The role of oceans in transient polar climate change

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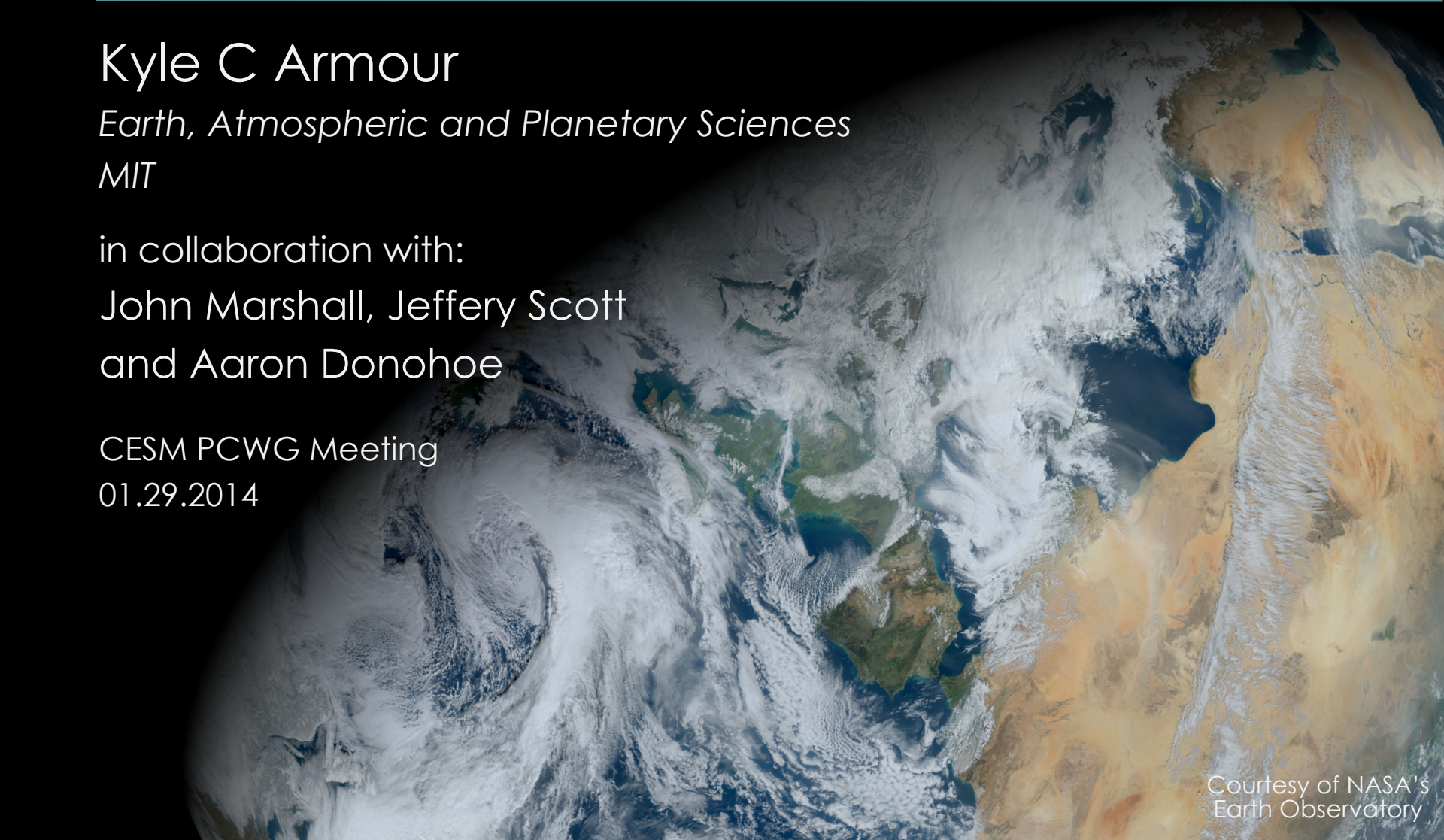
in collaboration with:
John Marshall, Jeffery Scott
and Aaron Donohoe

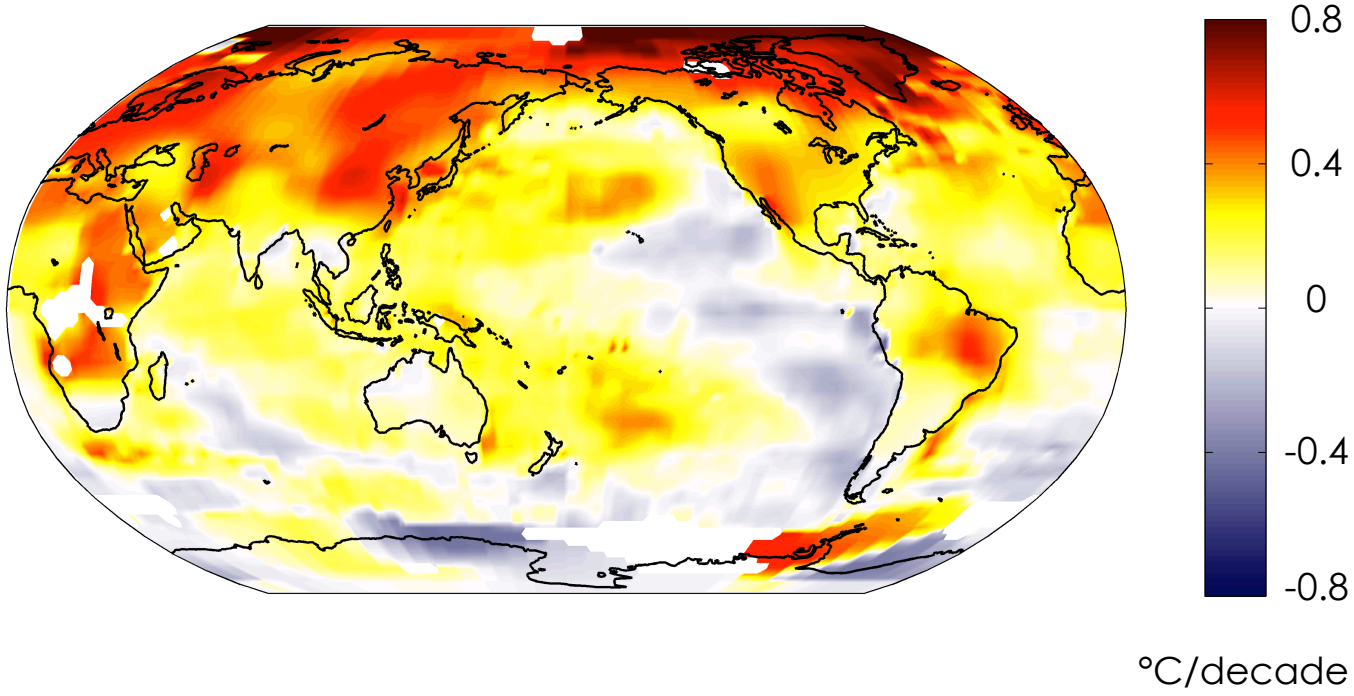
CESM PCWG Meeting
01.29.2014



Courtesy of NASA's Earth Observatory

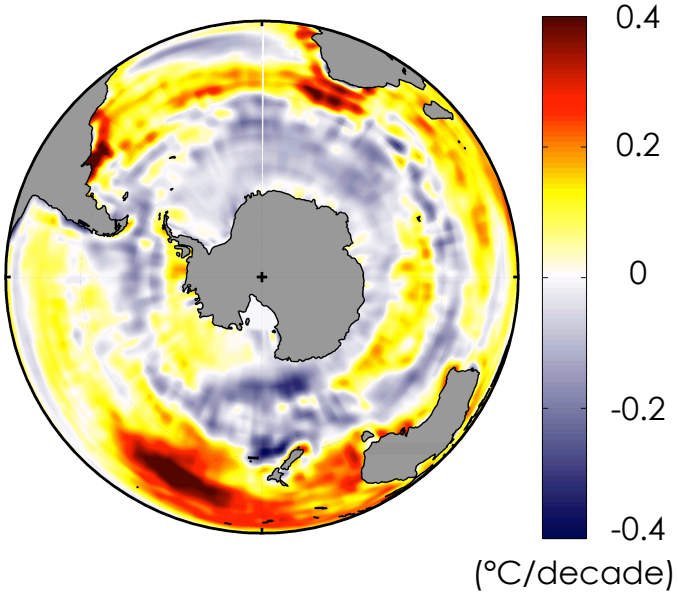
1979-2005 annual-mean surface temperature trends

- NASA GISS surface temperature analysis (GISTEMP)



Observed Southern Ocean trends

1984-2009 sea-surface temperature



NOAA Optimum Interpolation SST
Version 2 (Reynolds et al 2002)

- Cooling over much of the Southern Ocean, consistent with increasing sea-ice extent

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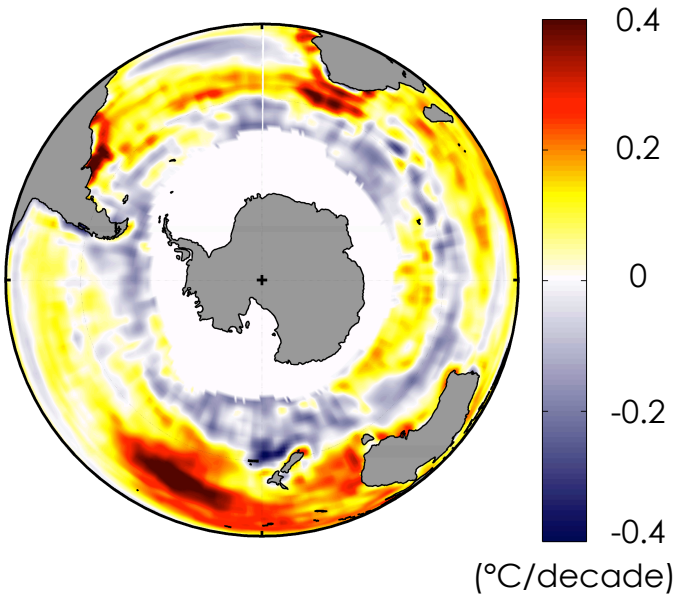

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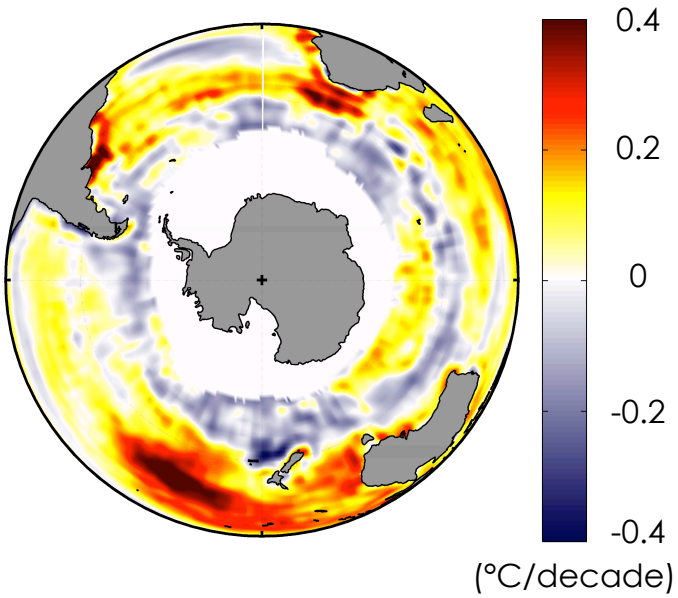

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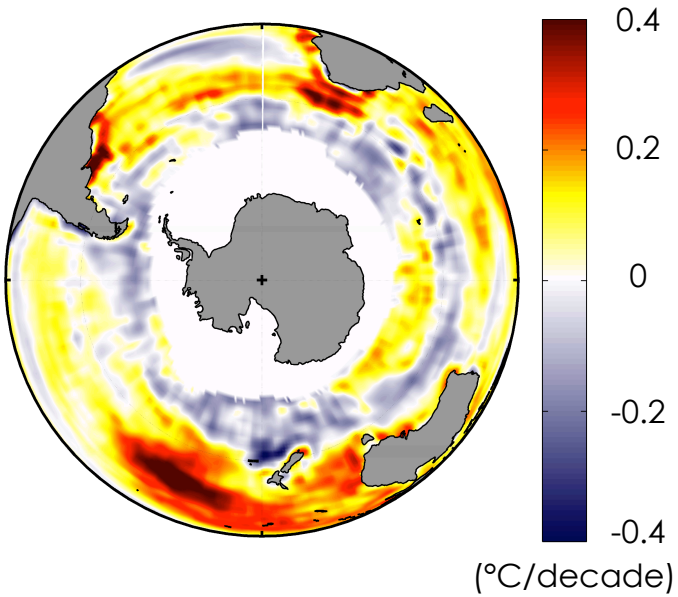

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Observed Southern Ocean trends

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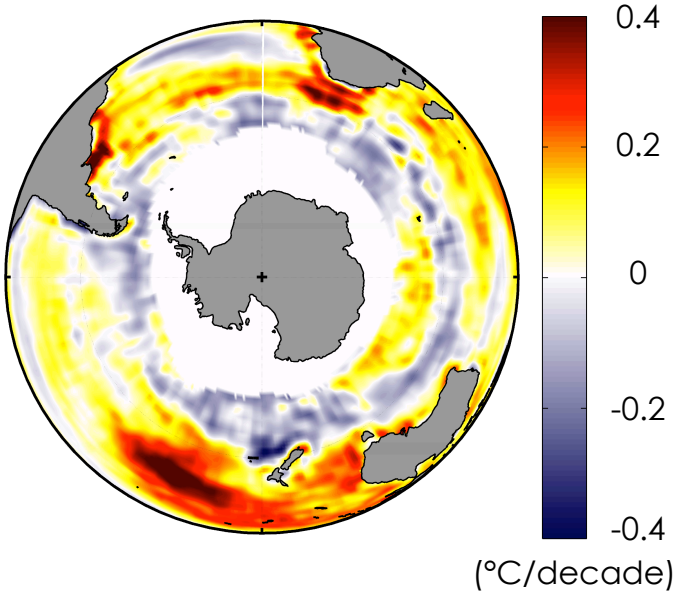

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2. *What sets the observed pattern of Southern Ocean SST changes?*

Observed Southern Ocean trends

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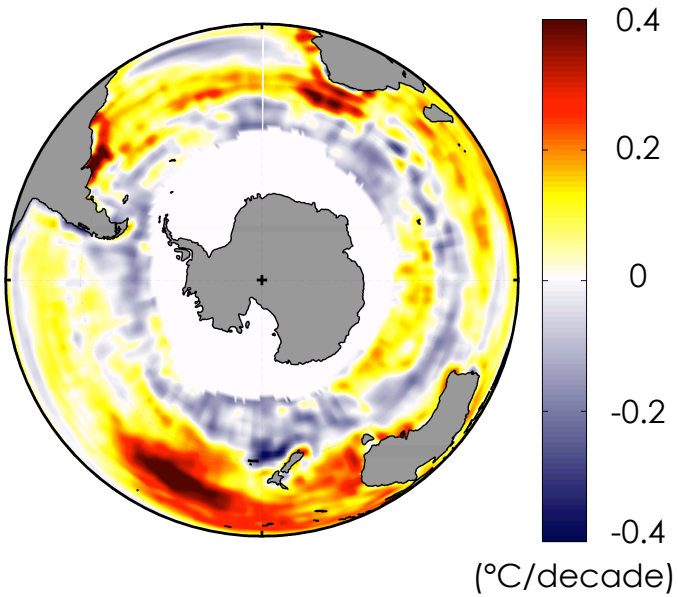

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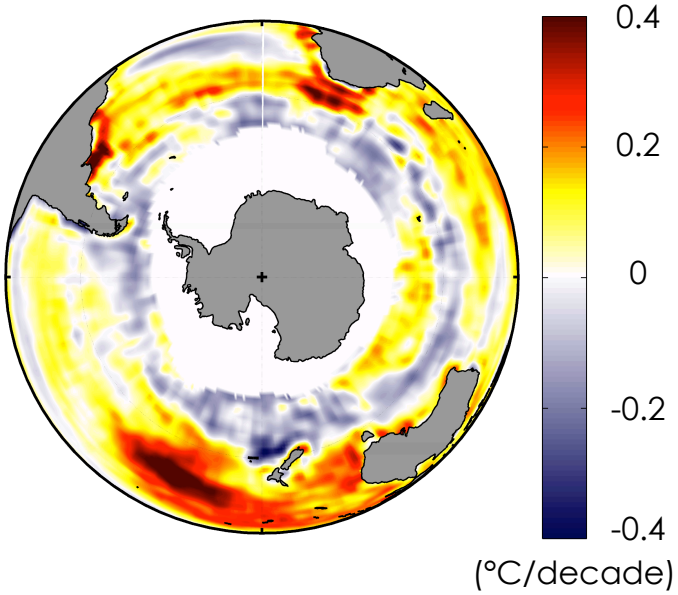
1. *Why hasn't the Southern Ocean warmed like the Arctic Ocean has?*
2. *What sets the observed pattern of Southern Ocean SST changes?*
3. *Why has the Southern Ocean been cooling in recent decades?*

Observed Southern Ocean trends

1984-2009 sea-surface temperature



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Drivers of Southern Ocean SST trends:

- surface heat flux
- deep ocean heat storage
- surface wind changes
- surface salinity changes

Observed Southern Ocean trends

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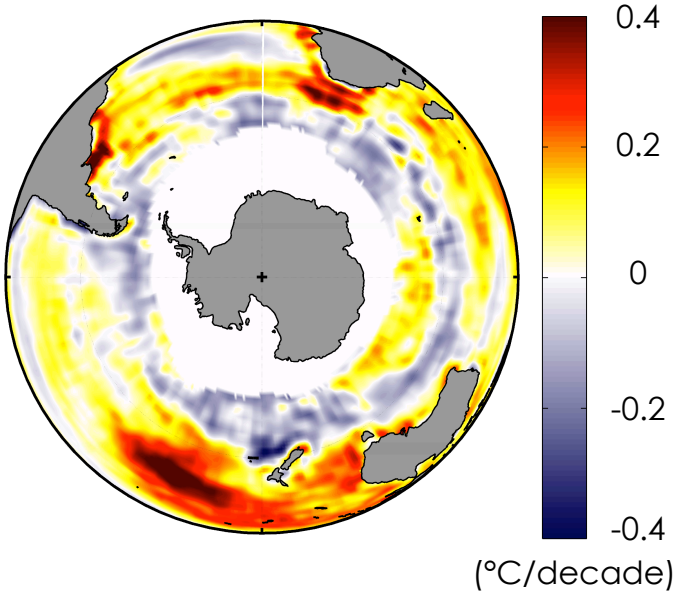

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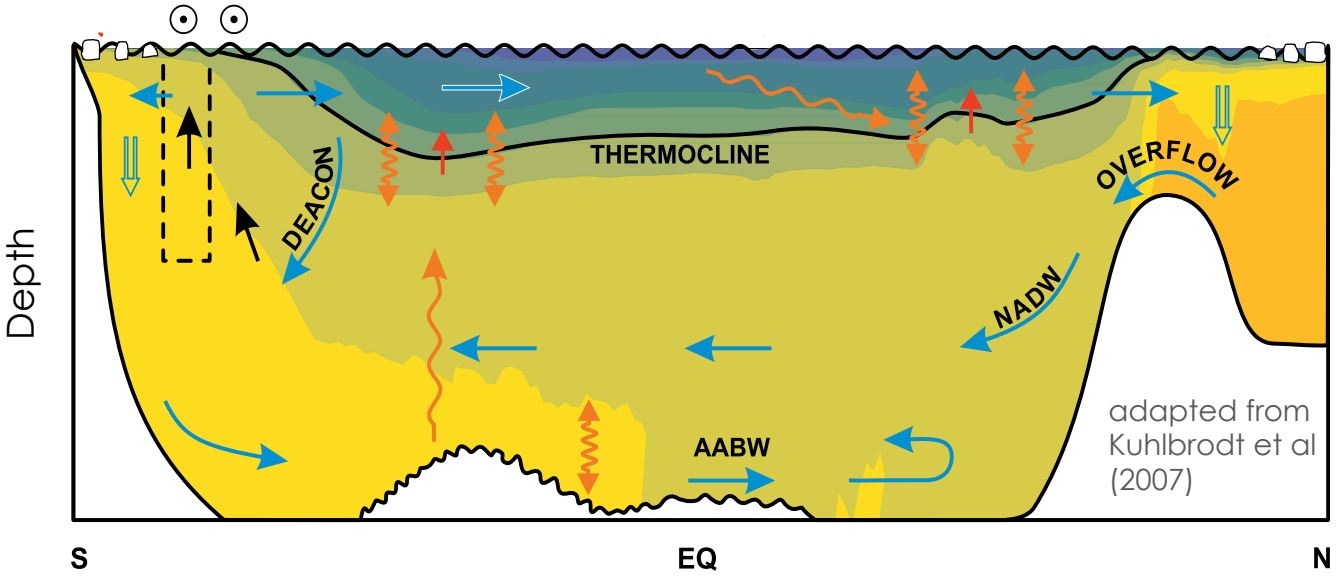
- **Southern Ocean circulation**

Role of ocean circulation in patterns of warming



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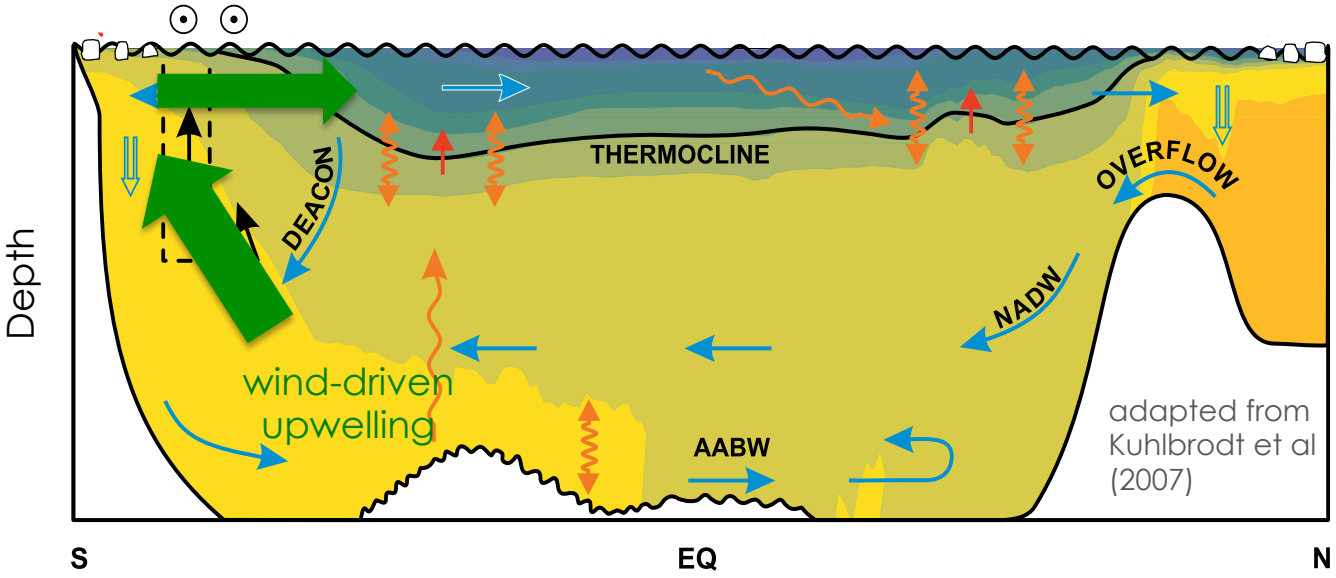
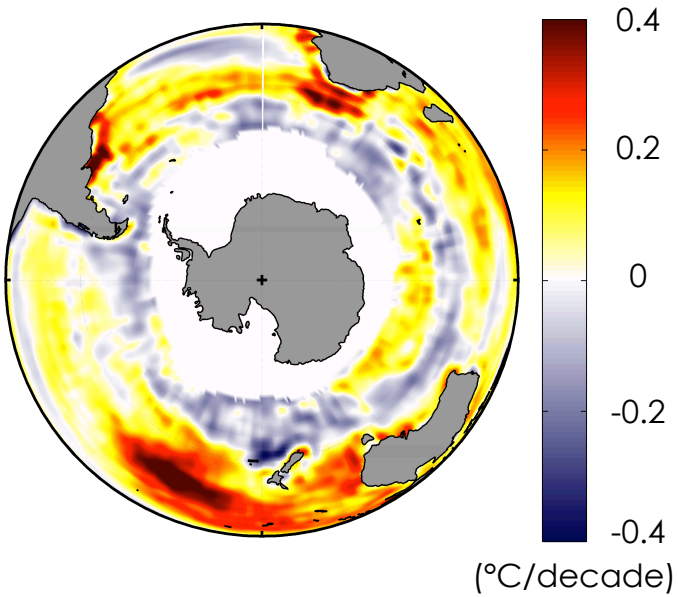


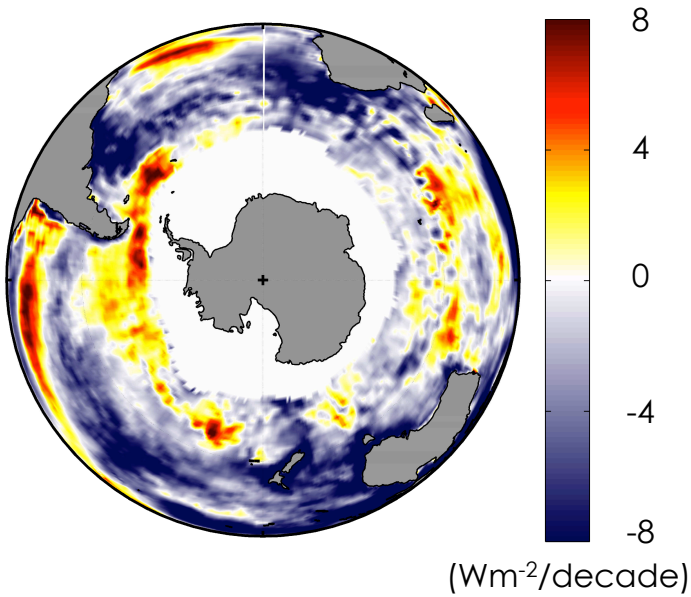
Ekman upwelling of unmodified water from depth around Antarctica acts as a 'thermostat', delaying anthropogenic warming poleward of the ACC

Observed Southern Ocean trends

1984-2009 sea-surface temperature



1984-2009 surface heat flux



AO Flux (Yu and Weller 2007)

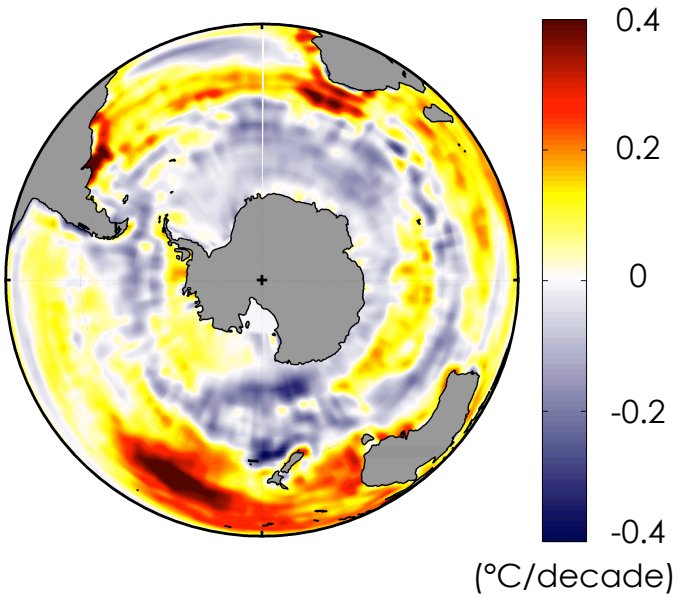
- Regions of decreasing SST are generally gaining heat at the surface
- Regions of increasing SST are generally losing heat at the surface

→

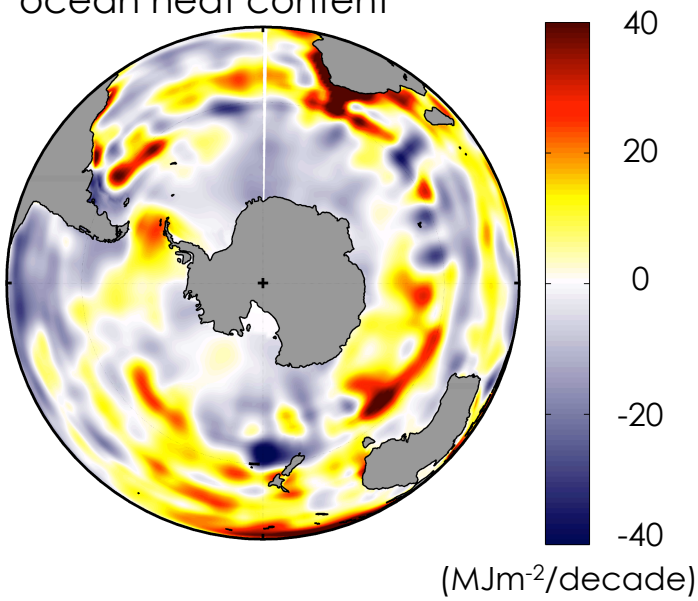
Patterns of air-sea heat fluxes are driven by the ocean

Observed Southern Ocean trends

1984-2009 sea-surface temperature



1984-2009 vertically integrated ocean heat content



Hadley Centre EN3

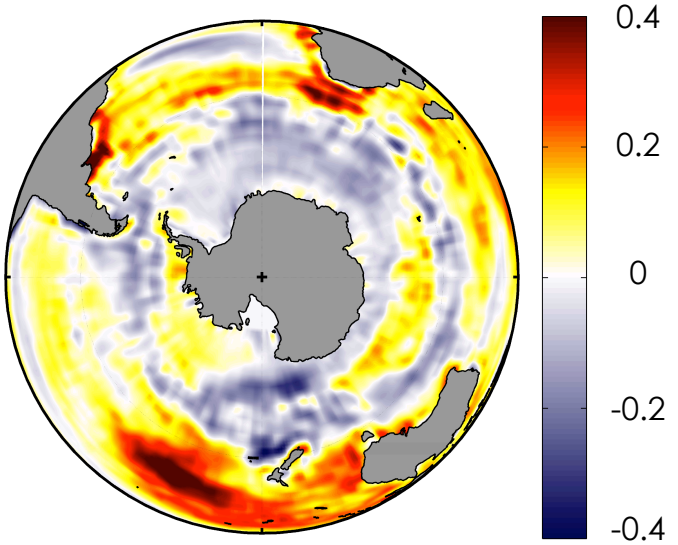
- Regions of decreasing SST show generally decreasing heat content
- Regions of increasing SST show generally increasing heat content

→

SST patterns are not simply driven by local deep ocean heat storage

Observed Southern Ocean trends

1984-2009 sea-surface temperature



1971-2010 zonal-mean ocean temperature

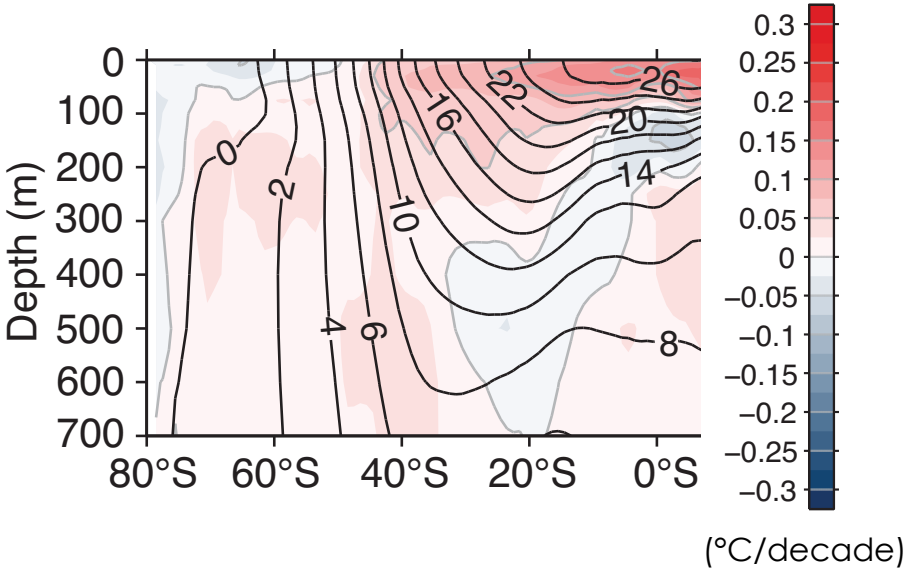


Figure modified from IPCC AR5 based on Levitus et al (2009)

- Regions of decreasing SST show generally decreasing heat content

- Regions of increasing SST show generally increasing heat content

→

SST patterns are not simply driven by local deep ocean heat storage

Modeling evidence for a Southern Ocean thermostat

Two sets of idealized climate perturbation experiments:

- Ensemble of 16 models from the Coupled Model Intercomparison Project phase 5 (CMIP5)
  - response to an abrupt CO_2 quadrupling from pre-industrial ($4xCO_2$)
  - average over a wide range of atmospheric and oceanic physics, and reduce influence of internal variability

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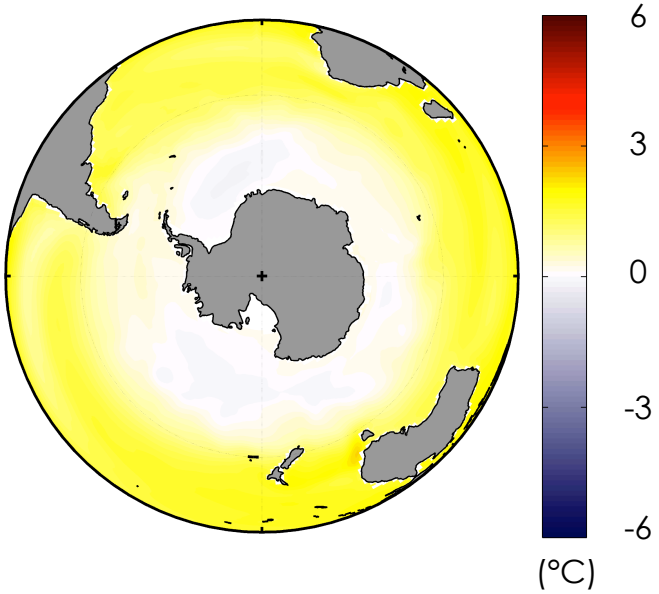
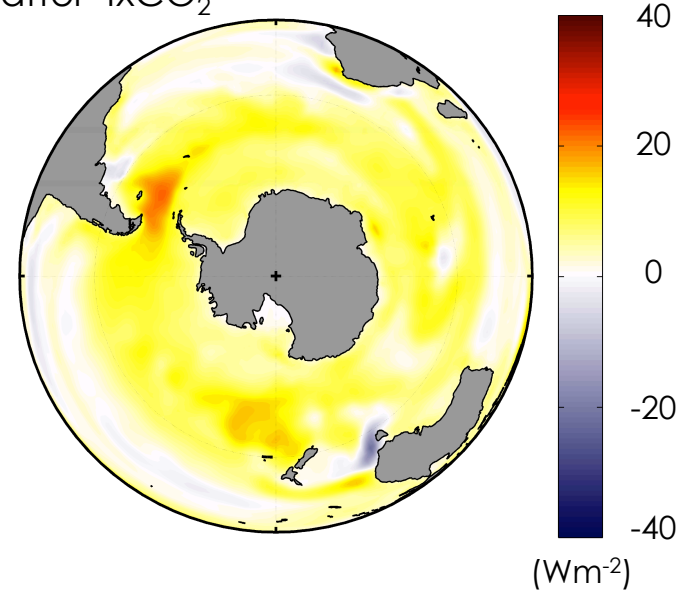
- Ocean-only configuration of the MITgcm (Ocean-only)
  - controlled surface flux conditions
  - isolate the role of the ocean in the transient climate response to forcing

CMIP5: Sea-surface temperature and heat flux

SST anomaly a decade after $4xCO_2$

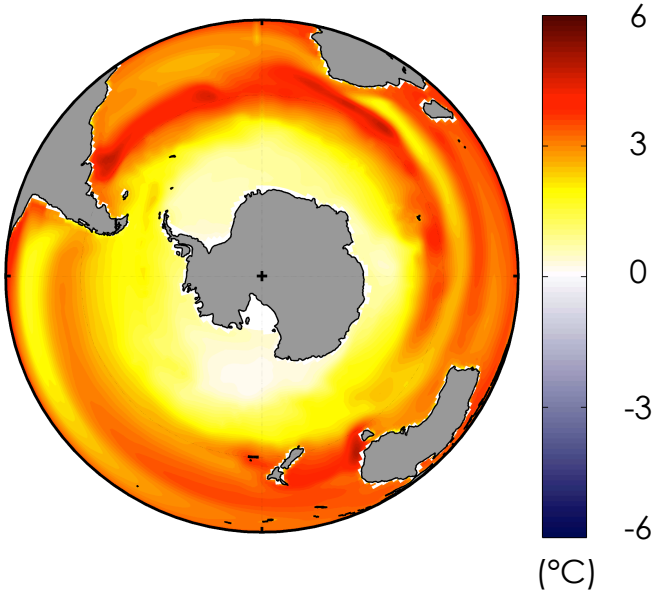


Surface heat flux anomaly a decade after $4xCO_2$



CMIP5: Sea-surface temperature and heat flux

SST anomaly a century after 4xCO_2



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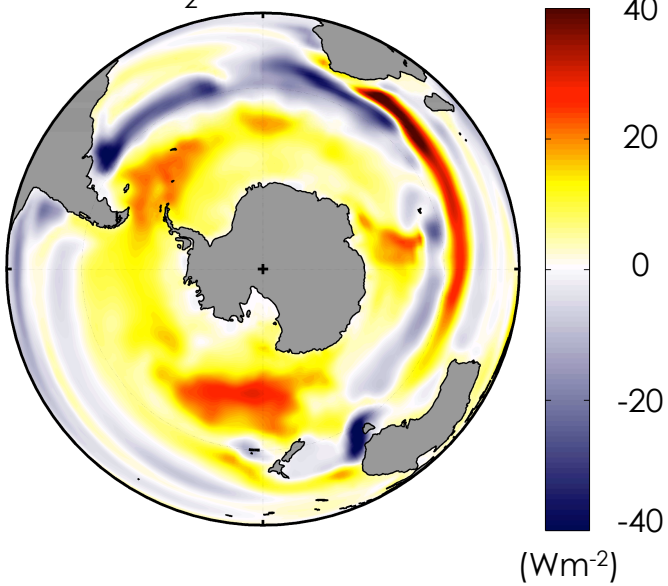

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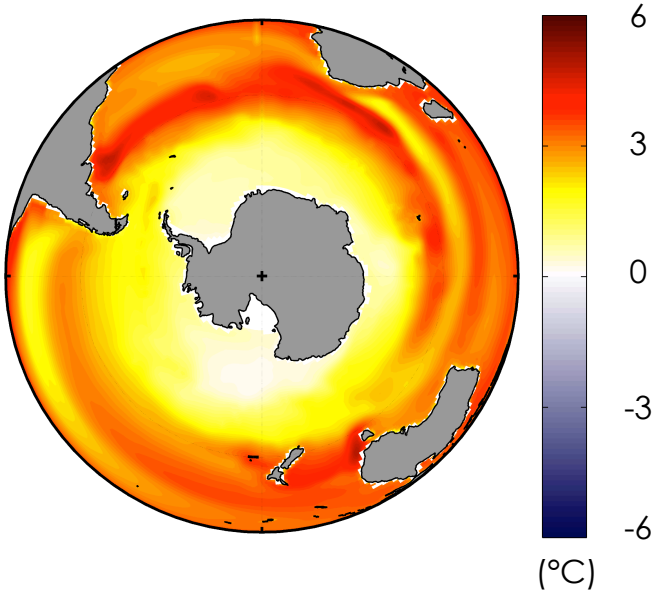
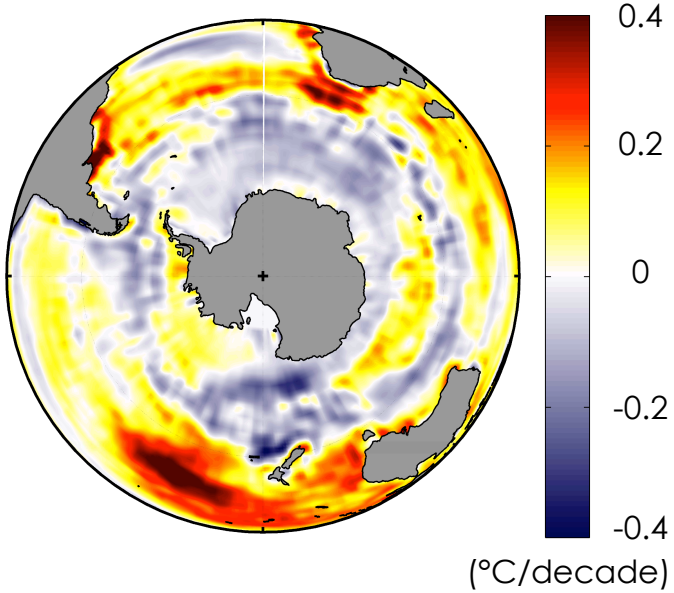
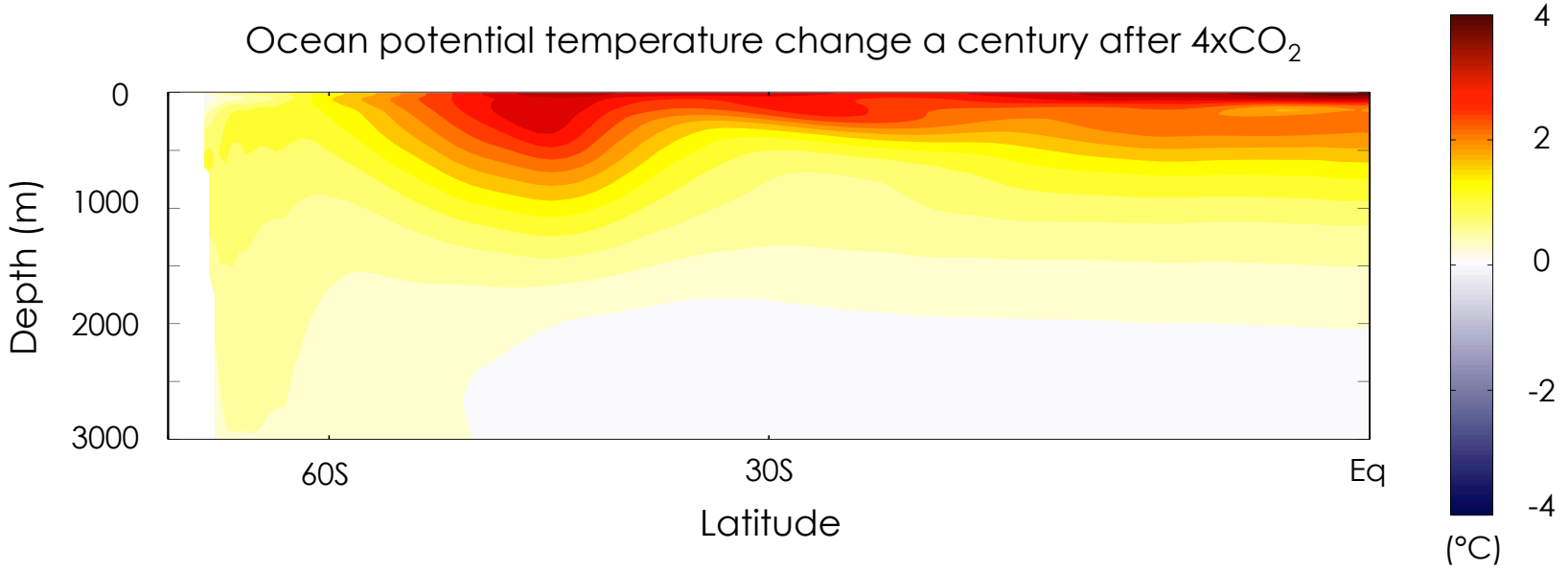
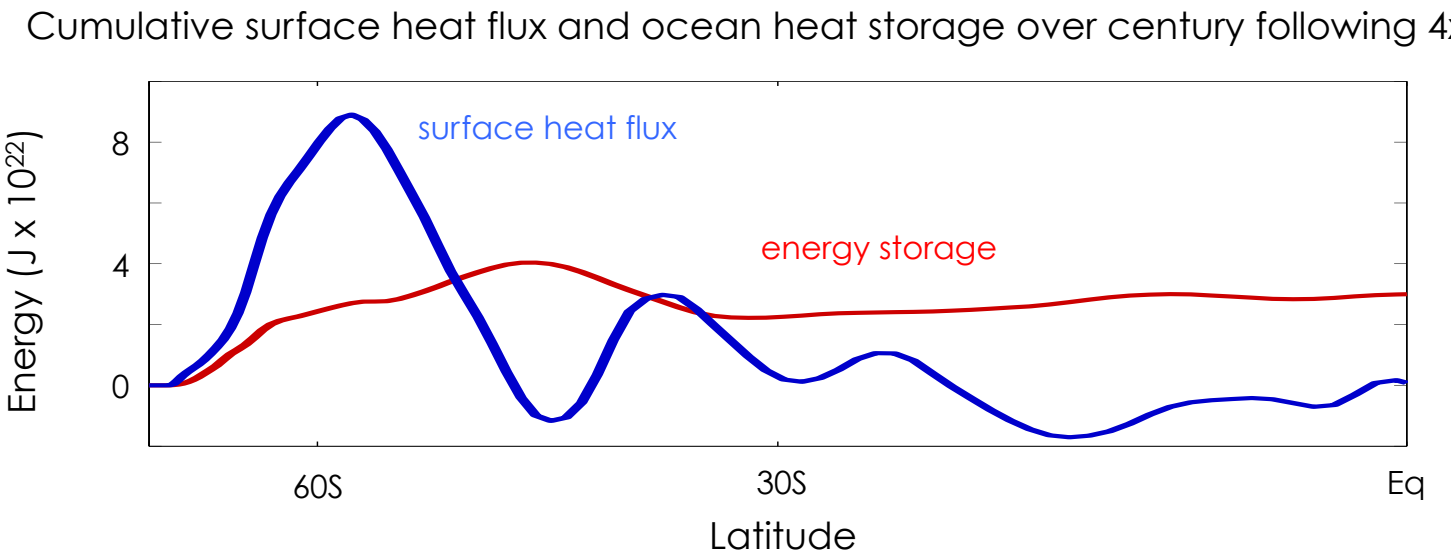


Observed 1984-2009 SST trend



CMIP5: surface heat uptake and ocean heat storage





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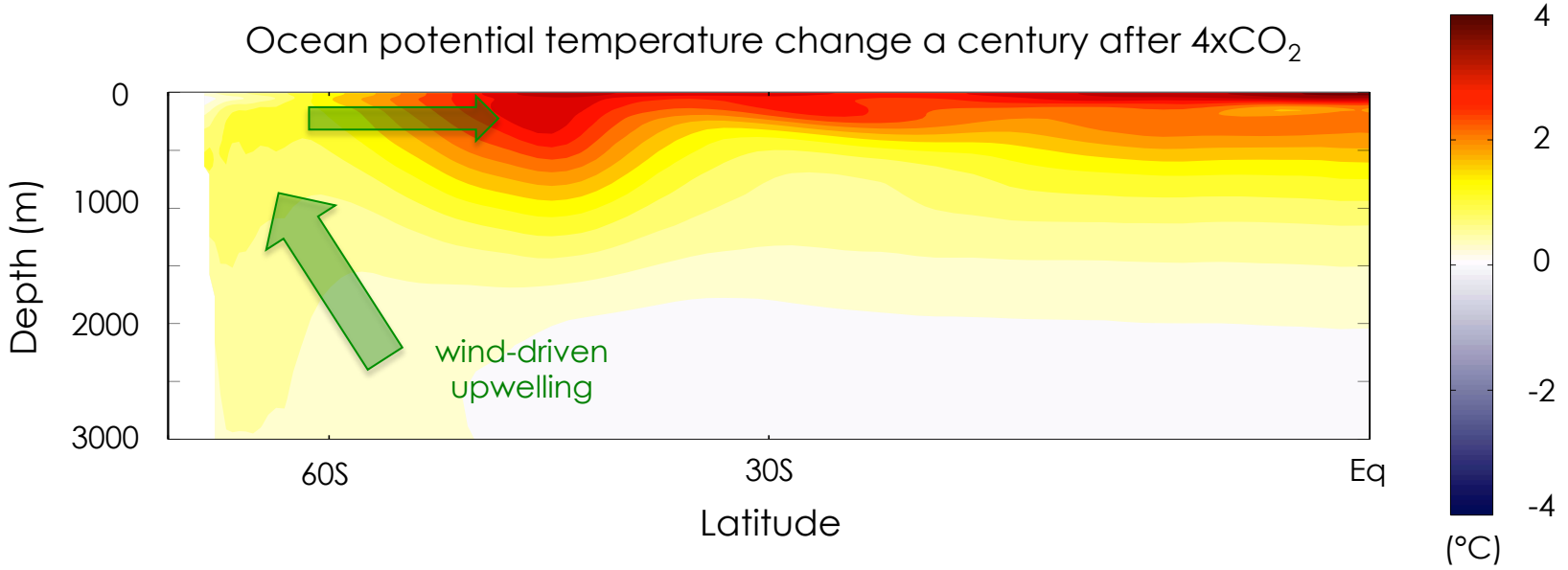
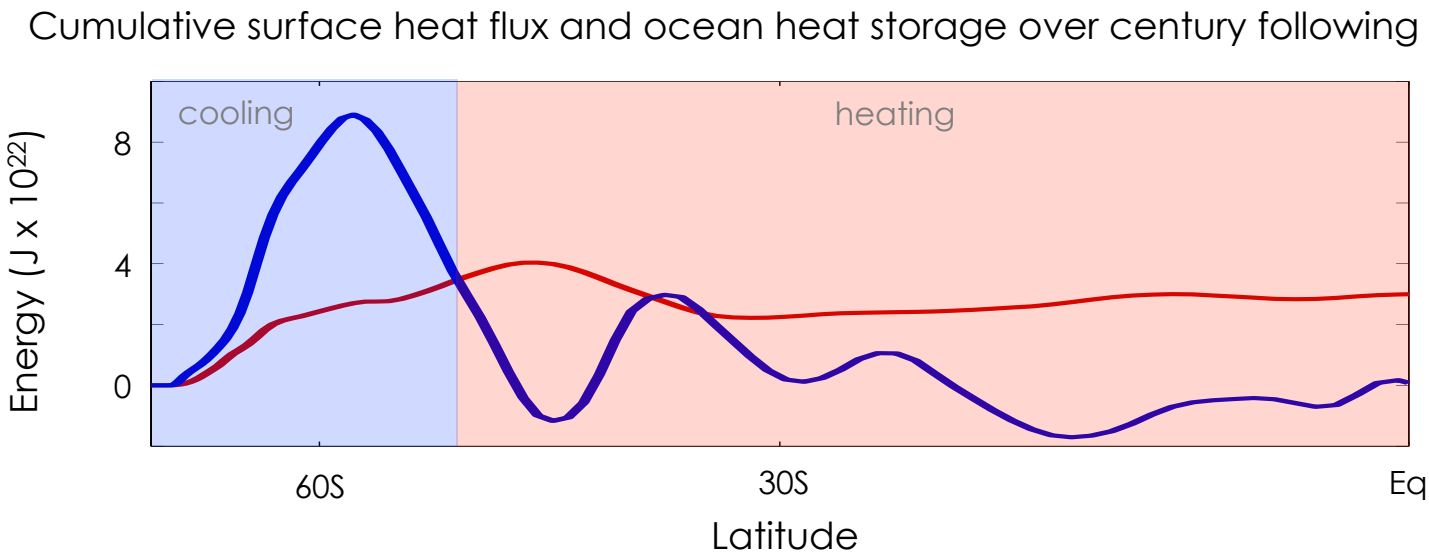




Ocean-only MITgcm simulation

- Ocean-only simulation with the MITgcm
  - global ocean with realistic land geometry
  - no atmosphere

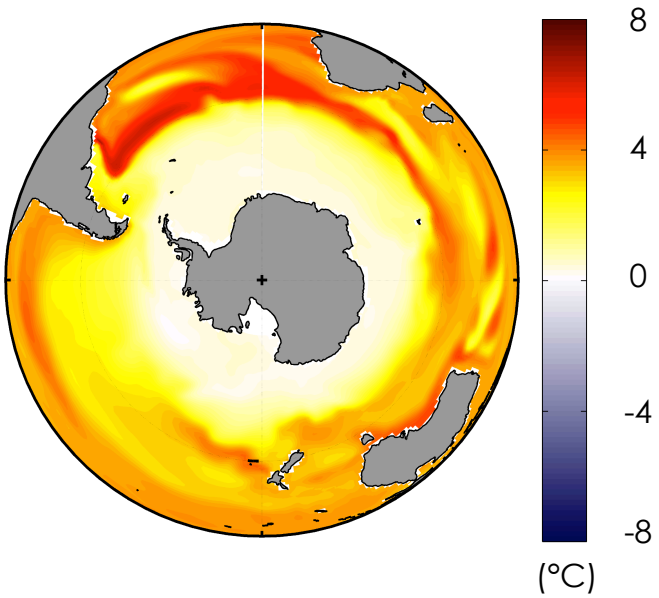
- Model run to equilibrium with air-sea fluxes prescribed through bulk formulae -- CORE protocol of Griffies et al (2009), with an annually repeating cycle

- Climate change experiment:
  - Abrupt, uniform surface forcing of R = 4 Wm^{-2} everywhere
  - Uniform radiative feedback of λ = -1 $Wm^{-2}K^{-1}$ everywhere
  - No other surface flux changes (wind, fresh water, etc)

→ *Any spatial structure in warming must arise from ocean circulation*

Ocean-only MITgcm: Sea-surface temperature

SST anomaly a century after 4 Wm^{-2} forcing



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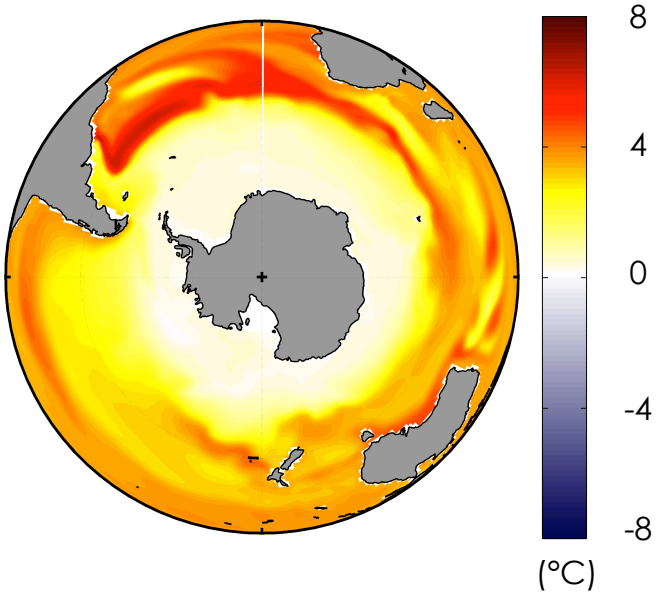

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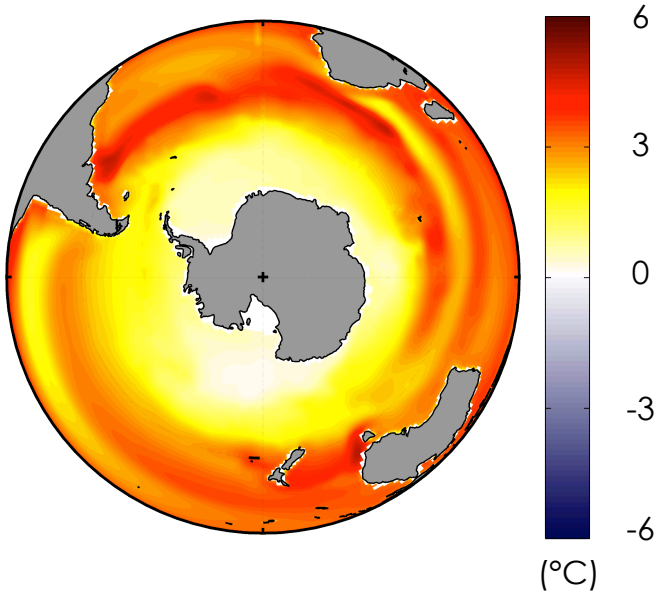
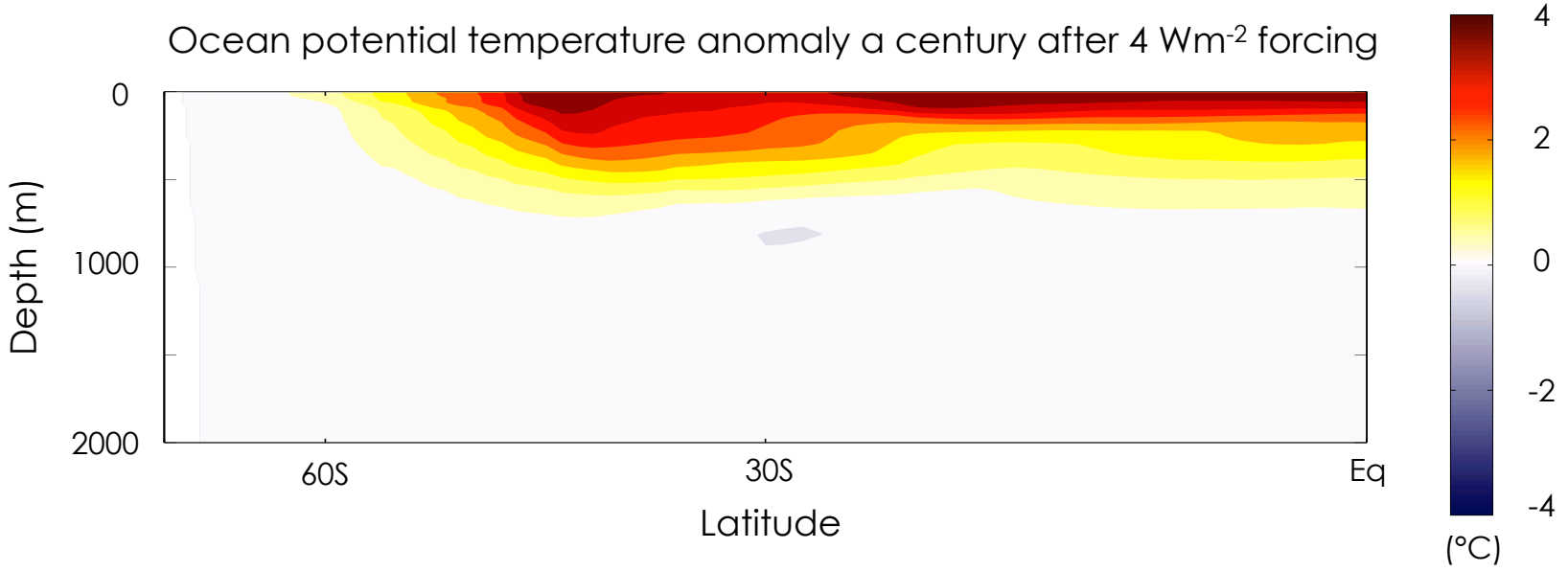
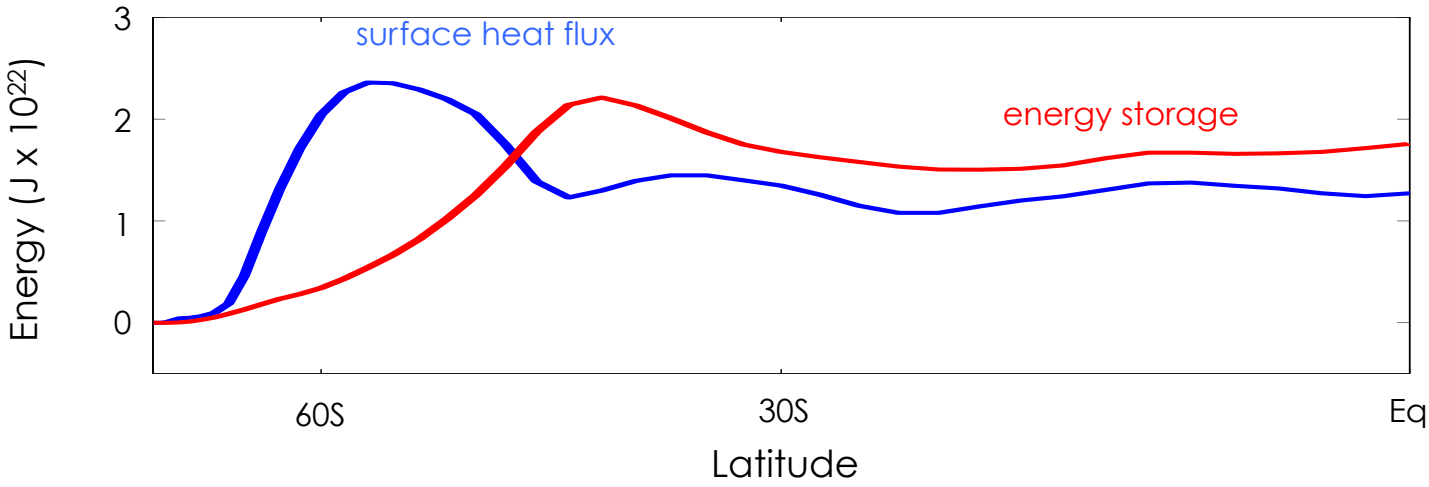


Ocean-only MITgcm: surface heat uptake and ocean heat storage



Cumulative surface heat flux and ocean heat storage over century following 4 Wm^{-2} forcing



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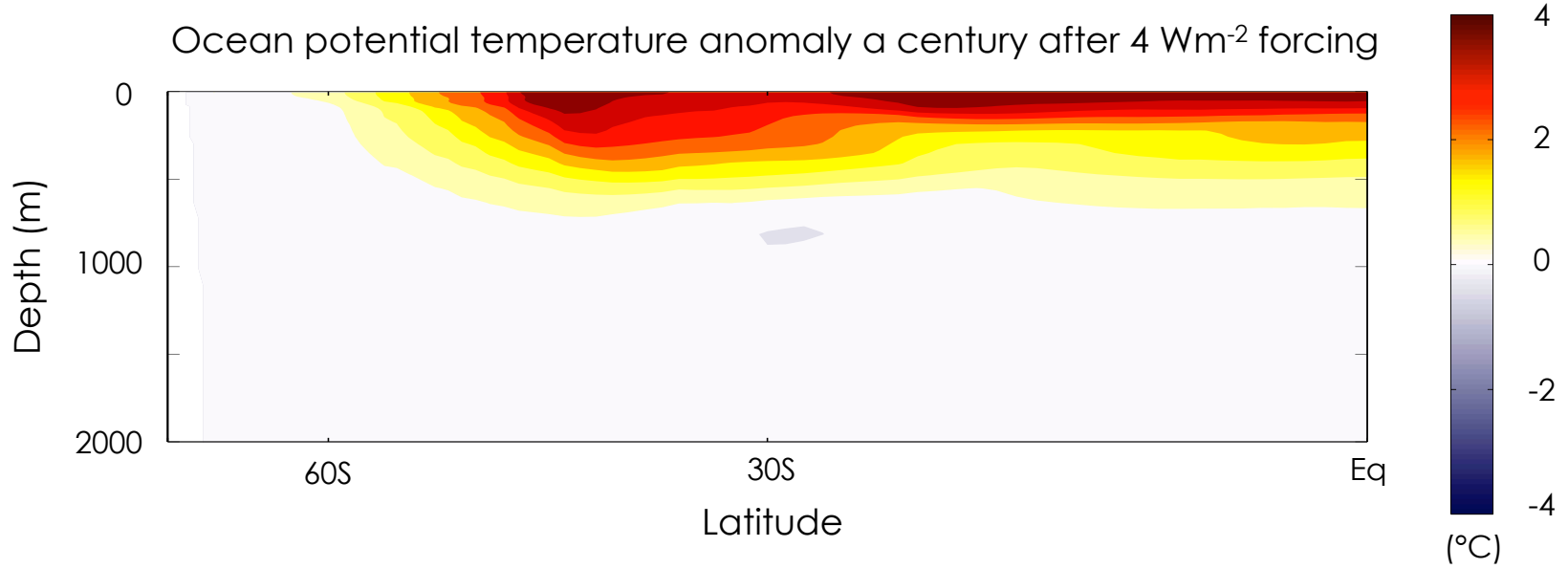

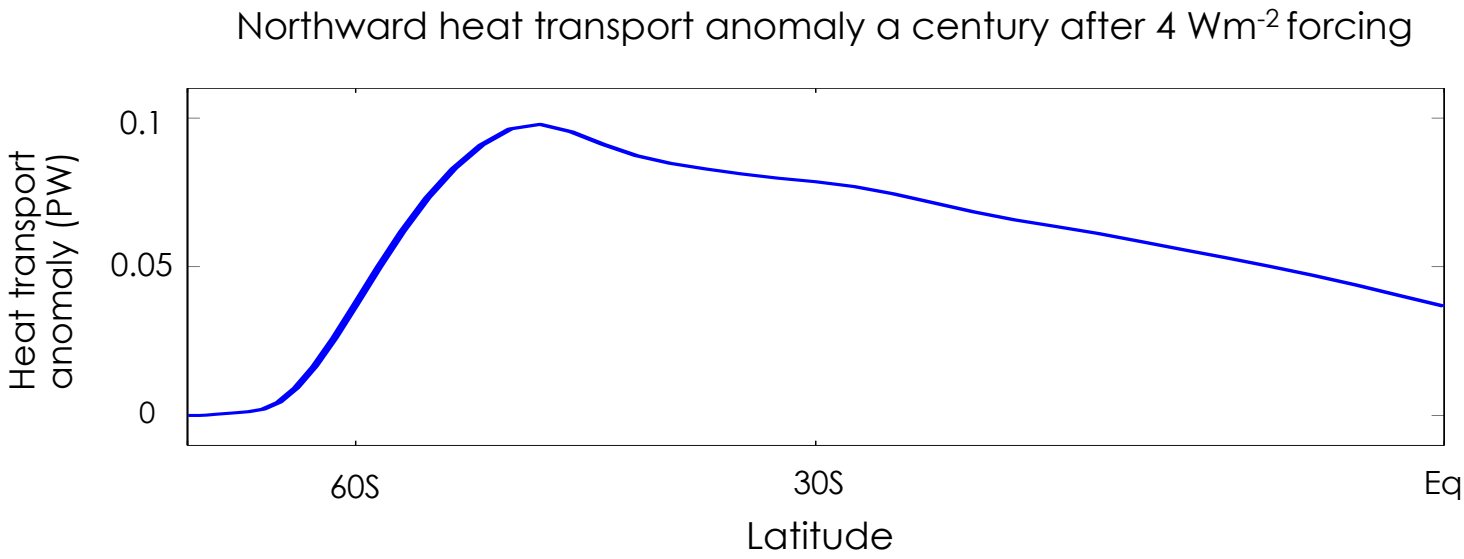

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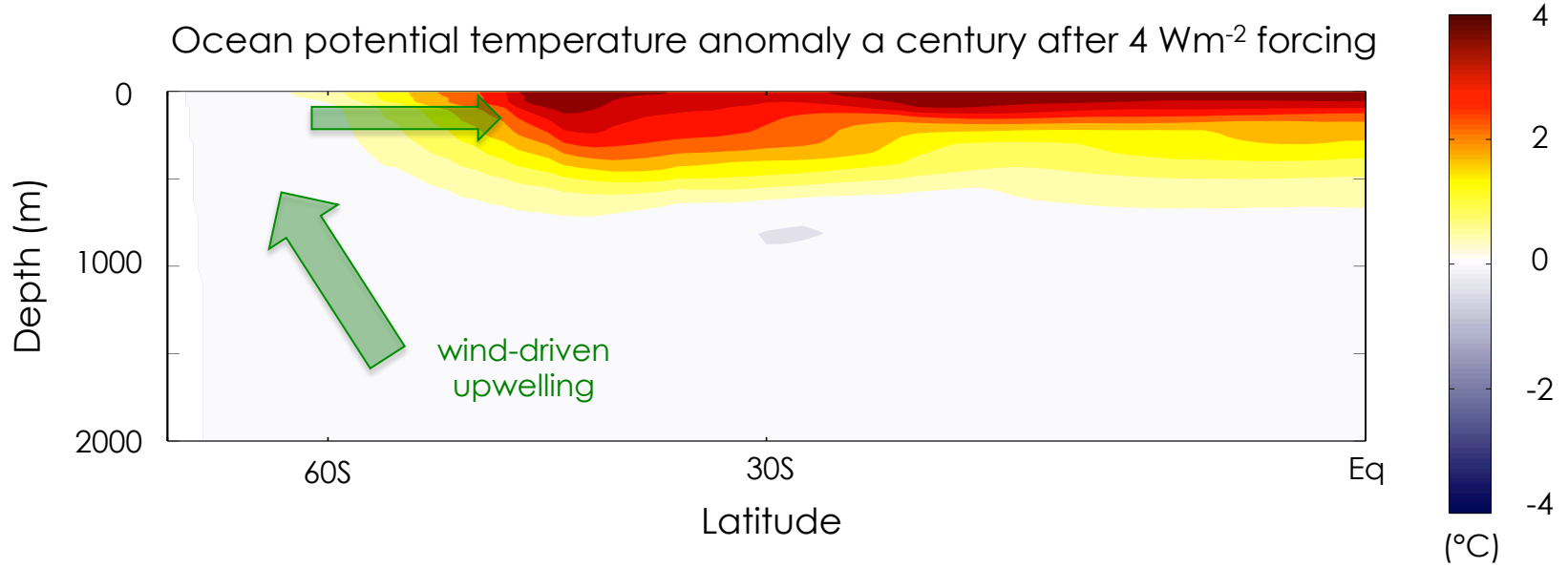
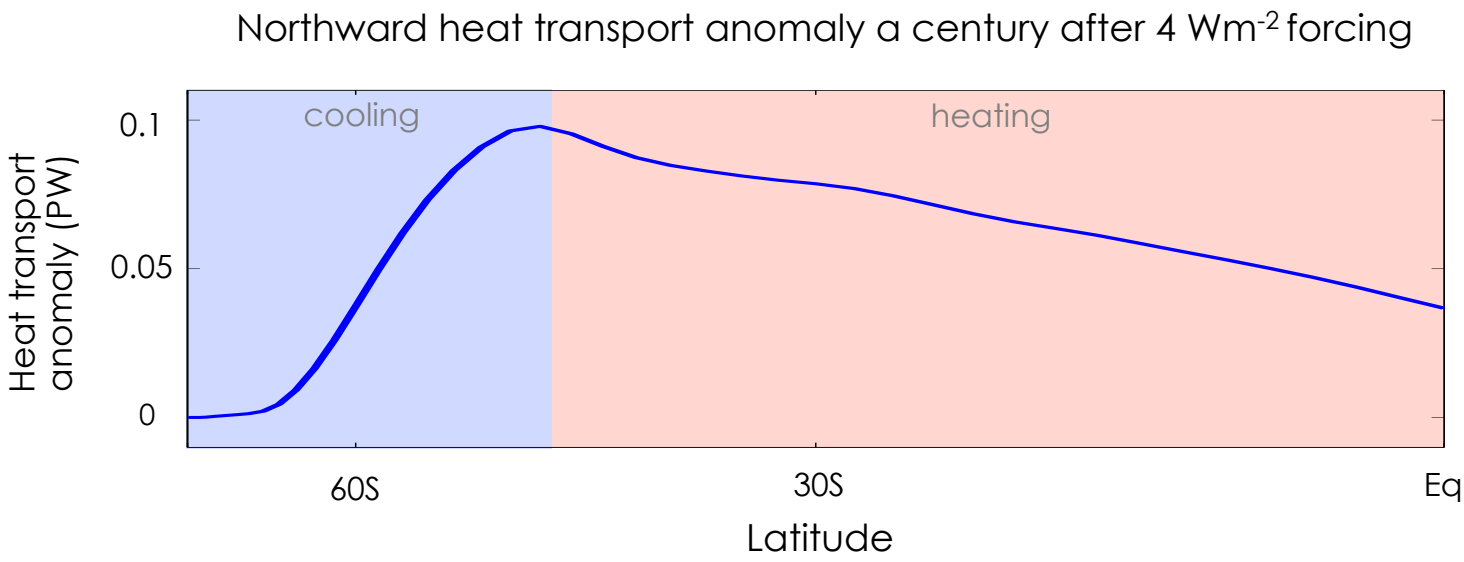
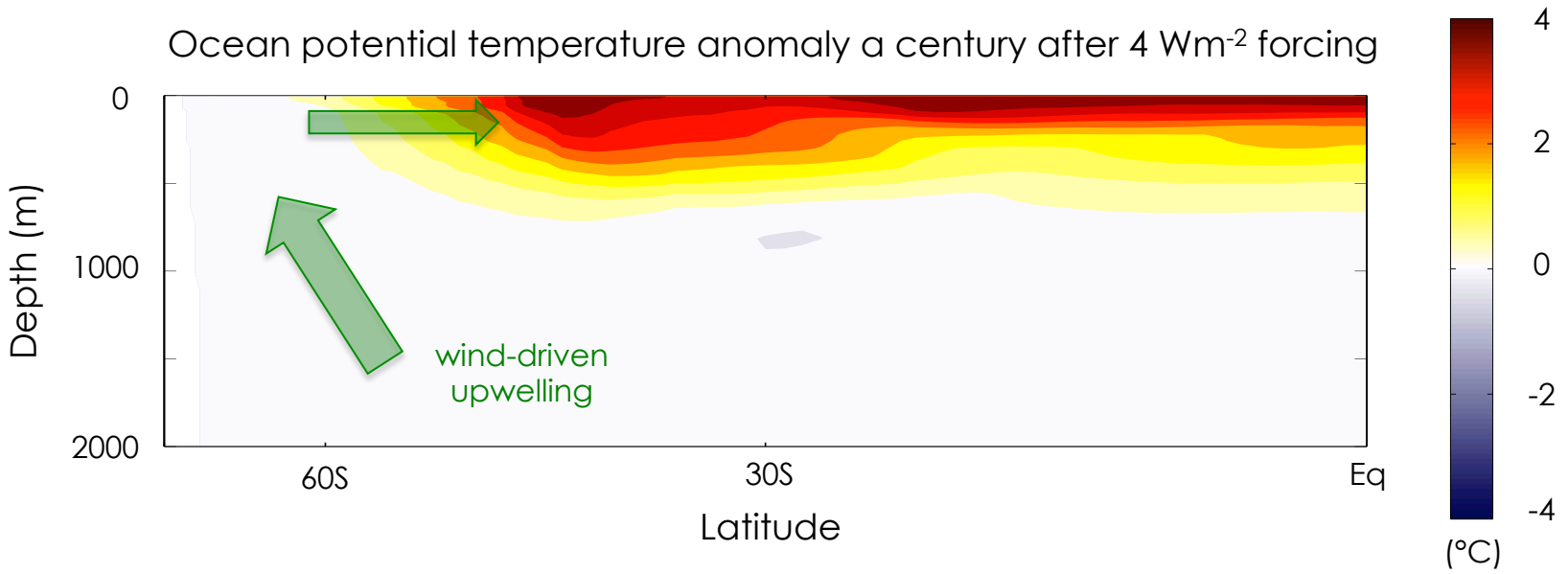




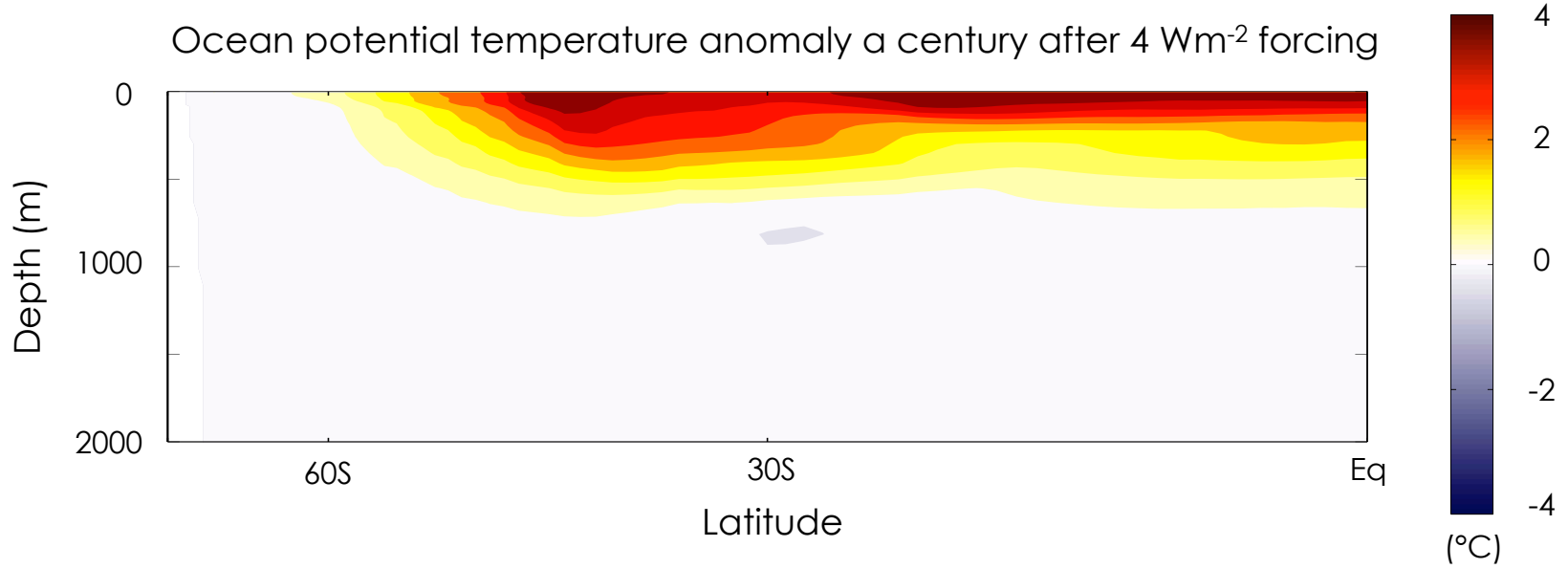
Ocean-only MITgcm: passive vs active role of ocean heat uptake

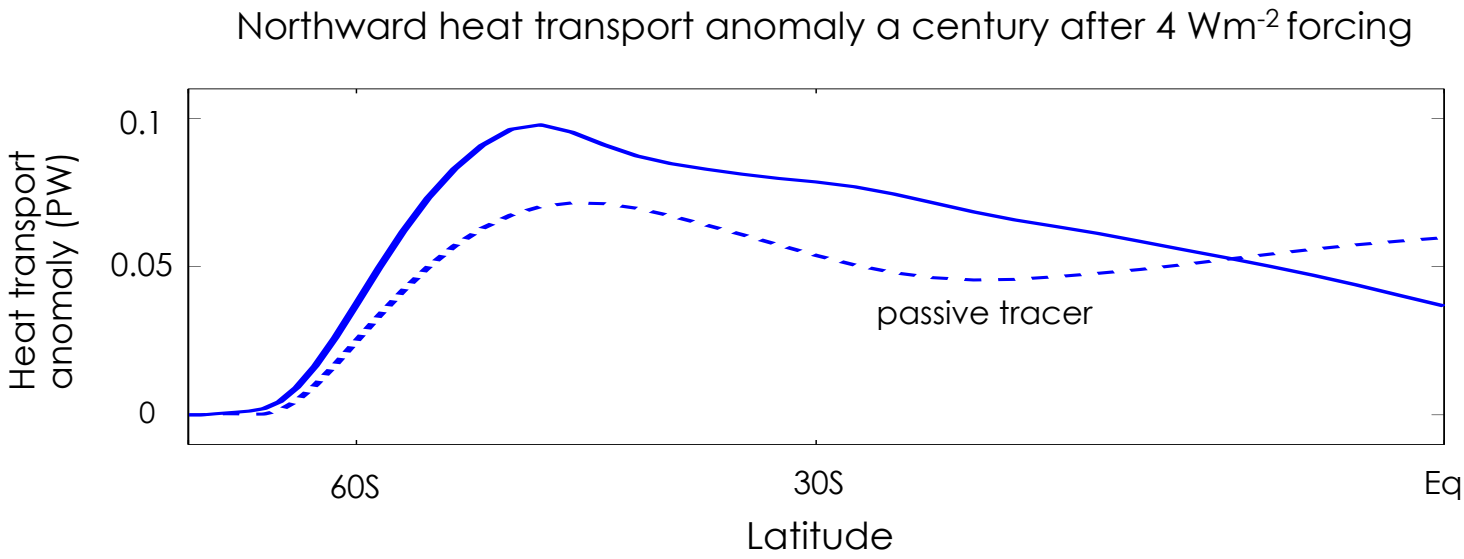


What portion of this response is due to changes in ocean circulation?

- Introduce a temperature-like passive tracer:
  - units of temperature
  - forced and damped at the surface like temperature
  - does not influence ocean circulation

Ocean-only MITgcm: passive vs active role of ocean heat uptake





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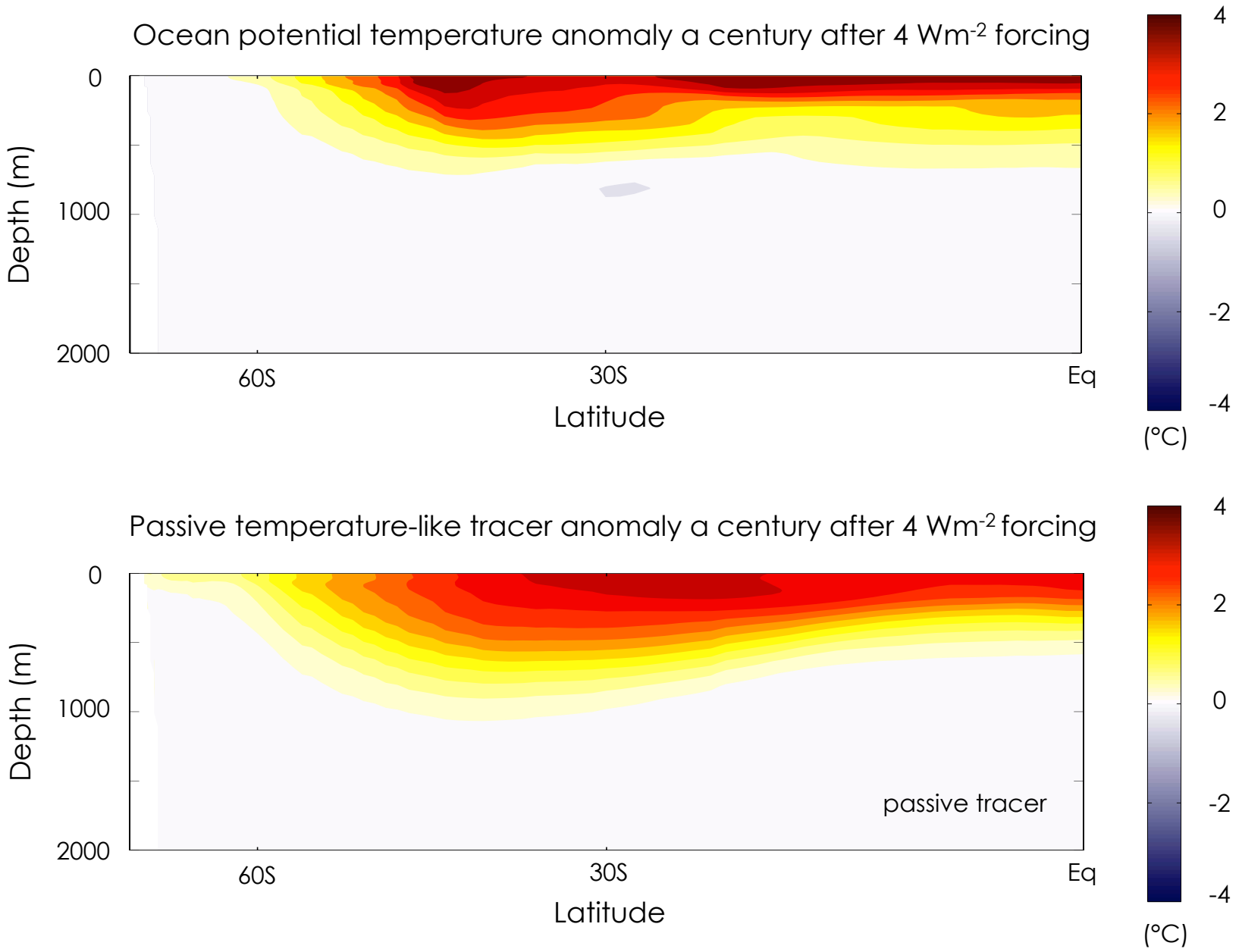
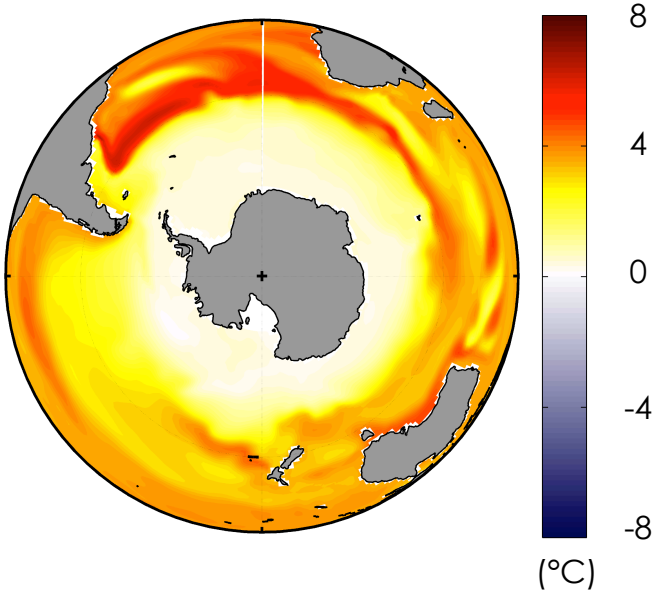
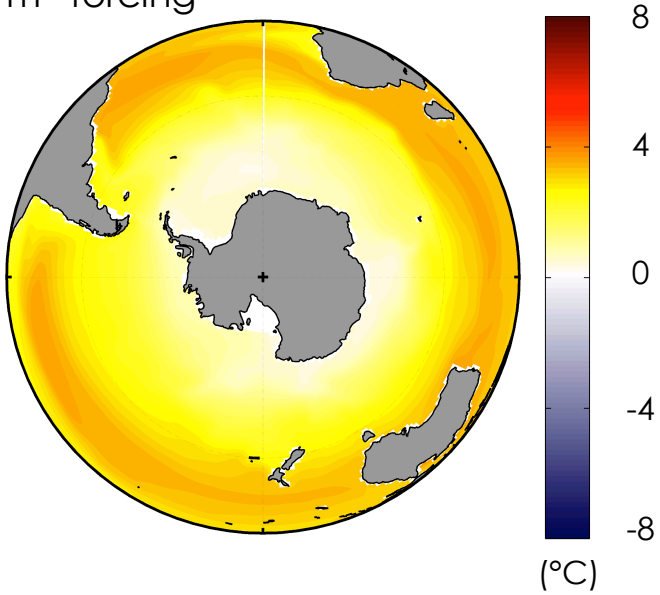


Ocean-only MITgcm: passive vs active role of ocean heat uptake

SST anomaly a century after 4 Wm^{-2} forcing



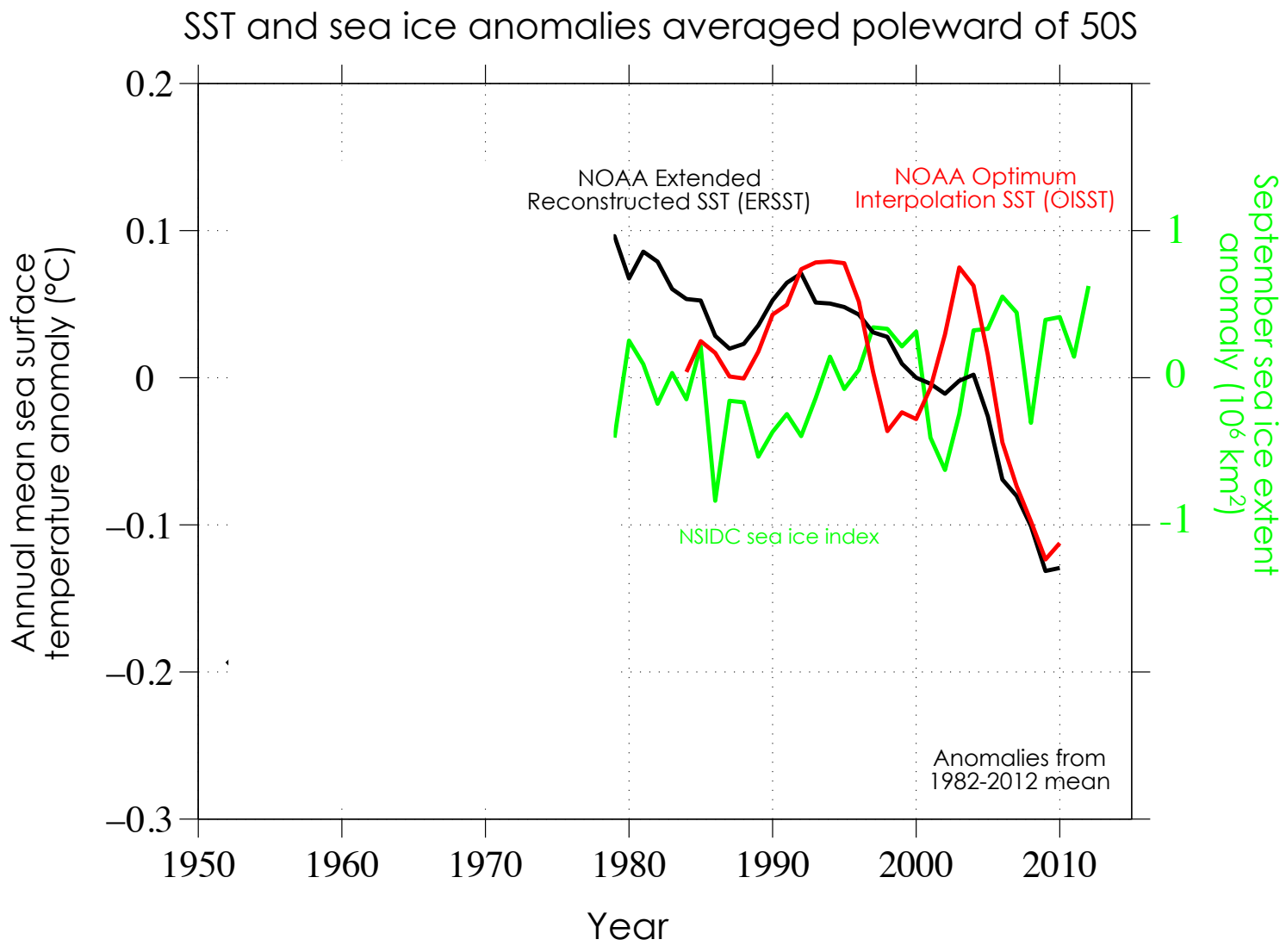
Passive tracer anomaly a century after 4 Wm^{-2} forcing



- Overall warming pattern is mainly due to passive advection of the temperature signal by climatological currents

- Detailed structure (banding) is due to changing circulation in response to heat uptake

Observed sea-surface temperature and sea-ice extent



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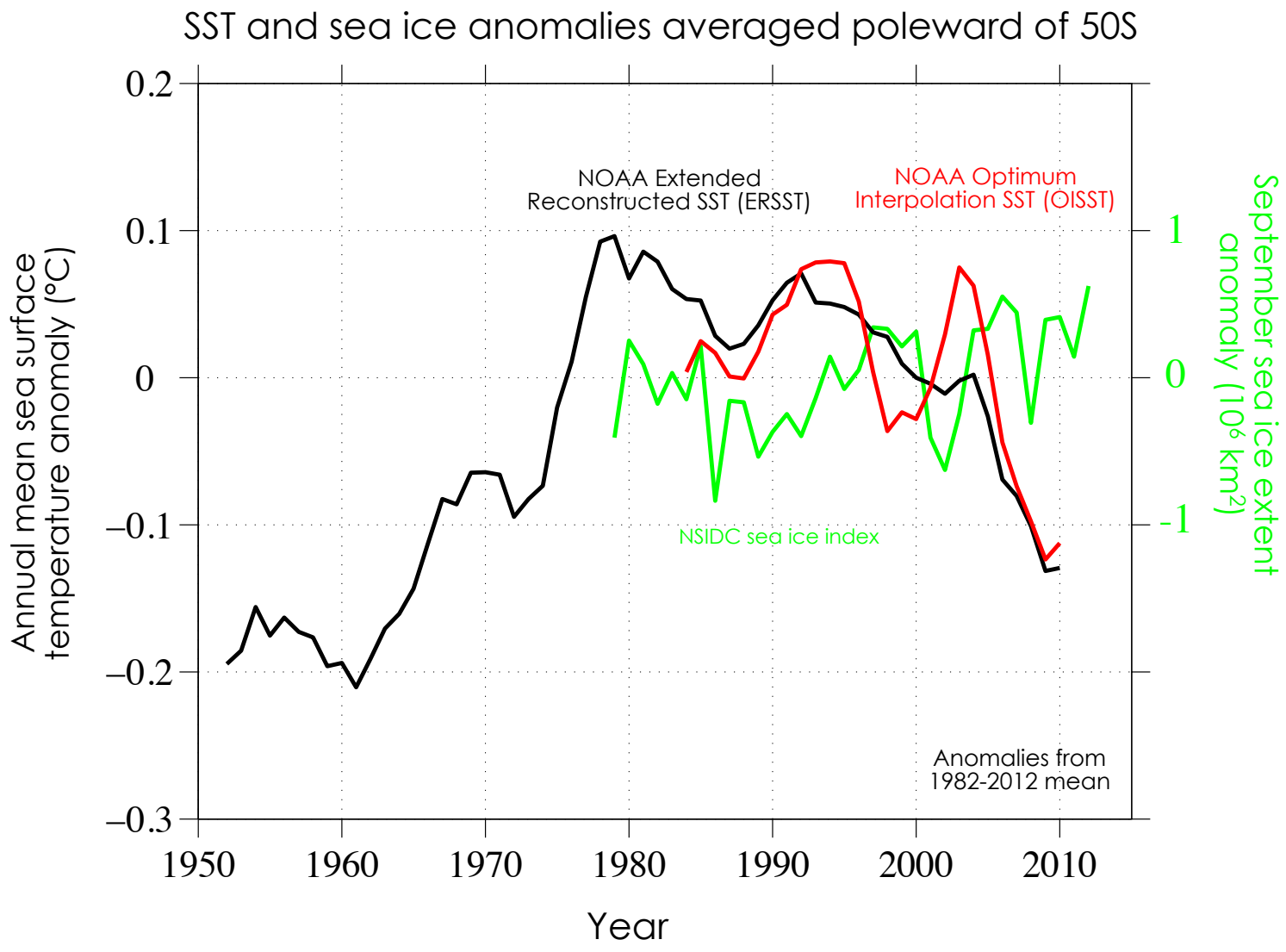

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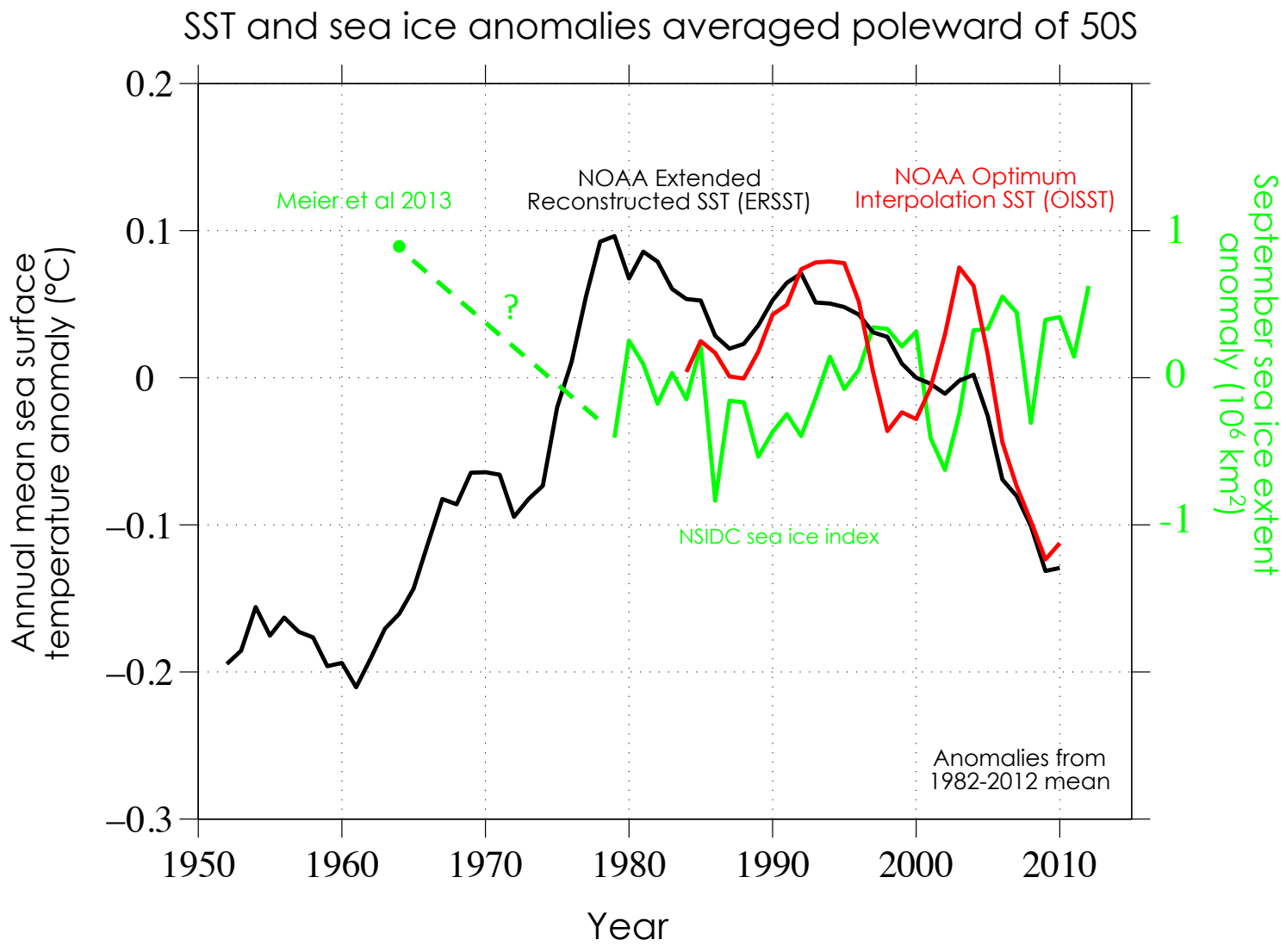
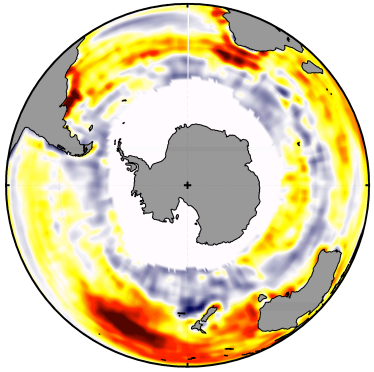
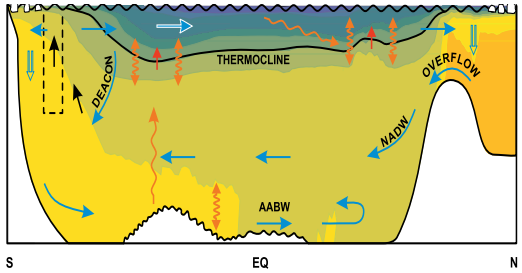


Southern Ocean summary

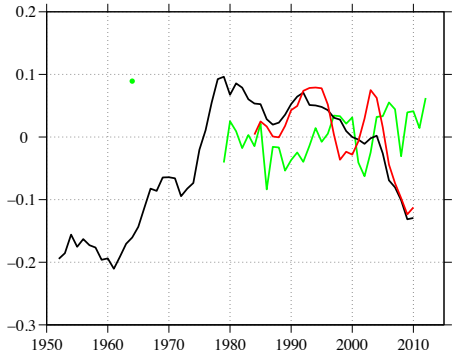
- Observed cooling around Antarctica extends beyond the sea-ice edge, out to the ACC where intense warming has occurred



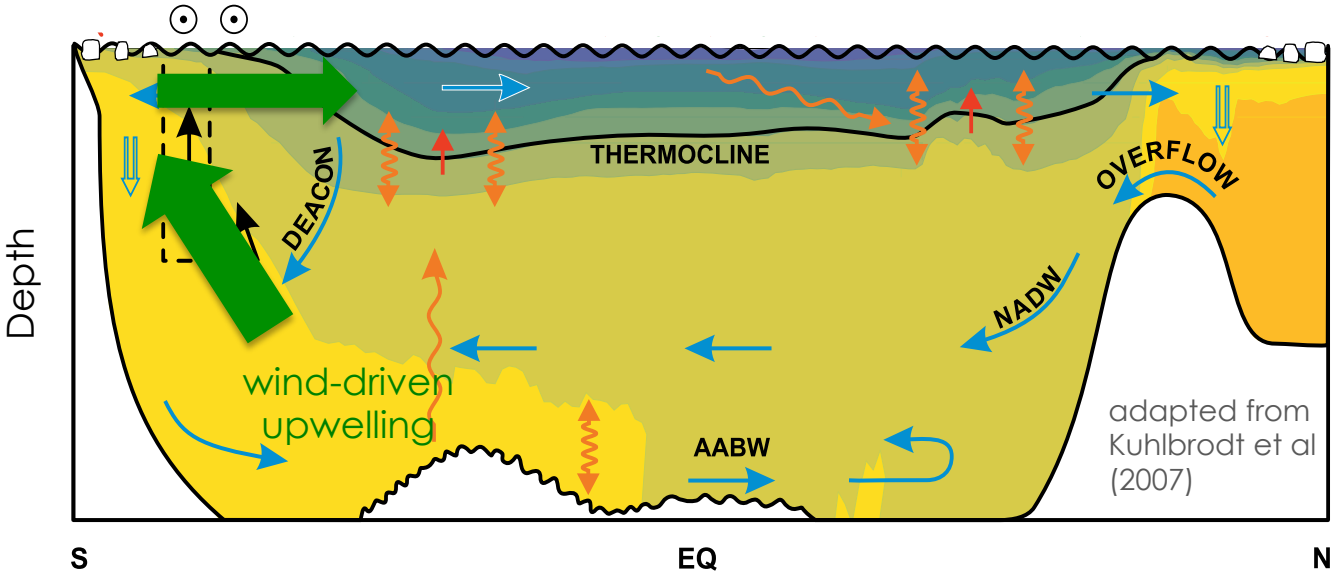
- Ekman upwelling of unmodified water from depth delays surface warming
  - overall patterns are consistent with passive advection of the warming signal by climatological currents
  - detailed structure is due to changes in circulation
  - suggests millennial adjustment timescale for the SO



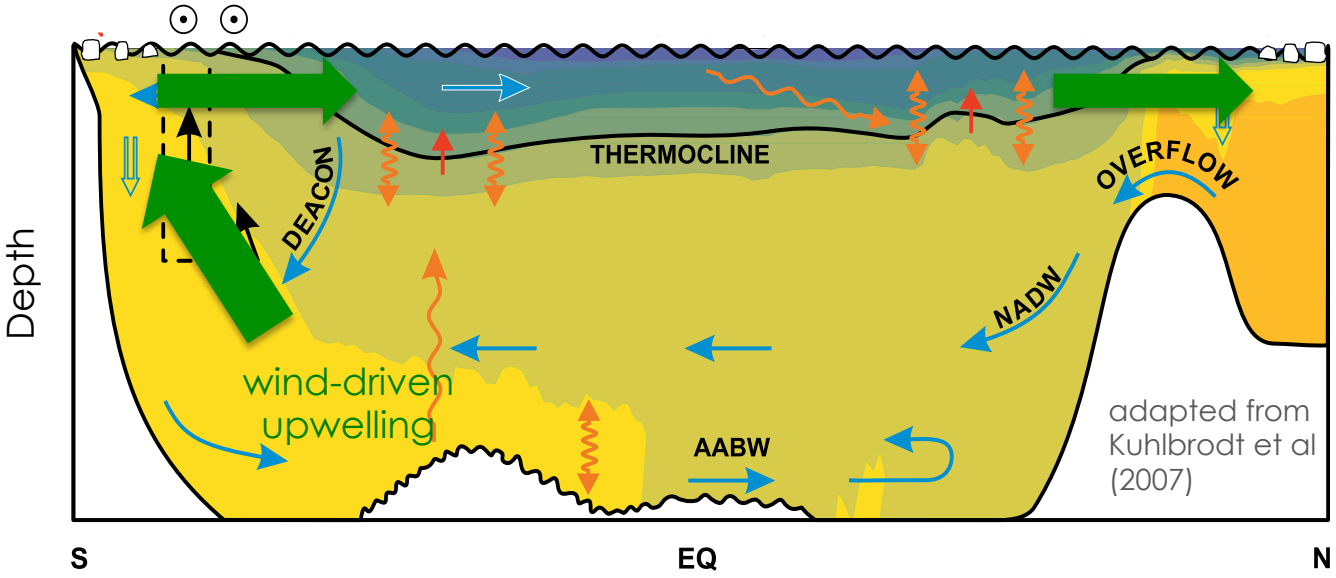
- The observed cooling south of the ACC seems likely to be caused by natural variability (possibly on top of a very slow warming trend)
  - this could not have occurred without a Southern Ocean thermostat



Role of ocean circulation in Arctic warming

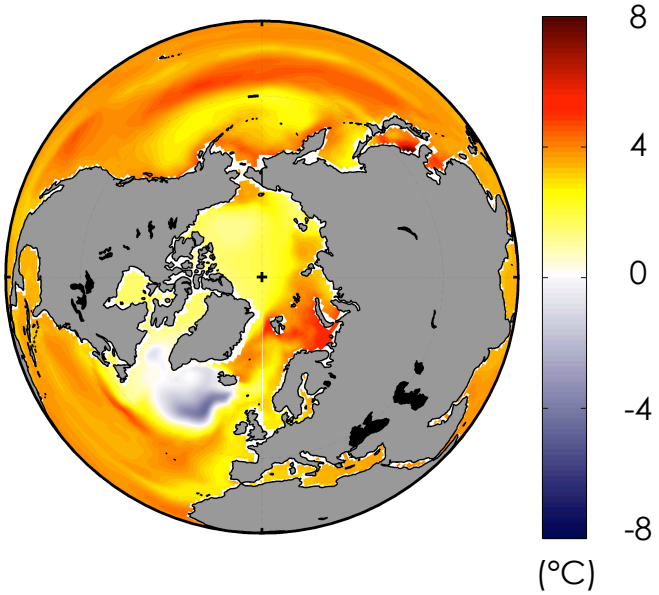


Role of ocean circulation in Arctic warming

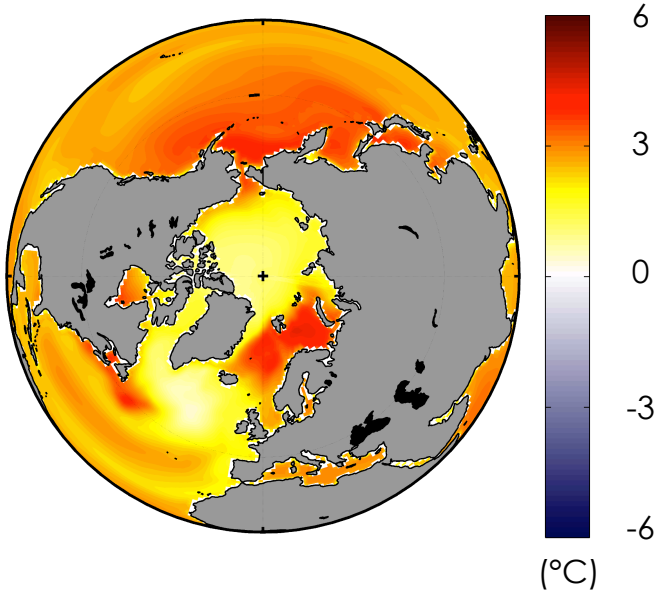


Ocean-only MITgcm vs CMIP5

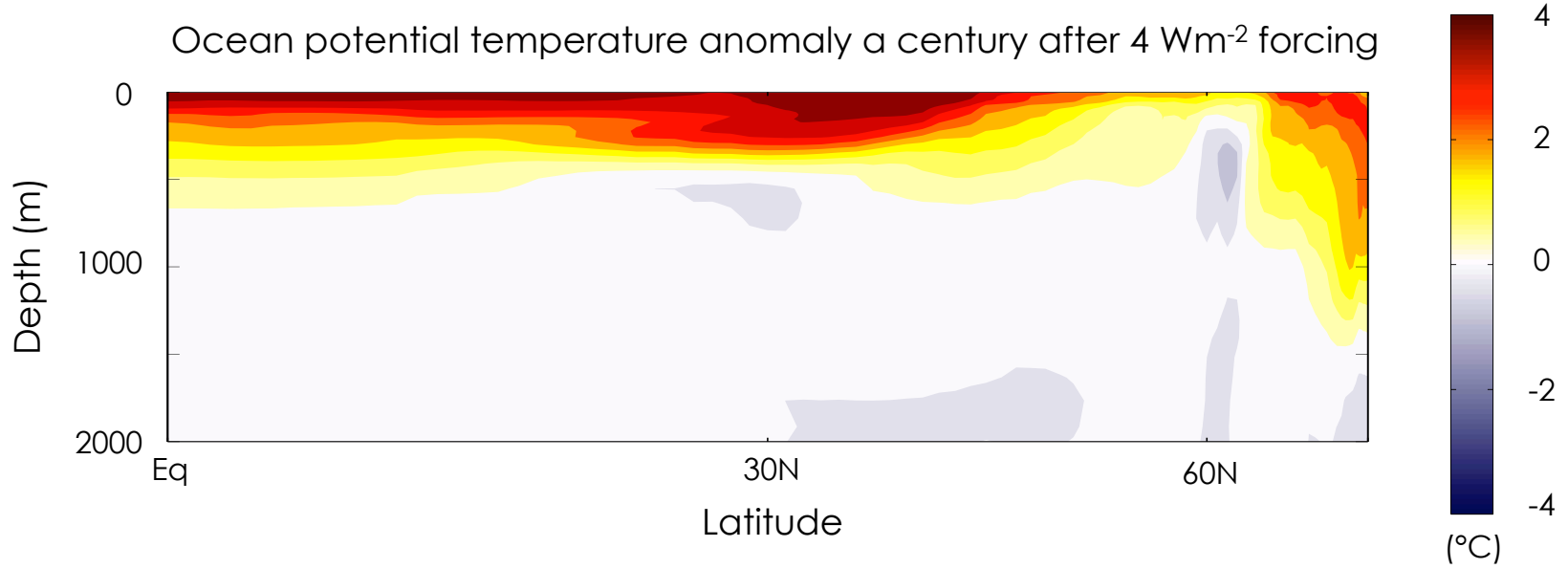
SST anomaly a century after 4 Wm^{-2} forcing

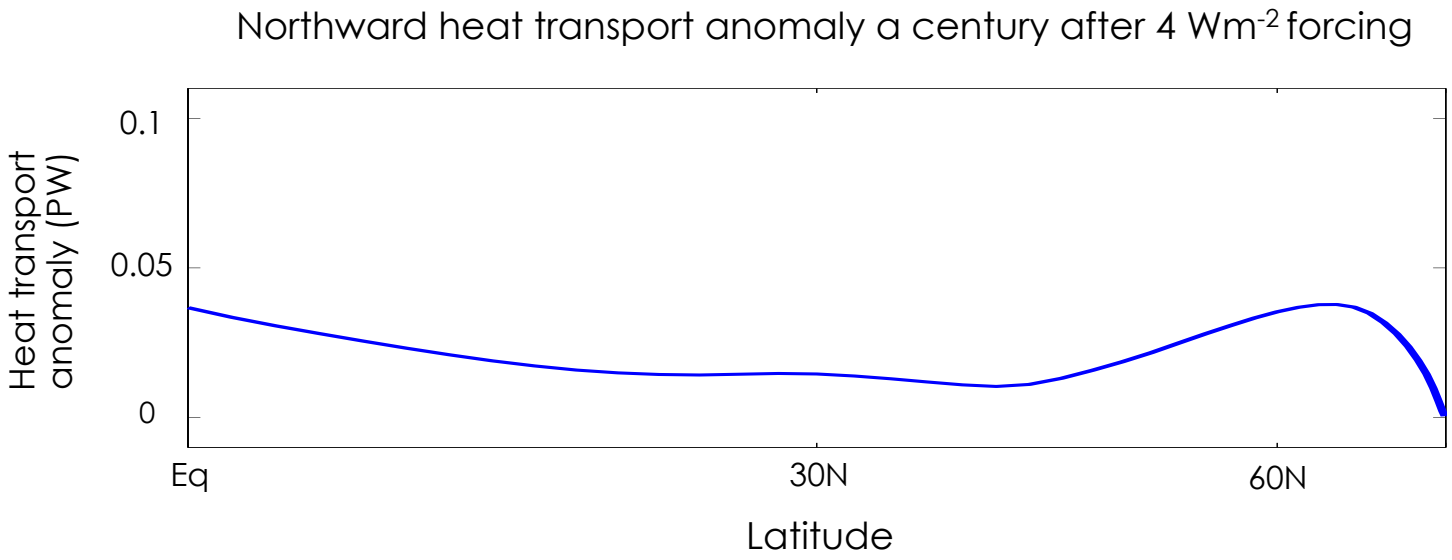


CMIP5 SST anomaly a century after $4xCO_2$

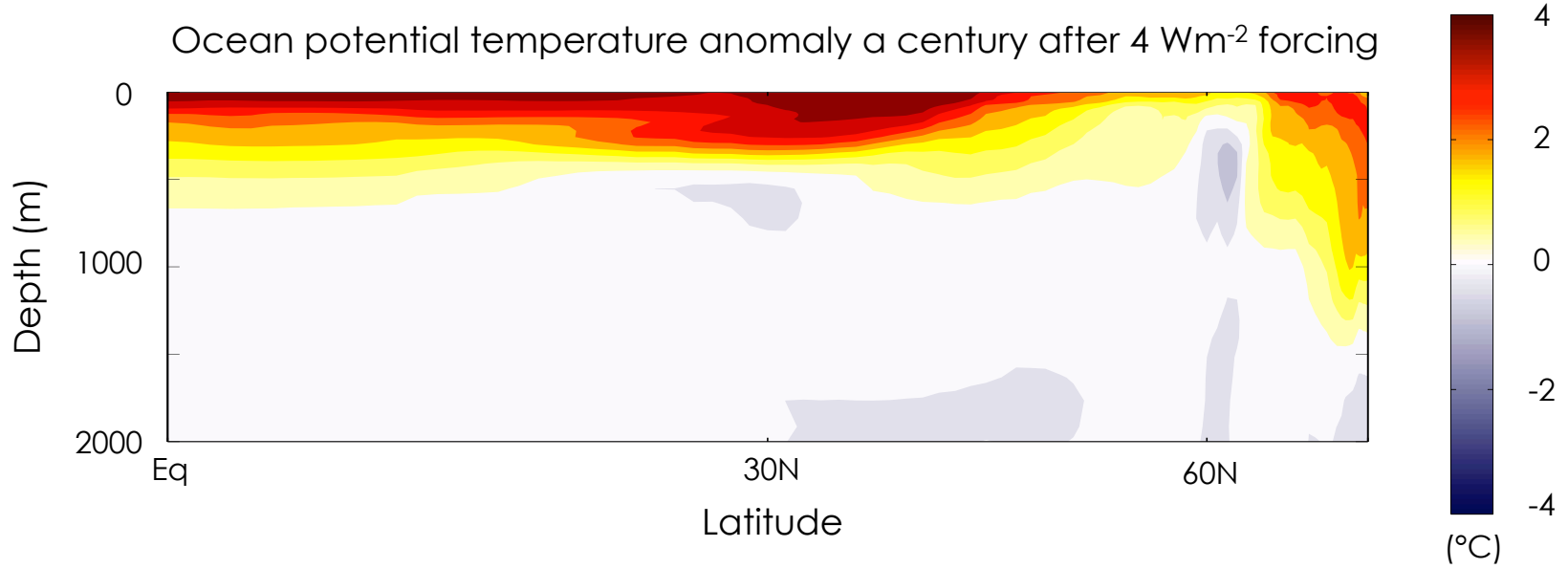


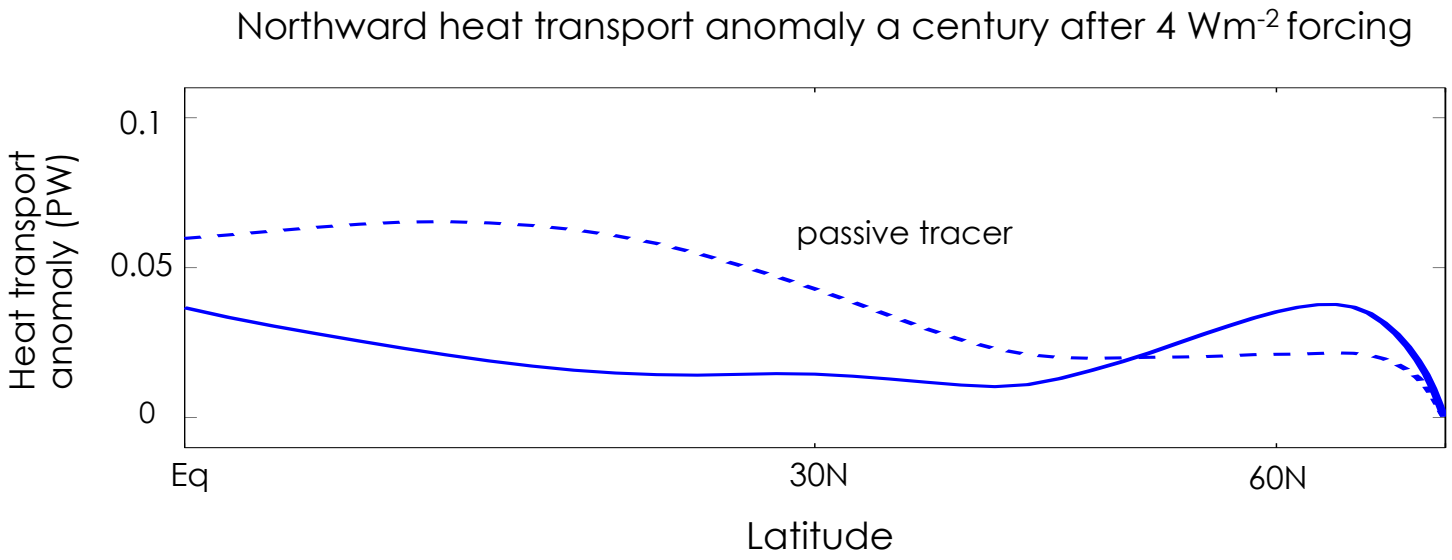
Ocean-only MITgcm: surface heat uptake and ocean heat storage



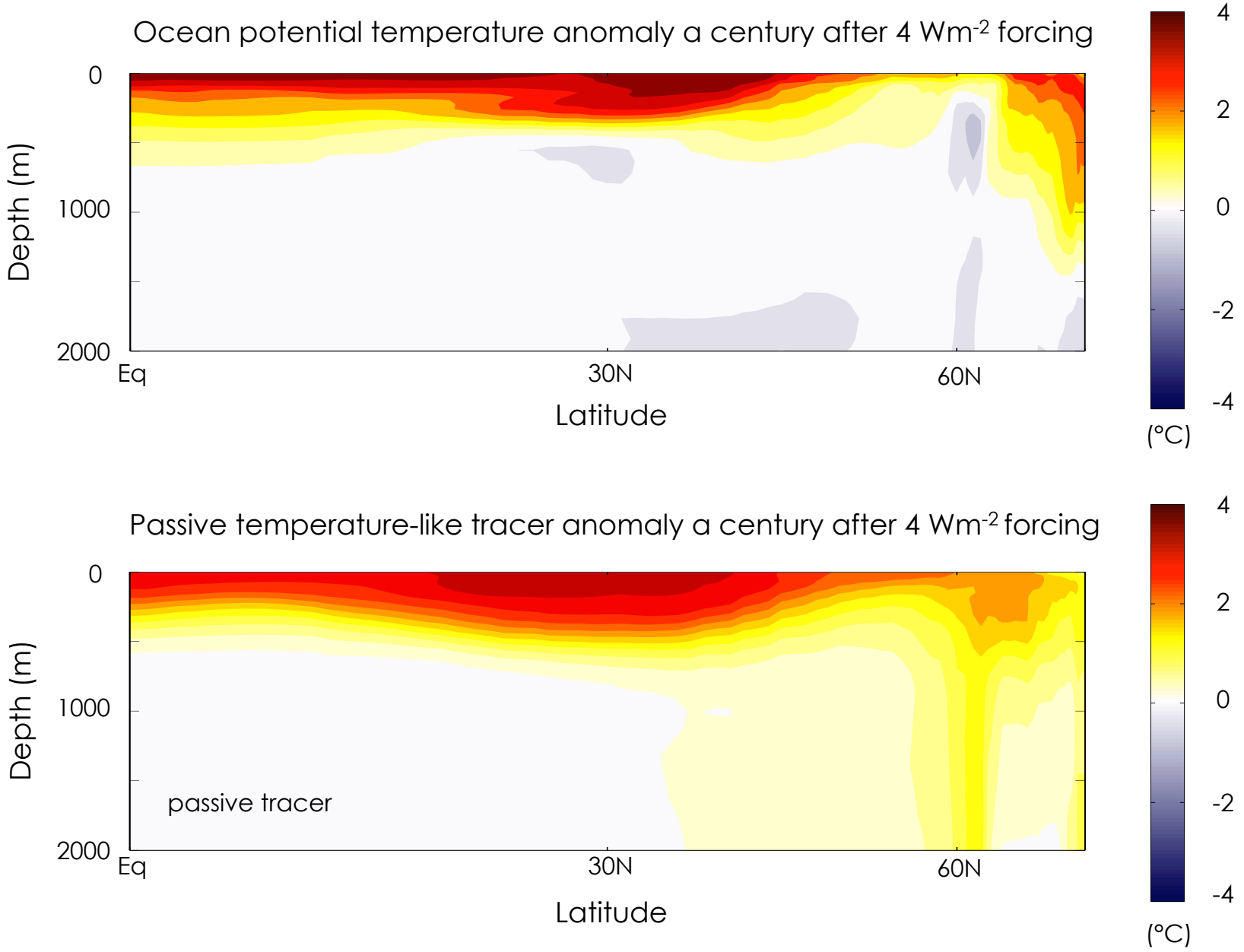


Ocean-only MITgcm: passive vs active role of ocean heat uptake



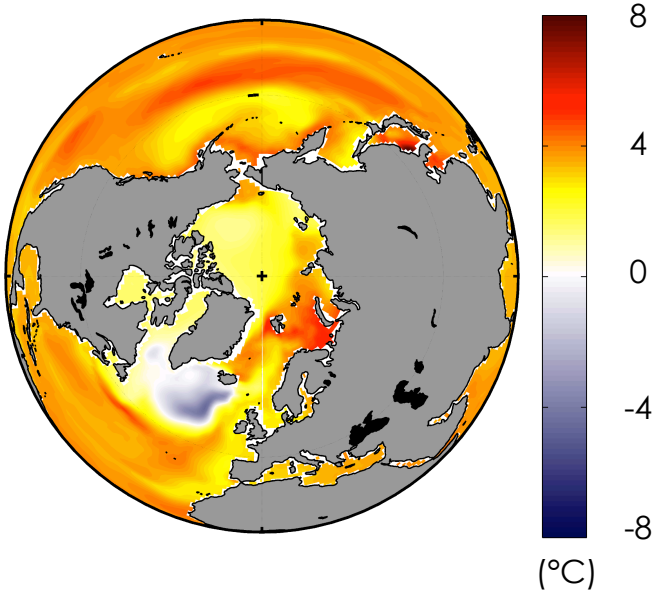


Ocean-only MITgcm: passive vs active role of ocean heat uptake

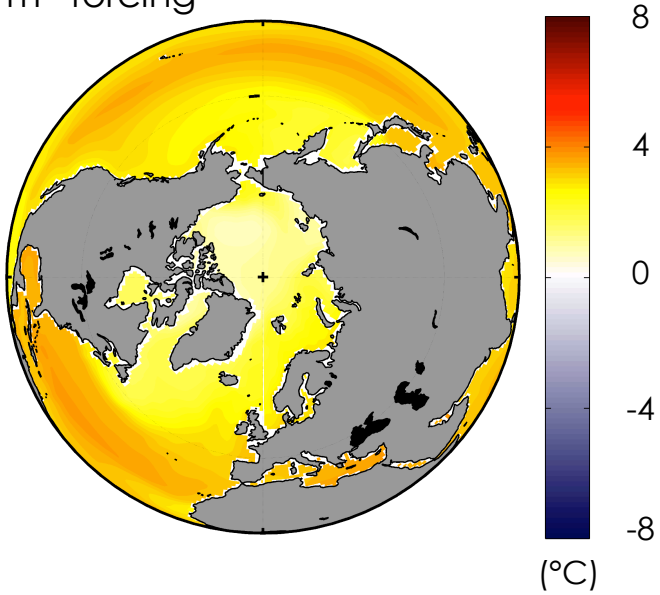


Ocean-only MITgcm: passive vs active role of ocean heat uptake

SST anomaly a century after 4 Wm^{-2} forcing



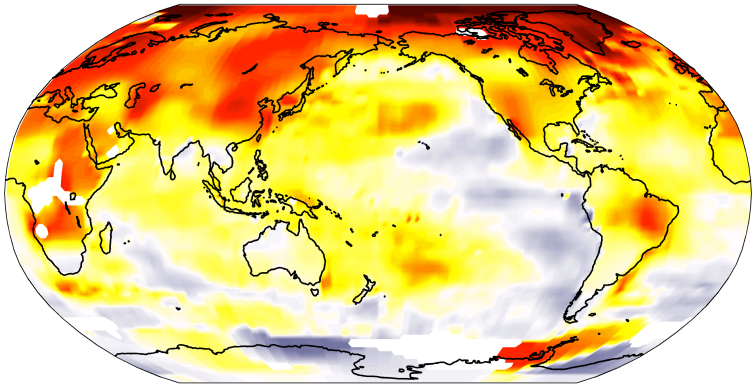
Passive tracer anomaly a century after 4 Wm^{-2} forcing



Bonus slides

1979-2005 annual-mean surface temperature trends

- Observations: GISTEMP



- Models: mean of 16 CMIP5 GCMs