Extratropical Mixing, Ocean Temperatures and Heat Transport

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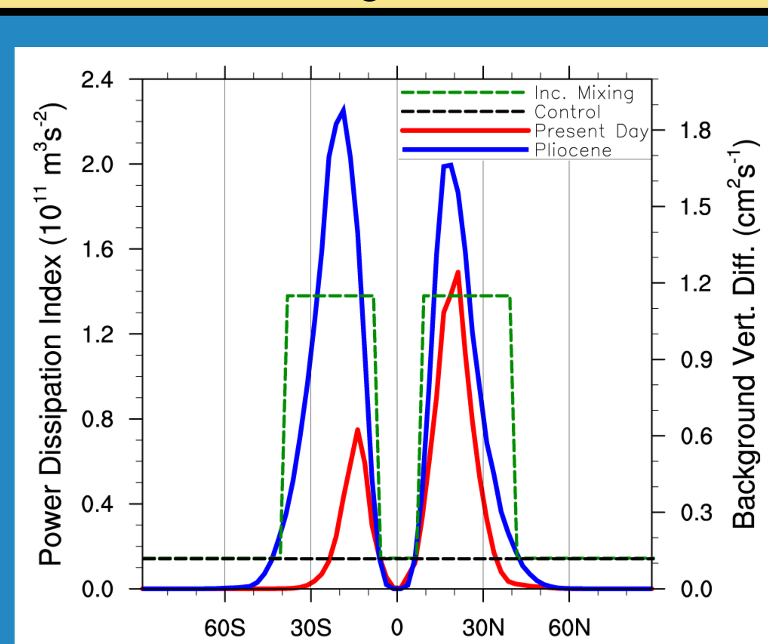
Introduction

The impact of tropical cyclones on the large-scale climate is still debated. Tropical cyclones (TC) rapidly mix the water column beneath them, bringing cold water to the surface. One way to parameterise this process in a climate model is to introduce an additional vertical diffusivity term, that can either be constant (Jansen & Ferrari, 2009) or dependent on the atmospheric state (Korty et al., 2008). Recent work has suggested that there may have increased upper ocean vertical mixing in the early Pliocene (Brierley et al., 2009), and that tropical cyclones could have been the source of this additional mixing.

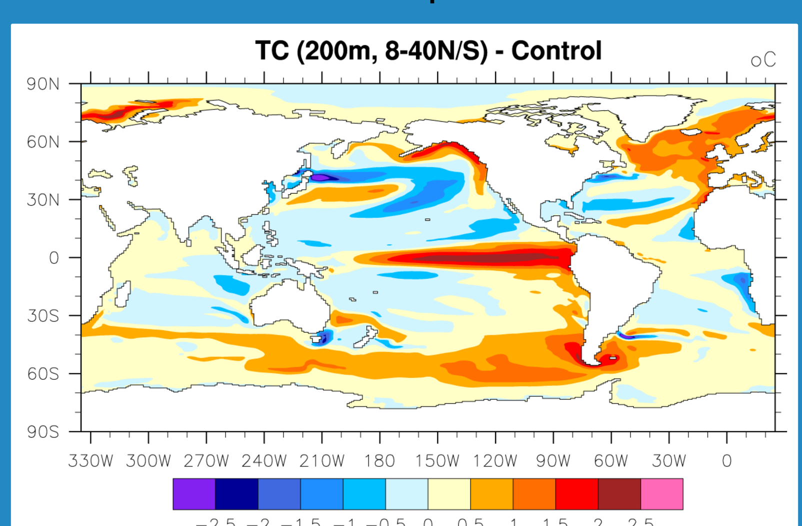
To test this idea, we add an band of increased mixing to the ocean of a coupled climate model (CCSM3). The background vertical diffusivity is increased by a factor of 10 to 1.1 cm²s⁻¹, see **1**. This additional mixing occurs in the top 200m and between 8º-40º N/S throughout the globe.



1: Mixing related to tropical cyclones. *The zonally integrated, annual average power dissipation index, as derived from the modeled climate, for the present day (red line) and the early Pliocene (blue line) – left-hand scale. The background vertical diffusivity in the two coupled model simulations – right-hand scale.*

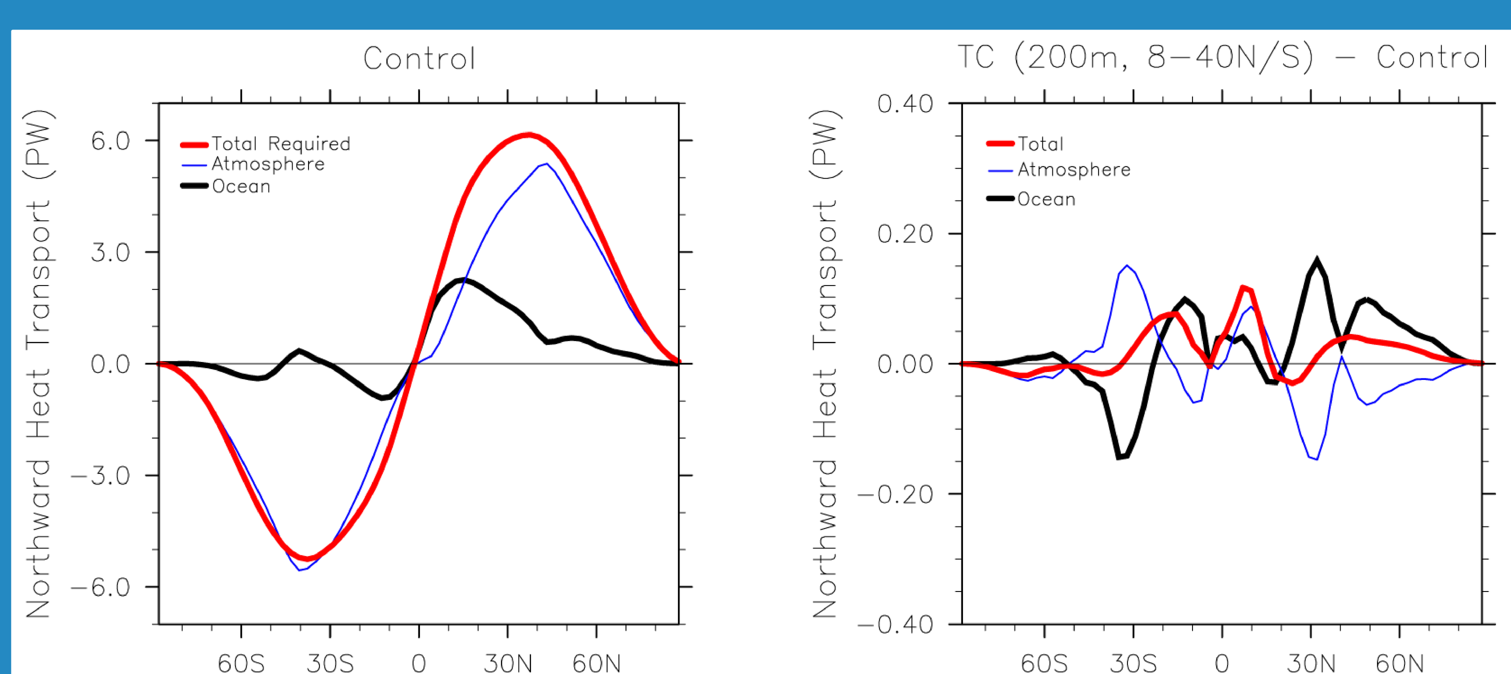
Results

The additional vertical mixing, putatively sourced from tropical cyclones, leads to a dramatic warming of the eastern equatorial Pacific (**2**). This state is somewhat similar to the form of 'permanent El Niño' described by Brierley et al. (2009).



2: Impact of Tropical Cyclone Mixing on SST. *The difference between the simulation with two bands of additional vertical mixing and the present-day control simulation. There is a warming of the high latitudes and eastern tropical Pacific, but cooling in other regions.*

These temperature changes are caused by alterations in the poleward heat transport (**3**). There is an increase in ocean's heat transport polewards of 20ºN in both hemispheres. There is significant asymmetry in the tropical response, partly caused by equatorial warming in **2** altering the seasonal cycle of the ITCZ.

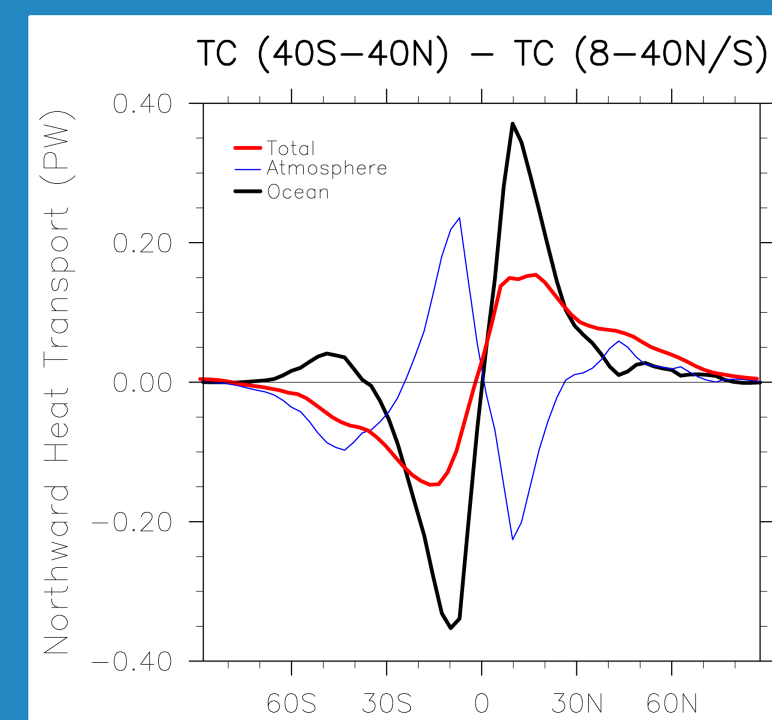


3: Poleward Heat Transport *in the control (left) and the change caused tropical cyclones (right). The transports are from heat fluxes calculated at the top and bottom of the atmosphere*

Sensitivity to Parameters - Latitude

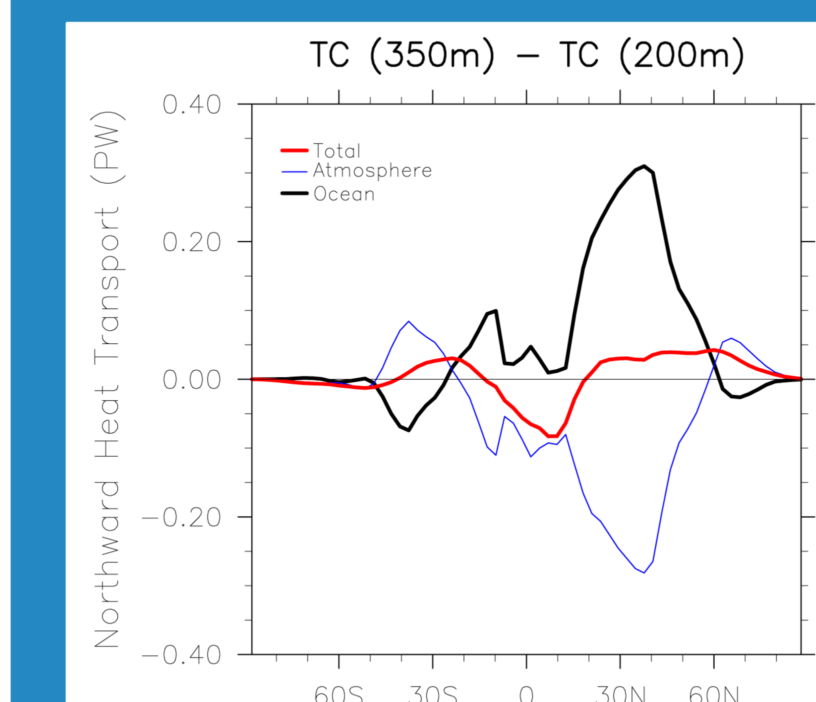
The strength of the equatorial warming and the poleward heat transport are crucially dependent on the width of the gap between the two bands of tropical cyclone mixing. In the extreme case where there is no gap, there is a significant increase in the amount of heat moved polewards by the tropical ocean (**4**).

This is tempered by a reduction in the strength of the Hadley Circulation and the atmosphere's heat transport. The asymmetrical response between the hemispheres are lost, when the gap is removed.



4: Sensitivity to width of the gap. *The difference in poleward heat transport between a simulation with mixing throughout the tropics and one with mixing in the bands shown in 1.*

Sensitivity to Parameters - Depth

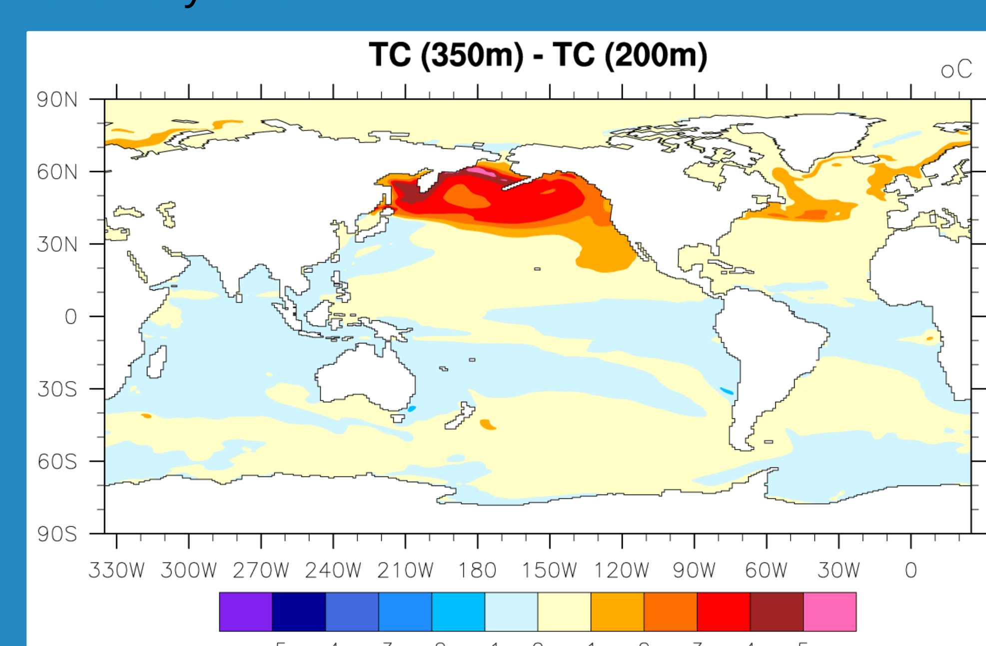


5: Sensitivity to depth of mixing. *The difference in heat transport between runs with mixing in the top 350m and top 250m*

The depth to which the additional mixing is imposed also has some important consequences on the poleward heat transport (**5**). If the mixing is imposed down to 350m (instead of 200m), there is a large increase in the ocean heat transport in the northern mid-latitudes. The vast majority of tropical cyclone mixing occurs in the top 200m, but impacts have been observed at 350m. Most of the ocean transport is compensated by atmosphere changes, leaving only a small increase in total heat transport.

The additional poleward ocean heat transport occurs mainly in the Pacific and leads to a significant warming of the subpolar gyre (**6**). Although there is some warming of the North Atlantic, it is minor compared to the Pacific response. The impact s in the Southern Ocean are very small.

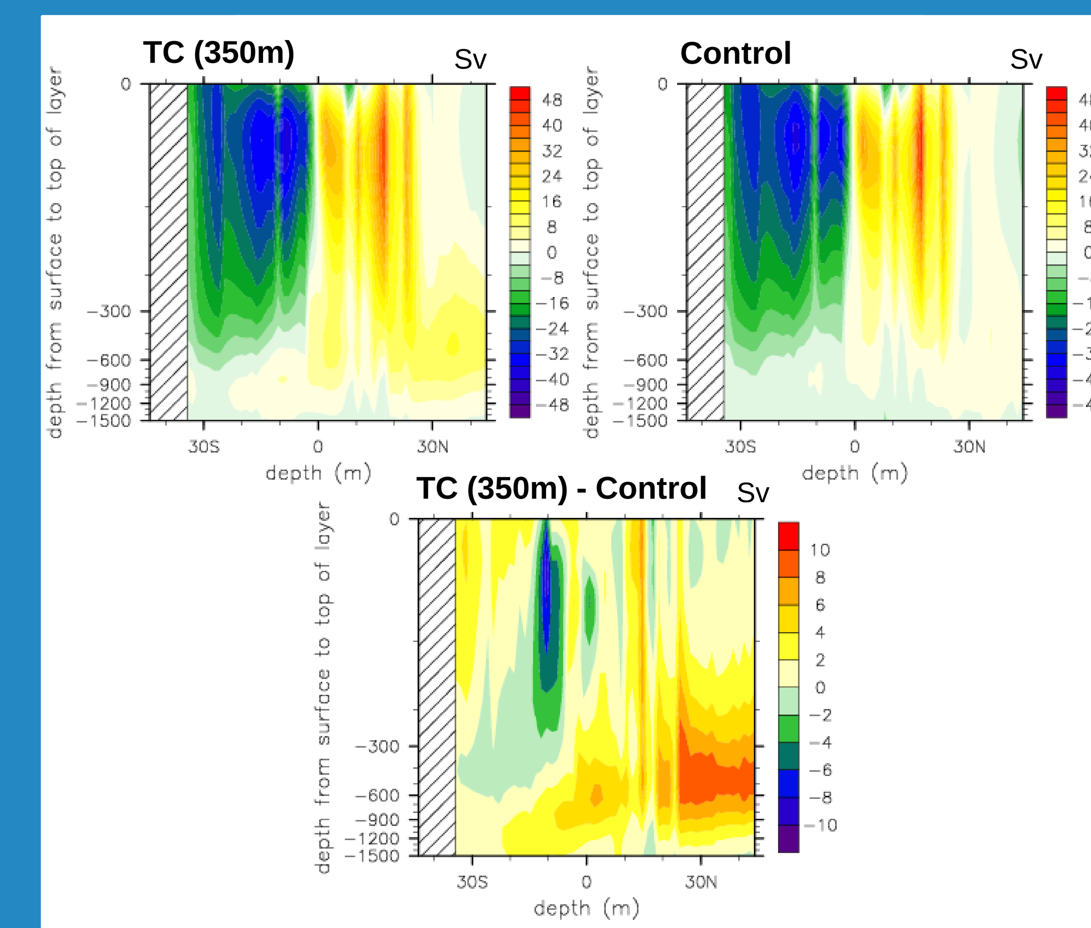
6: Impact of Deeper Tropical Cyclone Mixing on SST. *The difference between runs with vertical mixing in the top 350m and top 250m. There is a slight reduction in warming of the cold tongue, but substantial extra warming in the North Pacific. Note the different color scale than* **2**.



A Pacific Meridional Overturning Cell ?

The explanation for the warming of the North Pacific seen in **6** is that deep TC mixing is able to activate a pacific meridional overturning circulation (MOC), as shown in **7**. This Pacific MOC is both shallower and weaker than its Atlantic equivalent. The deepest portion of the Atlantic MOC is weaker, but its total transport stays approximately constant in the simulation with deep mixing.

7: Meridional Overturning Circulation in the Pacific. *The zonally averaged streamfunction in the upper Pacific ocean for the deep TC mixing (left), the control run with no TC mixing and the difference between them (bottom). Wind driven cells dominate the overturning in the top 300m for both simulations.*



Conclusions

- **Tropical Cyclones are a source of vertical mixing in the ocean**
- **This mixing can change the poleward heat transport of both the atmosphere and oceans.**
- **The amount and nature of these changes in heat transport are strongly dependent on the location of the mixing.**
- **In certain circumstances, the additional mixing can spin up a Pacific meridional overturning circulation.**

Future Work

- **More extensive exploration of parameter space needed to determine threshold for existence of PMOC**
- **More refined parameterization of vertical mixing needed to validate real world values impact of tropical cyclones**
- **Further paleoobservations needed to elucidate tropical cyclones role in the "permanent El Niño" of the Pliocene.**

References

Jansen & Ferrari, 2009, Impact of the latitudinal distribution of tropical cyclones on ocean heat transport *Geophysical Research Letters*, 2009, *36*, L06604

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