Constraining the cloud-feedback pattern effect using (mostly) CERES data

CERES Science Team Meeting
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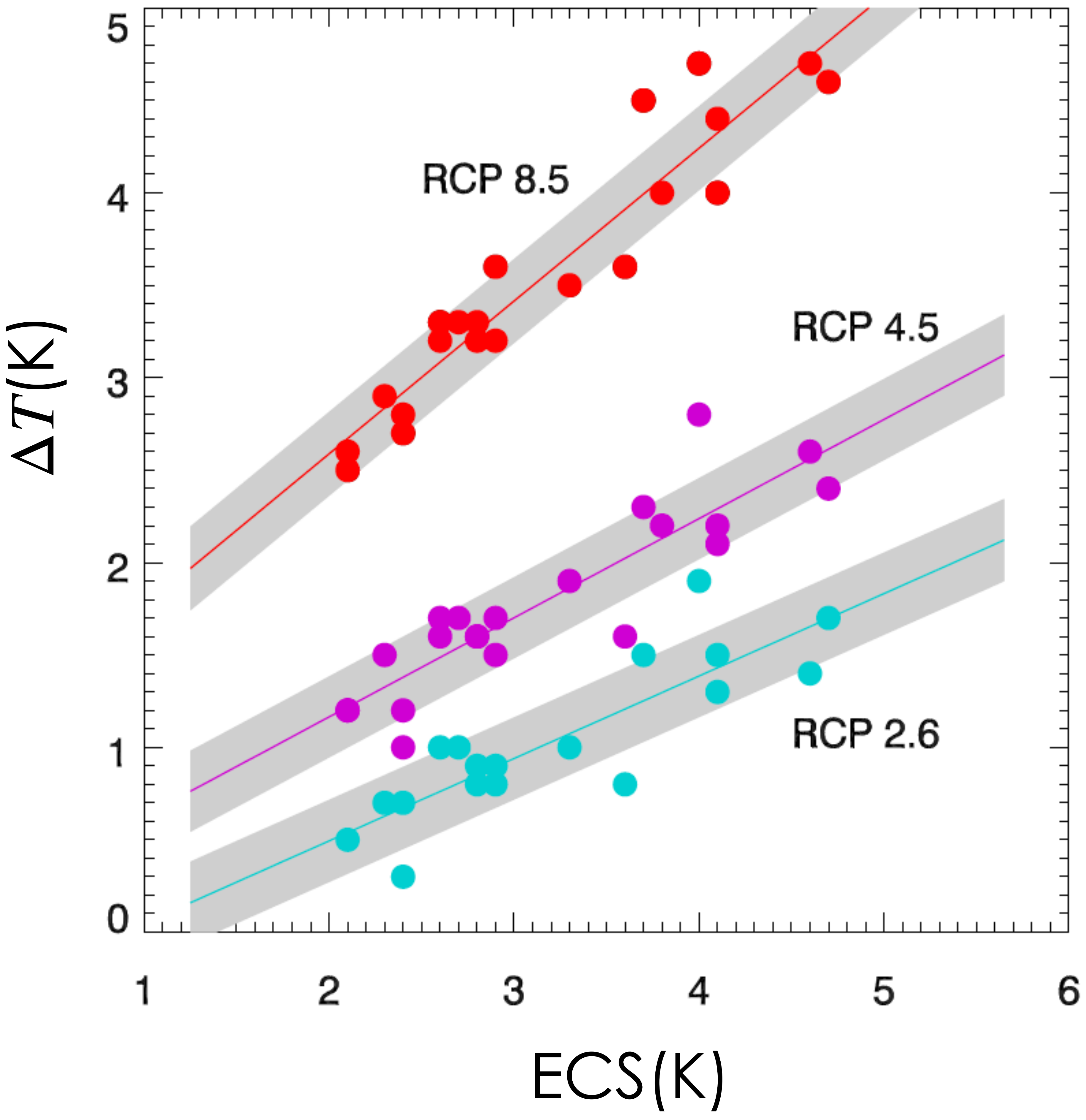
Equilibrium Climate Sensitivity (ECS)

"Equilibrium change in Earth's global mean surface temperature, in response to a doubling of atmospheric CO_2 relative to pre-industrial conditions" (IPCC)

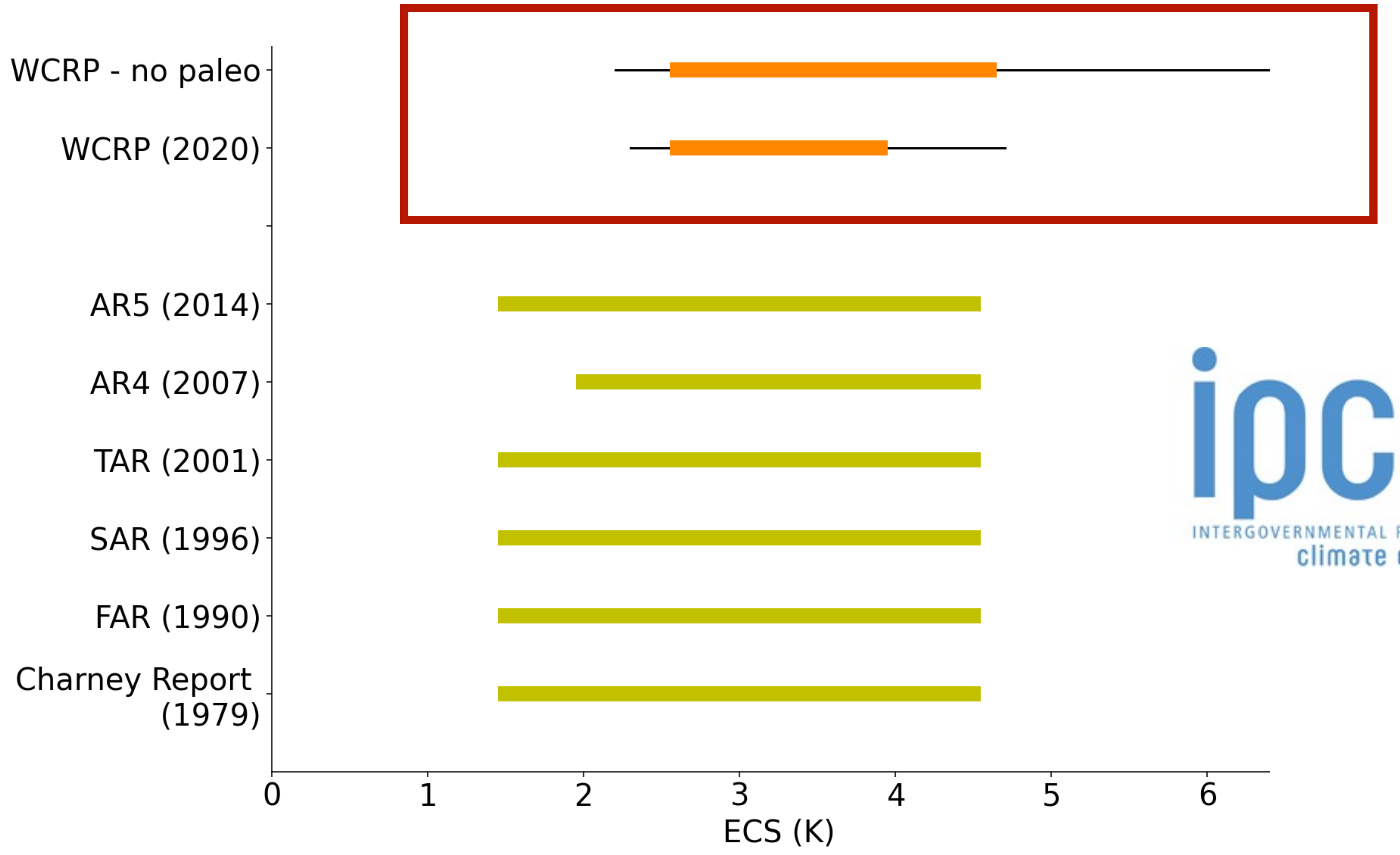
ECS is a good predictor of future warming

Warming by end of century



Sherwood, Webb, et al 2020

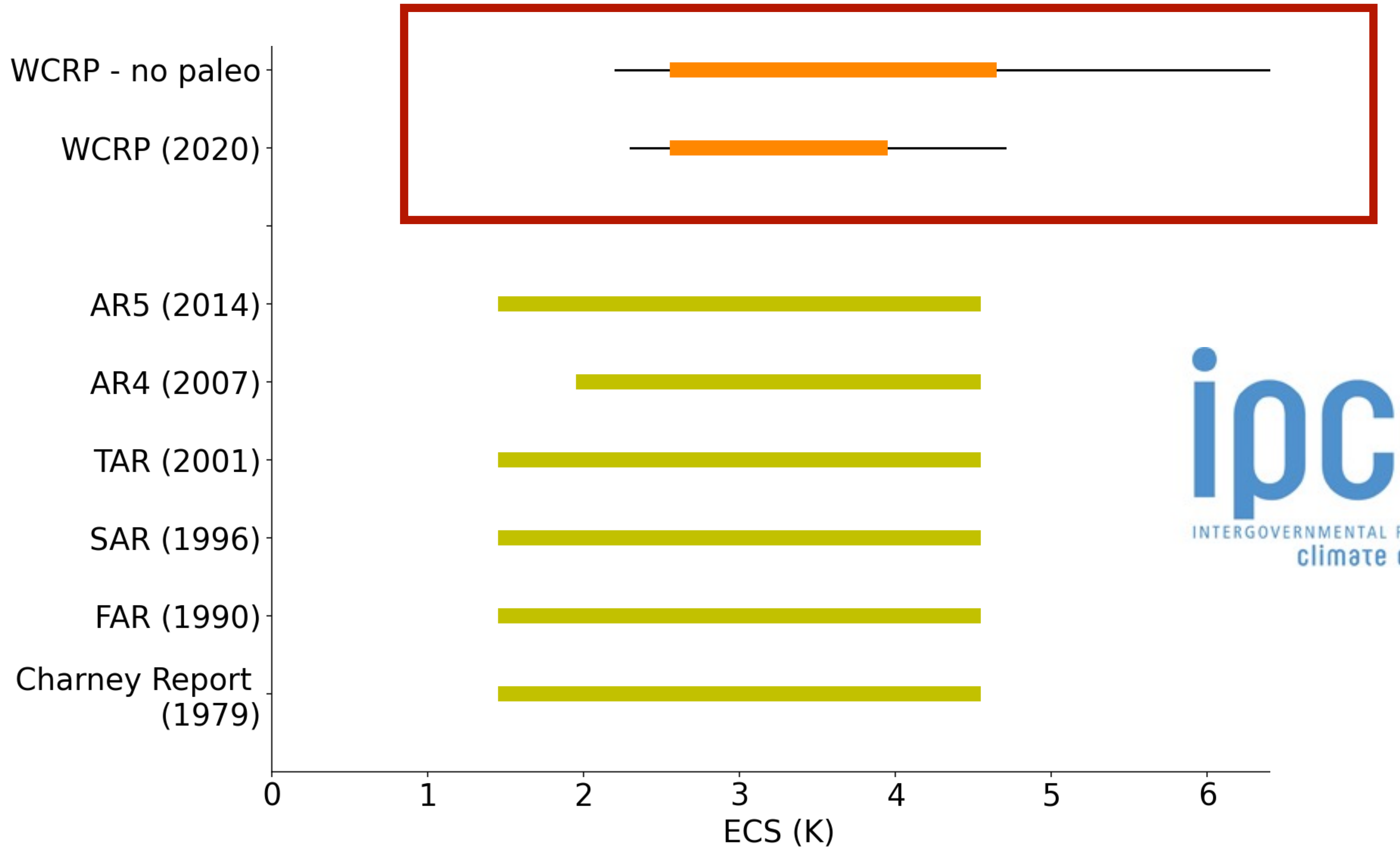
Observational constraints are weak (as are model-constraints)



Sherwood, Webb et al 2020

Observational constraints are weak (as are model-constraints)

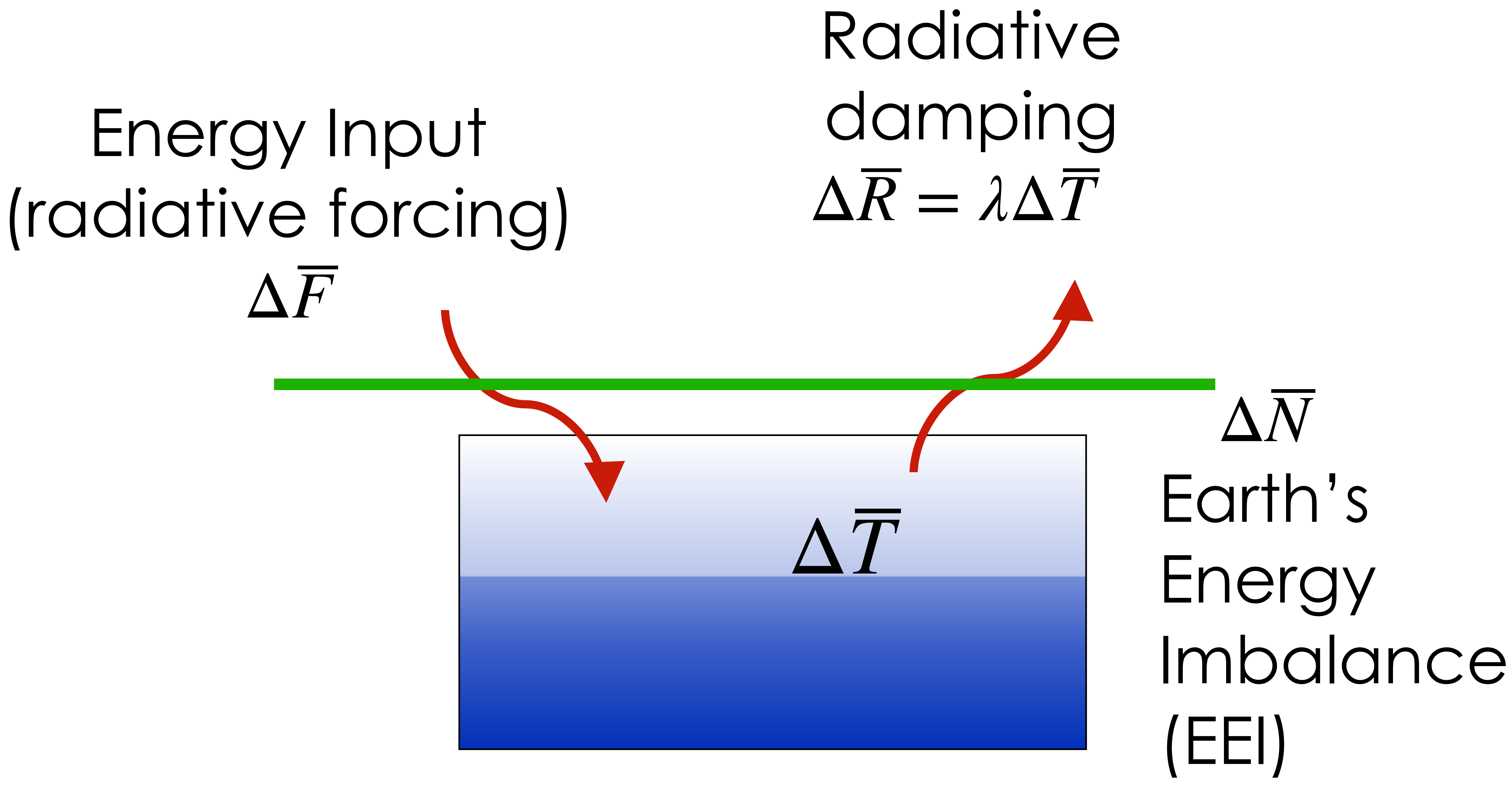
Can we bring better observational constraints?



Sherwood, Webb et al 2020

ECS: all about the λ

Energy Budget: $\Delta N = \Delta F - \lambda \Delta T$



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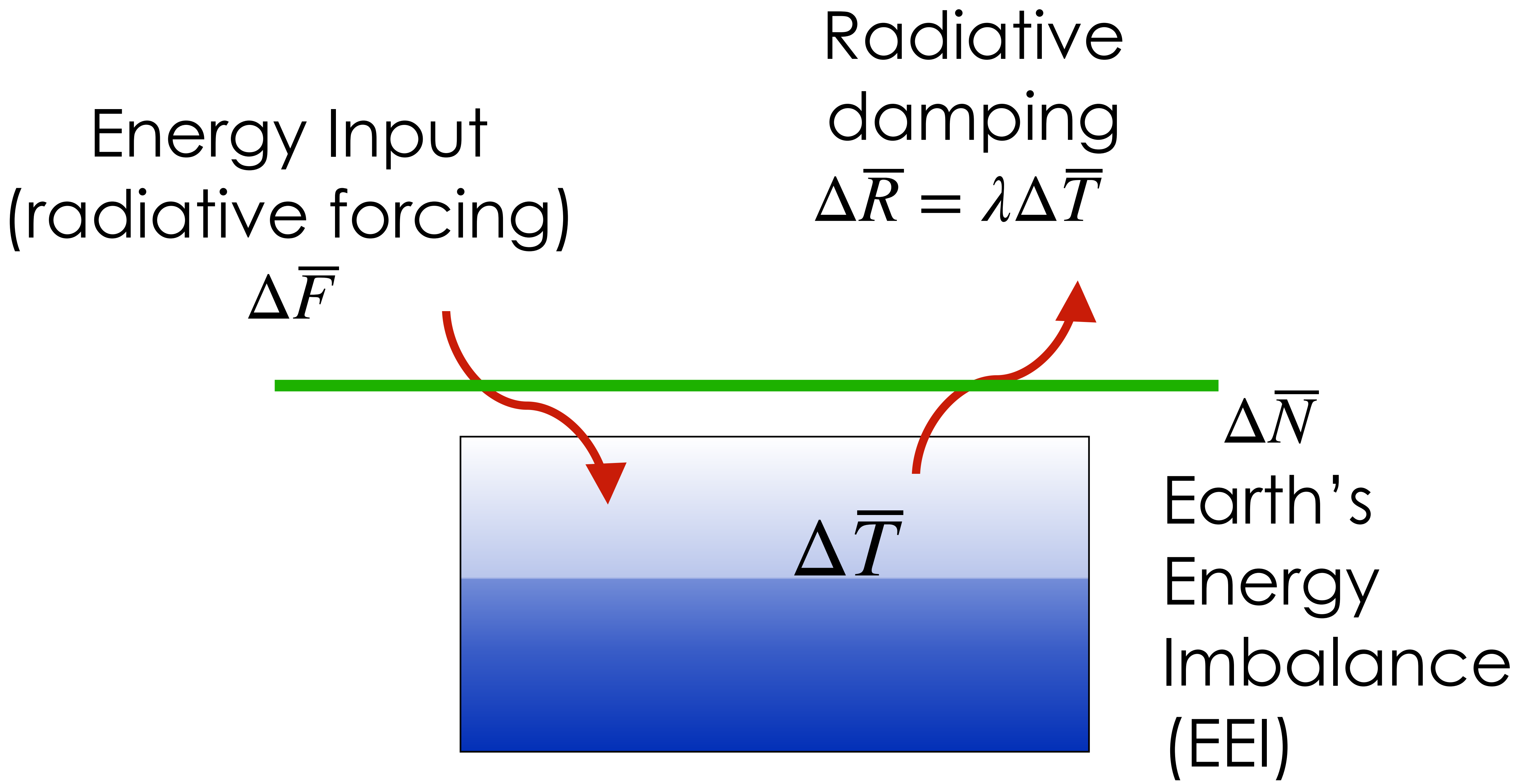

Equilibrium Climate Sensitivity

$$\Delta Q = 0$$

$$ECS = \Delta T_{2\times} = \frac{\Delta F_{2\times}}{\lambda}$$

ECS: all about the λ

Energy Budget: $\Delta N = \Delta F - \lambda \Delta T$

Changes since pre-industrial
(ΔN from ARGO)

λ_{hist}

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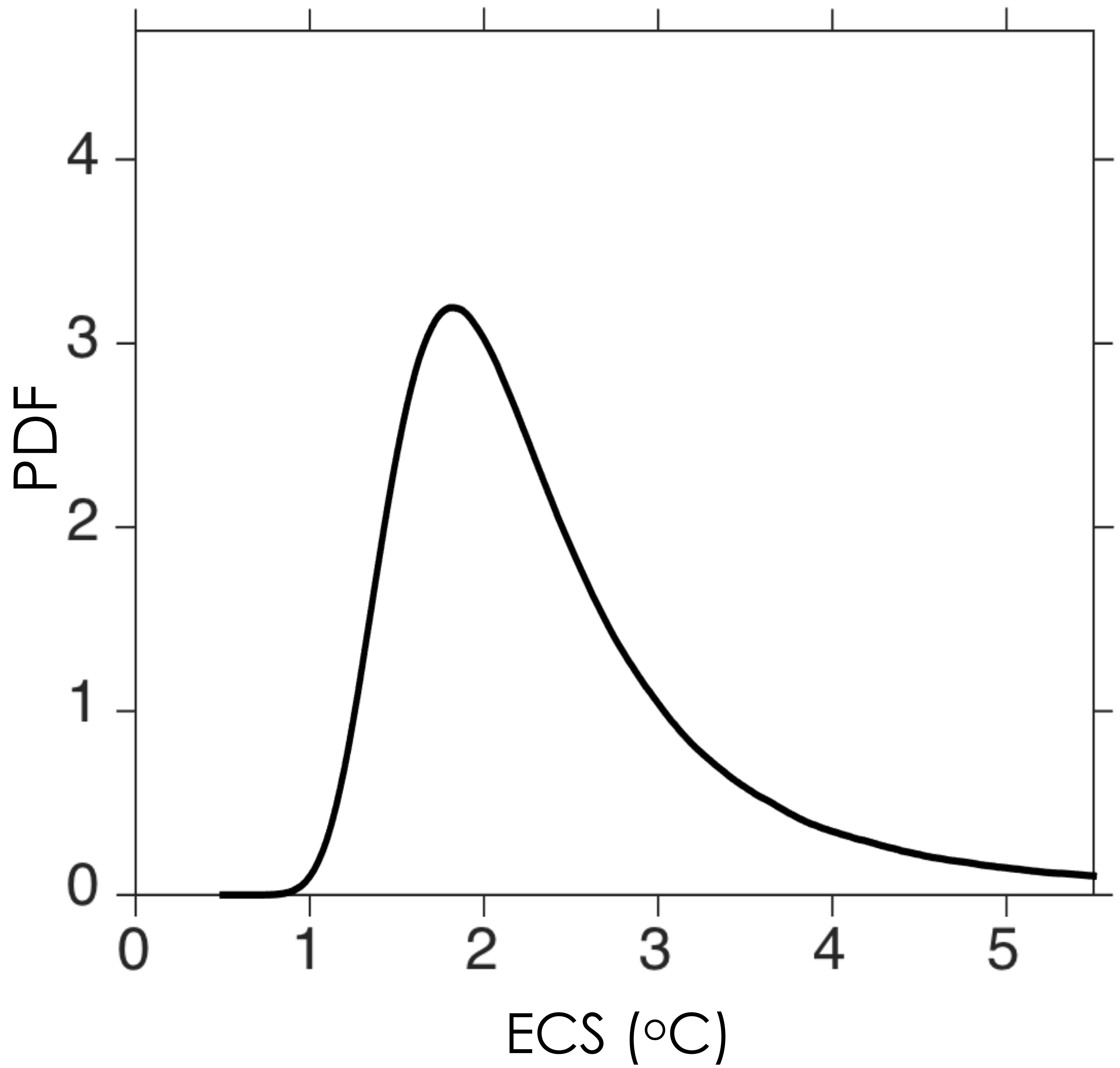
Equilibrium Climate Sensitivity

$$ECS_{inf} = \frac{\Delta F_{2\times}}{\lambda_{hist}}$$

ECS: all about the λ



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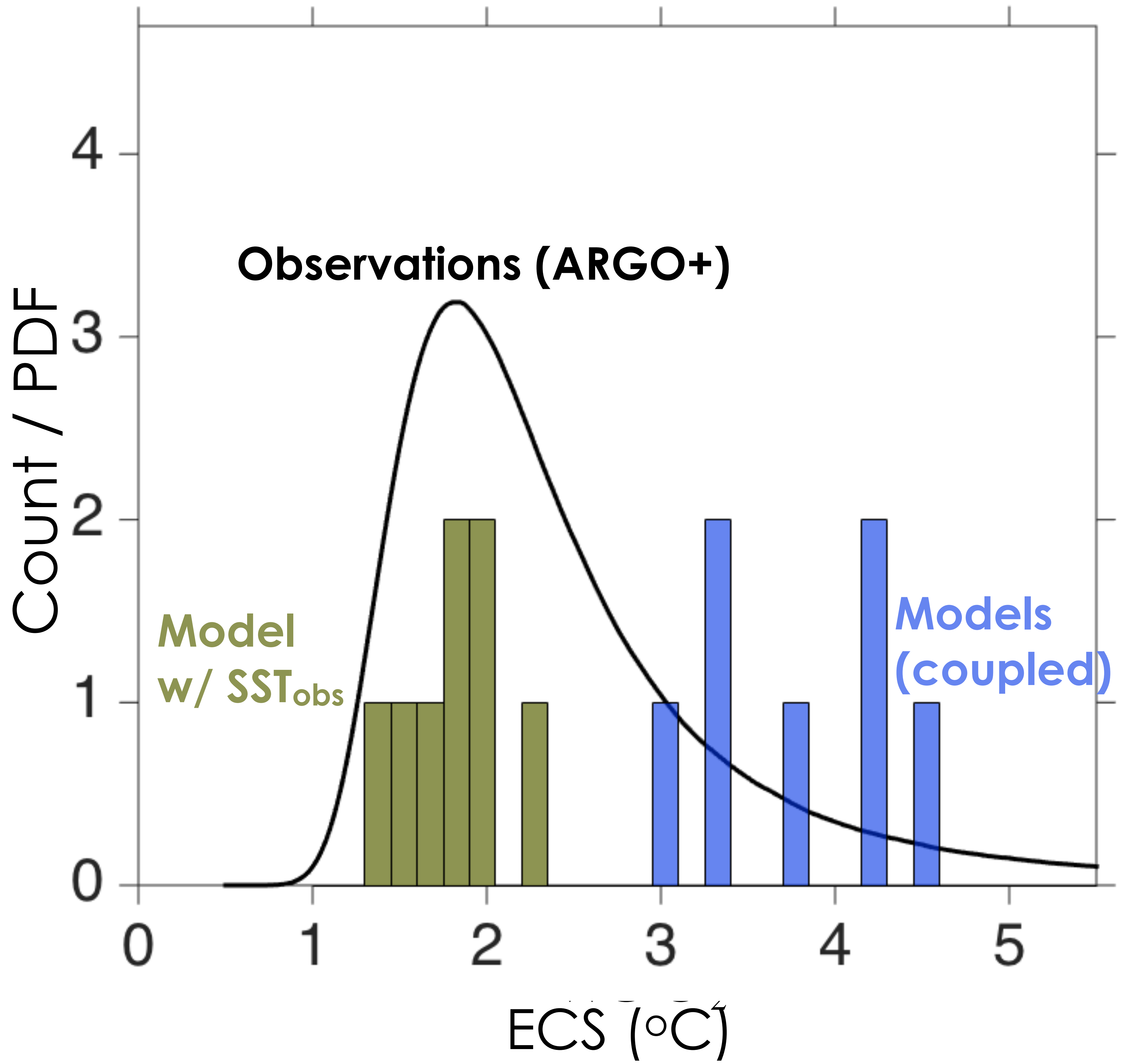
$$ECS_{inf} = \frac{\Delta F_{2\times}}{\lambda_{hist}}$$

Pattern effect correction



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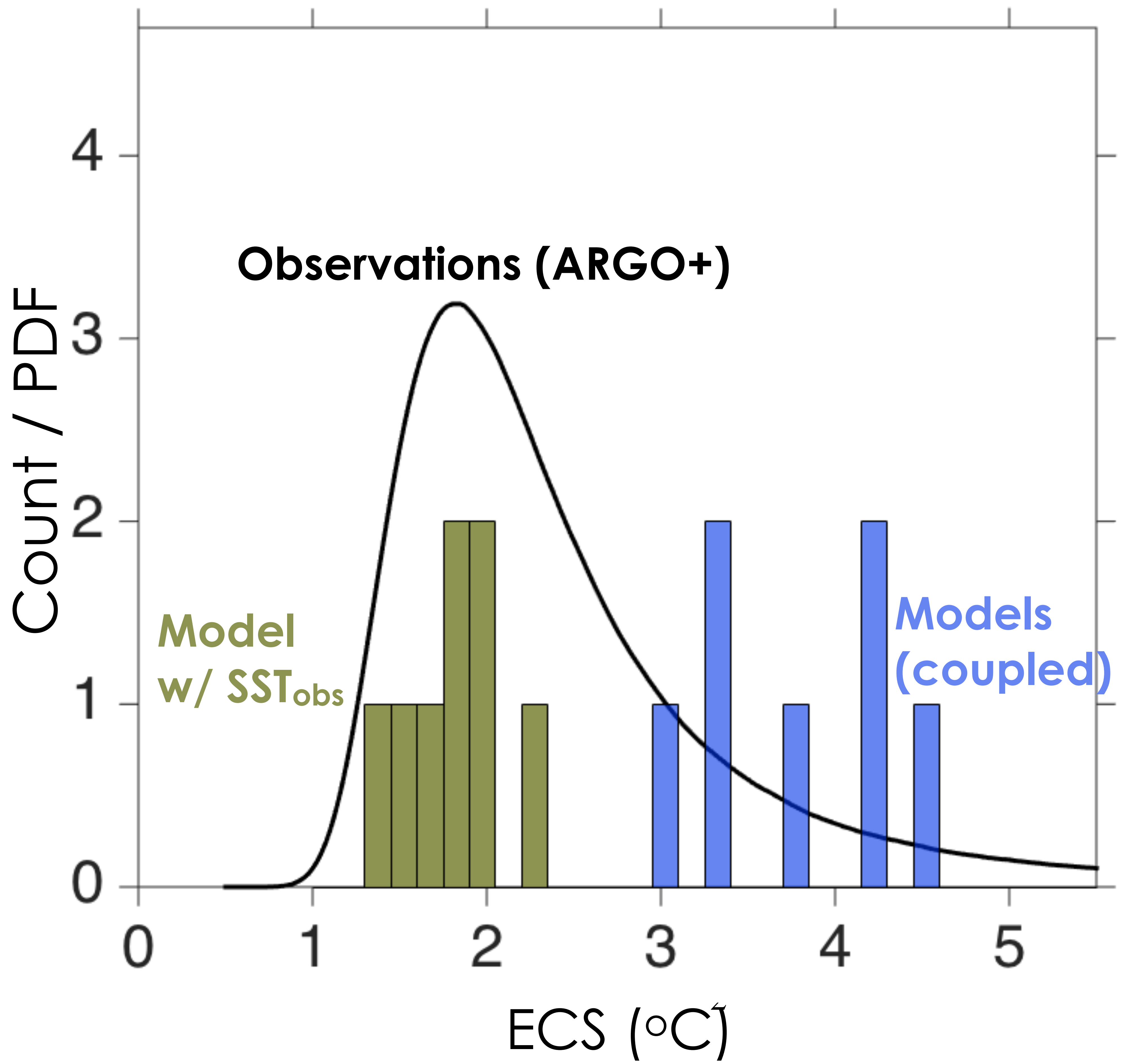


Equilibrium Climate Sensitivity

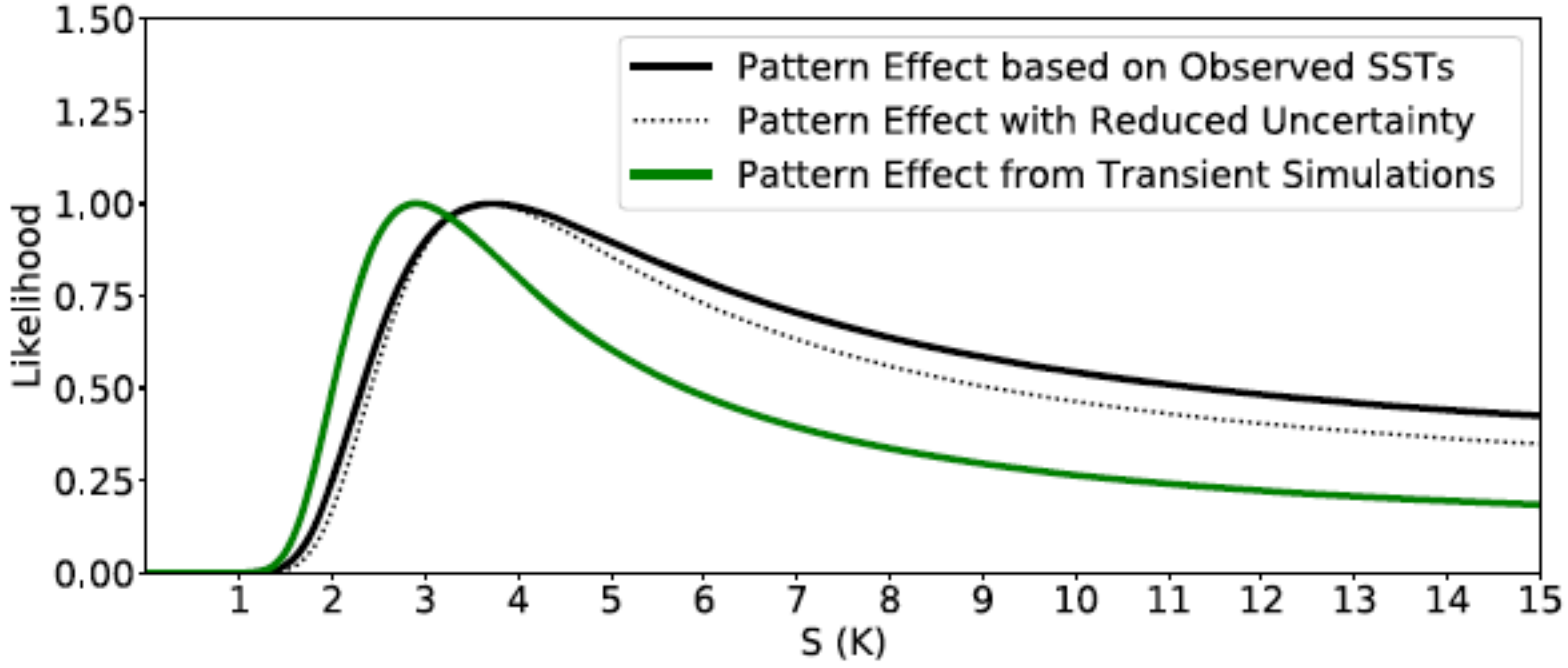
$$ECS = \frac{\Delta F_{2\times}}{\lambda_{hist} - \Delta\lambda}$$

ARGO

GCMs

$\Delta\lambda = 0.5 \pm 0.5 \mathrm{W/m^2/K}$

Pattern effect correction



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WCRP assessment - Sherwood, Webb et al 2020

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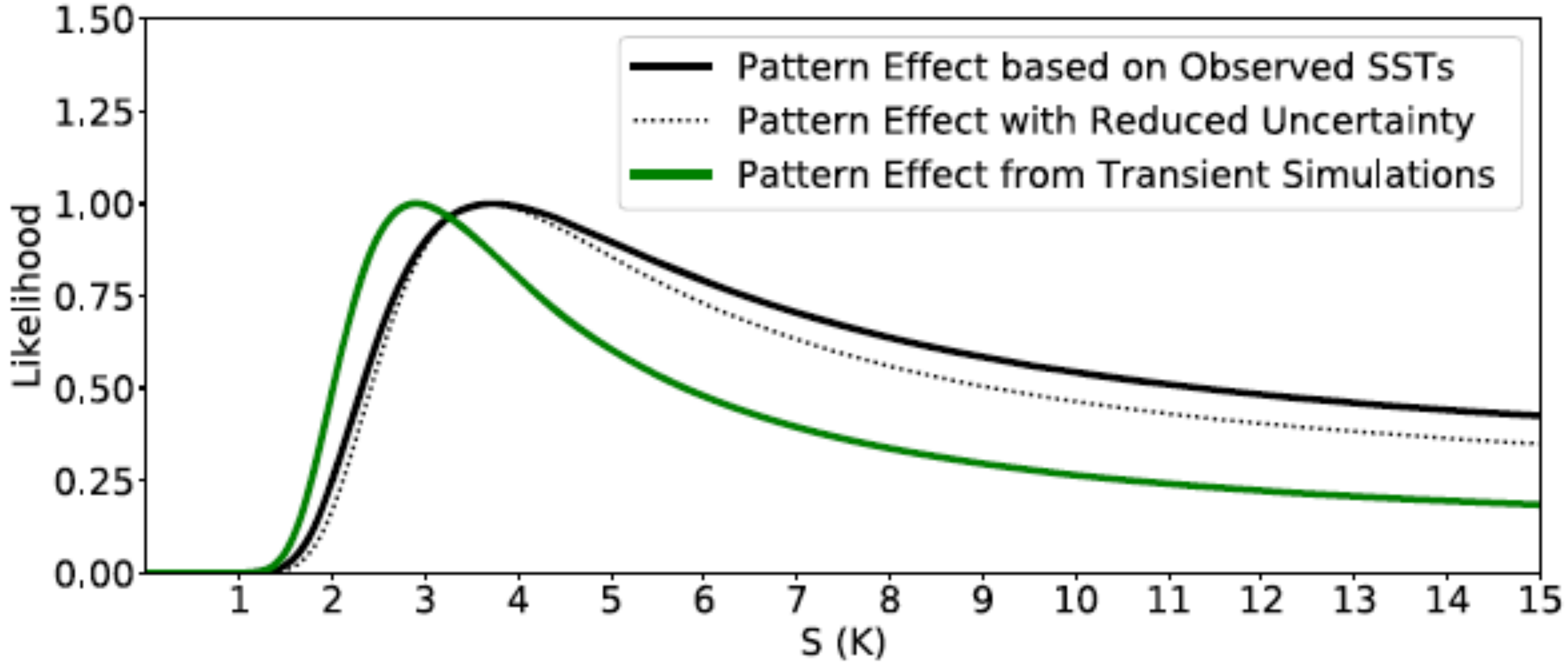

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ARGO

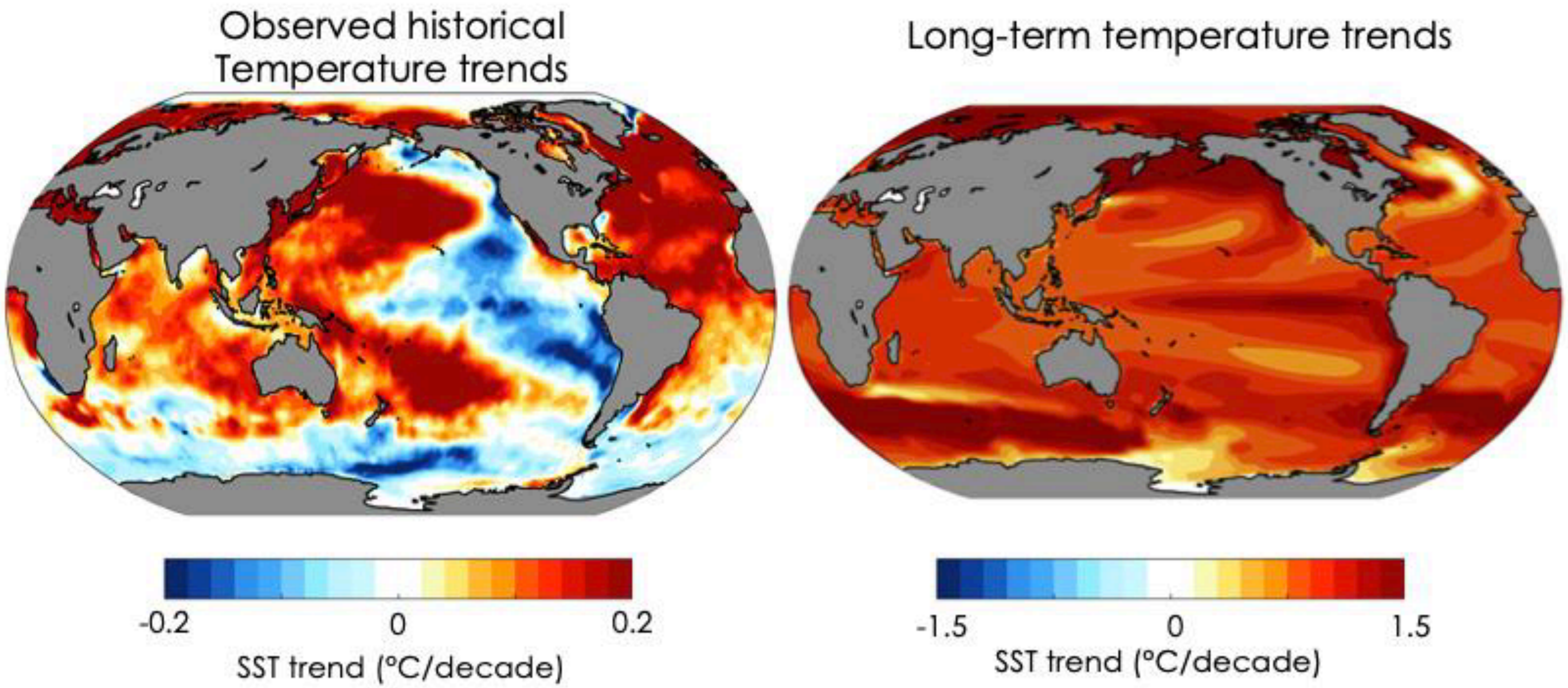
GCMs

$\Delta\lambda = 0.5 \pm 0.5 \mathrm{W/m^2/K}$

use CERES to constrain $\Delta\lambda$

WCRP assessment - Sherwood, Webb et al 2020

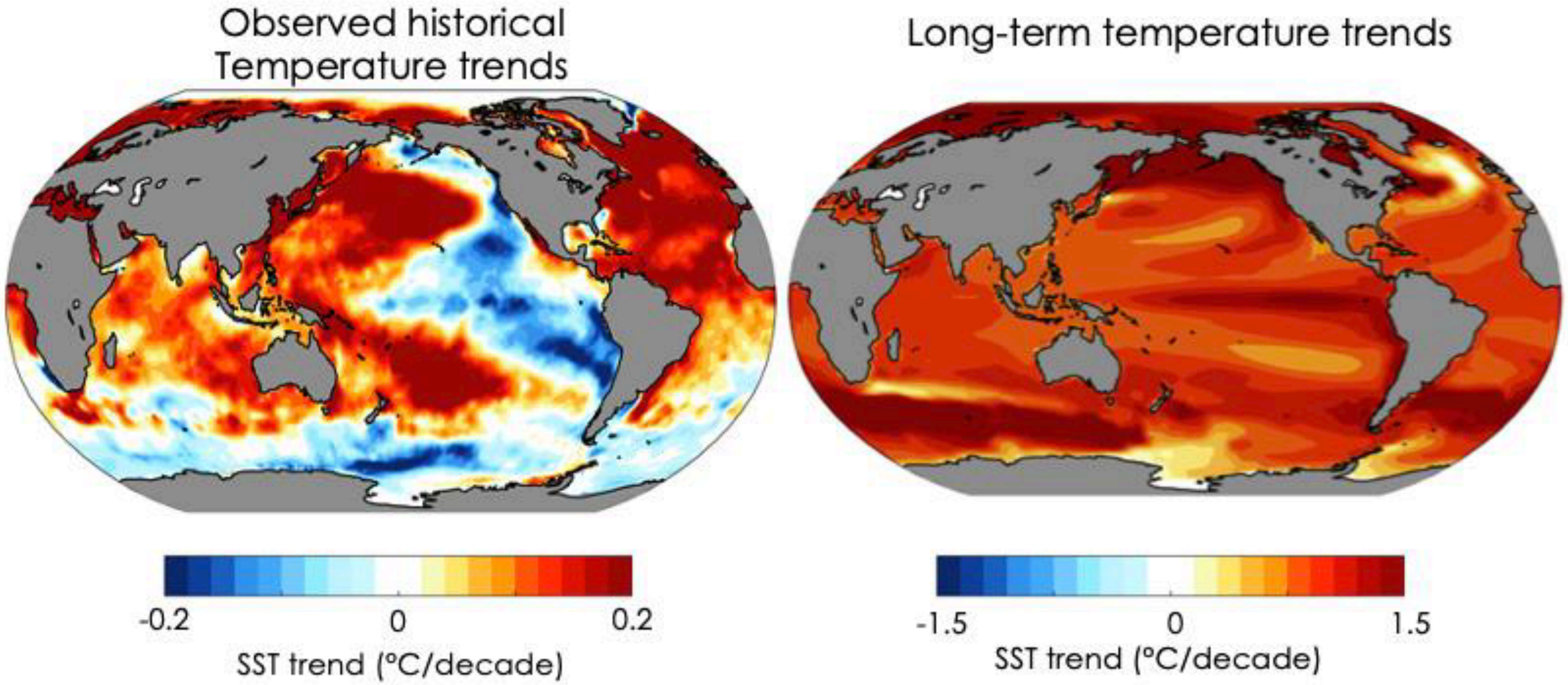
Pattern effect: feedback depends on warming pattern



$$\overline{R} = \lambda \overline{T}$$

$$\lambda_{eq} \stackrel{???}{=} \lambda_{hist}$$

Pattern effect: feedback depends on warming pattern



$$\overline{R} = \lambda \overline{T}$$

$$\lambda_{eq} \overset{???}{=} \lambda_{hist}$$

$$\overline{R} \approx \overset{\lambda}{\boxed{\frac{\partial \overline{R}}{\partial \overline{T}}}} \overline{T}$$

Pattern effect: feedback depends on warming pattern

$$\frac{\overline{R}}{\overline{T}} \approx \frac{\partial \overline{R}}{\partial \overline{T}}$$

$$\frac{\overline{R}}{\overline{T}} \approx \sum_{x,y} \frac{\partial R(x)}{\partial T(y)} \frac{T(y)}{\overline{T}}$$

atmospheric radiative response

surface warming pattern

Cloud feedback decomposition

$$\frac{\overline{R}}{\overline{T}} \approx \sum_{x,y,\tau,p} \boxed{\frac{\partial R(x)}{\partial f(x,\tau,p)}} \boxed{\frac{\partial f(x,\tau,p)}{\partial C(x)}} \boxed{\frac{\partial C(x)}{\partial T(y)}} \boxed{\frac{T(y)}{\overline{T}}}$$

Cloud Radiative kernels (radiation vs cloud fraction)
Cloud amount change (cloud frac vs cloud controlling factors)
Atmospheric Circulation (atmospheric state vs surface temperature)
Warming Pattern

Cloud feedback decomposition

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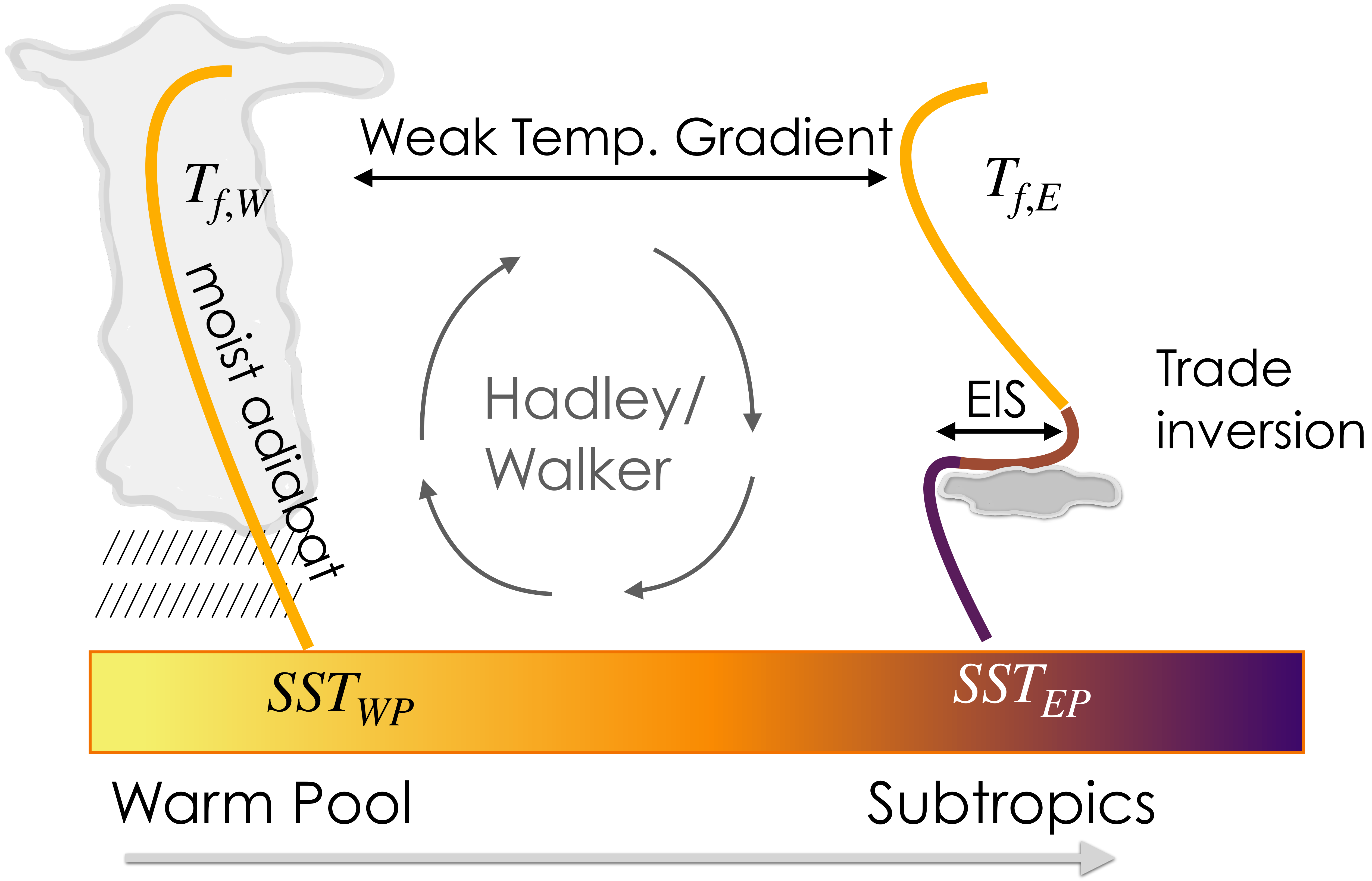
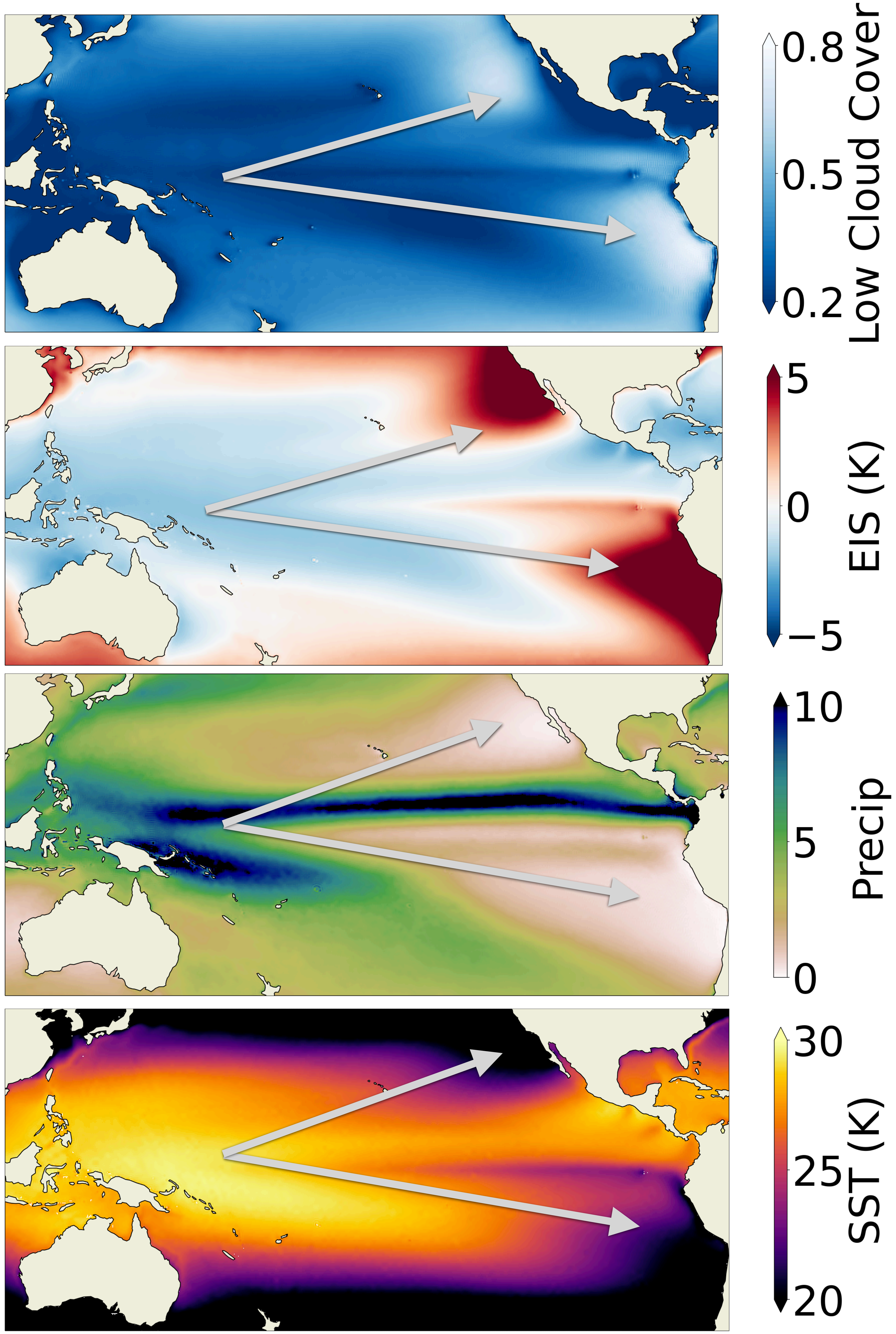
Warming Pattern

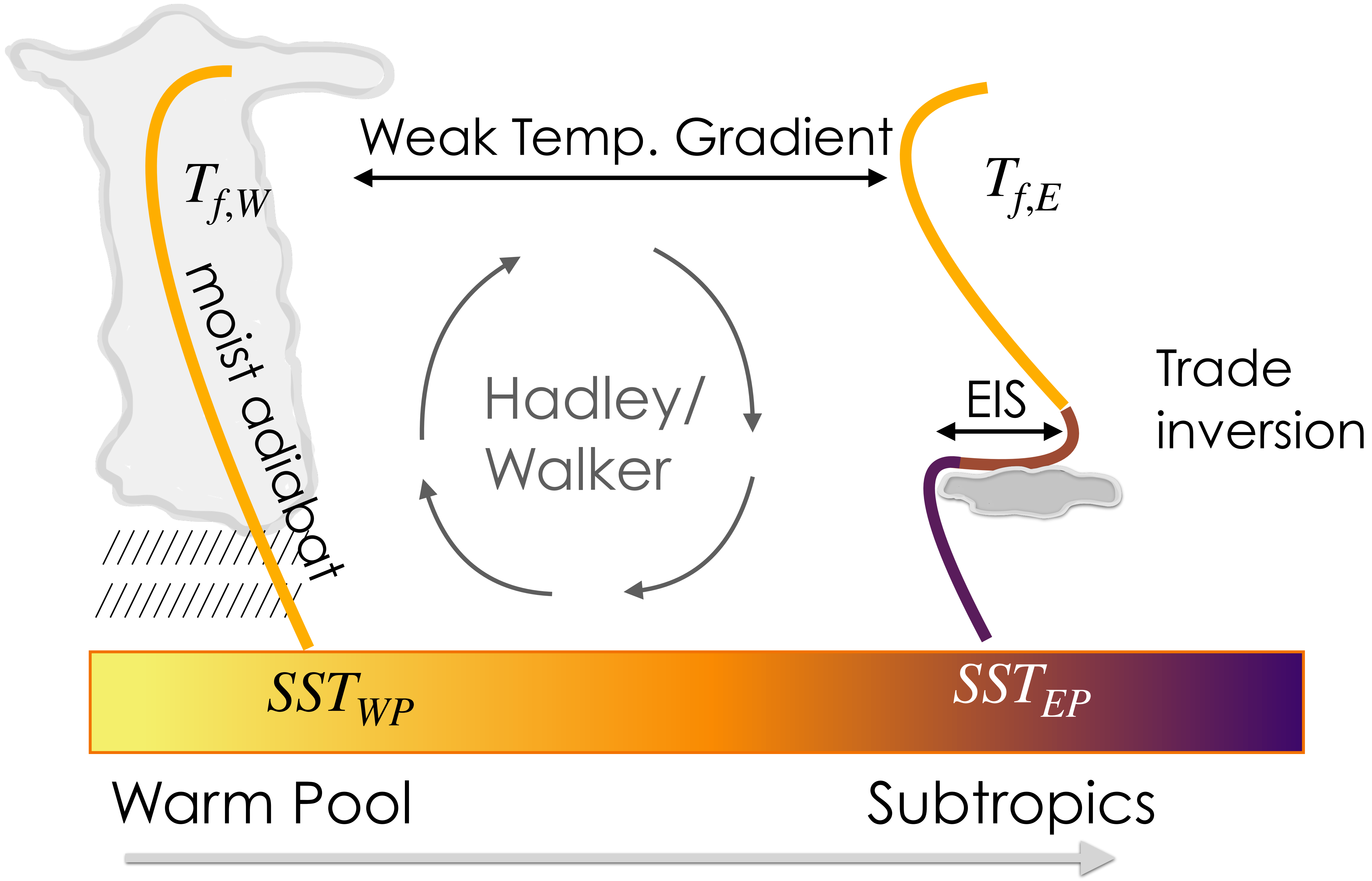
Tropical Climate Dynamics



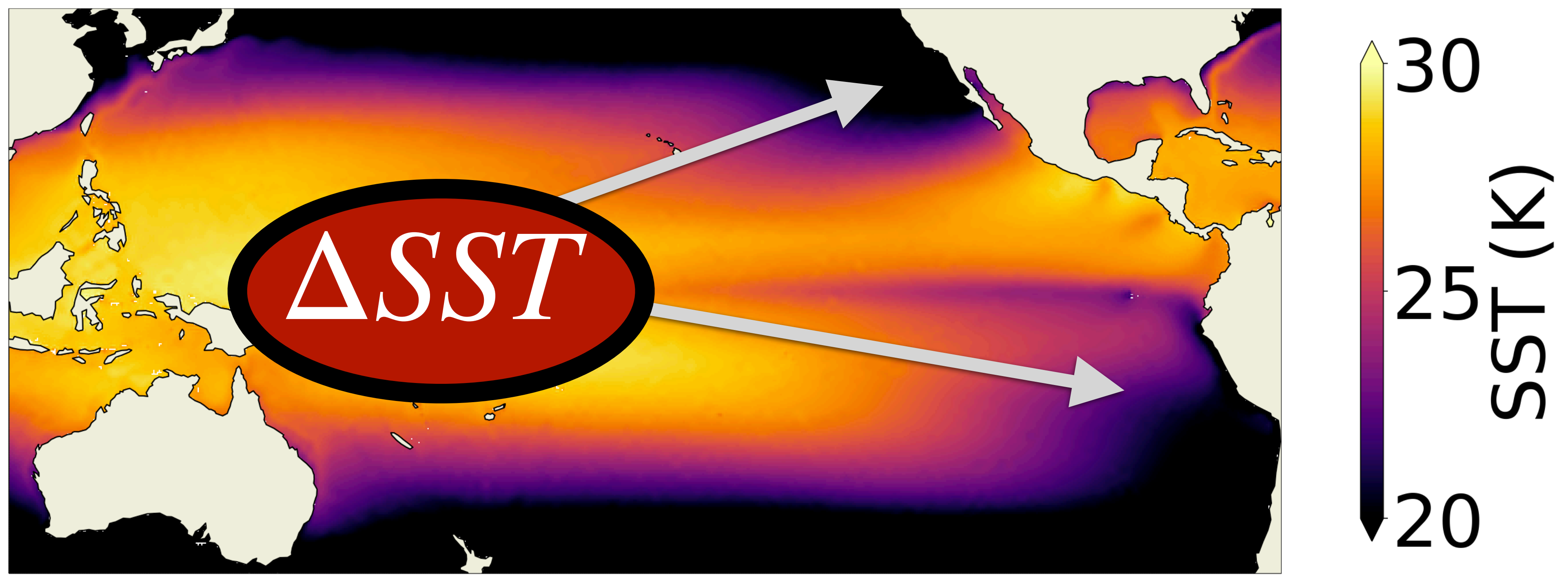
Arakawa 1975
Stevens 2005



Response to Warm Pool warming



$$\frac{\overline{R}}{\overline{T}} \approx \sum_{x,y,\tau,p} \frac{\partial R(x)}{\partial f(x,\tau,p)} \frac{\partial f(x,\tau,p)}{\partial C(x)} \frac{\partial C(x)}{\partial T(y)} \boxed{\frac{T(y)}{\overline{T}}}$$



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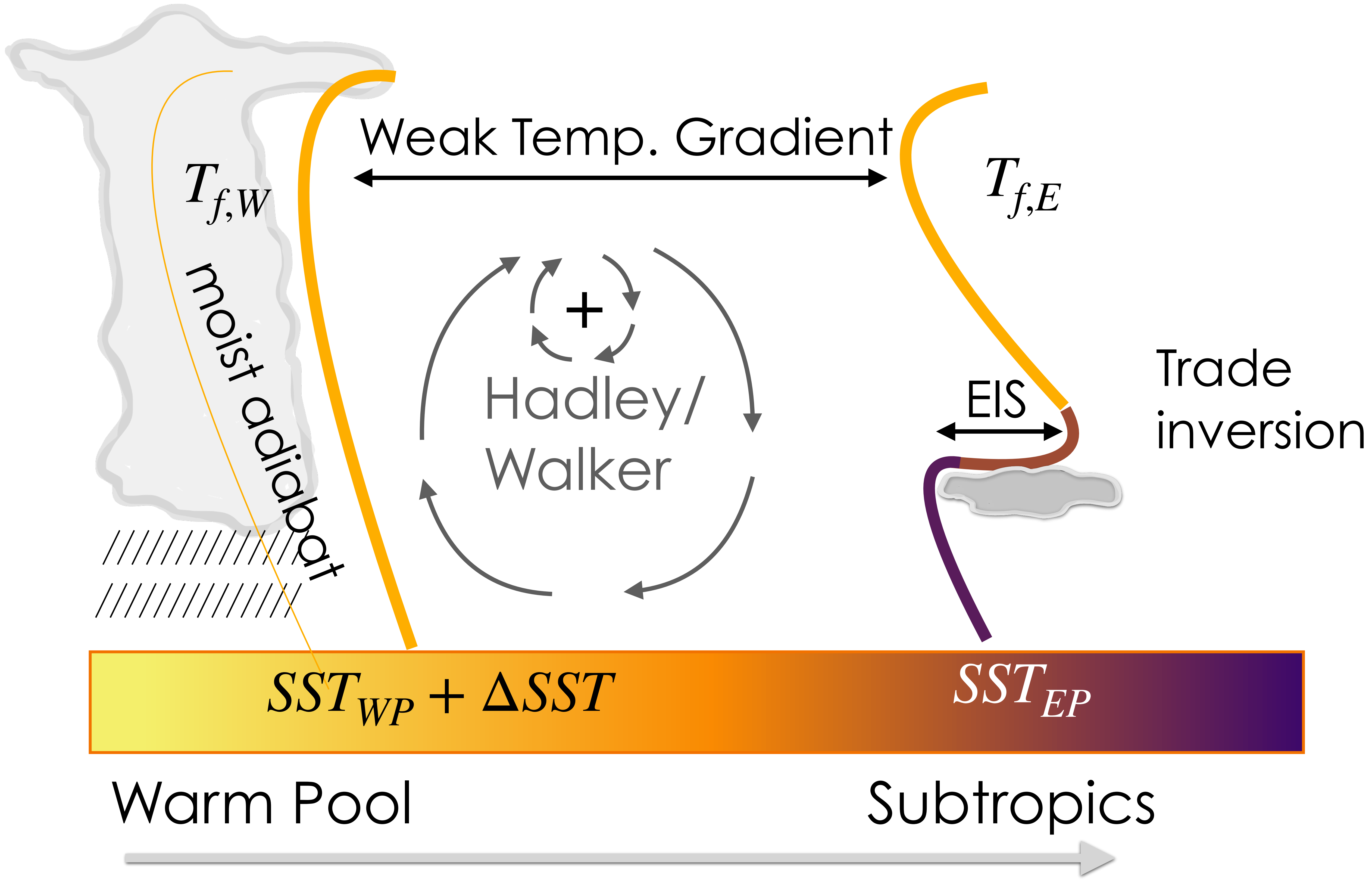

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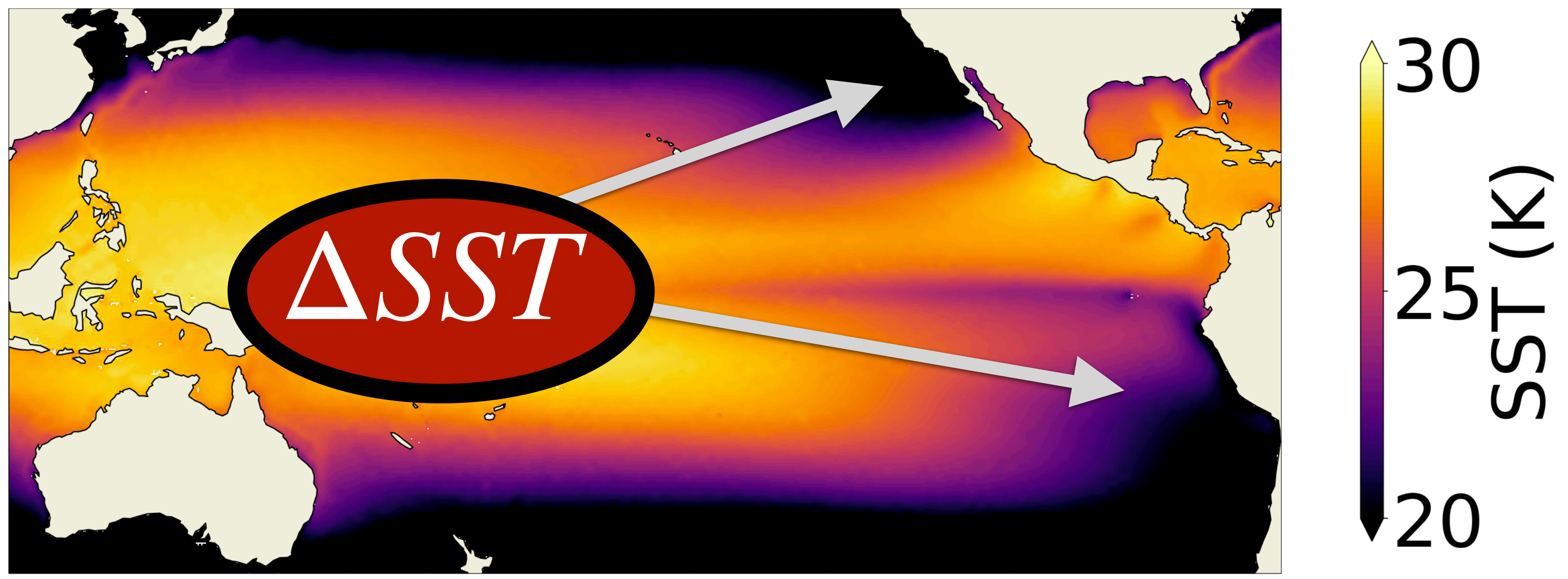

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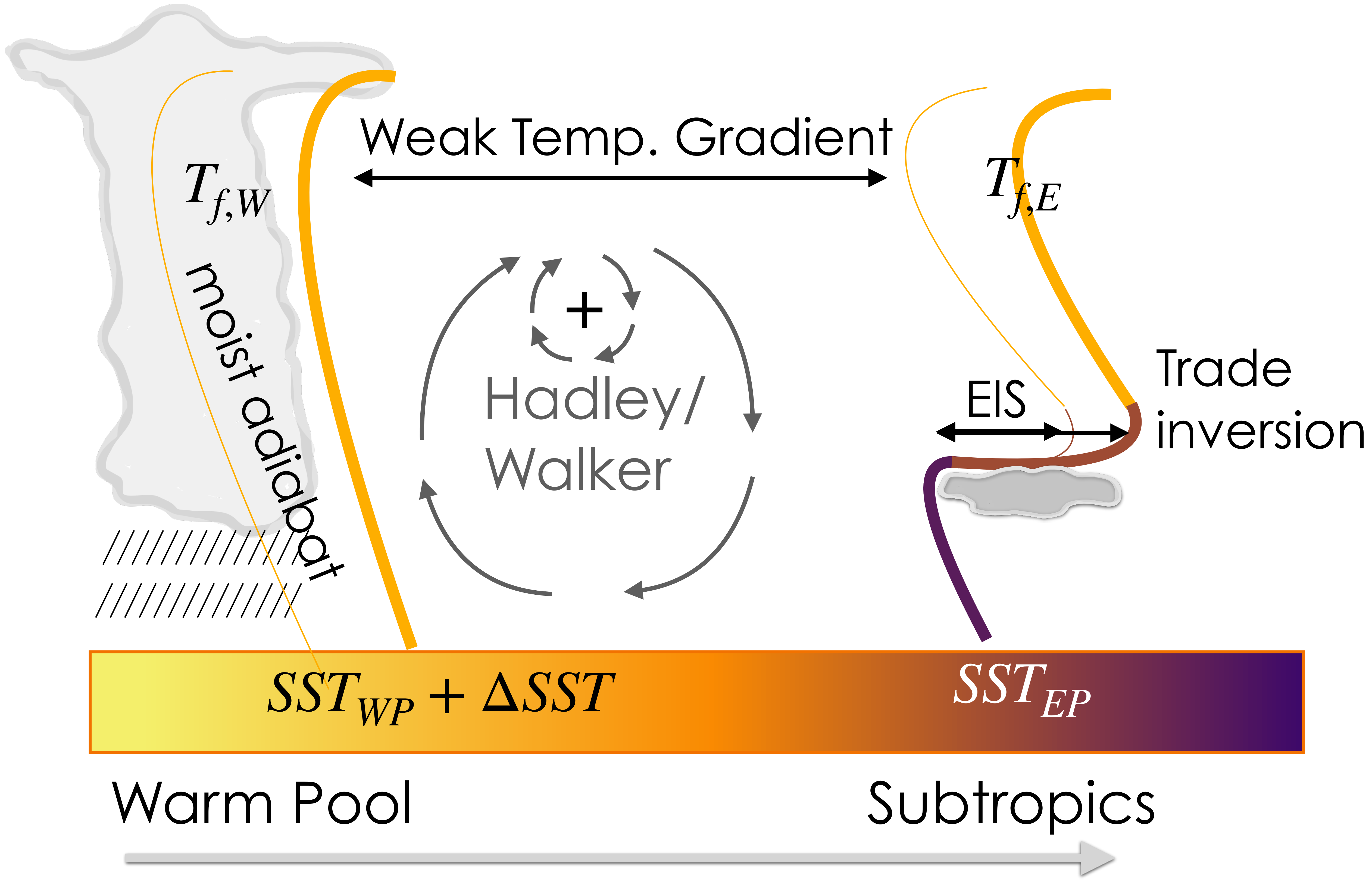

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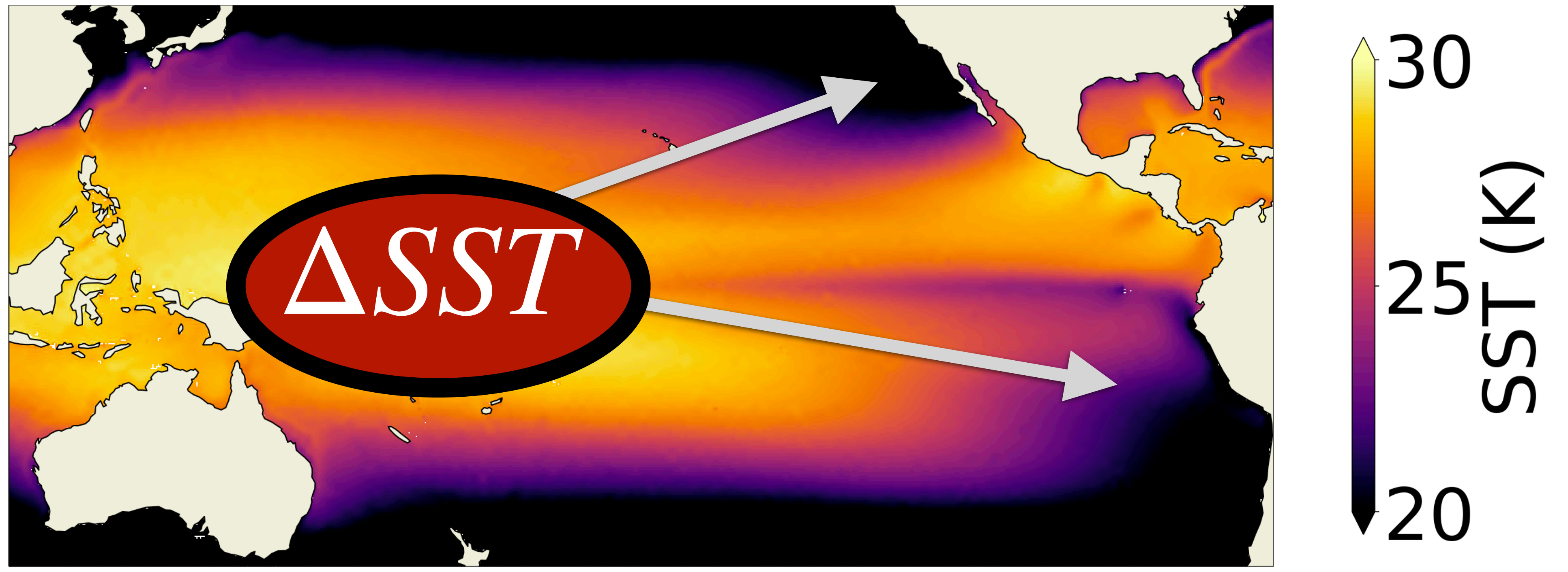

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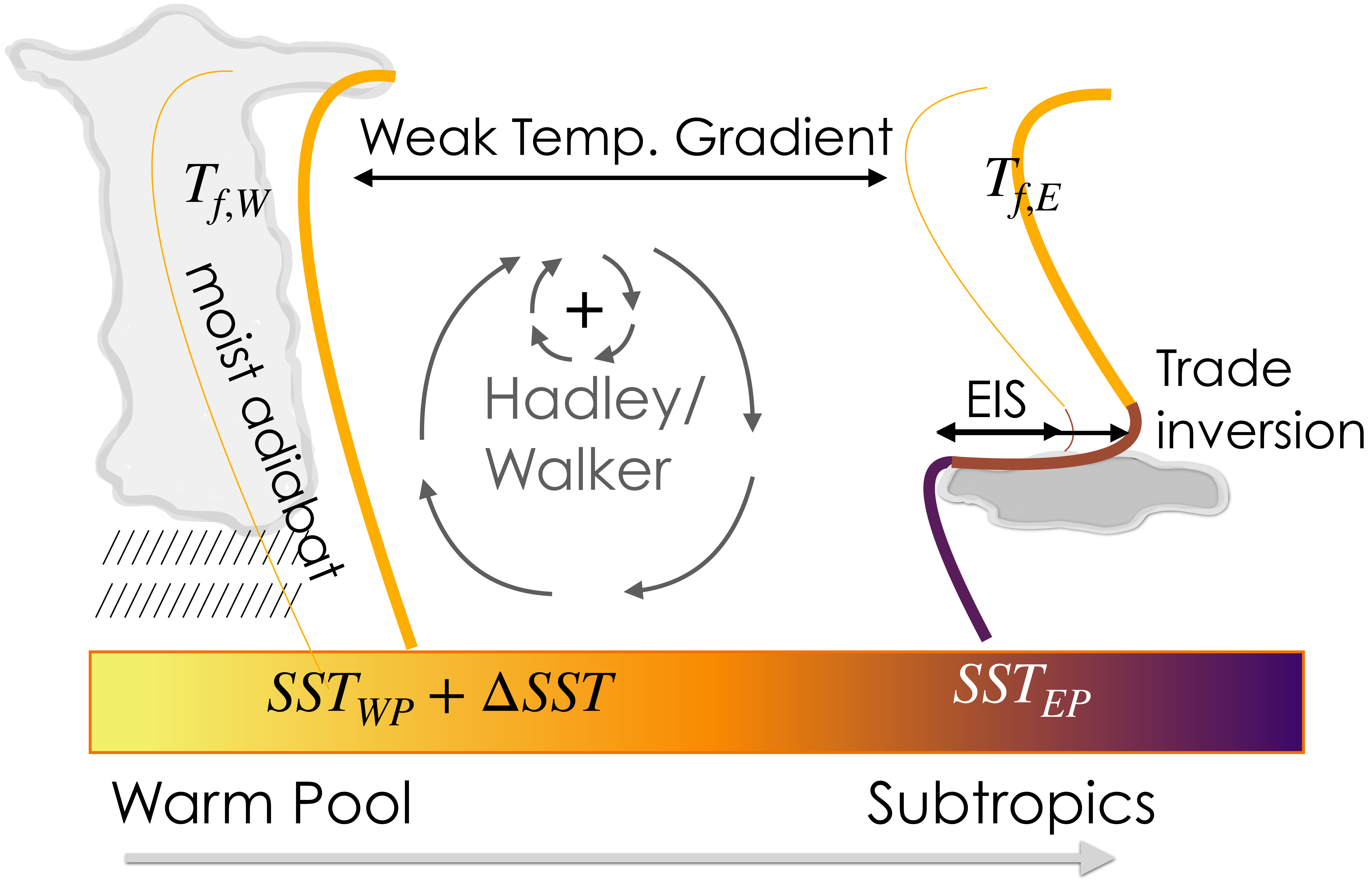

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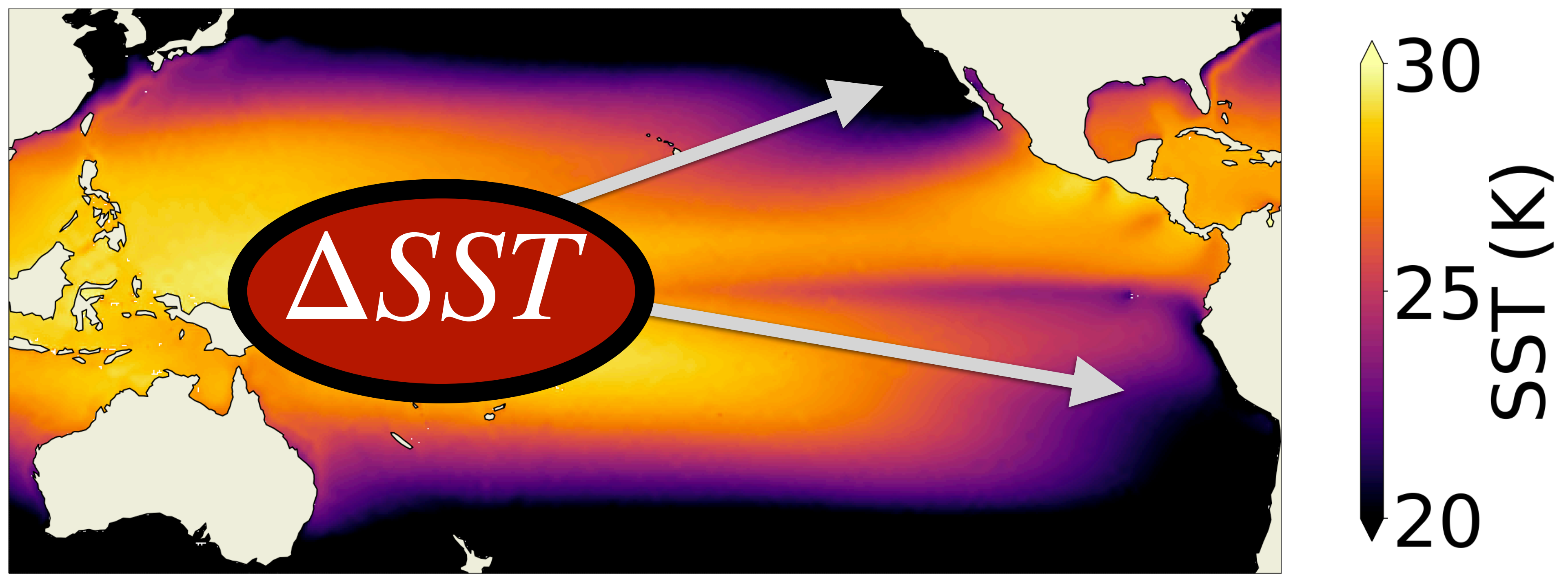

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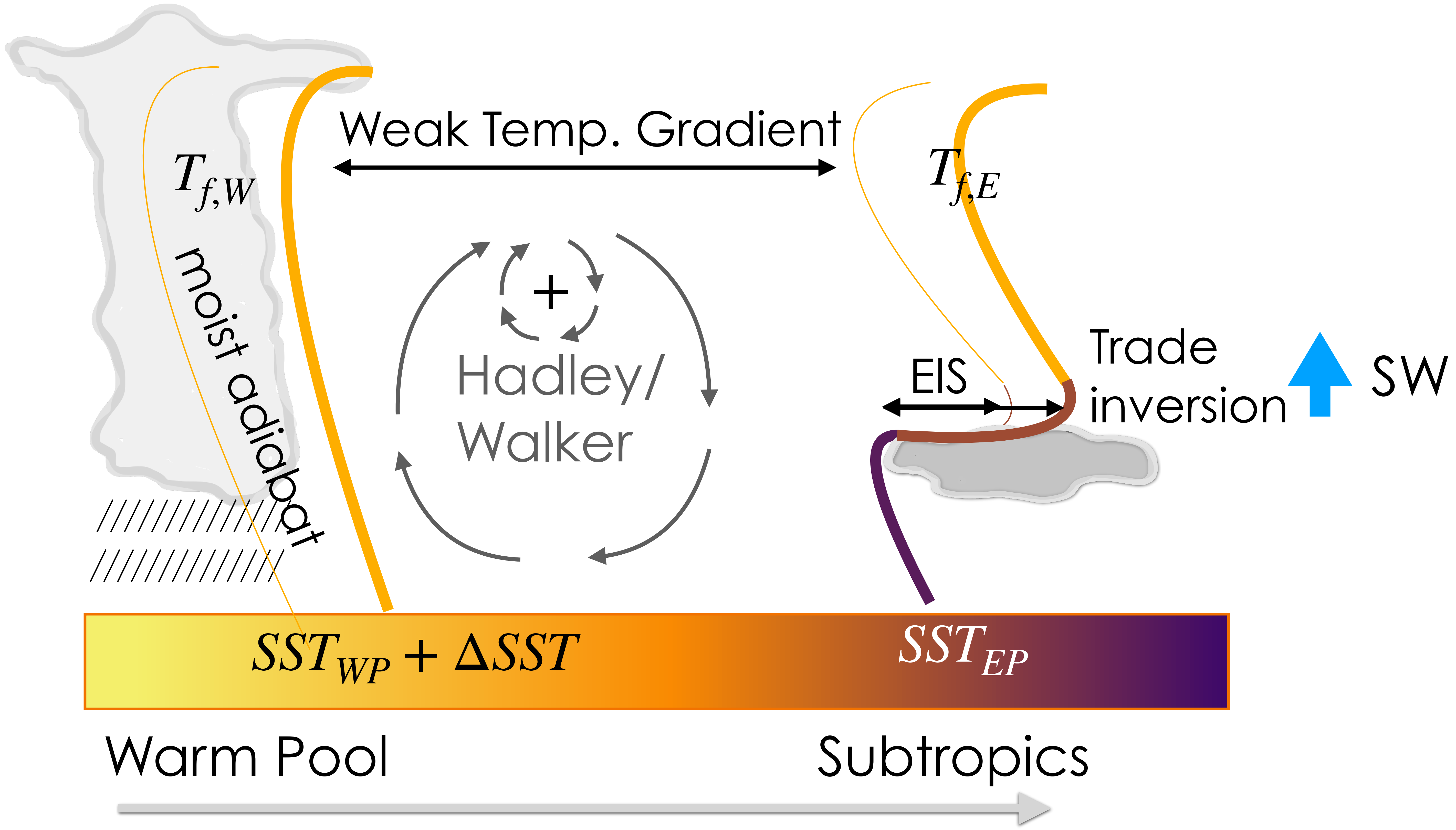

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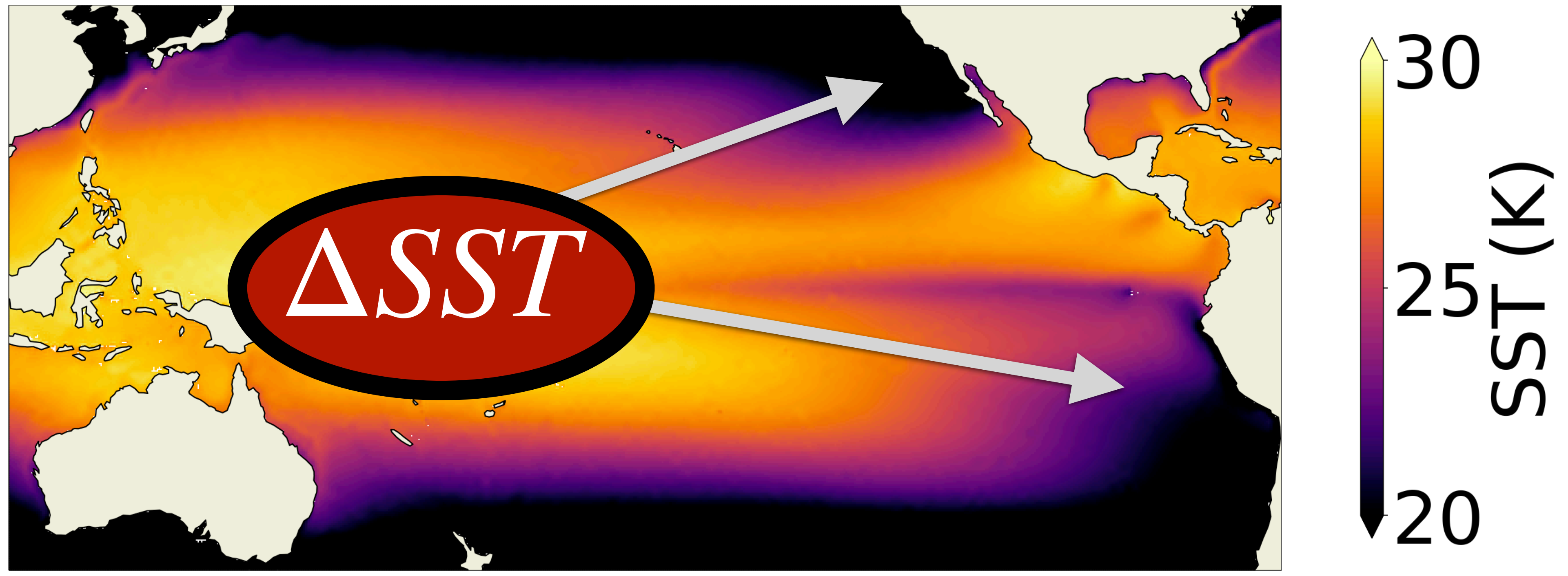

How to constrain cloud feedbacks?

$$\frac{\overline{R}}{\overline{T}} \approx \sum_{x,y,\tau,p} \boxed{\frac{\partial R(x)}{\partial f(x,\tau,p)}} \boxed{\frac{\partial f(x,\tau,p)}{\partial C(x)}} \boxed{\frac{\partial C(x)}{\partial T(y)}} \boxed{\frac{T(y)}{\overline{T}}}$$

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Warming Pattern

Constraining net feedback

$$\frac{\overline{R}}{\overline{T}} \approx \sum_{x,y,\tau,p} \boxed{\frac{\partial R(x)}{\partial f(x,\tau,p)}} \boxed{\frac{\partial f(x,\tau,p)}{\partial C(x)}} \boxed{\frac{\partial C(x)}{\partial T(y)}} \boxed{\frac{T(y)}{\overline{T}}}$$

Radiative transfer

MODIS

GCMs (4xCO2)

Klein et al 2017

Constraining net feedback

$$\frac{\overline{R}}{\overline{T}} \approx \sum_{x,y,\tau,p} \boxed{\frac{\partial R(x)}{\partial f(x,\tau,p)}} \boxed{\frac{\partial f(x,\tau,p)}{\partial C(x)}} \boxed{\frac{\partial C(x)}{\partial T(y)}} \boxed{\frac{T(y)}{\overline{T}}}$$

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CERES

GCMs (4xCO2)

Scott et al 2020
Myers et al 2021

Method 1: T + EIS

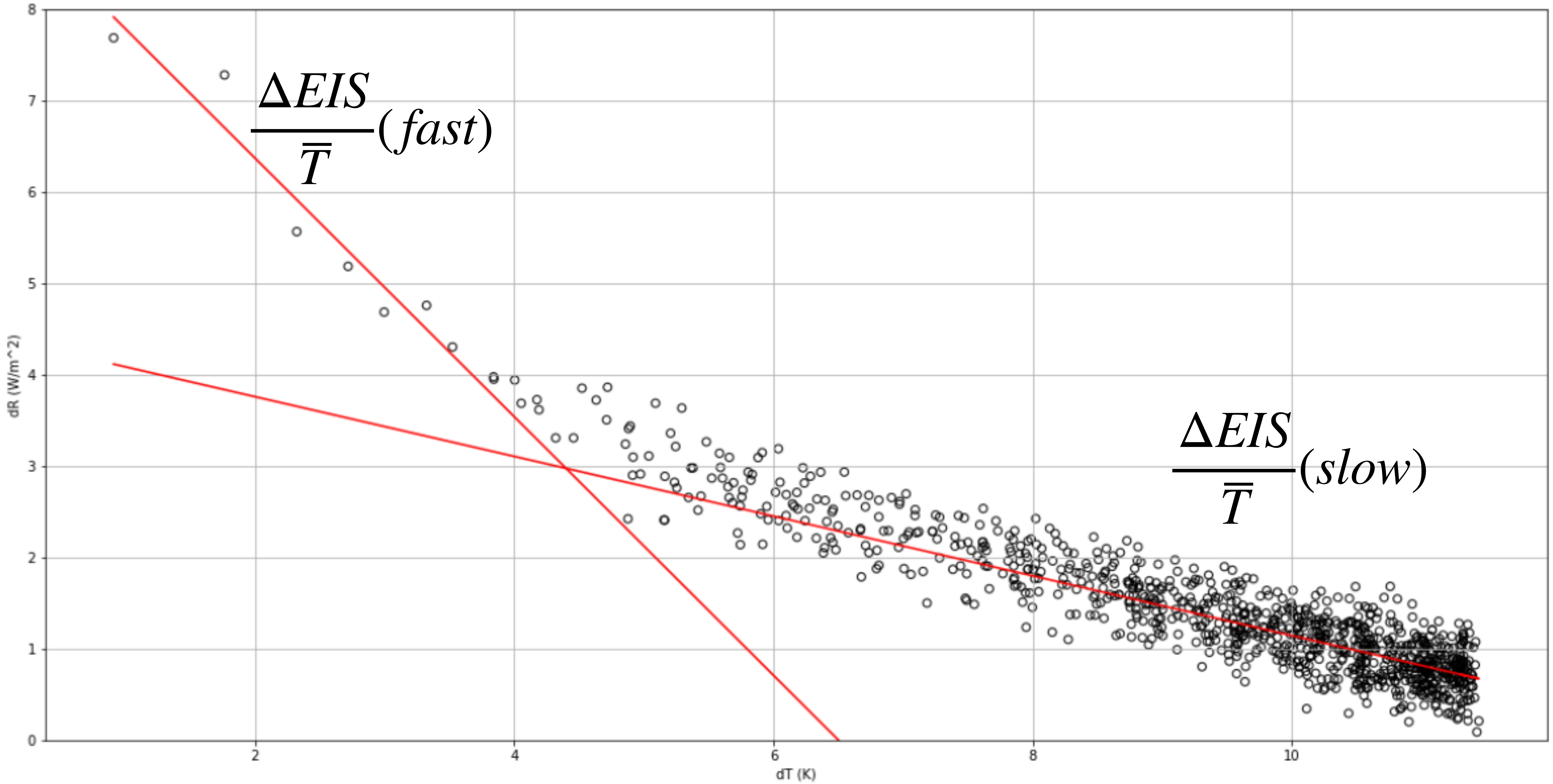
$$\frac{\overline{R}}{\overline{\overline{T}}} \approx \sum_{x,y,\tau,p} \boxed{\frac{\partial R(x)}{\partial C(x)}} \boxed{\frac{\partial C(x)}{\partial T(y)} \frac{T(y)}{\overline{\overline{T}}}}$$

$$\frac{\overline{R}}{\overline{\overline{T}}} \approx \boxed{\frac{\partial R}{\partial \overline{\overline{T}}}} + \boxed{\frac{\partial R}{\partial EIS}} \boxed{\frac{\Delta EIS}{\overline{\overline{T}}}}$$

Ceppi and Gregory 2018

Method 1: T + EIS

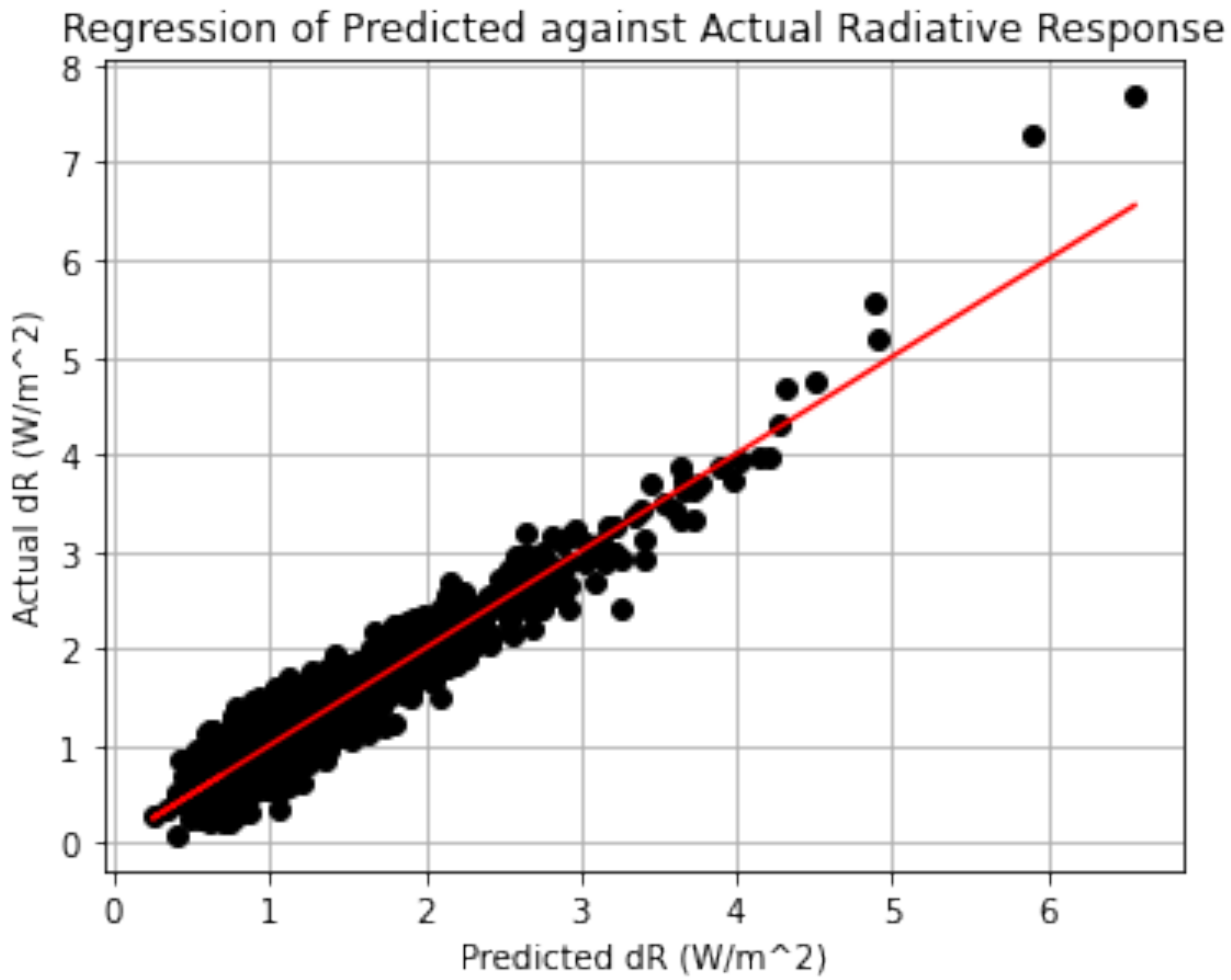
CESM2 Abrupt 4xCO2



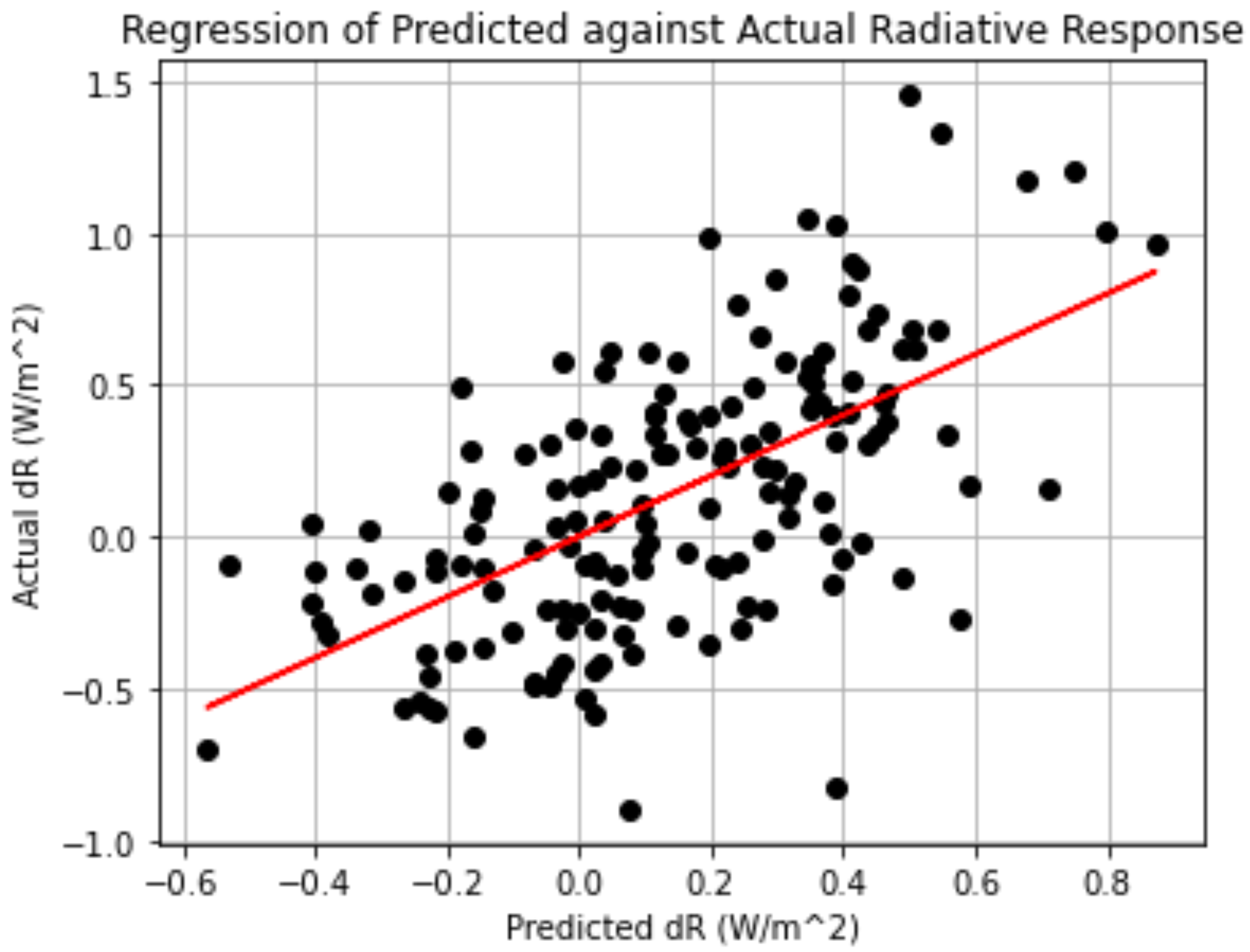
Method 1: T + EIS

CRE 30S-30N

CESM2 Abrupt 4xCO2



CESM2 AMIP
(band-pass filtered to ENSO)



$$\overline{R} = \approx \frac{\partial R}{\partial \overline{T}}\overline{T} + \frac{\partial R}{\partial EIS}\Delta EIS$$

Constrainable from CERES

Constraining feedback change

$$\frac{\overline{R}}{\overline{T}} \approx \sum_{x,y,\tau,p} \boxed{\frac{\partial R(x)}{\partial f(x,\tau,p)}} \boxed{\frac{\partial f(x,\tau,p)}{\partial C(x)}} \boxed{\frac{\partial C(x)}{\partial T(y)}} \boxed{\frac{T(y)}{\overline{T}}}$$

$$\frac{\overline{R}}{\overline{T}} \approx \lambda_{hist} + \sum_{x,y} \boxed{\frac{\partial R(x)}{\partial C(x)}} \boxed{\frac{\partial C(x)}{\partial T(y)}} \boxed{\frac{\Delta T(y)}{\overline{T}}} \qquad \Delta\lambda$$

CERES ERA

GCMs (4xCO2)

Constraining feedback change

$$\frac{\overline{R}}{\overline{T}} \approx \sum_{x,y,\tau,p} \frac{\partial R(x)}{\partial f(x,\tau,p)} \frac{\partial f(x,\tau,p)}{\partial C(x)} \frac{\partial C(x)}{\partial T(y)} \frac{T(y)}{\overline{T}}$$

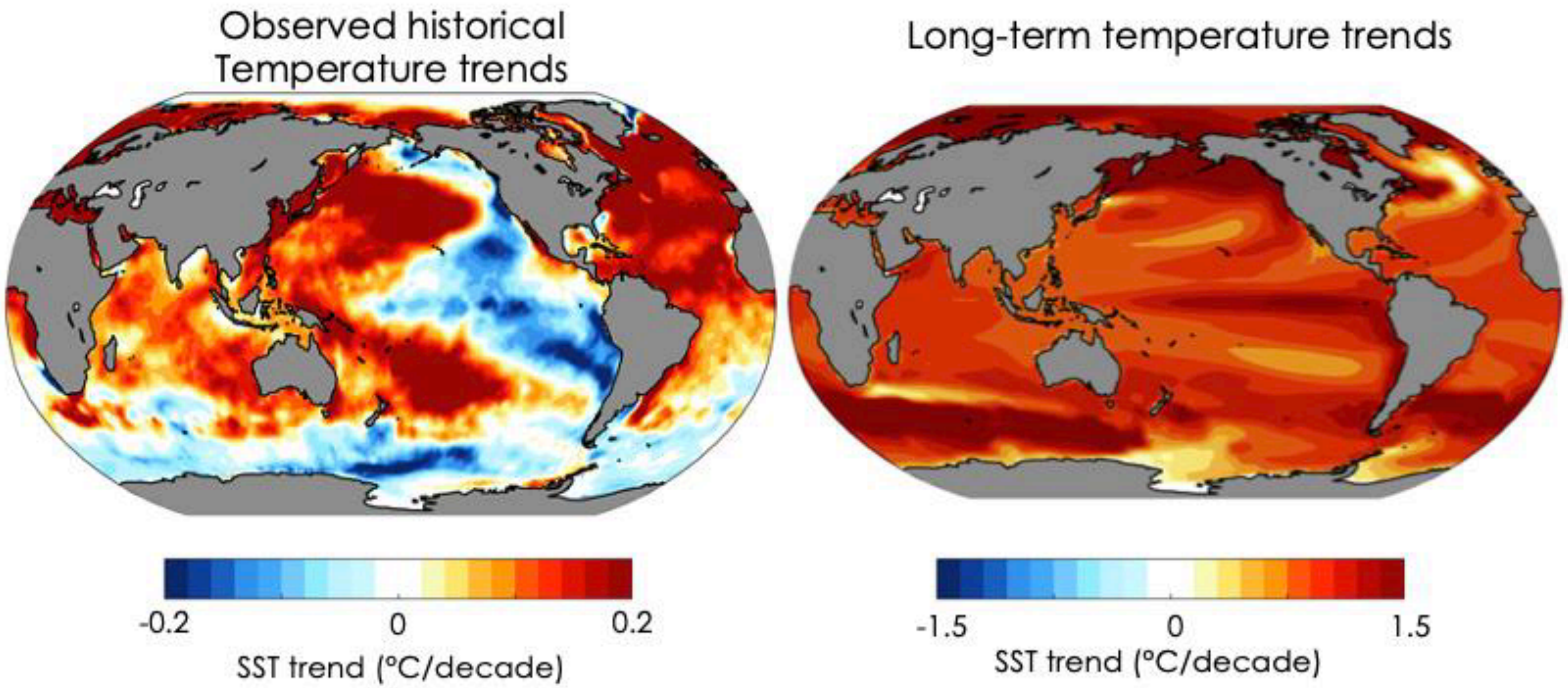
$$\frac{\overline{R}}{\overline{T}} \approx \lambda_{hist} + \sum_{x,y} \frac{\partial R(x)}{\partial C(x)} \frac{\partial C(x)}{\partial \psi} \frac{\Delta \psi}{\overline{T}}$$

$$\Delta \lambda$$

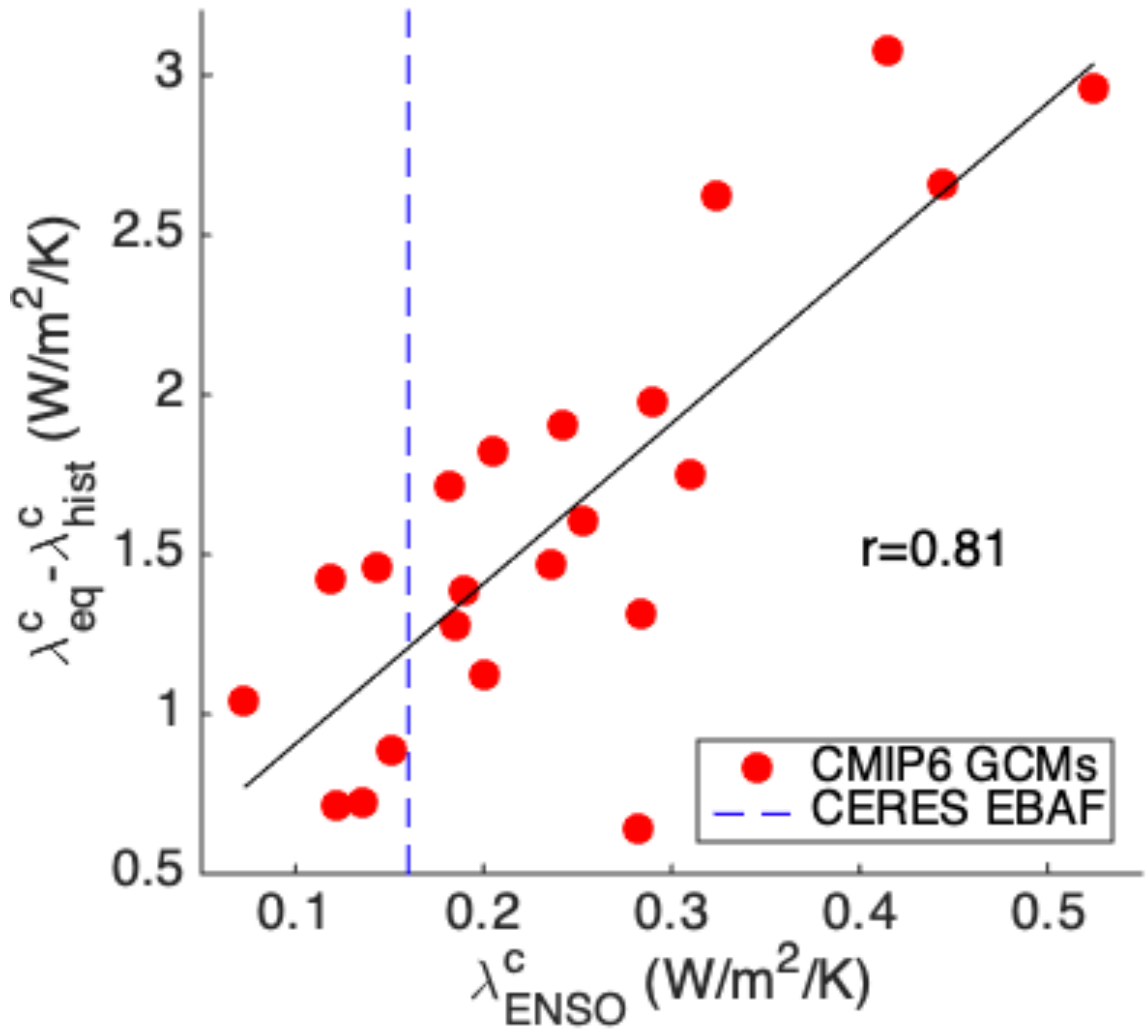
CERES ERA

GCMs (4xCO2)

Change in pattern looks like ENSO



Method 2: Emergent constraint



λ^c_{ENSO}=CRE regressed onto nino3.4

Uncertainty Quantification needed

Constraining feedback change vs ENSO

$$\frac{\overline{R}}{\overline{T}} \approx \sum_{x,y,\tau,p} \boxed{\frac{\partial R(x)}{\partial f(x,\tau,p)}} \boxed{\frac{\partial f(x,\tau,p)}{\partial C(x)}} \boxed{\frac{\partial C(x)}{\partial T(y)}} \boxed{\frac{T(y)}{\overline{T}}}$$

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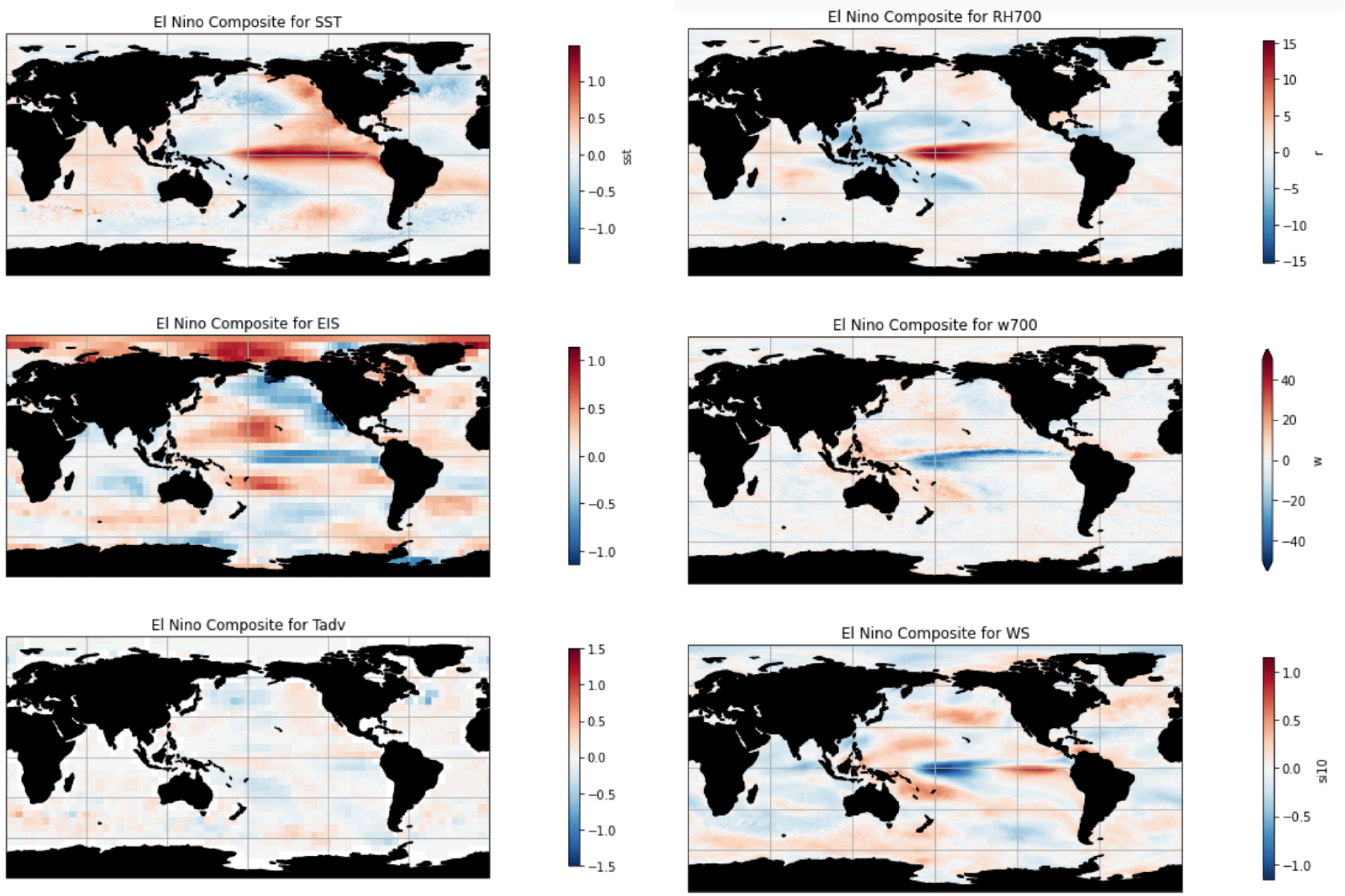
CERES ERA GCMs (4xCO2)

Constraining feedback change with respect to ENSO



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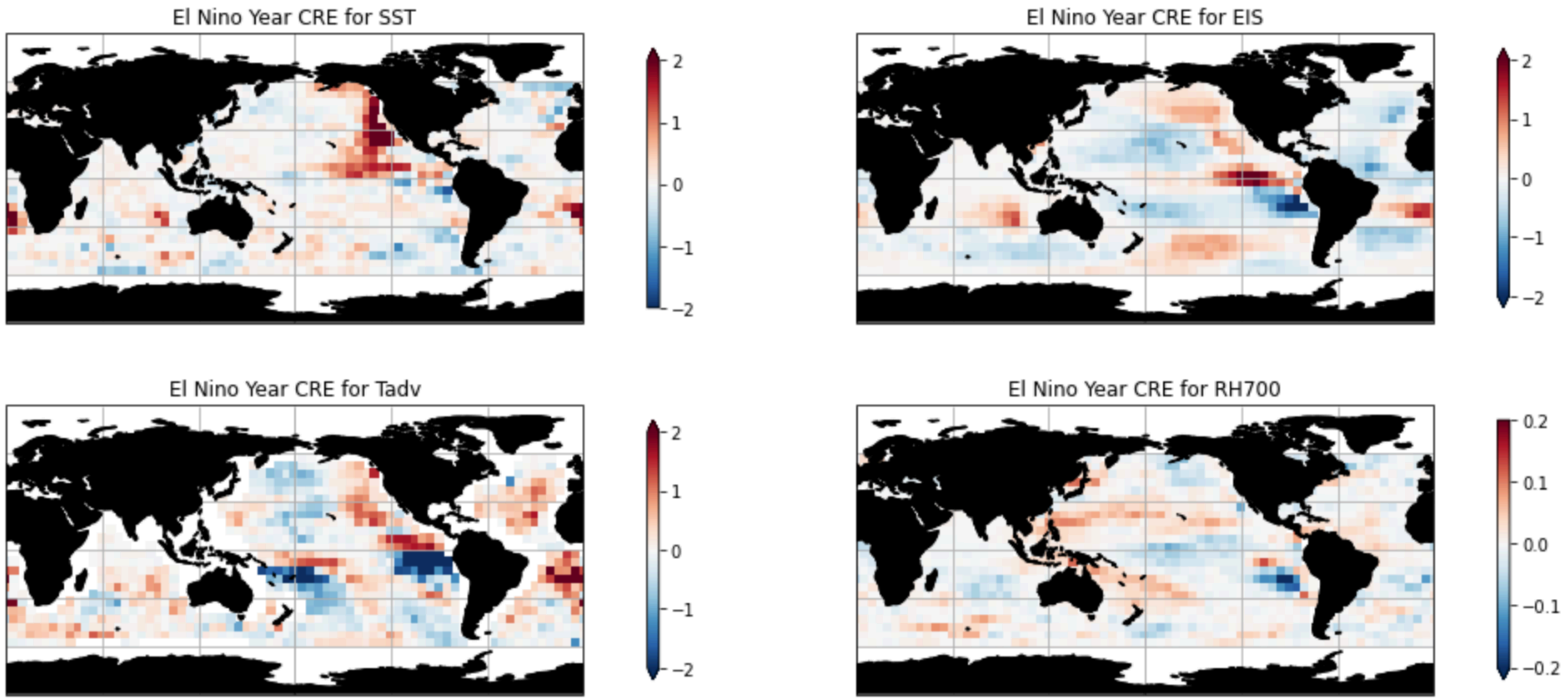

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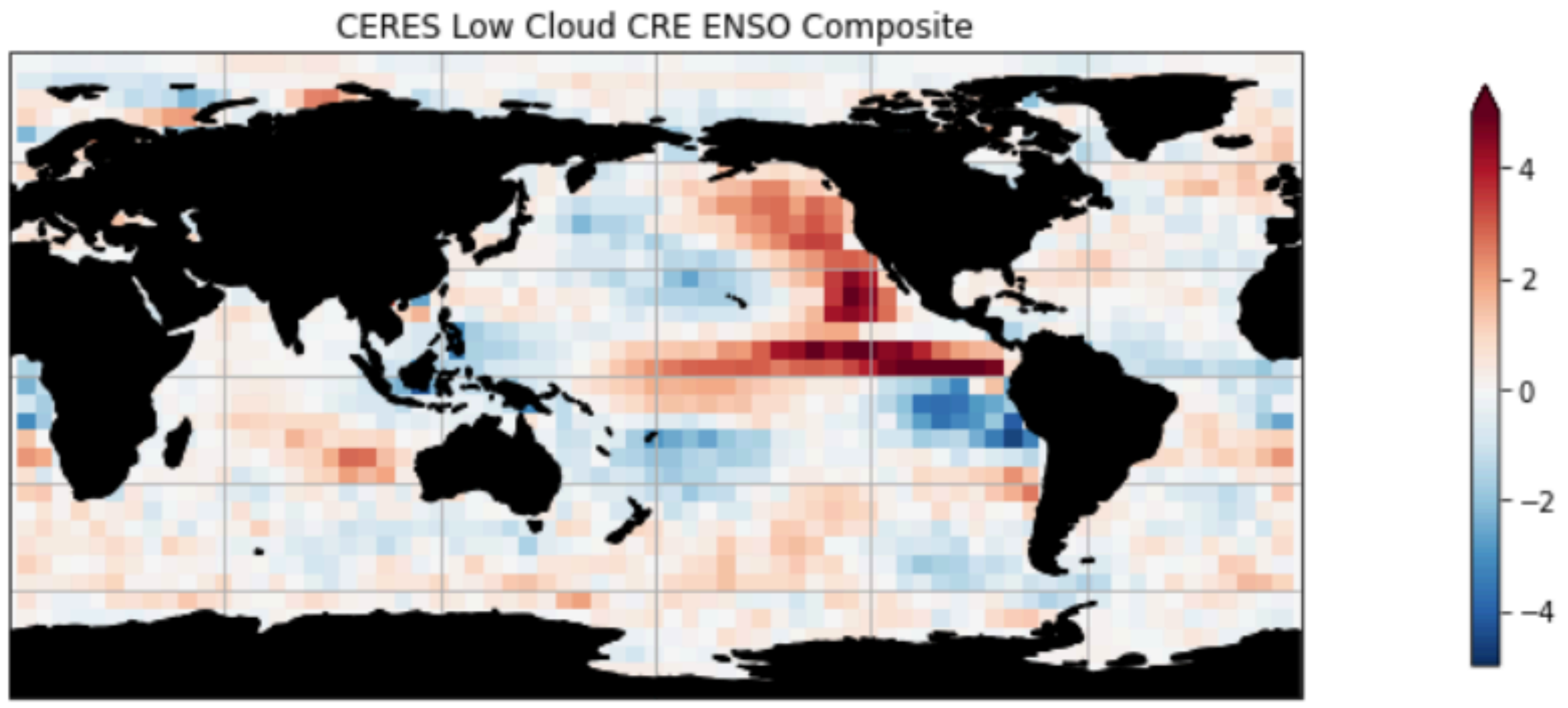
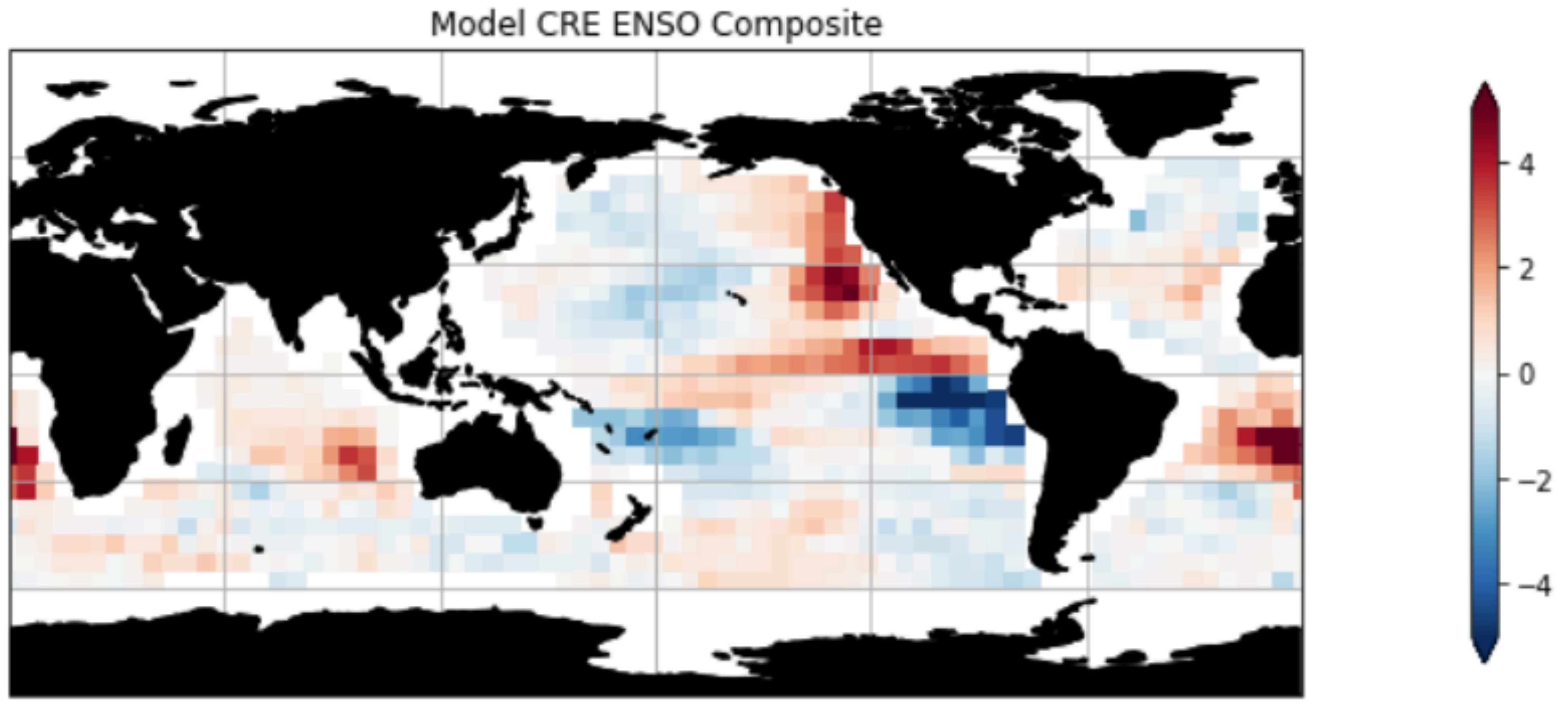
Scott et al 2020

Constraining feedback change with respect to ENSO



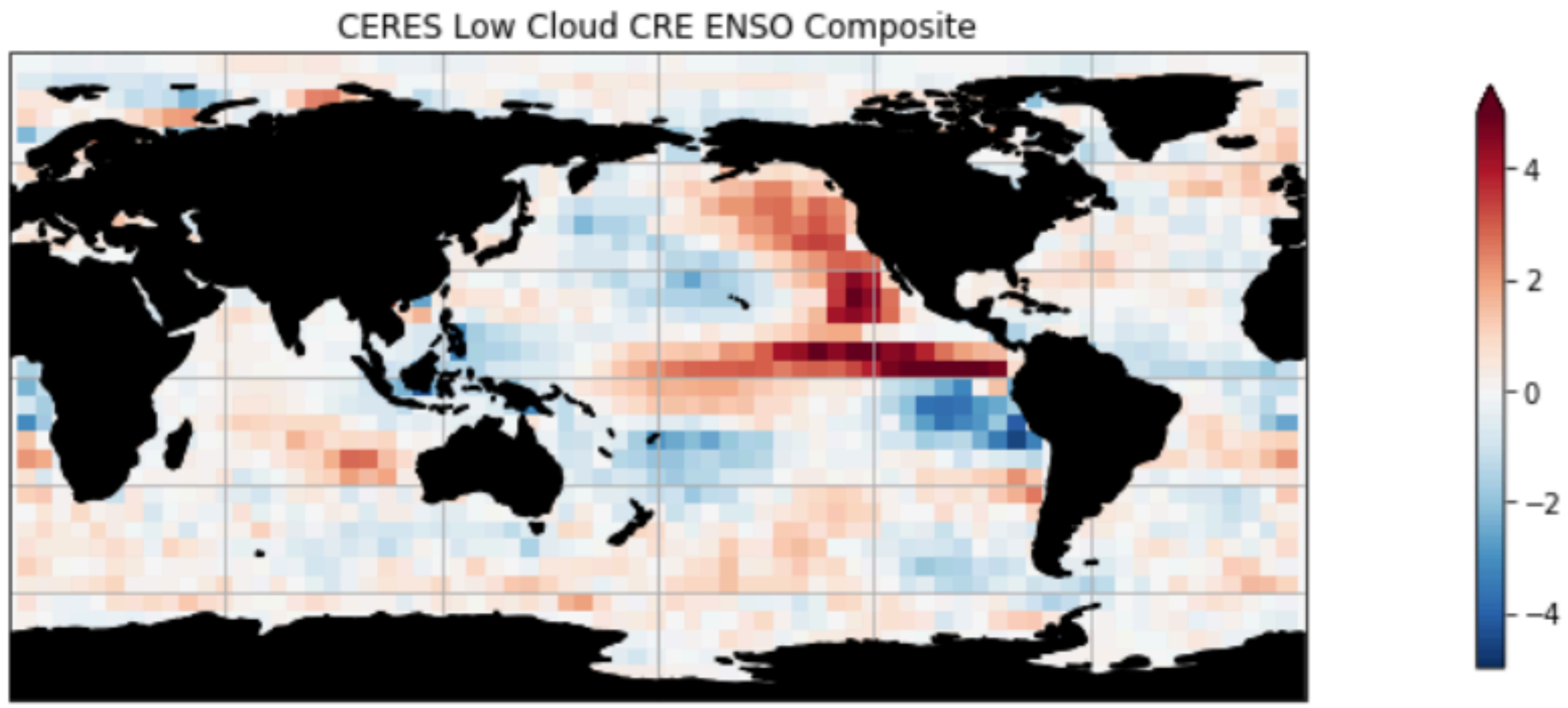


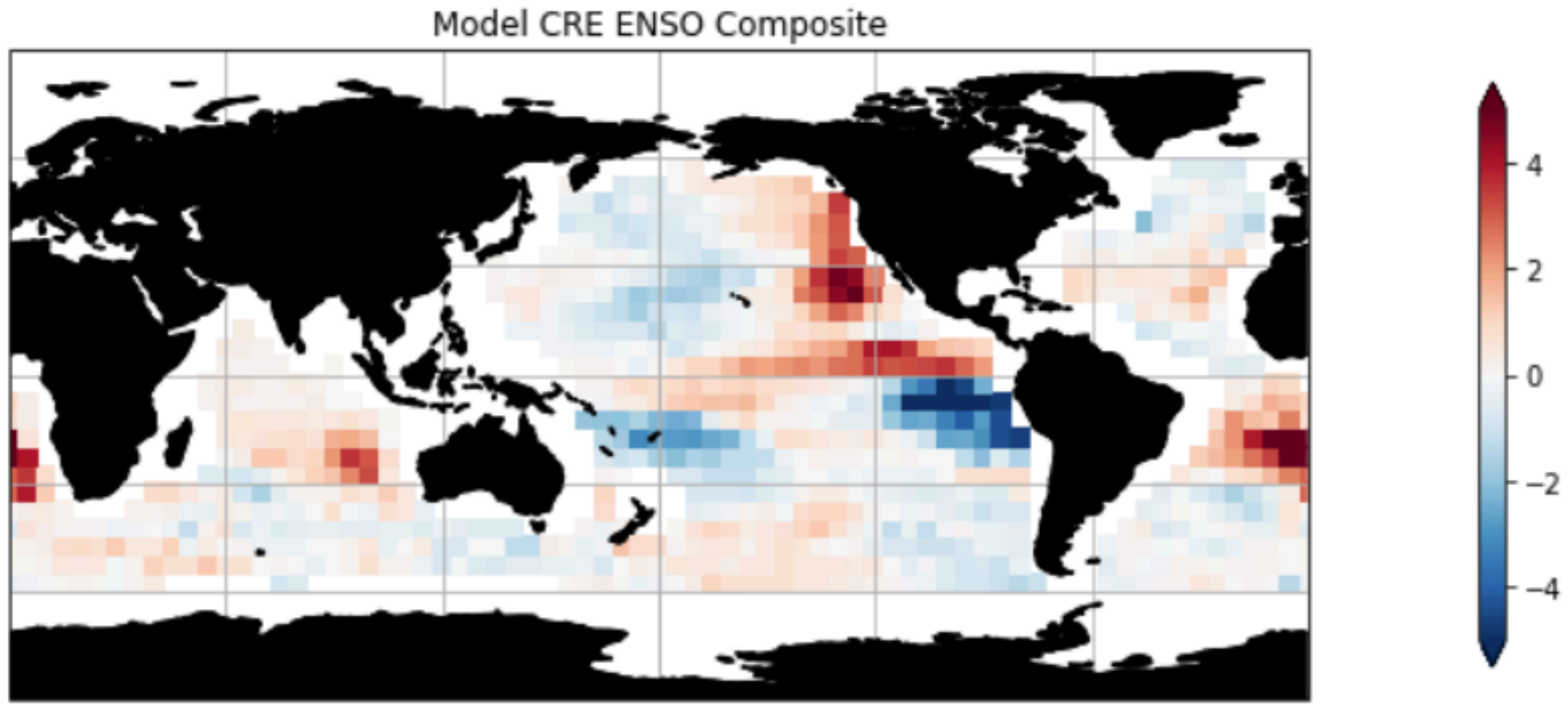
Get from GCMs

$$\frac{\overline{R}}{\overline{T}} \approx \lambda_{hist} + \sum_{x,y,\tau,p} \boxed{\frac{\partial R(x)}{\partial C(x)} \frac{\partial C(x)}{\partial \psi}} \frac{\Delta \psi}{\overline{T}}$$

Scott et al 2020

Constraining feedback change with respect to ENSO





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Scott et al 2020

Summary

Equilibrium Climate Sensitivity

$$ECS = \frac{\Delta F_{2\times}}{\lambda_{hist} - \Delta\lambda}$$

ARGO

CERES

Pattern effect can be constrained from CERES

- Reduced dimension - CRE vs dominant CCF
- Emergent Constraints on ENSO feedback
- Detailed analysis of CRE response to ENSO + how does ENSO state changes?