# Model bias in climate sensitivity tied to biases in surface temperature patterns over the tropical Indo-Pacific.


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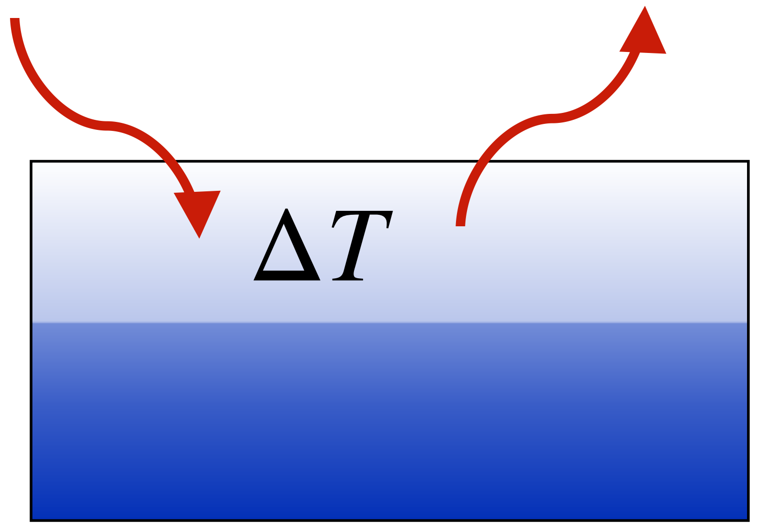
# Earth's **Equilibrium** Energy Balance

$$\boxed{\Delta F = \Delta R}$$

Energy Input
(radiative forcing)
$\Delta F$

Radiative damping
$R = \lambda \Delta T$




Radiative feedback
(Efficiency of radiative damping)

$$\lambda = \frac{\Delta R}{\Delta T}$$

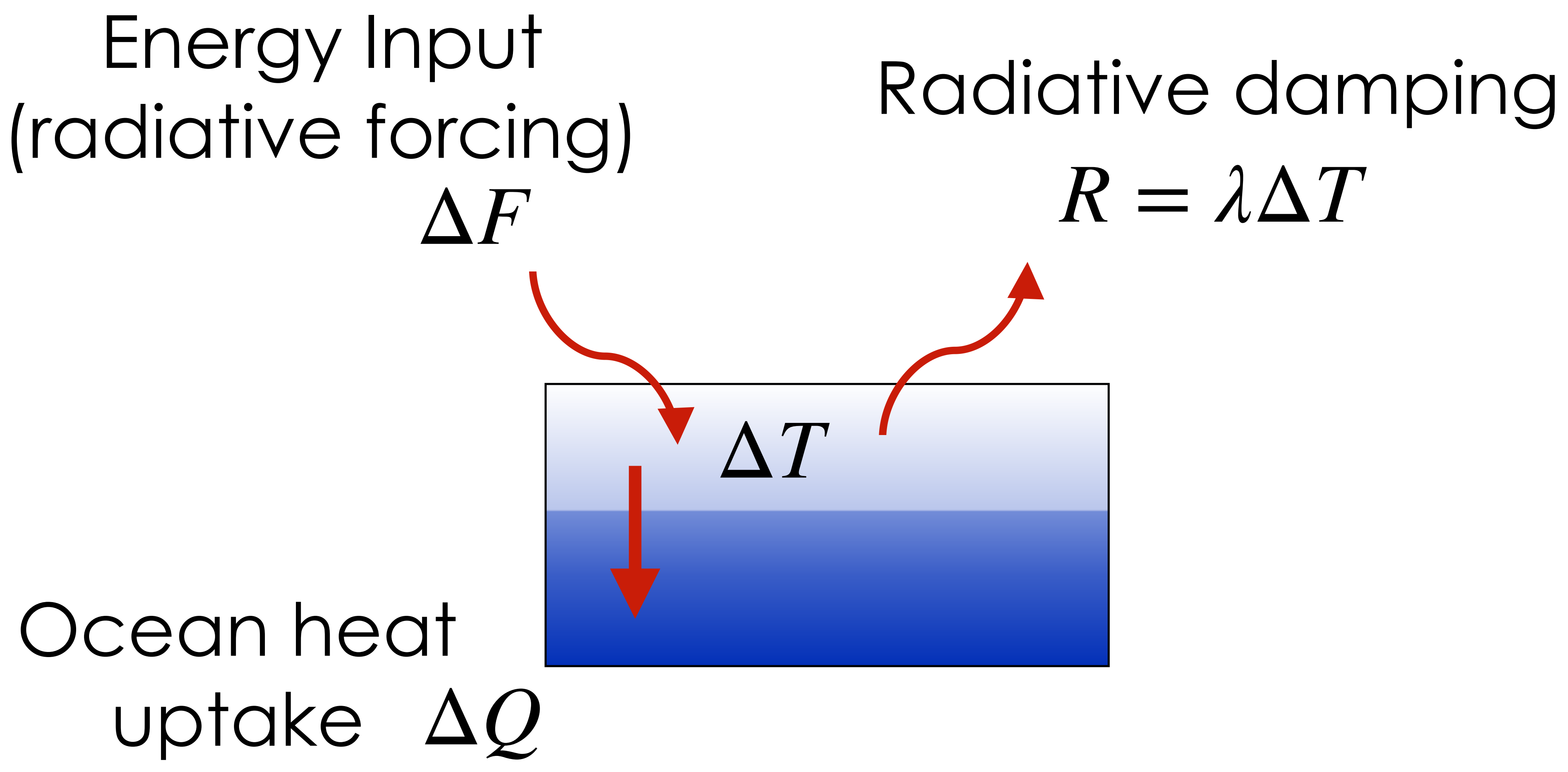
Equilibrium Climate Sensitivity:

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

Determined by "How efficient is the Earth at restoring energy balance through warming?"

# Earth's **Transient** Energy Balance

$$\boxed{\Delta F(t) + \Delta Q(t) = R(t)}$$




**Instantaneous** Radiative feedback

(Efficiency of radiative damping)

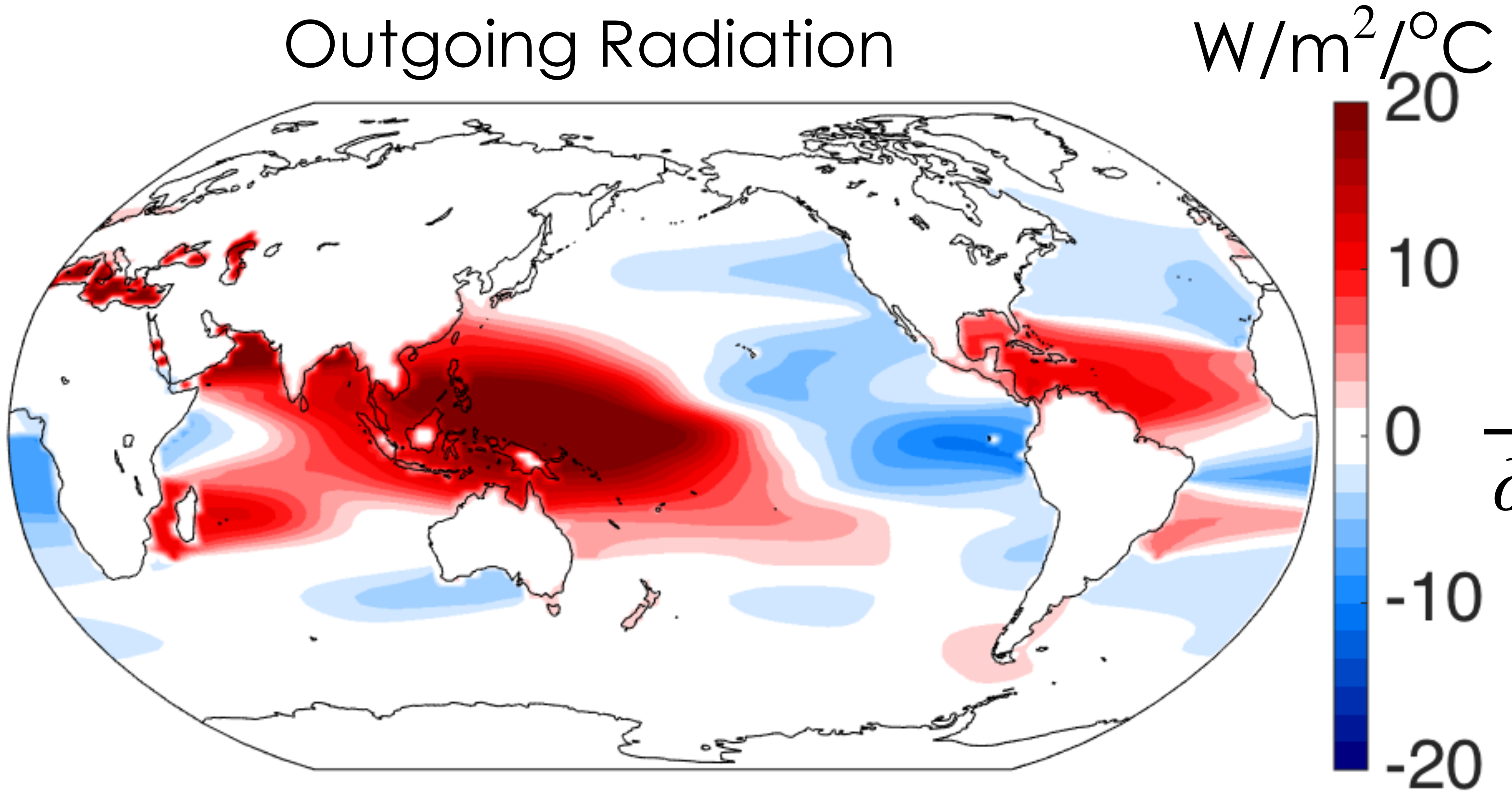
$$\lambda(t) = \frac{\Delta R(t)}{\Delta T(t)}$$

Inferred Climate Sensitivity:

$$\Delta T_{2\times} = \frac{\Delta F_{2\times}}{\lambda(t)}$$

Determined by "How efficient is the Earth at restoring energy balance through warming?"

# Radiative feedback depends on **pattern** of warming




$$\frac{\partial \overline{R}}{\partial T(\mathbf{x})}$$

Global radiation response to
- 1$^o$C of warming in West Pacific:  +30 W/m$^2$
- 1$^o$C of warming in East Pacific:   -10 W/m$^2$

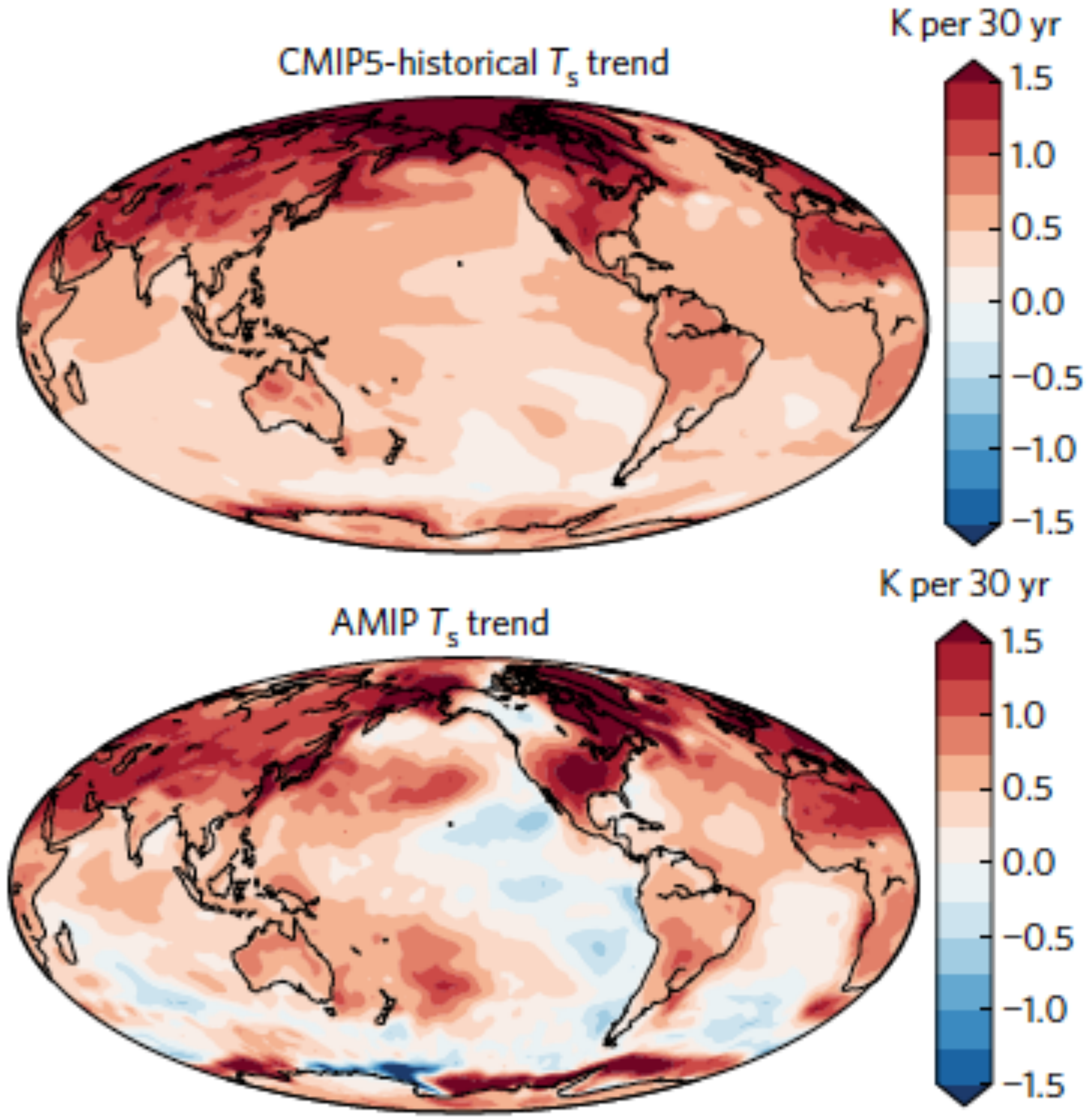
**Instantaneous** Radiative feedback
(Efficiency of radiative damping)

$$\lambda(t) = \frac{\Delta R(t)}{\Delta T(t)}$$

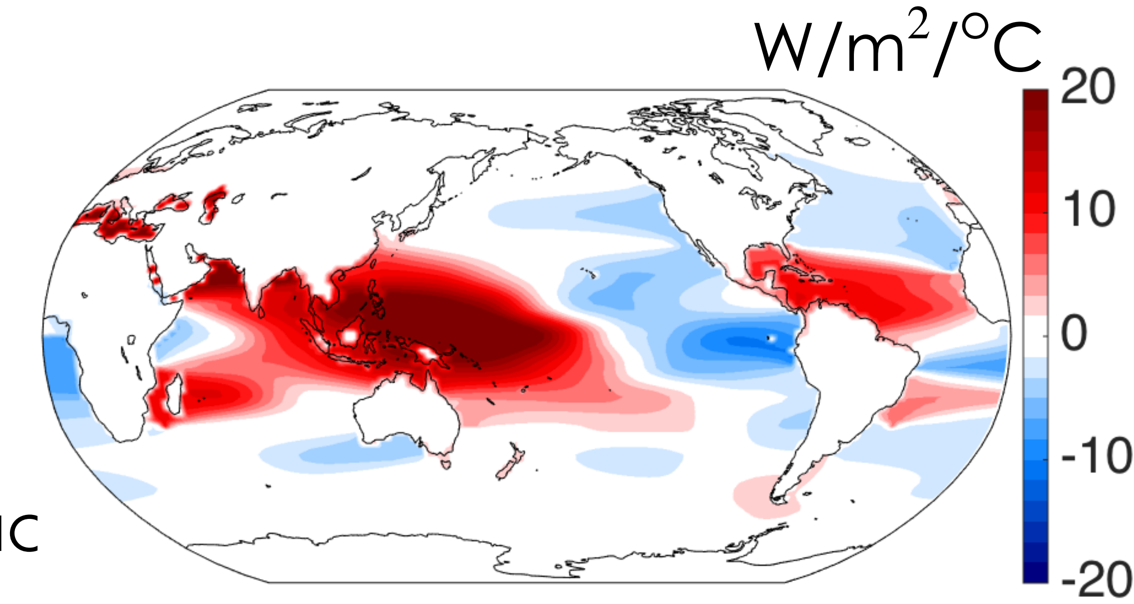
$$\boxed{\Delta R = \int_y \frac{\partial \overline{R}}{\partial T(x)} dT}$$

Dong, Proistosescu, et al 2019

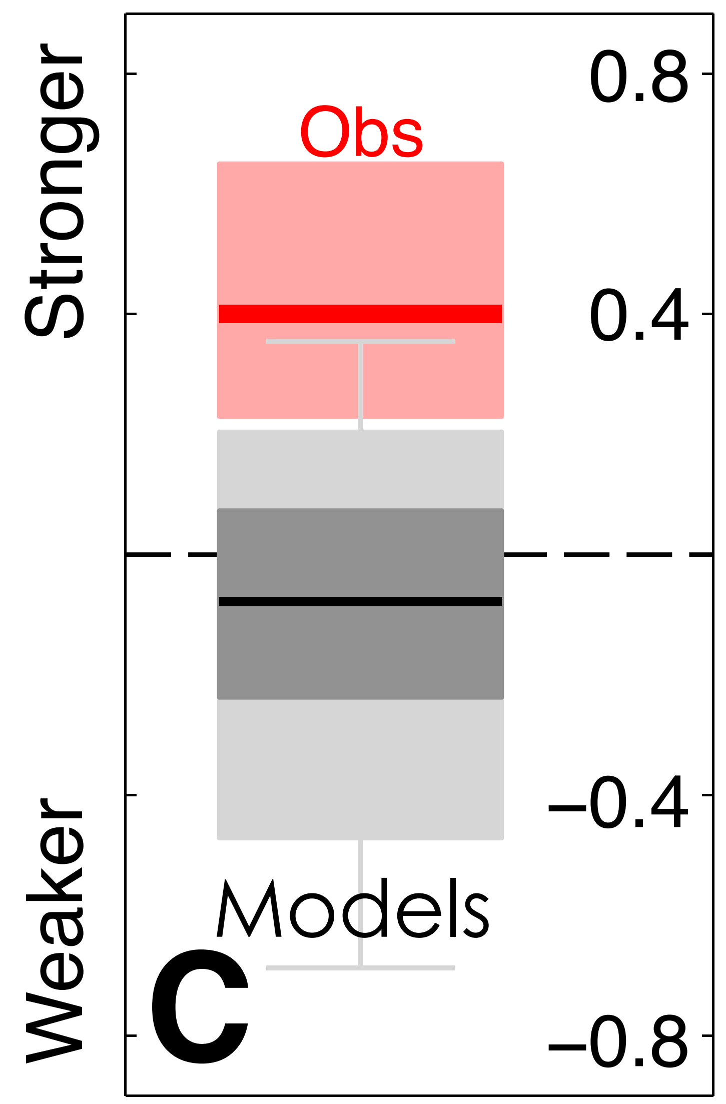
# Models do not reproduce the observed pattern of warming




Zhou et al 2016




Changes in W-E Equatorial Pac SST gradient (C/century)

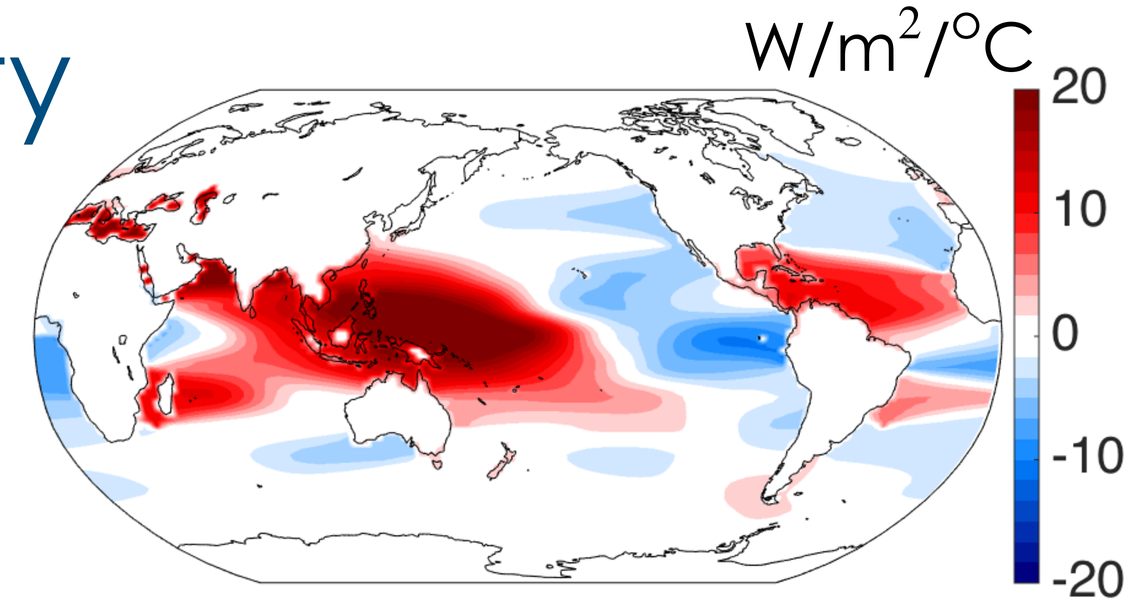


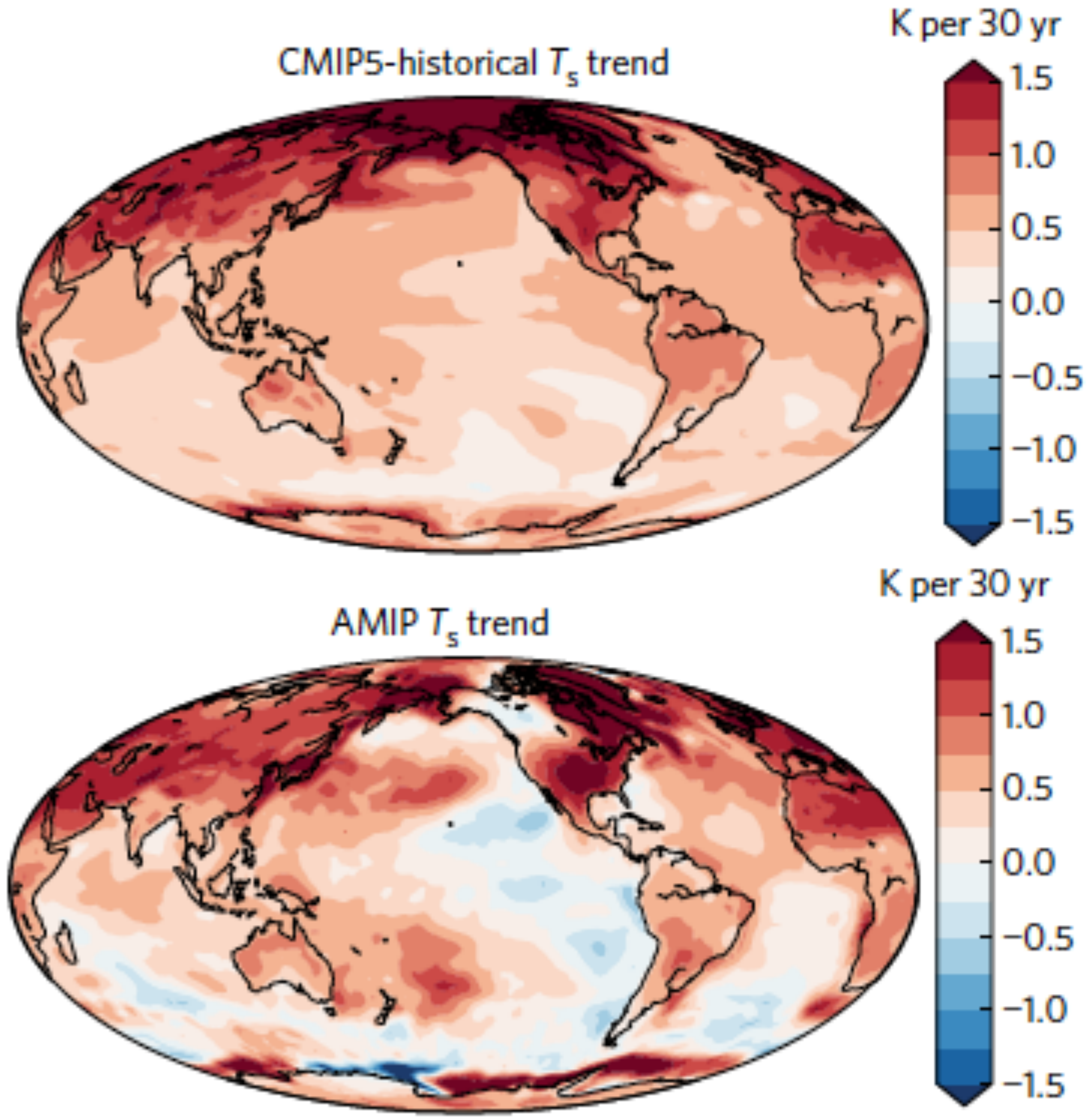

Coates and Karnauskas 2018

- *historical* :coupled models with dynamical oceans, forced with historical radiative forcing
- *AMIP:* atmosphere models forced with the *observed* history of SSTs

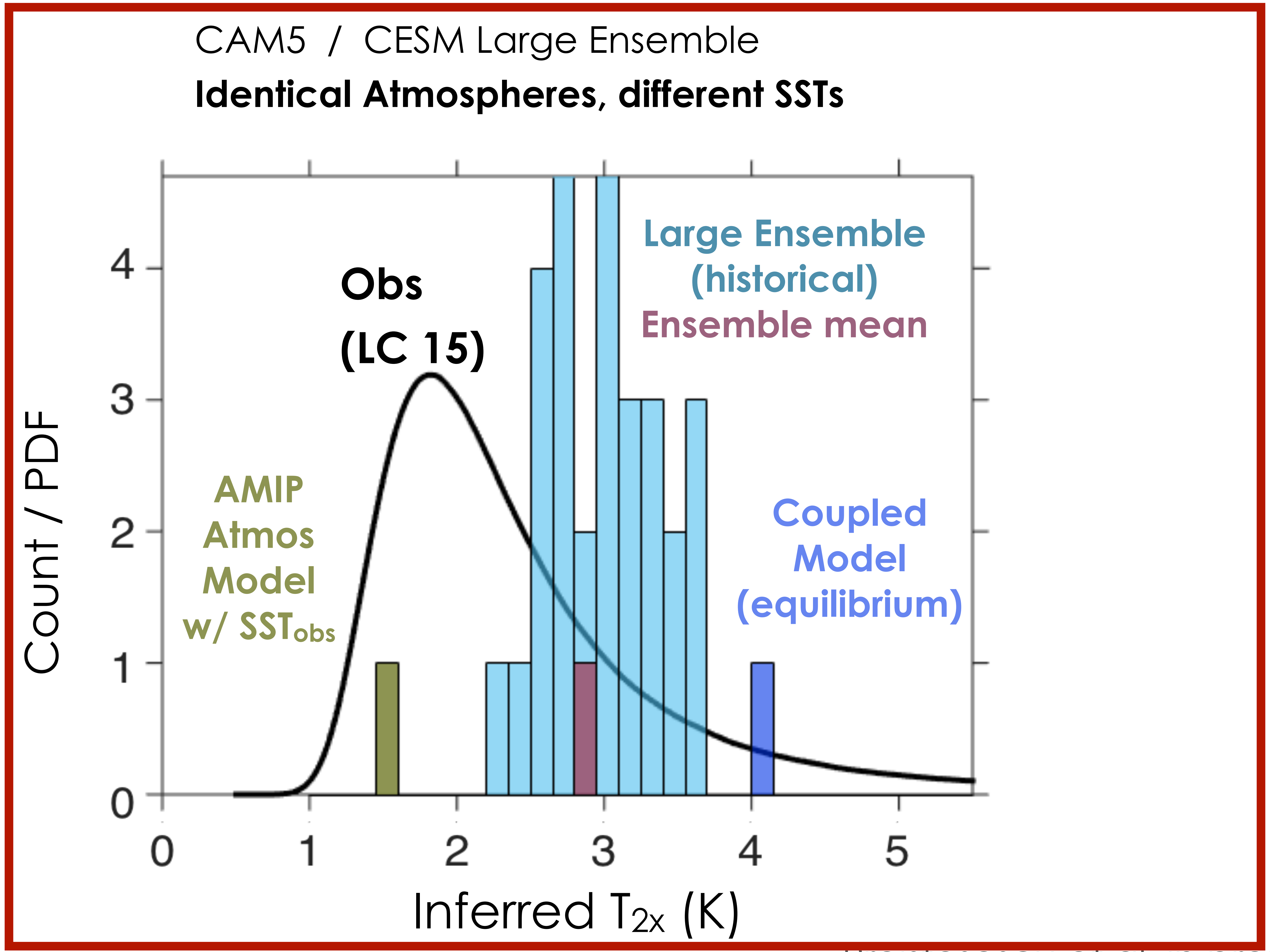
Coupled climate models are generally note able to reproduce the observed evolution of Sea Surface Temperature (SST) patterns

# SST mismatches lead to large differences in inferred climate sensitivity




Zhou et al 2016




Proistosescu et al, in prep

# Pattern change in **historical** SSTs

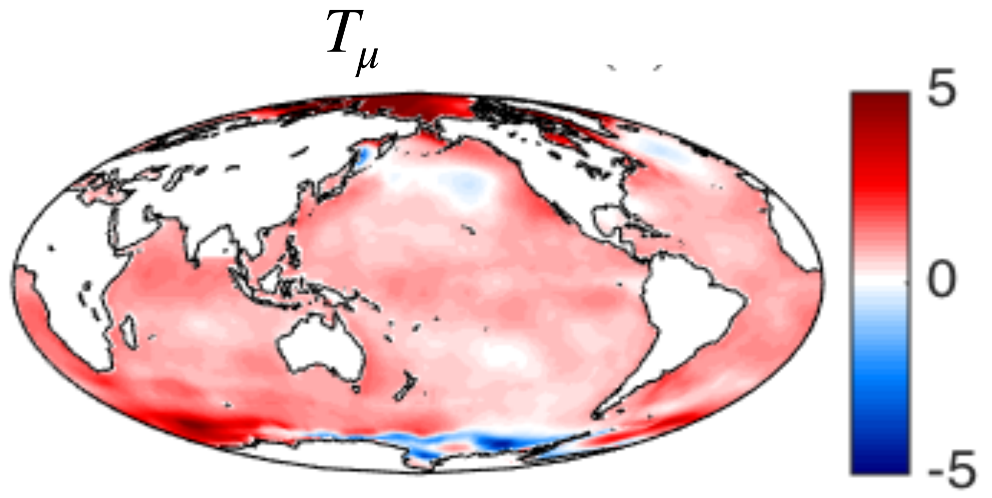
Mean pattern
(constant feedback)

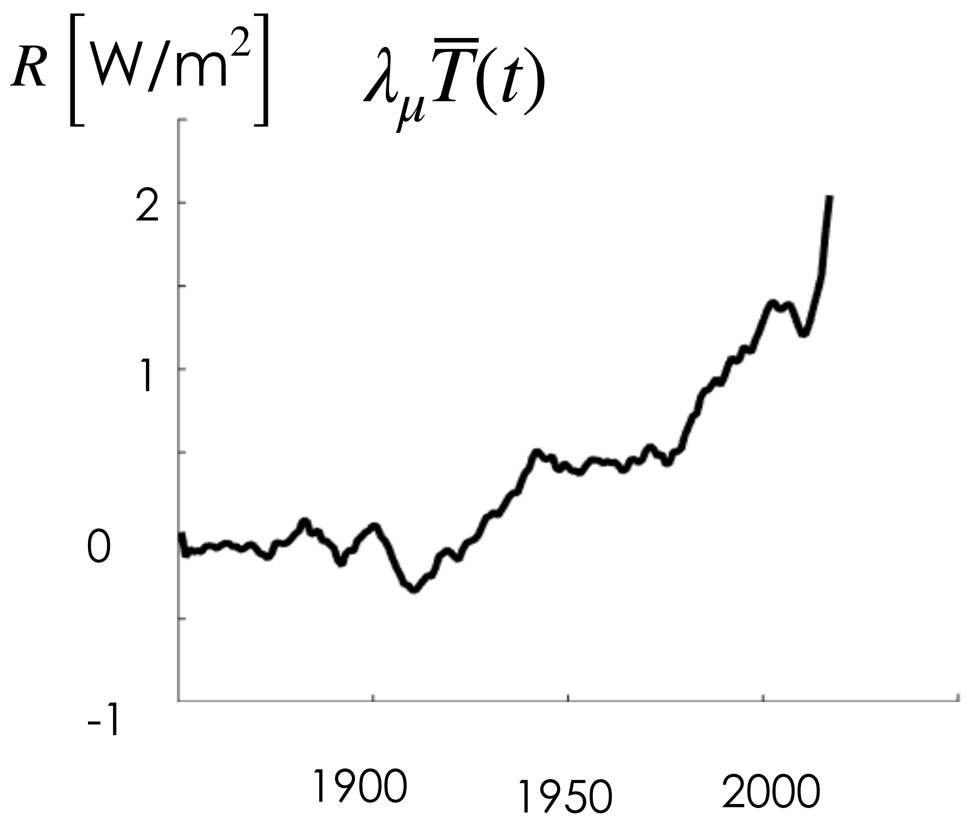
Patterned SST field

$$\lambda(t) = \lambda_\mu + \frac{R_{\text{patterned}}(t)}{\overline{T}(t)}$$

Constant pattern
Constant feedback

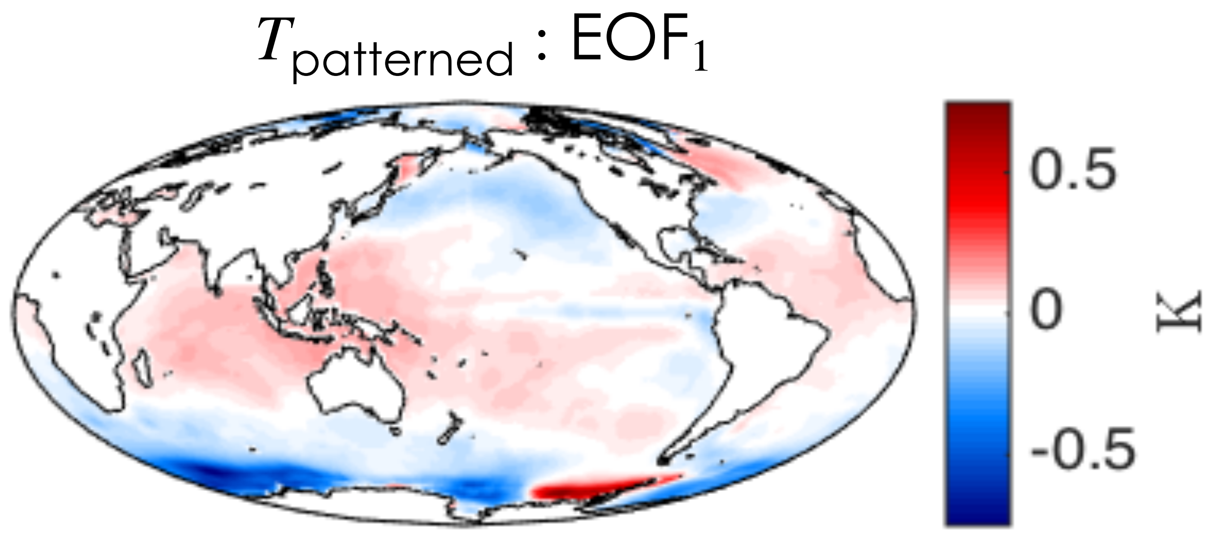
$$\lambda_\mu = \int \frac{\partial \overline{R}}{T(\mathbf{x})} T_\mu(\mathbf{x})$$

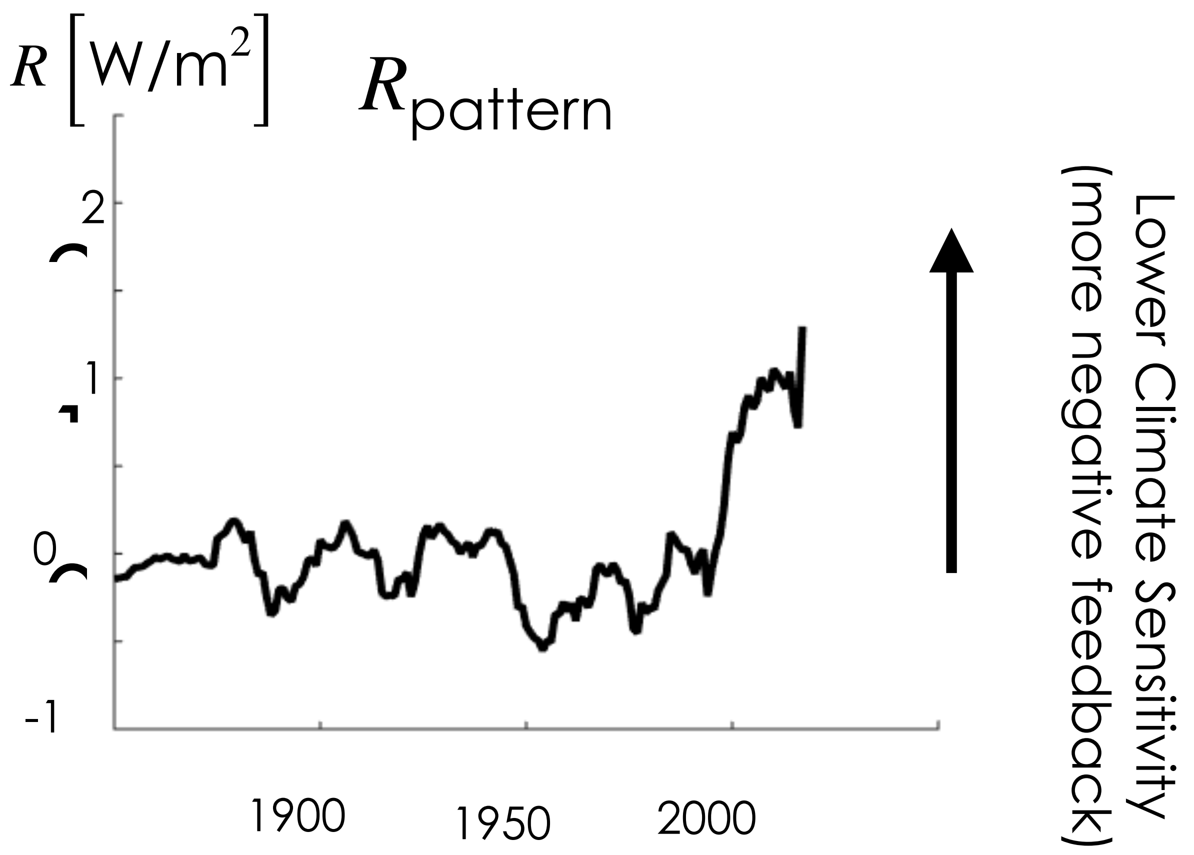



Changes in SST pattern
(Zero global mean)

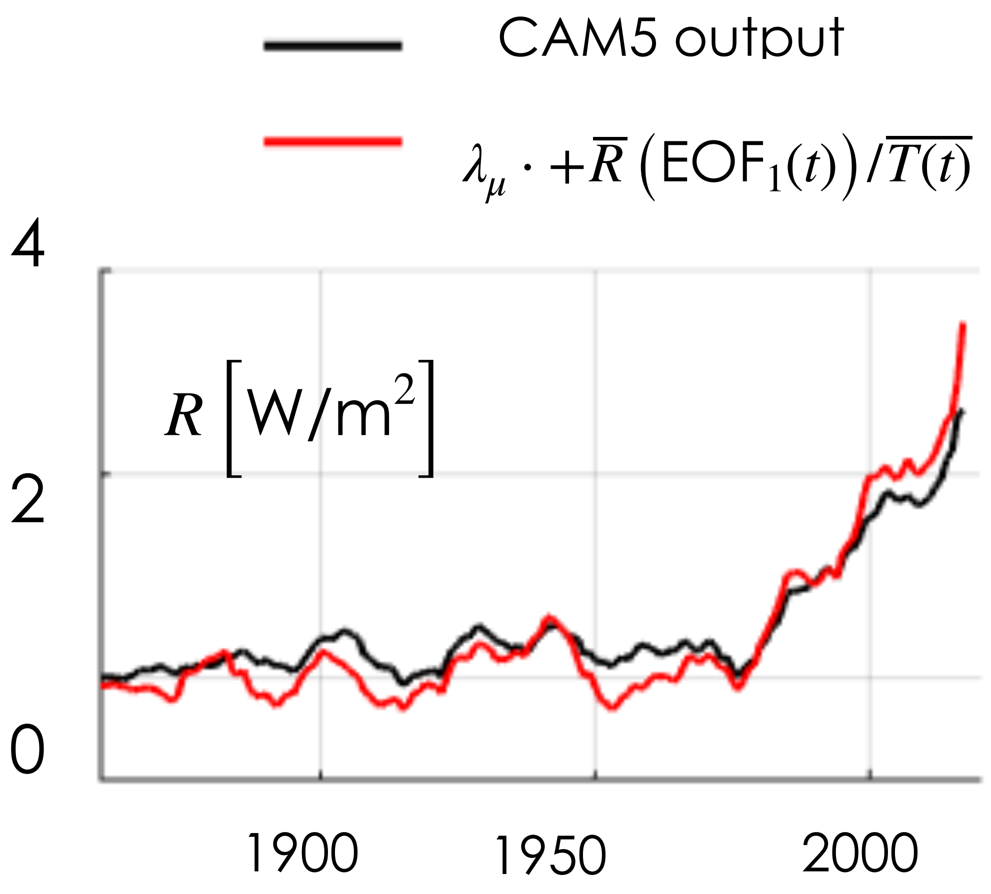
$$R_{\text{pattern}}(t) = \int \frac{\partial \overline{R}}{T(\mathbf{x})} T_{\text{patterm}}(\mathbf{x}, t)$$



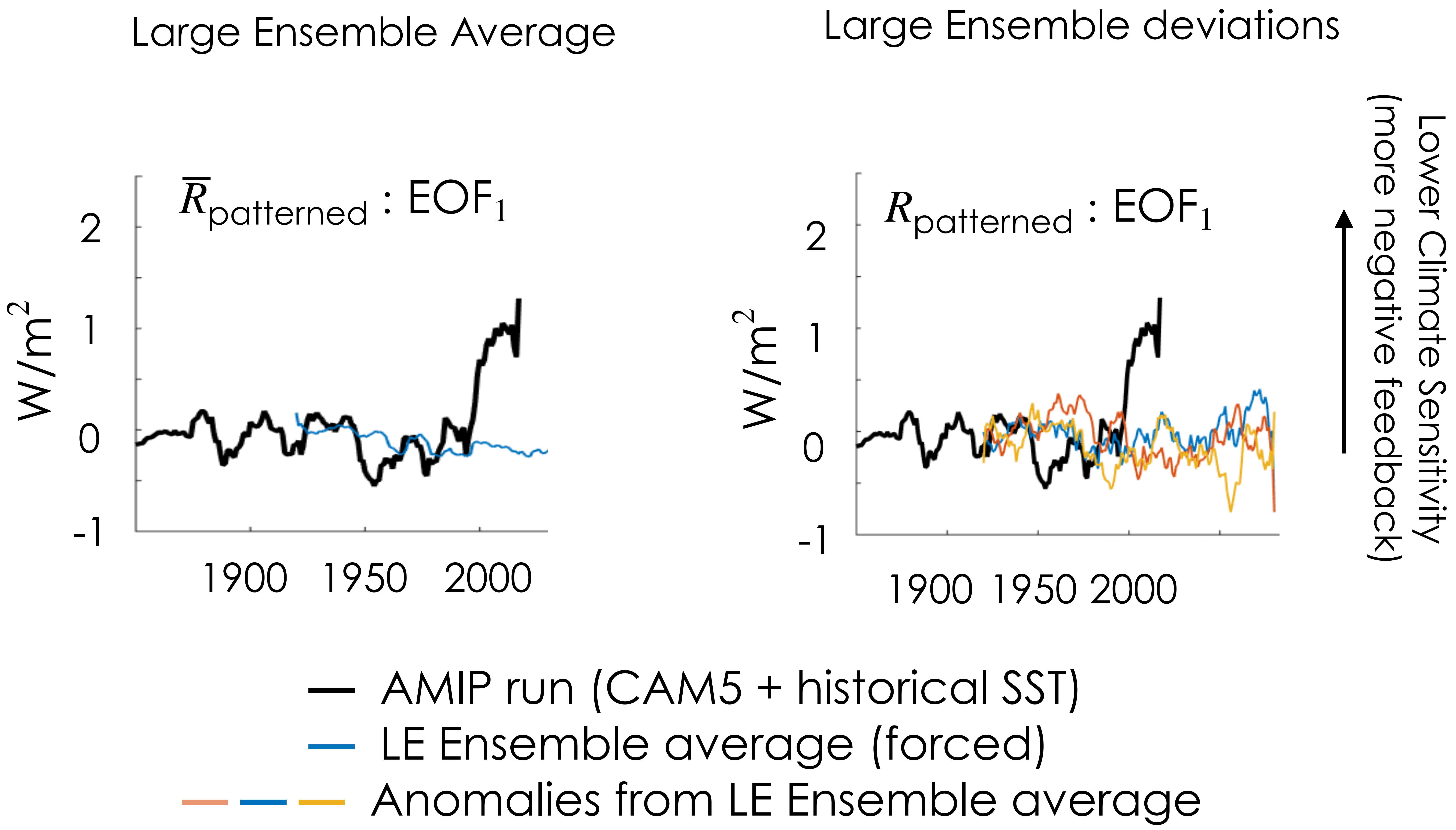




We decompose the feedback into a constant feedback plus a contribution from changing SST patterns (the pattern effect).

Mean Pattern + 1st EOF of *SSTs weighted by green's function* are sufficient to explain changes in outgoing radiation in CAM5-AMIP



# Coupled model SSTs lack significant pattern effect



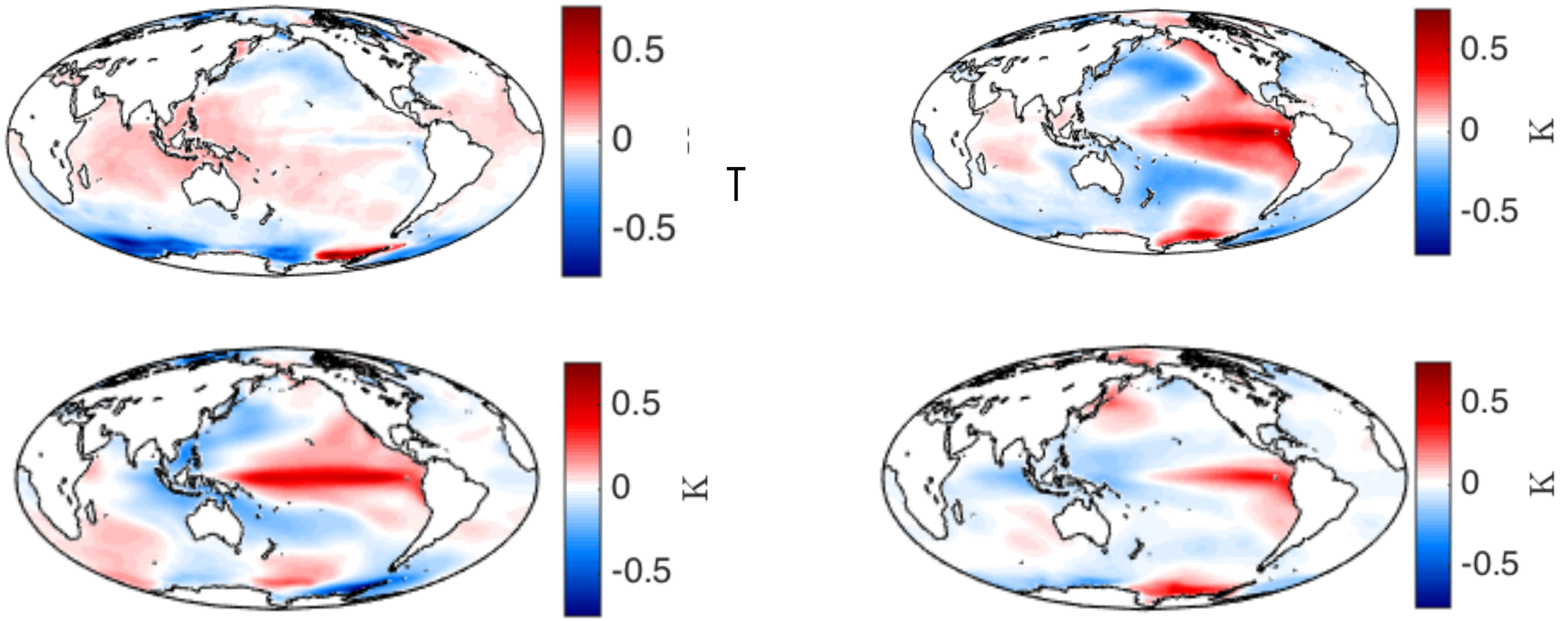
# Coupled model SSTs lack sufficient variability in Indo-Pacific Warm pool

EOFs of : $T(x,t) \cdot \dfrac{\partial \overline{R}}{\partial T(x)}$

EOF 1 | EOF 2

Observed SSTs

Large Ensemble



# Thank You!

# Questions?

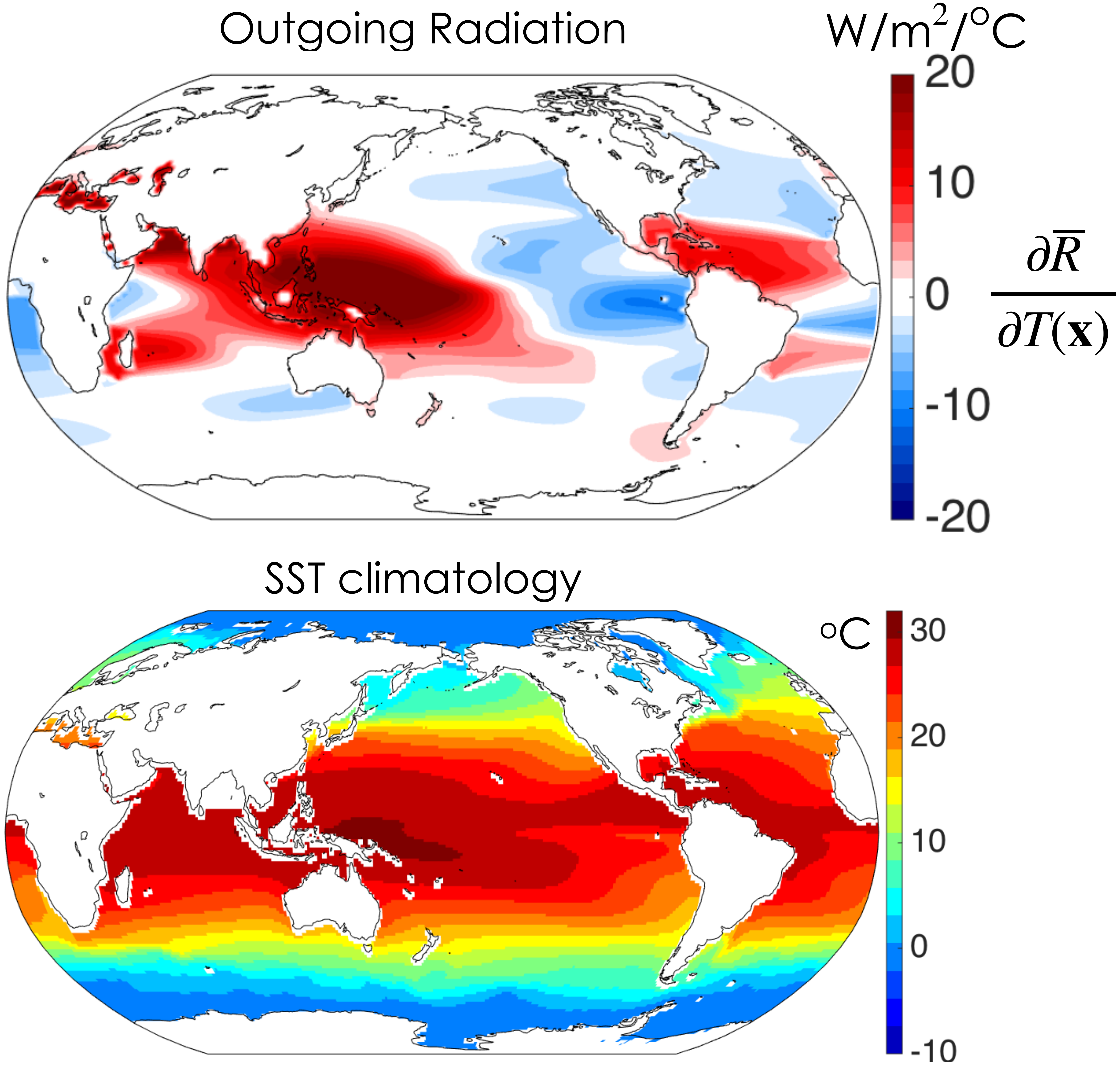
**Collaborators:**

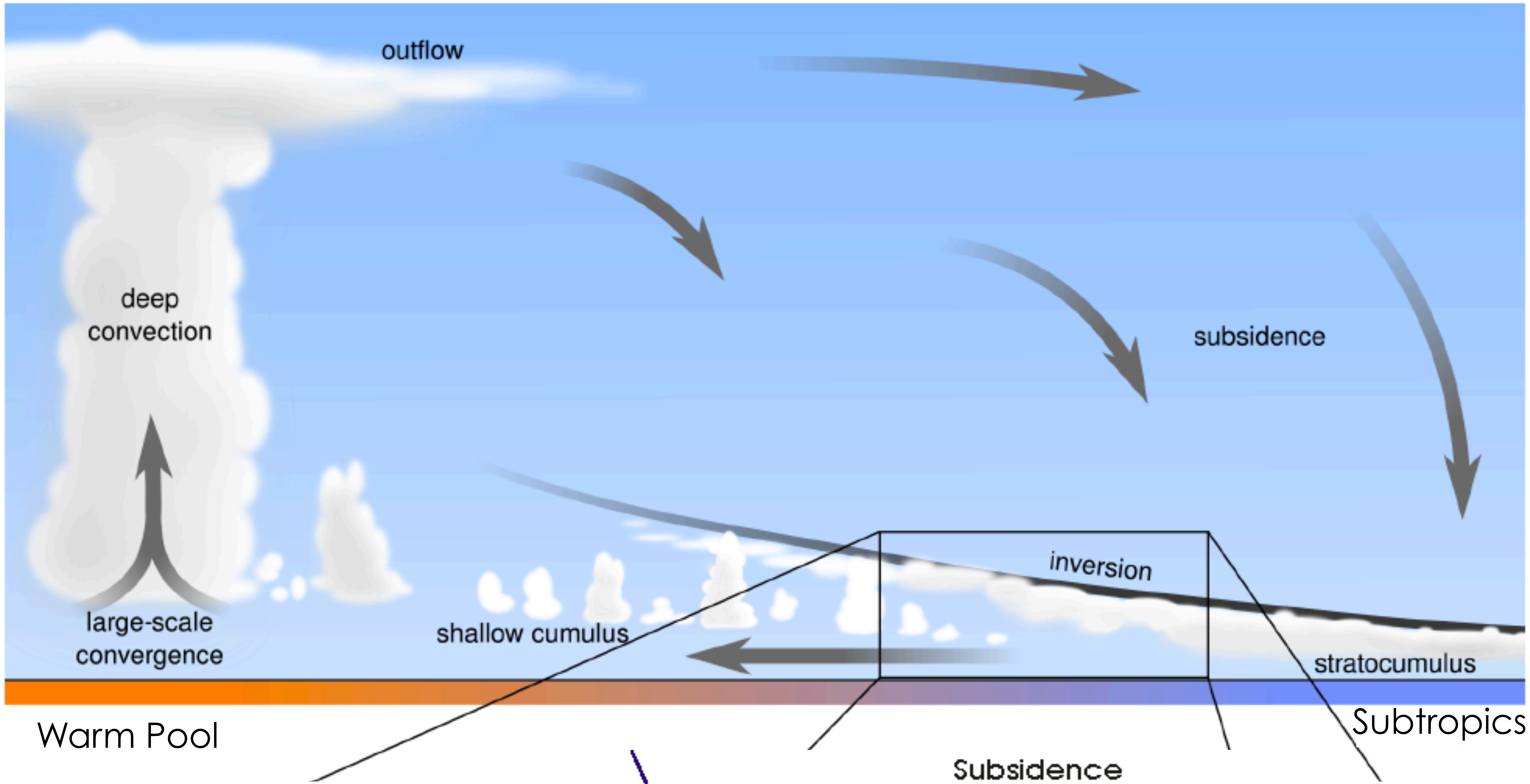
| | |
|---|---|
| Yue Dong | - University of Washington, Atmospheric Sciences, |
| Malte Stuecker | - University of Hawaii, Oceanography |
| Kyle Armour | - University of Washington, School of Oceanography |
| David Battisti | - University of Washington, Atmospheric Sciences |
| Rob Wills | - University of Washington, Atmospheric Sciences, |
| Luke Parsons | - University of Washington, Atmospheric Sciences |

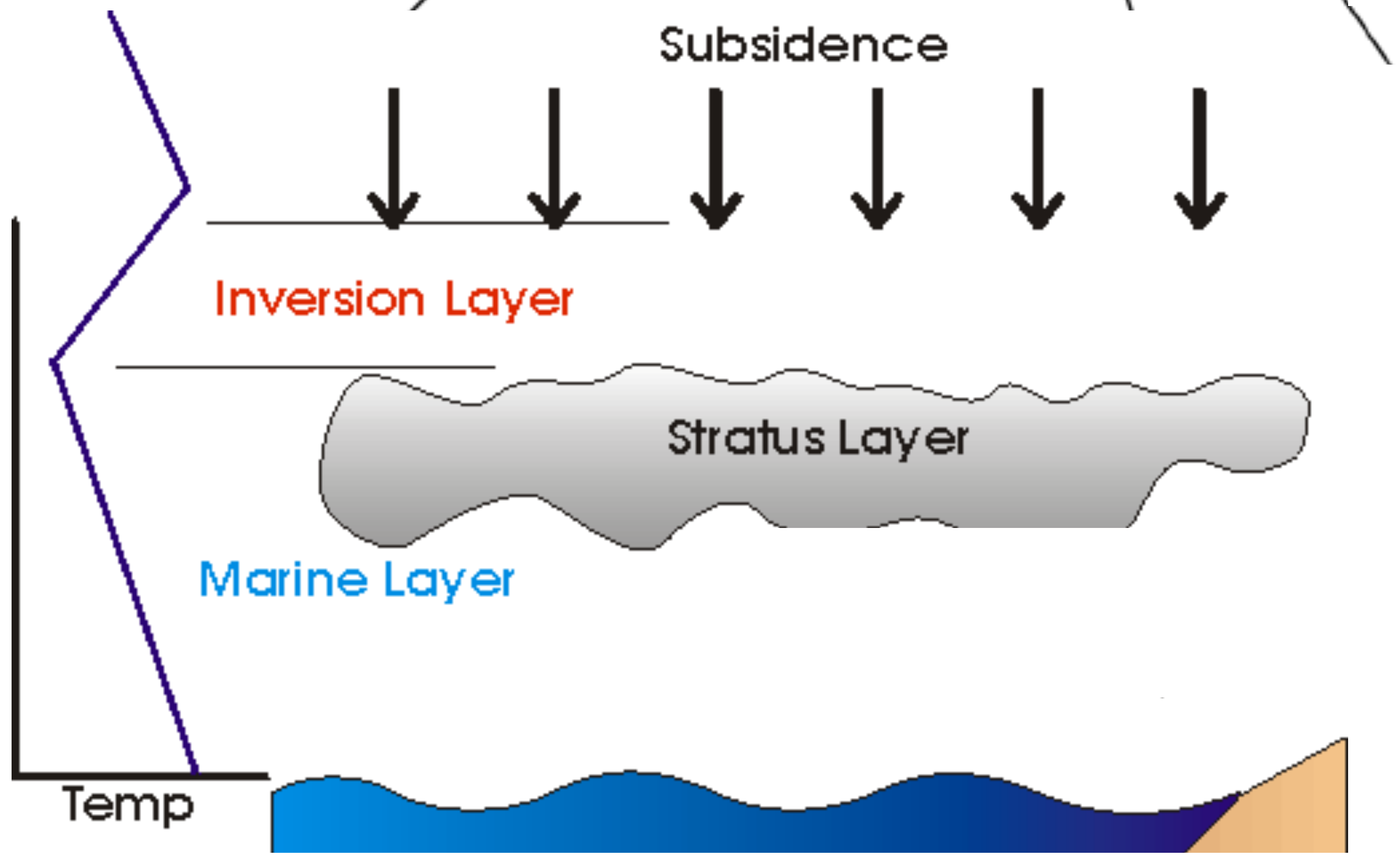
# Supplementary Slides

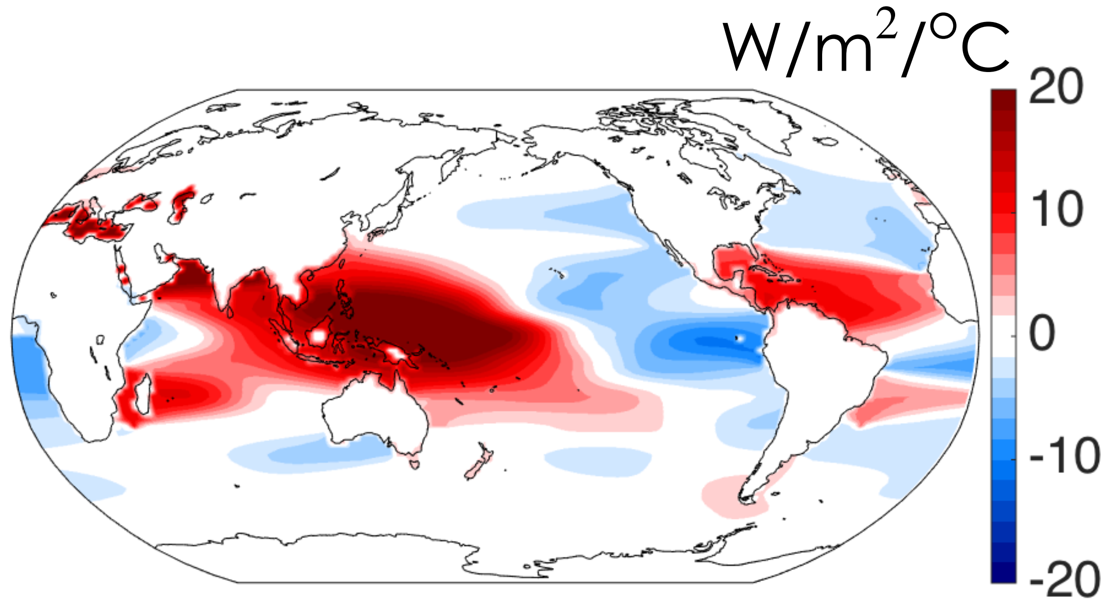
# How does radiation depend on the pattern of warming?

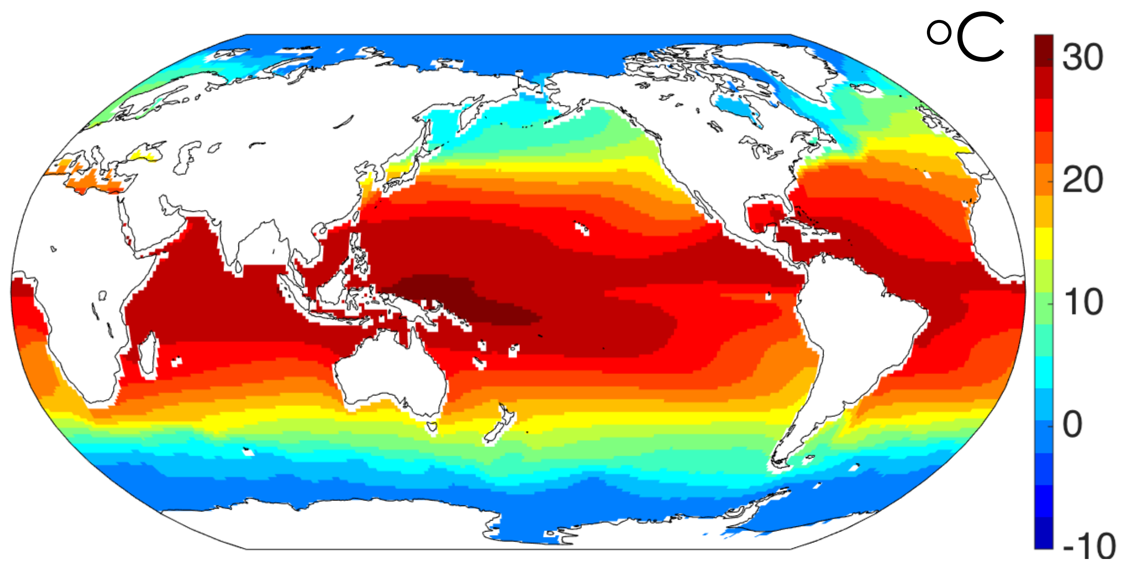
## Radiative response to local warming **tied to SST climatology**





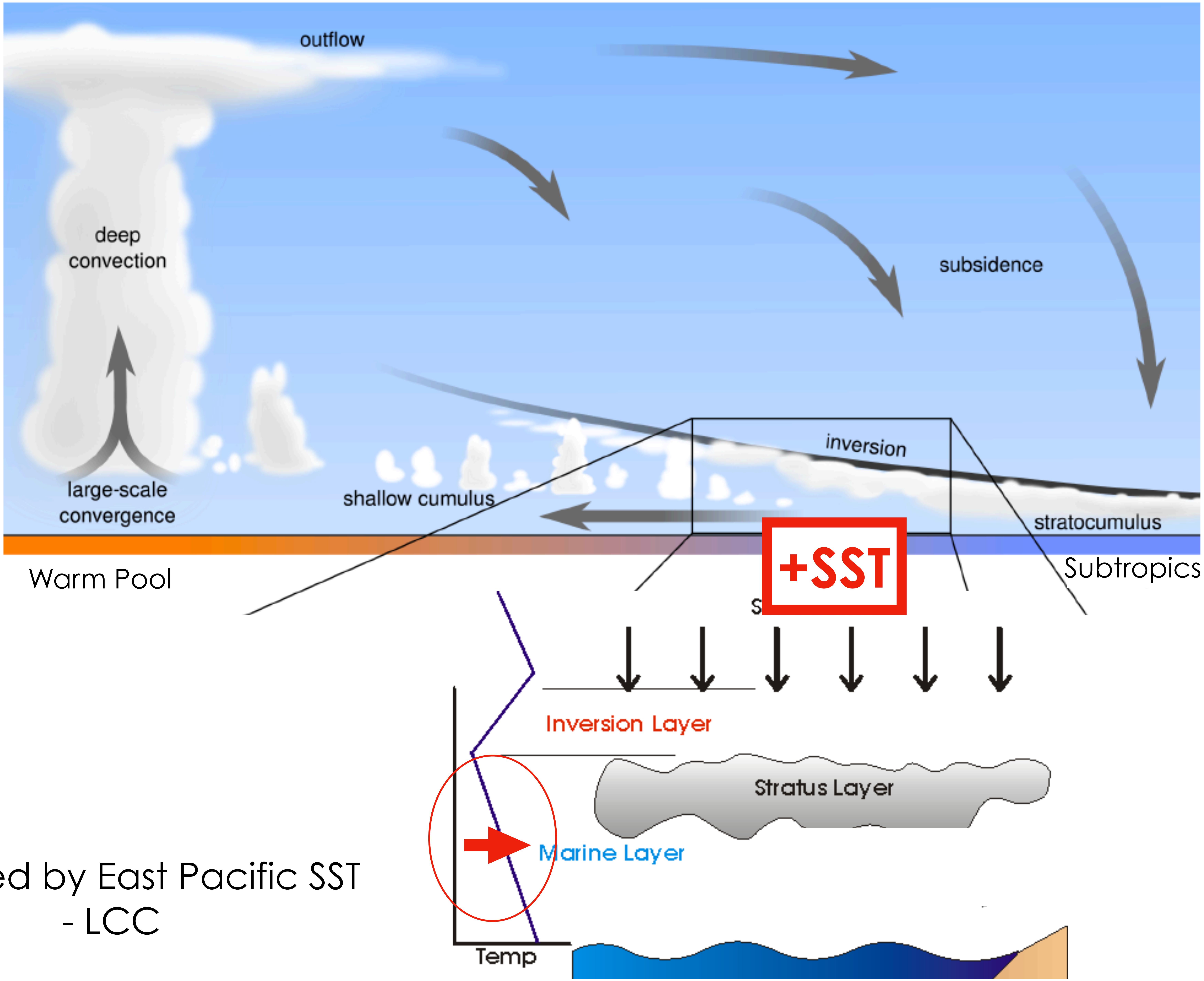



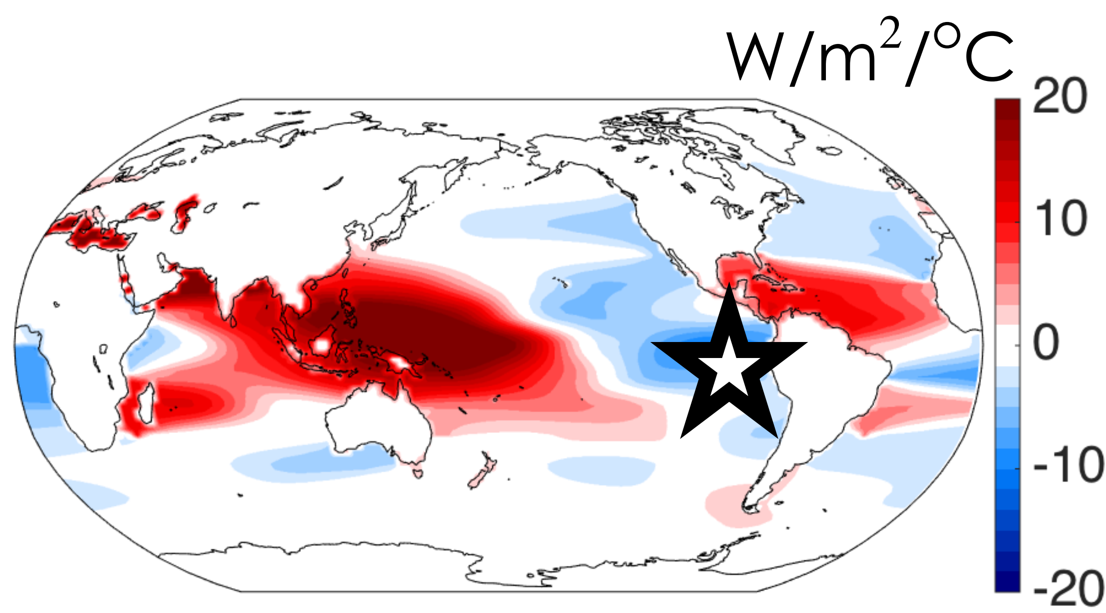



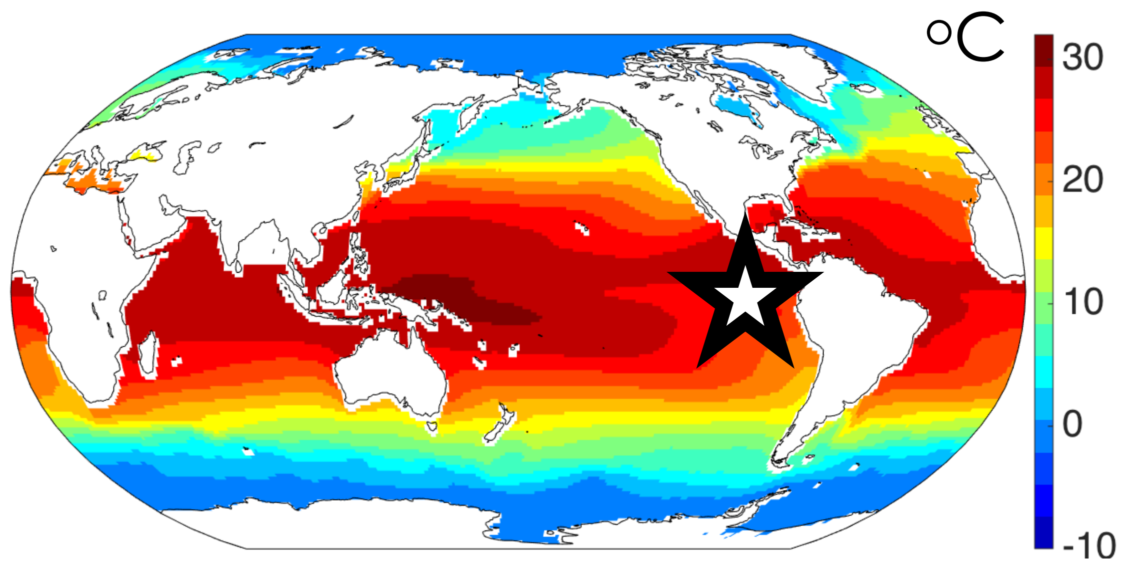




Low cloud amount depends on strength of inversion and local temperature

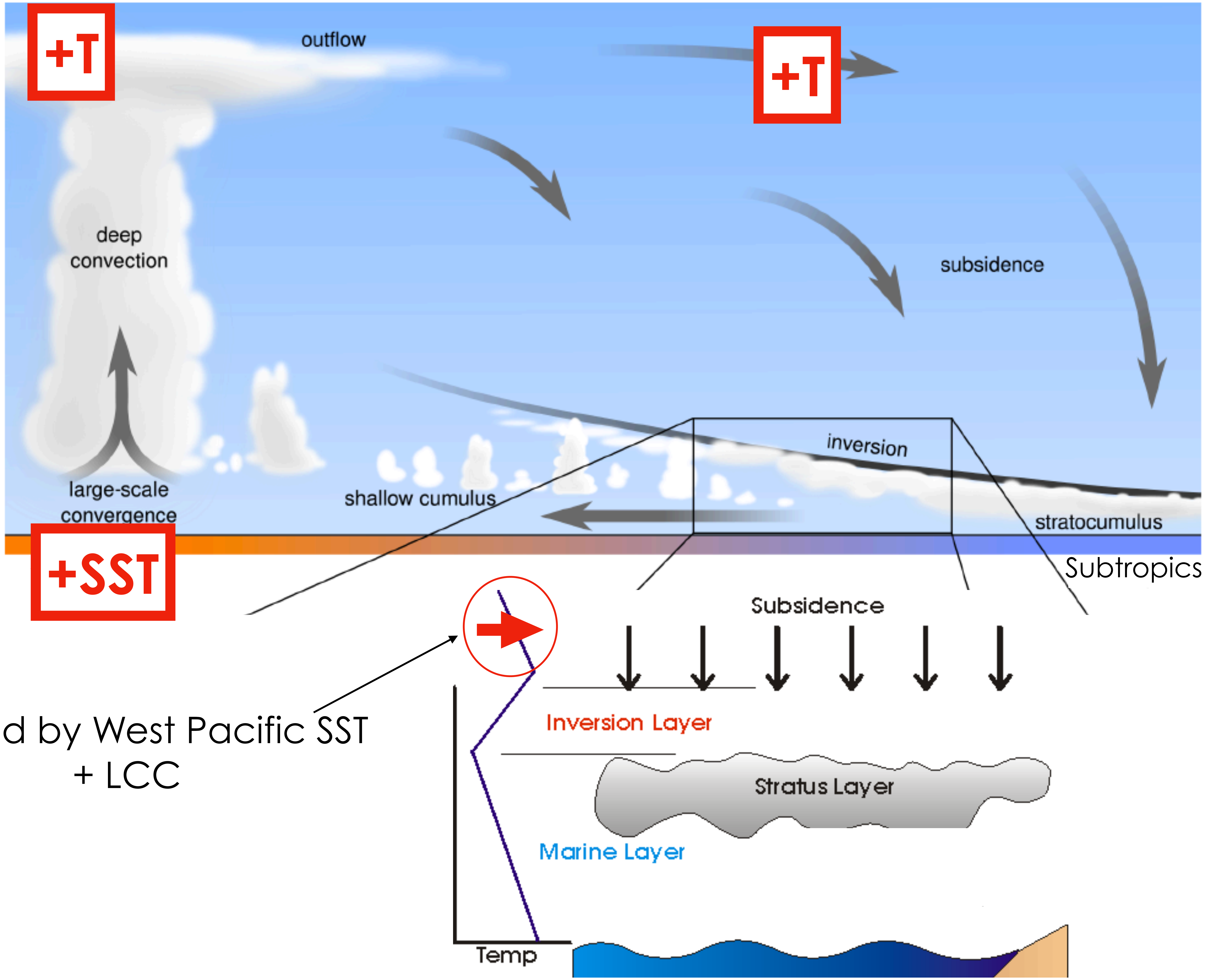
Klein and Hartman 1993,
Wood & Bretherton 2006 ,
Bretherton & Blossey 2014

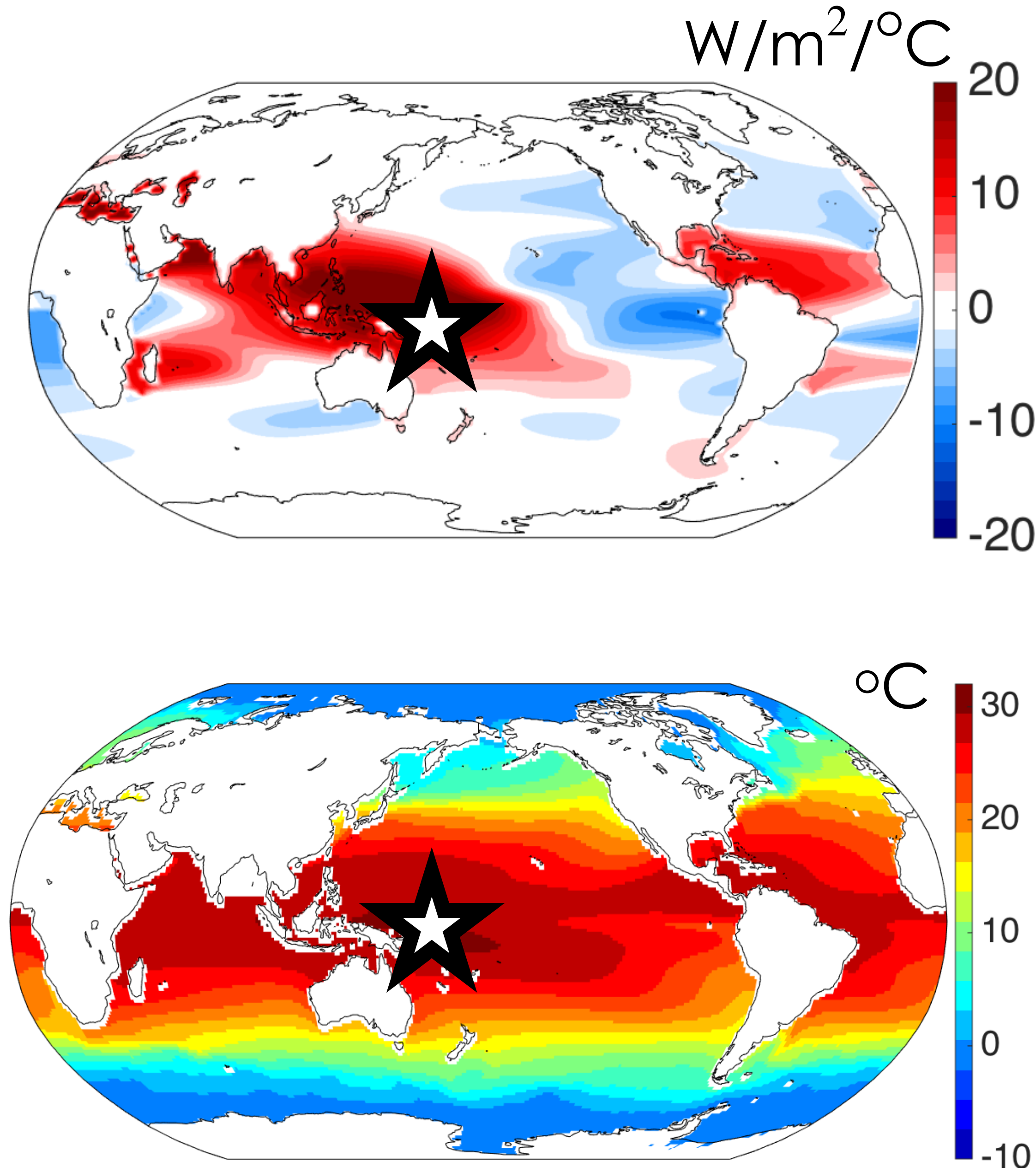



Controlled by East Pacific SST
+EP SST - LCC

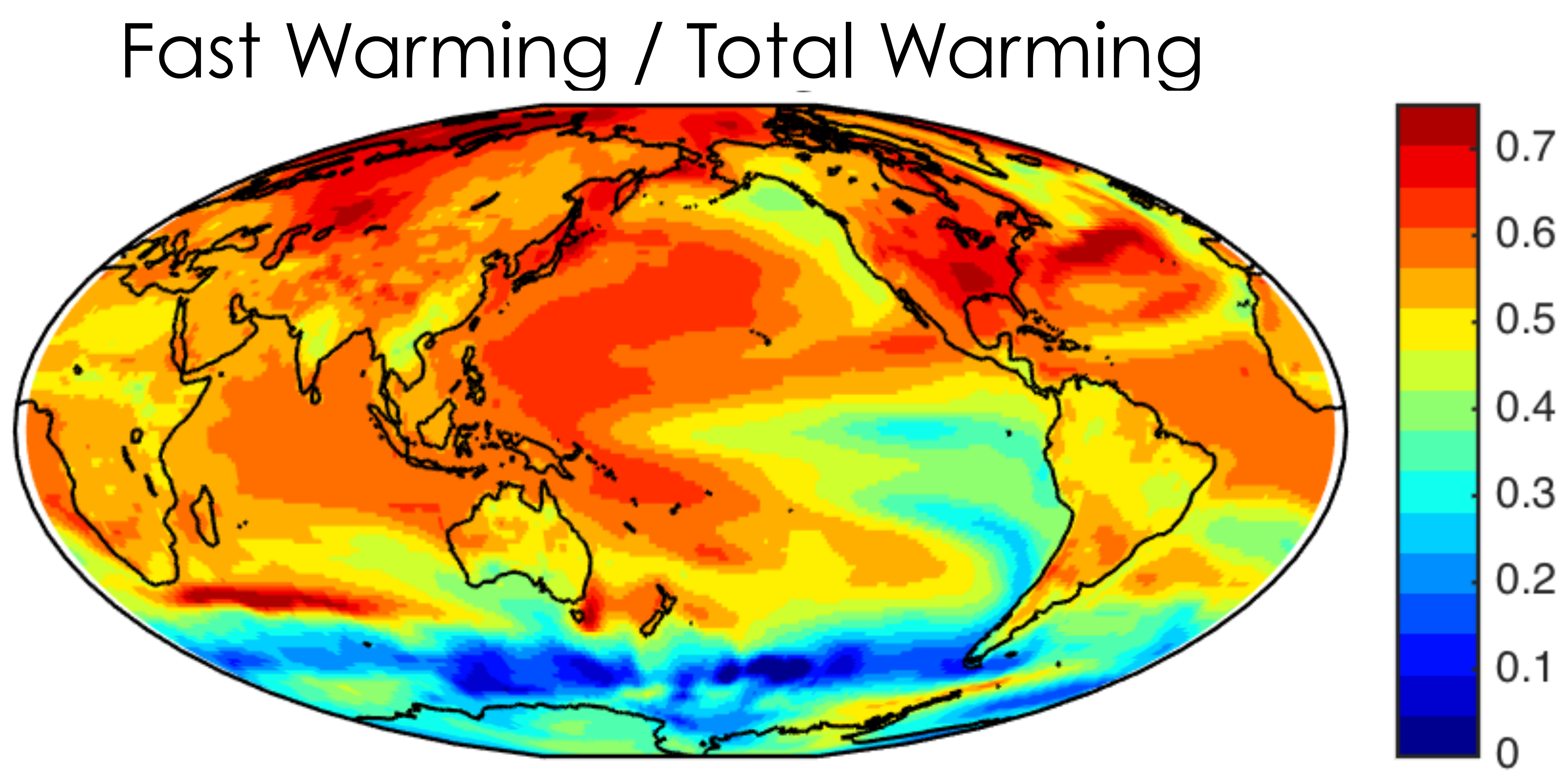


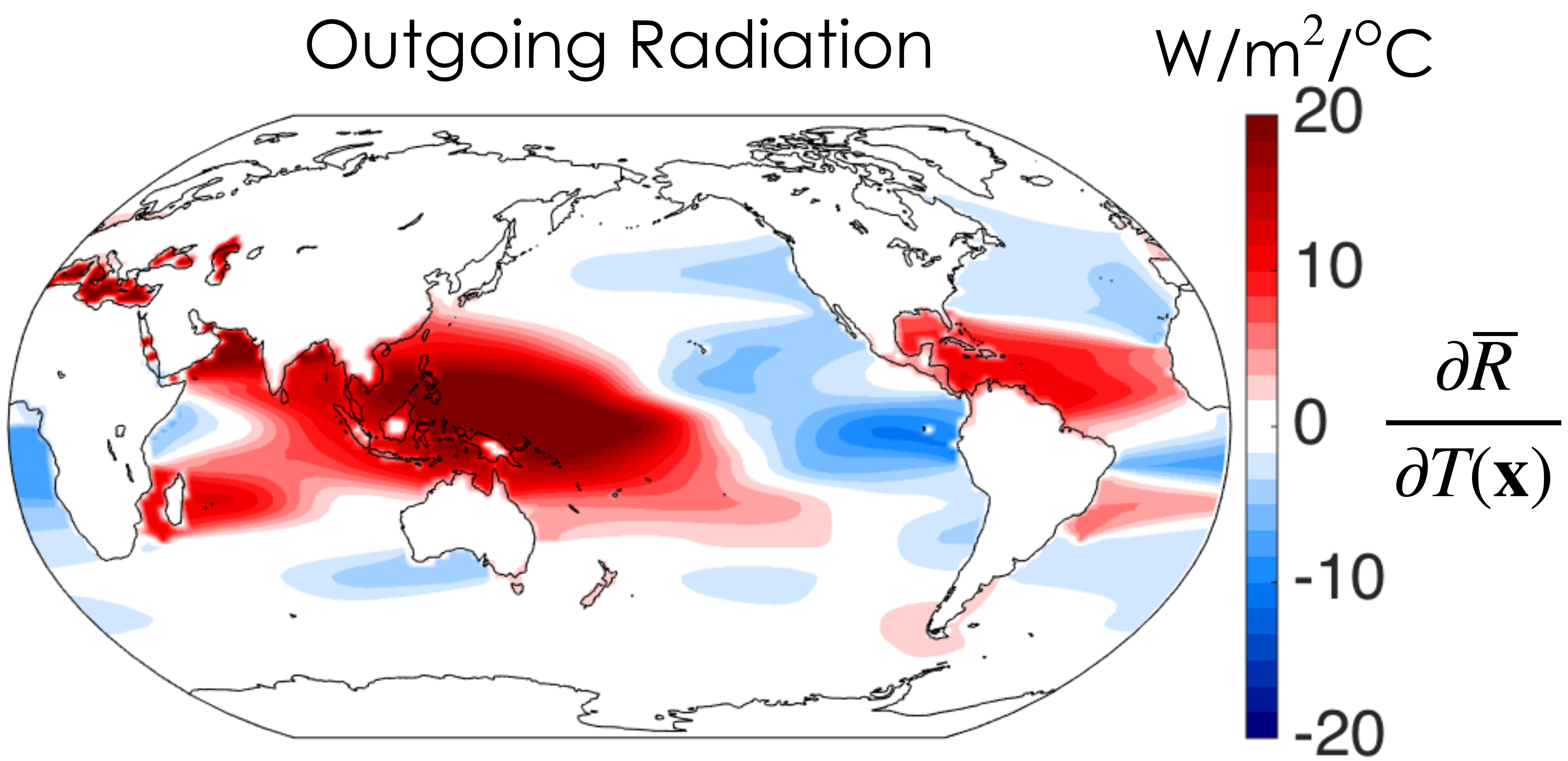




Controlled by West Pacific SST

+WP SST + LCC

# The "Pattern Effect" summary




**Pattern effect:**

- **Fast modes of warming:**
- Land + Mixed Layer
- More West Pacific warming
- More efficient at radiating to space

- **Slow warming:**
- Regions of deep ocean heat uptake + East Pacific
- Less efficient at radiating to space

Proistosescu & Huybers 2017
Dong, Proistosescu, Armour, Battisti, 2019