean dominates global heat uptake in CMIP5.
- Huge spread in Southern Ocean heat uptake: $\pm 40\%$ (1σ).
- Smaller spread in Southern Ocean carbon uptake: $\pm 10\%$.



Frölicher et al. (2015)

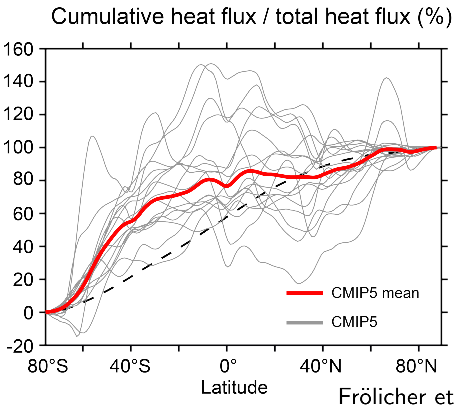
Modelled Southern Ocean warming

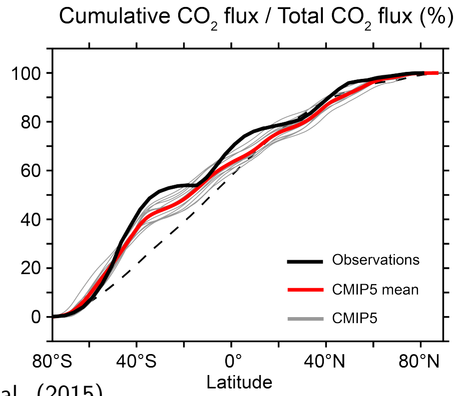
Dependent on:

- ocean transport processes (mixing, eddies, overturning, ...)
- atmospheric processes (aerosols, clouds, ...)

Dependent on:

- atmospheric CO_2
- [solubility, buffering, overturning change]

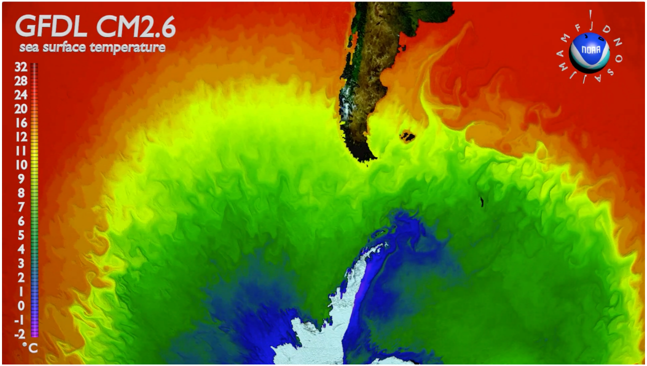




Frölicher et al. (2015)

CM2.6: GFDL's eddying, global coupled model

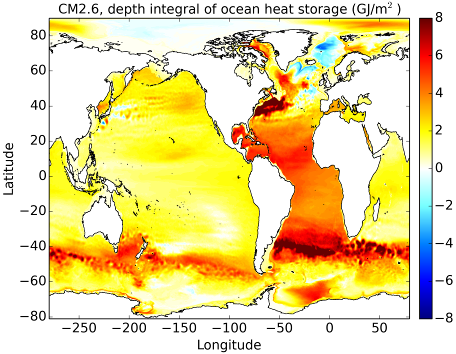
- MOM5 ocean, **1/10° resolution**, 50 vertical levels
- **No eddy parameterisations** (diffusive or advective)
- Coupled to sea ice, land, 50 km atmosphere models
- Ocean vertical mixing schemes include: internal gravity wave breaking, coastal mixing, KPP boundary layer, etc (zero background diffusion).
- Fox-Kemper mixed layer submesoscale restratification scheme.

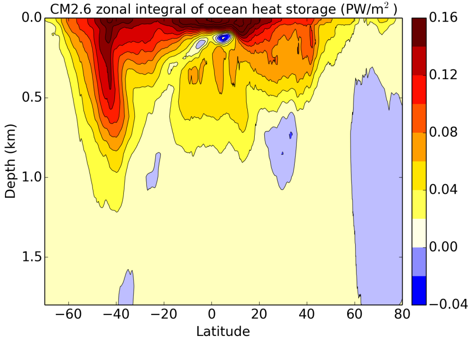


Whit Anderson

CM2.6 heat uptake

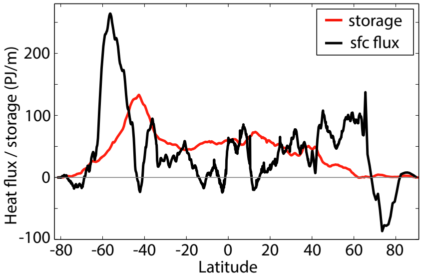
- 120 year spinup with preindustrial CO_2
- 80 year idealised 1%/yr CO_2 experiment, analysis of 20 yr average at 2xCO_2 (yrs 61-80)

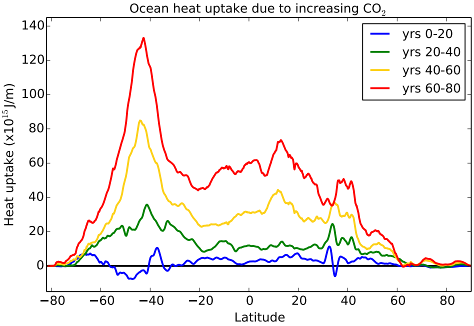




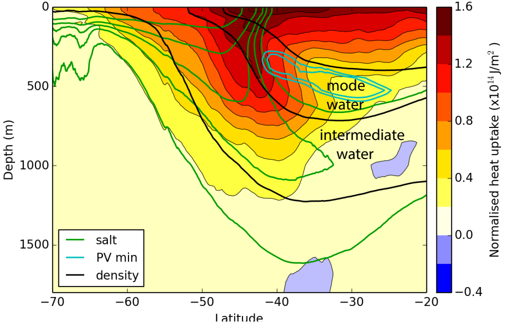
CM2.6 heat uptake

- Anomalous surface flux (dominated by sensible heat) is over upwelling region, 50-60°S, where SST is relatively constrained.
- Peak storage fixed at 40-45°S.

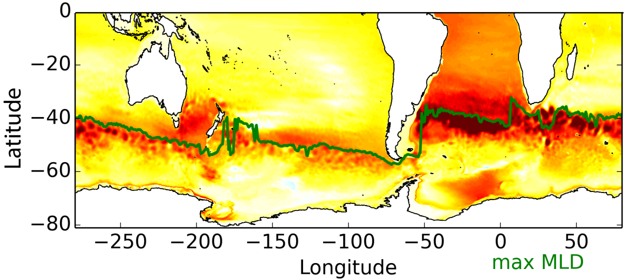




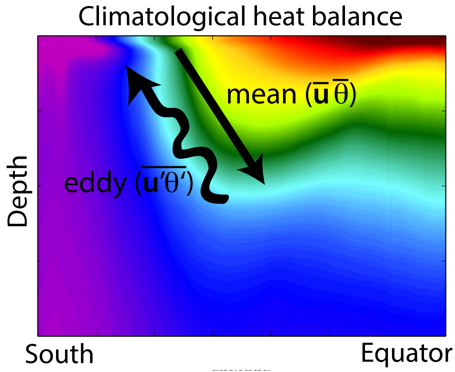
Peak warming location



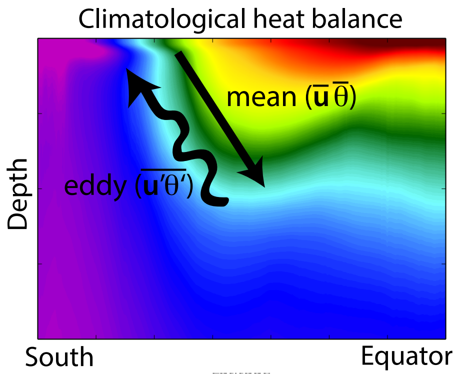
- Maximum warming aligned with deep mixed layers.
- Very little heat transport into mode / intermediate waters.

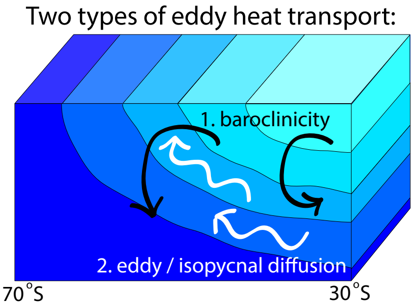


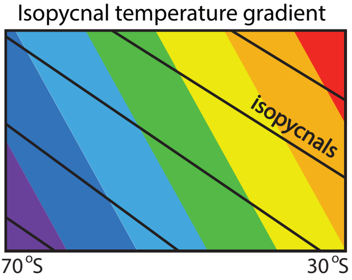
Dominant transport processes / mechanisms



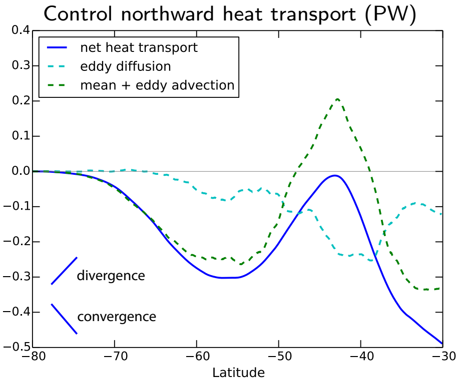
Dominant transport processes / mechanisms







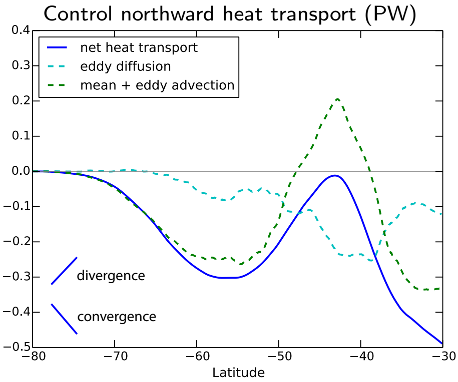
Meridional heat transport

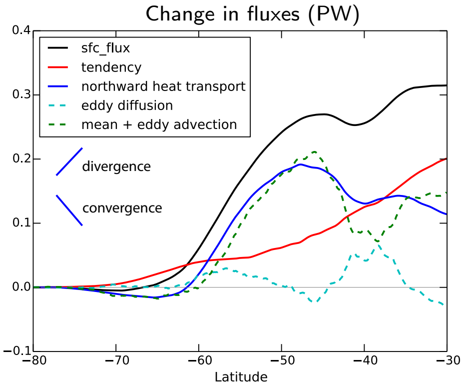


Following eddy decomposition of Lee et al. 2007:

$$\overline{\mathbf{v}\theta h} = \frac{\overline{\mathbf{v}h}}{\overline{h}}\frac{\overline{\theta h}}{\overline{h}}\overline{h} + \overline{\left(\mathbf{v} - \frac{\overline{\mathbf{v}h}}{\overline{h}}\right)\left(\theta - \frac{\overline{\theta h}}{\overline{h}}\right)h}$$

Meridional heat transport





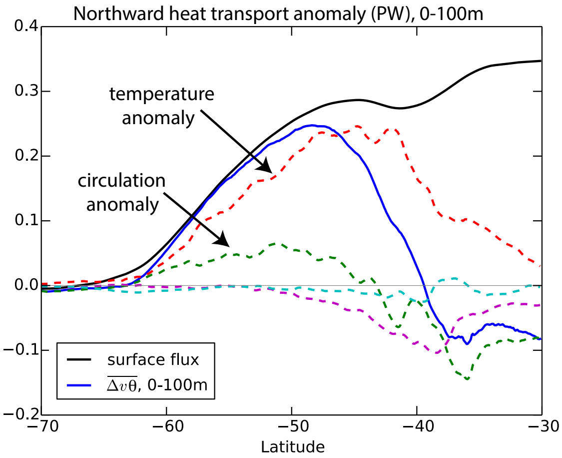
- Main heat convergence in deep mixed layers (40-45°S) is driven by advection changes.
- Warming north of deep mixed layers (30-40°S) is driven by isopycnal diffusion changes (which respond to peak warming further south).

What drives the advective changes in the south?

- Is the enhanced heat transport at 50°S due to increased overturning or warmer Ekman layer?
- Maximum overturning increases by 13%
(wind stress +6%, 1.5° shift south, increased buoyancy flux)

What drives the advective changes in the south?

- Is the enhanced heat transport at 50°S due to increased overturning or warmer Ekman layer?
- Maximum overturning increases by 13% (wind stress +6%, 1.5° shift south, increased buoyancy flux)

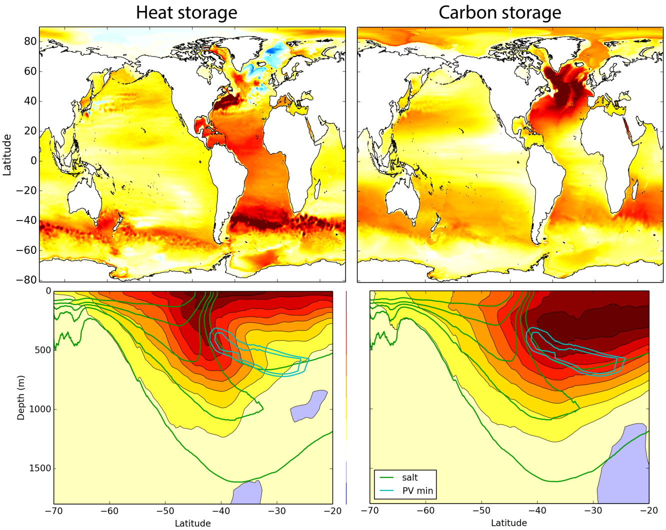


$$\Delta\overline{\mathbf{v}\theta} = \overline{v}_{ref}\Delta\overline{\theta} + (\Delta\overline{v})\overline{\theta}_{ref} + \Delta\overline{v}\Delta\overline{\theta} + \Delta\overline{v'\theta'}$$

Increased upwelling has minor impact on heat transport.

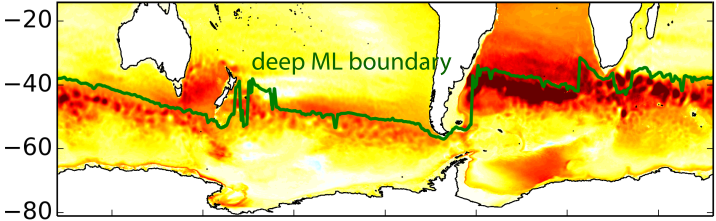
What drives the advective changes in the north?

Heat is not a passive tracer - Stommel's demon: only cold, dense water is selected out of mixed layer into mode / intermediate waters.



Also:
Banks and Gregory 2006
Winton et al. 2013
Frolicher et al. 2015

Conclusions



- Intense Southern Ocean warming is due to advective convergence at deep mixed layers.
- Eddy diffusion transports heat northwards from deep mixed layers (equally as important as mode / intermediate water advection).
- Mode / intermediate water formation processes are critical.
- Enhanced upwelling has only minor impact.