Factors influencing changes in regional sea level projected by AOGCMs

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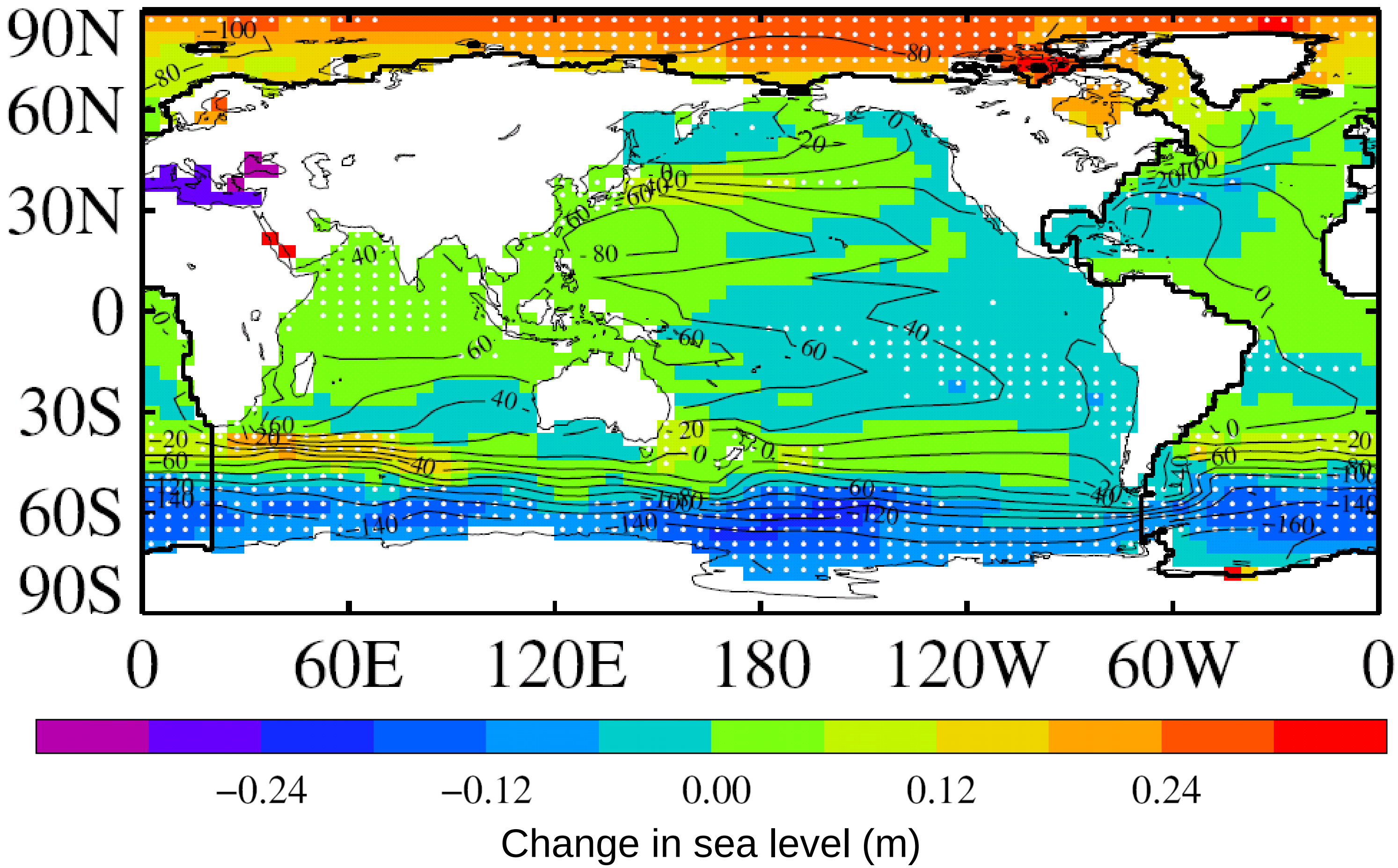
Outline

- Regional patterns of sea level change in the IPCC AR4 models, and their causes
- Analysis of ocean heat uptake processes in HiGEM 1.2
  - Case study: Indian Ocean at the latitudes of the Antarctic Circumpolar Current
- Fluxes vs. fields: Role of a model's initial tracer distribution for modelled sea level change

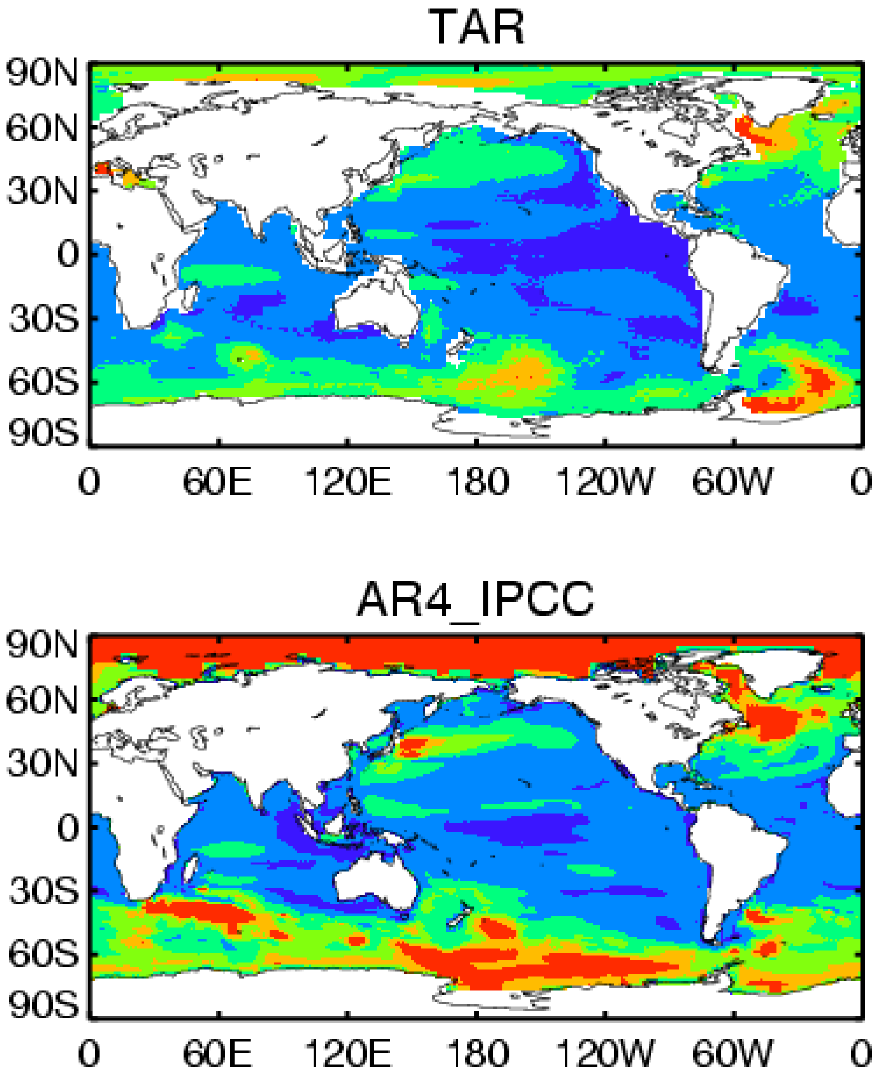
CMIP3 (IPCC AR4) model mean (w.r.t. global mean)



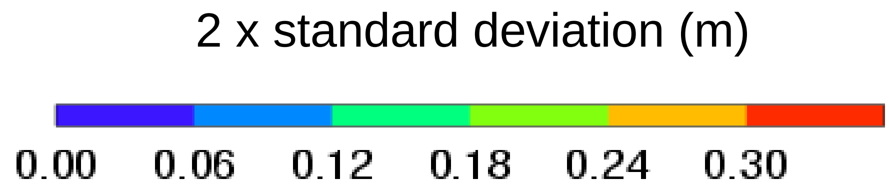
Pardaens et al. (2011)

- SRES A1B, end of 21st century
- Projected sea level change is not globally uniform

Large uncertainty in projections of regional sea level change



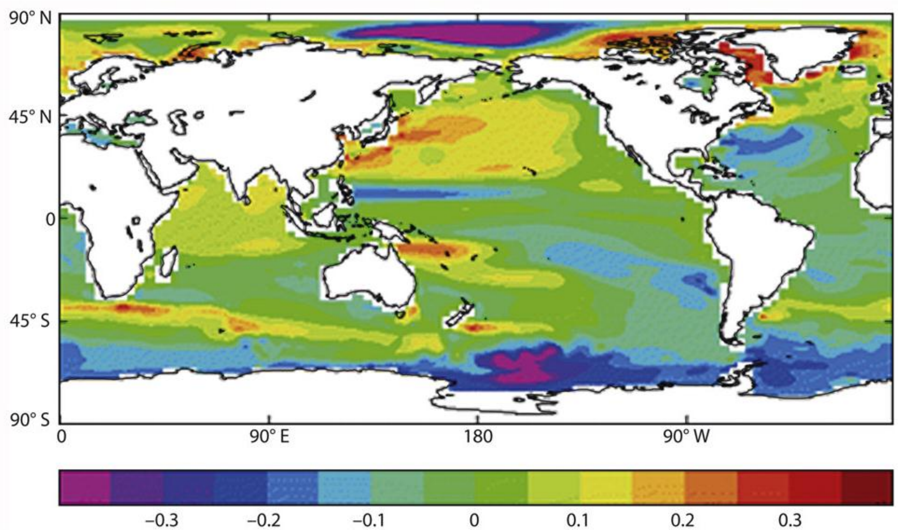
Spread in projections has not been reduced since the TAR.



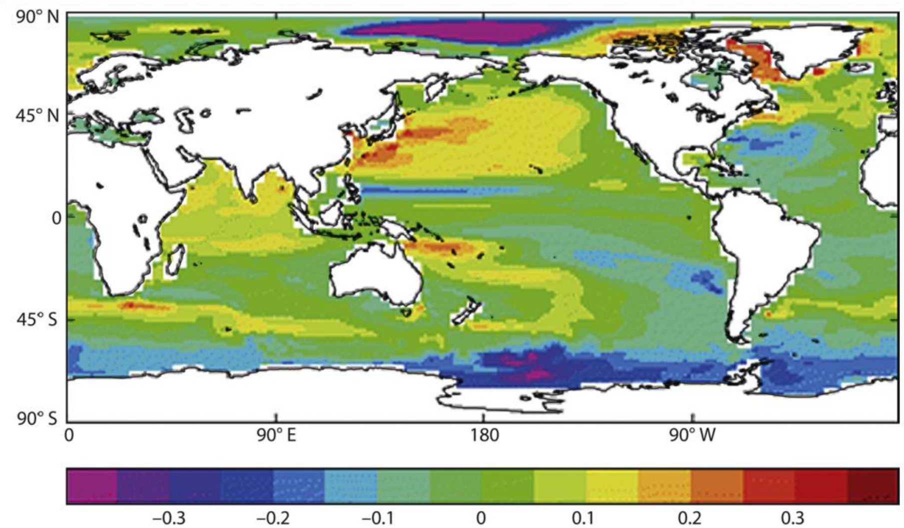
Pardaens et al. (2011)

Dynamical decomposition of sea level change in HadCM3 under 2% CO_2

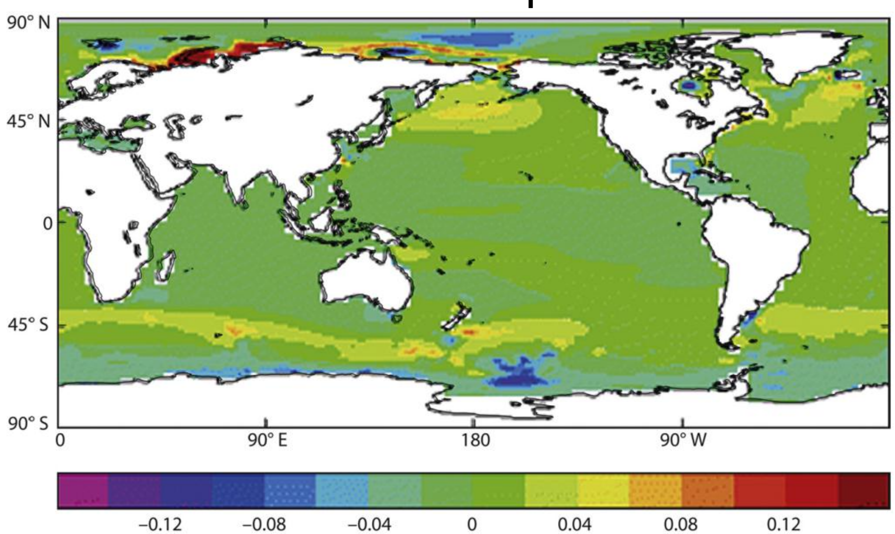
Sea level change (m) wrt global mean



Baroclinic



Barotropic



$$g\nabla\eta' = -\frac{g}{H\rho_0}\int_{-H}^{0}\int_{z}^{0}\nabla\rho\,dz'\,dz - f\underline{k}\times\overline{\underline{u}}$$

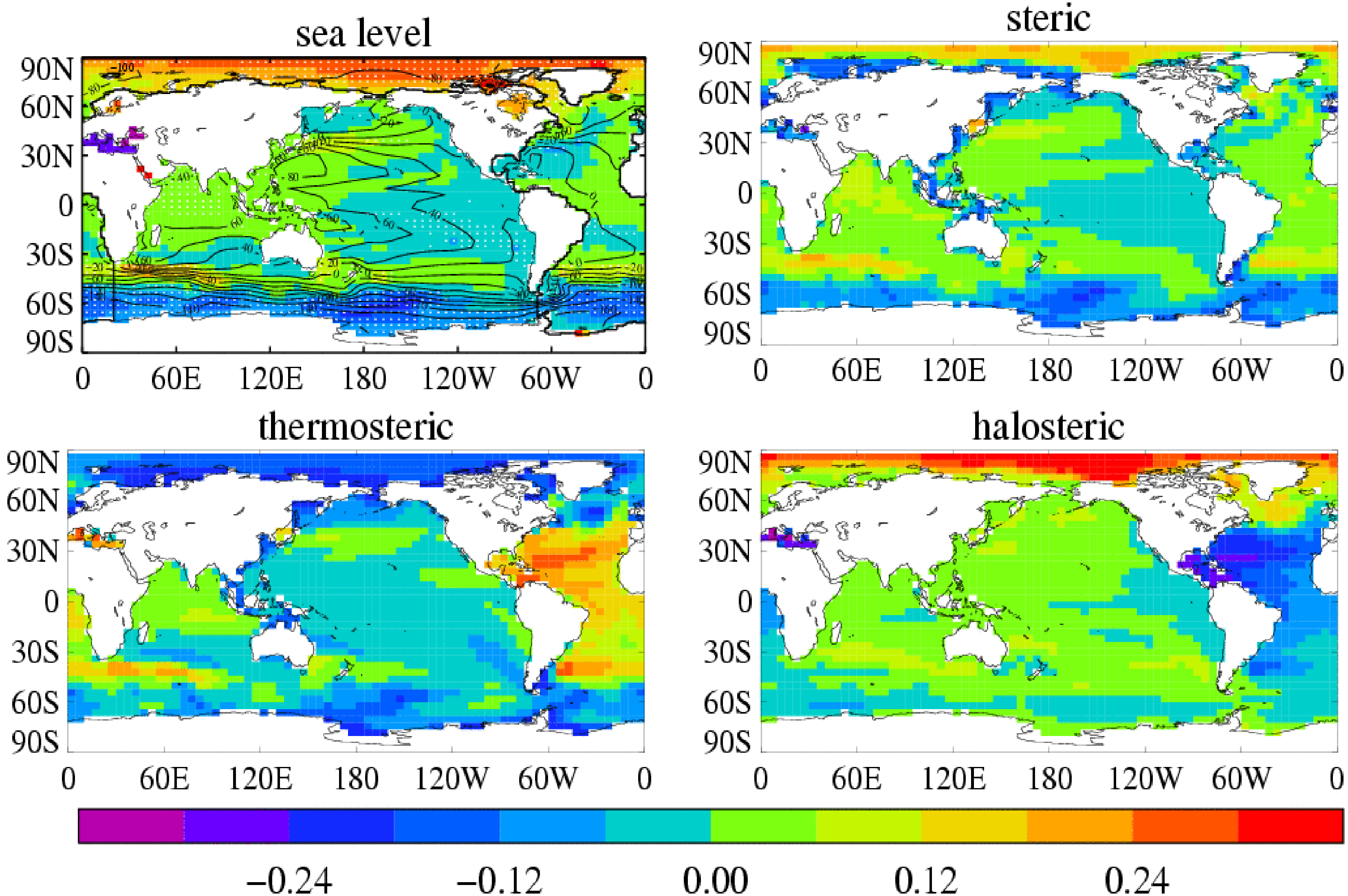
Sea level

Baroclinic ≈ Steric

Barotropic

Lowe and Gregory (2006)

Geographical pattern is predominantly steric

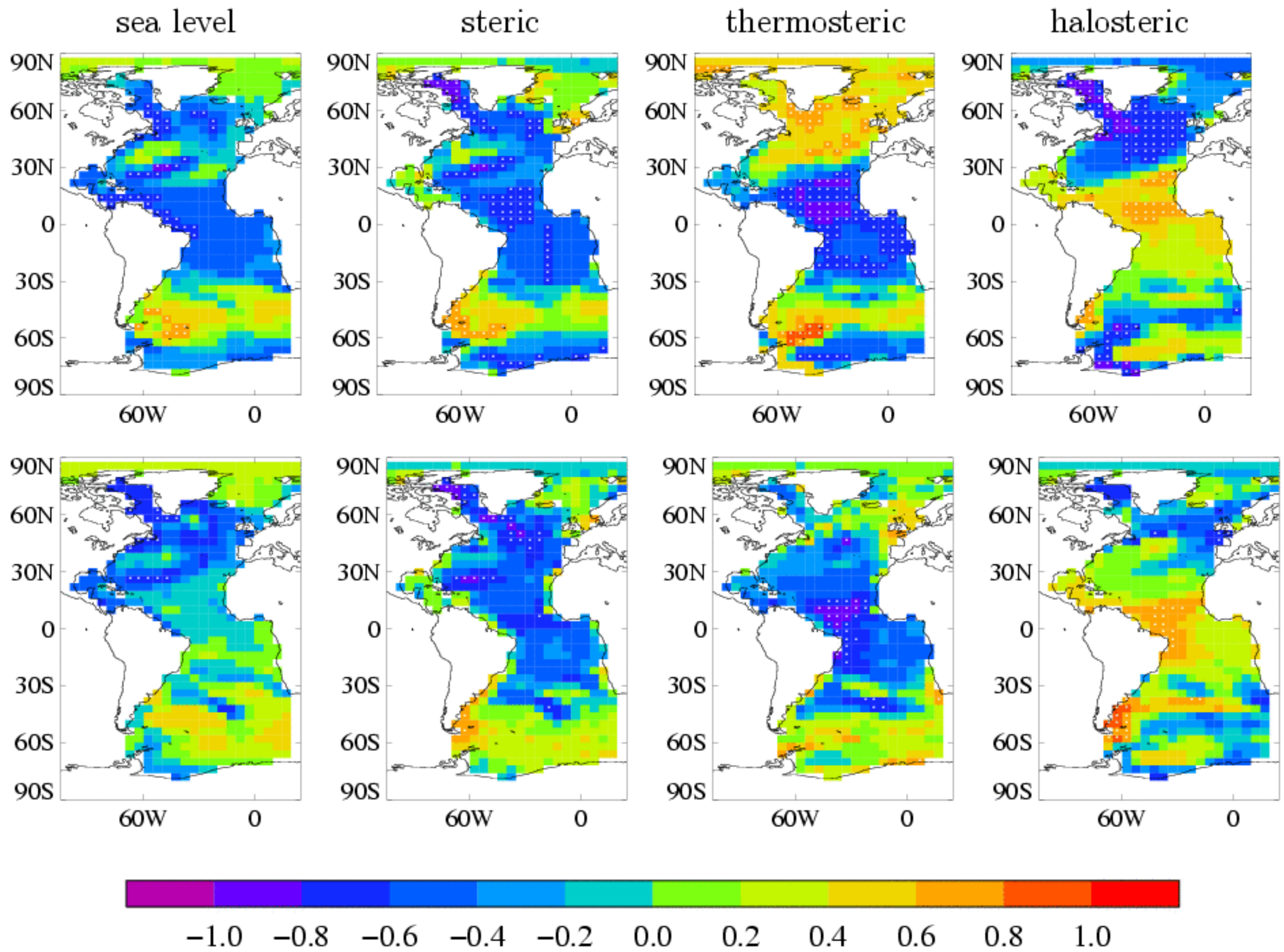


Pardaens et al. (2011)

Correlation coefficients between sea level change and AMOC change at 30N

11 models

8 models (excluding GISS models)



Pardaens et al. (2011)

HiGEM 1.2

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- Coupled GCM based on UKMO HadGEM1, higher resolution
- Atmosphere: 0.83° lat x 1.25° lon (N144)
- Ocean: eddy-permitting 1/3° x 1/3°
  - Gent & McWilliams parameterisation of eddy-induced transports not used
  - Constant isopycnal diffusivity
  - Sea ice model integrated in ocean component, using elements of CICE
- Details in Shaffrey et al., J. Clim., 2009

HiGEM 1.2 model runs

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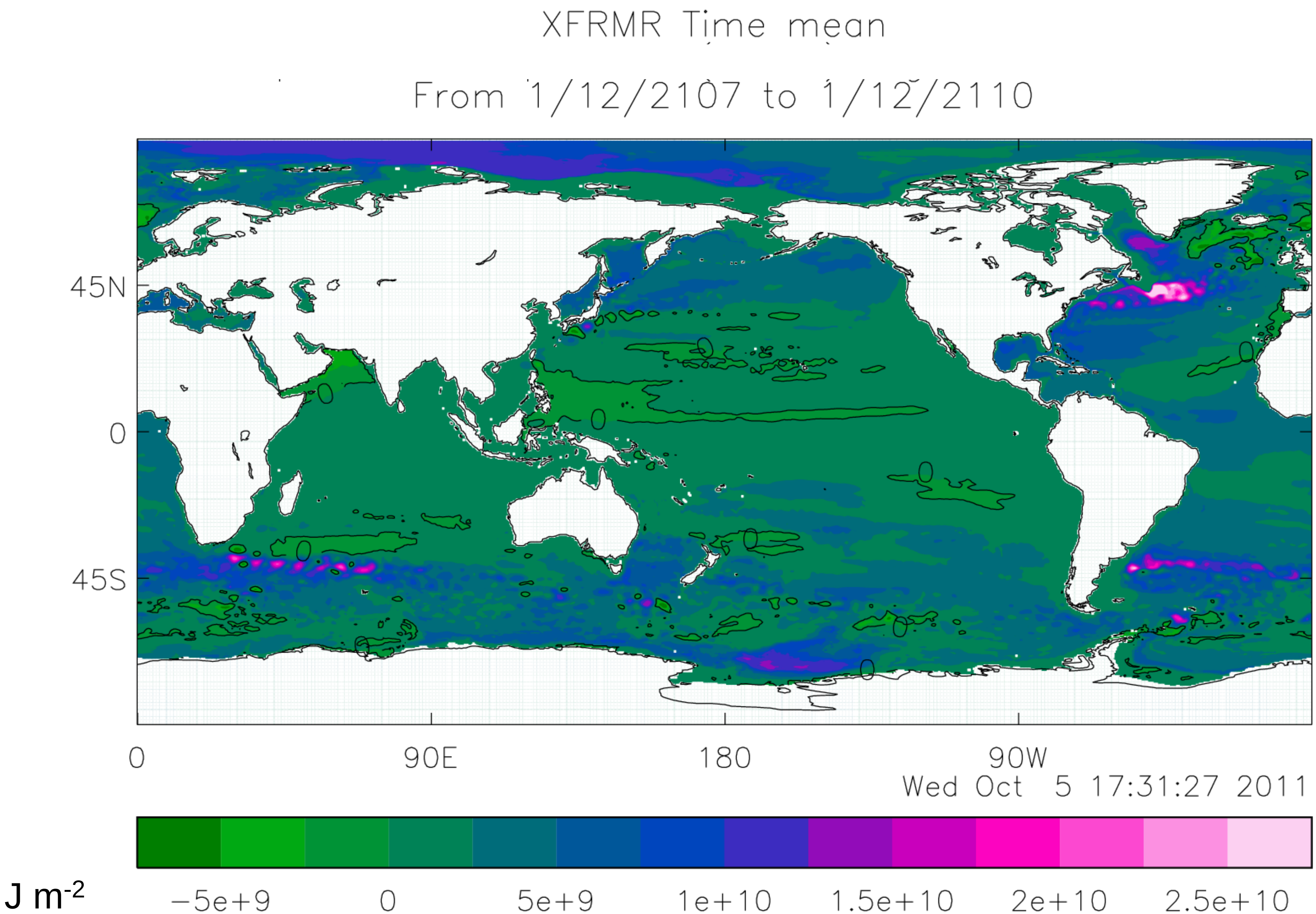
- **Control run** extended by 24 years (total length is now 135 years)
- **CO_2 run:** $4xCO_2$ instantaneously, run for 20 years
- Climate sensitivity is ~2.5K
- Compare last three years of the CO_2 run (2107 to 2110) with the respective years of the control run
- **Detailed diagnostics of the heat advection equation *($d\theta/dt$)*:**

Diffusion (x-, y- and z-component)	Surface fluxes
Penetrating solar radiation	Ice physics (mainly from melting)
Mixed layer physics	Convection
Advection	(Polar Fourier filtering)

- Preliminary results

Ocean heat uptake in the CO_2 run



Zonal total of OHU

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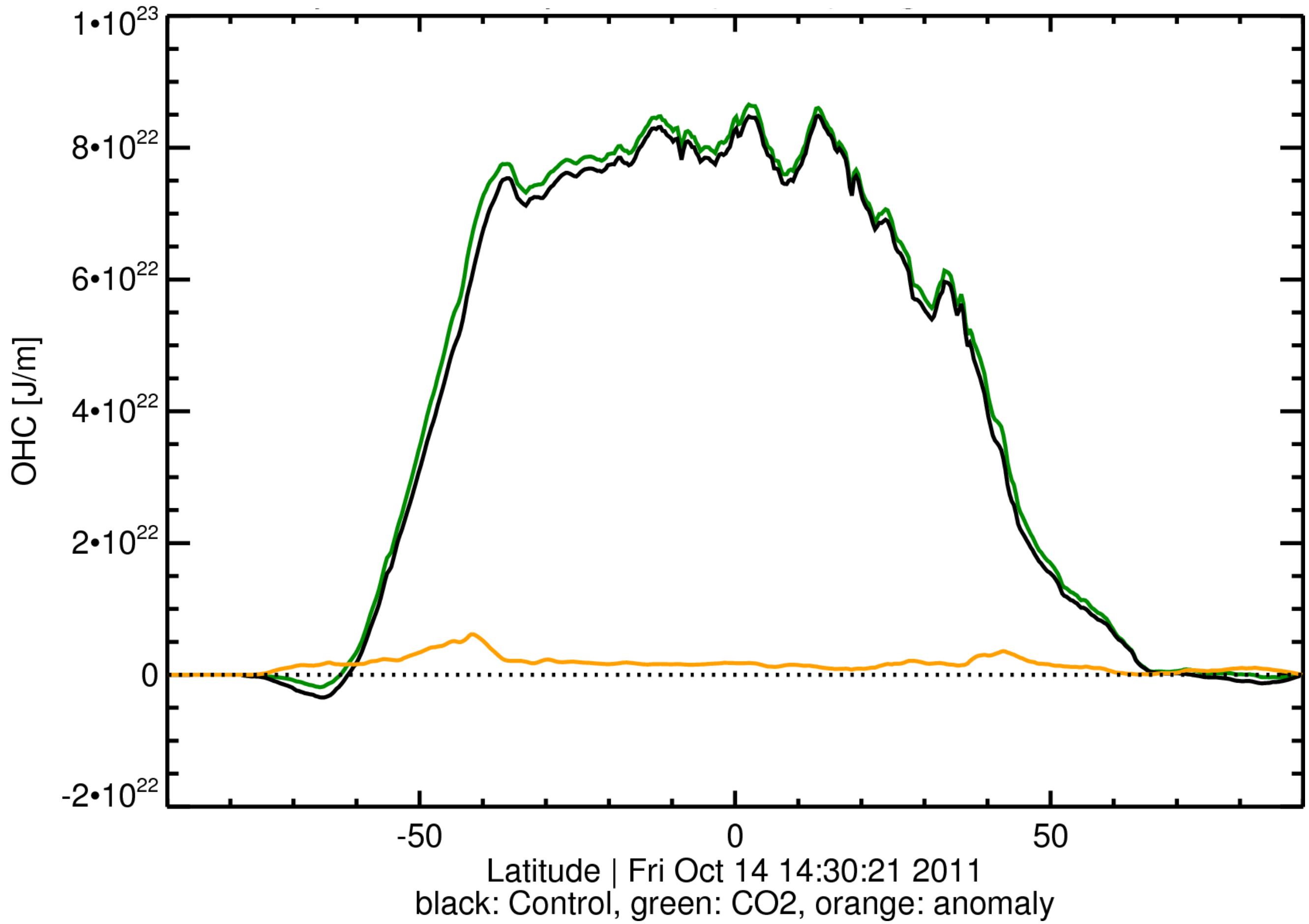
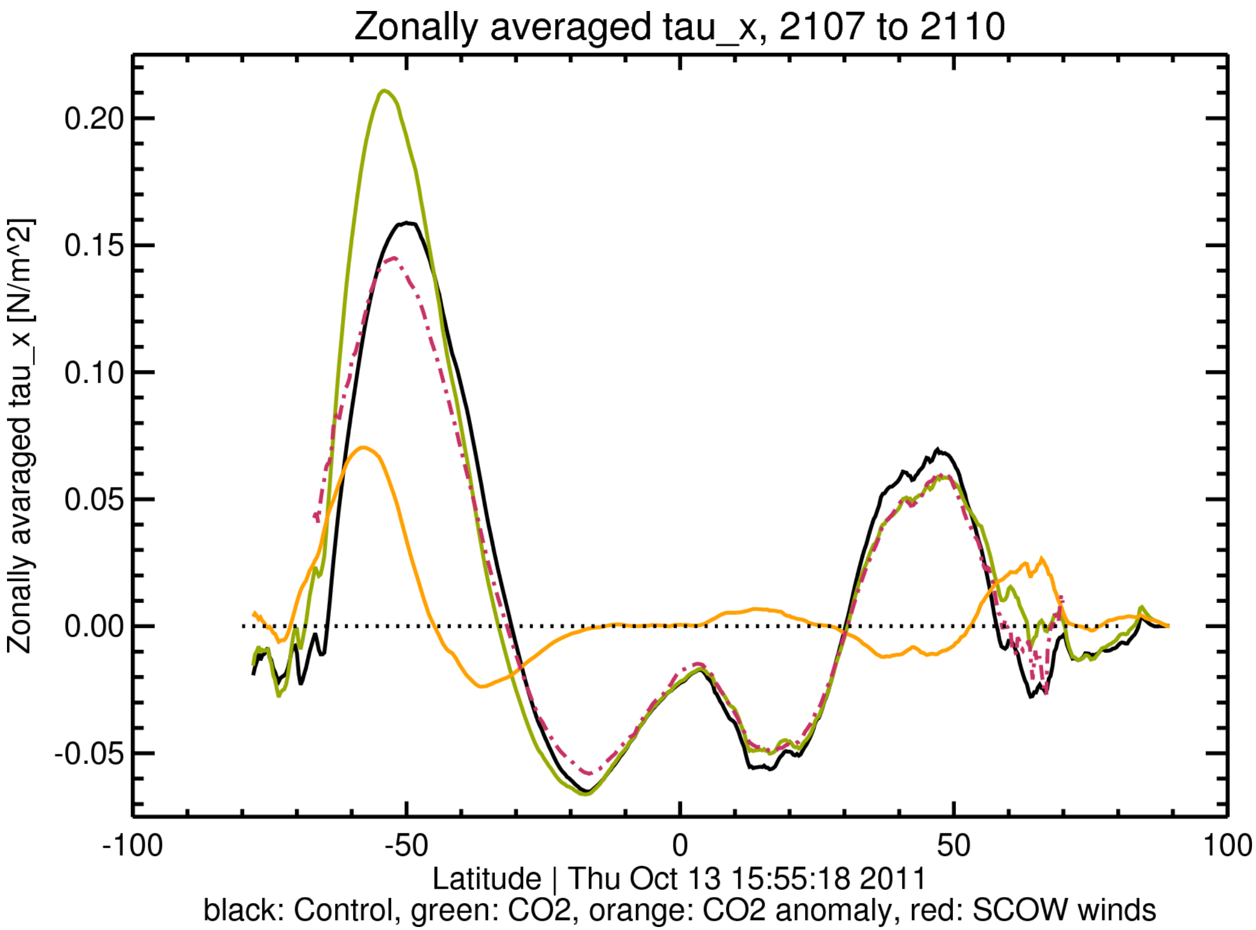


- Global maximum (per degree latitude) in Southern Ocean

Changes of zonal wind stress



- In the CO_2 run the zonal wind stress maximum in the SO becomes stronger and moves poleward
- In the SO, the meridional gradient of zonally averaged τ_x steepens

Ocean heat uptake in CO_2 run

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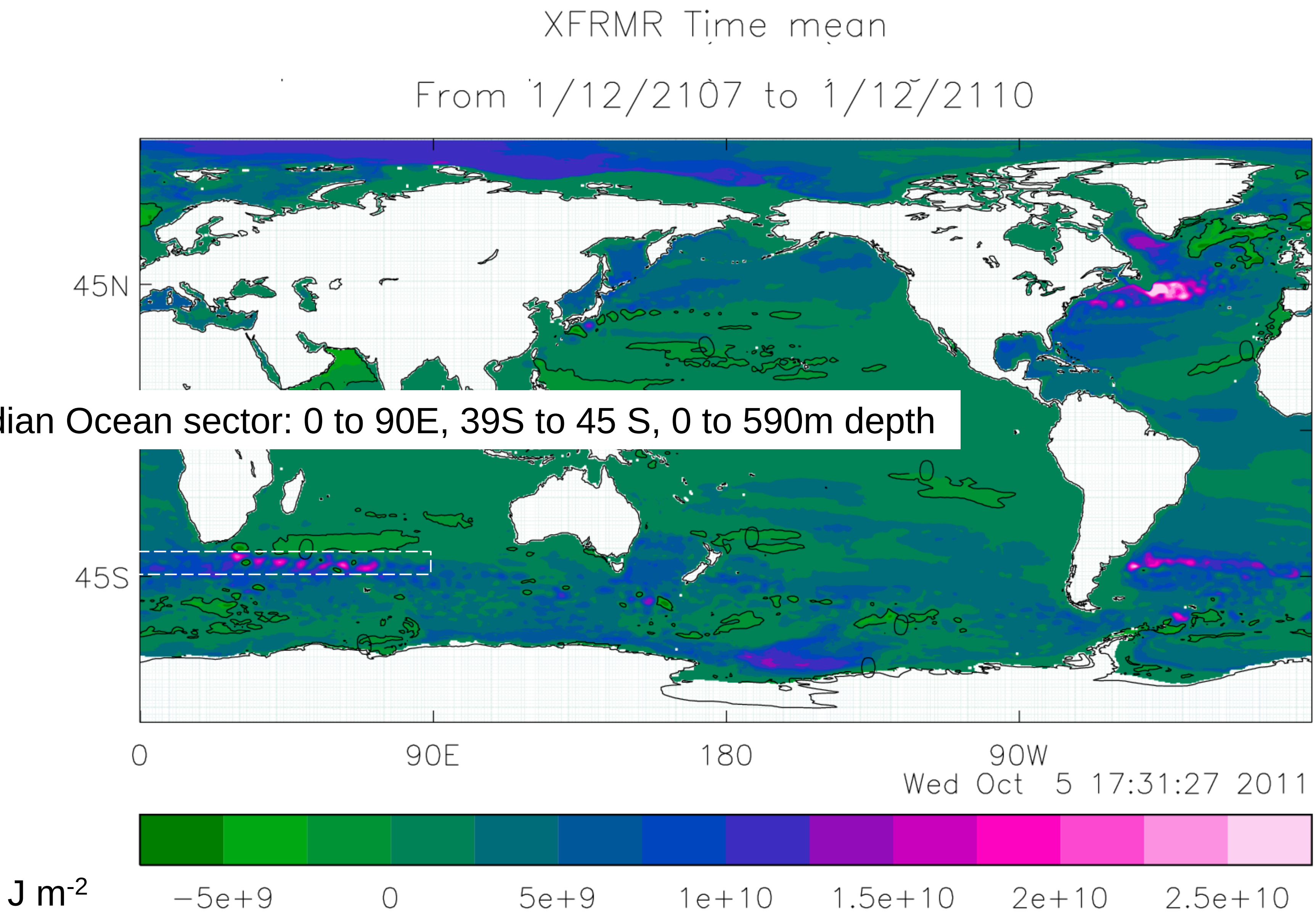
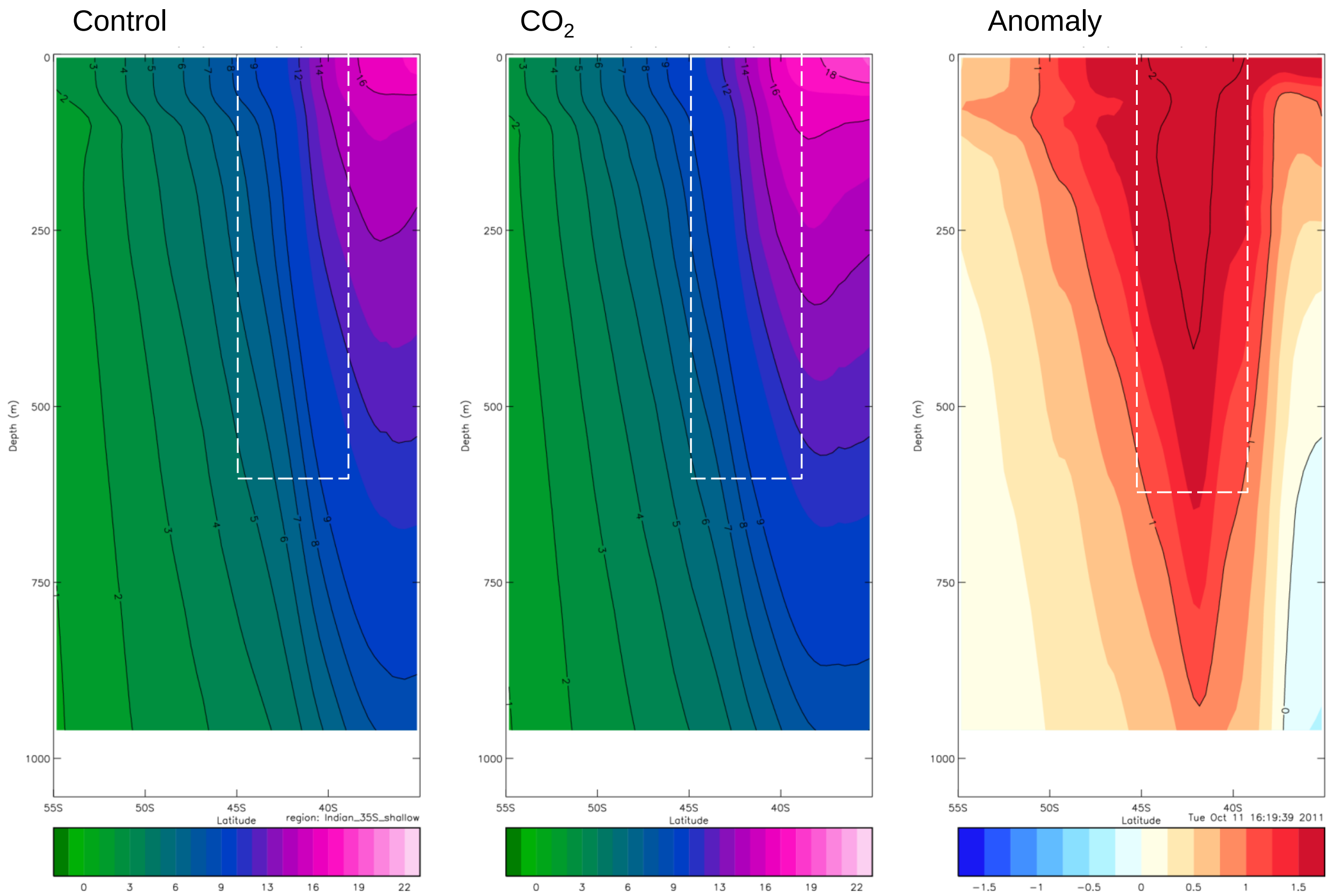


Indian Ocean sector: 0 to 90E, 39S to 45 S, 0 to 590m depth

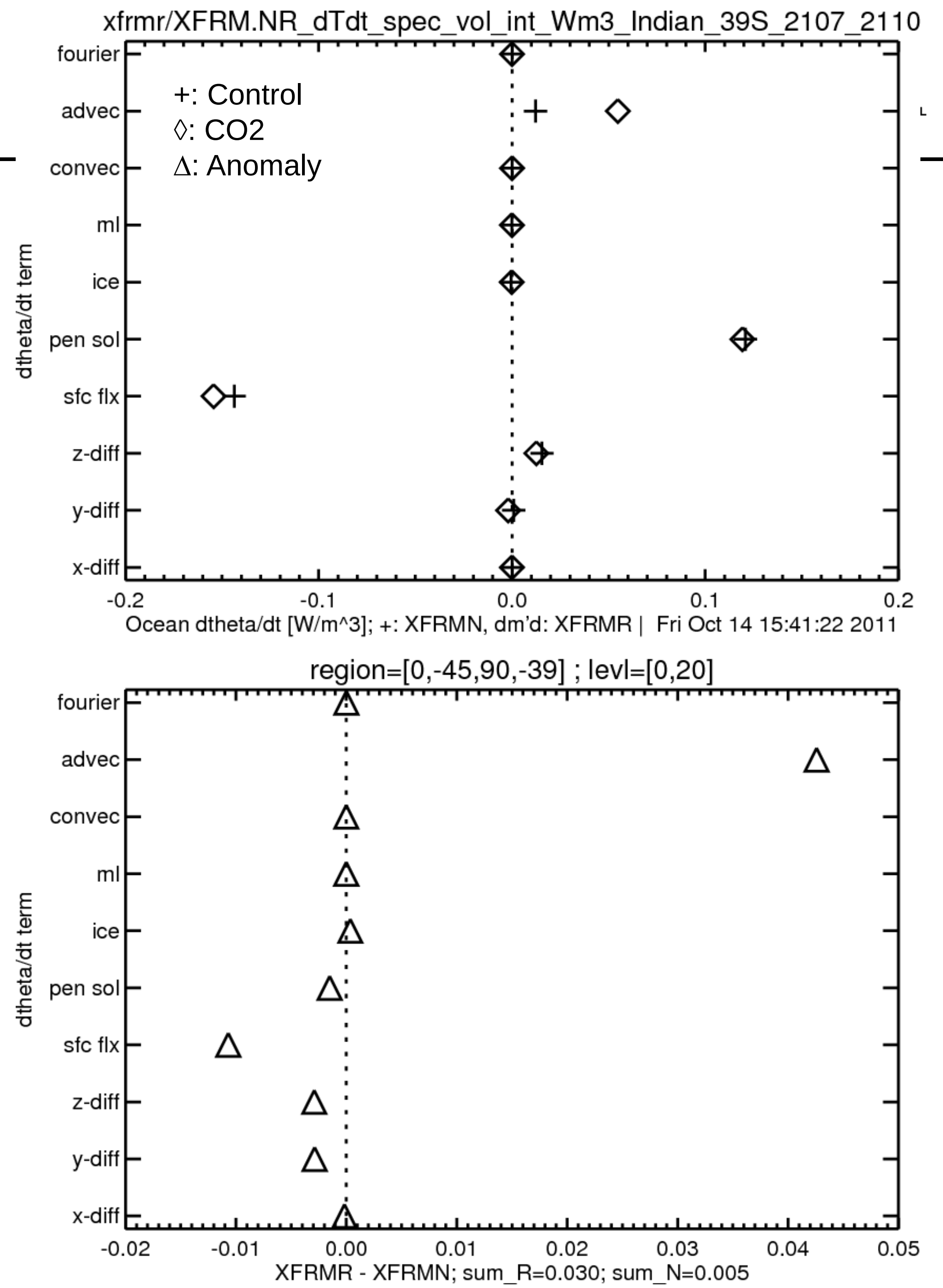
Temperature profile: 0E to 90E averaged



- Pronounced warming in the upper ~1500 m south of 38S

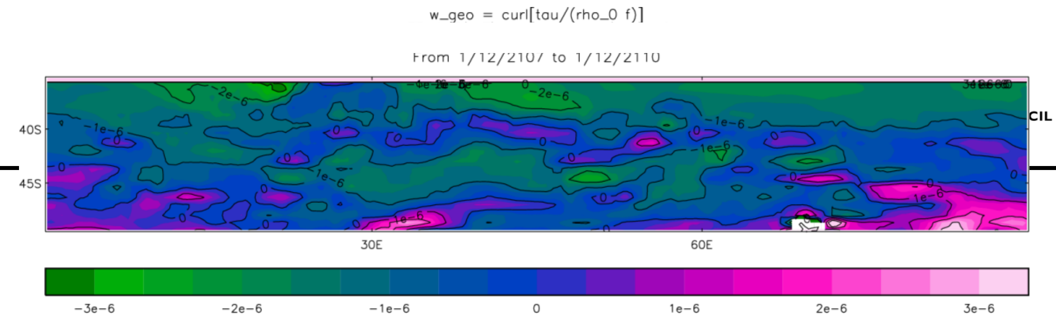
Indian Ocean sector

- The $d\theta/dt$ terms analysis suggests that the heat uptake in this area is mainly due to a large additional warming through advection
- This is, to some extent, compensated by more cooling from surface fluxes and slightly less warming from penetrating solar radiation

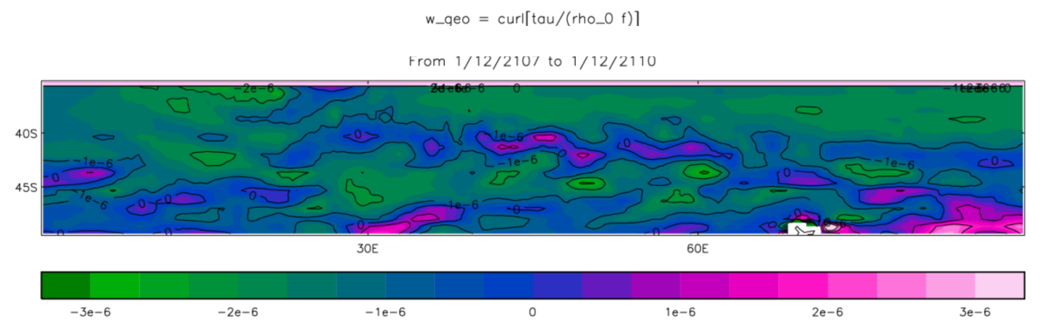


Ekman Pumping

- Upwelling velocity at the base of the Ekman layer
  $w = curl[\tau/(\rho_0 f)]$
- More downwelling due to wind stress changes

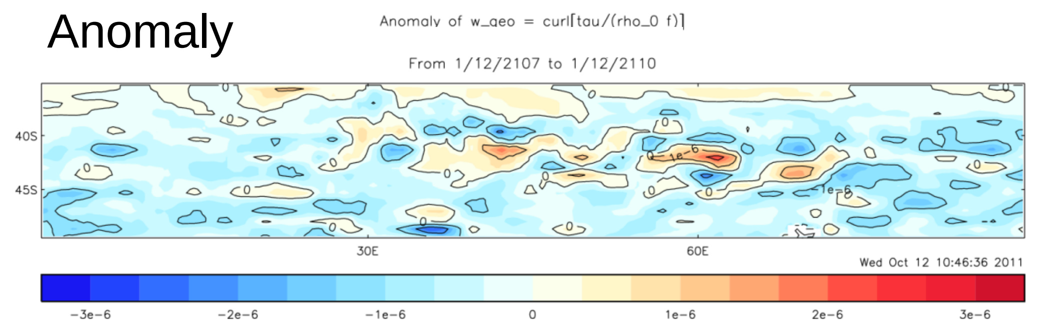


Control



CO_2

Anomaly



Sea Level Change: Fluxes vs. Fields

- Is modelled dynamical SLC determined by the surface fluxes or rather by the initial fields of temperature and velocity?
- Experiment: use two GCMs, HadCM3 and FAMOUS
- FAMOUS: low-resolution, reduced physics version of HadCM3 (Smith et al., 2008)
- Idealized 1%/yr CO_2 runs (100 years, averages over last 10 years)
- Apply anomalous fluxes of heat, water and momentum (from the CO_2 runs) to the FAMOUS control run
- Use a passive anomalous tracer (Banks & Gregory, 2006)

FAMOUS with FAMOUS anomalous fluxes

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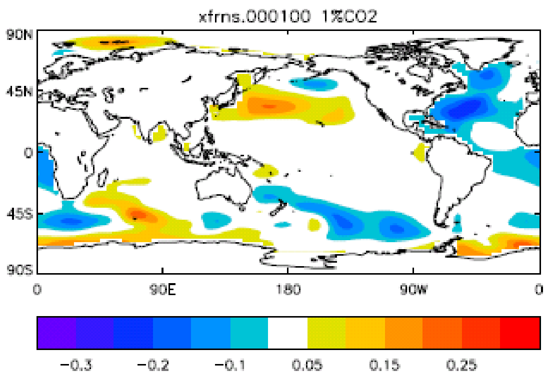
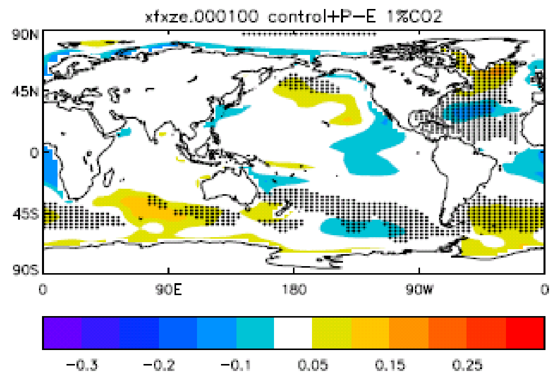
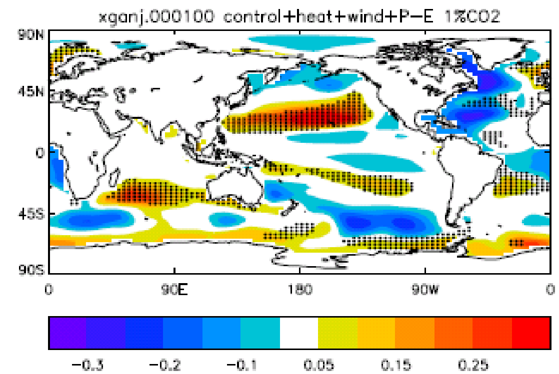
1%CO2



Control+ P-E

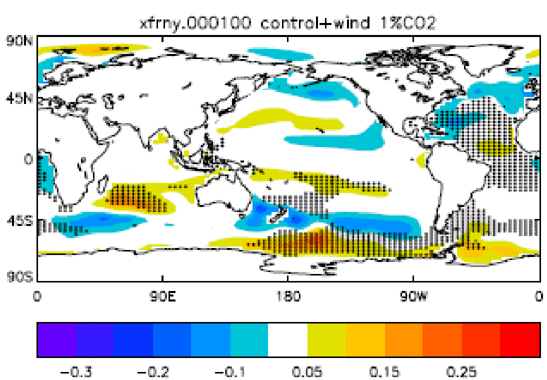


Control+ wind+P-E+heat

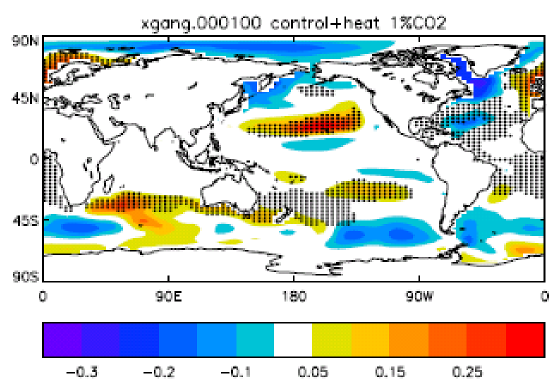


- Looks similar to 1%CO2 run

Control+ wind



Control+ heat



correlation for wind 0.48
correlation for P-E 0.39
correlation for heat 0.49
Correlation for all 0.72

FAMOUS with HadCM3 anomalous fluxes

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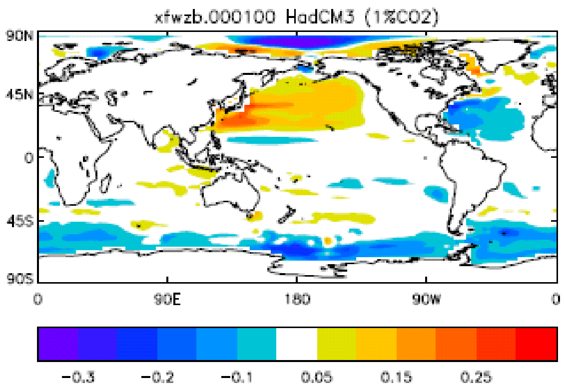
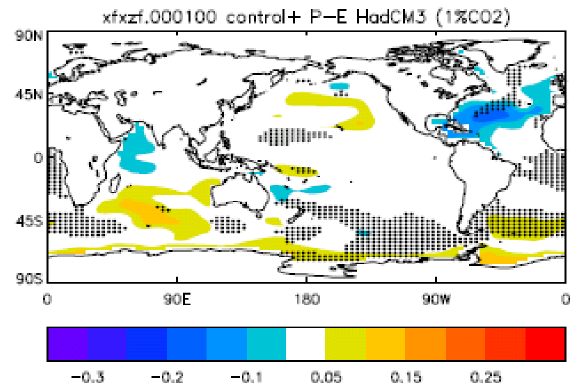
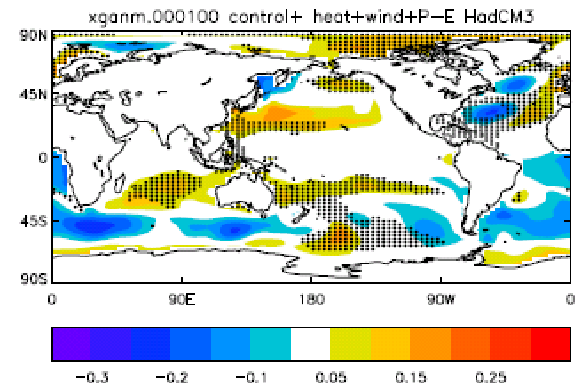
1%CO2 HadCM3



Control+ P-E

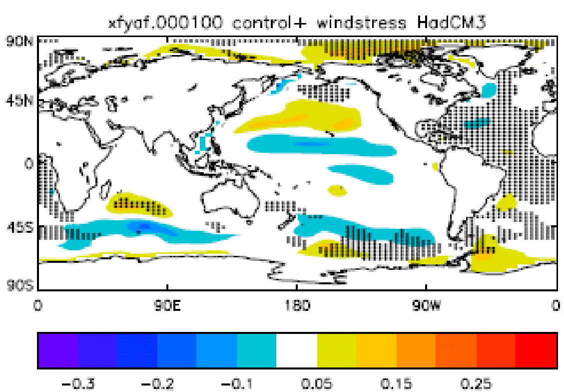


Control+ wind+P-E+heat

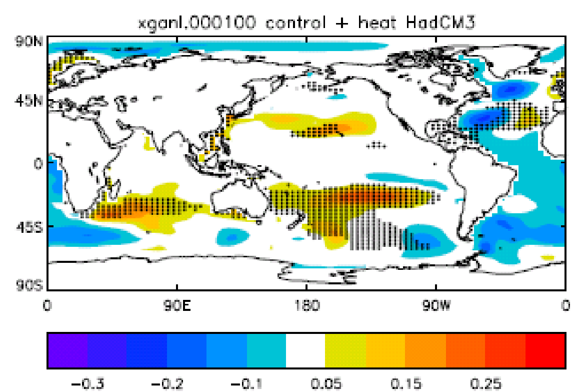


- Doesn’t look very similar to 1%CO2 run
- Especially in the Southern Ocean

Control+ wind



Control+ heat



<u>Correlation with HadCM3</u>

correlation for wind 0.10
correlation for P-E 0.09
correlation for heat 0.34
correlation for all 0.32

<u>Correlation with FAMOUS</u>

correlation for wind 0.34
correlation for P-E 0.63
correlation for heat 0.53
correlation for all 0.51

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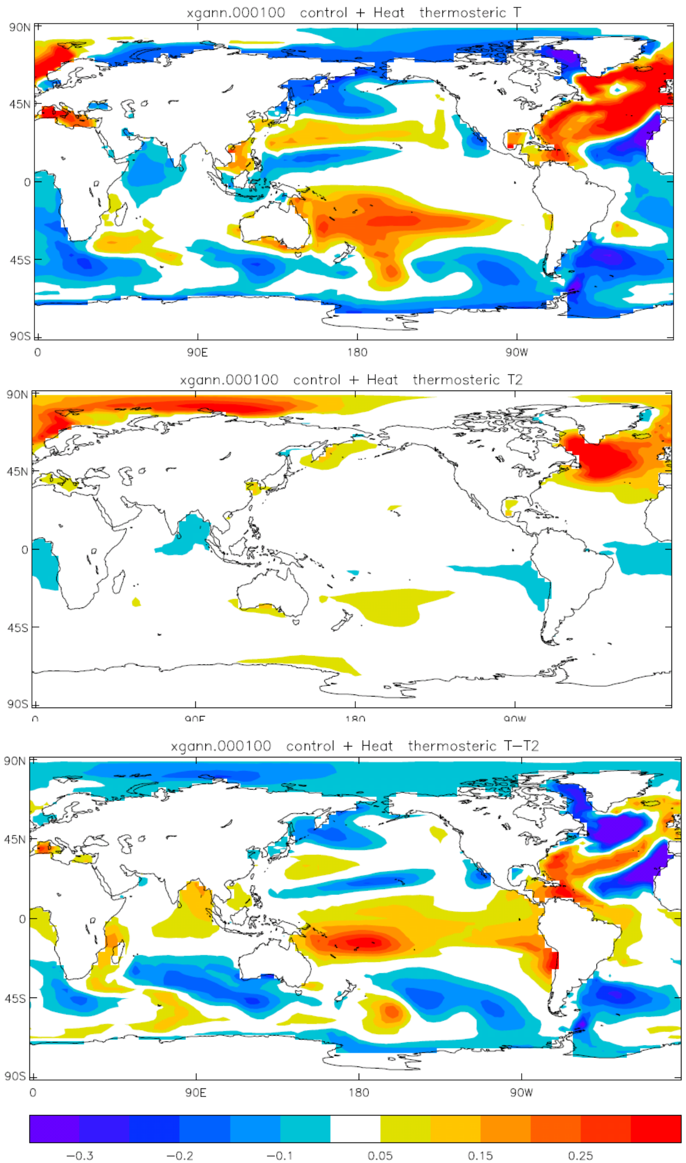
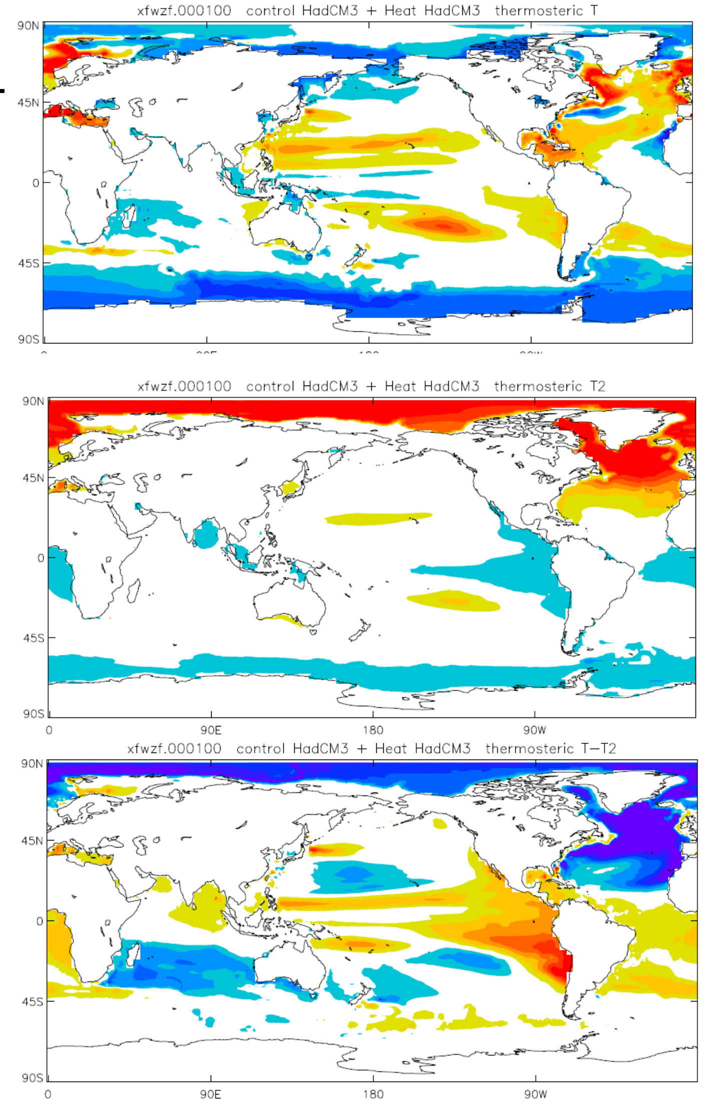
FAMOUS + heat HadCM3



HadCM3 + heat HadCM3



Thermosteric sea level

Contribution from anomalous flux

Different in the Southern Ocean

Reservoir redistribution

Redistribution more important: role of
- Change of circulation
- Initial field

Summary (1)

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- The TAR and AR4 (CMIP3) climate models show a large spatial variability of sea level change, but disagree about details of patterns
- Patterns are principally baroclinic and steric
- More than average SL rise in Arctic is halosteric, presumably hydrological
- Strong compensation in Atlantic between halosteric and thermosteric, associated with changes in advection by AMOC
- Less than average SL rise near Antarctica is thermosteric

Summary (2)

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- The HiGEM 1.2 runs, with the comprehensive diagnostics, permit a detailed understanding of ocean heat uptake processes
  - The ocean heat uptake maximum in the Indian sector of the Southern Ocean is wind-driven through increased Ekman pumping
  - See posters today **(M165A)** and on Thursday **(Th22A)**
- "Swapped anomalous fluxes" experiments with FAMOUS and HadCM3 suggest that, for modelled sea level change, the initial fields and the redistribution are more important than the anomalous fluxes

Questions?