Ocean heat redistribution during climate stabilization at different global warming levels

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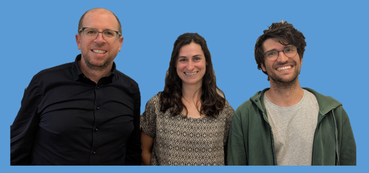


Motivation

- Increasing greenhouse gas concentrations in the atmosphere trap excess heat in the Earth System. This additional heat warms the Earth surface but mostly ends up in the ocean.
- The ocean will **continue to warm** long beyond transient global warming, even if surface temperature stabilizes.

How is ocean heat redistributed after global warming stabilizes?

Do the spatial patterns scale linearly with the level of global warming?

How is it affected by changes and potential recovery of the meridional overturning circulation?

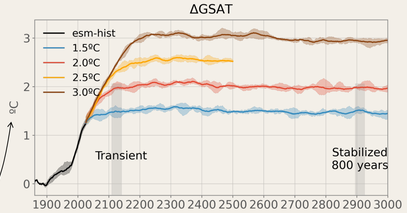
Are they sensitive to the GWL?

Is there a critical threshold above which non-linear changes occur?

Modelling framework

Following an emission-driven historical simulation, CO_2 emissions are adapted every 5 years to reach and stabilize at a prescribed warming level
(adaptive emission reduction approach, AERA; Terhaar et al. 2022, Silvy et al. 2024)

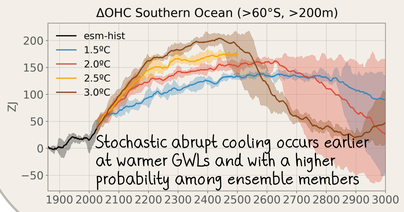
- 5 ensemble members
(shading=min-max range)
- GFDL-ESM2M
fully-coupled model
(Dunne et al. 2012, 2013)



Global warming level (GWL)

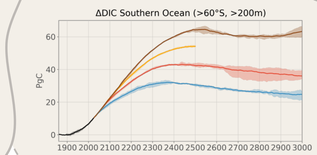
Focus on the Southern Ocean

Southern Ocean response



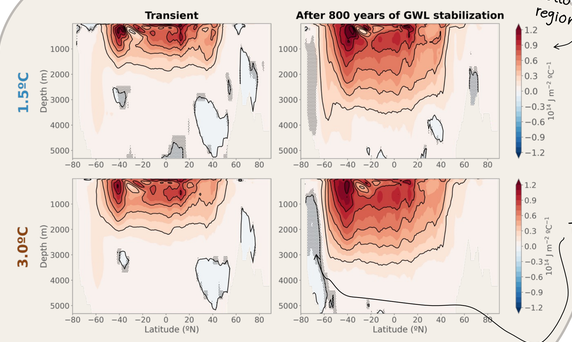
Subsurface heat storage

Carbon content is much less affected



Subsurface carbon storage

Regional heat response



Heat continues to go down following similar regional patterns

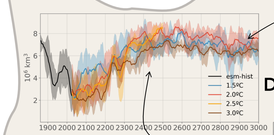
The subsurface Southern Ocean is cooler at 2ºC and 3ºC but not at 1.5ºC …

… and ensemble members disagree on the sign of the change (stippled)

Zonally-integrated heat content anomaly / GWL

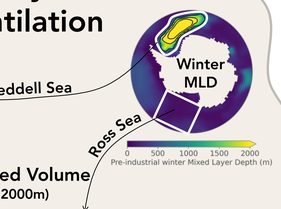
Why is this happening?

Recovery of the ventilation

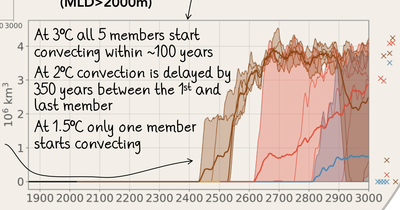


Weddell Sea convection recovers but does not explain the abrupt shifts in subsurface heat content…

…instead, a new convection site pops up in the Ross Sea

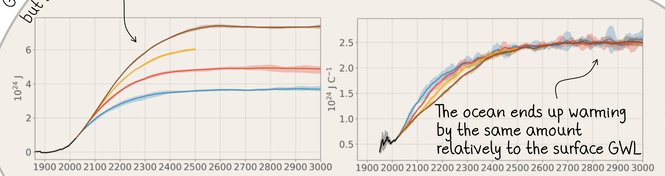


Deep Mixed Volume
(MLD>2000m)



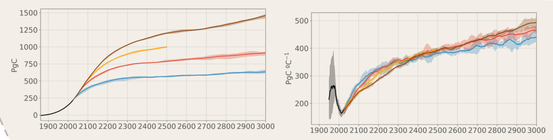
Global ocean heating lags behind GSAT but stabilizes with a ~300-year delay

Global response



Ocean heat storage

Ocean heat storage / GWL
→ "efficiency"

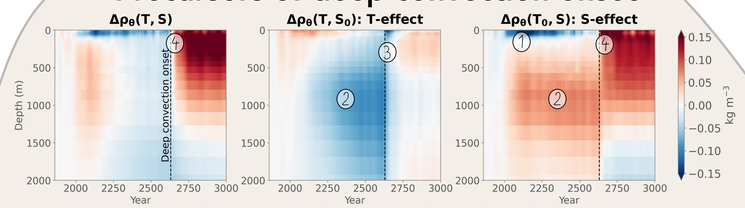


Ocean carbon storage

Ocean carbon storage / GWL

Bonus: take a look at the difference with the carbon response

Precursors of deep convection onset



Potential density anomaly in the Ross Sea

① Surface freshening isolates subsurface waters

② Build up of subsurface heat & salt (competing effects on stability)

③ Heat wins: destabilization & release of heat to the surface then atmosphere

④ Salty waters are brought back up and trigger deep convection

Conclusion

- The ocean takes up heat for centuries, sequestering it at all depths, even after global warming stabilizes.
- We find **non-linear responses across warming levels**, especially in the Southern Ocean, where **abrupt stochastic cooling** occurs at depth earlier and with higher probability with greater surface warming.
- The cooling is caused by a **new deep convection site in the Ross Sea**, triggered by the buildup of heat underneath a very fresh surface layer. This heat ends up breaking the stratification, is released to the atmosphere while the surface waters get saltier, which kickstarts deep convection.

Stay tuned! Next up:
- What is triggering the heat release?
- Early warning indicator for Ross Sea deep convection?
- GWL-dependence of the subtropical gyres heat content, where most of the heat is in fact stored

Work in progress!

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Dejargonizer

GWL: global warming level
GSAT: global surface air temperature OHC: ocean heat content DIC: dissolved inorganic carbon MLD: mixed layer depth Δ: anomaly relative to 1861-1900