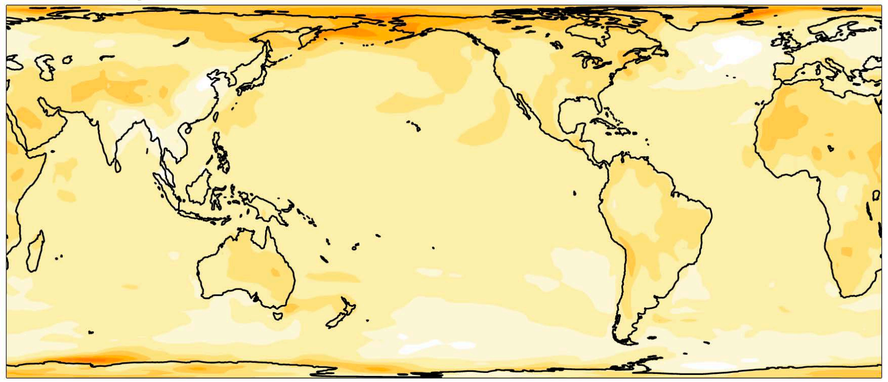
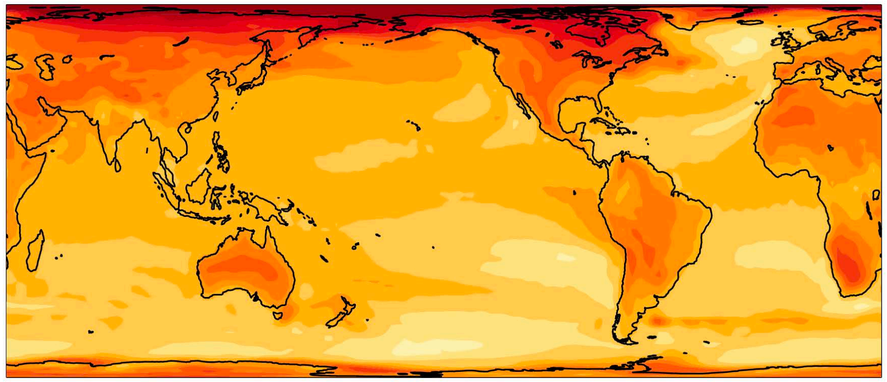
The pattern effect: perspectives and history

Maria Rugenstein with input from Cristi Proistosescu,
Kyle Armour, Yue Dong, Kris Karnauskas, and Norman Loeb

Defining the pattern effect

historical warming





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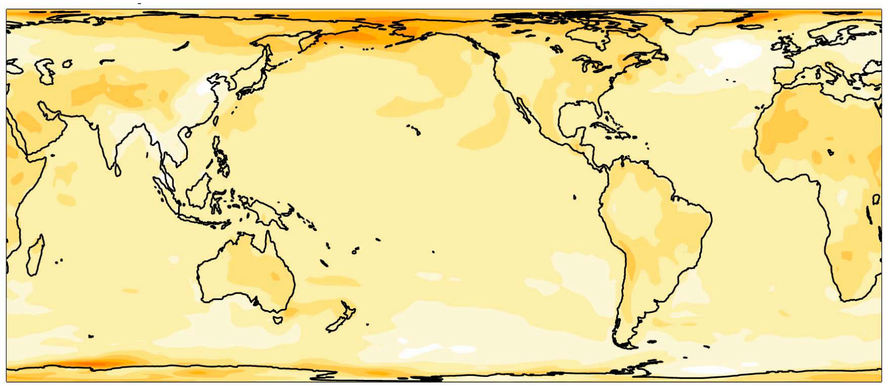

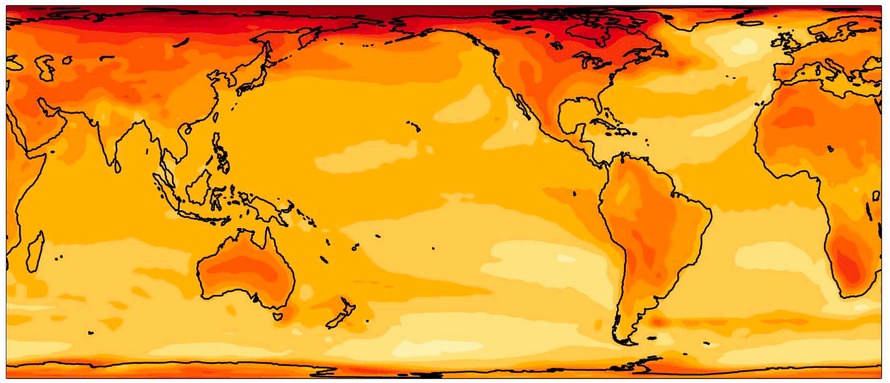

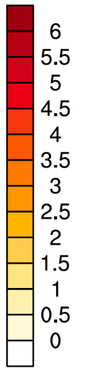

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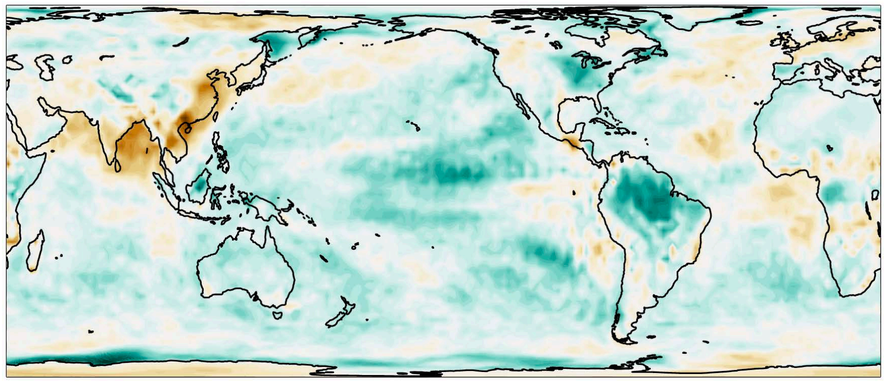

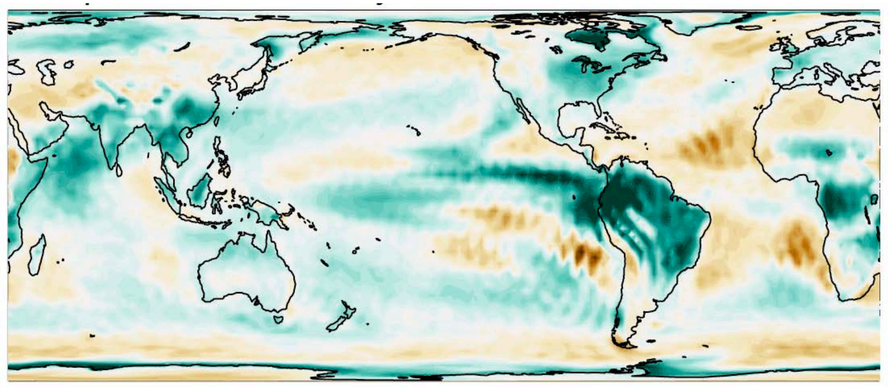

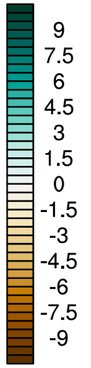

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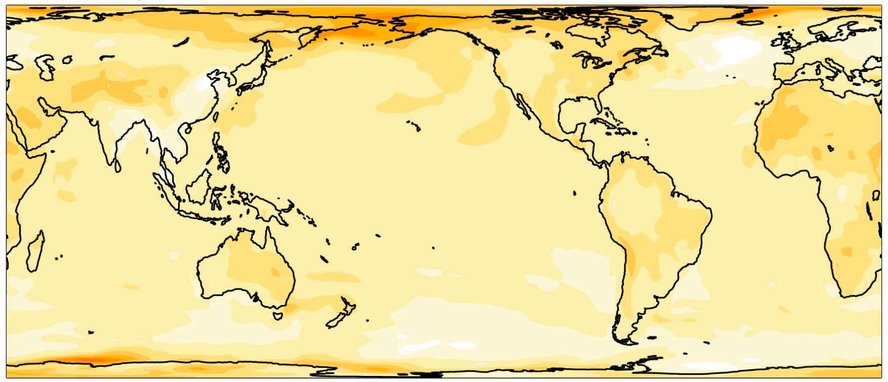

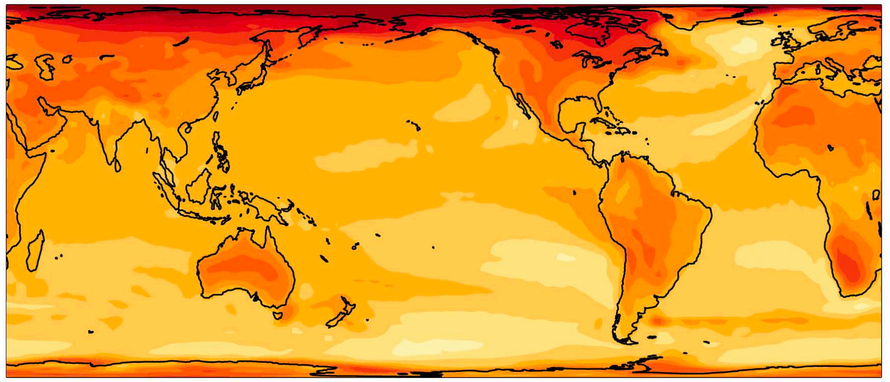

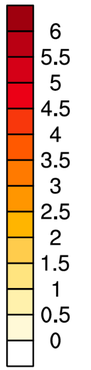

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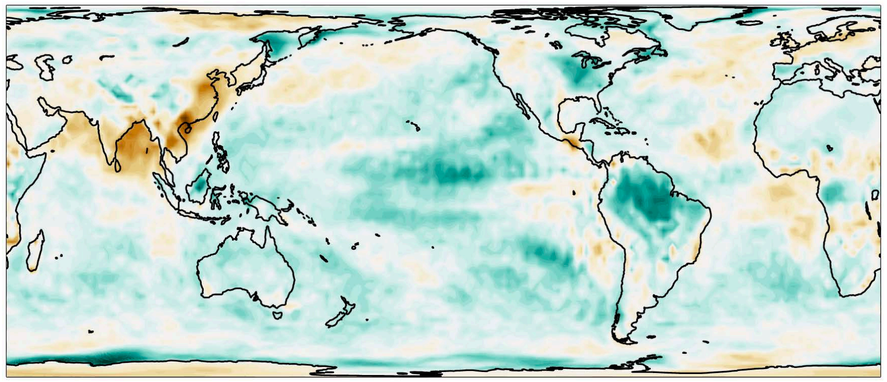

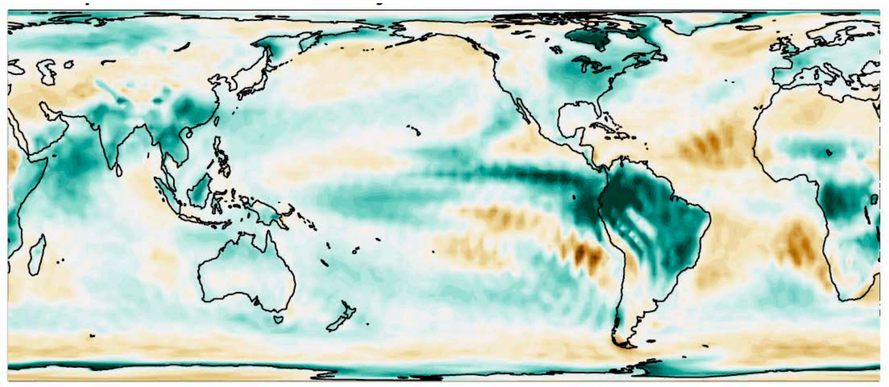

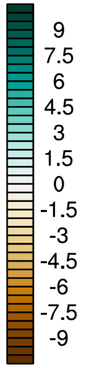

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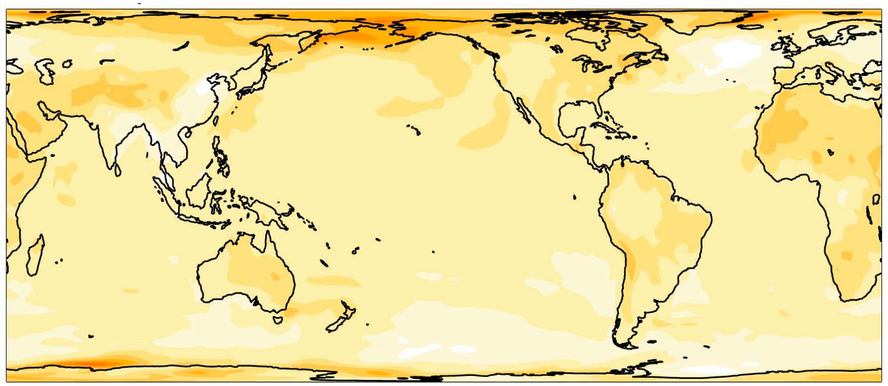

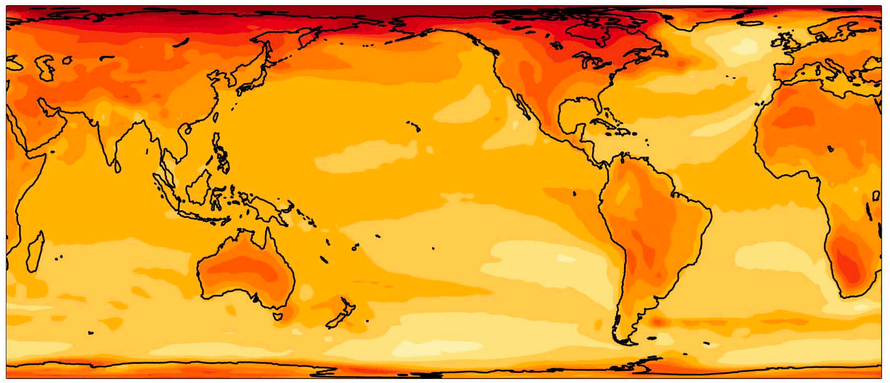

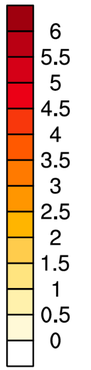

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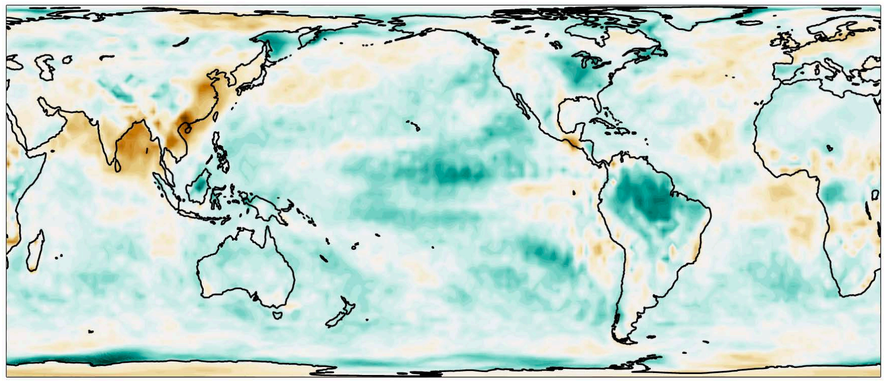

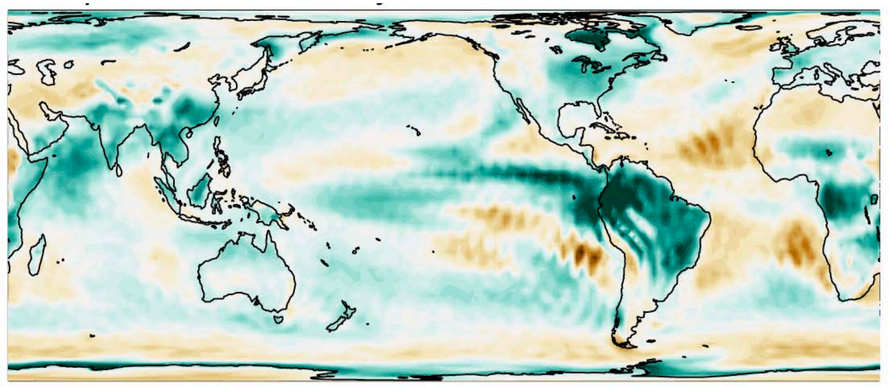

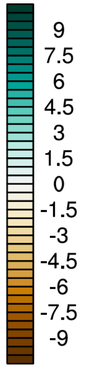

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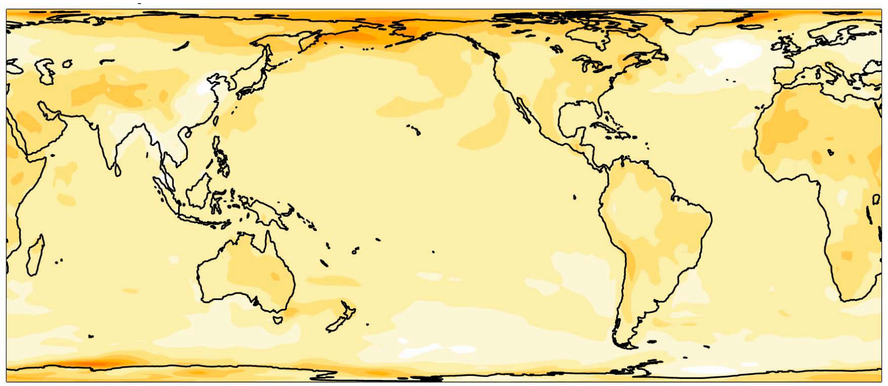

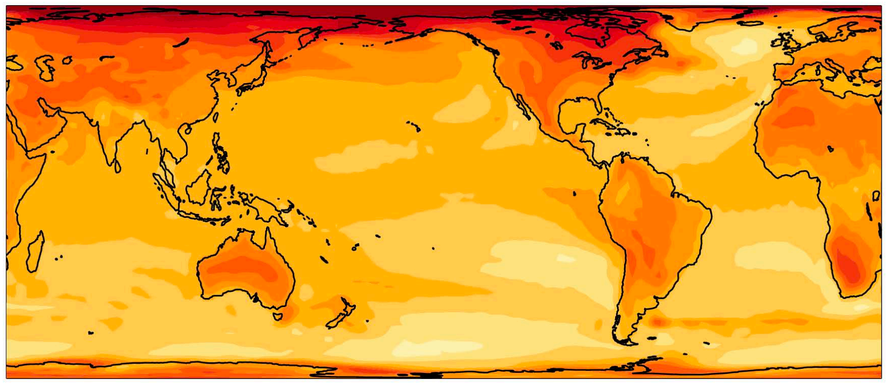

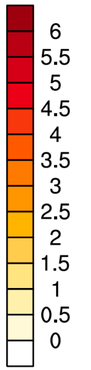

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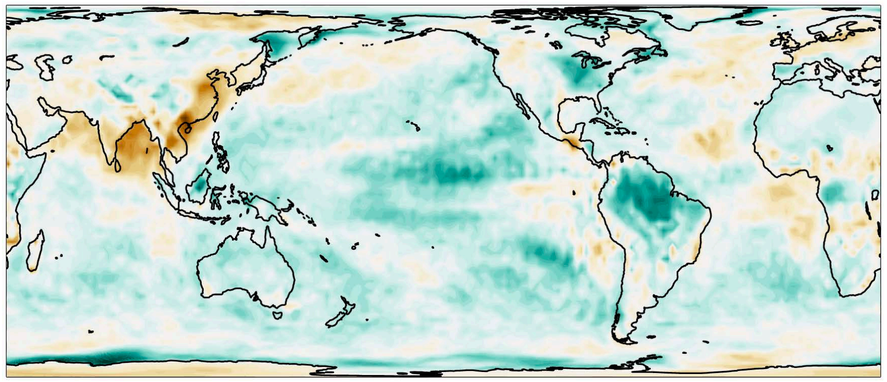

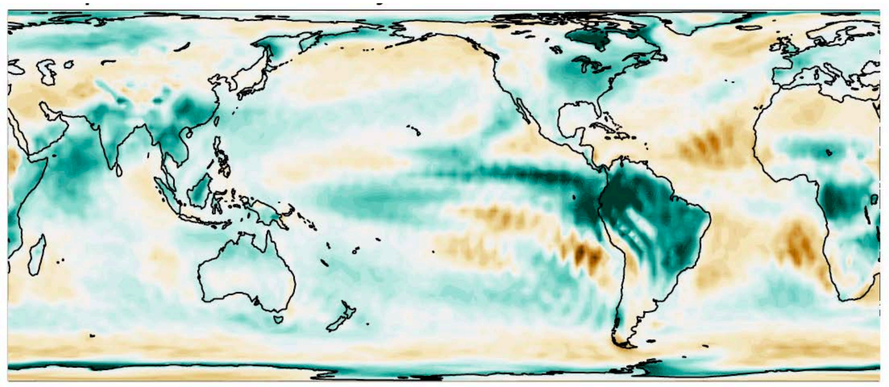

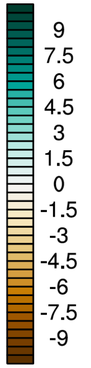

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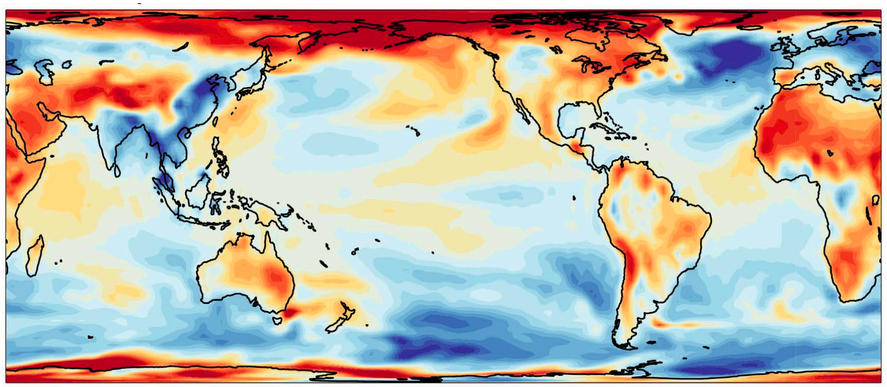

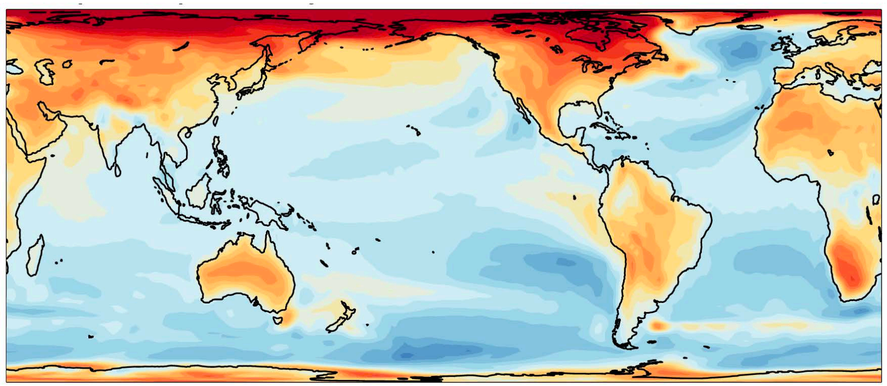

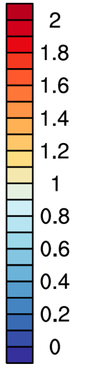

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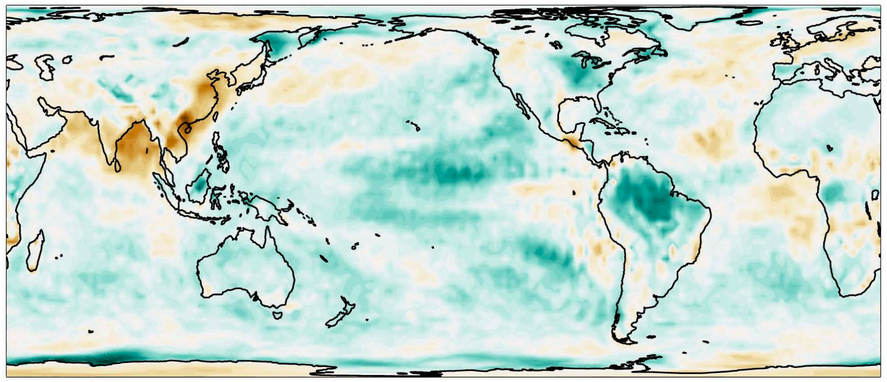

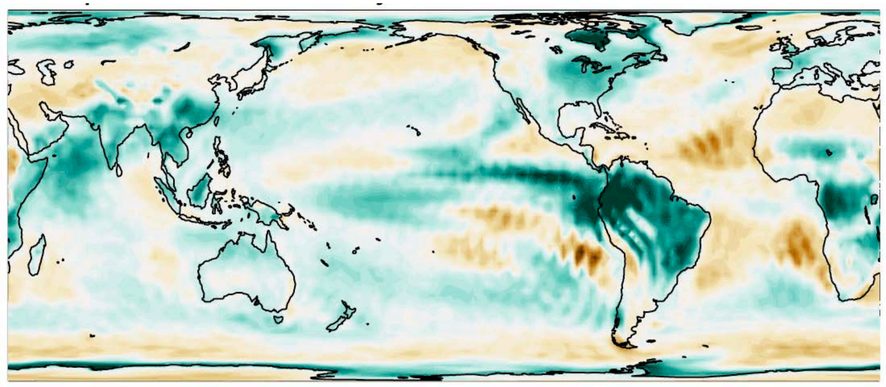

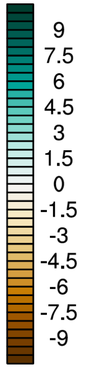

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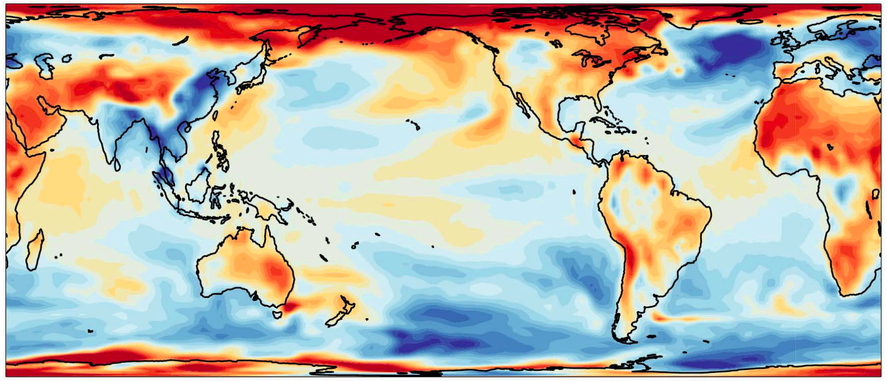
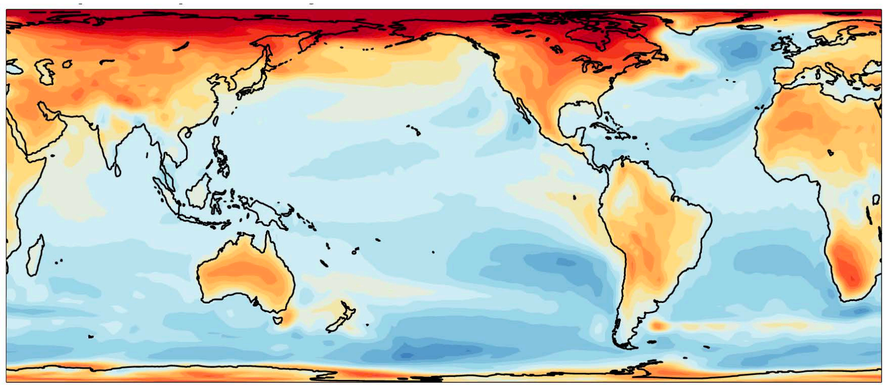
Relevance of the pattern effect: ECS estimation

historical warming





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$$\lambda = \frac{\Delta R}{\Delta T} = \frac{N - F}{\Delta T}$$

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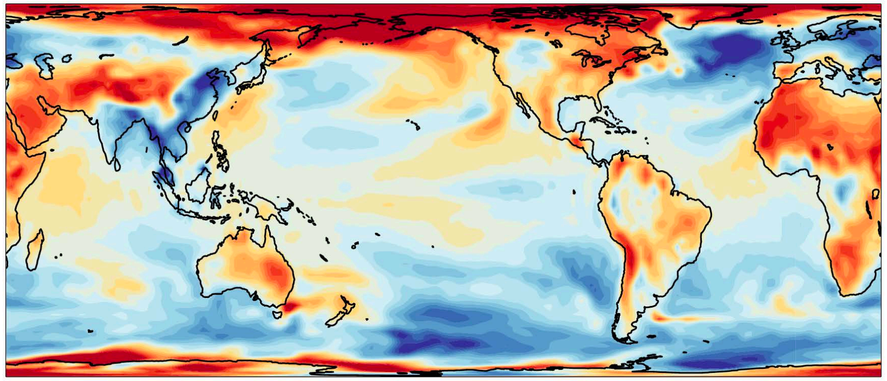

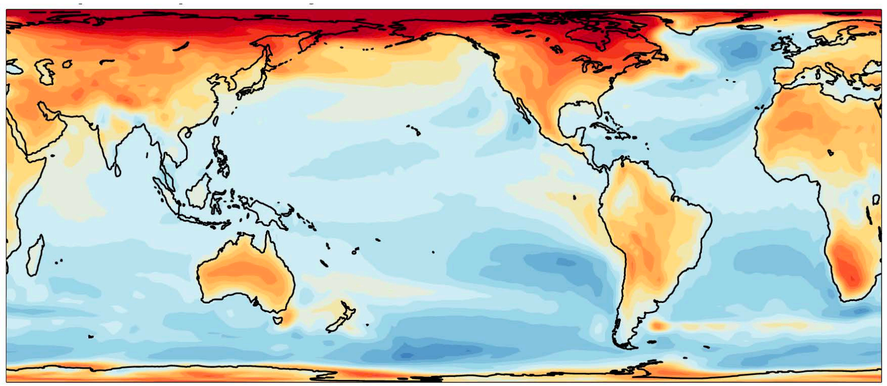

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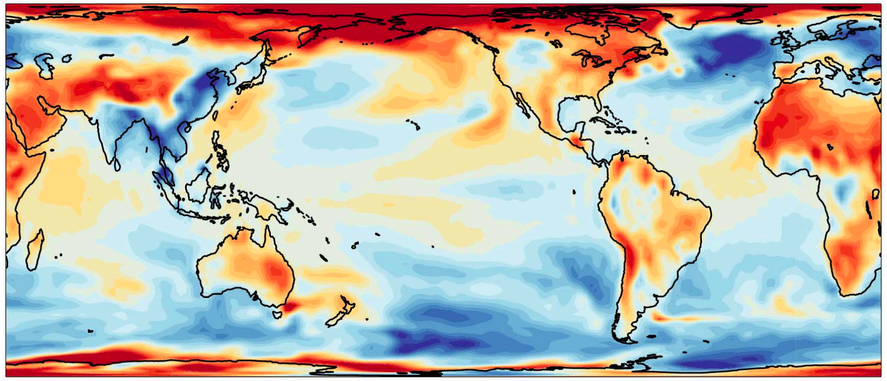

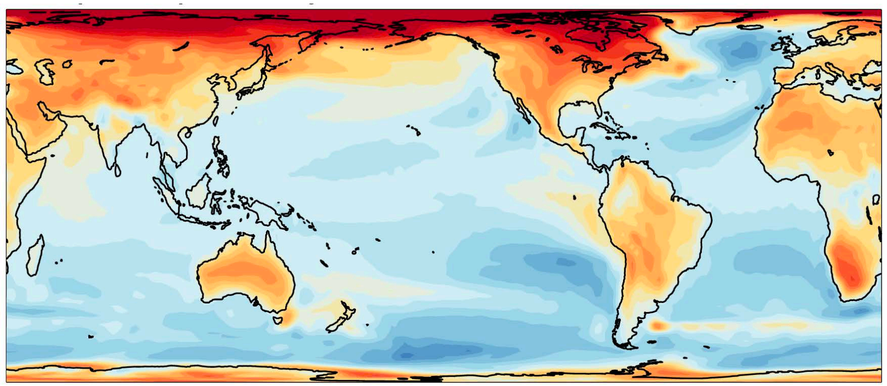

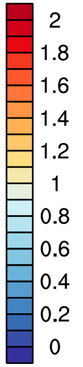

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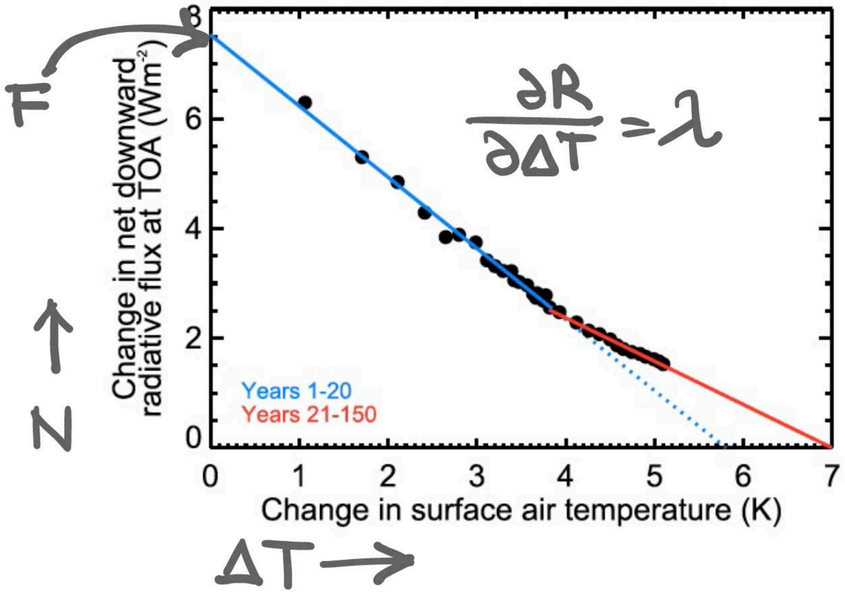

modified from Andrews et al. 2015

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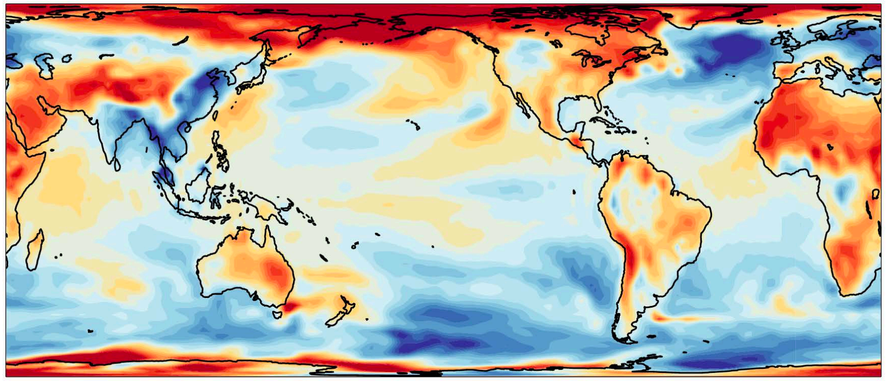

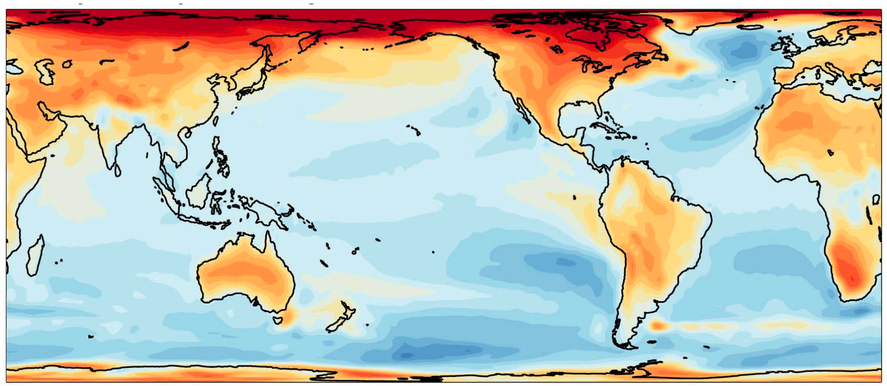

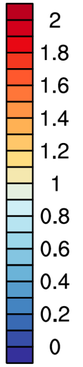

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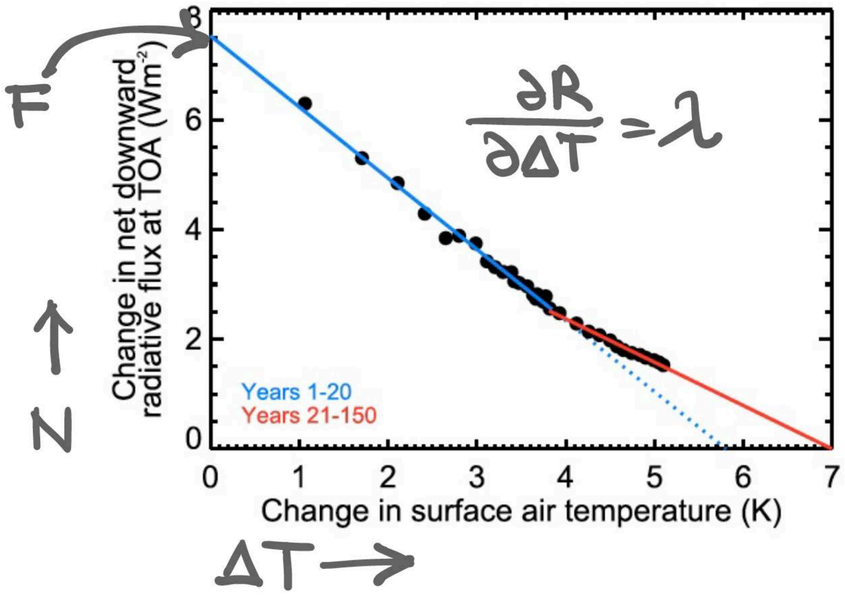

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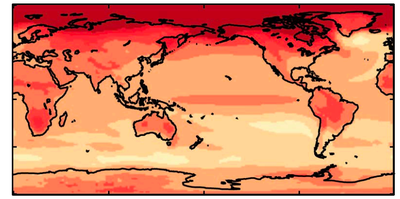
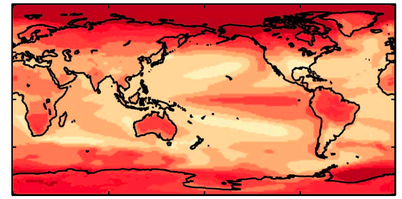
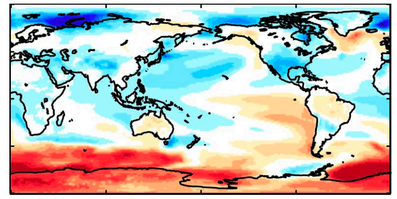


yr 1-20



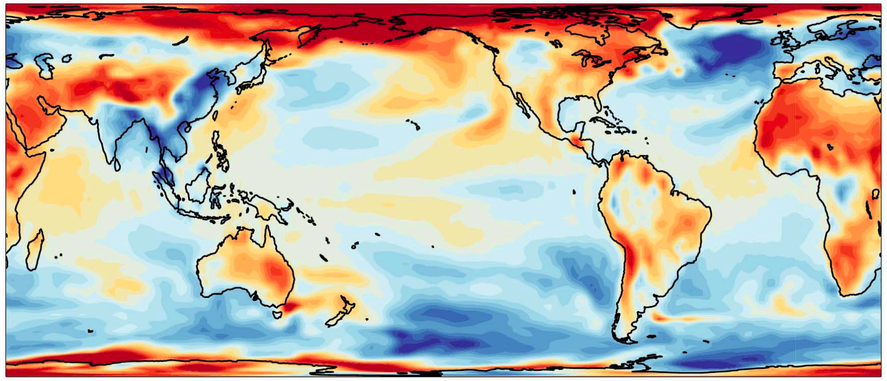
yr 21-150

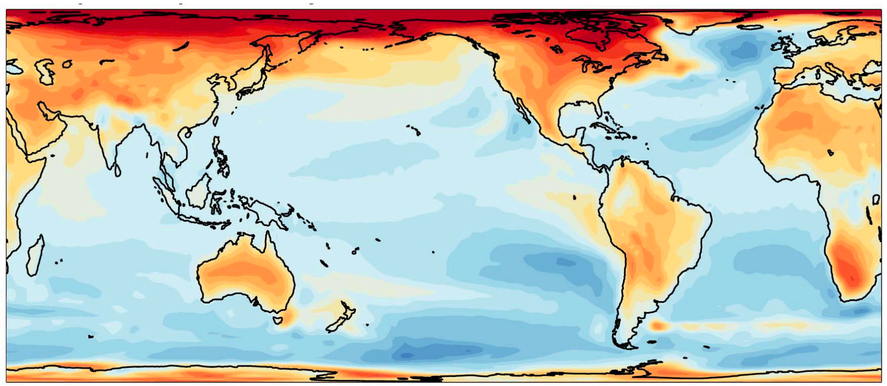


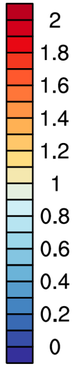
difference

Relevance of the pattern effect: ECS estimation

historical warming







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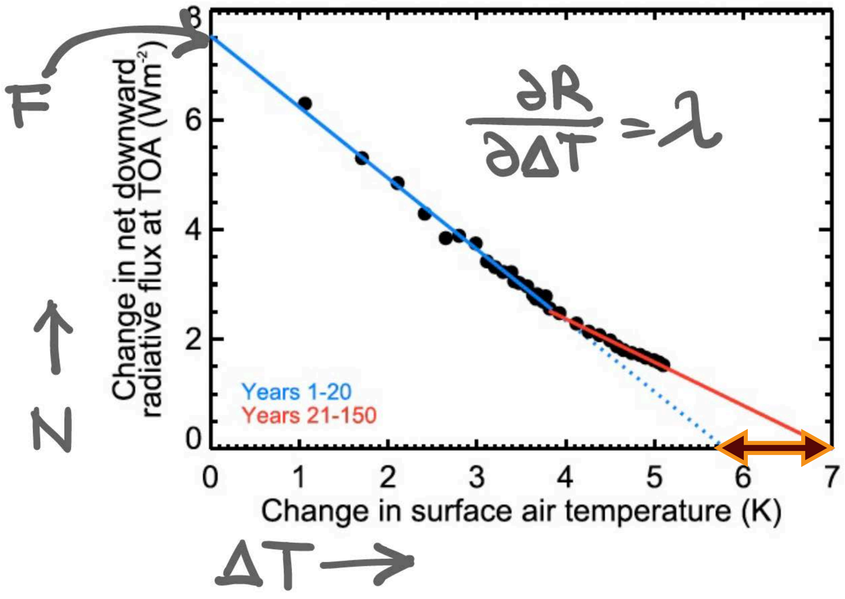
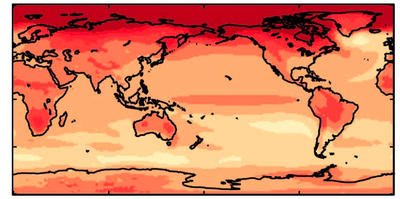
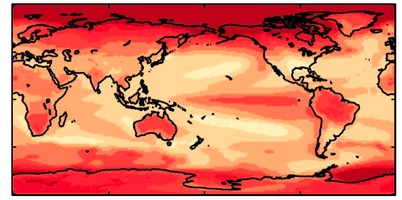




yr 1-20



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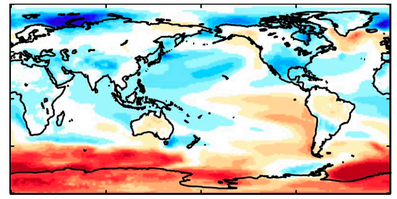

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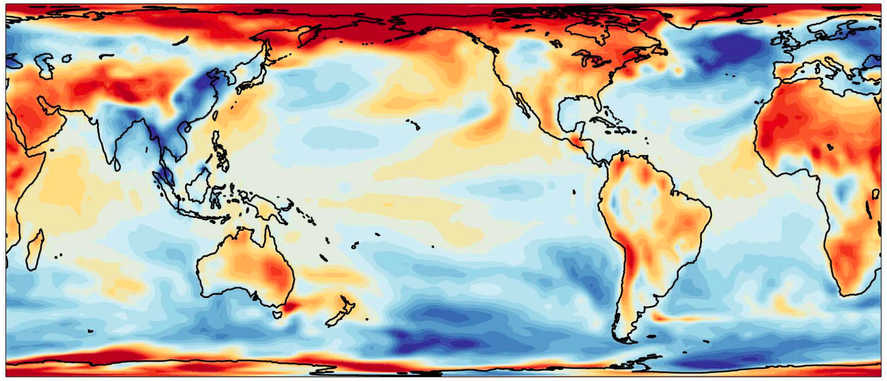
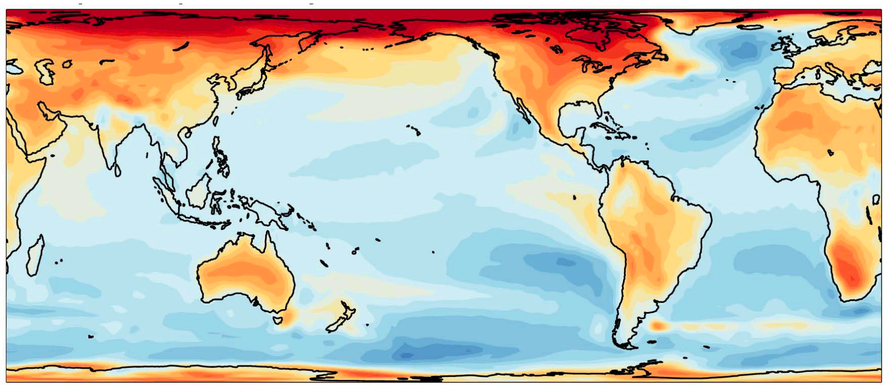
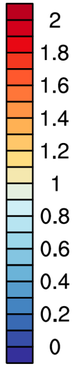
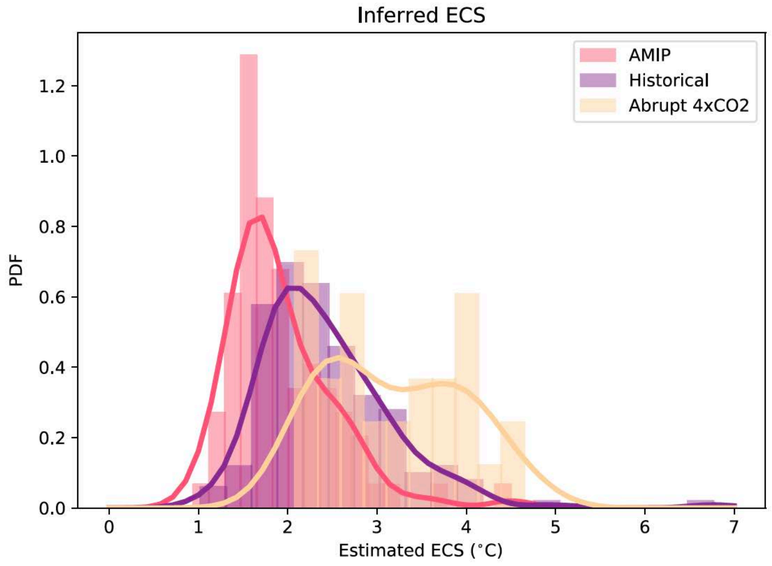
historical warming



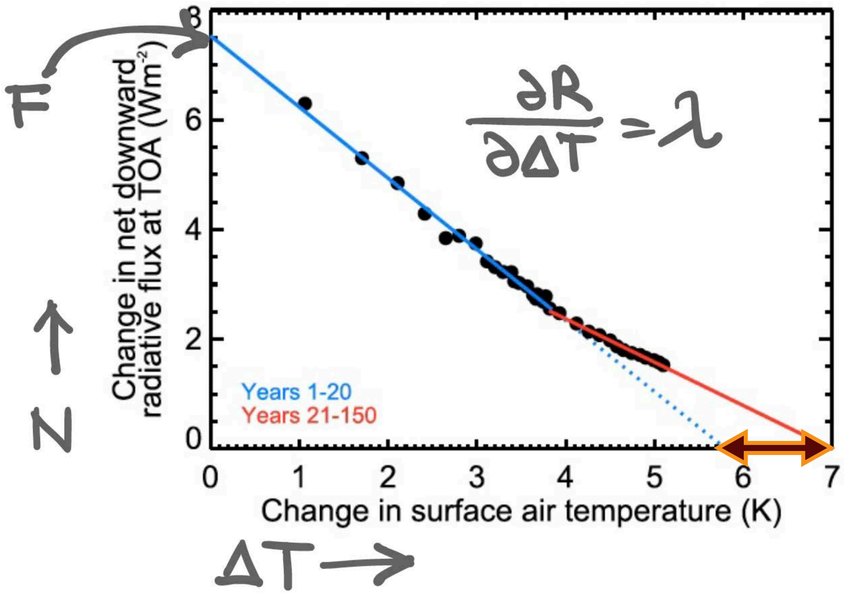




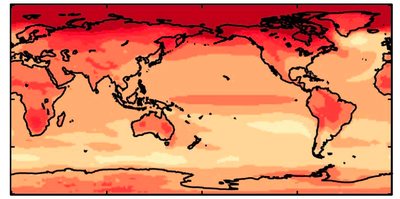
forced warming



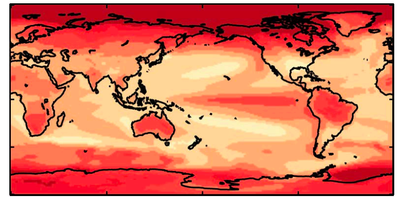
modified from Marvel et al. 2018



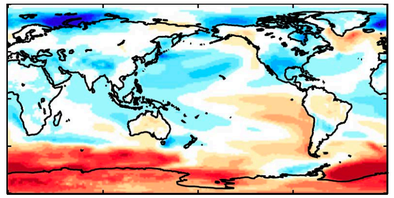
modified from Andrews et al. 2015



yr 1-20



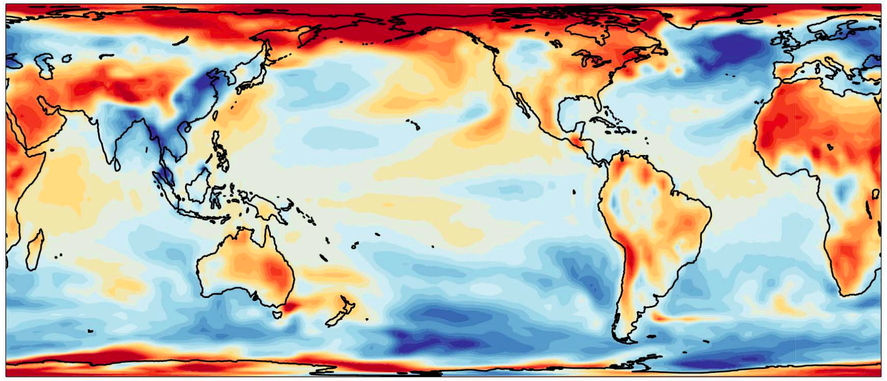
yr 21-150

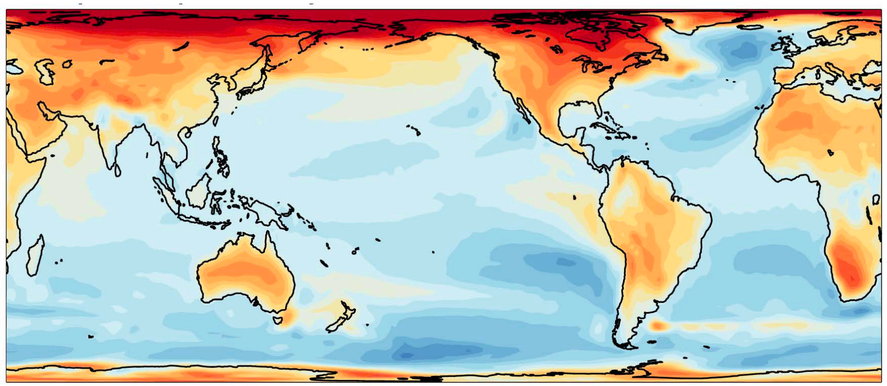


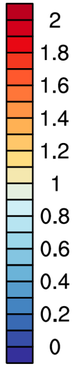
difference

Relevance of the pattern effect: ECS estimation

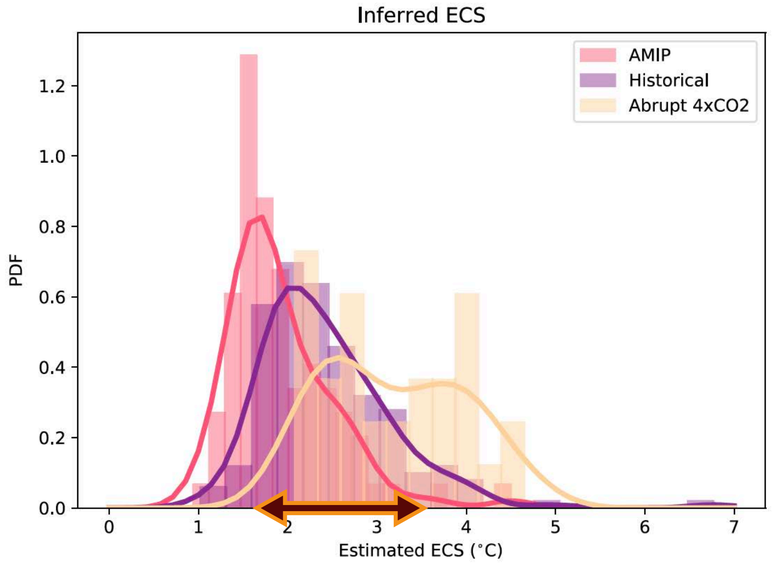
historical warming







forced warming



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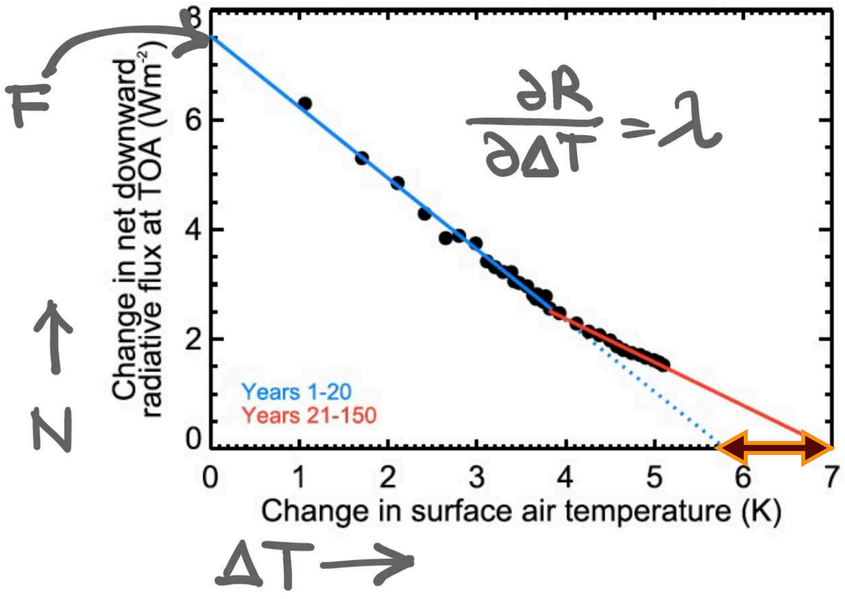

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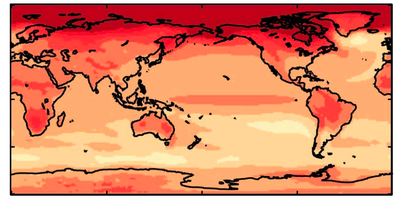

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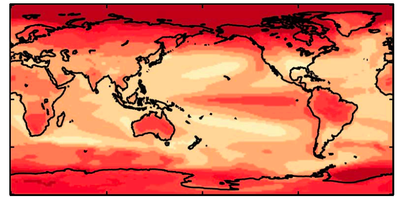

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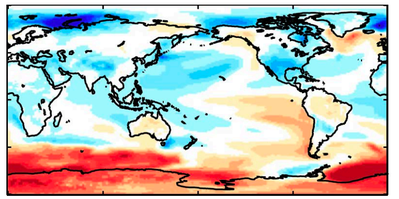
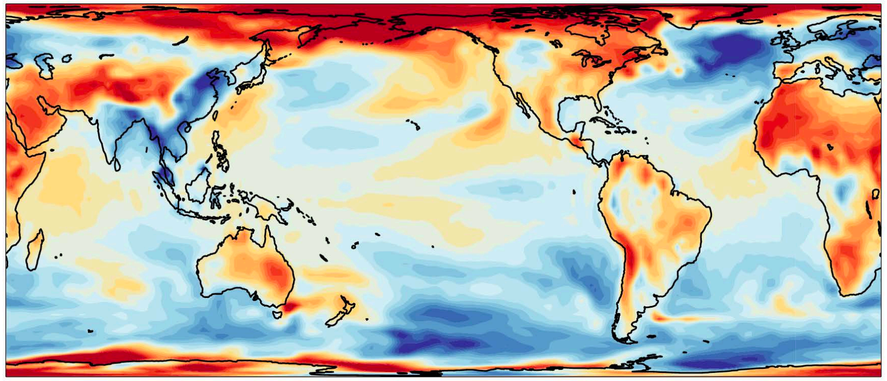
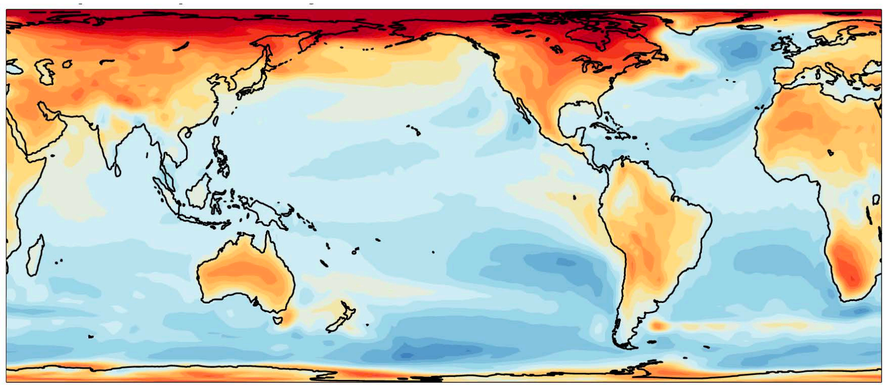


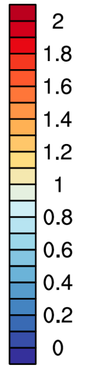
difference

Relevance of the pattern effect: near-term projections

historical warming

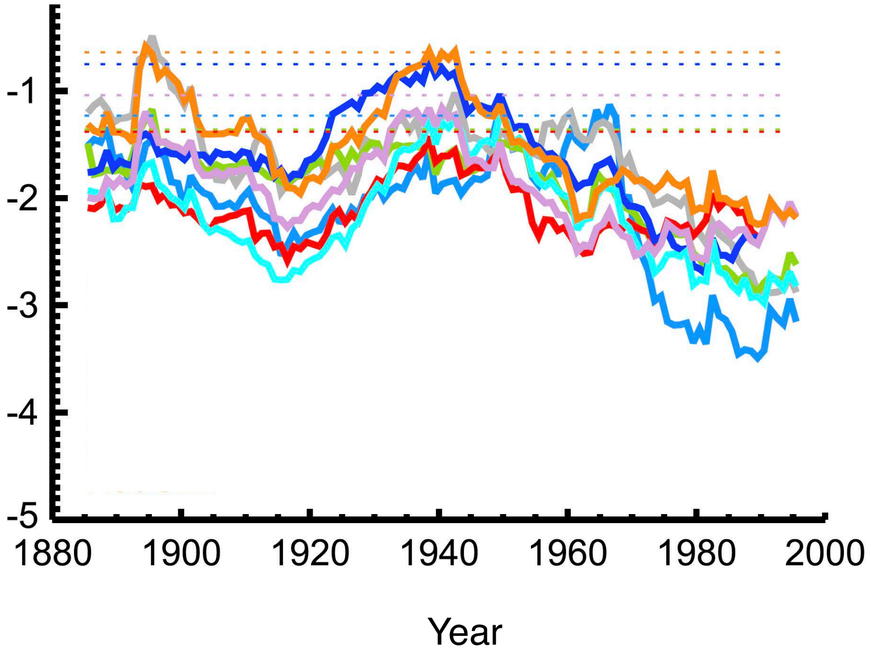






forced warming

Feedback parameter ($Wm^{-2}K^{-1}$)

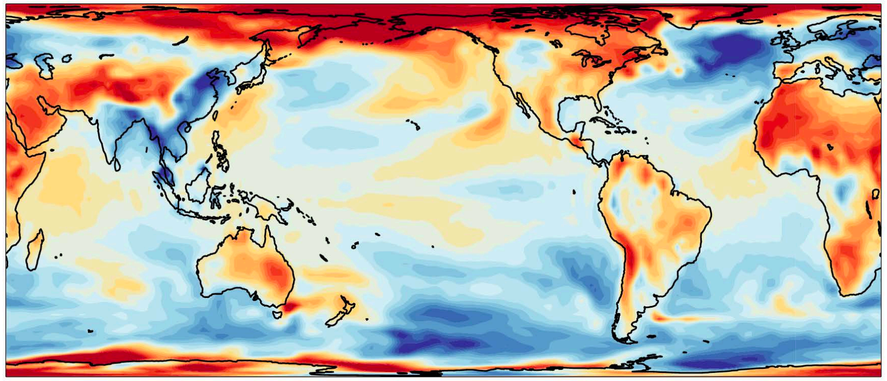


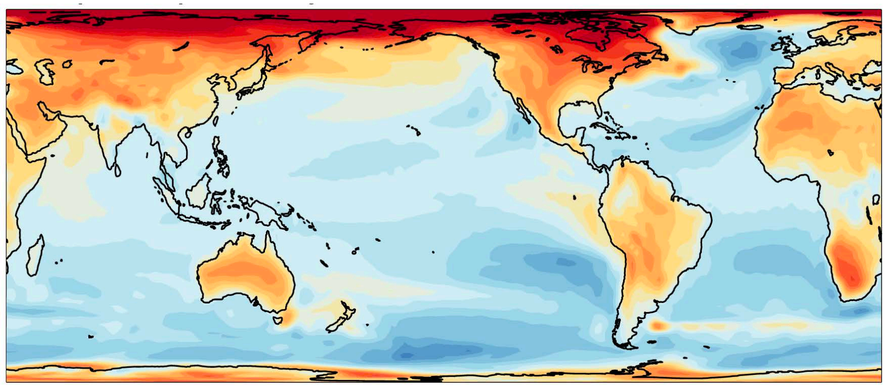
$$\lambda_1 = \frac{\Delta R}{\Delta T} = \frac{-2.2 Wm^{-2}}{0.9K} = -2.5 \frac{Wm^{-2}}{K}$$

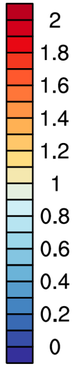
modified from Andrews et al. 2018

Relevance of the pattern effect: near-term projections

historical warming







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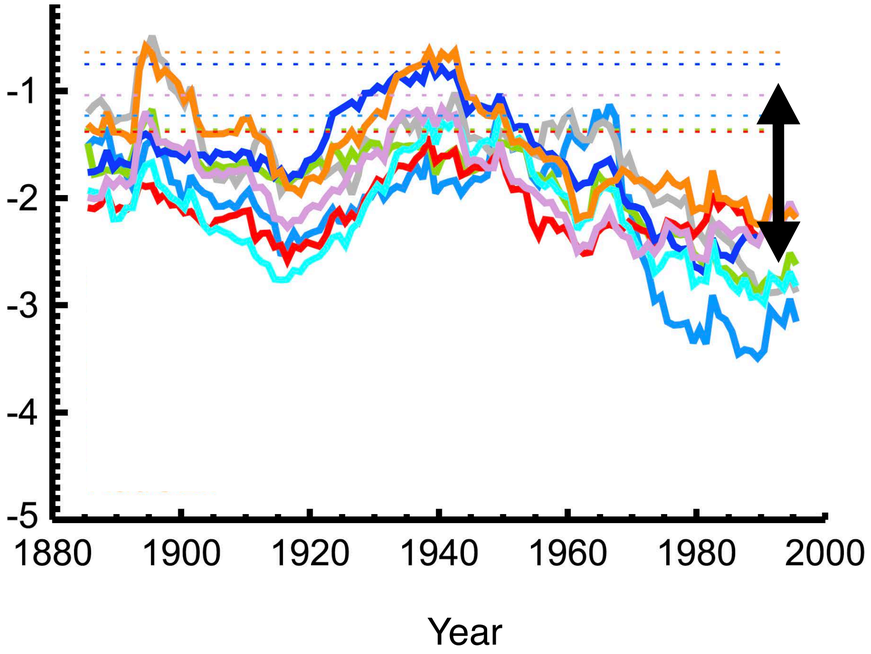

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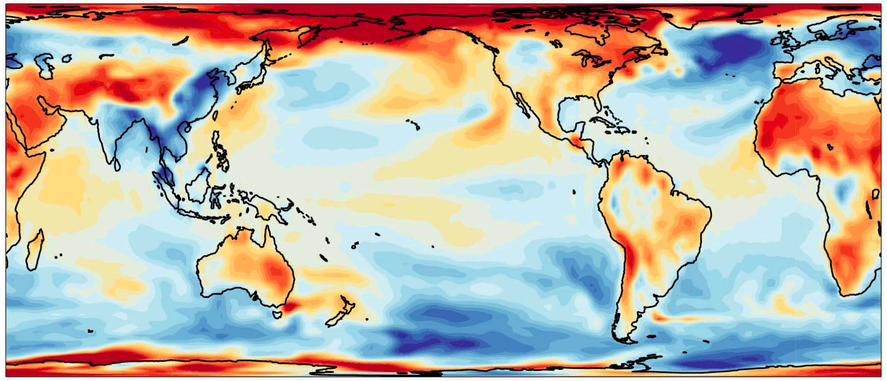
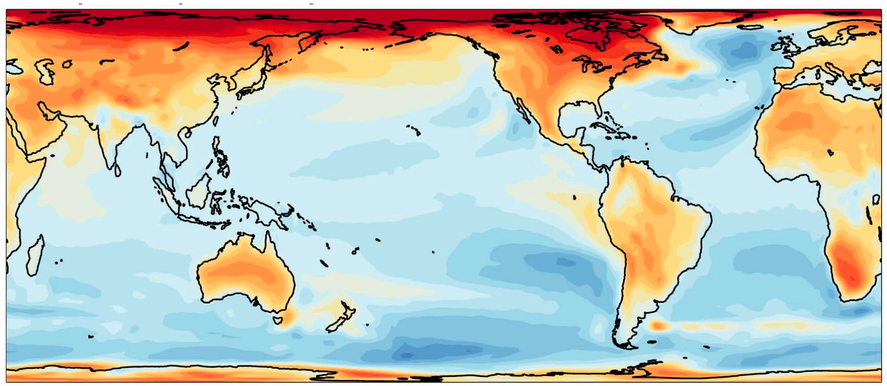
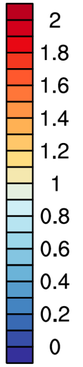
Relevance of the pattern effect: near-term projections

historical warming

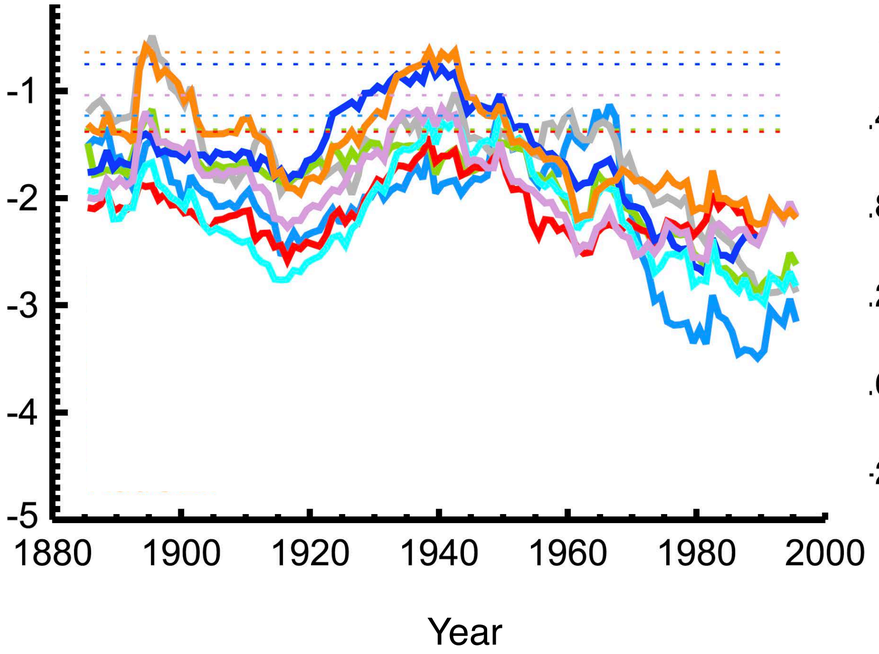


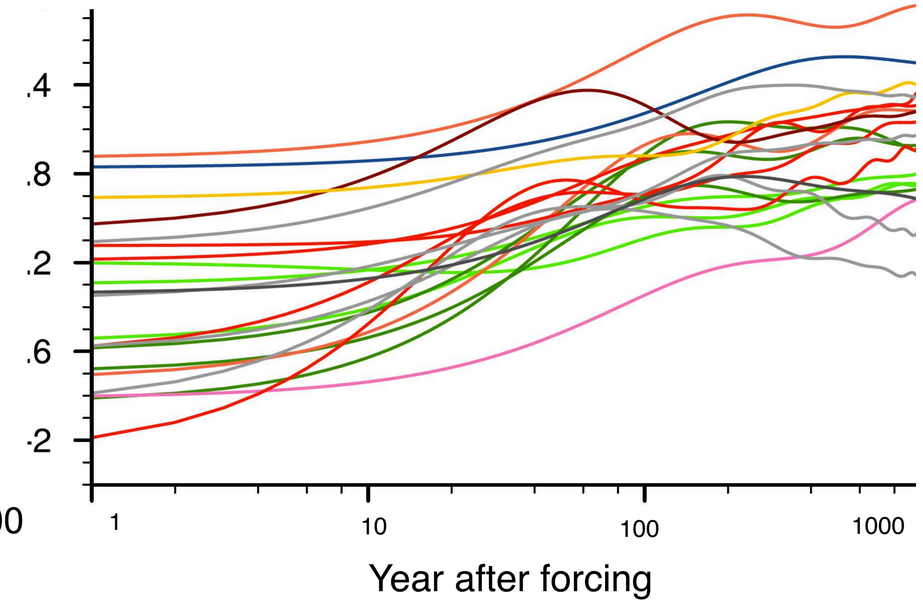




forced warming

Feedback parameter ($Wm^{-2}K^{-1}$)





less stable
warmer world

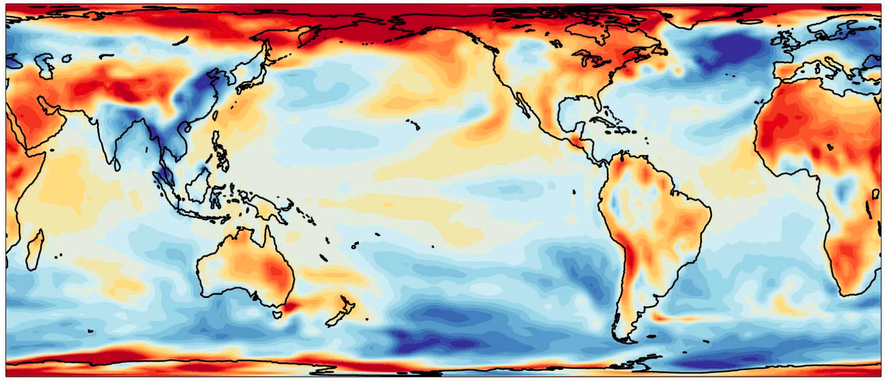
more stable
colder world

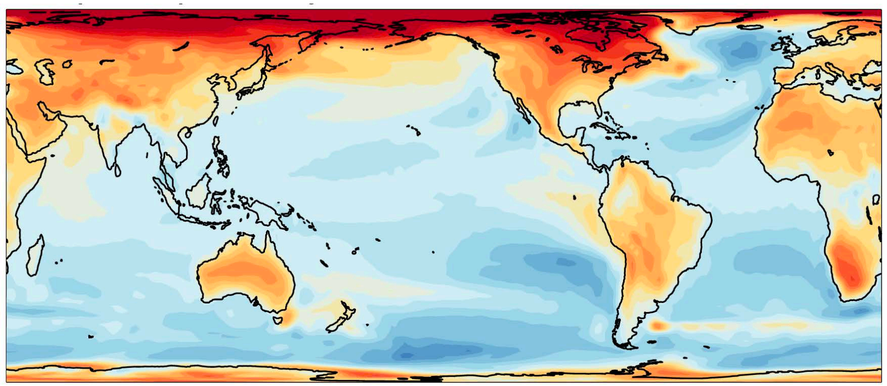
modified from Andrews et al. 2018

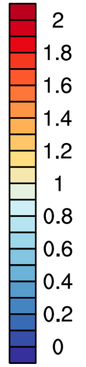
modified from Rugenstein et al. 2020

Relevance of the pattern effect: near-term projections

historical warming

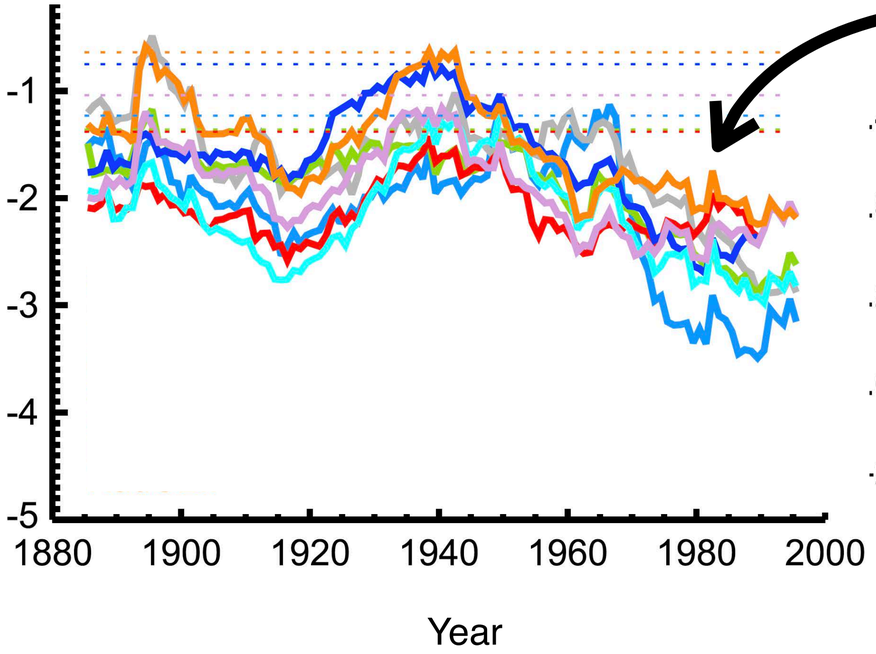


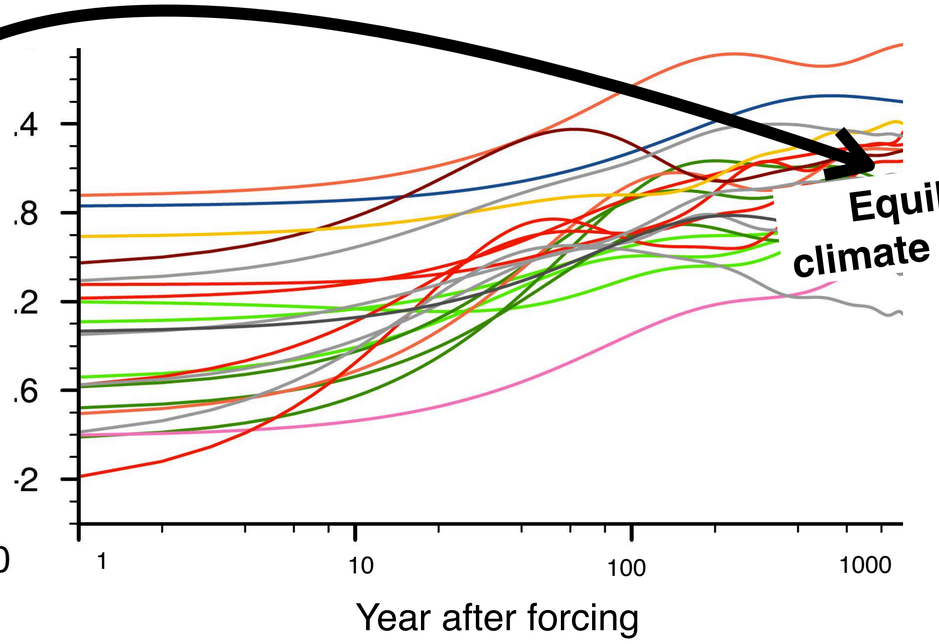




forced warming

Feedback parameter ($Wm^{-2}K^{-1}$)





less stable
warmer world

Equilibrium climate sensitivity

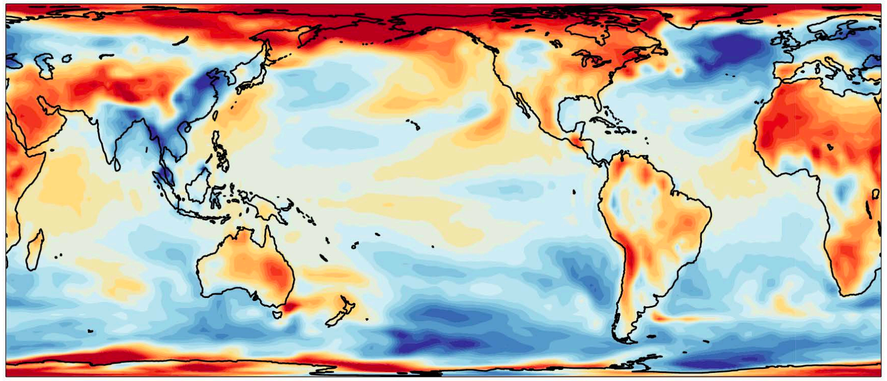
more stable
colder world

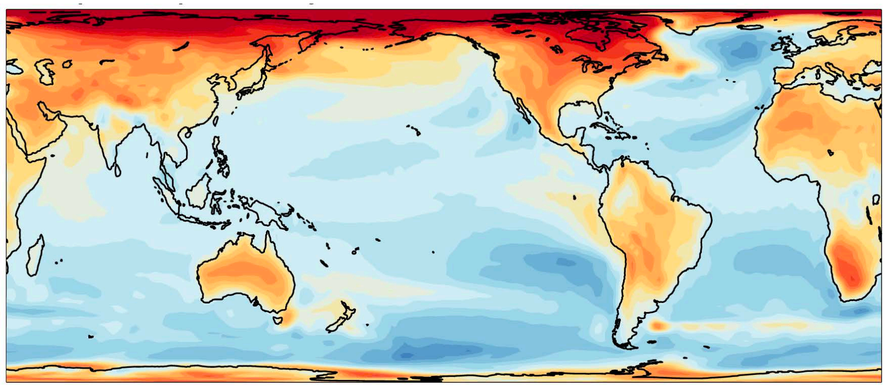
modified from Andrews et al. 2018

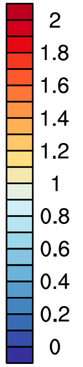
modified from Rugenstein et al. 2020

Relevance of the pattern effect: near-term projections

historical warming

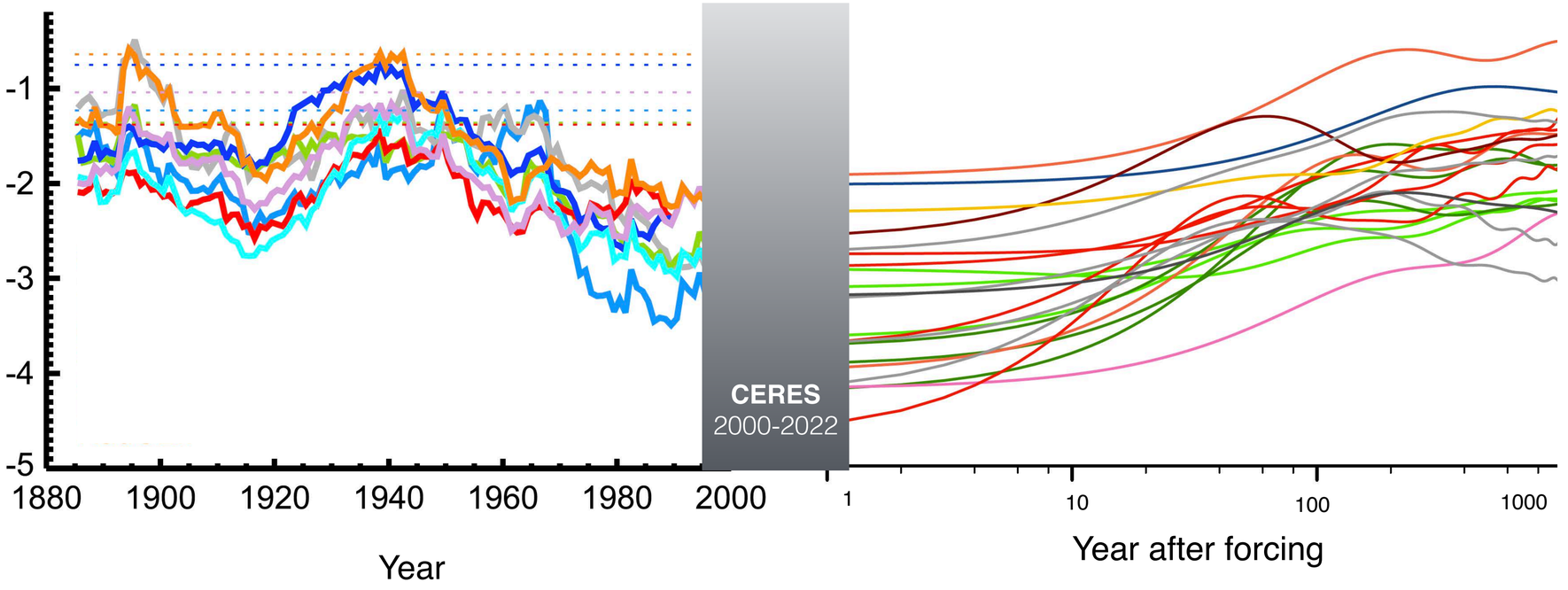






forced warming

Feedback parameter ($Wm^{-2}K^{-1}$)



less stable
warmer world

more stable
colder world

modified from Andrews et al. 2018

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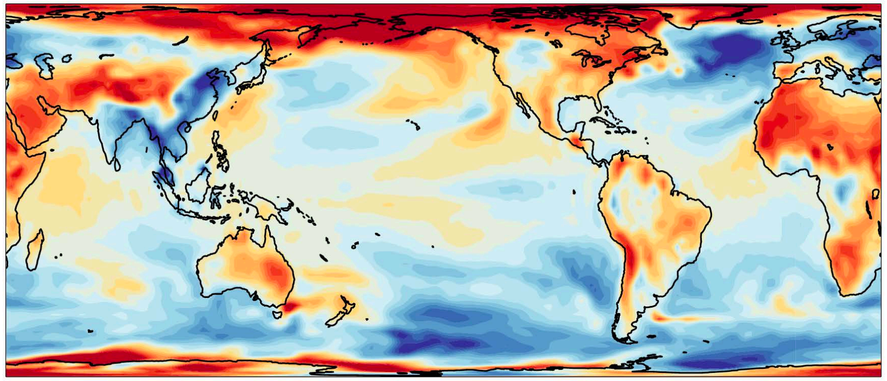
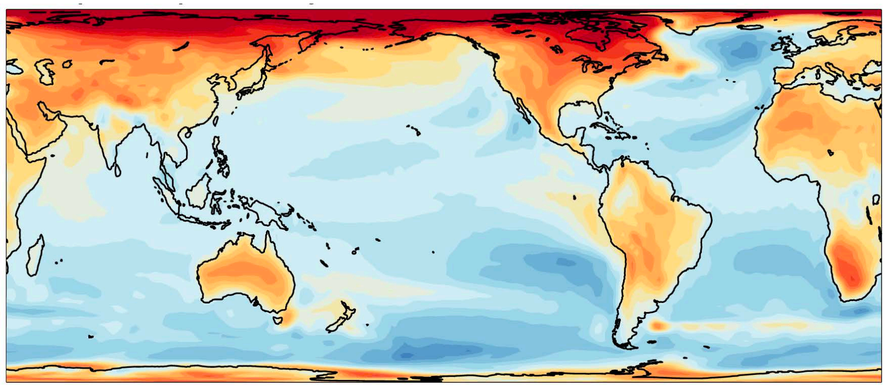
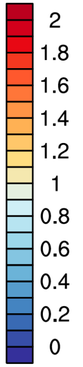
Relevance of the pattern effect: near-term projections

historical warming

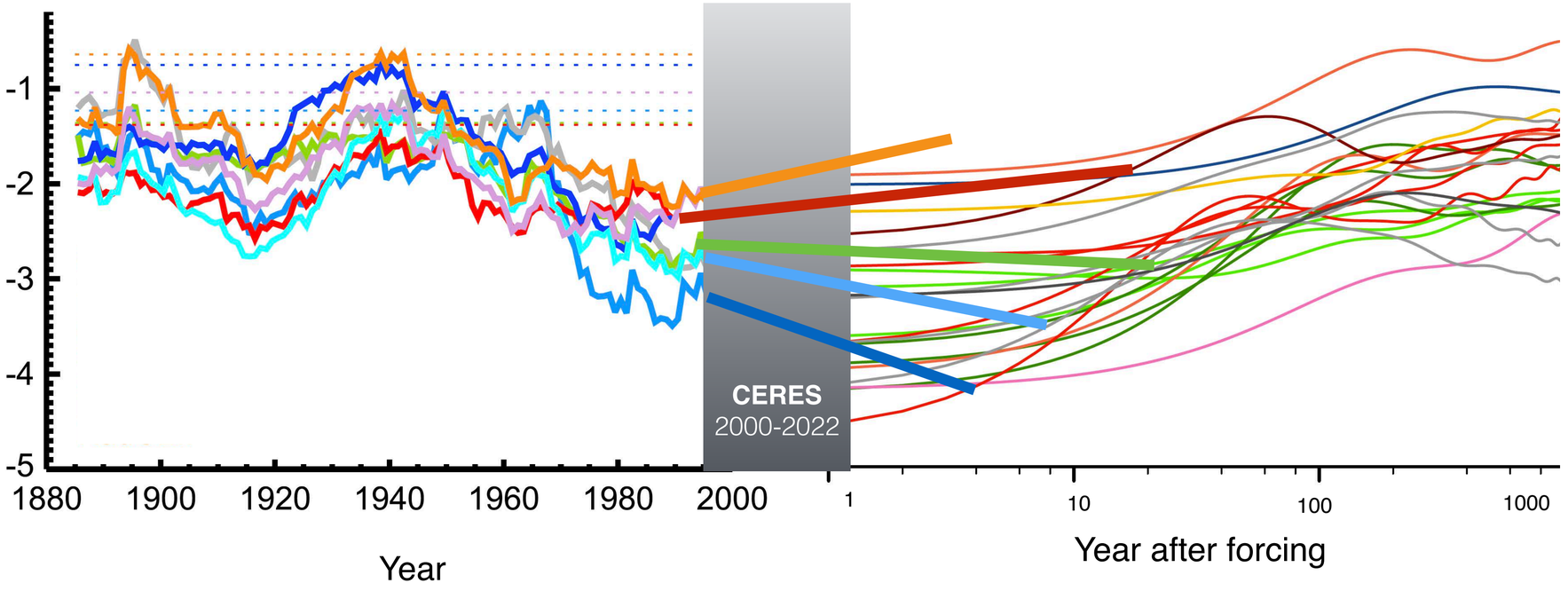






forced warming

Feedback parameter ($Wm^{-2}K^{-1}$)



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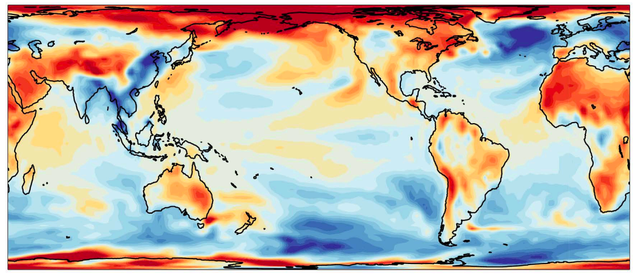
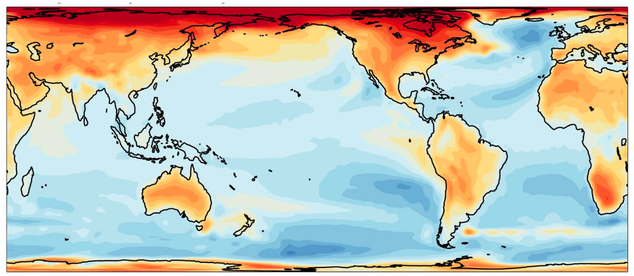
History of the pattern effect

historical warming
internal variability
observations' based





forced or idealized
warming
mechanisms

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Marvel et al. 2018 — ECS lower from AMIP < coupled historical < abruptCO2
Silvers et al. 2018 — fleshing out decadal cloud feedbacks
Gregory et al. 2020 — forcing agents and internal variability through historical
Dessler et al. 2020 — pattern effect of internal variability; all sea ice?
Loeb et al. 2020 — models forced with observed SSTs are doing well at TOA
Sherwood et al. 2020 — pattern effect as major constrain to ECS pdf
Lewis and Mauritsen 2021 — pattern effect depends on input dataset
Zhou et al. 2021 — implications for current SSTs to emission commitment
Ceppi and Fueglisthaler 2021 — ENSO pattern effect
Fueglisthaler and Silvers 2021 — peculiar last few decades
Wills et al. 2021 — modes of variability in low vs high latitudes matter for ECS
Dong et al. 2021 — ECS estimates of historical and idealized simulations
Chao et al. 2021 — obs model comparison of feedbacks over obs record
Andrews et al. 2022 — methods, datasets, this is robust, link to OHU, volcanoes
Chao et al. 2022 — unforced pattern effect

Murphy 1995 — effective climate sensitivity, short-wave feedback variations
Senior and Mitchel 2000 — relative SH/NH surface and tropospheric warming
Winton et al. 2010 — ocean heat uptake efficacy
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Newsom et al. 2020 — ocean GF
Dunne et al. 2020 — ECS estimation methods
Winton et al. 2020 — ECS estimation methods and more
Rugenstein et al. 2020 — ECS estimation methods
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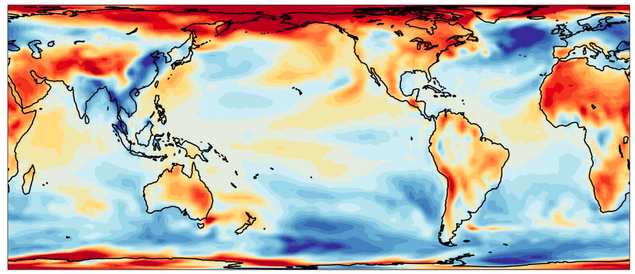
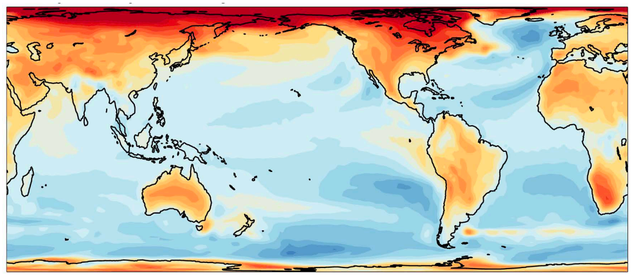
Lin et al. 2021 — connecting SOM-GF to SST-GF: SO HU changes tropical SSTs
Tierney et al. 2019, 2020 — pattern effect in LGM/deep-time paleo
Eiselt and Graversen 2022 — feedback change in the Arctic, lapse rate vs other feedbacks
Singh et al. 2022 — ocean heat transport influences radiative feedbacks

History of the pattern effect

historical warming
internal variability
observations' based





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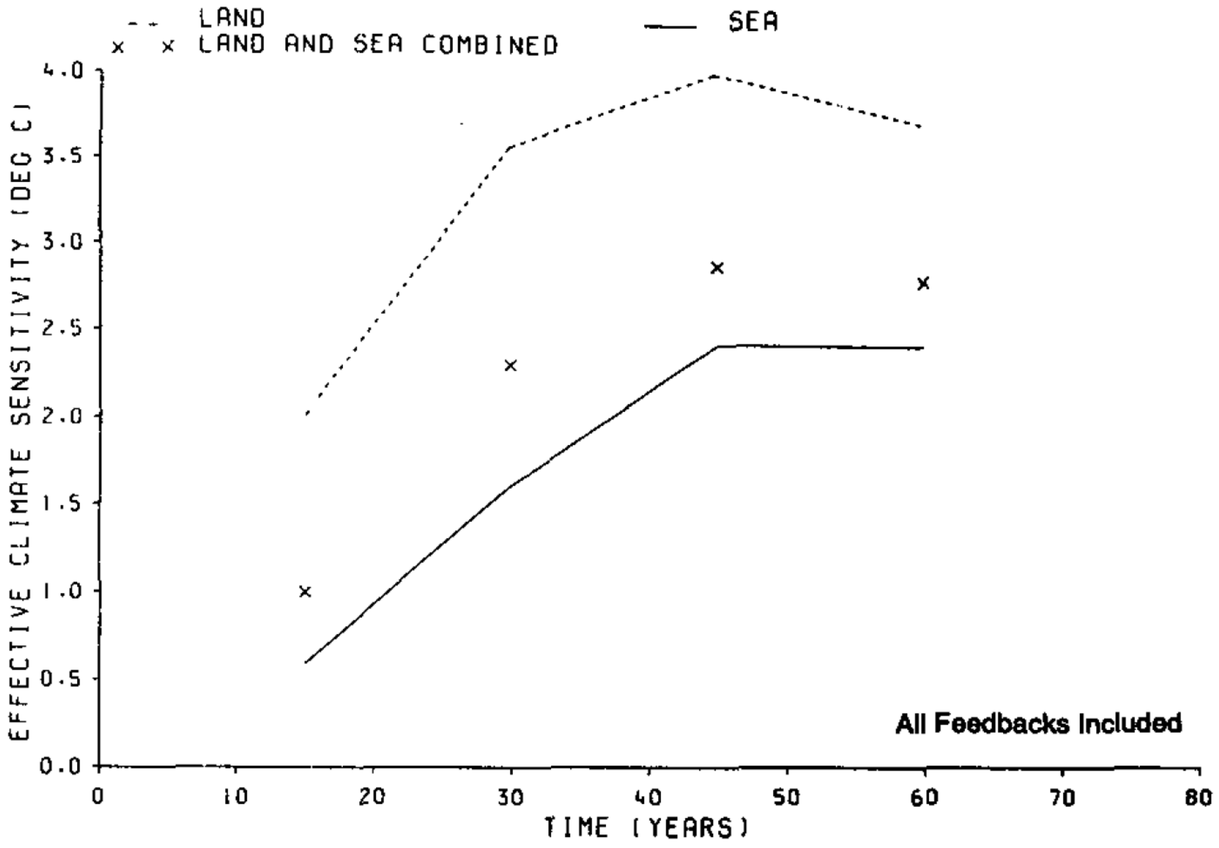
Murphy 1995c – effective climate sensitivity



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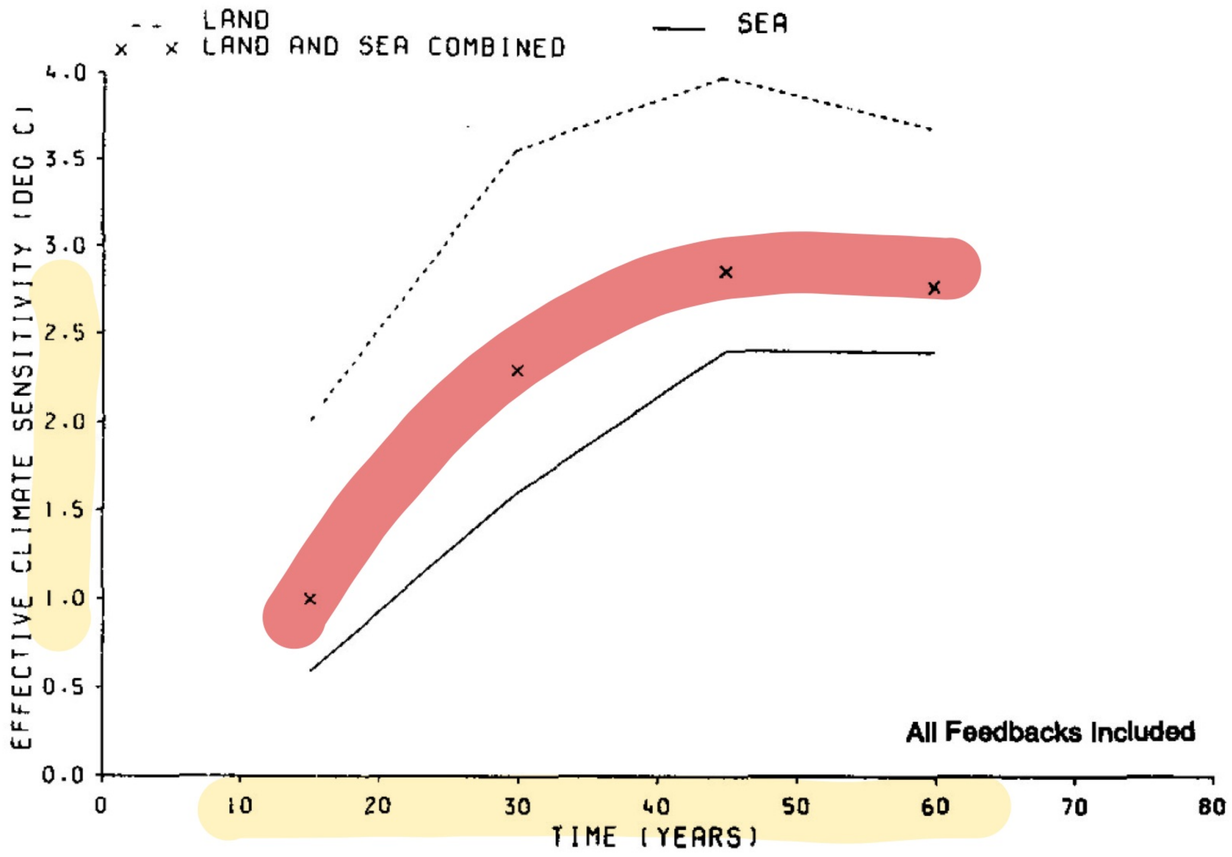
The results in this paper emphasize the need to use full three-dimensional coupled general circulation models to capture the nonlinear influence of climate feedbacks on the transient response. In particular, the assumptions of constant feedback strength and constant effective oceanic heat capacity usually made in idealized simple models are shown not to be valid in the present AOGCM experiment

Murphy 1995c – effective climate sensitivity



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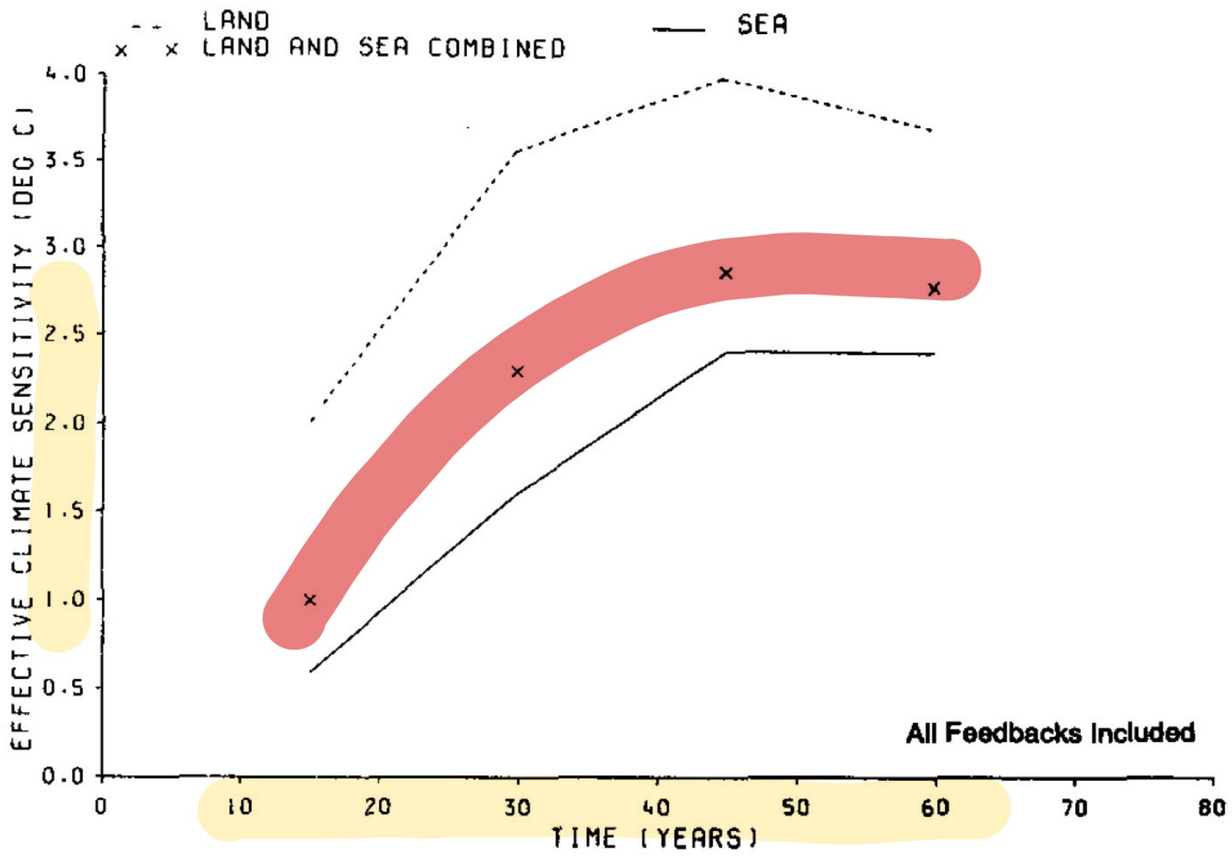

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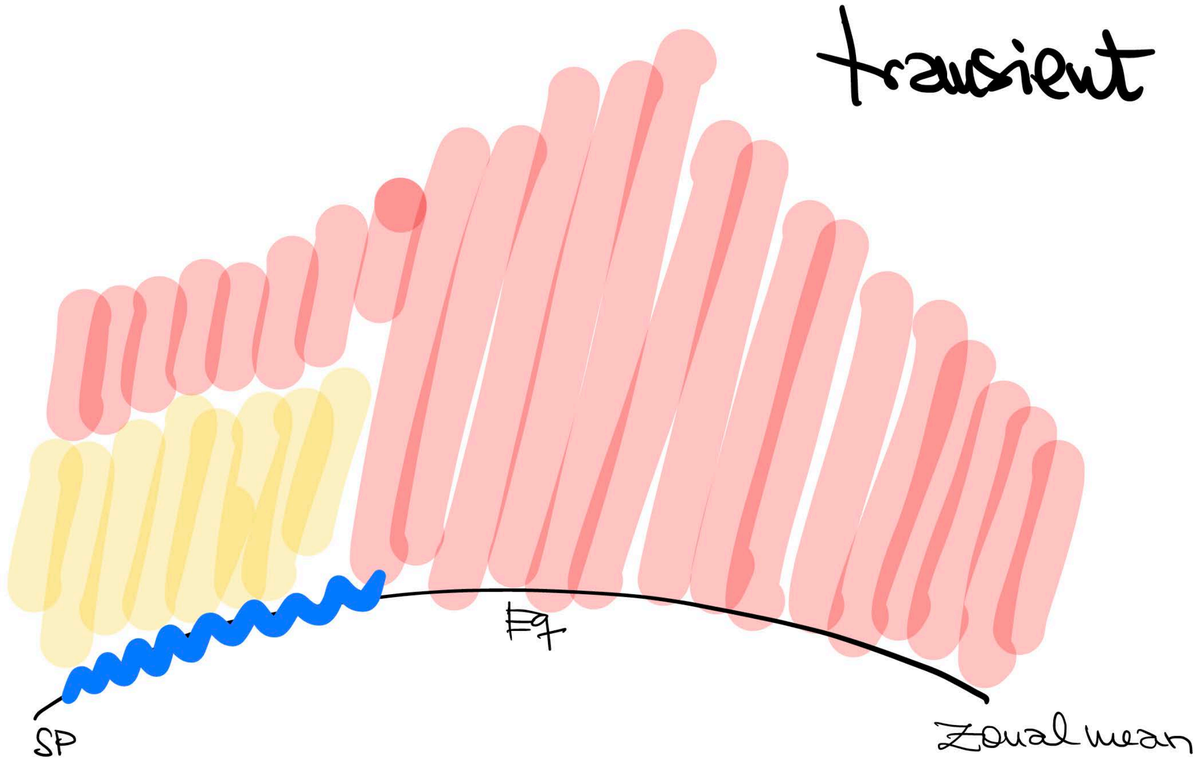

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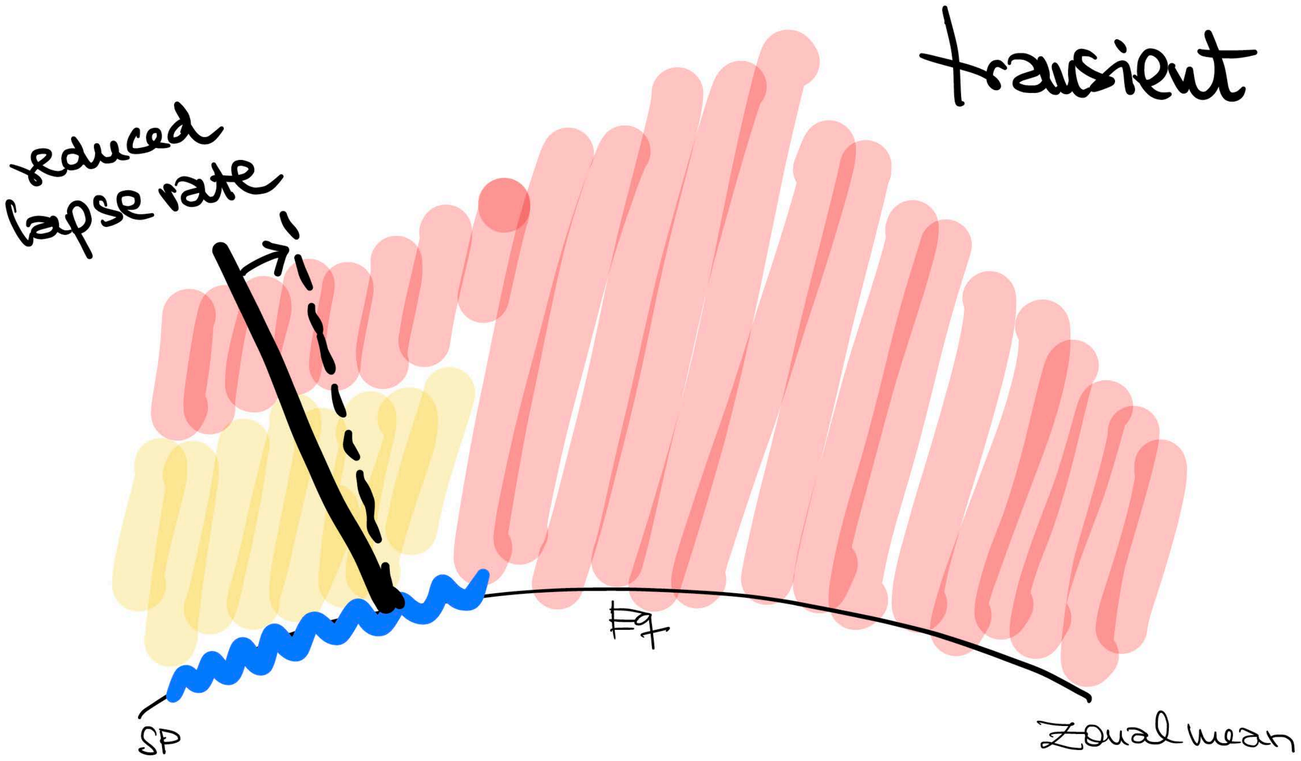

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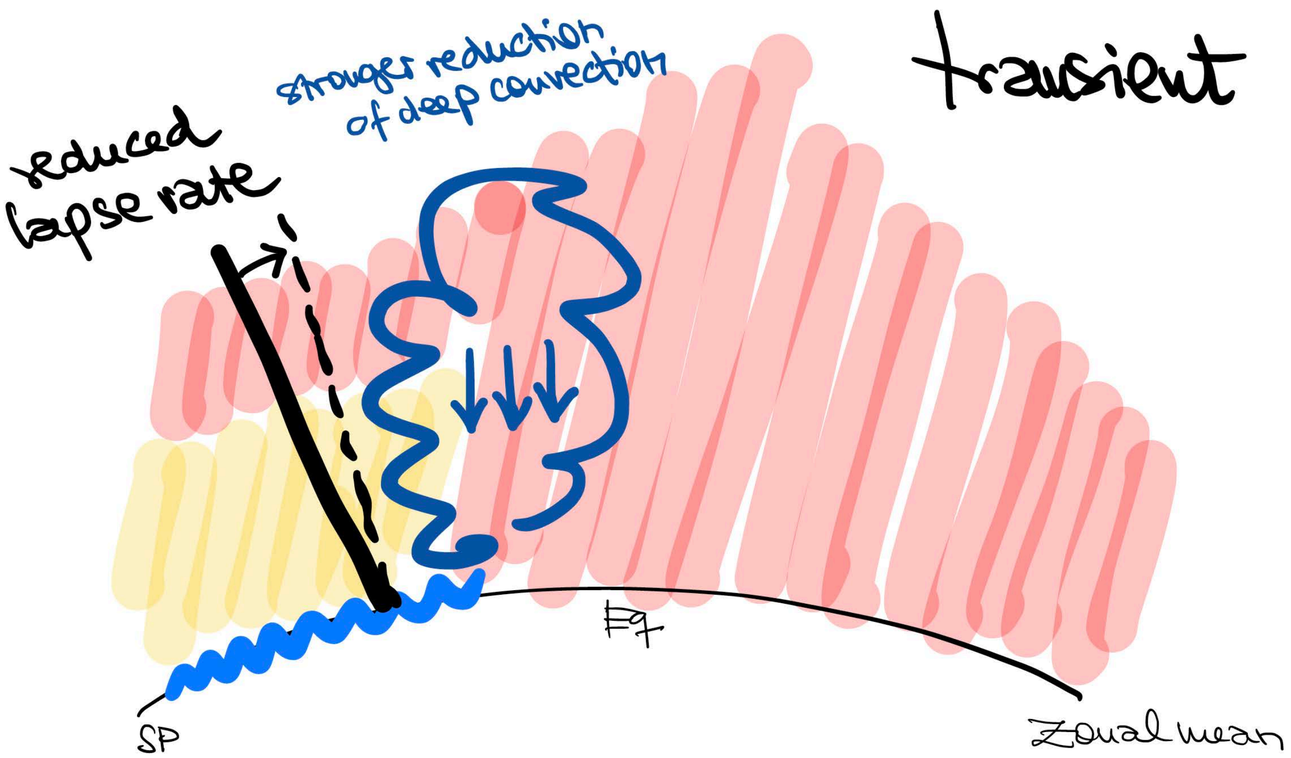

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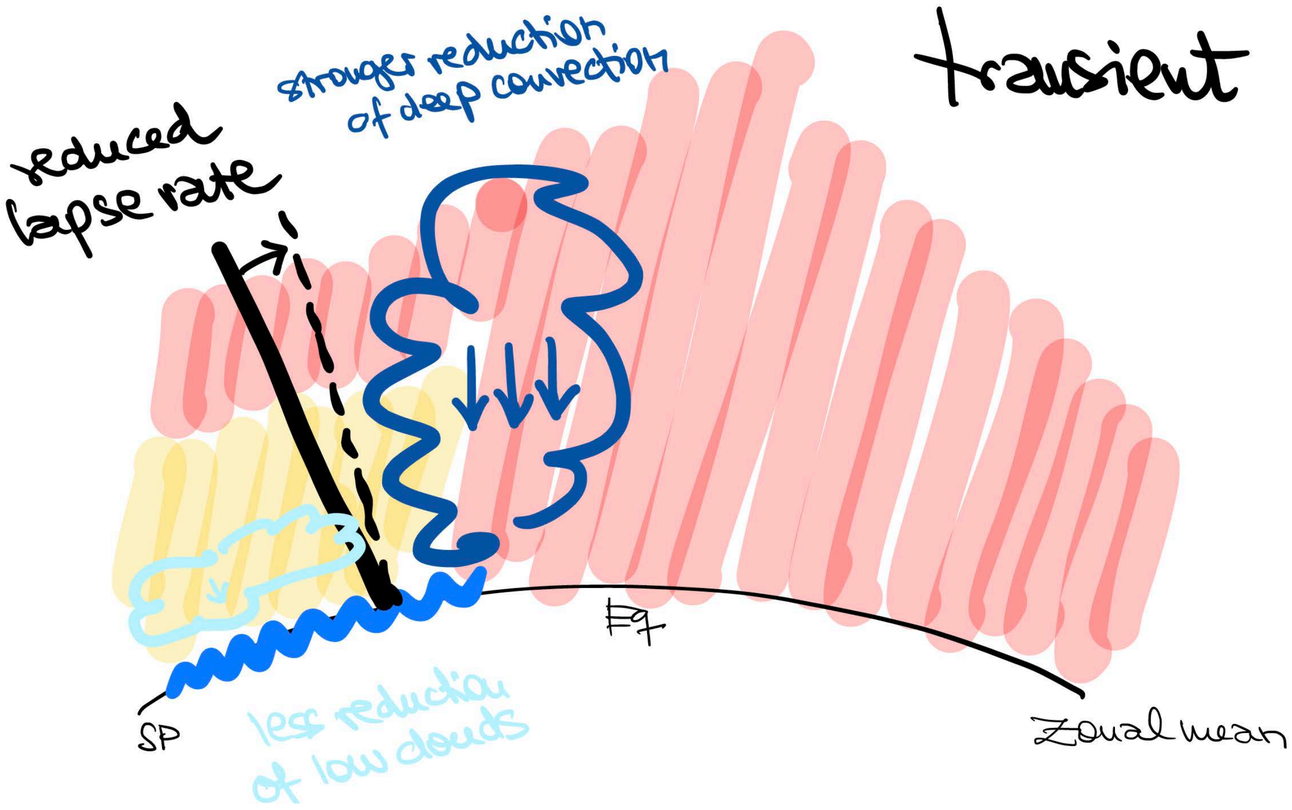

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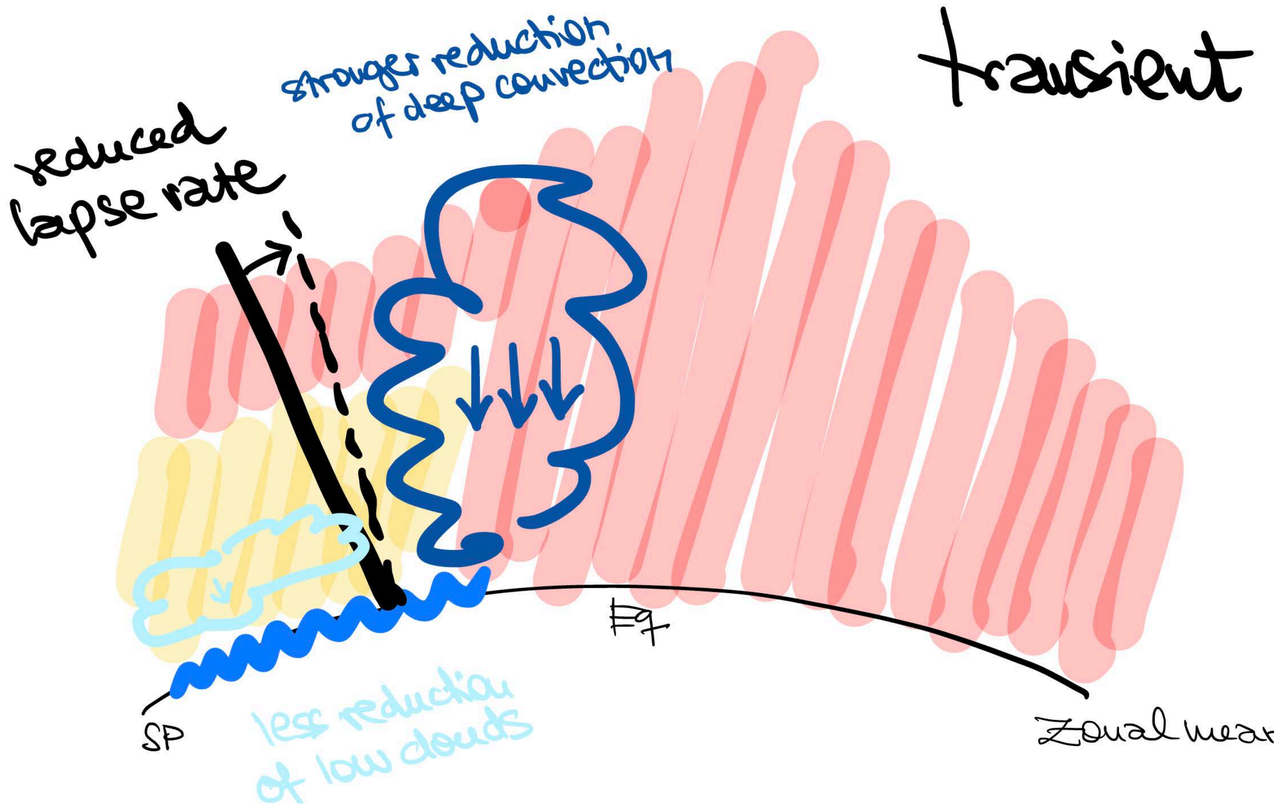
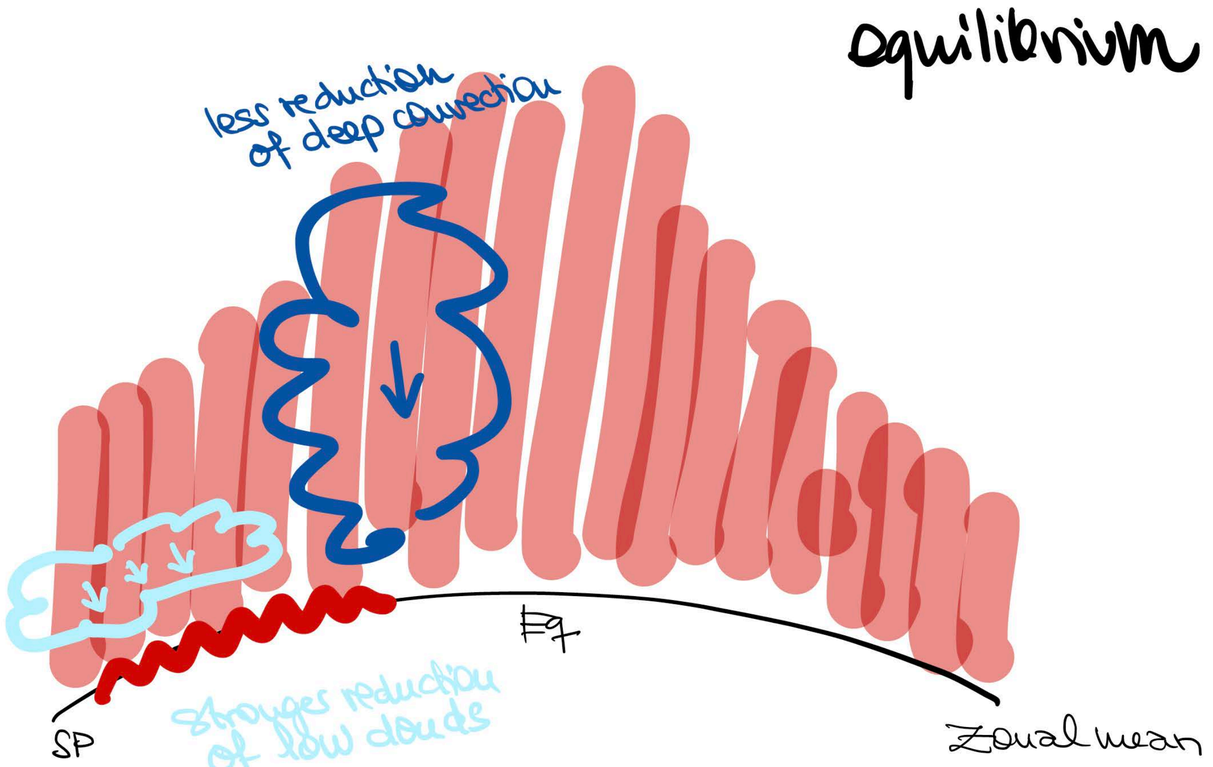
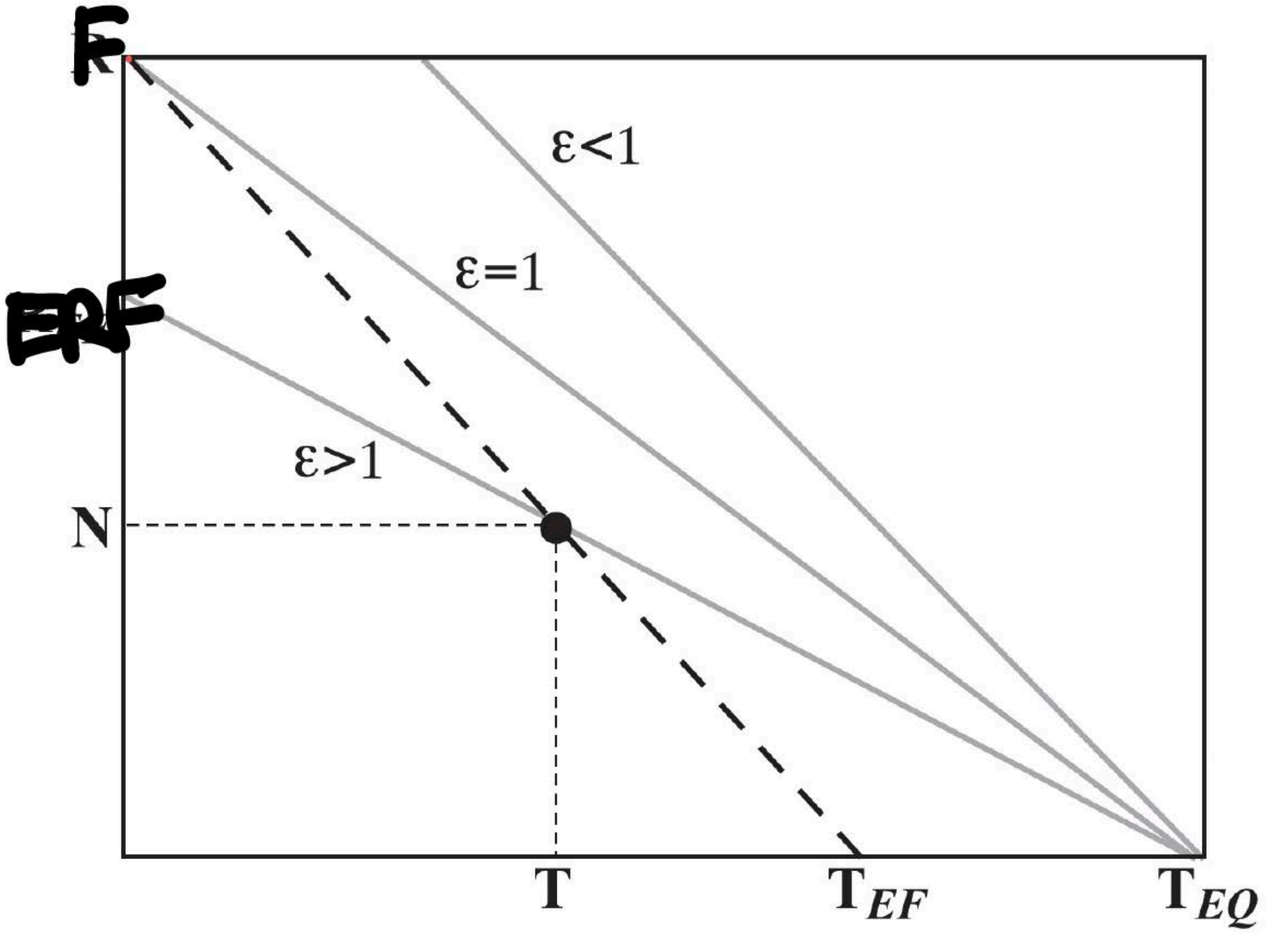




Winton et al. 2010 – ocean heat uptake efficacy



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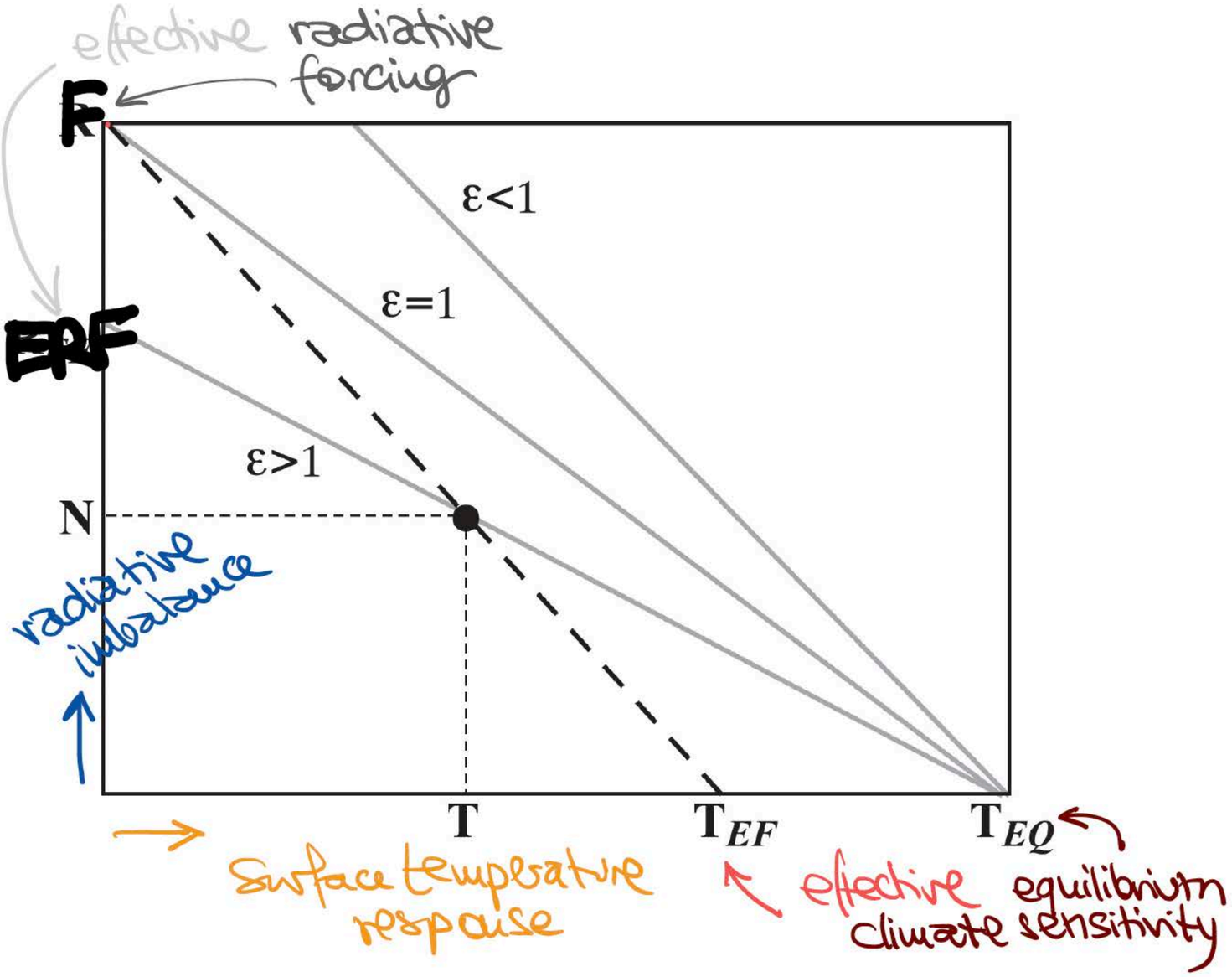

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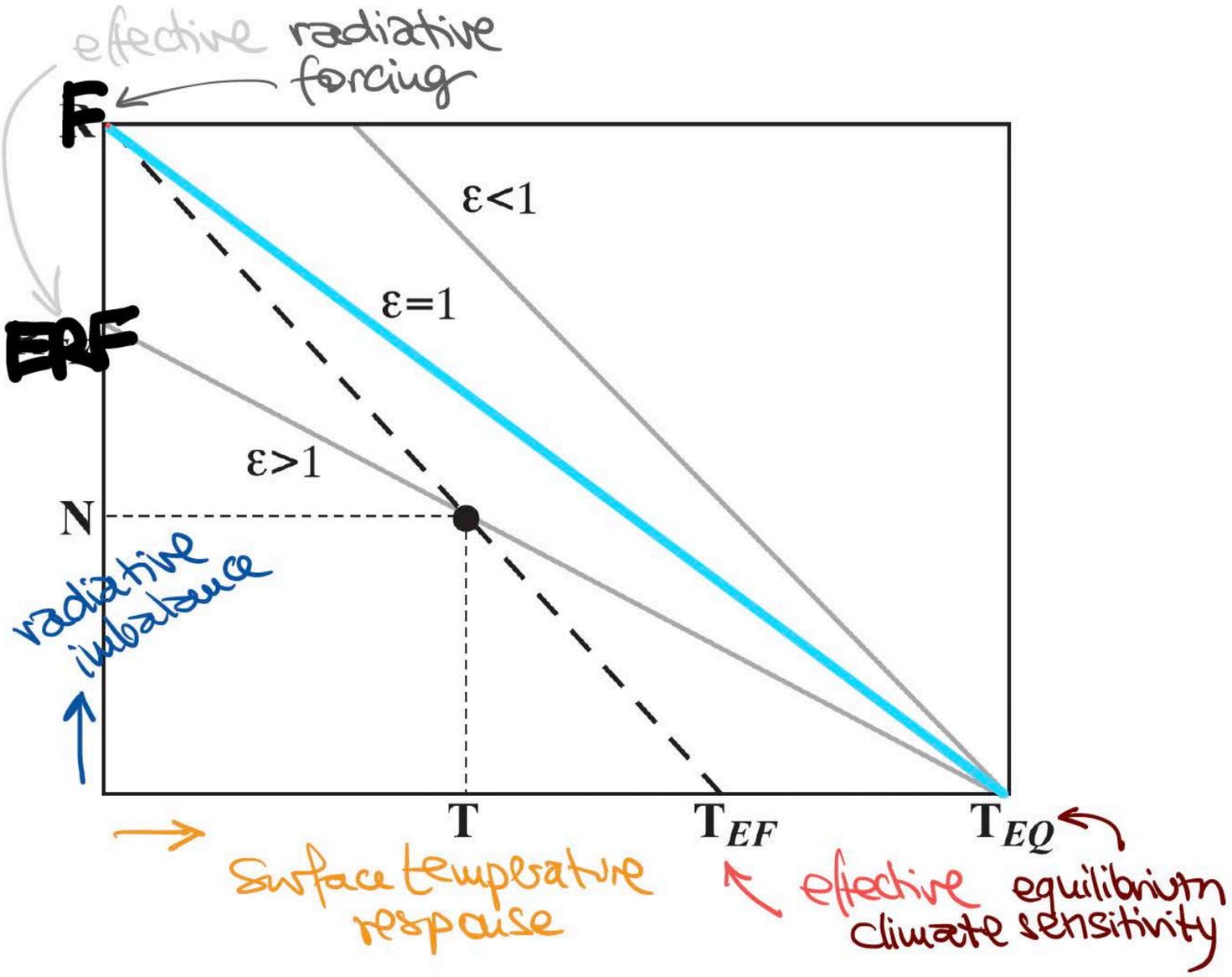

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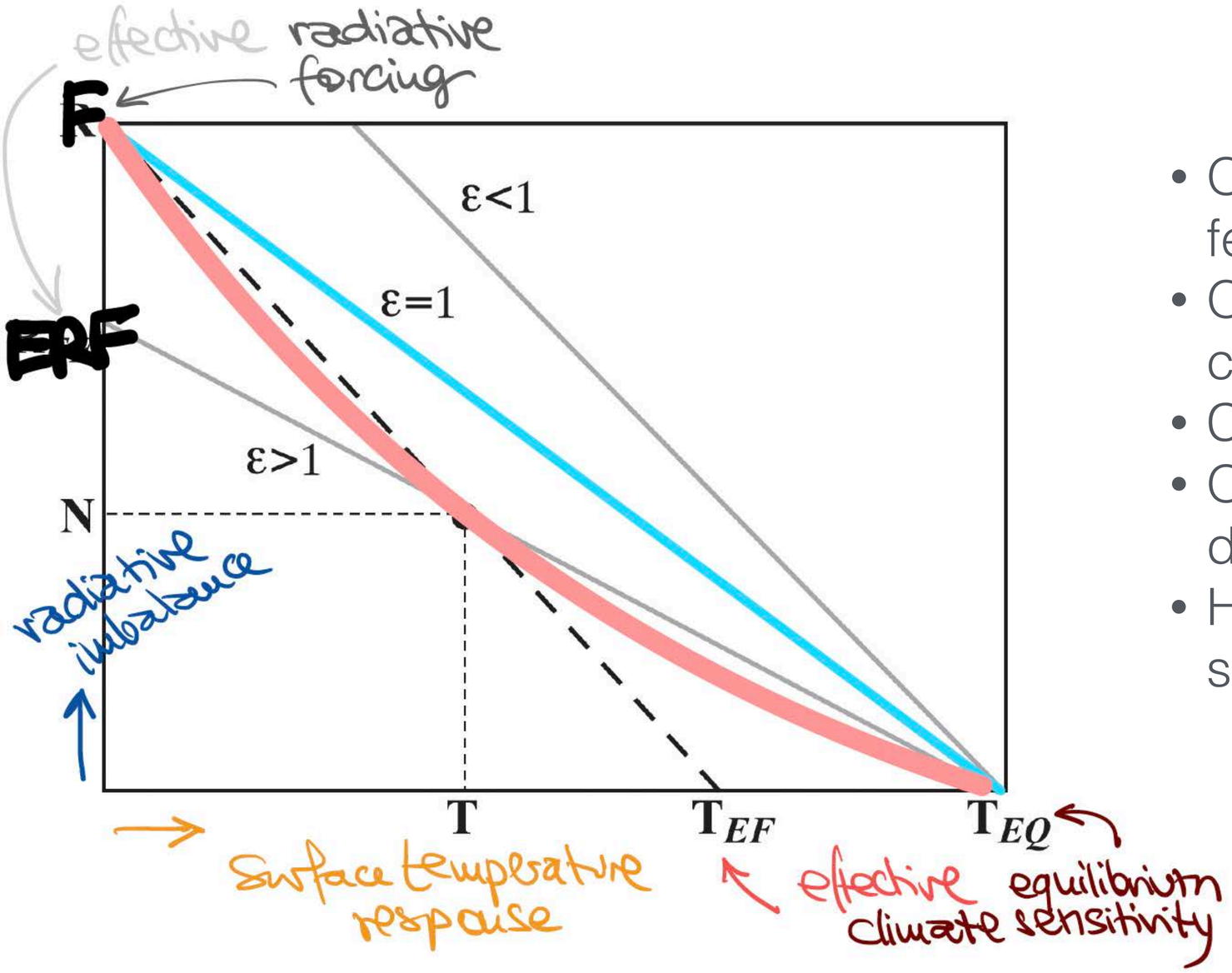
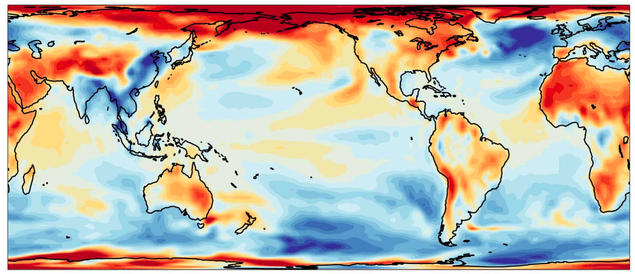
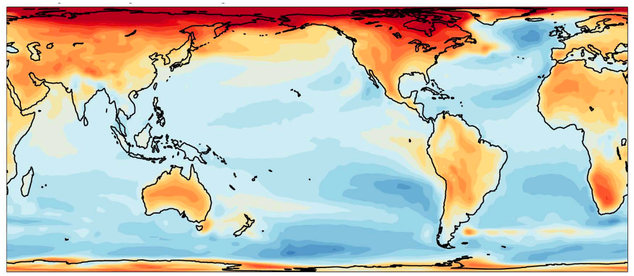


- Ocean heat uptake influences feedbacks through SST patterns
- Ocean heat uptake efficacy not constant
- Cloud feedback 50% of net effect
- OHU efficacy and ECS are unrelated, different model characteristics
- Historical changes might not be sufficient to predict ECS/future

History of the pattern effect

historical warming
internal variability
observations' based





forced or idealized
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mechanisms

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Ocean heat uptake versus SST as forcing

historical warming
internal variability
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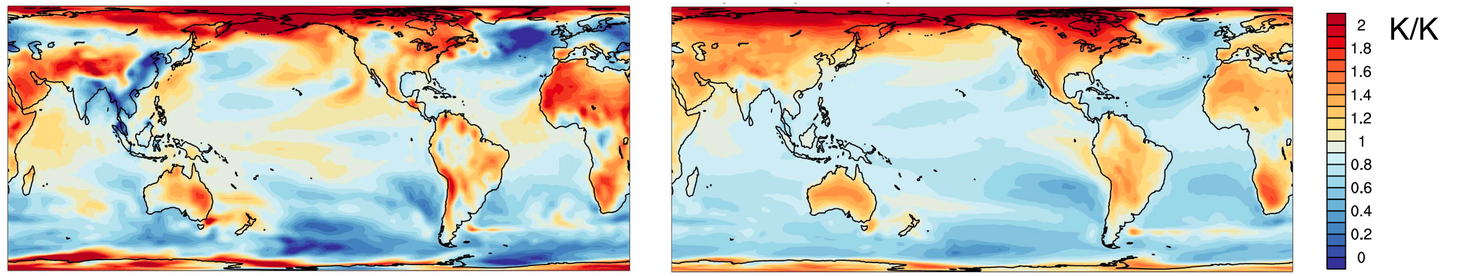

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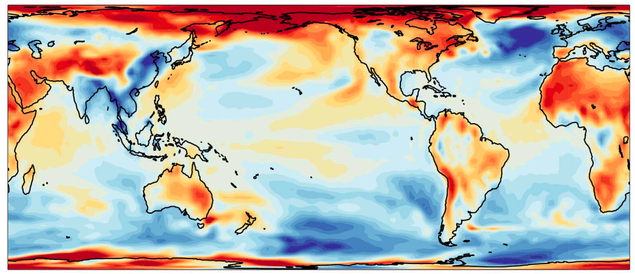
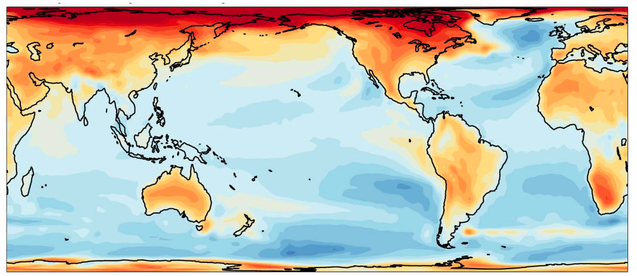
Ocean heat uptake versus SST as forcing

historical warming
internal variability
observations' based





forced or idealized
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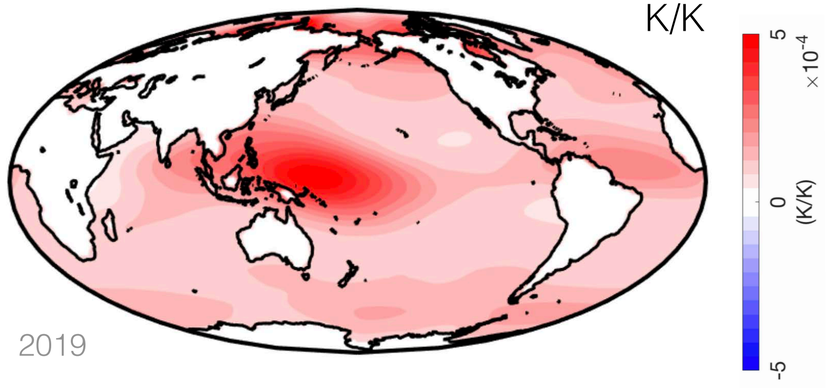

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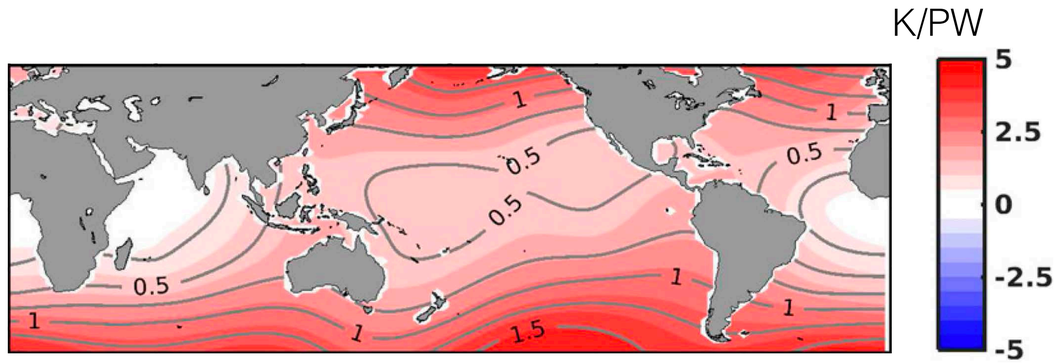

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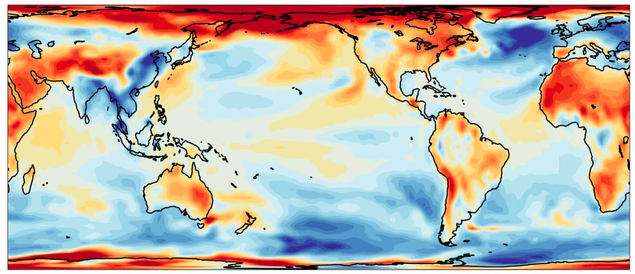
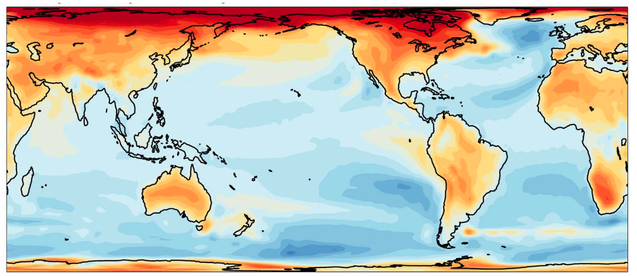
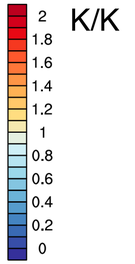
Few studies reconciling these view points

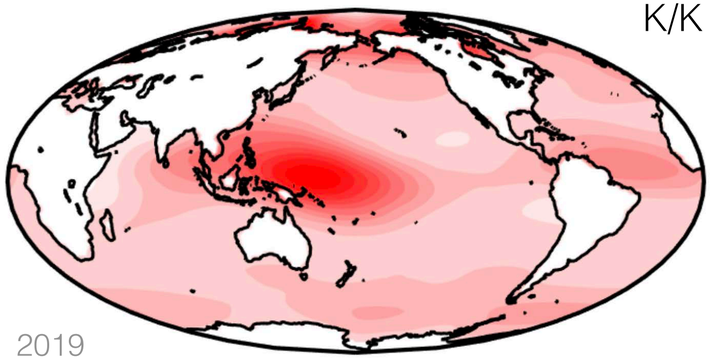
historical warming
internal variability
observations' based







forced or idealized
warming
mechanisms



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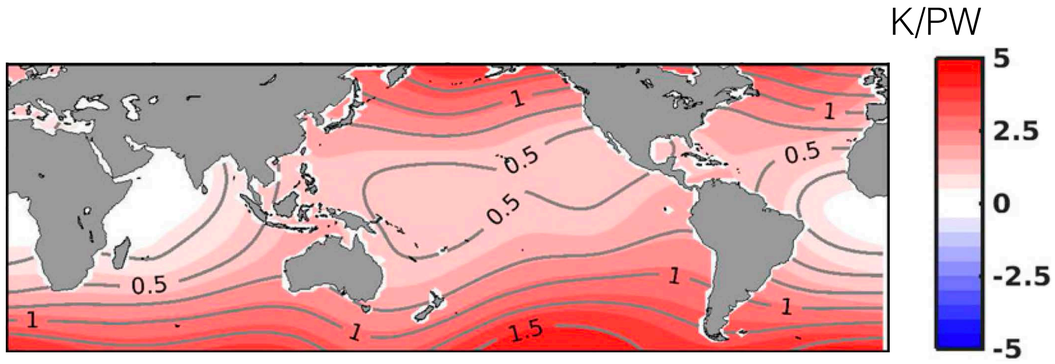

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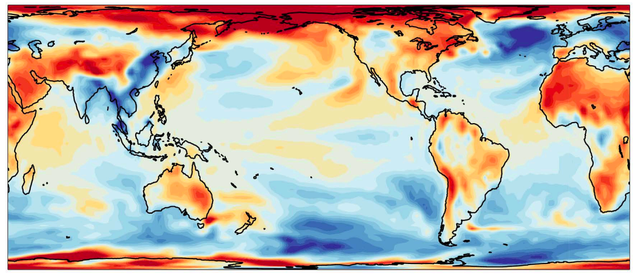
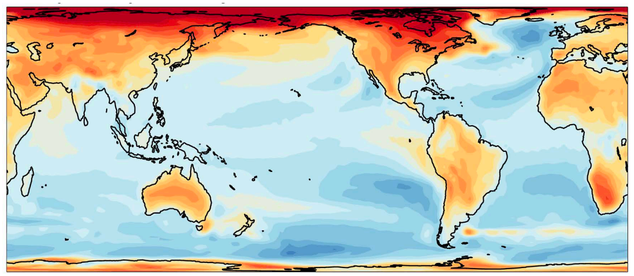
How do SST patterns come about?

historical warming
internal variability
observations' based





forced or idealized
warming
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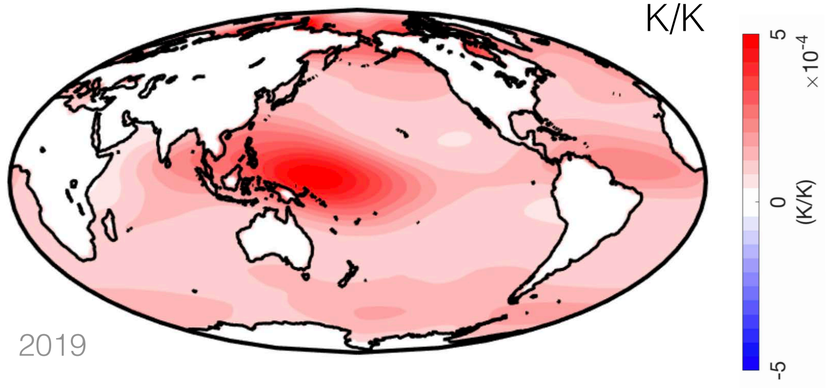


Dong et al. 2019

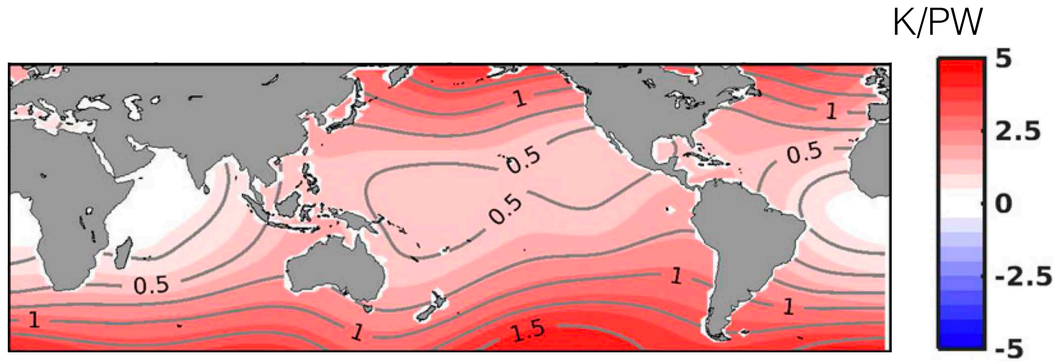
Which processes set the pace and magnitude of warming in different regions?

To what degree are the tropics influenced by the extra-tropics?

How much of the forced response is observable?

Should/can/do models simulate the observed pattern?

How peculiar are the last few decades?



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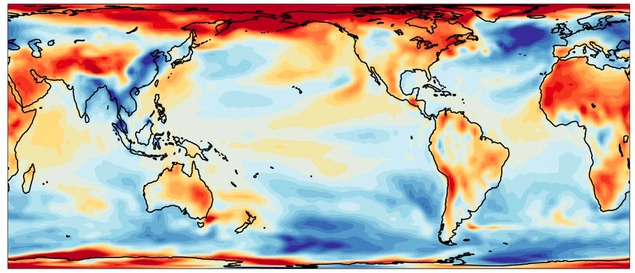
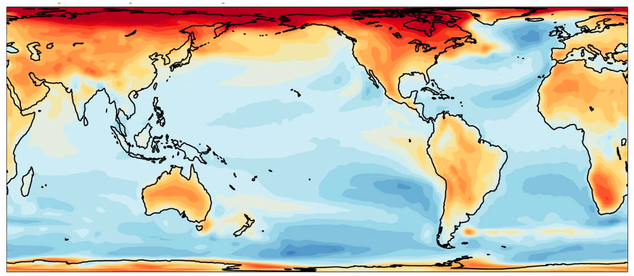
Mechanisms of non-constant radiative feedbacks

historical warming
internal variability
observations' based





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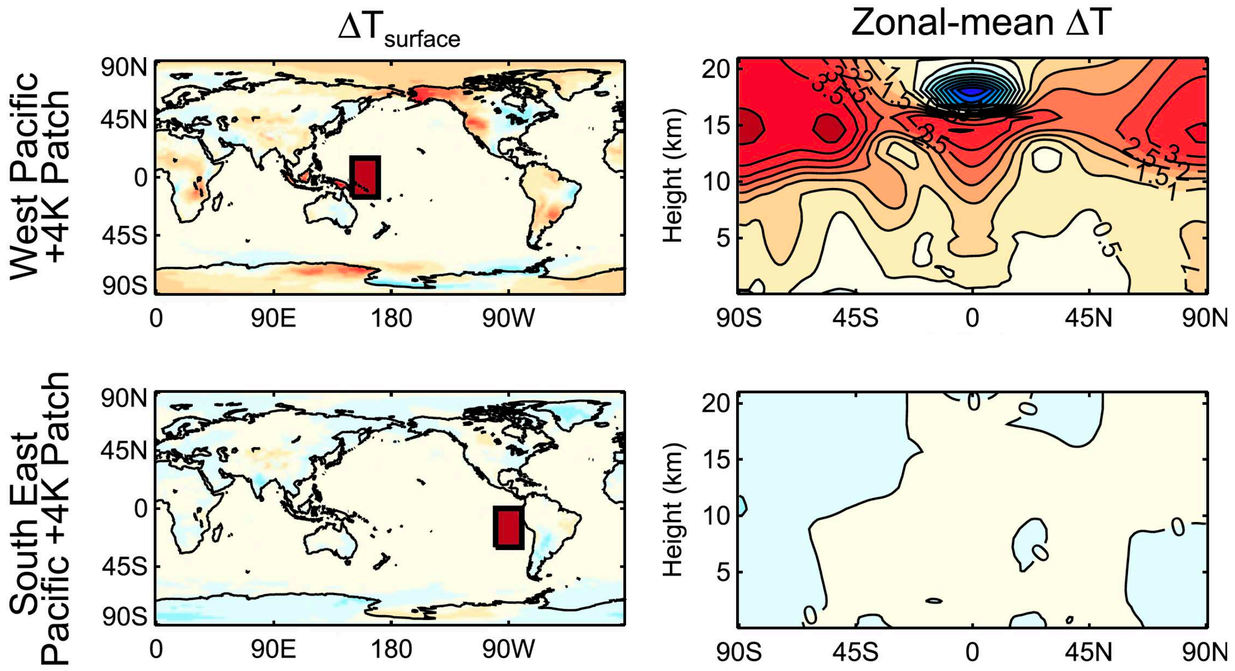

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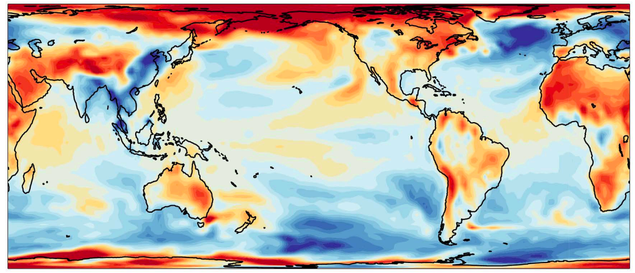
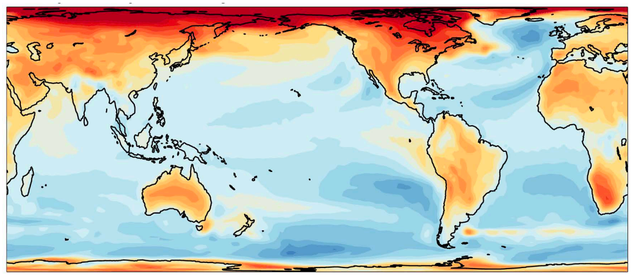
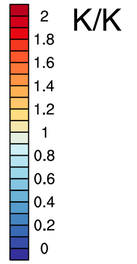
Equilibrium climate sensitivity estimation methods

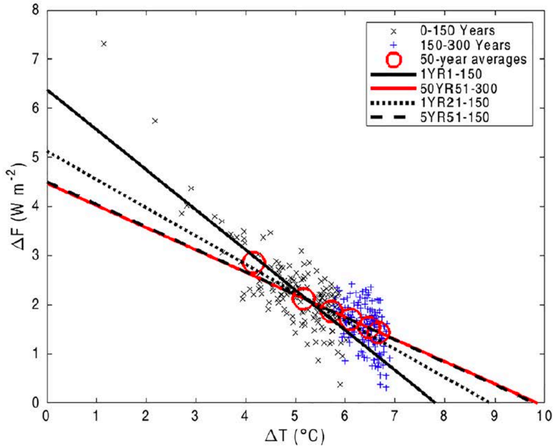
historical warming
internal variability
observations' based

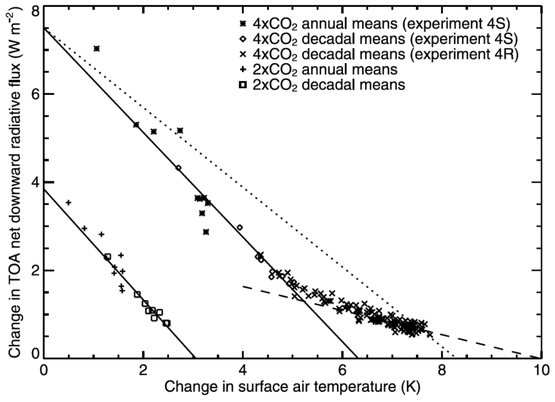


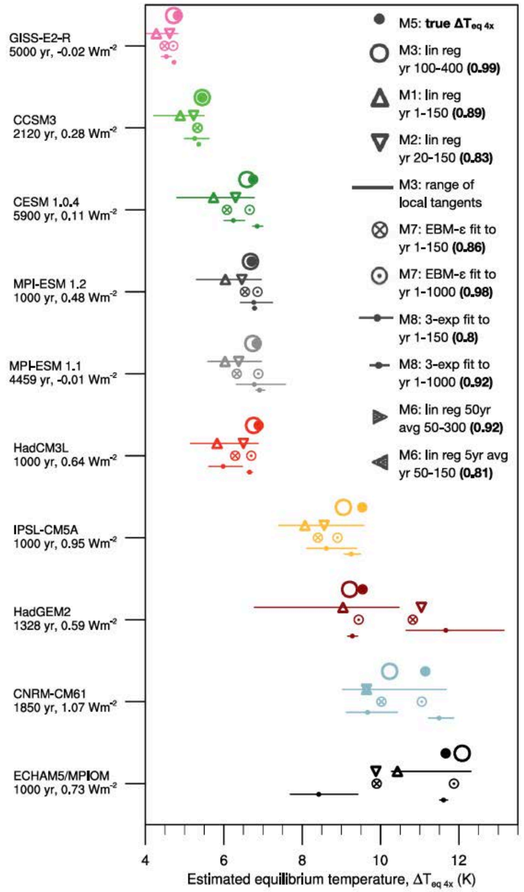




forced or idealized
warming
mechanisms







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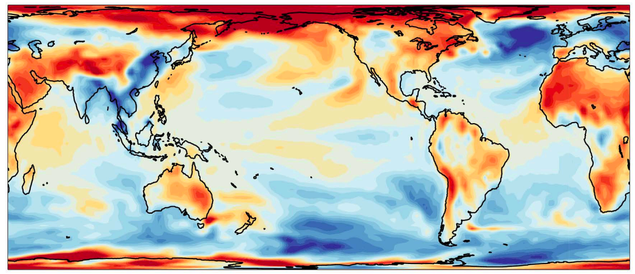
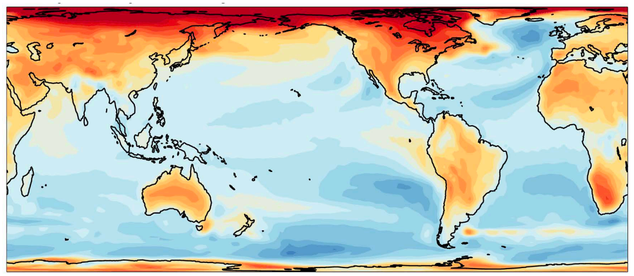
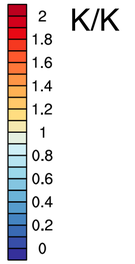
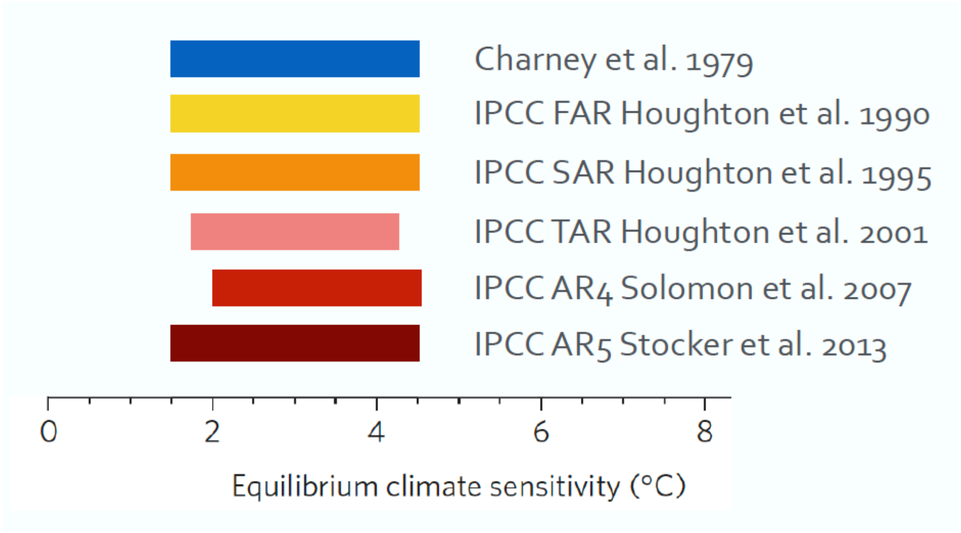
historical warming
internal variability
observations' based







forced or idealized
warming
mechanisms



Andrews et al. 2012 — feedbacks still constant
Otto et al. 2013 — lower ECS evidence from historical
AR5 in 2013— revised ECS estimates down, acknowledged problem

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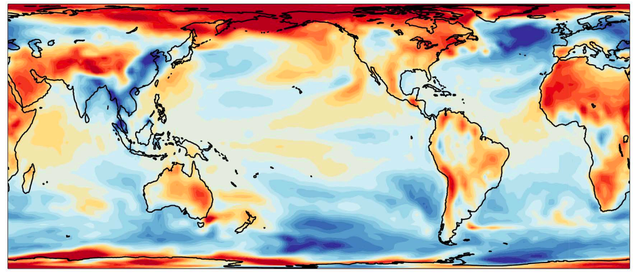
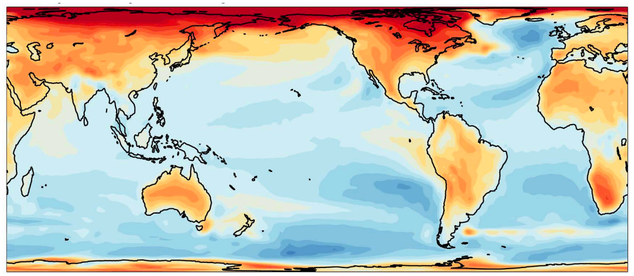
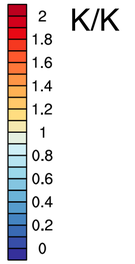
Feedback temperature dependence

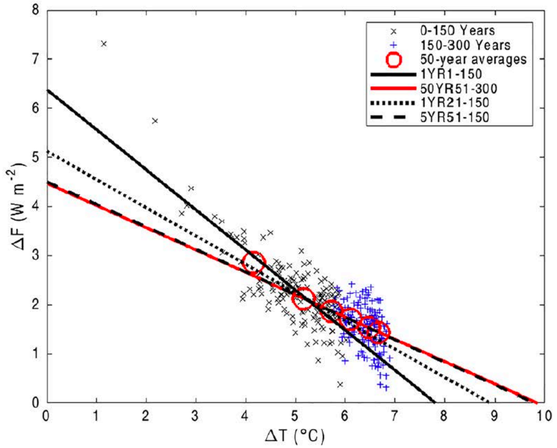
historical warming
internal variability
observations' based

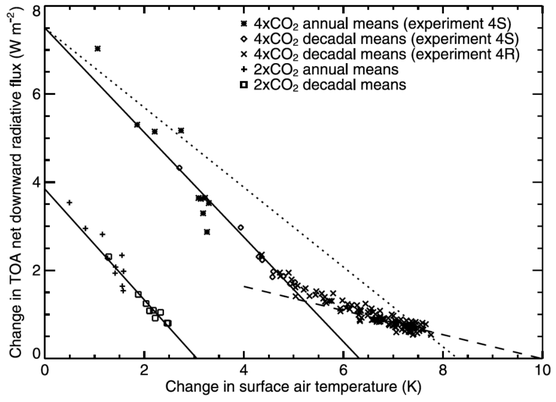


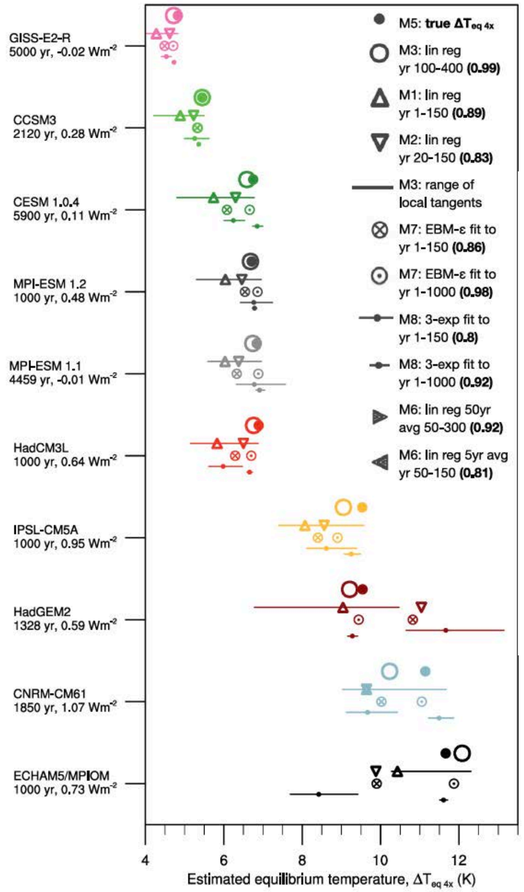


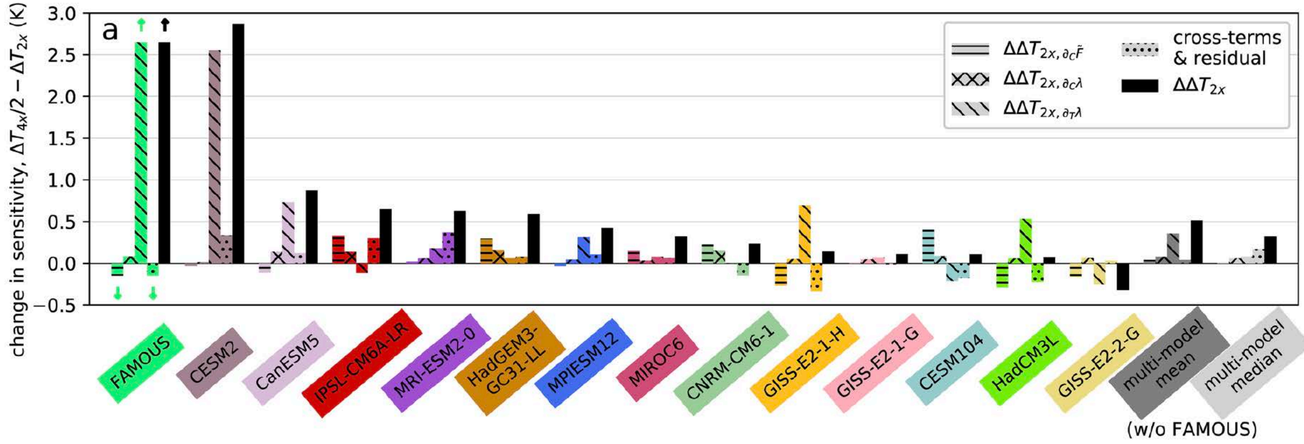


forced or idealized
warming
mechanisms





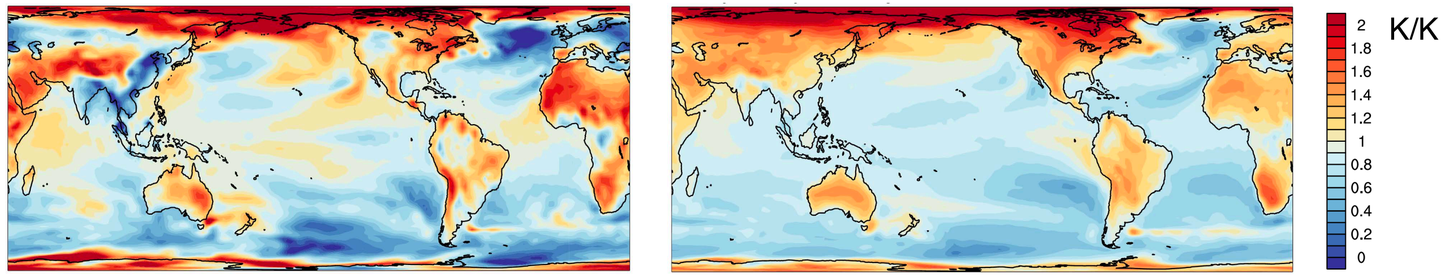




Bloch-Johnson et al. 2021

Pattern effect of internal variability

historical warming
internal variability
observations' based



forced or idealized
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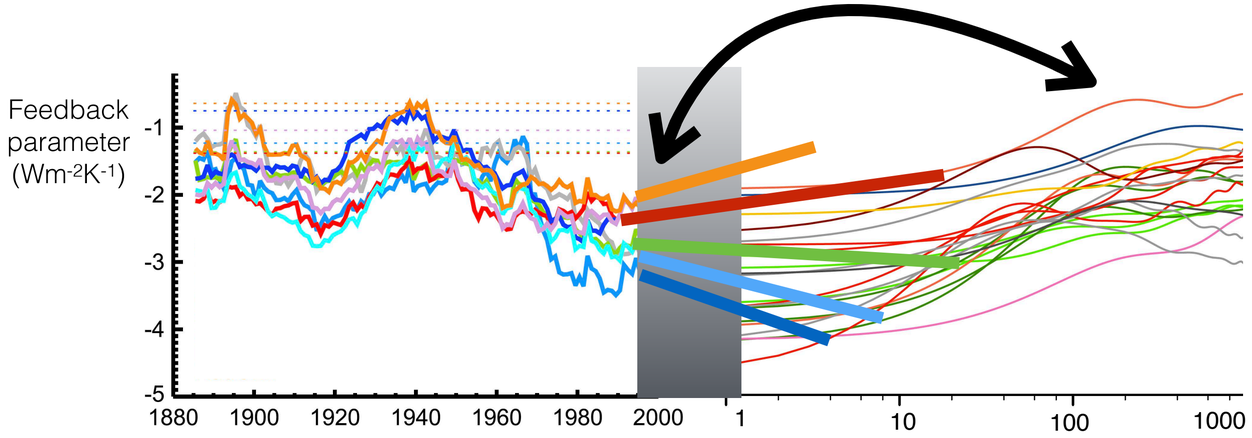
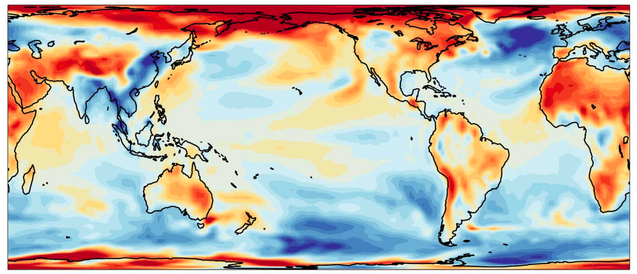
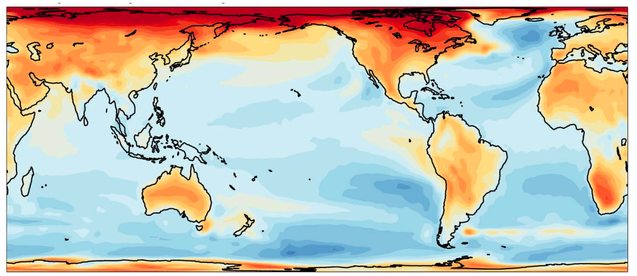
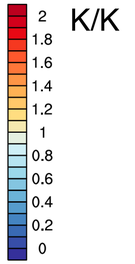


Quantifying the pattern effect

historical warming
internal variability
observations' based







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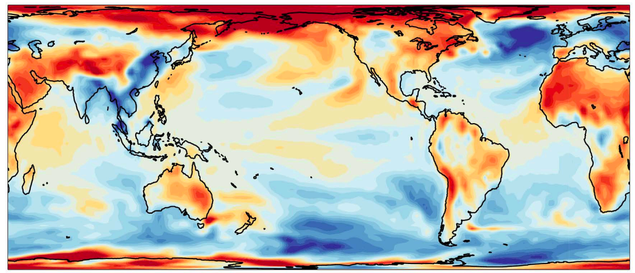
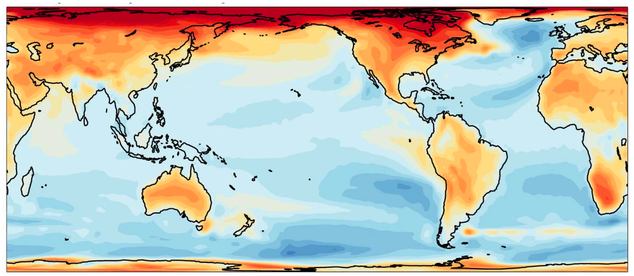
ean heat transport influences radiative feedbacks

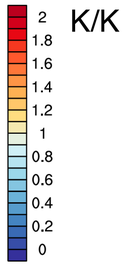
$$\Delta\lambda = \lambda_{4\times CO_2\ 150yr} - \lambda_{hist} = 0.5 \pm 0.5\ \frac{W}{m^2K}$$

Quantifying the pattern effect

historical warming
internal variability
observations' based







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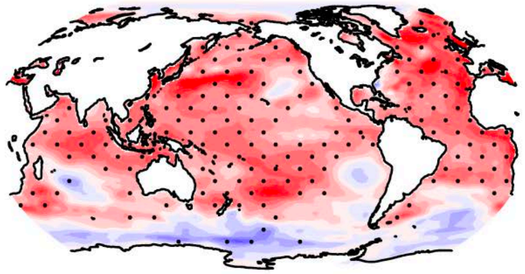
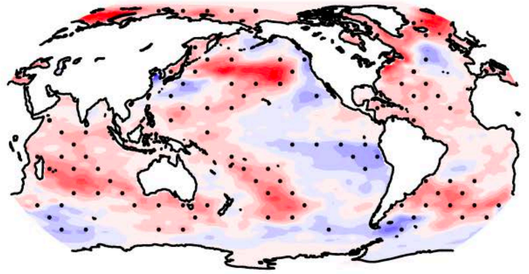
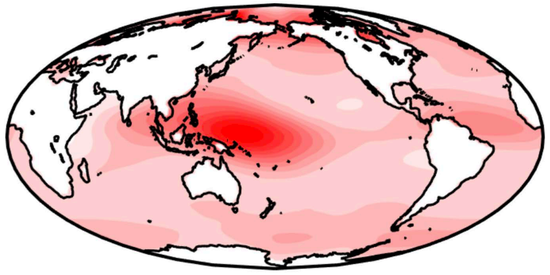
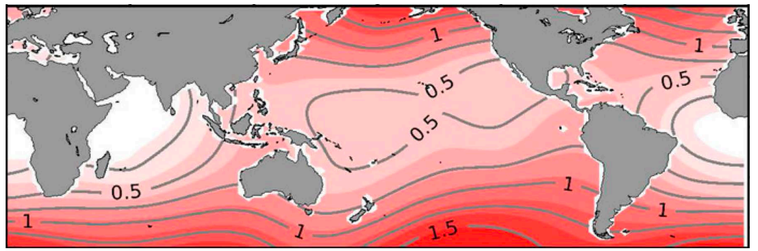
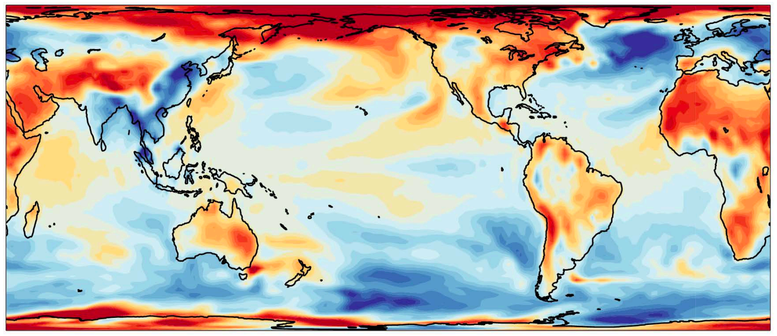
Outstanding questions

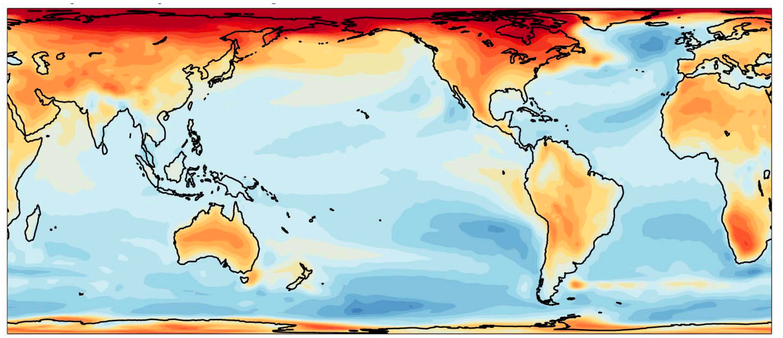


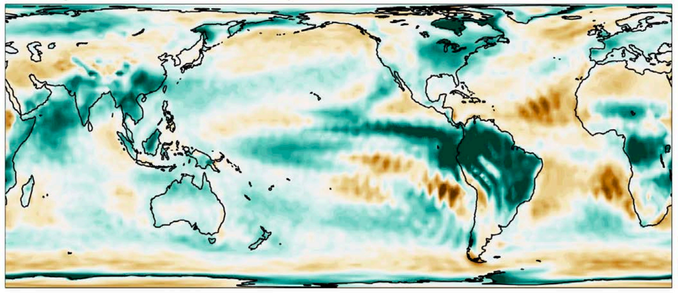


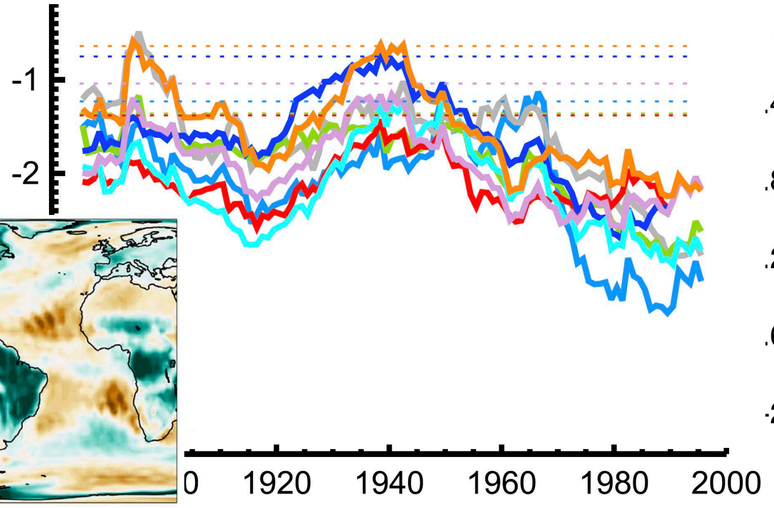


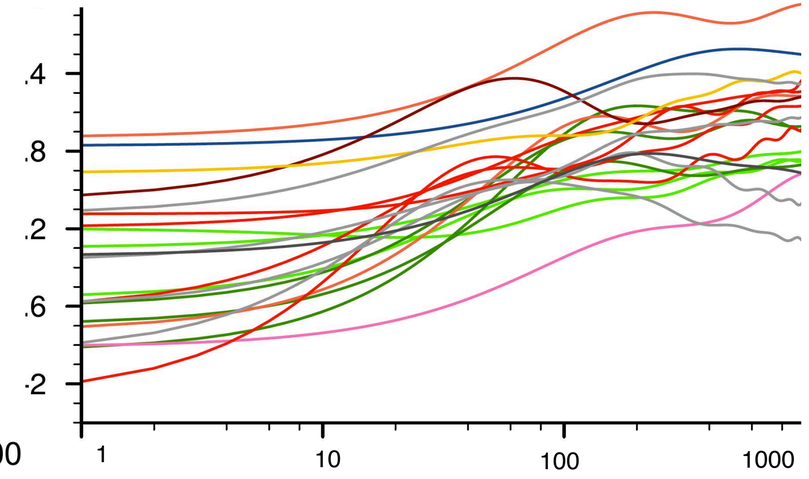




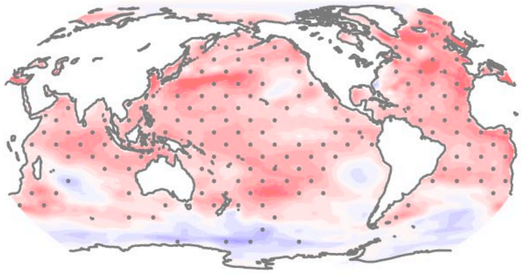


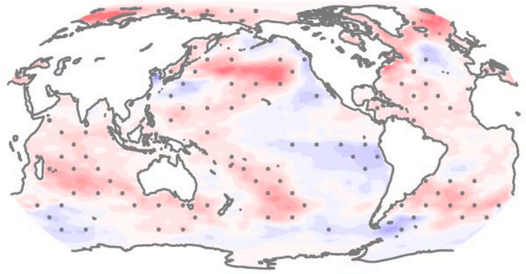


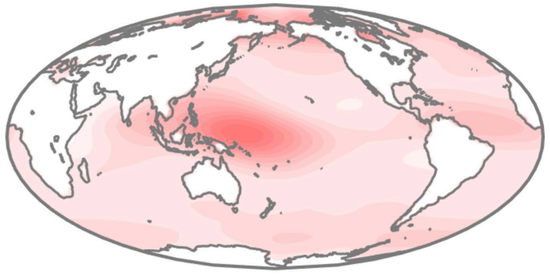


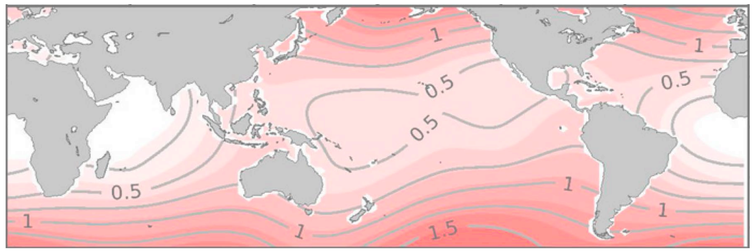


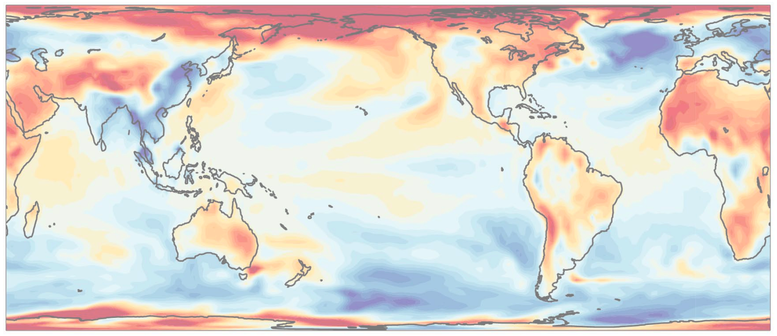
Outstanding questions

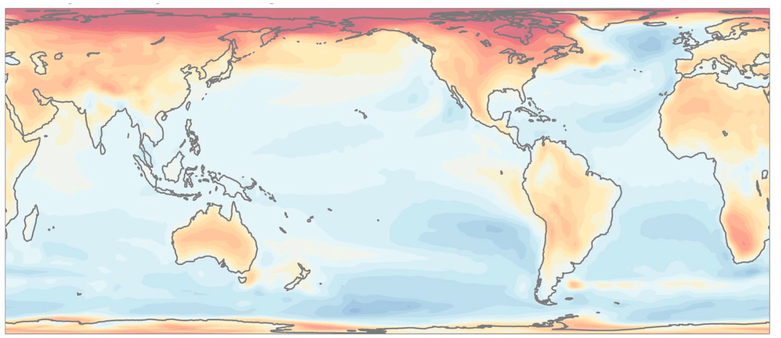












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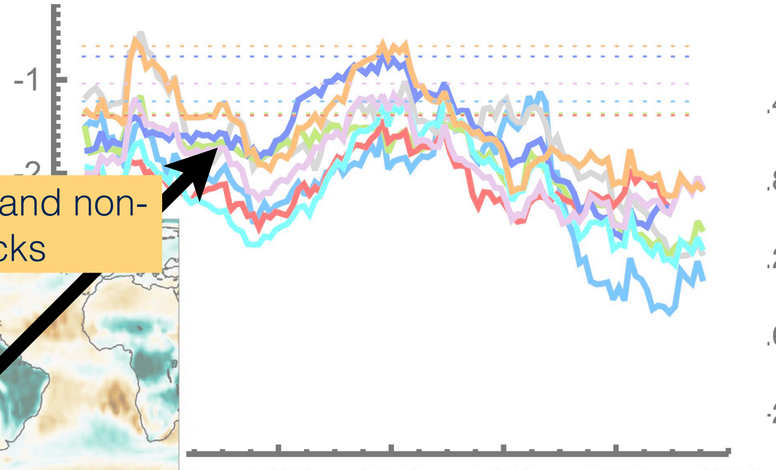

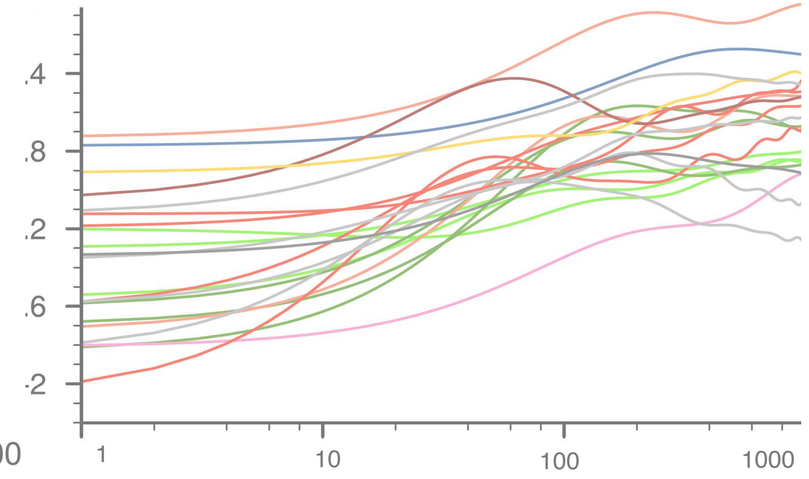

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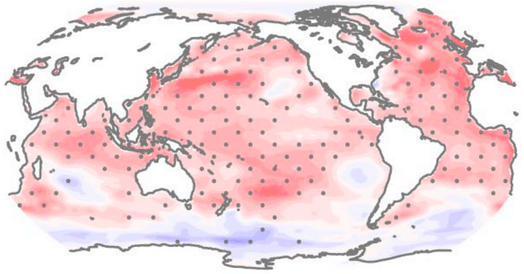

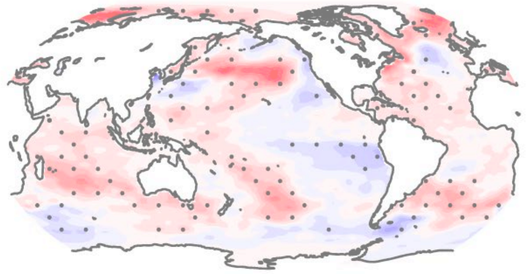

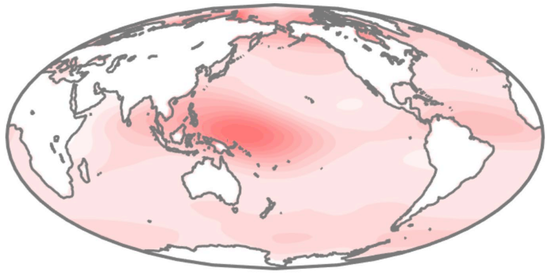

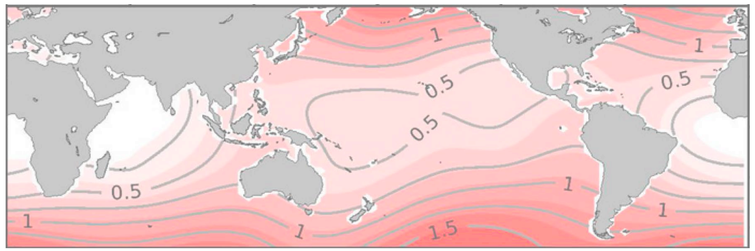

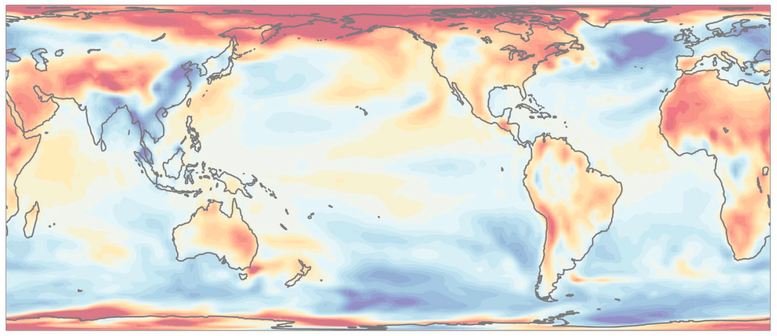

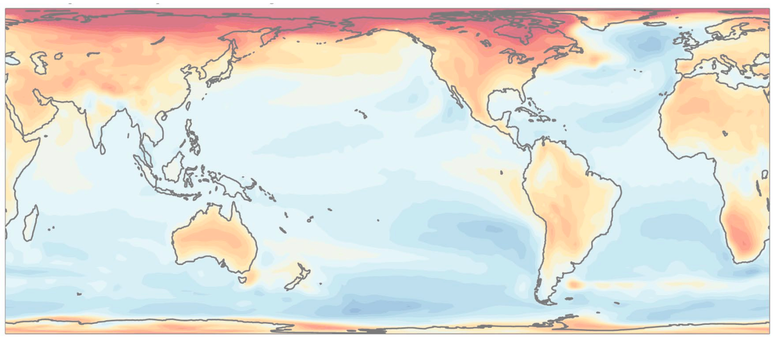

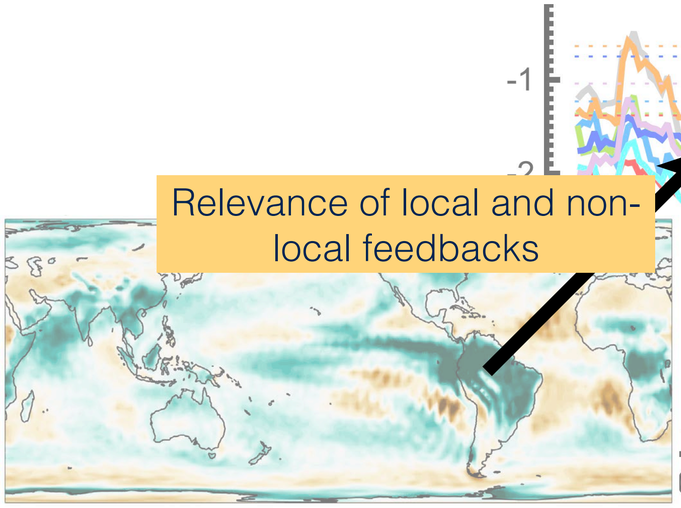

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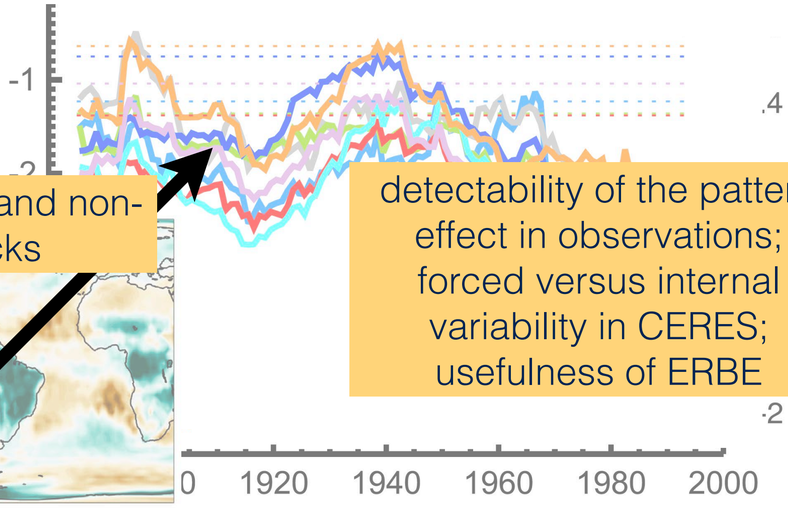

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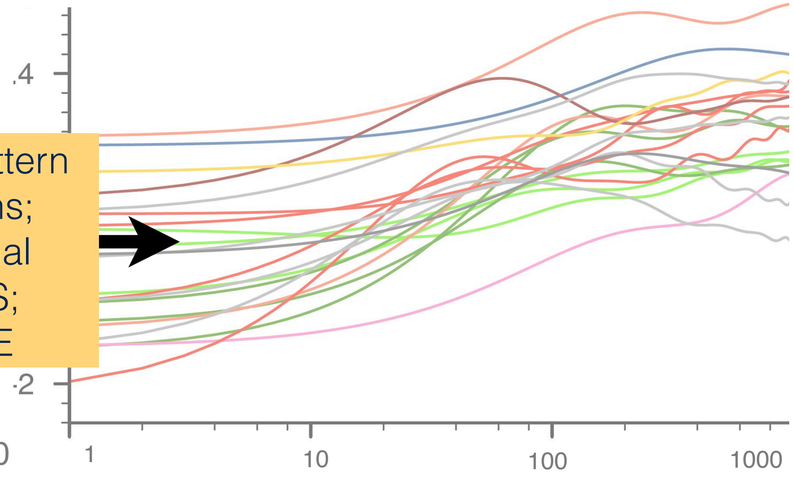

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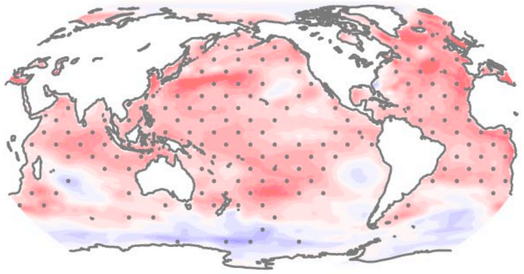

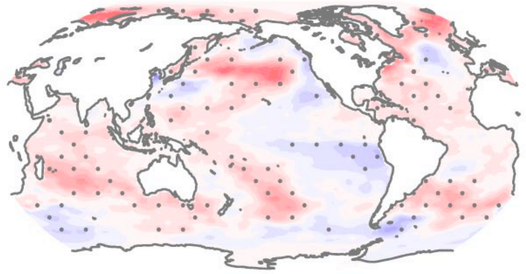

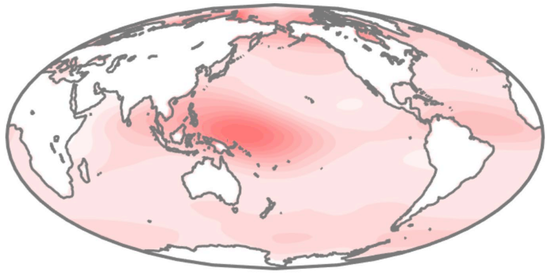

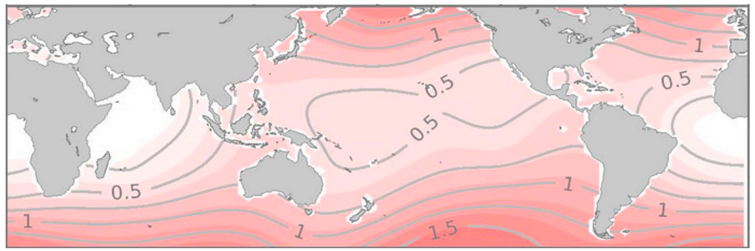

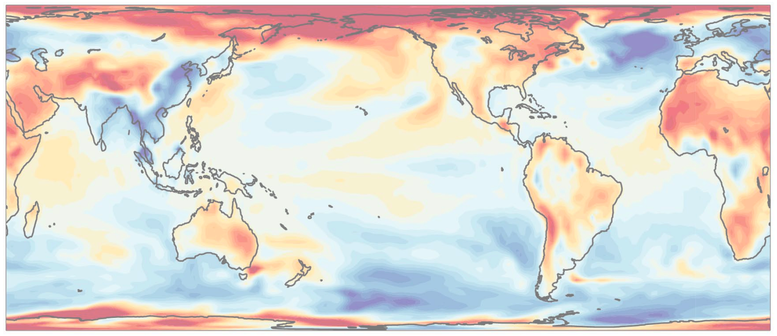

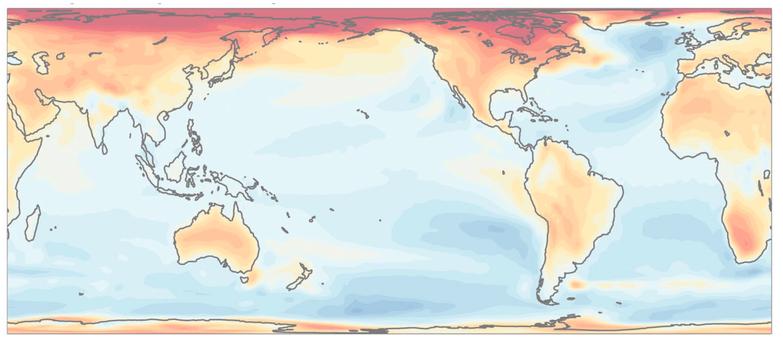

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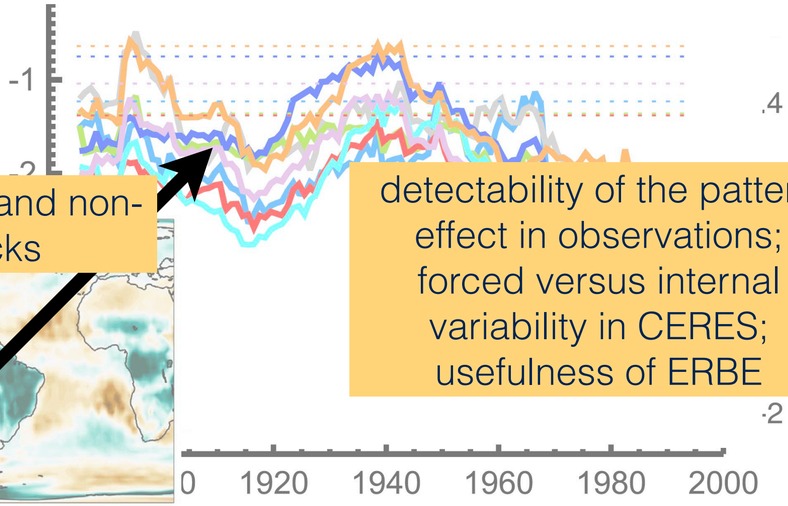

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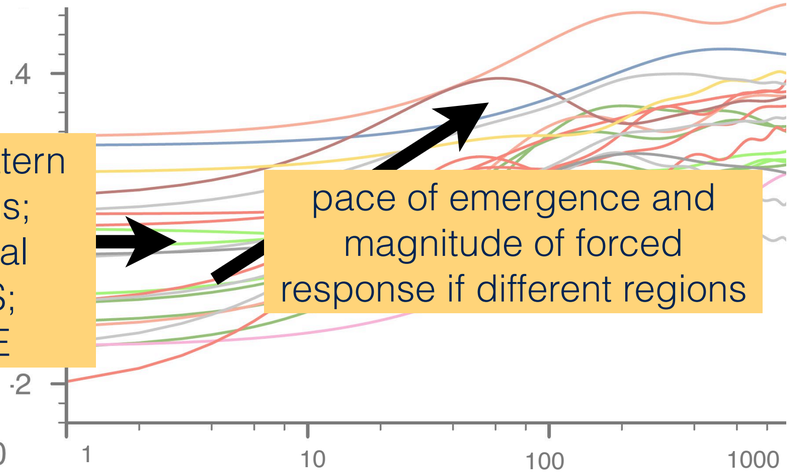

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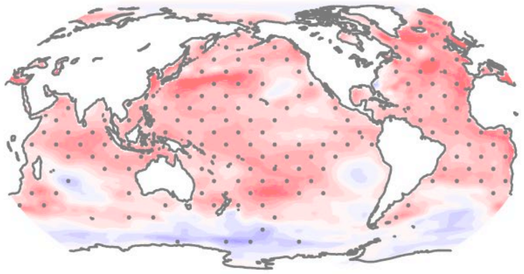

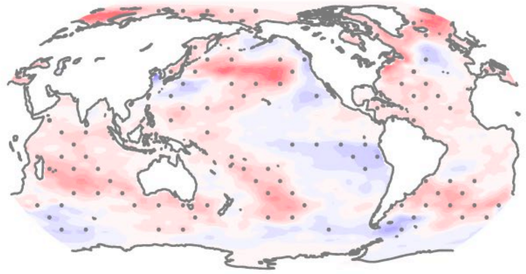

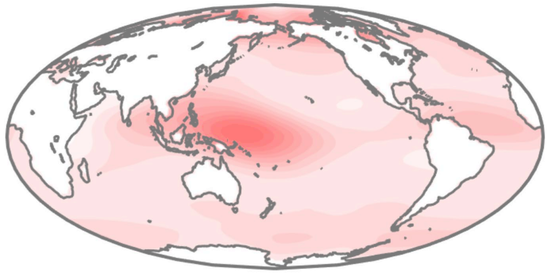

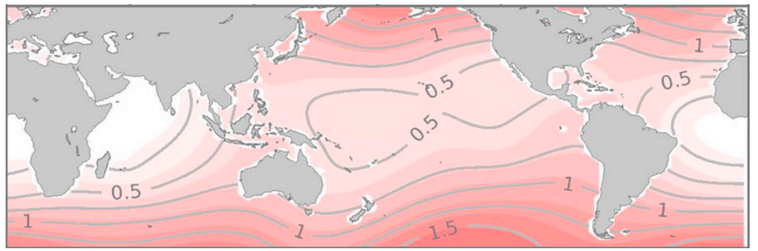

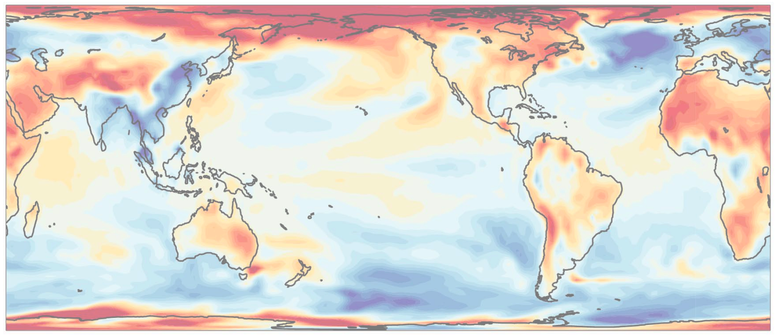

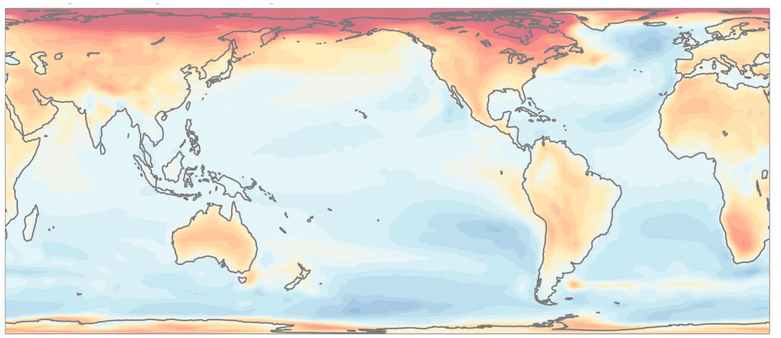

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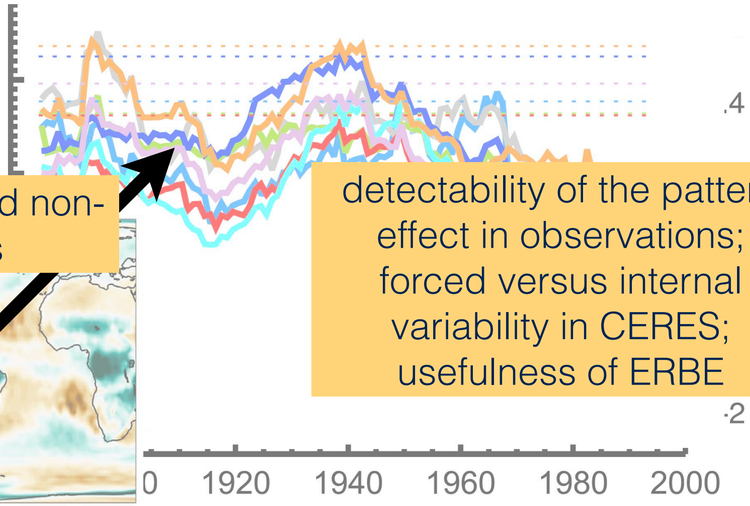

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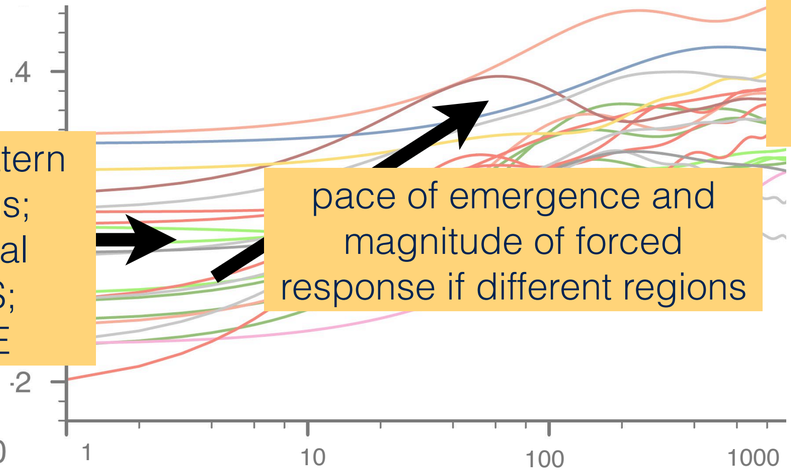

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Lines of evidence for ECS constraints;
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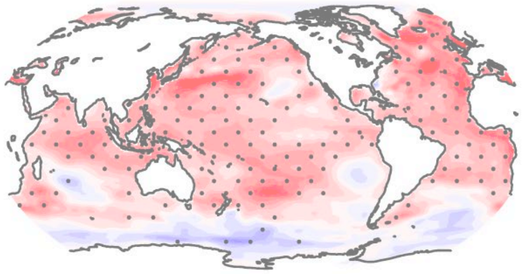

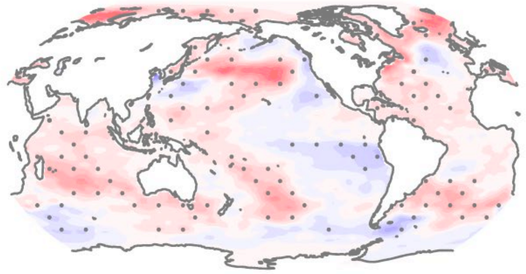

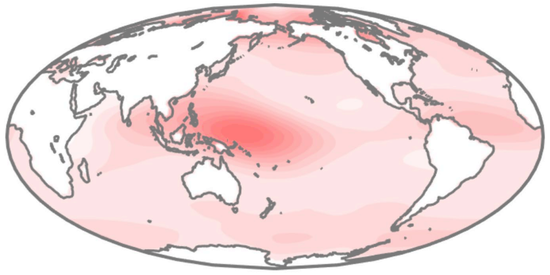

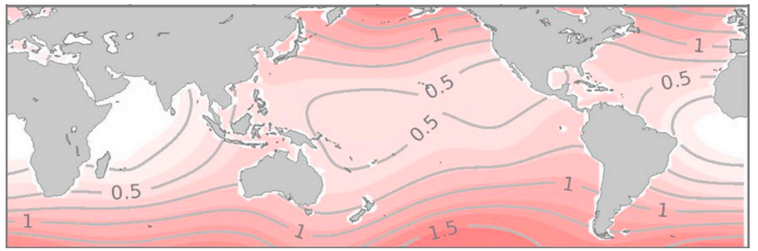

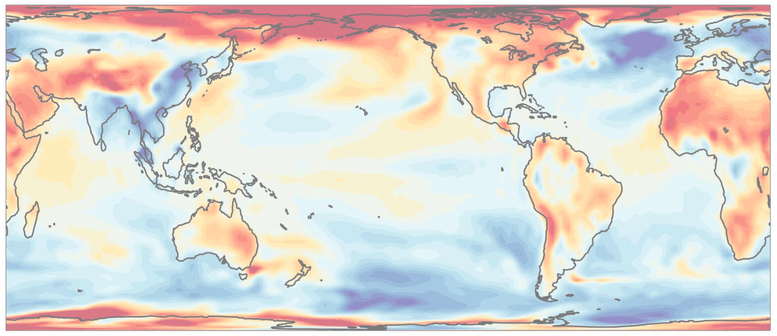

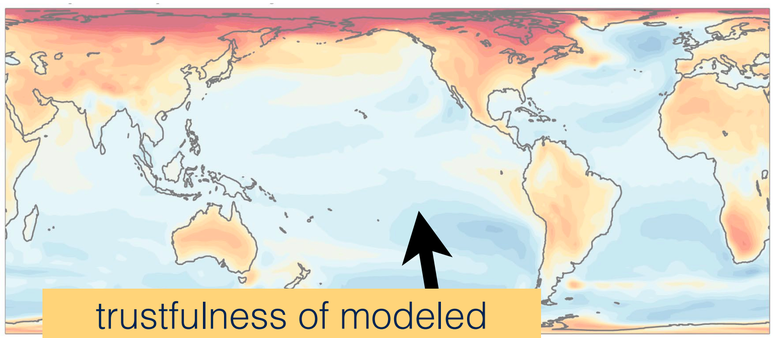

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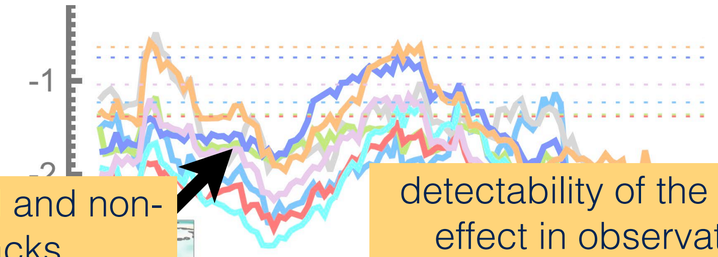

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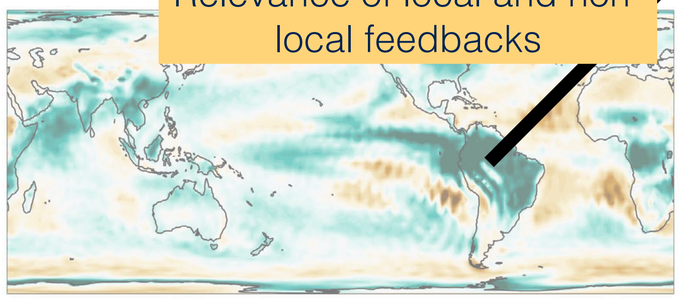

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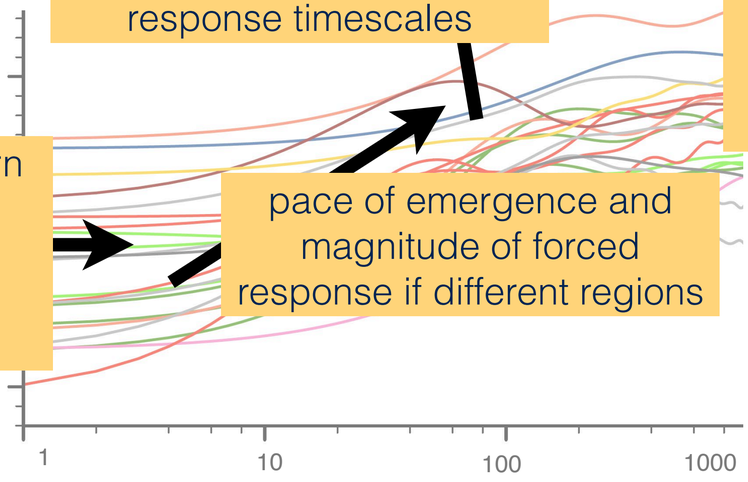

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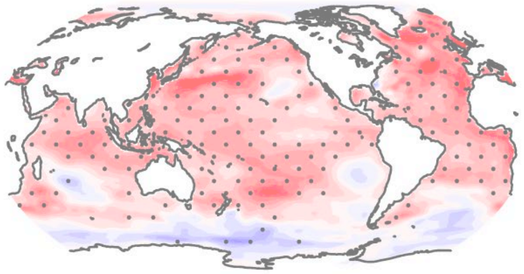

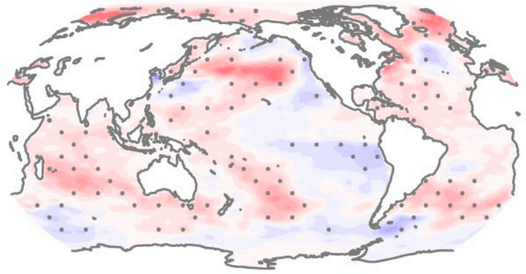

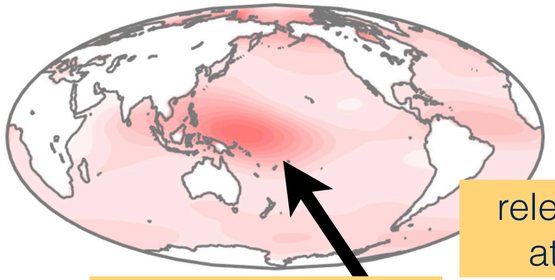

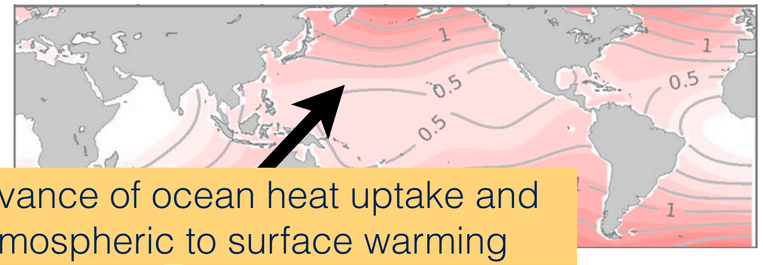

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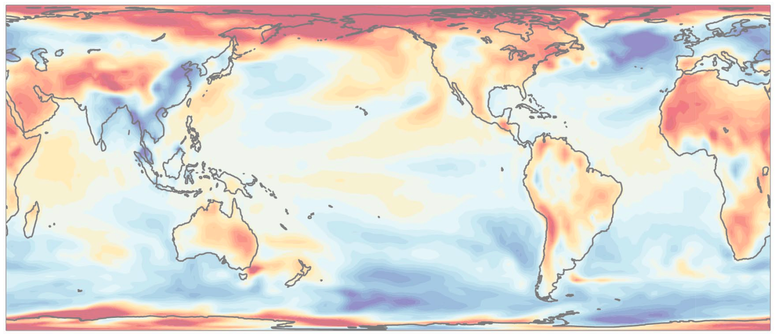

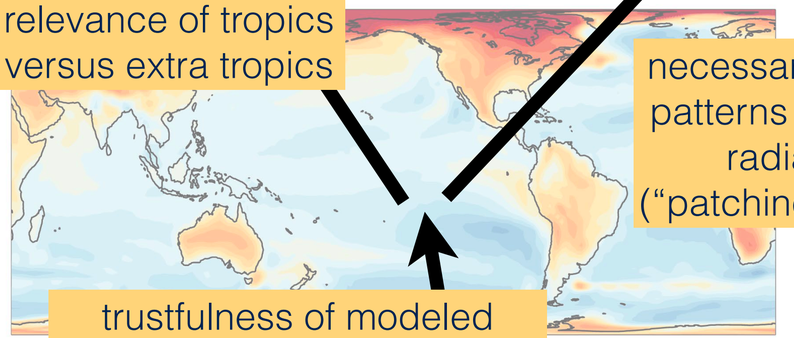

necessary scale of warming patterns to matter for global radiative feedback (“patchiness of SST pattern”)

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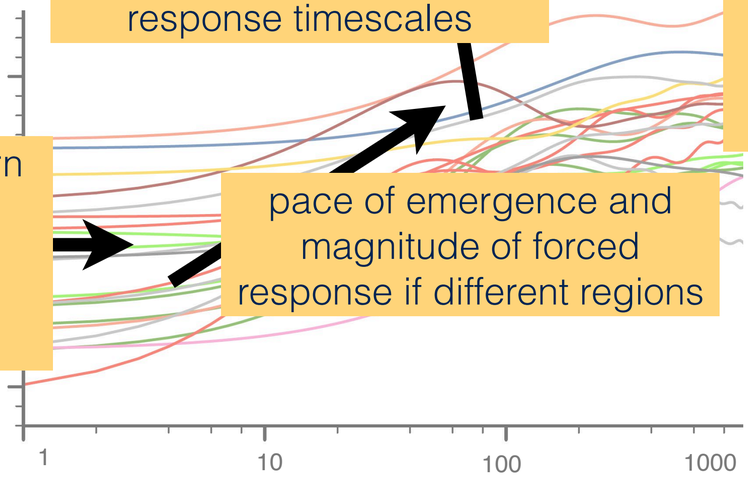

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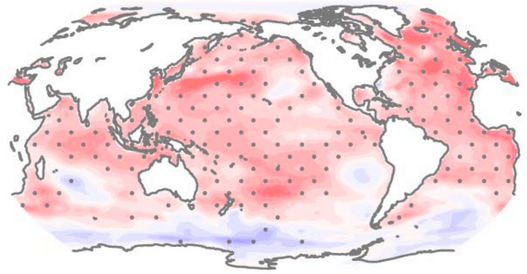
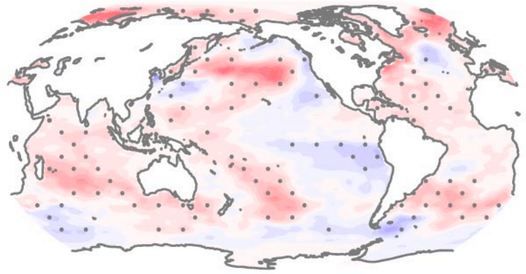
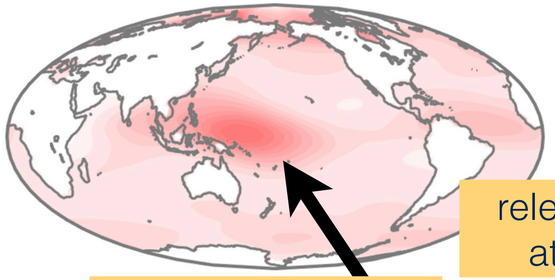
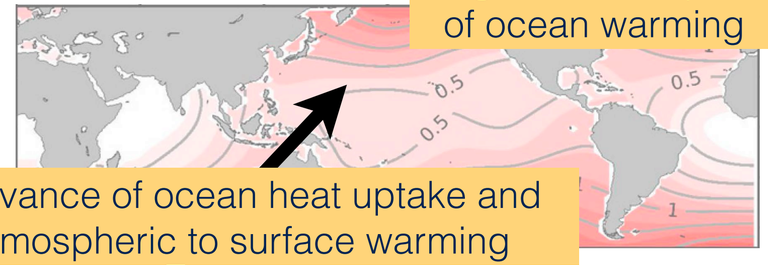






magnitude and pace of ocean warming



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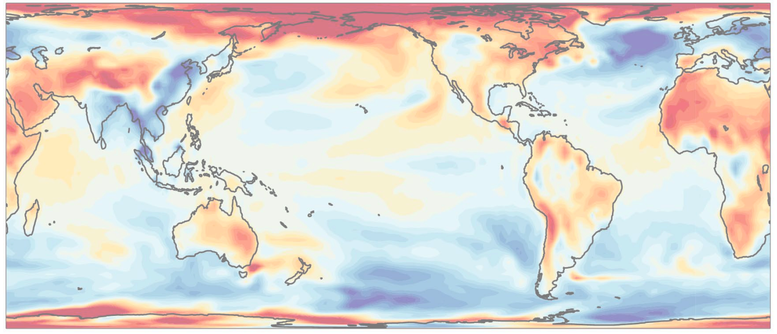

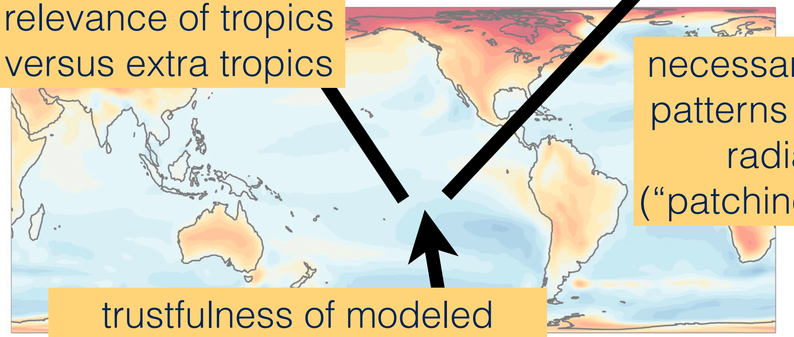

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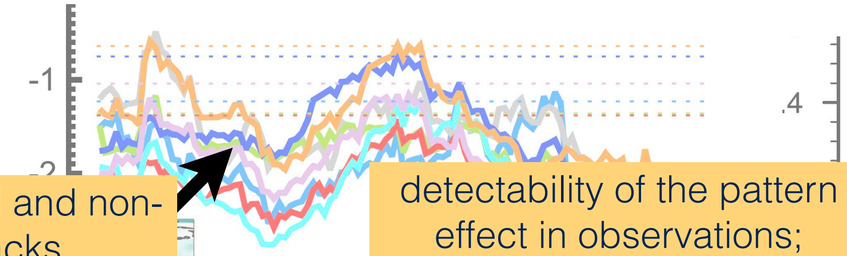

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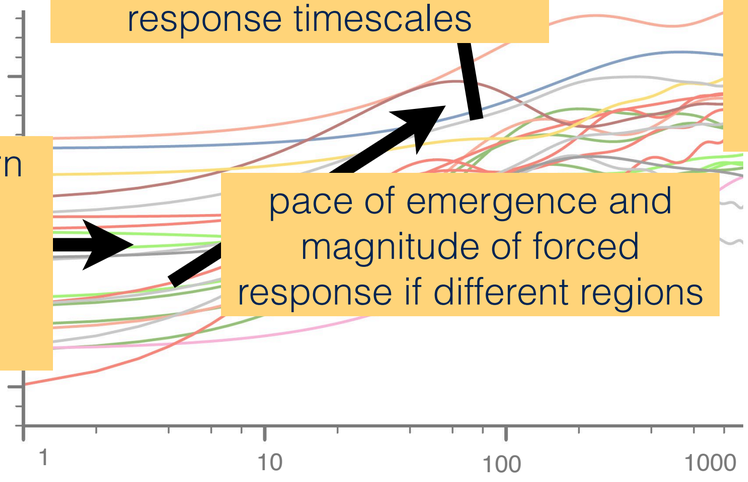

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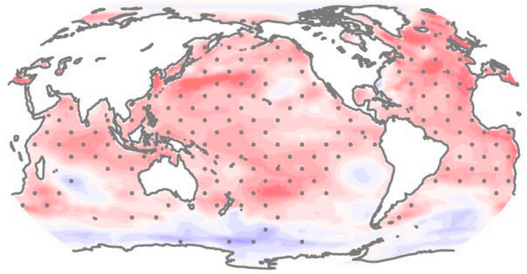

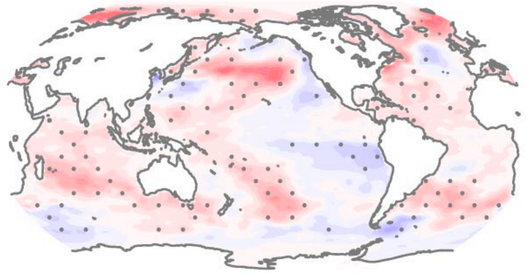

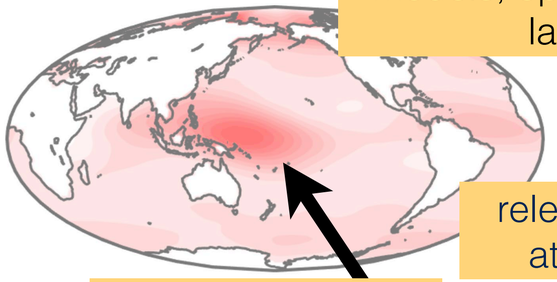

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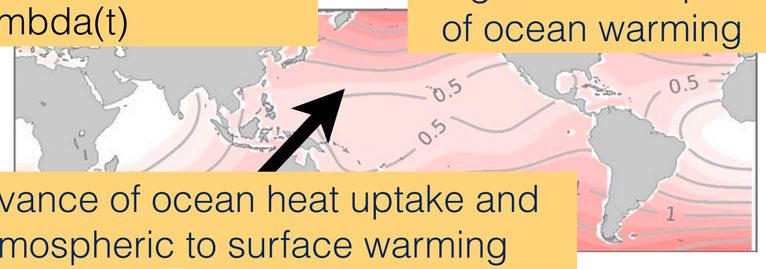

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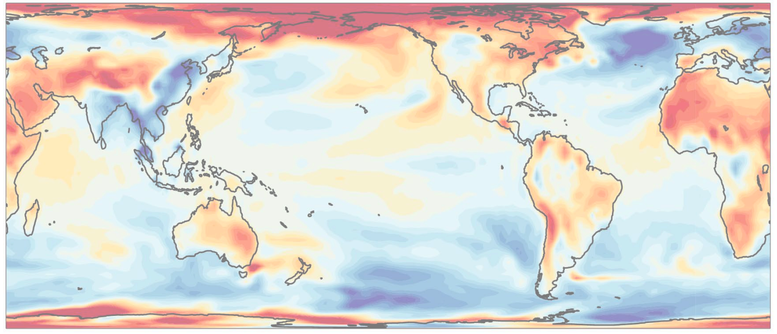

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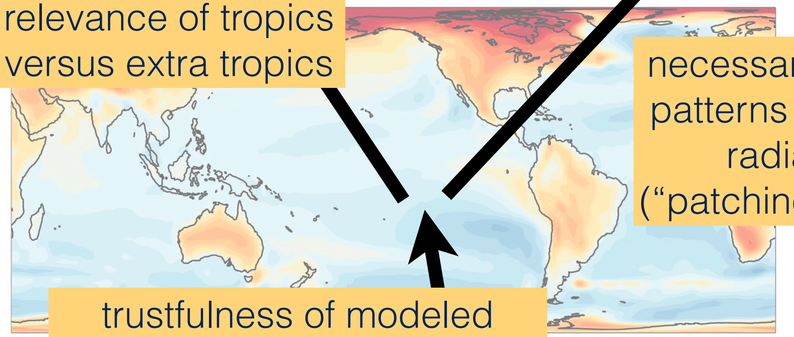

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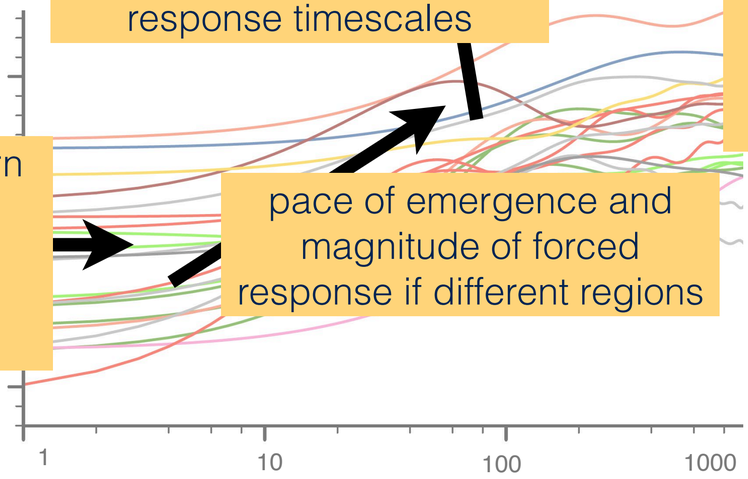

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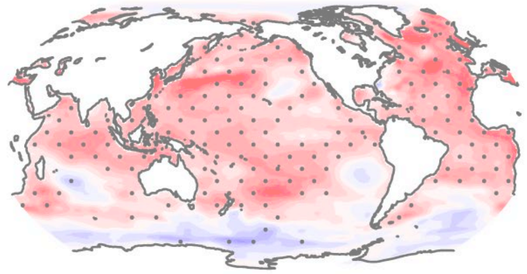

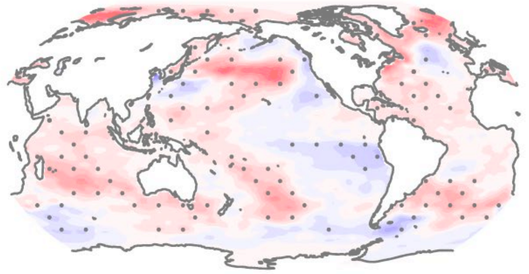

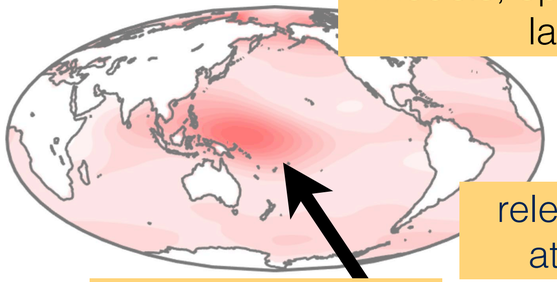

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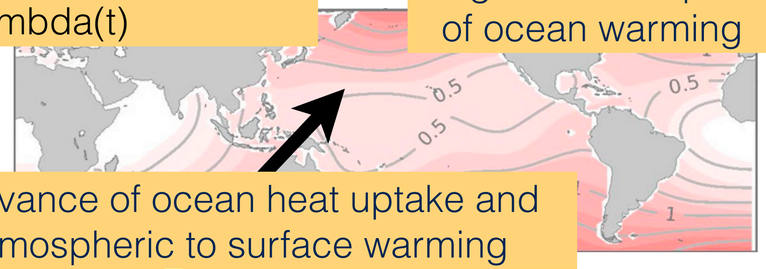

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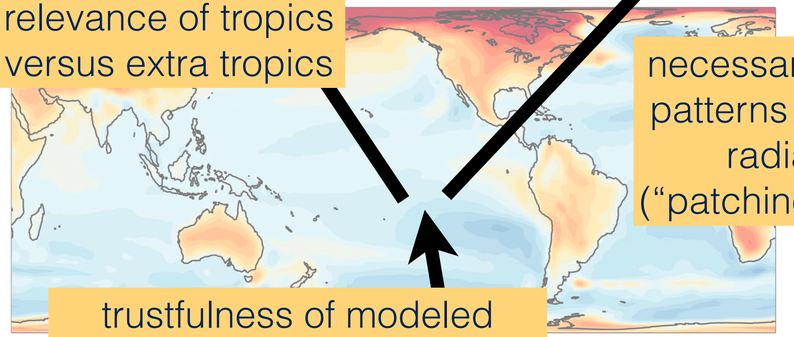

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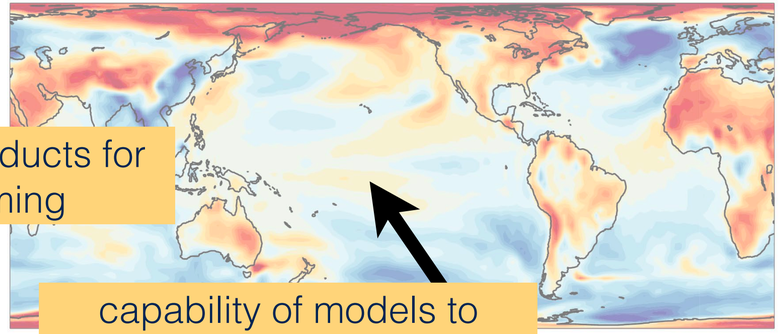

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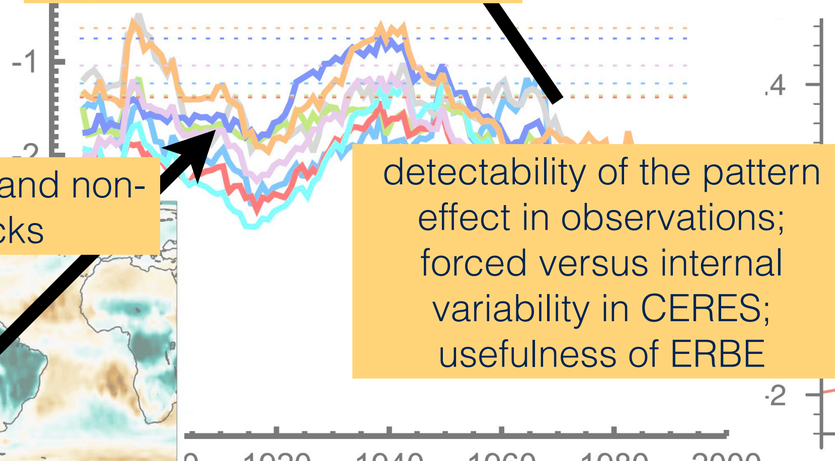

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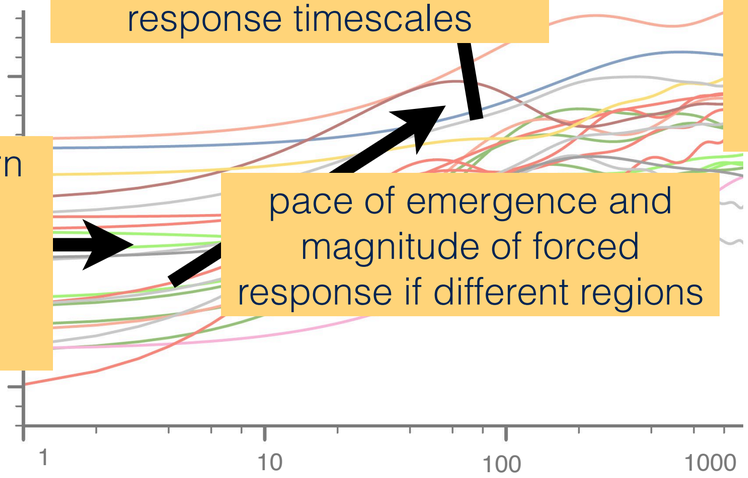

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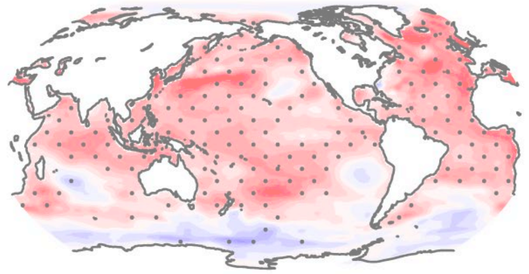

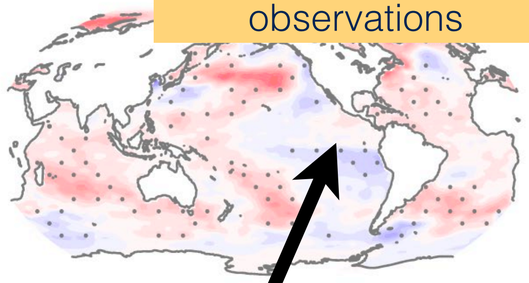

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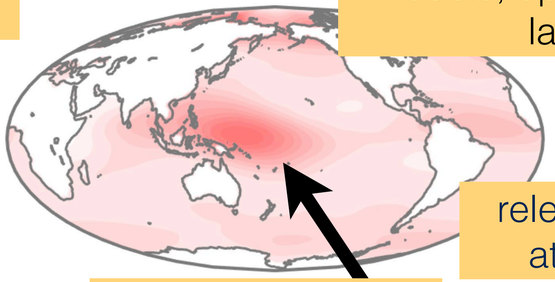

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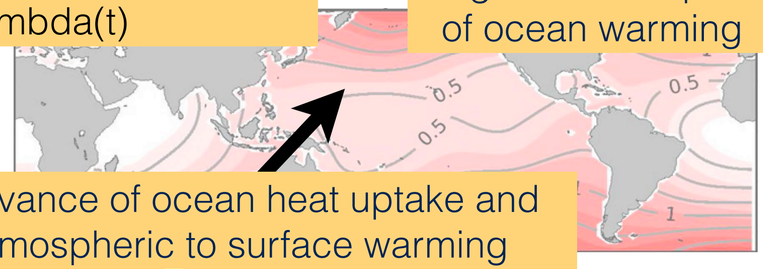

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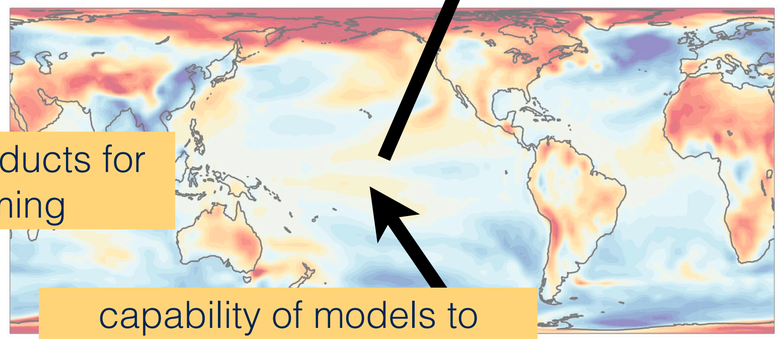

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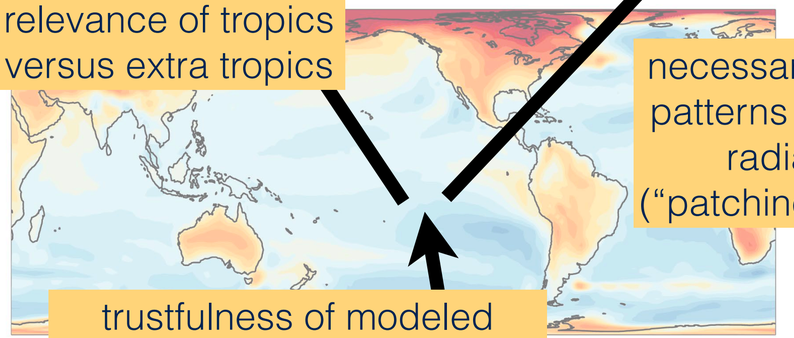

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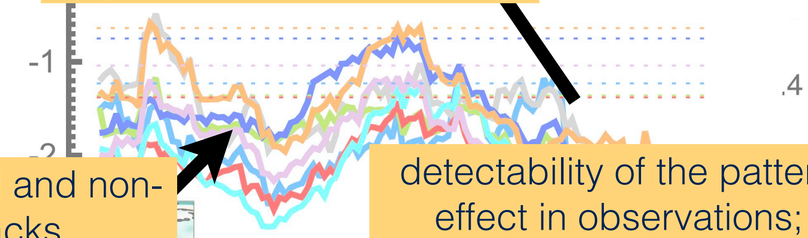

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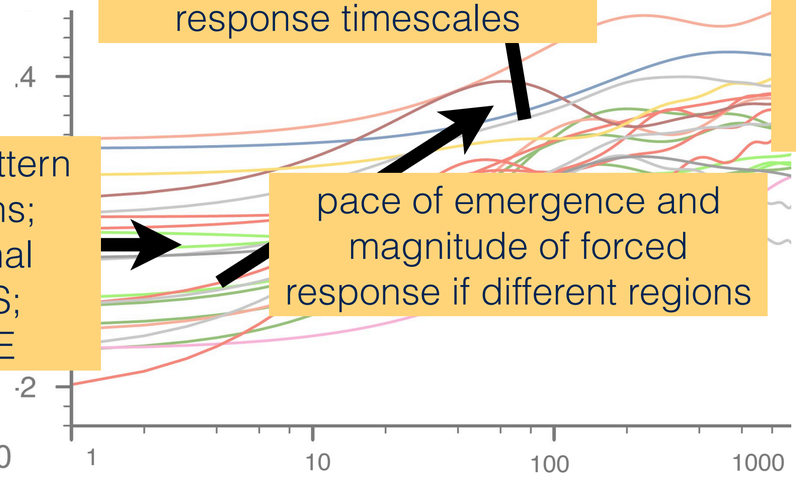

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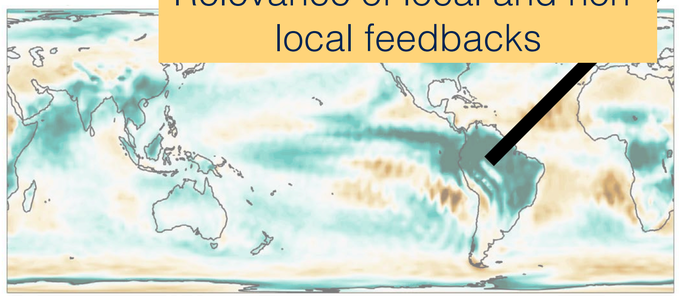

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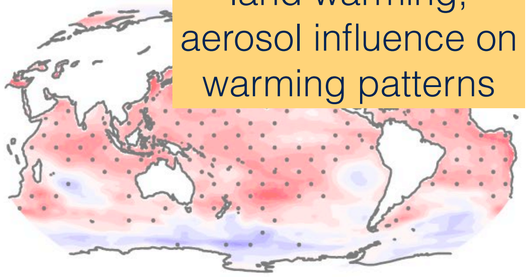

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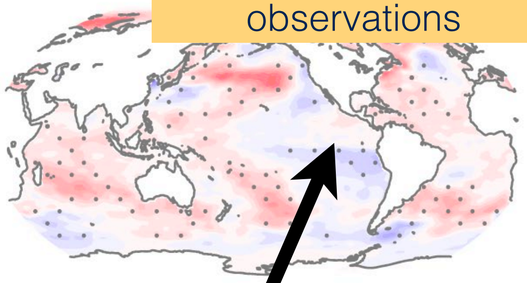

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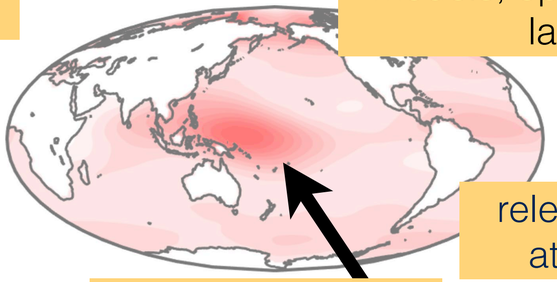

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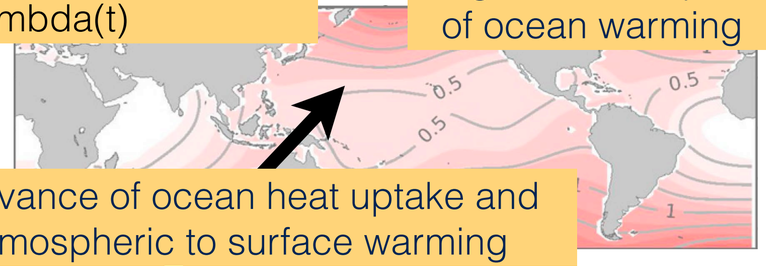

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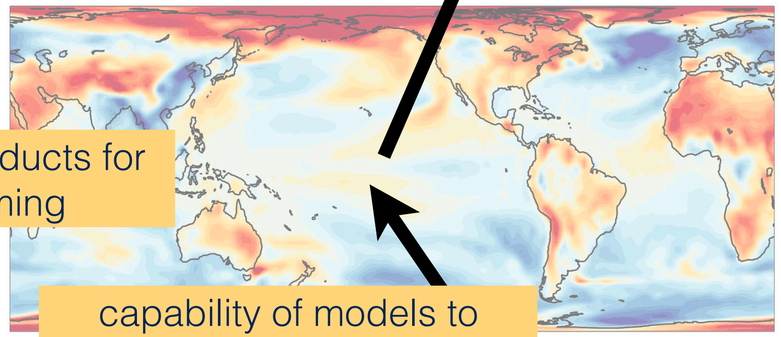

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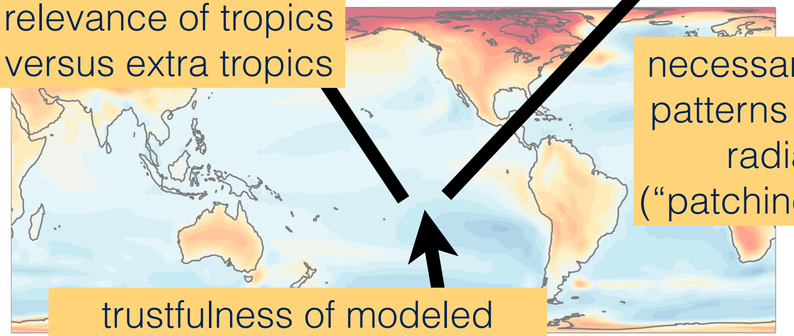

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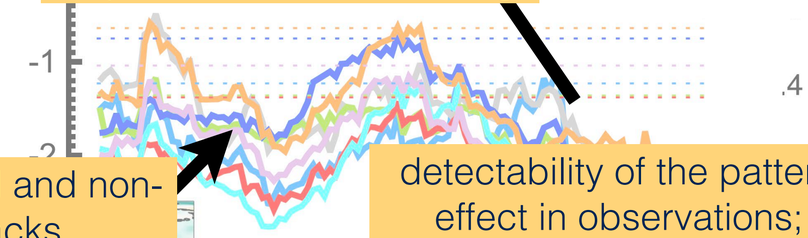

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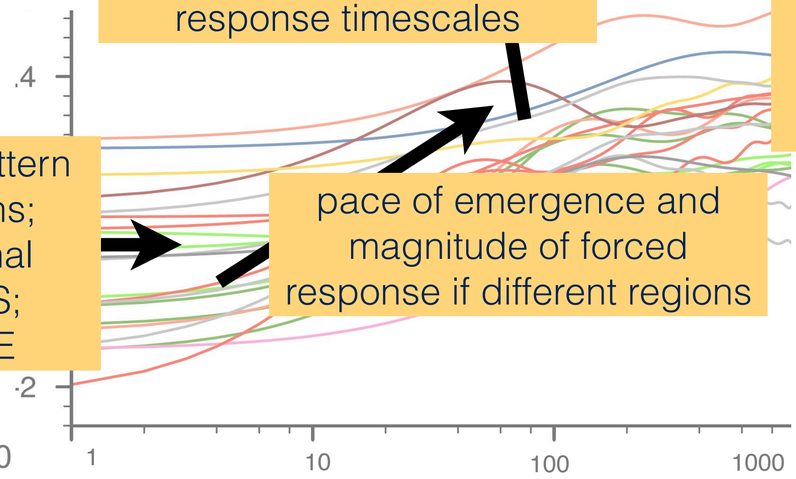

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