Convective conversion efficiency – a link between tropical convection and anvil clouds

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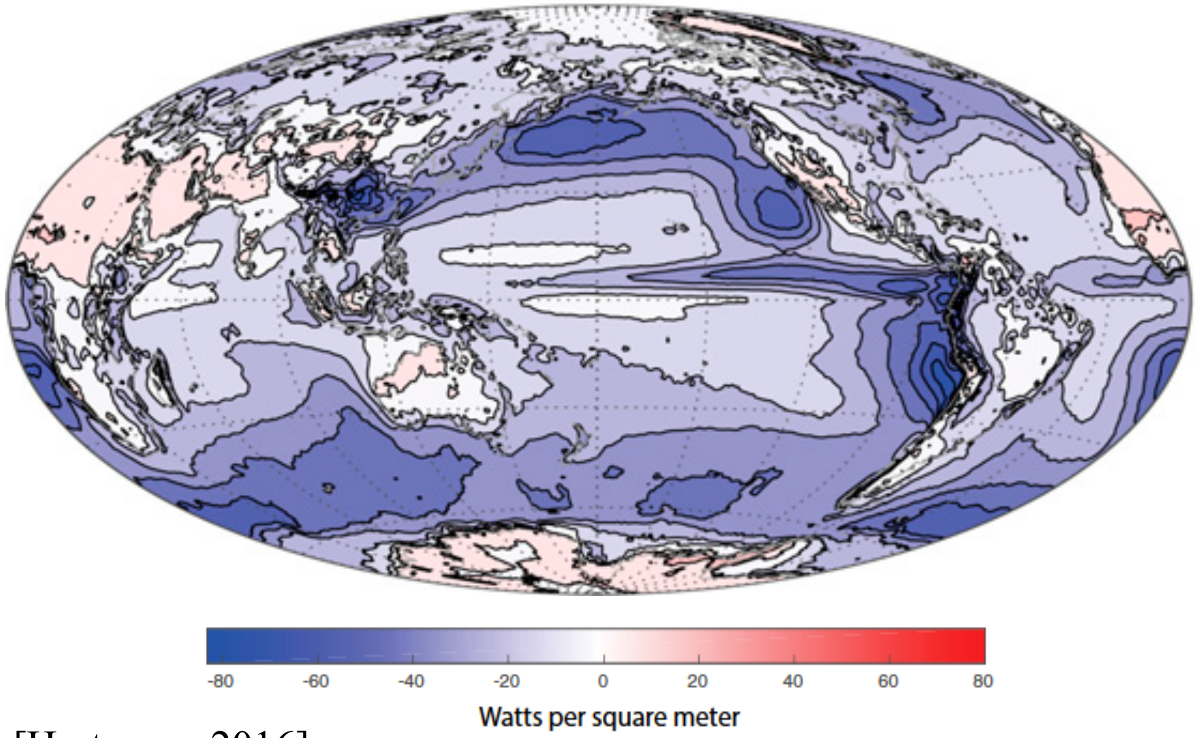
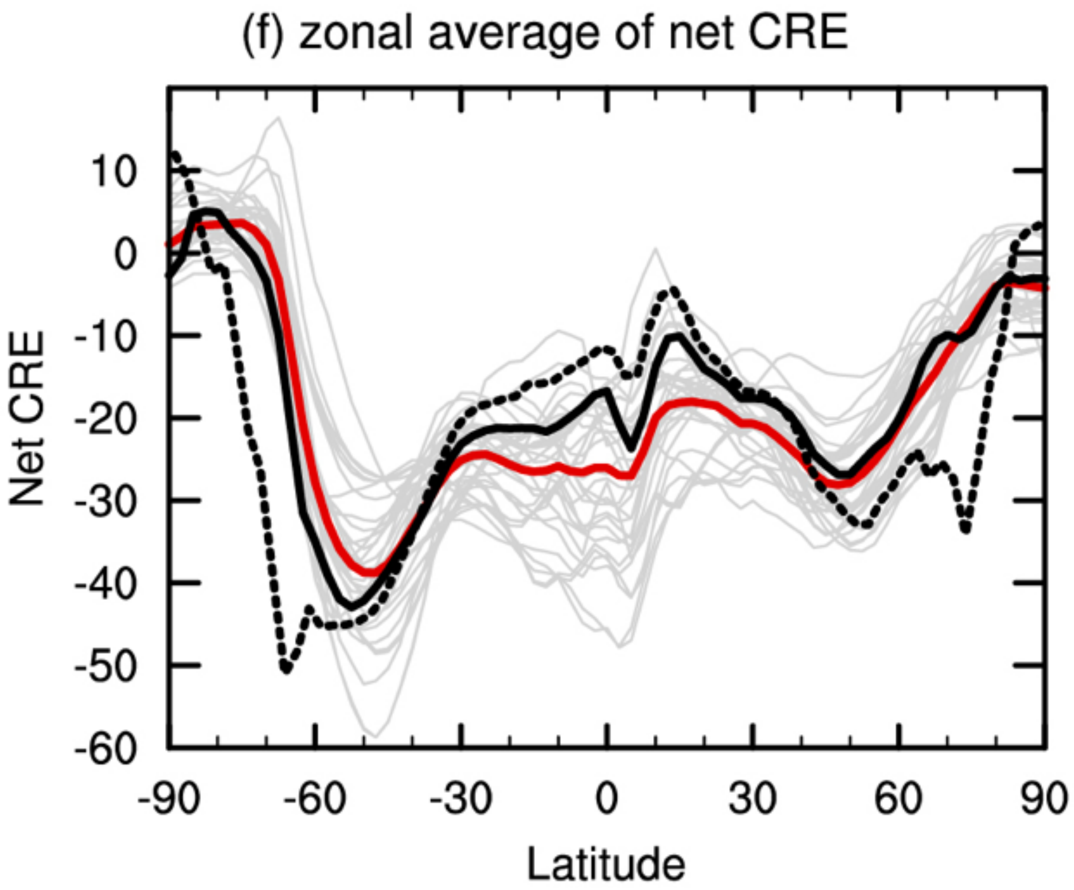
CERES 2000–2013 annual mean net CRE



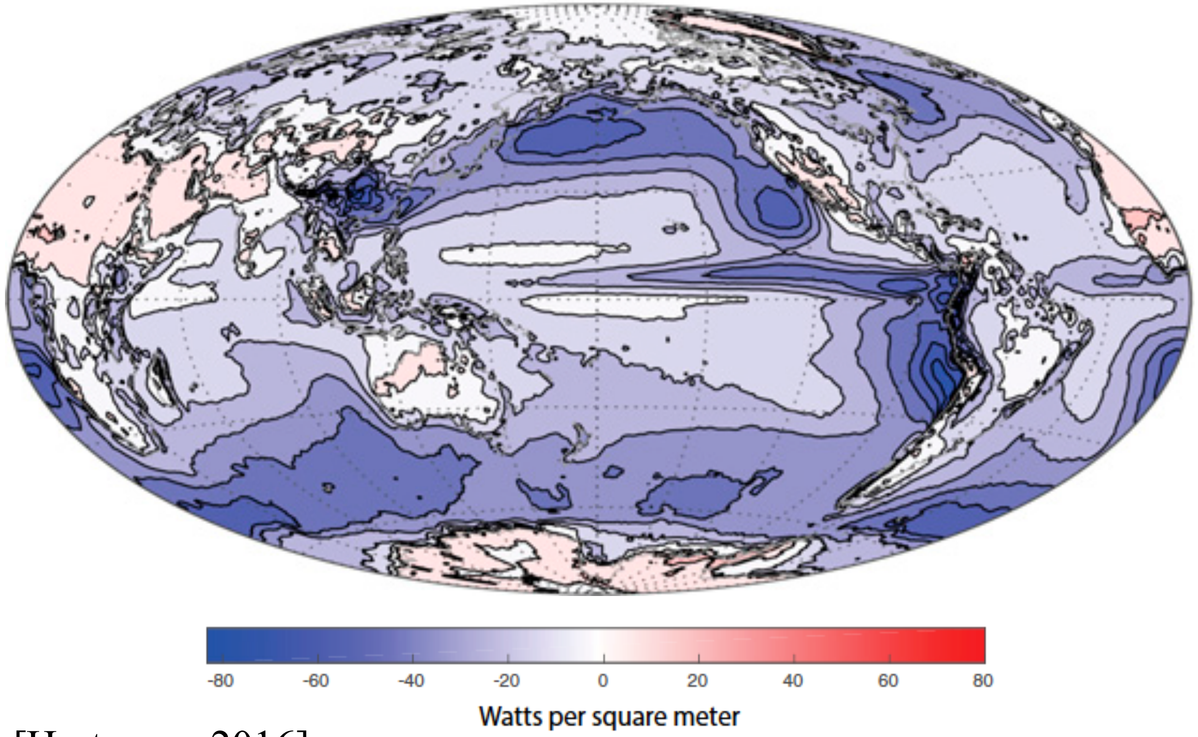
[Hartmann 2016]



Solid black: CERES observations
Grey: CMIP5 models
Red: CMIP5 mean
[IPCC AR5 Ch9]

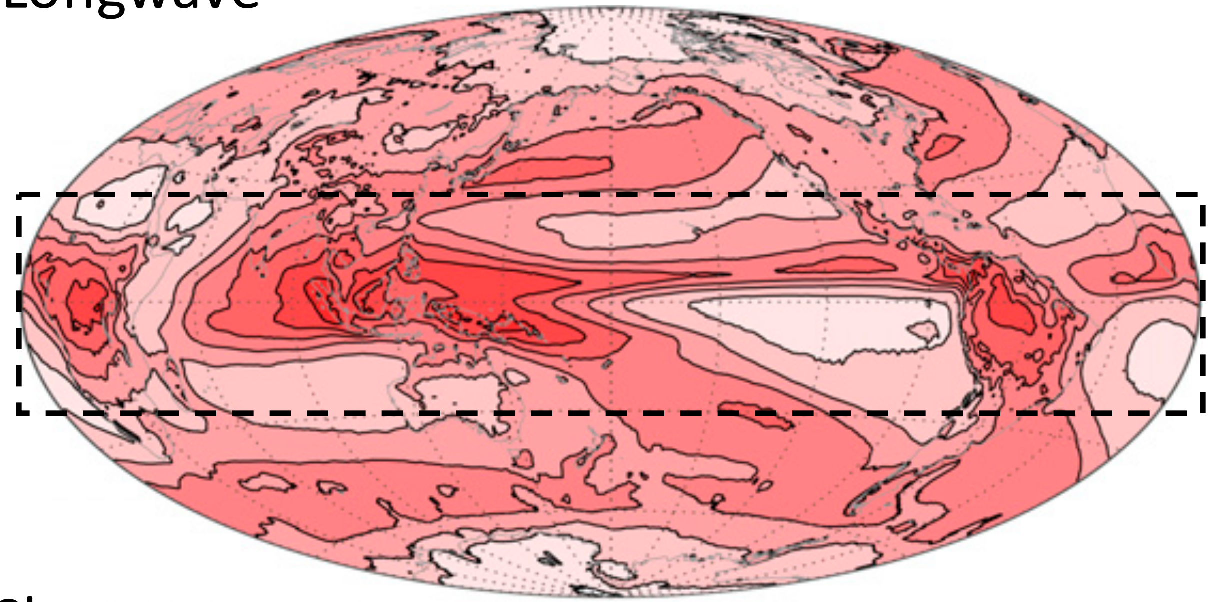
High inter-model spread in
tropical Cloud Radiative Effect

Net CRE

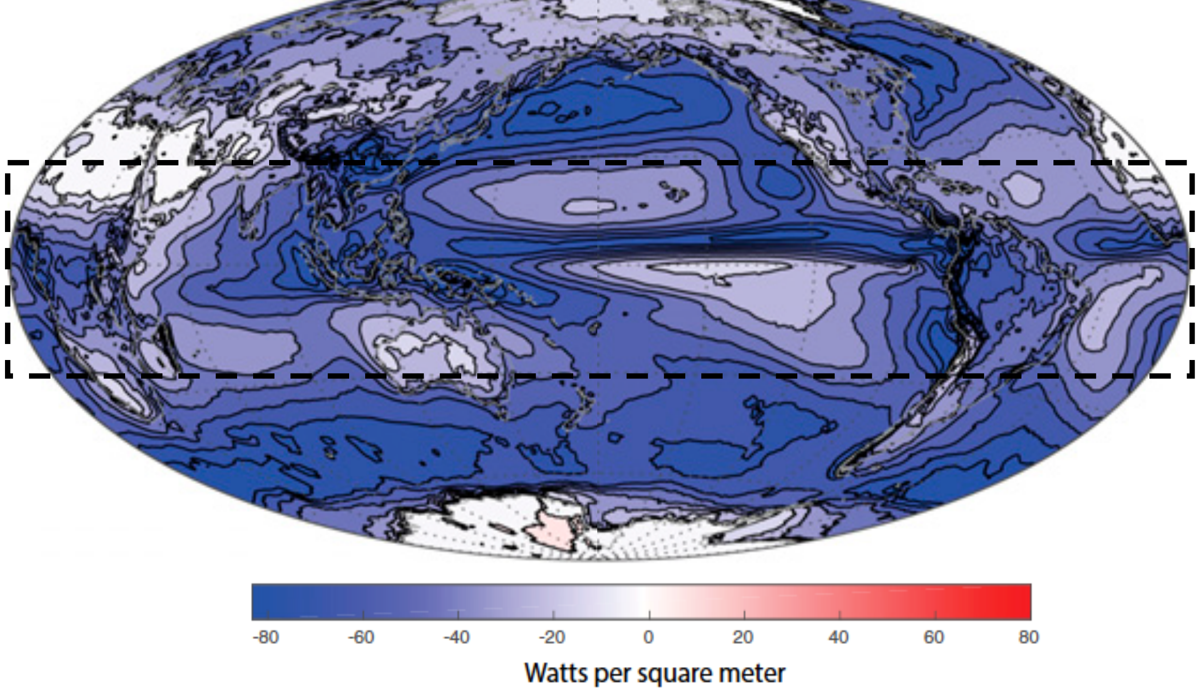


[Hartmann 2016]

Longwave



Shortwave



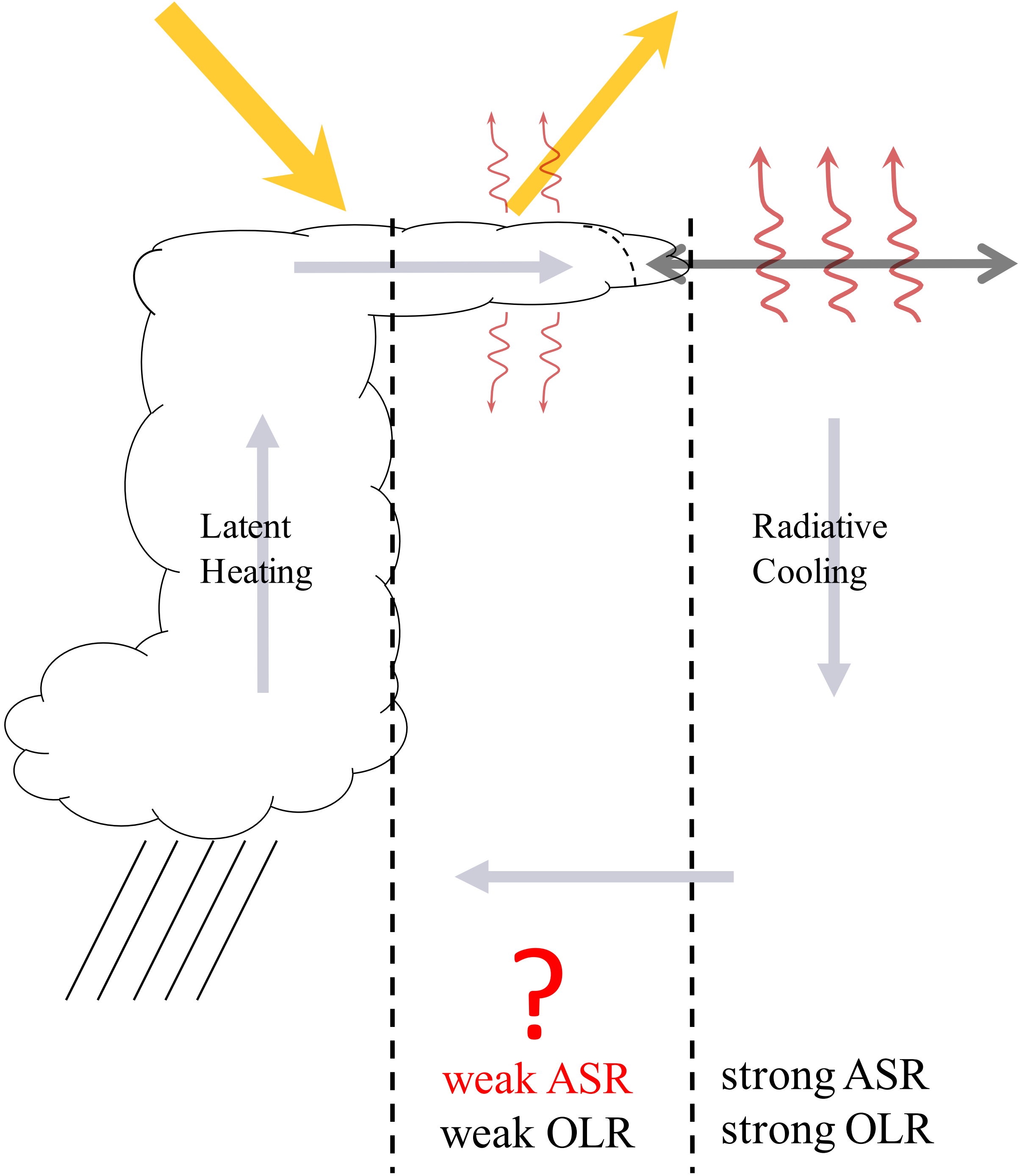
An interesting cancellation of two large terms – coincidence?

Tropical Anvil Clouds

Recent studies have suggested a number of hypotheses for this SW/LW cancellation over the Pacific warm pool (Wall et al. 2018), but "neither the reason why this close balance occurs nor whether this balance will change as the Earth warms or cools is understood" (Hartmann et al. 2018).

Is the cancellation due to the albedo of anvil clouds?

How will the LW/SW cancellation change with warming?



PERSPECTIVE

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nature geoscience

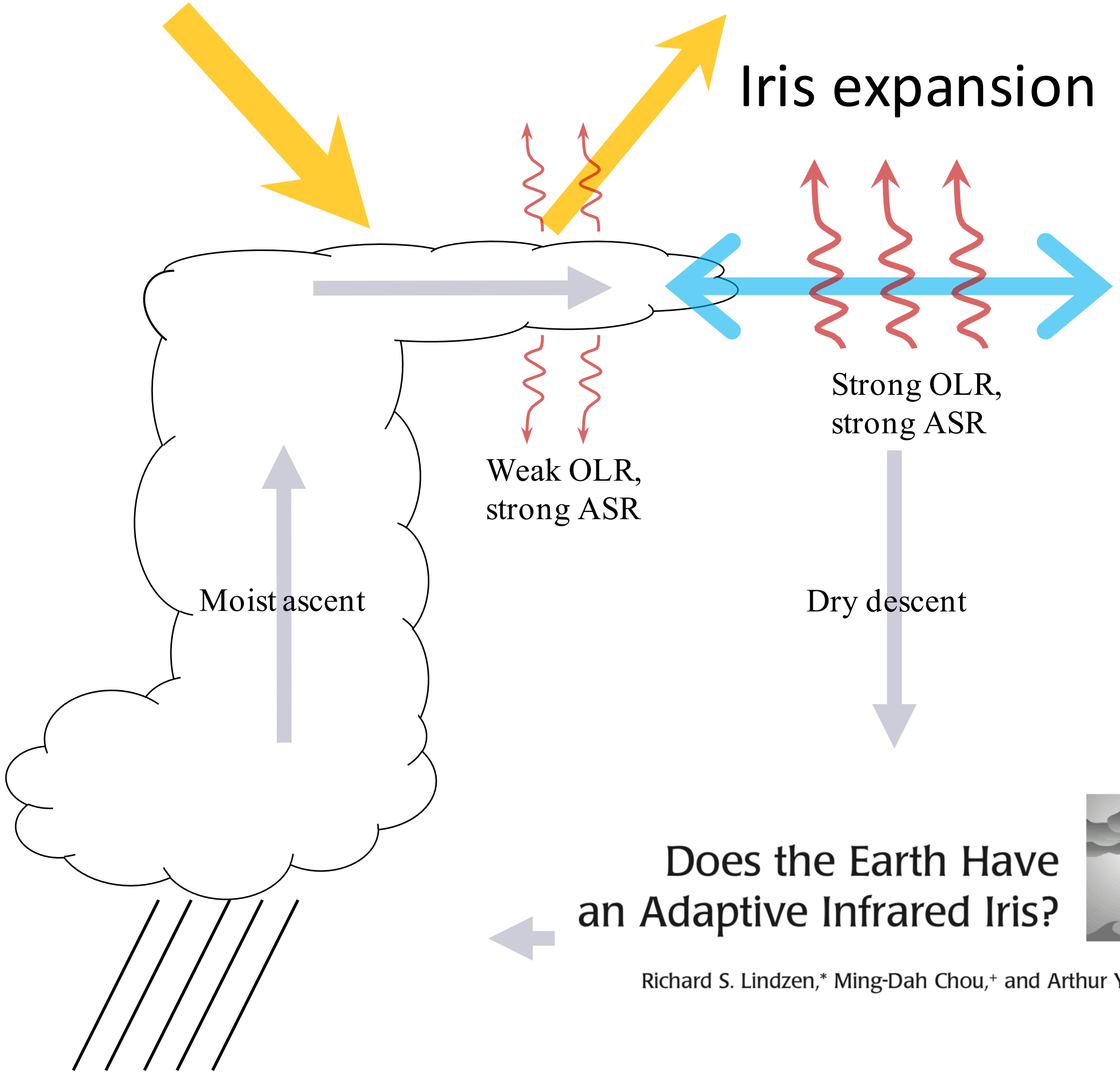
Missing iris effect as a possible cause of muted hydrological change and high climate sensitivity in models

Thorsten Mauritsen* and Bjorn Stevens

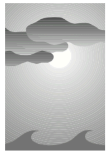
If the degree of convective self-aggregation depends on temperature, one could parameterize its effects by increasing the default GCM convective condensate-rain conversion rate, C_0, with surface temperature (Mauritsen and Stevens 2015):

$$C_p = C_0(1 + I_e)^{\frac{T_s - T_0}{1K}}$$

In aggregated convection, concentrated updrafts may be shielded from dry air entrainment, enhancing precipitation production.



Does the Earth Have an Adaptive Infrared Iris?

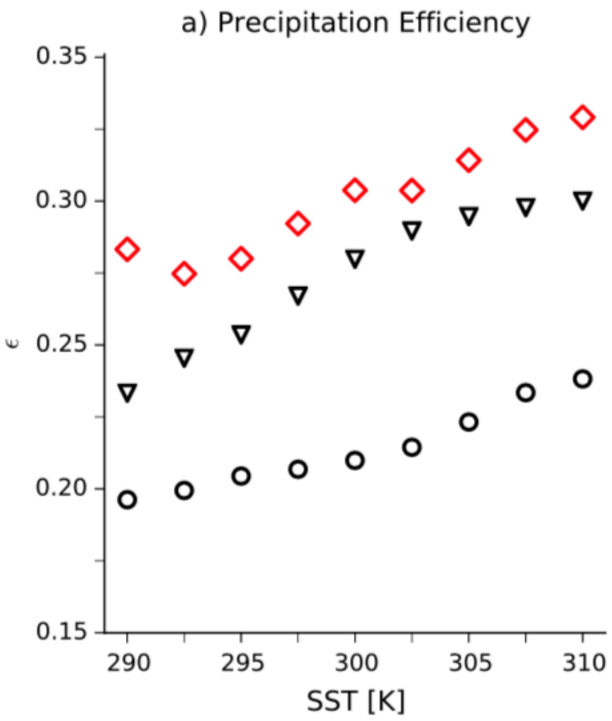


Richard S. Lindzen,* Ming-Dah Chou,+ and Arthur Y. Hou+

With warming, cumulus towers may become more efficient at precipitating, which could lead to less cirrus cloud cover (Lindzen et al. 2001).

Precipitation Efficiency (ε) vs. Conversion Efficiency (C_p)

$$\varepsilon = \frac{P_s}{C}$$



[Lutsko and Cronin 2018]

Mass flux cumulus scheme

Updraft condensate

Source (i.e. large-scale condensation)

$$\frac{d}{dz}(M_u l) = -D_u l + \rho C_u - \rho R_u$$

Detrainment

Precipitation

$$\rho R_u = C_p M_u l$$

[Zhang and McFarlane 1995]

GCM Setup

NCAR CESM 1.2.2 coupled to a thermodynamic slab ocean, scaling the convective conversion efficiency by:

$$C_p(T) = \begin{cases} C_0, & if\ T_s \leq T_0 \\ C_0(1+I_e)^{\frac{T_s - T_0}{1K}}, & if\ T_s > T_0 \end{cases}$$

where $C_0 = 2.0\times10^{-3} m^{-1}$, and choosing $T_0 = 25°C$ confines the changes to within the tropics.

"iris strengths" I_e = 0, 0.2, 0.5, and 1.0, after Mauritsen and Stevens (2015).

Initiated with pre-industrial atmospheric CO_2 and abruptly doubled in warming experiments.

$$\frac{d}{dz}(M_u l) = -Dl + \rho C - \rho R$$

Reduces detrained condensate, if all else equal.

Global and tropical (in brackets) climatology

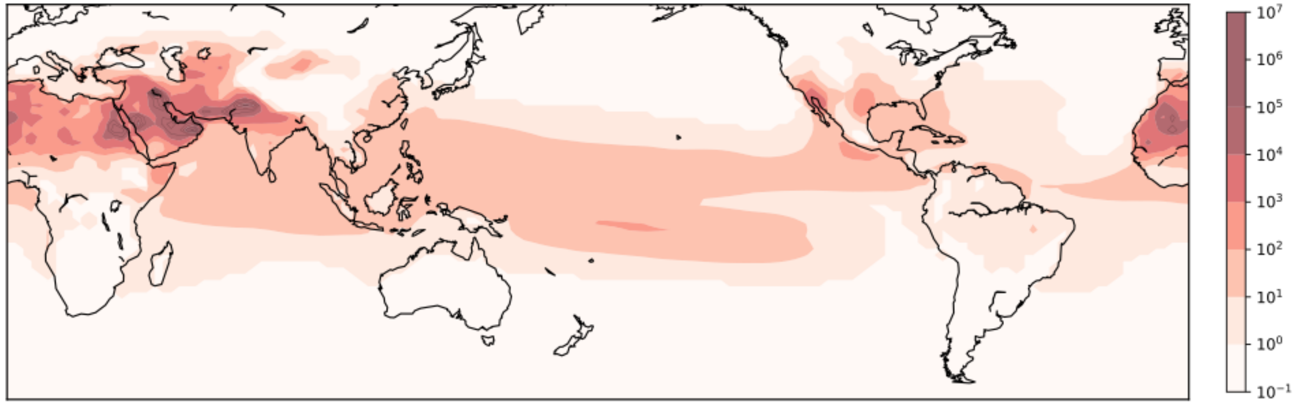
Case	CESM	IRIS2	IRIS5	IRIS10
I_e	0	0.2	0.5	1.0
Surface Precipitation [mm/day]	3.1 (3.8)	3.2 (3.9)	3.2 (4.0)	3.3 (4.0)
Total cloud cover [%]	62.6 (56.5)	62.4 (56.3)	62.3 (56.1)	62.0 (55.7)
Cloud LWP [g/m^2]	40.6 (44.0)	38.6 (39.7)	37.2 (36.3)	36.0 (33.2)
Cloud IWP [g/m^2]	16.3 (15.5)	15.2 (13.5)	14.2 (11.8)	13.1 (10.2)

[Li et al. 2019, under revision]

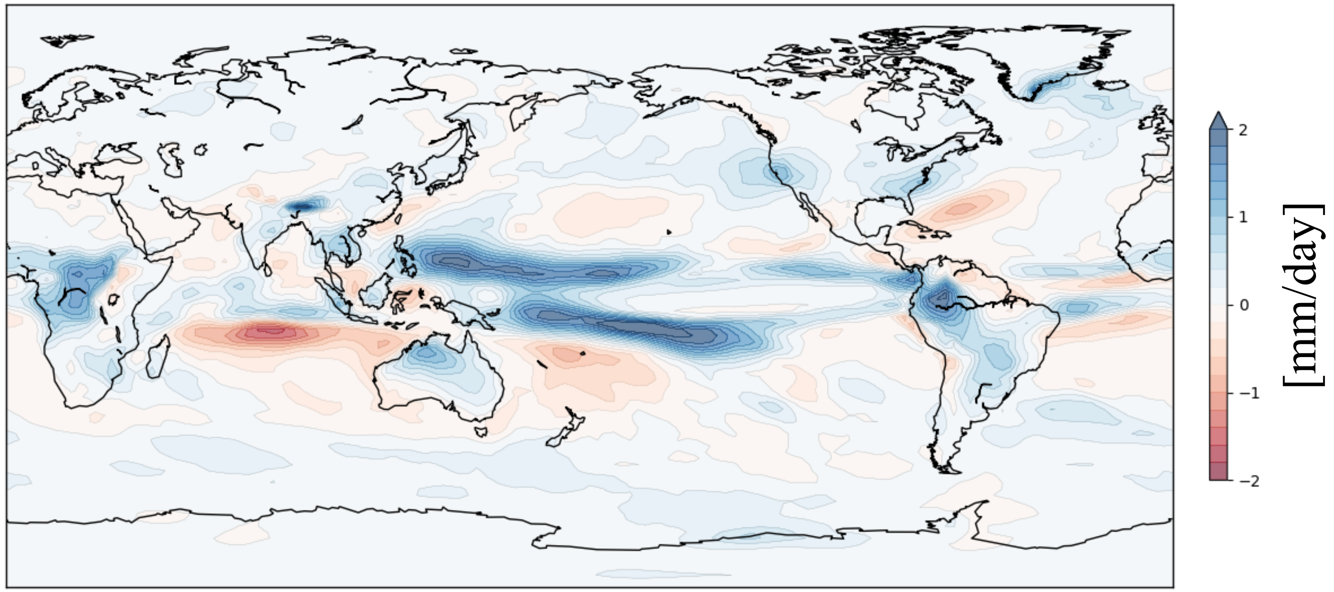
$$C_p(T) = \begin{cases} C_0, & if\ T_s \le T_0 \\ C_0(1+I_e)^{\frac{T_s - T_0}{1K}}, & if\ T_s > T_0 \end{cases}$$

Largest I_e change (doubling of the conversion efficiency per 1 degree) leads to a ~65 mm increase in annual precipitation (~3%) over the entire tropics.

$$(1+1.0)^{\frac{T_s - T_0}{1K}}$$

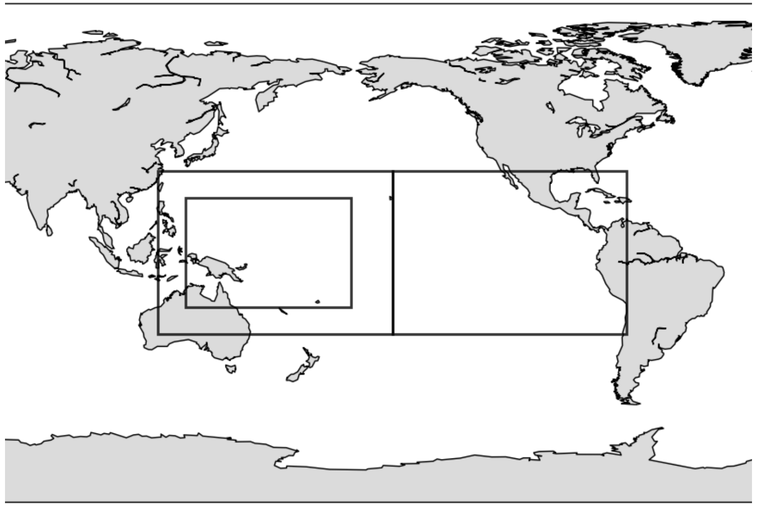


Precipitation: IRIS10 – CESM



[Li et al. 2019, under revision]

CRE over Tropical Oceans

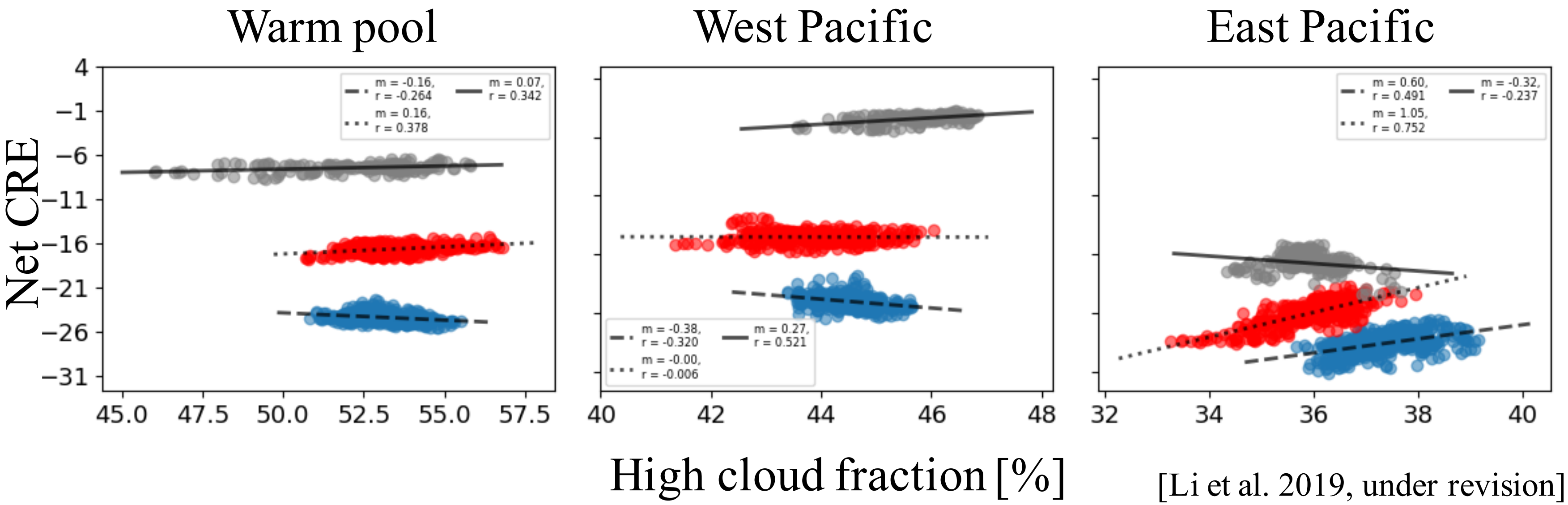


Grey: CERES observations
Blue: CESM
Red: IRIS10

Net CRE is well correlated with high cloud fraction.

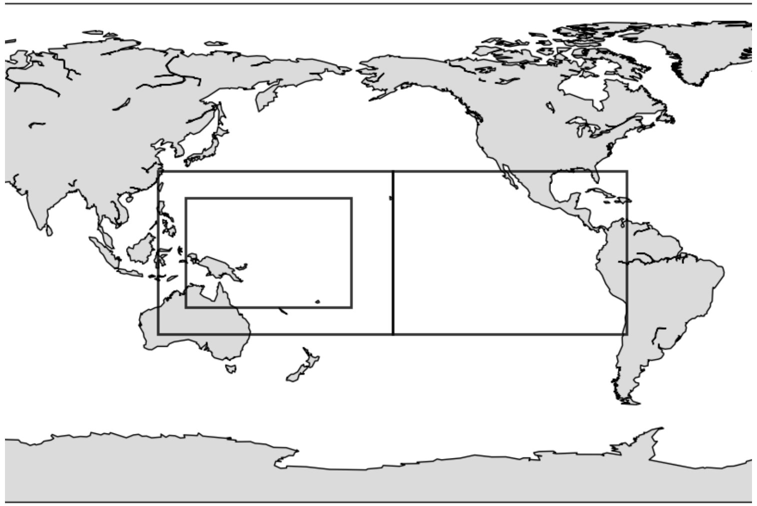
While there are biases in the magnitude, the model represents the observed slope well.

Suggests that the cloud feedback associated with reducing anvil cloud fraction is small.



[Li et al. 2019, under revision]

CRE over Tropical Oceans



Grey: CERES observations
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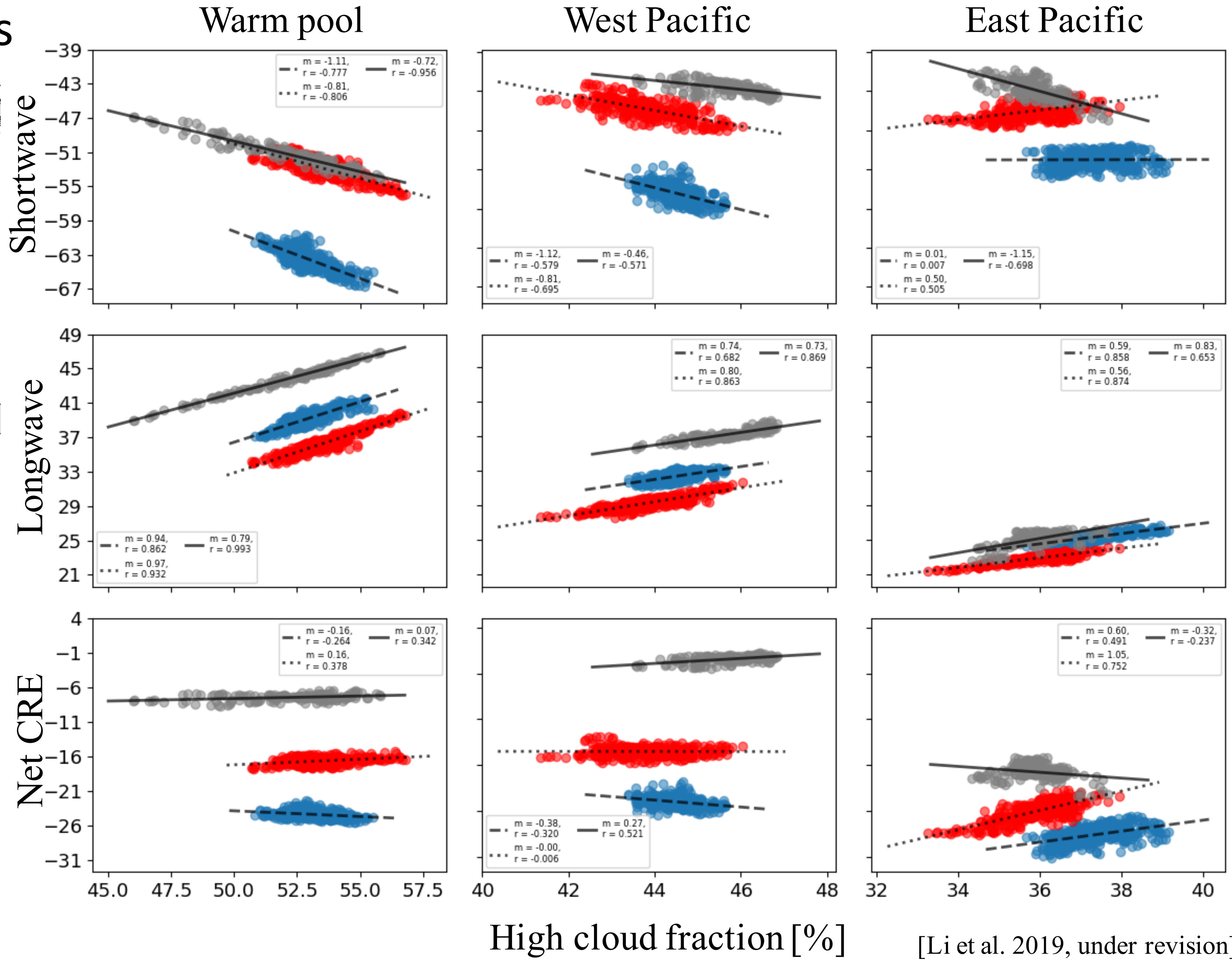
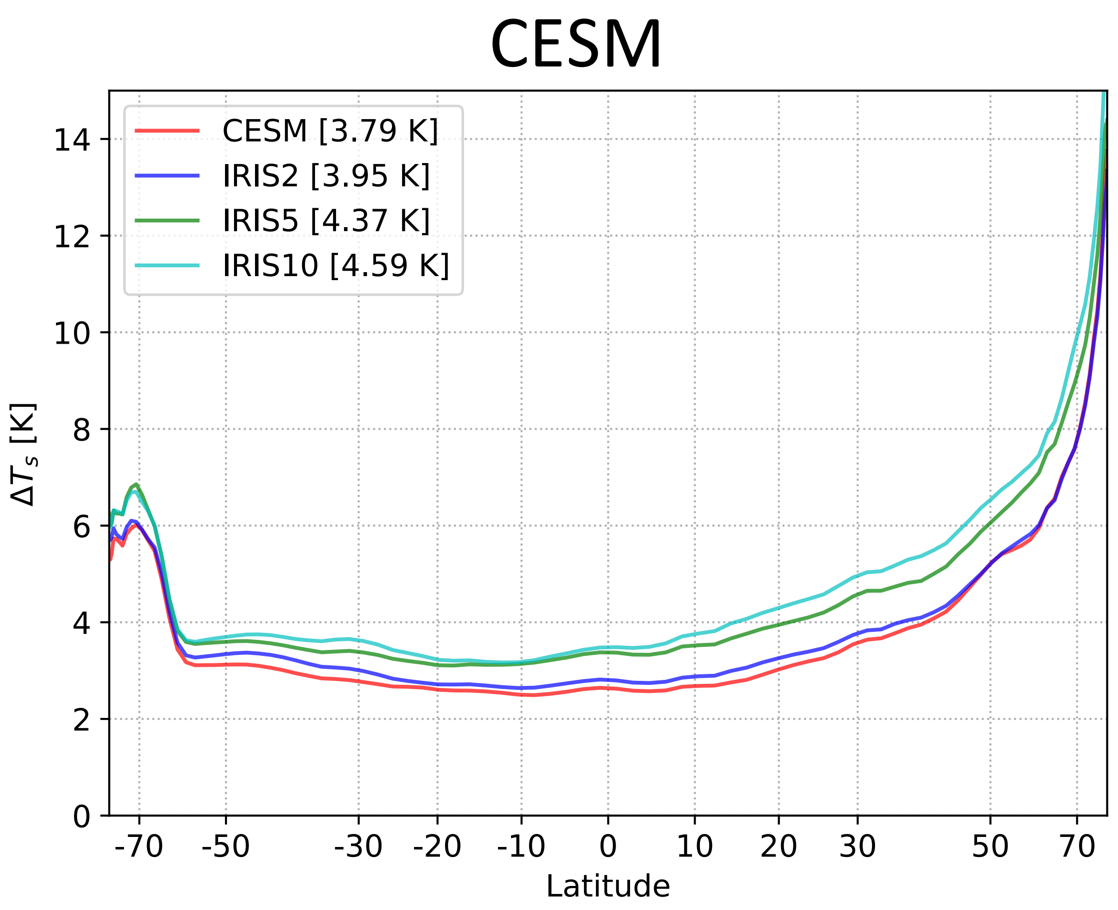
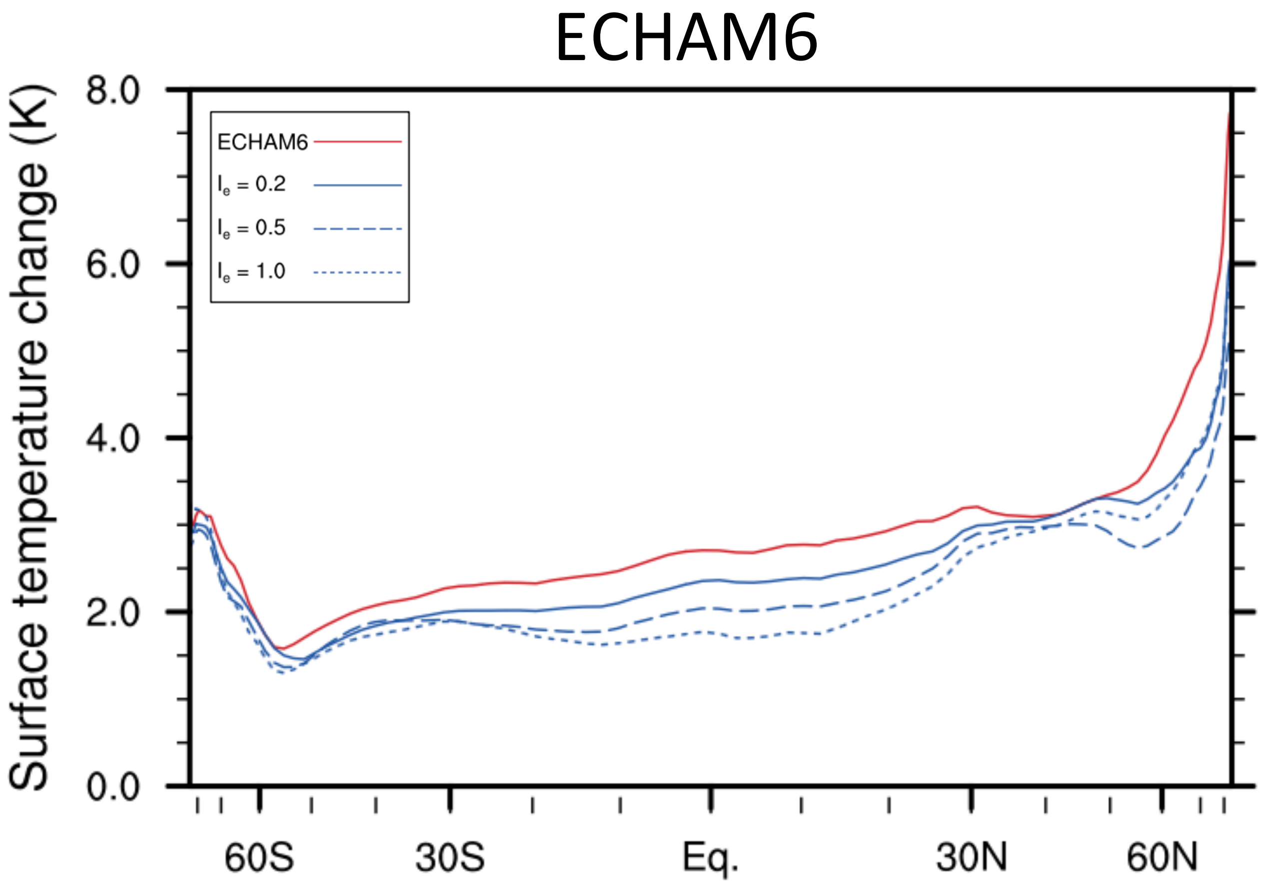
SW/LW cancellation is likely due to anvil clouds, which are strongly correlated with both SW and LW CRE.



[Li et al. 2019, under revision]

Equilibrium Climate Sensitivity

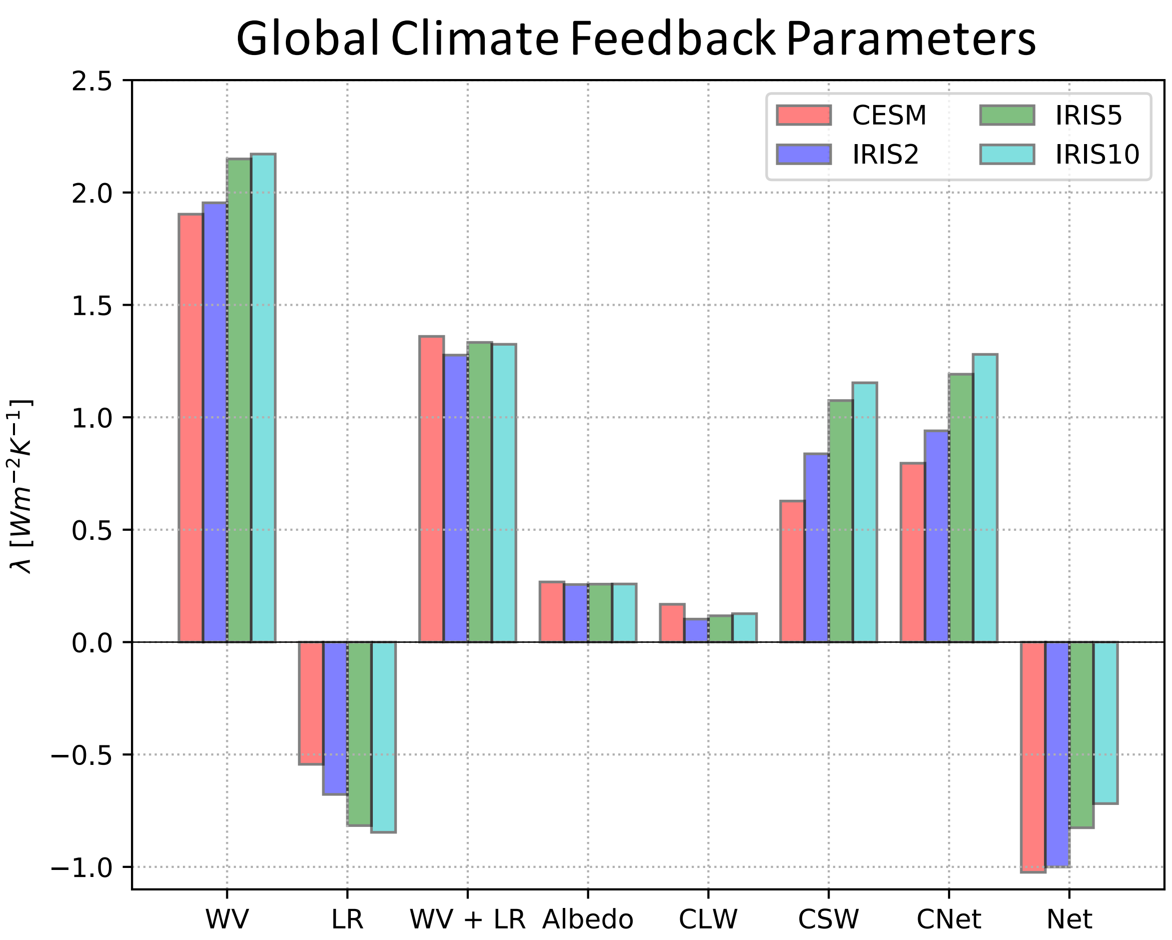


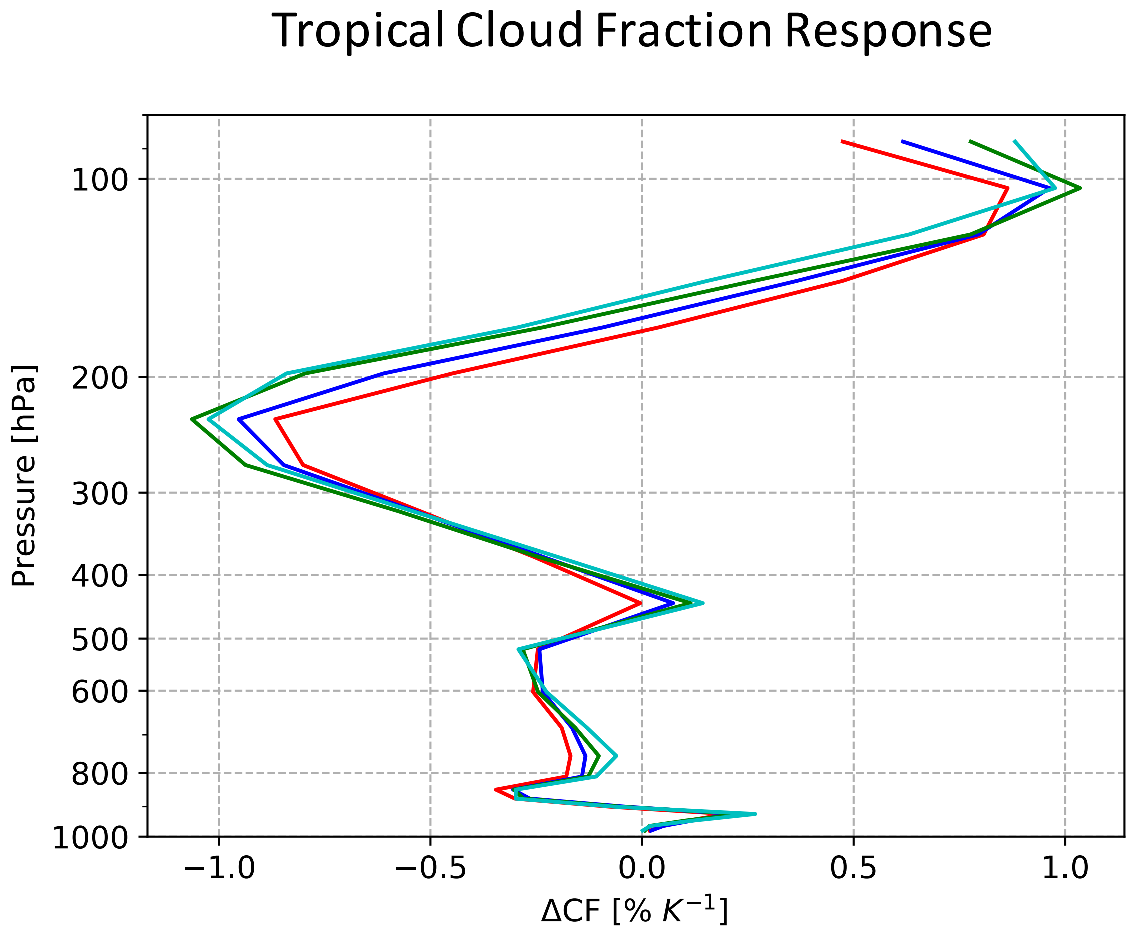


[Mauritsen and Stevens 2015]

Same forcing, opposite response

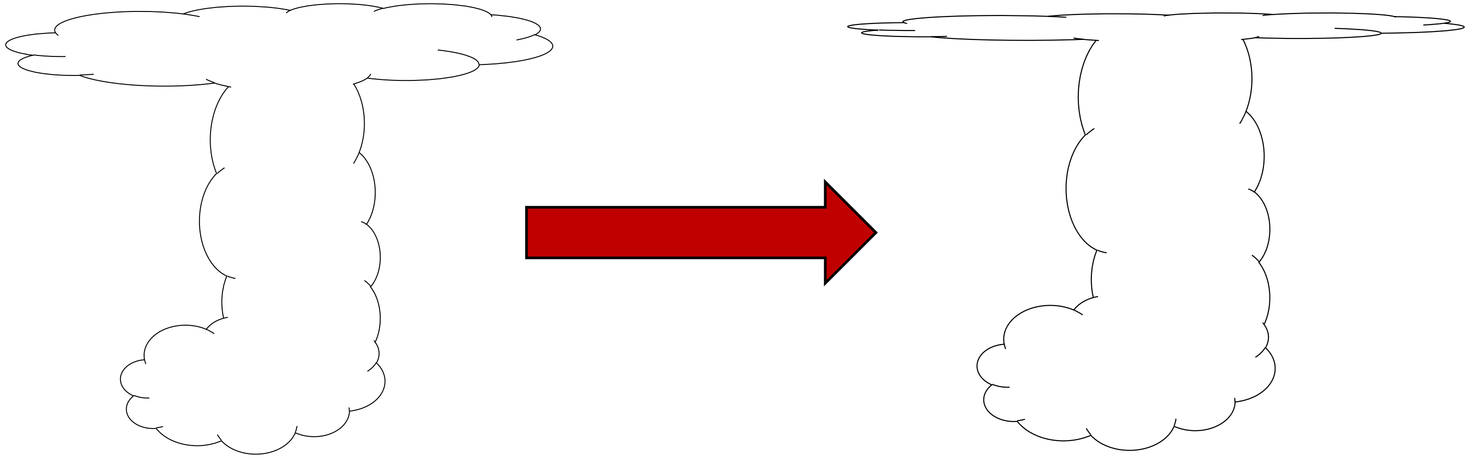
Equilibrium response to abrupt 2xCO_2



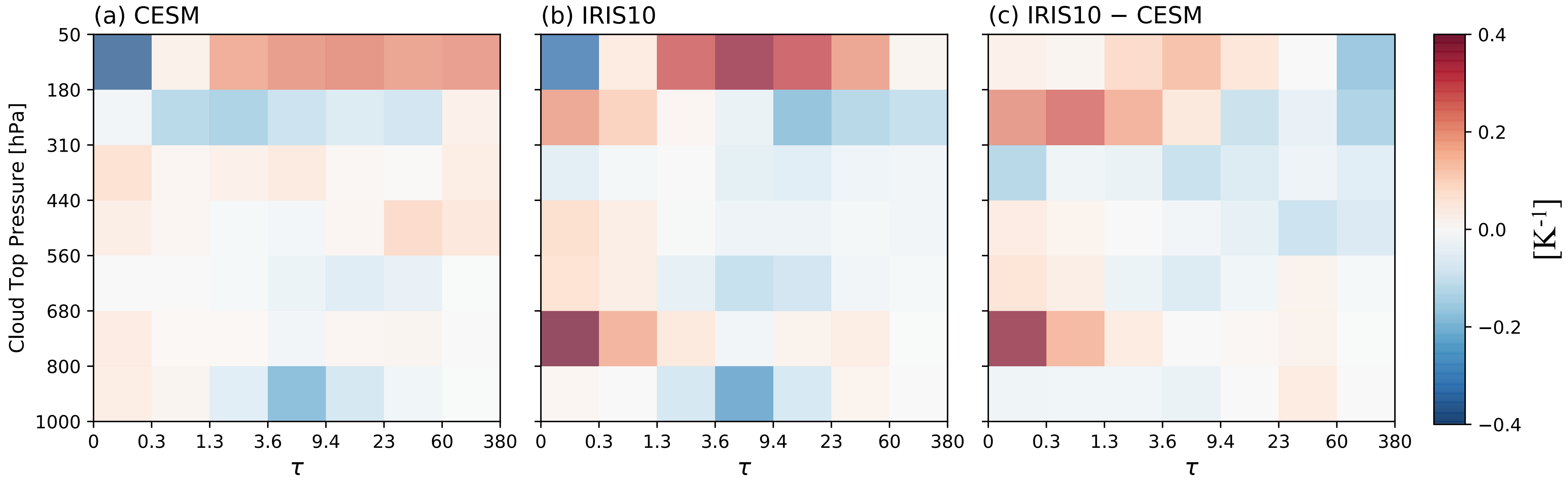


[Li et al. 2019, under revision]

Anvil Thinning



Cloud fraction responses viewed through the satellite simulator



[Li et al. 2019, under revision]

Summary

Two extreme cases that could result from C_p increasing with temperature: (i) a reduction of cloud fraction, (ii) anvil thinning (reduced cloud optical depth), or a combination of both.

1. In CESM, changes in optical depth dominates (ii), leading to a positive cloud feedback and higher climate sensitivity.
2. If (i) dominates, an iris effect (LW cloud amount feedback) would be weak, due to the observed longwave & shortwave cancellation for high clouds.

The same parameterization in two different models gives a response of the opposite sign – requires a better understanding of the range of C_p, as well as how it interacts with tropical anvil cloud cover and albedo, in which the delicate balance of cloud radiative effects depend critically on.