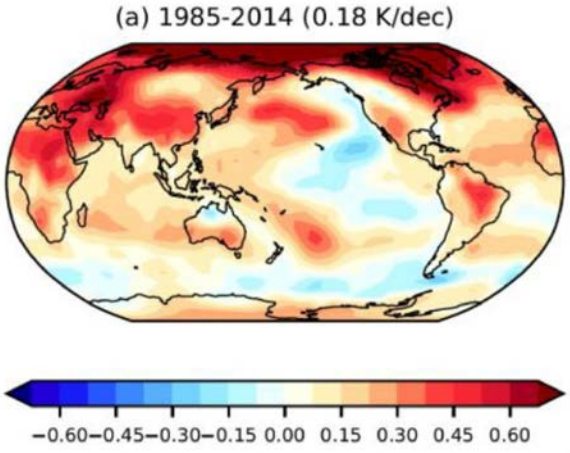
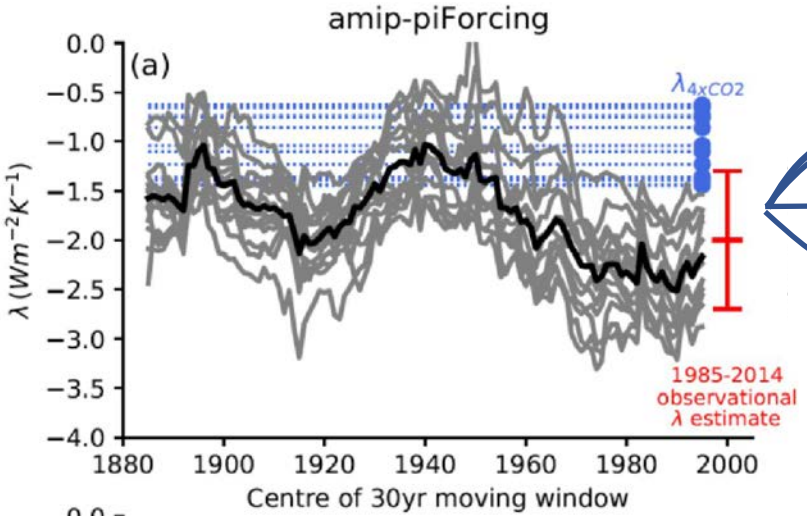
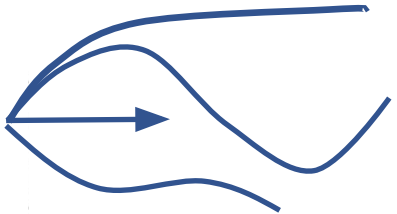
Discussion: Predicting the near future depends on unravelling the near past







We've started to get a good handle on understanding how feedbacks depend on a given SST pattern, so the question becomes, how might the SST patterns evolve in the near future? This critically depends on understanding what caused the recent pattern, since difference hypothesis imply different futures….

Discussion: Predicting the near future depends on unravelling the recent past

A critical issue is to understand what caused the particular configuration of SST patterns over recent decades that drove such a large pattern effect (e.g. strong warming in the western Pacific while cooling in the eastern Pacific and Southern Ocean), since different hypothesis imply different futures. For example, various hypotheses have been put forward (note not an exhaustive list):

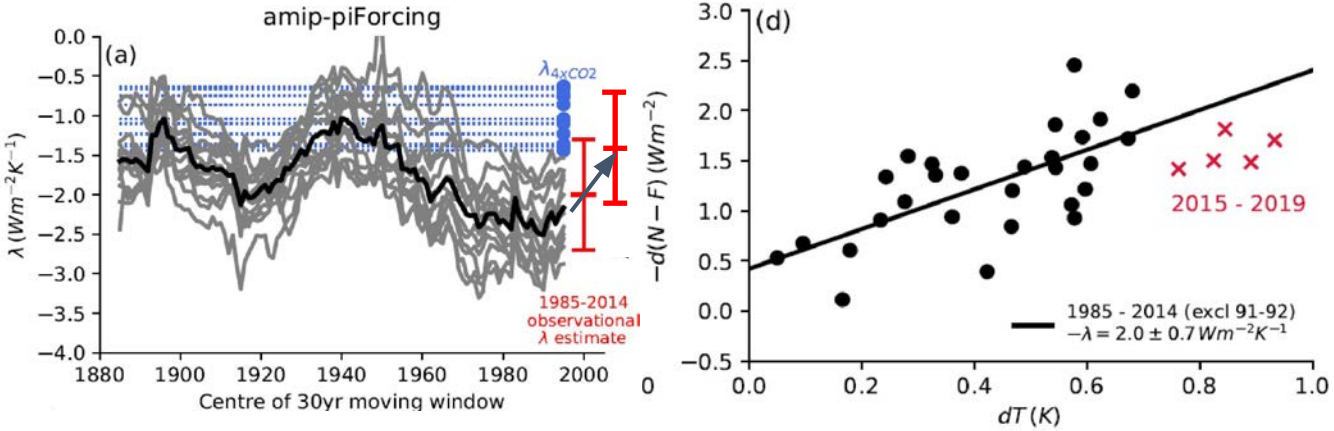
1. *Natural variability:* It could represent a mode of unforced coupled atmosphere-ocean variability (e.g. Xie et al., 2016; Watanabe et al. 2021), albeit an unusual one is that is rarely simulated by AOGCMs (Fueglistaler and Silvers, 2021). In this scenario, we might expect the pattern effect to reduce in the near-future as the configuration of tropical SST patterns shift to more warming in the east than the west. There is some evidence (Loeb et al. 2020; 2021) this has already begun in the most recent years. We might therefore, expect an acceleration of warming trends (unless buffered by changes in heat uptake efficiency).

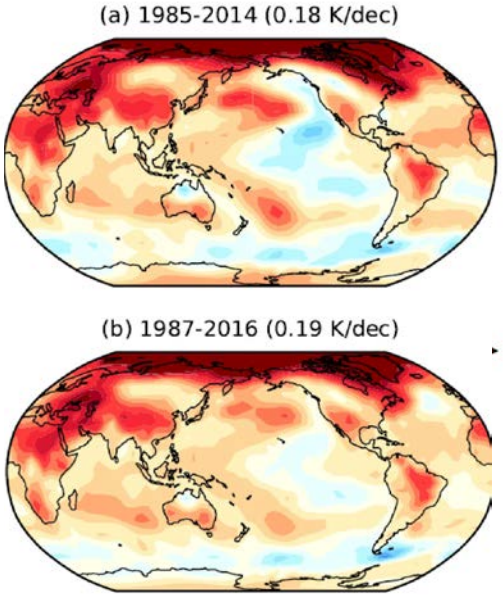
2. *Forcing*: Spatiotemporal variations in anthropogenic forcings such as aerosols (e.g., Smith et al., 2015; Takahashi & Watanabe, 2016; Heede and Fedorov, 2021) or explosive volcanic eruptions (Smith et al. 2015; Gregory et al. 2020) have been implicated in driving tropical Pacific SST patterns. In these scenarios, the pattern effect may decline with the reduction in aerosol emissions in the future, or continue to have decadal variations associated with future volcanism.

3. *Thermostat:* While not explain cooling per se, delayed warming in the eastern Pacific relative to the west is an expected transient response to forcing due to the upwelling of (as yet) unperturbed waters from below (Clement et al., 1993; Heede and Fedorov, 2021). The implication of this is that eventually the eastern Pacific will warm, and hence we might expect the pattern effect to reduce and ECS to increase.

4. *Teleconnections:* from either the Atlantic Ocean (McGregor et al. 2018) or Southern Ocean (Hwang et al. 2017) have potentially driven the tropical Pacific SST patterns. Under the scenario of a Southern Ocean influence, we might expect the pattern effect to reduce as the Southern Ocean surface warms; this could take years to decades if the Southern Ocean temperature trends have been largely mediated by internal variability (e.g., Zhang et al. 2019) but could take centuries or longer if Southern Ocean cooling continues due, for instance, to freshwater input (e.g., Sadai et al. 2020).

Are we already at a critical point?
Has the pattern effect already peaked?





- The major El-Nino event of 2015/16 associated with eastern Pacific warming caused a marked detectable change in the Earth's radiation budget (Loeb et al., 2020; 2021).
- This reduces the observed λ from ~2.0 to 1.5 $Wm^{-2}\,K^{-1}$ when calculated over 1990-2019 (25% reduction in magnitude compared to 1985-2014) and would suggest a much diminished pattern effect over the most recent data.
- *If a shift in the tropical Pacific warning is sustained longer term (perhaps associated with the PDO) the pattern effect may wane and we enter a period of substantially positive feedbacks…*

Meeting Notes:

1) **Follow up, Enable.**
2) **Computing/grant expiring Aug. 2022**

I like the cloud locking framework - It's causal and fully coupled. What to do? A world without cloud feedbacks?

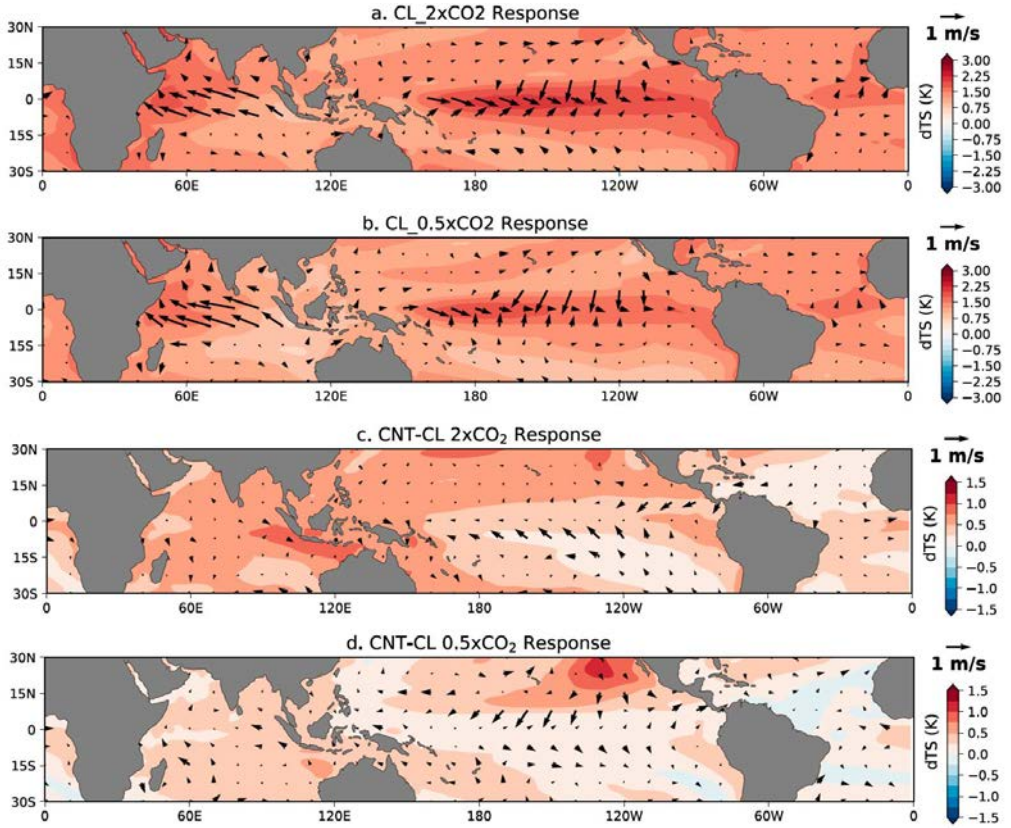


FIG. 15. Tropical ocean total response (average over years 100–150): (a) 2 × CO_2 without cloud radiative feedbacks (CL_2×CO_2) surface temperature change (colors) and surface wind changes (black arrows); (b) as in (a), but for 0.5 × CO_2, (c) as in (a), but 2 × CO_2 cloud influence; and (d) as in (a), but 0.5 × CO_2 cloud influence. Cloud influence is calculated by differencing simulations with and without cloud radiative feedbacks (CNT-CL). Note that in (c) and (d) dTS color contours are scaled at half of (a) and (b).

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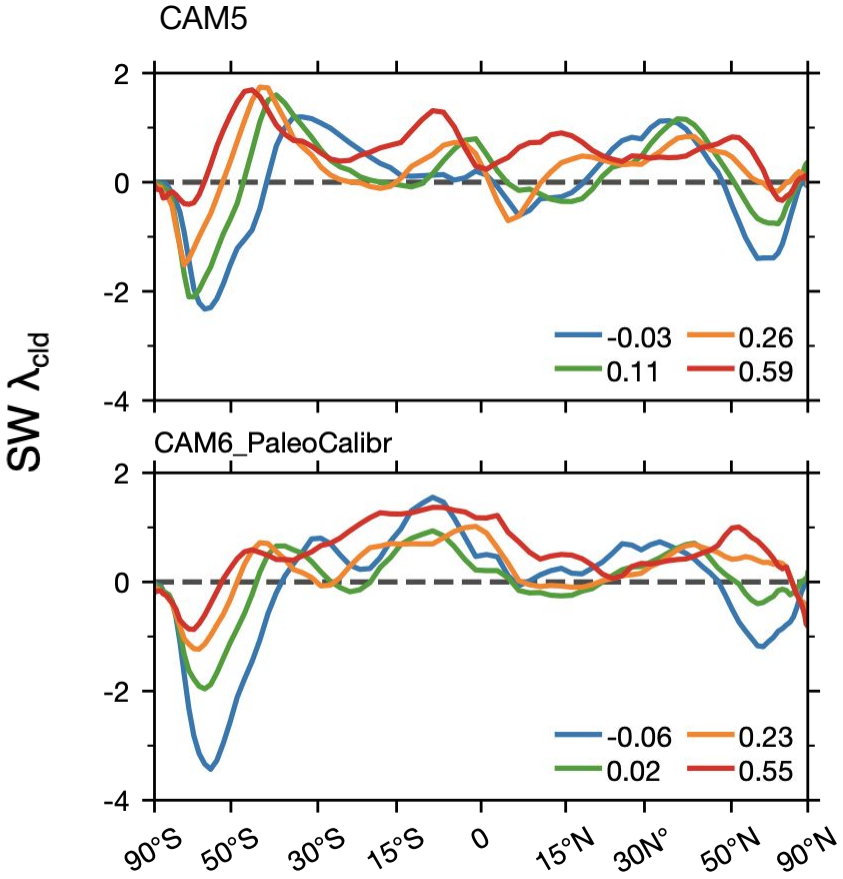
State dependence & the pattern effect: do we have a unified framework?

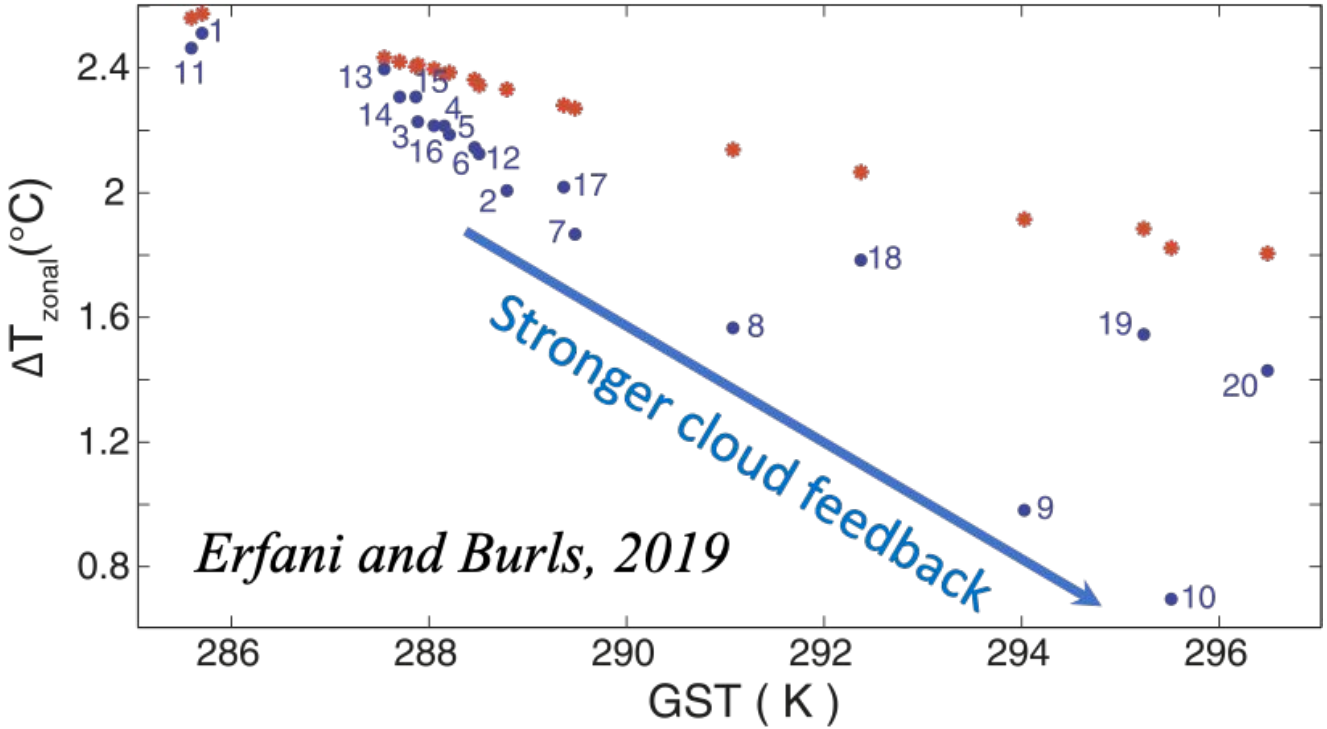


Uniform warming/cooling

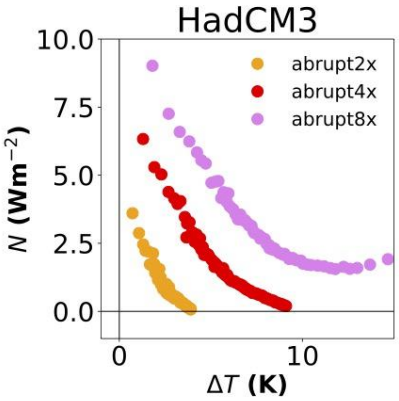
- **SST–4K**
- **piSST**
- **SST+4K**
- **SST+8K**
- **SST+12K**

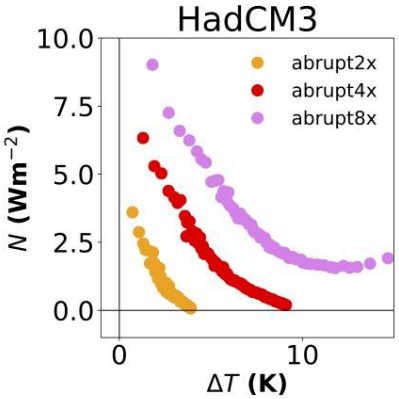
A two-way interaction between clouds & the SST pattern

— ***Can we get a targeted SST pattern through "altering" the cloud feedback?***



See also, Mauritsen & Stevens (2015)


HadCM3
abrupt2x
abrupt4x
abrupt8x
10.0
7.5
5.0
2.5
0.0
N (Wm−2)
0
10
ΔT (K)


HadCM3
abrupt2x
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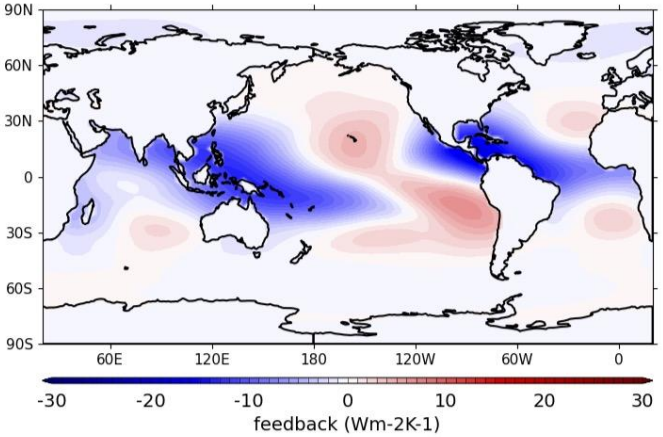
ΔT (K)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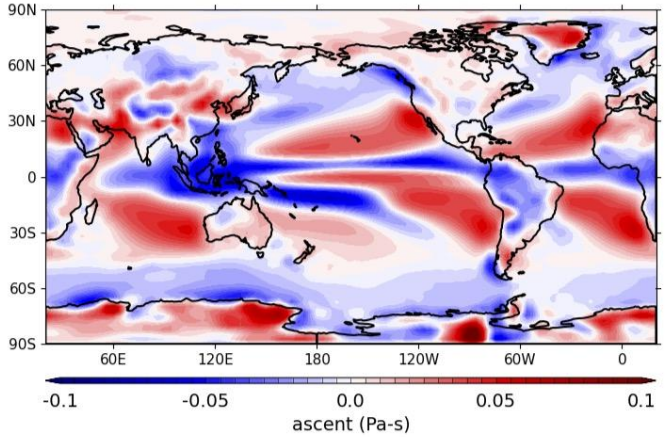
30
feedback (Wm-2K-1)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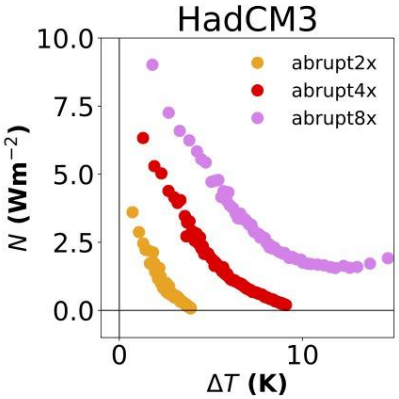
ascent (Pa-s)


HadCM3
abrupt2x
abrupt4x
abrupt8x
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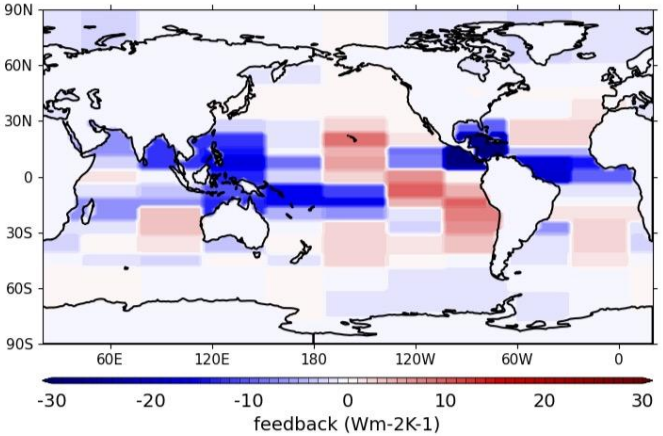
N (Wm^{-2})
0
10
ΔT (K)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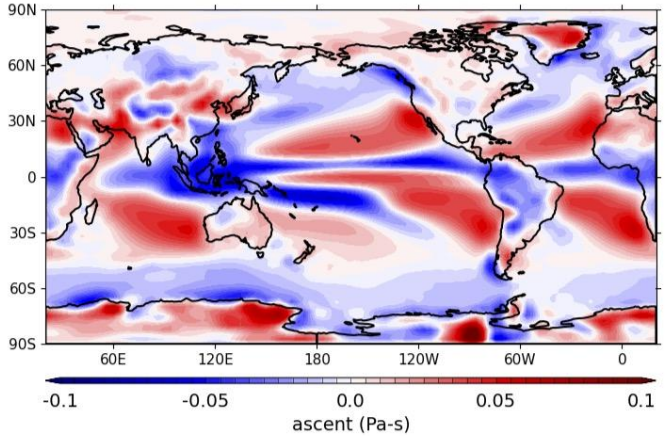
feedback (Wm-2K-1)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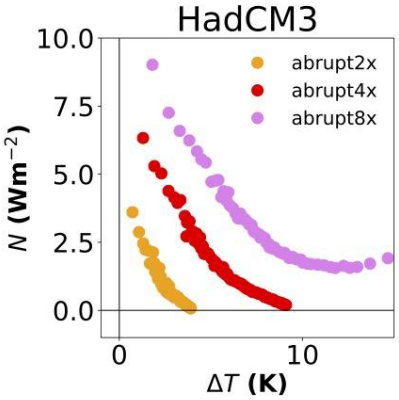
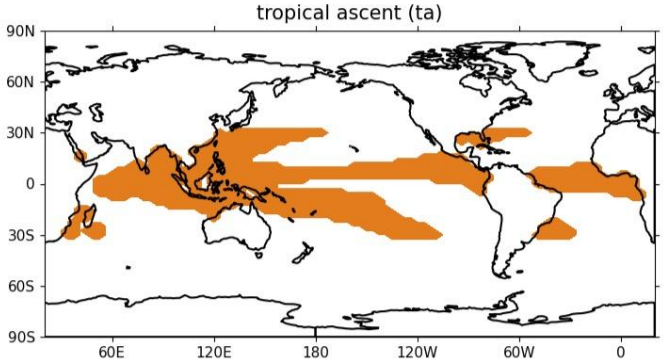
ascent (Pa-s)


HadCM3
abrupt2x
abrupt4x
abrupt8x
10.0
7.5
5.0
2.5
0.0
N (Wm^{-2})
0
10
ΔT (K)


tropical ascent (ta)
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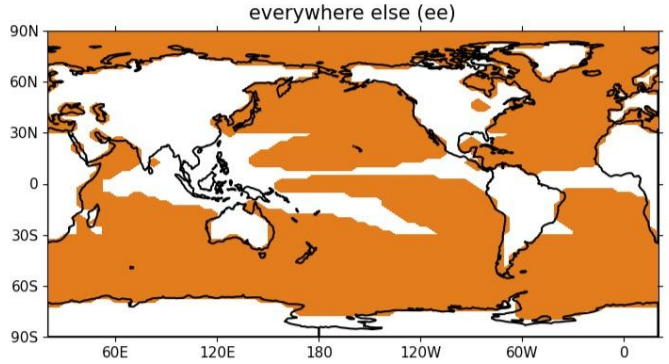
everywhere else (ee)
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90S
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180
120W
60W
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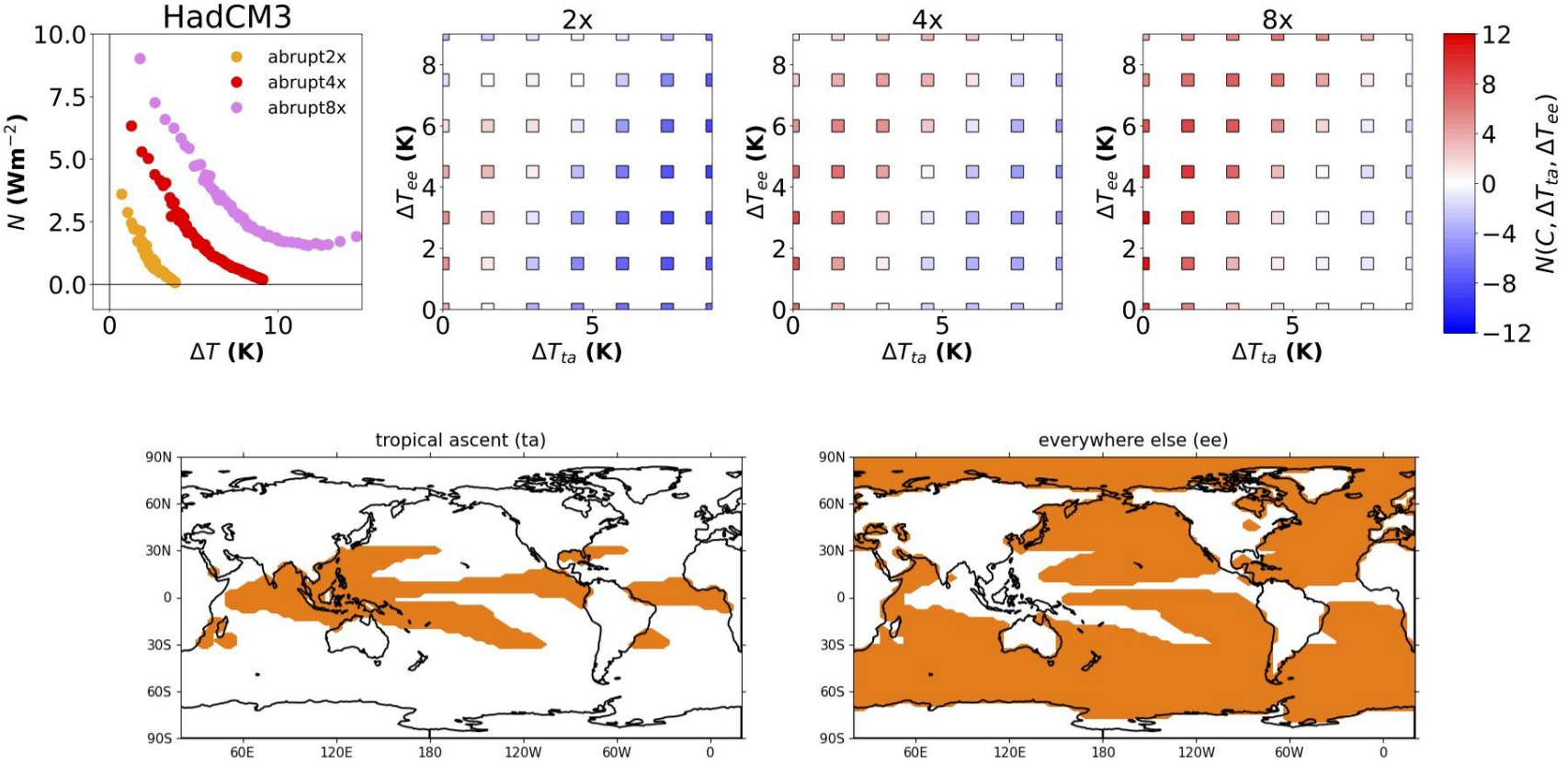
HadCM3
abrupt2x
abrupt4x
abrupt8x
N (Wm⁻²)
ΔT (K)
2x
4x
8x
ΔTee (K)
ΔTta (K)
N(C, ΔTta, ΔTee)
tropical ascent (ta)
everywhere else (ee)
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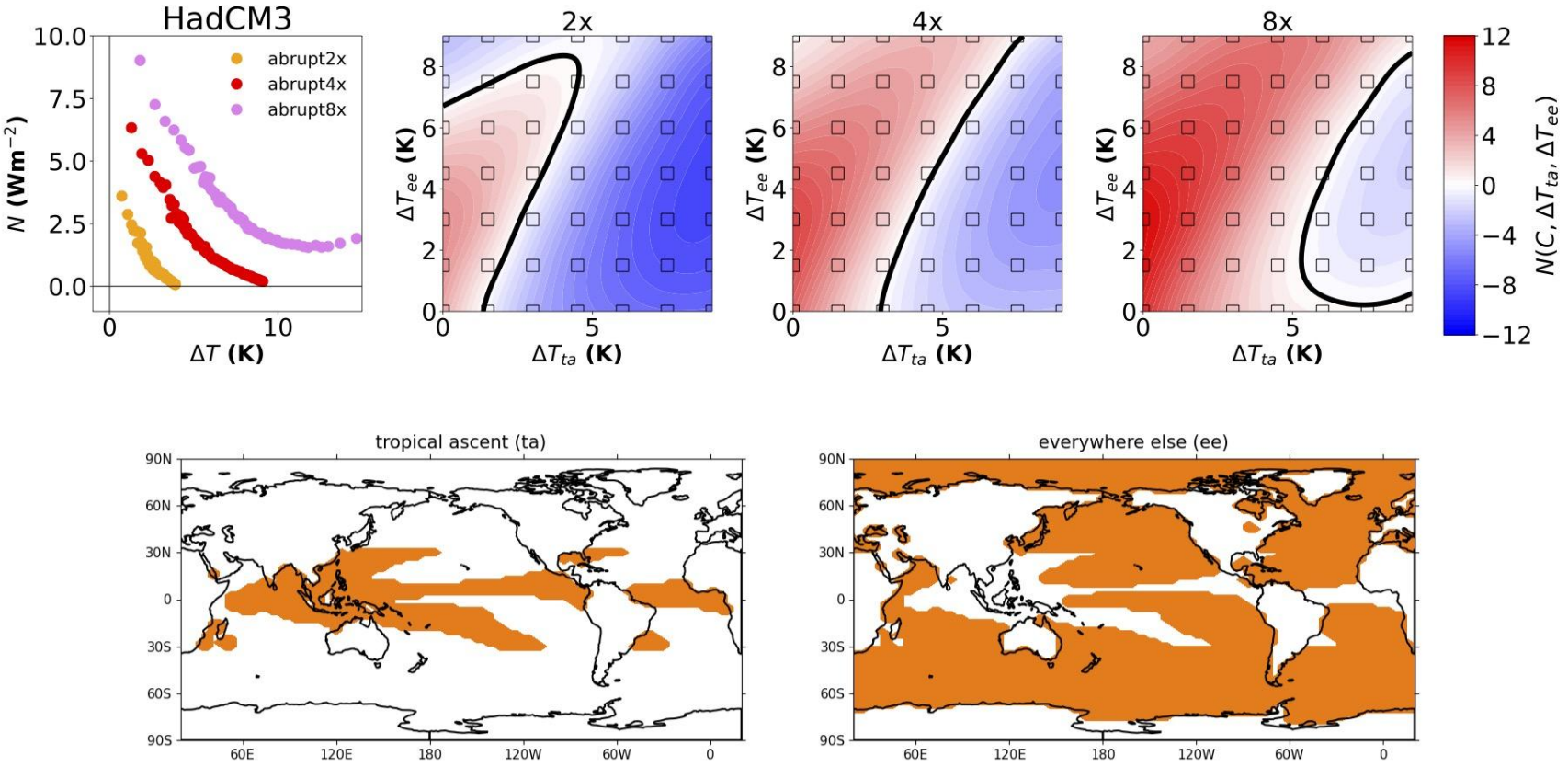
HadCM3
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ΔTee (K)
ΔTta (K)
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tropical ascent (ta)
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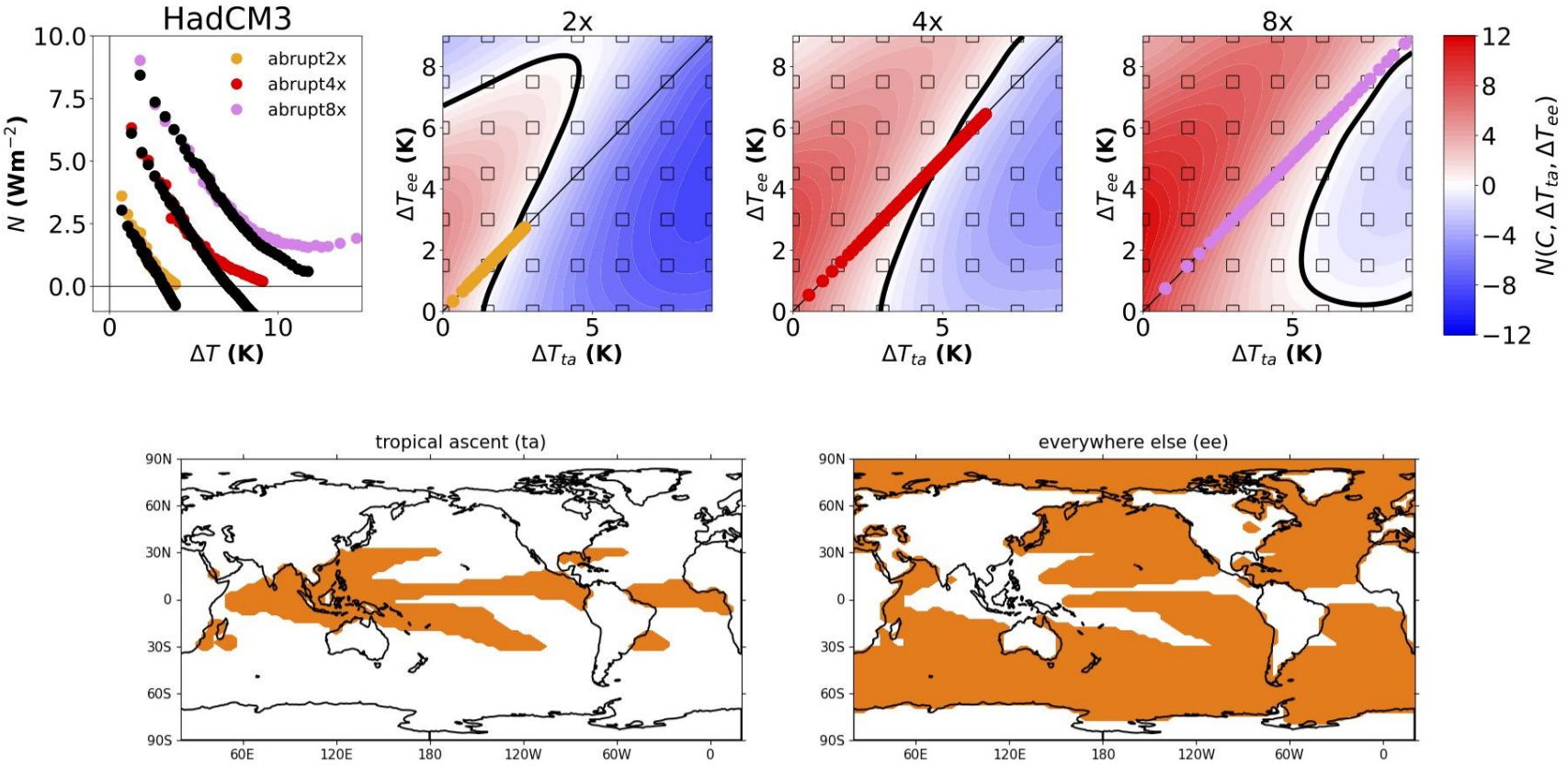
HadCM3
abrupt2x
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N (Wm⁻²)
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ΔTee (K)
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N(C, ΔTta, ΔTee)
tropical ascent (ta)
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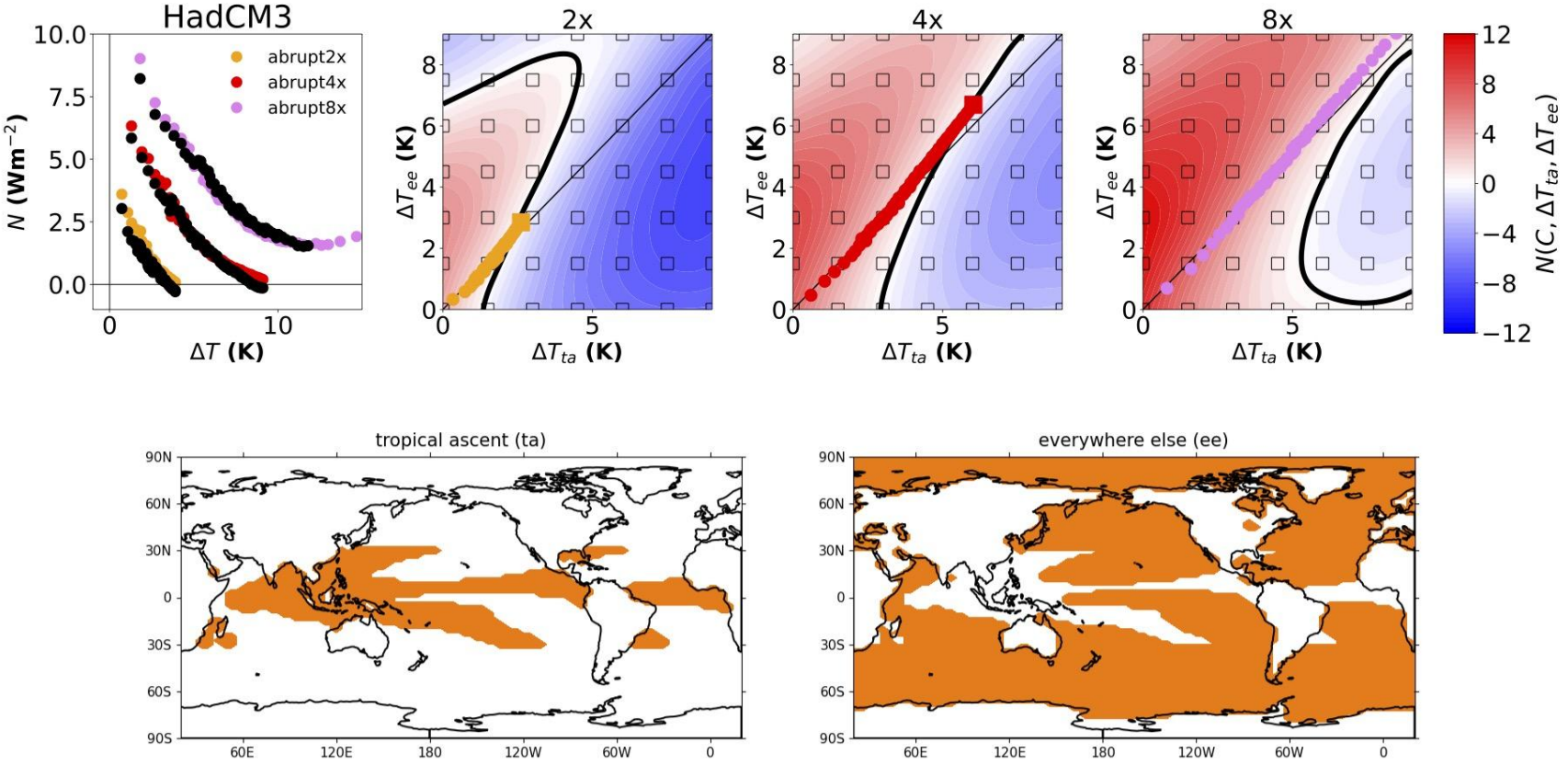
HadCM3
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abrupt8x
N (Wm⁻²)
ΔT (K)
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4x
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ΔTee (K)
ΔTta (K)
N(C, ΔTta, ΔTee)
tropical ascent (ta)
everywhere else (ee)
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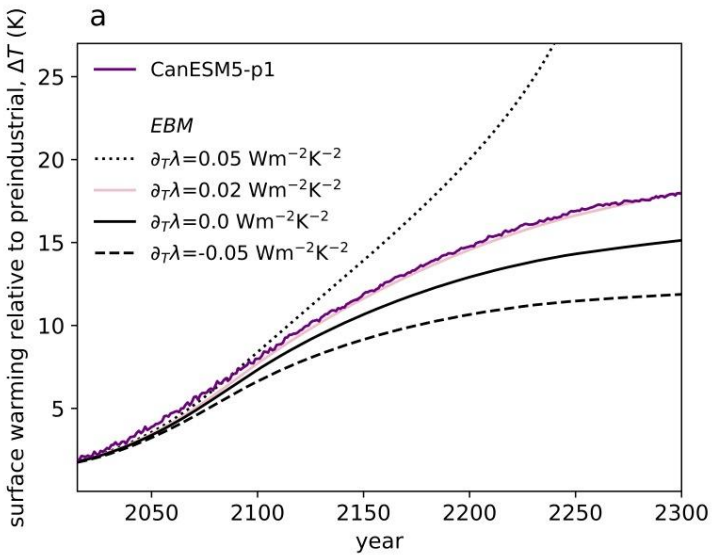
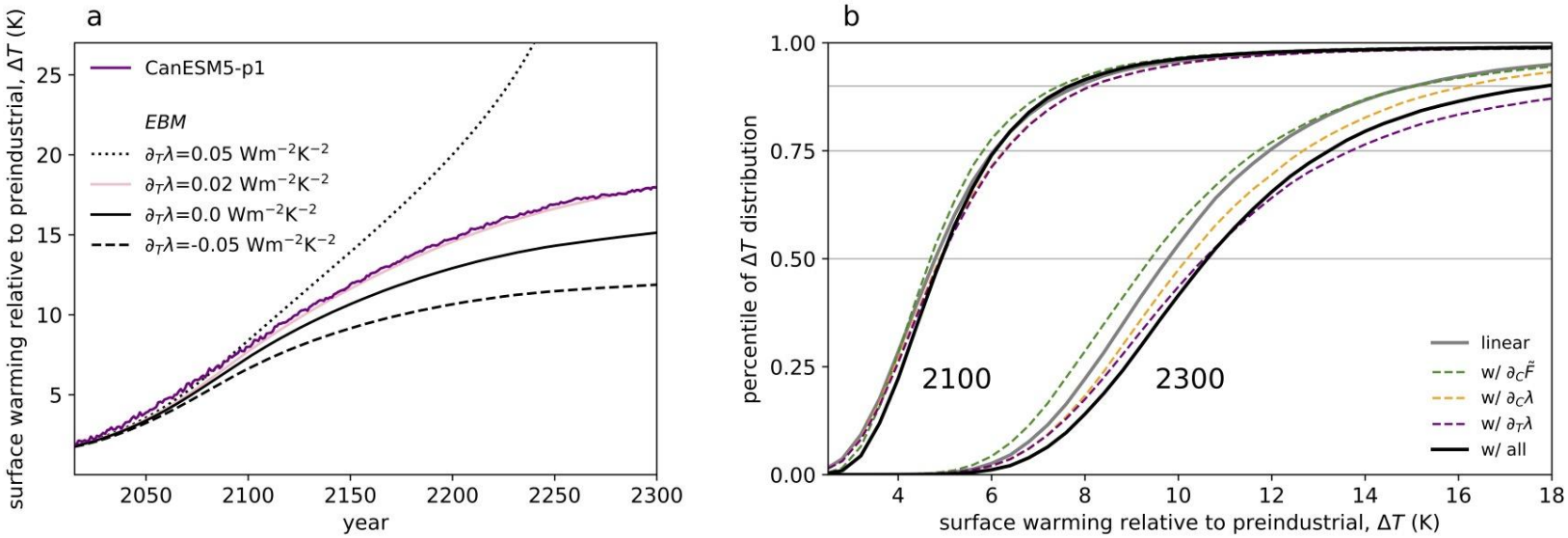

a
CanESM5-p1
EBM
$\partial_T\lambda$=0.05 Wm^{-2}K^{-2}
$\partial_T\lambda$=0.02 Wm^{-2}K^{-2}
$\partial_T\lambda$=0.0 Wm^{-2}K^{-2}
$\partial_T\lambda$=-0.05 Wm^{-2}K^{-2}
surface warming relative to preindustrial, ΔT (K)
25
20
15
10
5
2050
2100
2150
2200
2250
2300
year


a
CanESM5-p1
EBM
$\partial_T\lambda$=0.05 Wm^{-2}K^{-2}
$\partial_T\lambda$=0.02 Wm^{-2}K^{-2}
$\partial_T\lambda$=0.0 Wm^{-2}K^{-2}
$\partial_T\lambda$=-0.05 Wm^{-2}K^{-2}
surface warming relative to preindustrial, ΔT (K)
year
b
percentile of ΔT distribution
surface warming relative to preindustrial, ΔT (K)
2100
2300
linear
w/ $\partial_C\tilde{F}$
w/ $\partial_C\lambda$
w/ $\partial_T\lambda$
w/ all

A simple model for SST anomaly

$$\mathbf{x}(k+1) = \mathbf{A}\mathbf{x}(k) + \mathbf{u}(k+0.5) \qquad (1)$$

$\mathbf{x}$: SST anomaly, $\mathbf{A}$: time-stepping matrix, including effects of both A & O adjustments

$\mathbf{u}$: SST increment due the effective radiative forcing, $u = \dfrac{\Delta t}{\rho C_p \Delta z_{\text{top}}} u_{\text{RF}}$

Eq (1) is a generalisation of the top-layer model $C_u \dfrac{\partial T_u}{\partial t} = F - \rho T_u$

Simplify the SST system by projecting SST onto eigenmodes

$$\mathbf{AW} = \mathbf{W}\boldsymbol{\Lambda},\ \tilde{\mathbf{x}} = \mathbf{W}^{-1}\mathbf{x},\ \tilde{\mathbf{u}} = \mathbf{W}^{-1}\mathbf{u},\ \tilde{\mathbf{x}}(k+1) = \mathbf{W}^{-1}\mathbf{A}\mathbf{W}\tilde{\mathbf{x}}(k) + \tilde{\mathbf{u}}(k+0.5)$$

$$\tilde{\mathbf{x}}(k+1) = \boldsymbol{\Lambda}\tilde{\mathbf{x}}(k) + \tilde{\mathbf{u}}(k+0.5)$$

Dynamics of different eigenmodes are independent, hence can be examined separately.

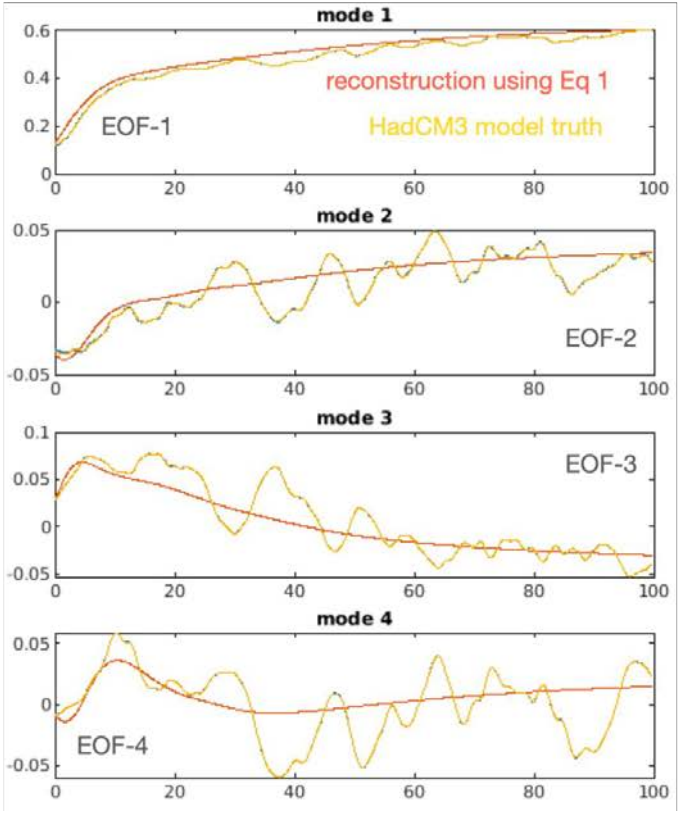
$\tilde{x}_n(k+1) = \lambda_n \tilde{x}_n(k) + \tilde{u}_n(k)$, for stable systems $|\lambda_n| < 1$

If $\tilde{u}_n$ is constant, $\tilde{x}_n(k) = C\lambda_n^k + \dfrac{\tilde{u}_n}{1-\lambda_n}$, $\tilde{x}_n(\infty) = \dfrac{\tilde{u}_n}{1-\lambda_n}$

from Quran Wu)

HadCM3 abrupt4xCO2 SST EOFs

$$\mathbf{x}(k+1) = \mathbf{A}\mathbf{x}(k) + \mathbf{u}(k+0.5) \qquad (1)$$



In practice, we use EOFs as the coordinate system for Eq 1 to reduce the spatial dimension of the system.

We can fit Eq 1 to SST from a HadCM3 experiment to derive the A matrix for that experiment.

With the A matrix, we can run Eq 1 forward in time from initial conditions to reconstruct evolution of SST in the HadCM3 experiment.

Figure on the left shows an example for the first 100 years of the HadCM3 abrupt4x experiment.

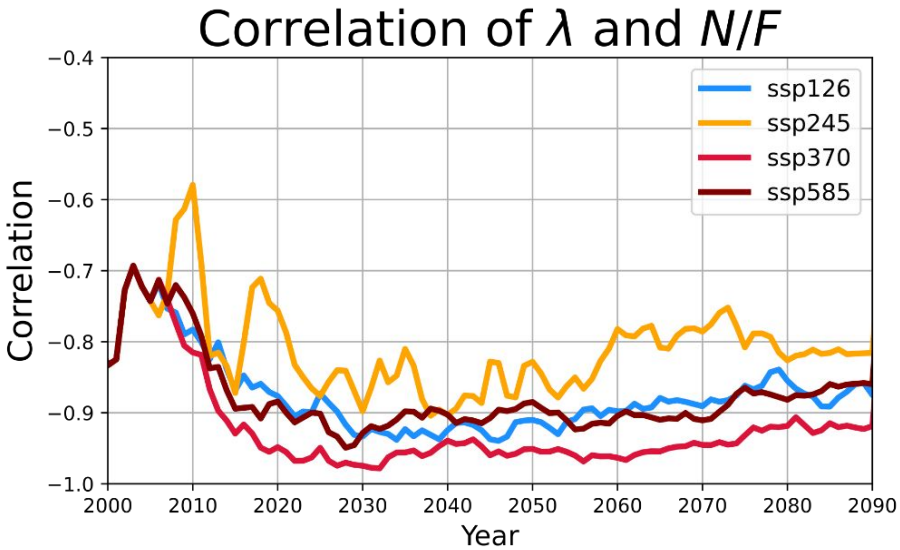
Eq 1 can reproduce the forced response well, but it fails to capture the unforced variability.

Question 1:

What is the relationship between ocean heat uptake, radiative feedbacks, and the pattern effect?

- Can't explain the variance across models in OHU using global-mean surface temperature alone (e.g., Gregory et al., in prep)

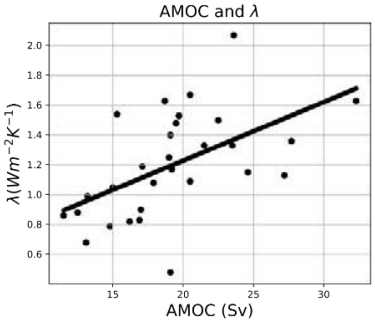
- Do models that have greater OHU tend to create SST patterns that weaken global feedbacks?

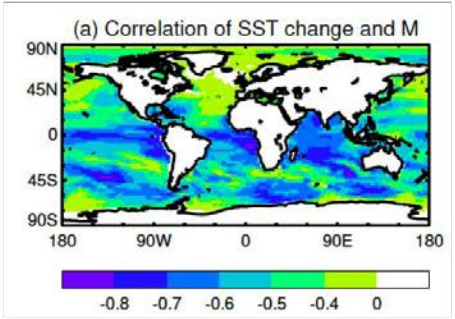


Similar to Williams et al., (R~-0.8 for 1pctCO2);
Vakilifard et al., in prep (R<-0.8 for RCP4.5)

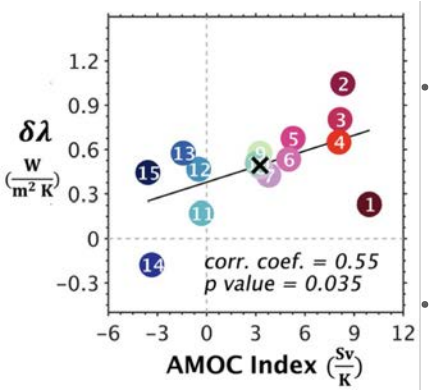
Question 1.5:

How is the AMOC and other aspects of the background ocean state linked to the pattern effect?





- AMOC control strength is linked to radiative feedback strength as well as OHUE (Gregory et al., in prep).
- AMOC strength correlates with a characteristic warming pattern.



- Others find a relationship between *change* in AMOC (late versus early) and *change* in λ (Yuan-Jen Lin et al., 2019).
-

Question 1.5:

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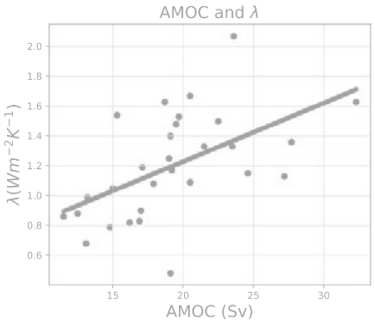
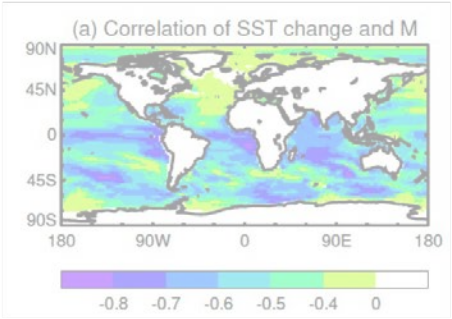


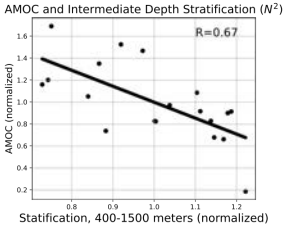


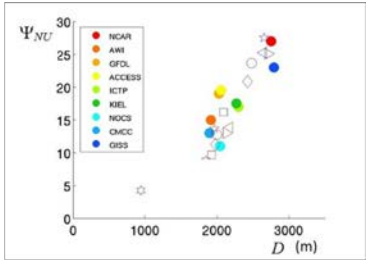
- AMOC control strength is linked to radiative feedback strength as well as OHUE (Gregory et al., in prep).
- AMOC strength correlates with a characteristic warming pattern.

- Others find a relationship between *change* in AMOC (late versus early) and *change* in λ (Yuan-Jen Lin et al., 2019).

AMOC correlates with other aspects of the background ocean state

- 1/Kgm (eddy-driven overturning in SO), depth of stratification (e.g., Marshall et al., 2017, Saenko et al., 2018).





Question 1.5:

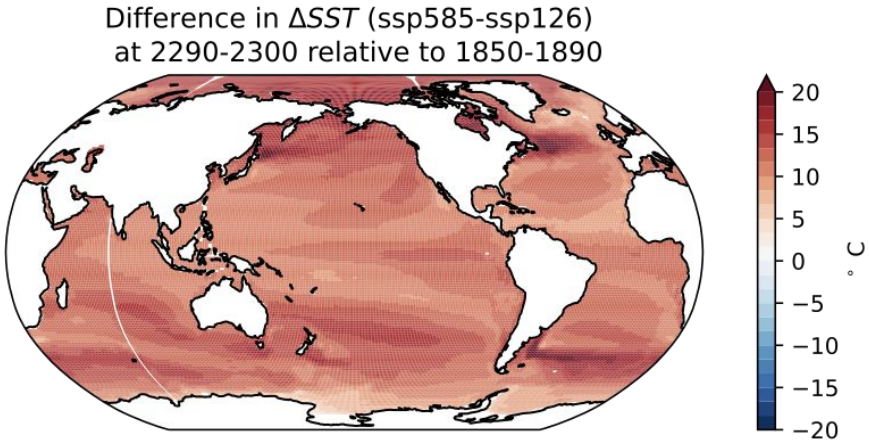
How is the AMOC and other aspects of the background ocean state linked to the pattern effect?

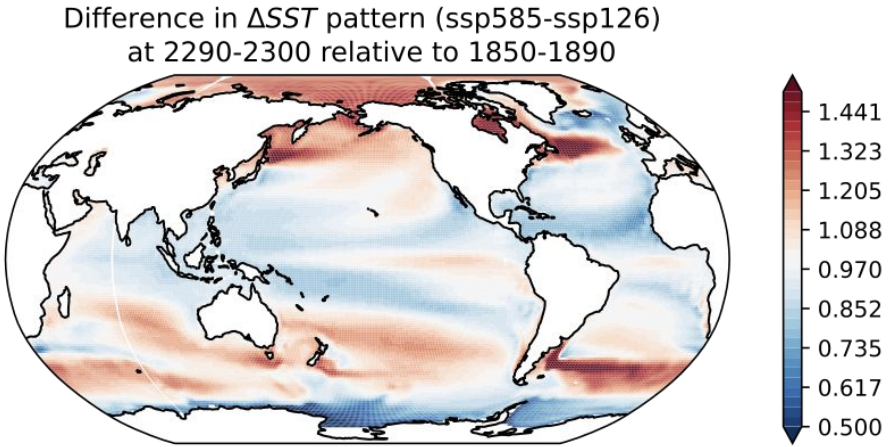
- **What couples AMOC to the strength of radiative feedbacks:** AMOC, change in AMOC, or other aspects of the ocean state that correlate with AMOC (stratification, inter-basin coupling, SO processes, meridional heat transport, etc…)

- **What's the best framework for studying this?** Coupling an atmosphere GF and an ocean GF? Coupling an atmosphere GF to a dynamic ocean? Coupling an MEBM to a simple ocean model (Bonan et al., in prep)?

Question 2:

How much does the forcing history impact the long term SST response, and thus the pattern effect?





CanESM5 long-term warming pattern in ssp 585 - ssp 126

- Reduced east-west gradient in the equatorial Pacific, more SO warming.