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**OS1.6 Improved Understanding of Ocean Variability & Climate**

# Intercomparison of anthropogenic ocean heat uptake processes in AOGCMs

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# Motivation

**What causes the spread of projections of regional future sea level under greenhouse gas forced climate change?**

Future ocean heat uptake is a key uncertainty

- Input of heat into ocean (air-sea flux) different for each model?
- Each ocean model has different sensitivity to heat input?

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# Typical approach (e.g. 1pctCO2):

Preindustrial: atmos-ocean fluxes of heat, momentum, water stable (different for each model)

Prescribe GHG emissions or atmospheric concentration

GHGs alter radiative balance & change climate

Atmos-Ocean Heat Flux

Atmos-Ocean Water Flux

Wind Stress (Momentum Flux)

Changes to ocean heat content (OHC)

**Is the model spread due to:**
- **Air sea fluxes changing by different amounts in each model?**
- **Or is each model ocean's sensitivity to change different?**

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## Flux-Anomaly-Forced MIP (FAFMIP):

Preindustrial: atmos-ocean fluxes of heat, momentum, water stable

Add common perturbation (based on mean 1pctCO2 flux changes) to:

Heat Flux

Water Flux

Wind Stress

Heat + Water + Stress

OHC

OHC

OHC

OHC

**Is the model spread due to:**

- ~~**Air sea fluxes changing by different amounts in each model?**~~
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# Decomposition of Ocean Heat Uptake

**Say you find a temperature anomaly somewhere in an ocean model.**
**Why has the heat content here changed?**

- Was heat added to climate during industrial era?
- Have changing ocean currents rearranged preindustrial heat?

Use more temperature tracers!

$T = T_a + T_r$

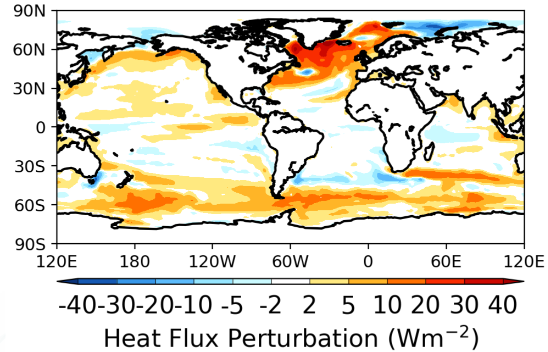
$T_a$: temperature added by perturbation (F)

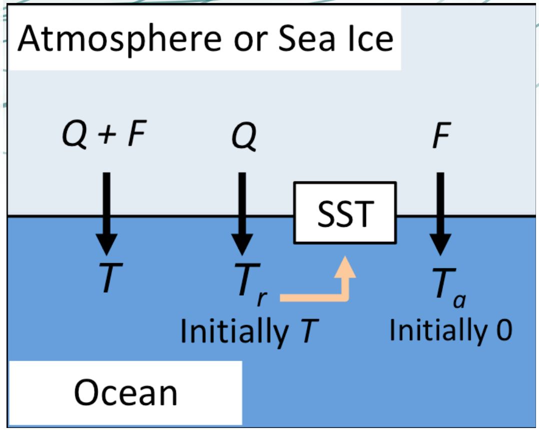
$T_r$: temperature redistributed by circulation

T decoupled from SST seen by atmosphere, instead coupled to $T_r$

T feels atmospheric flux (Q) and perturbation flux (F) but atmosphere only feels $T_r$

So perturbation (F) stays in ocean

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# Decomposition of Ocean Heat Uptake

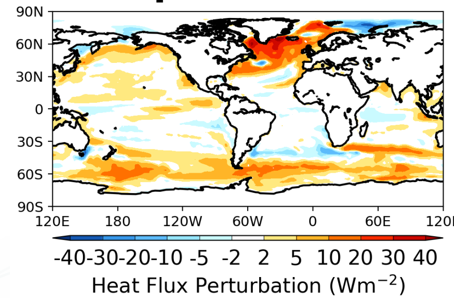
$\Phi$: all ocean circulation, brackets mean "acting on"

faf-heat: heat flux, F, added to ocean $T$ and $T_a$

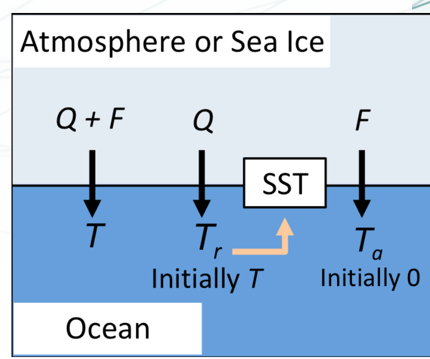
- $T$ changes $T = \overline{T} + T'$
- $\Phi$ changes $\Phi = \overline{\Phi} + \Phi'$

faf-passiveheat: heat added as passive tracer to $T_a$

- $T$ does not change $T = \overline{T}$, $T_a = T'$, $\Phi$ does not change $\Phi = \overline{\Phi}$




| | faf-heat | faf-passiveheat |
|---|---|---|
| T | Perturbed circulation acts on unperturbed and added heat $\Phi'(\overline{T}) + \Phi'(T')$ | Unperturbed circulation acts on unperturbed heat $\overline{\Phi}(\overline{T})$ |
| $T_r$ | Perturbed circulation acts on unperturbed heat $\Phi'(\overline{T})$ | NA (Identical to T) |
| $T_a$ | perturbed circulation acts on added temperature $\Phi'(T')$ | preindustrial circulation acts on added heat $\overline{\Phi}(T')$ |

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# Decomposition of OHU

Using temperature tracers from two experiments, we can decompose ocean heat content change, $\Delta h$

Into components due to

Transport of added heat by unperturbed circulation $\Delta h[\overline{\Phi}(T')]$

Redistribution of unperturbed heat $\Delta h[\Phi'(\overline{T})]$

Perturbed circulation redistributing added heat $\Delta h[\Phi'(T')]$

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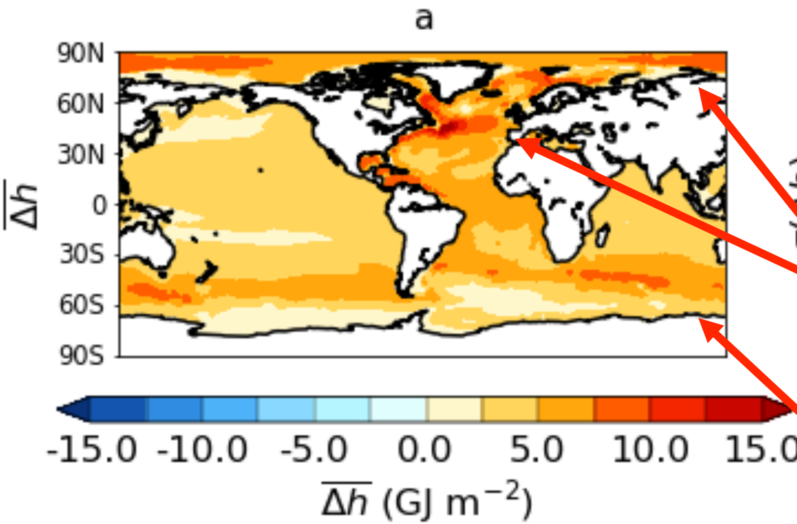
# Decomposition of OHU




faf-heat multi-model mean depth integrated change in ocean heat content

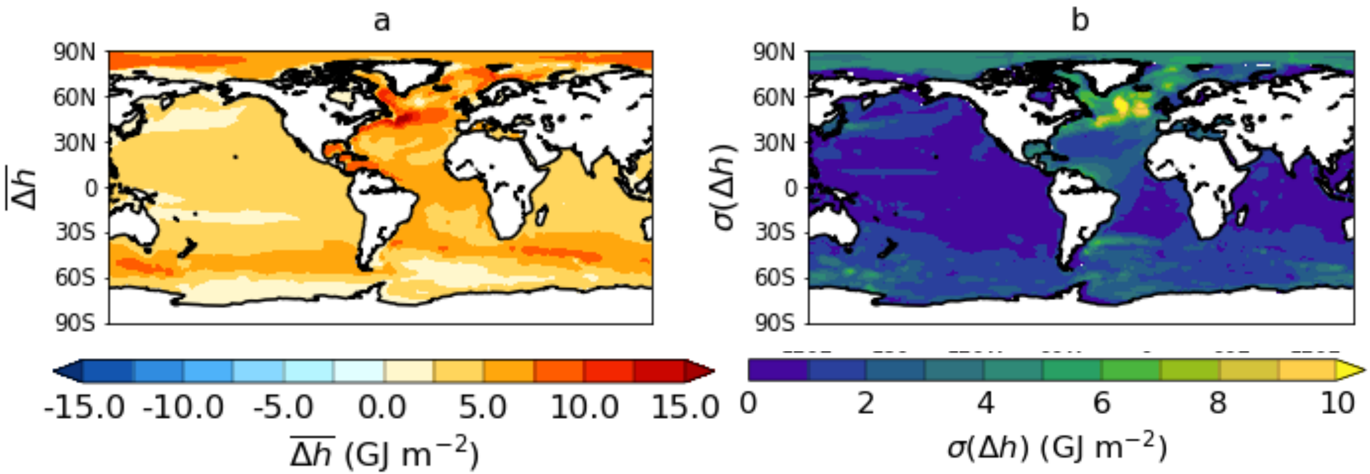
Large heat uptake per area in North Atlantic & Arctic

Large volume-integrated heat uptake in Southern Ocean

N=7 models

# Decomposition of OHU

faf-heat multi-model mean depth integrated change in ocean heat content (N=7 models)  Across-model standard deviation




Models disagree on spatial details of heat storage:

West vs. East Subpolar North Atlantic

Arctic

Southern Ocean South of Australasia, Western Weddell, Atlantic Sector

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# Decomposition of OHU

**Components of OHU as % of total**

Transport of added heat by unperturbed circulation

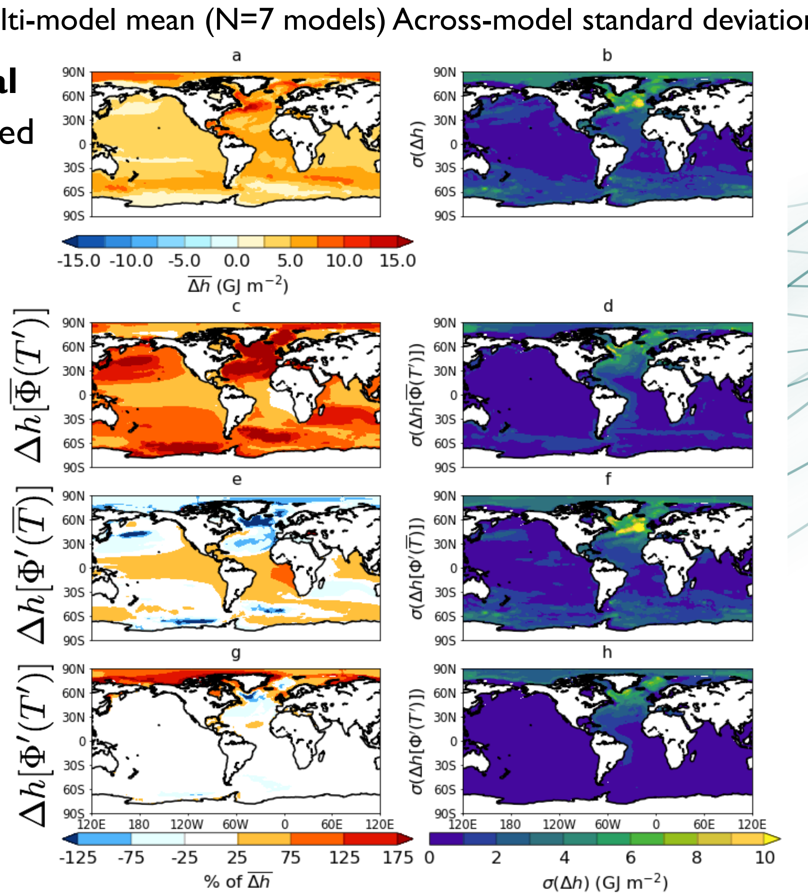
- Largest component
- Dominant in S. Ocean
- Good agreement (except N. Atlantic)

Redistribution of unperturbed heat

- Negative in N. Atlantic: reduced northward transport of heat by weakened circulation
- Poor agreement N. Atlantic, S. Ocean

Perturbed circulation redistributing added heat

- Perturbed circulation causes heat accumulation in Arctic
- Poor agreement

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# Summary of Key Findings

- FAFMIP method provides consistent way to investigate the spread of ocean heat uptake in AOGCMs
    - Force AOGCMs with identical air-sea inputs of heat, freshwater momentum (wind stress)
    - AOGCMs give diverse responses to common forcing
- Diversity in ocean model formulation causes spatial pattern of ocean heat uptake to differ across models
- Models agree that Southern Ocean is large sink for anthropogenic heat (taken up mostly like a passive tracer)
- All models' AMOC sensitive to heat input (but to differing degrees)
- Perturbed circulation weakens the removal of added heat from Arctic, enhancing local heat storage
- Further work will quantify the roles of specific ocean processes (advection, convection, diffusion, mesoscale processes etc.)

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# Thank you for your attention!

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