"Iris Effect" in Observations and Models

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Congratulations to Bill!

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Three-Dimensional Week-Long Simulations of TOGA COARE Convective Systems Using the MM5 Mesoscale Model

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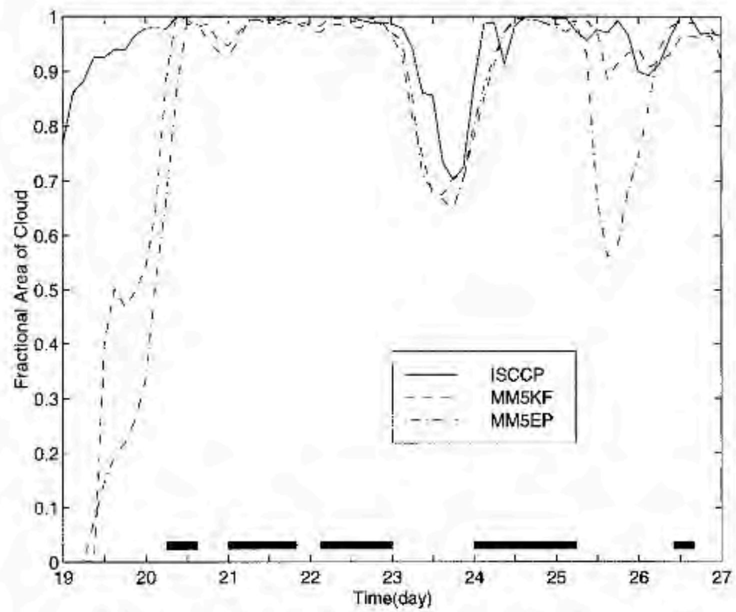
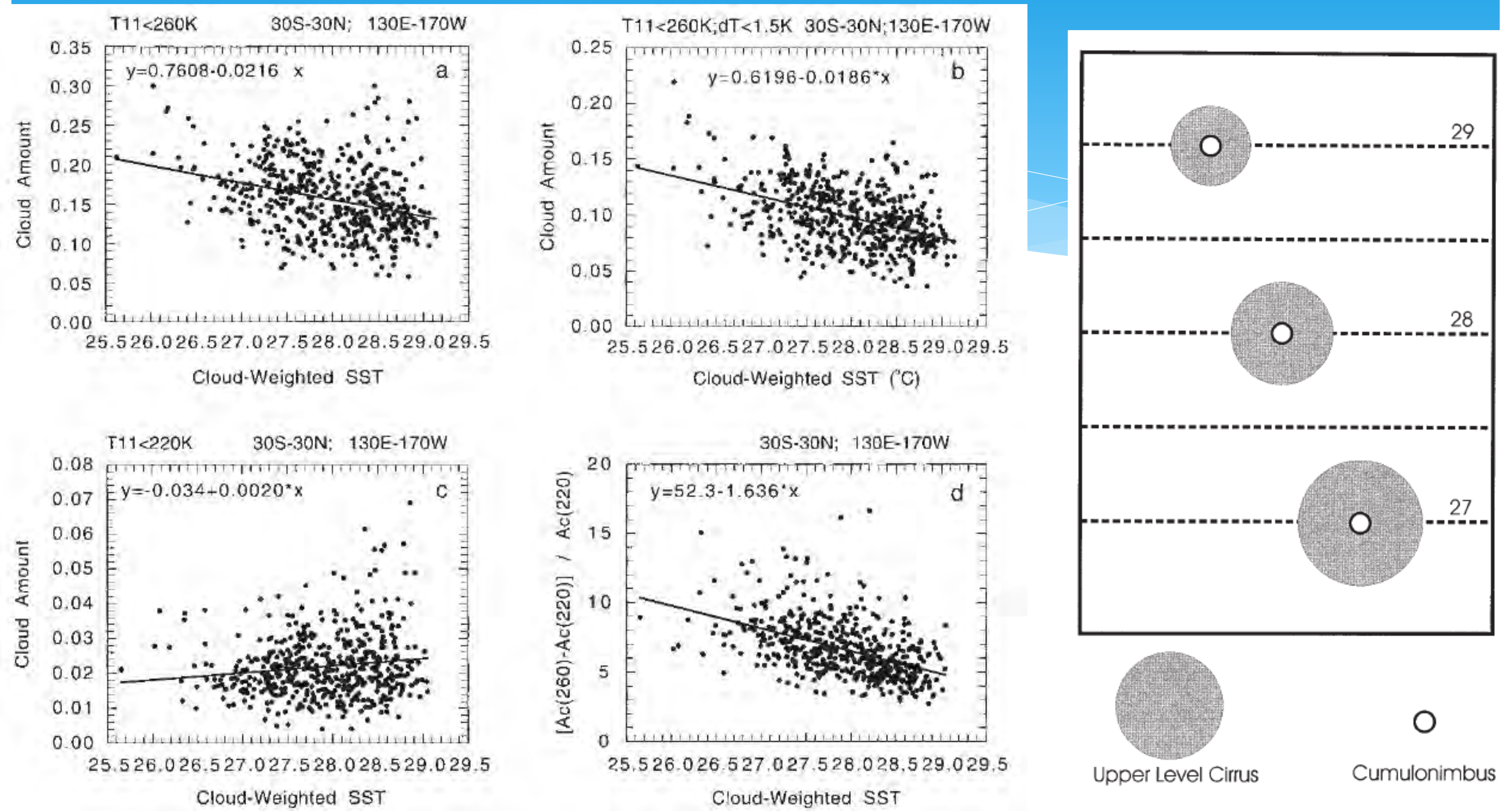


FIG. 8. Time series of fractional coverage of cloud over IFA for ISCCP data and two model simulations.

The Iris Hypothesis (2001)

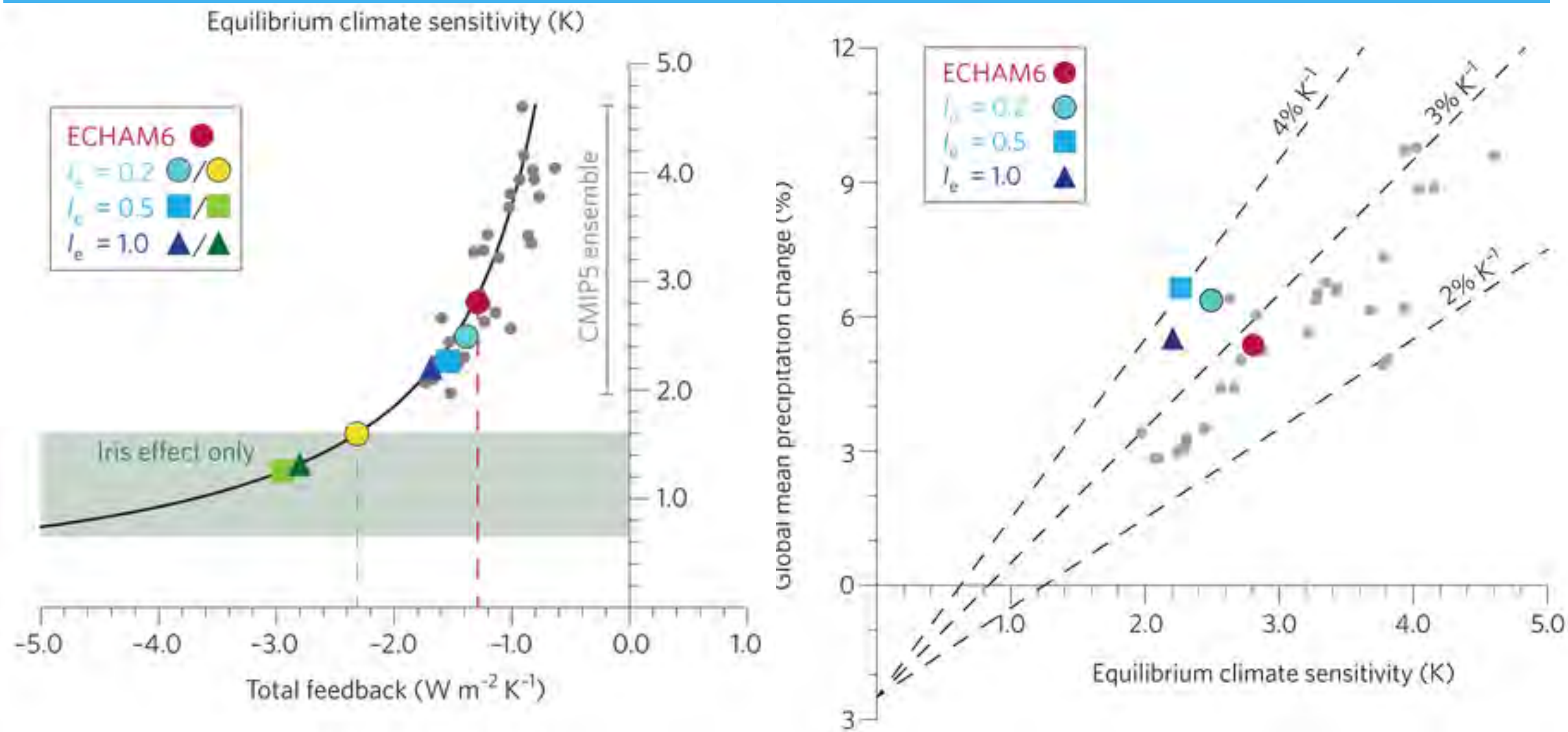


Lindzen et al. (2001, BAMS) suggested that cirrus cloud coverage normalized by a measure of cumulus coverage decreases about 22% per degree increase of SST, providing a negative feedback.

Counter Arguments Against the "Iris Effect"

- Hartmann and Michelsen (2002): meteorological forcing from mid-latitude
- Fu et al. (2002): Lindzen et al. (2001) overestimated the negative feedback
- Del Genio and Kovari (2002): precipitation efficiency and cirrus detrainment efficiency both increase with SST, with the former increasing faster
- Lin et al. (2002): Decreases in anvil clouds would cause a weak but significant positive feedback to the climate system, instead of providing a strong negative feedback.
- Lin et al. (2006): the area coverage of tropical deep convective systems increases with SST along with their precipitation efficiency
- Rapp et al. (2005): the ratio of deep convective cloud area to surface rainfall and found the ratio has no significant dependence on underlying SST
- Su et al. (2008): both tropical-mean UT cloud fraction and IWC are found to increase with CWT. An increase of IWP with SST yields an increase of net warming that corresponds to a positive feedback

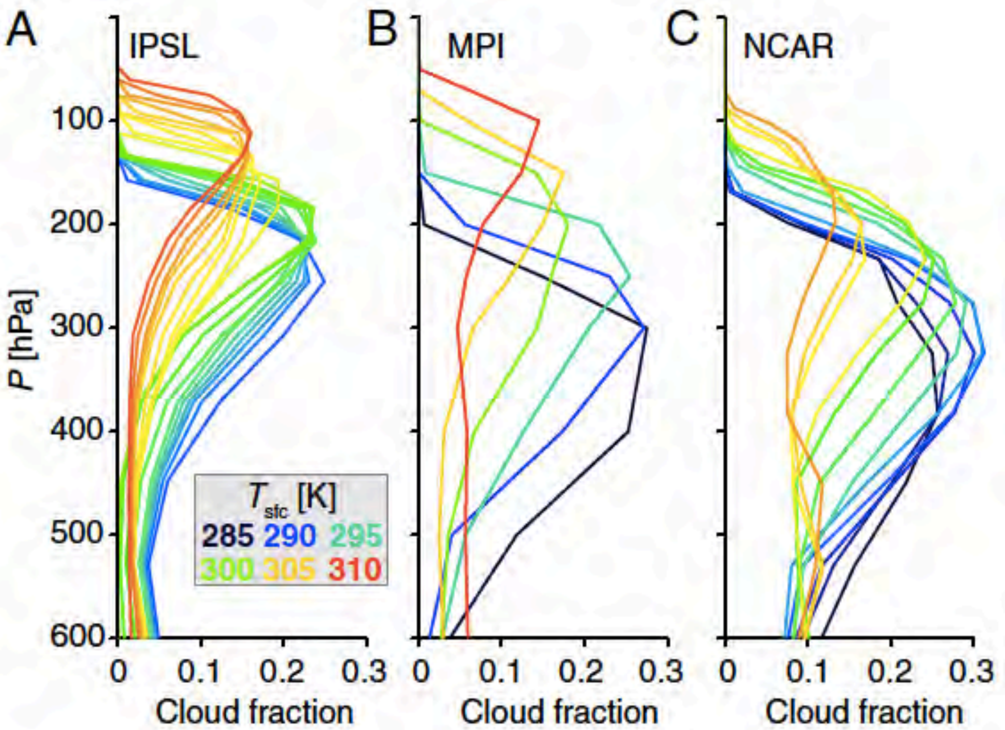
Revisit of the "Iris Effect"

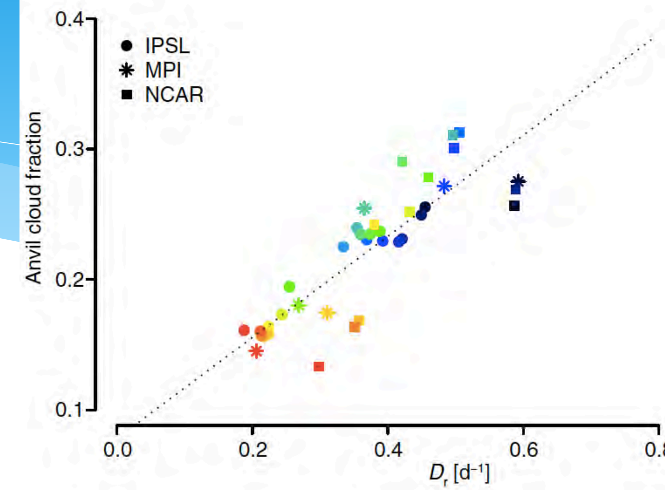


Mauritsen and Stevens (2015, *Nature Geosci.*)

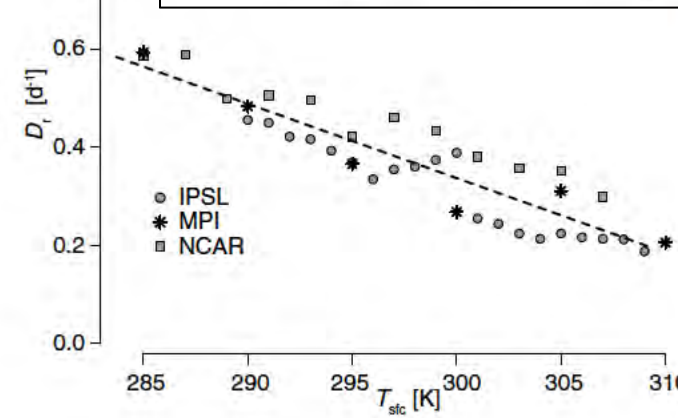
- Amplified "iris effect" lowering climate sensitivity and increasing hydrological sensitivity
- Convective aggregation may be a plausible mechanism for the "iris effect"

Thermodynamic Control of the "Iris Effect"





$$D_r = \frac{\partial \omega}{\partial P} \quad \text{with} \quad \omega = -\frac{Q_r}{S}.$$

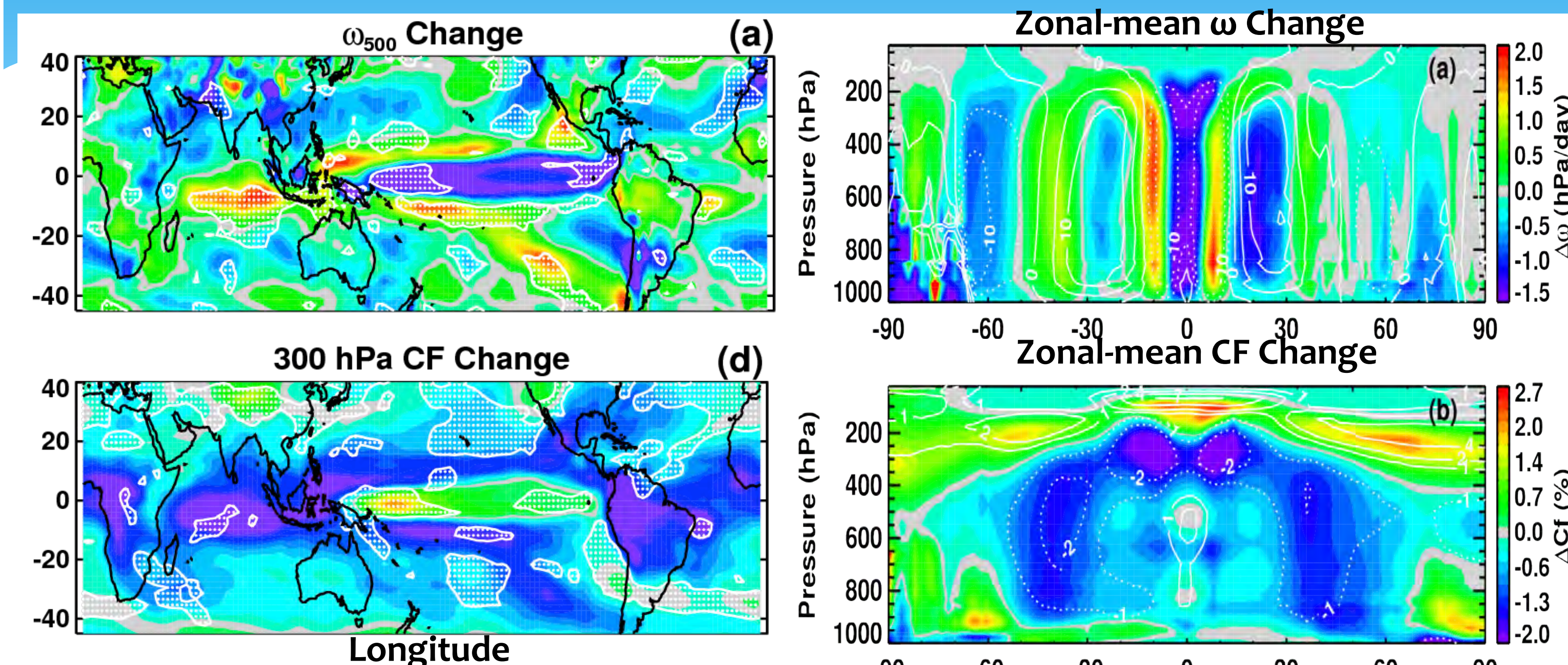


Bony et al. (2016, PNAS)

- Increased static stability with surface warming leads to reduced anvil cloud amount

The Role of Circulation in High Cloud Amount Change

Δ = 2074-2098 in “RCP4.5” – 1980-2004 in “historical run”



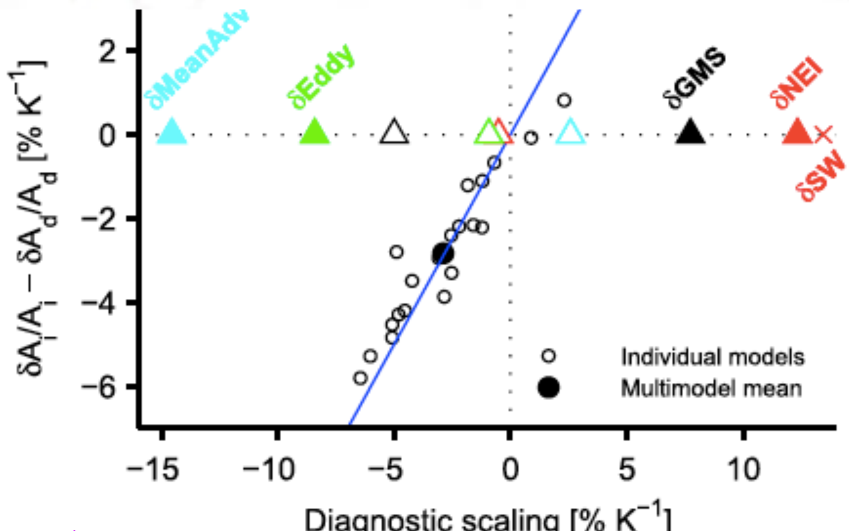
Su et al. (2014, JGR)

- Decrease of tropical high cloud amount is associated with the narrowing of the intro-tropical convergence zone (ITCZ), i.e., and the tightening of the ascending branch of the Hadley Circulation

Mechanisms for the Tightening of Hadley Circulation

$$\frac{\delta A_i}{A_i}-\frac{\delta A_d}{A_d}=\underbrace{\frac{\delta(\Delta h_i)}{\Delta h_i}-\frac{\delta(\Delta h_d)}{\Delta h_d}}_{\delta\text{GMS}}+\underbrace{\frac{1}{H_i}\left[\delta\langle\overline{S}-\overline{L}-\overline{O}\rangle_d\frac{H_i}{H_d}-\delta\langle\overline{S}-\overline{L}-\overline{O}\rangle_i\right]}_{\delta\text{NEI}}$$

$$\underbrace{-\frac{1}{H_i}\left[\delta\langle\{\overline{v}\cdot\nabla\overline{h}\}\rangle_d\frac{H_i}{H_d}-\delta\langle\{\overline{v}\cdot\nabla\overline{h}\}\rangle_i\right]}_{\delta\text{MeanAdv}}\underbrace{-\frac{1}{H_i}\left[\delta\langle\{\nabla\cdot\overline{v'h'}\}\rangle_d\frac{H_i}{H_d}-\delta\langle\{\nabla\cdot\overline{v'h'}\}\rangle_i\right]}_{\delta\text{Eddy}}$$

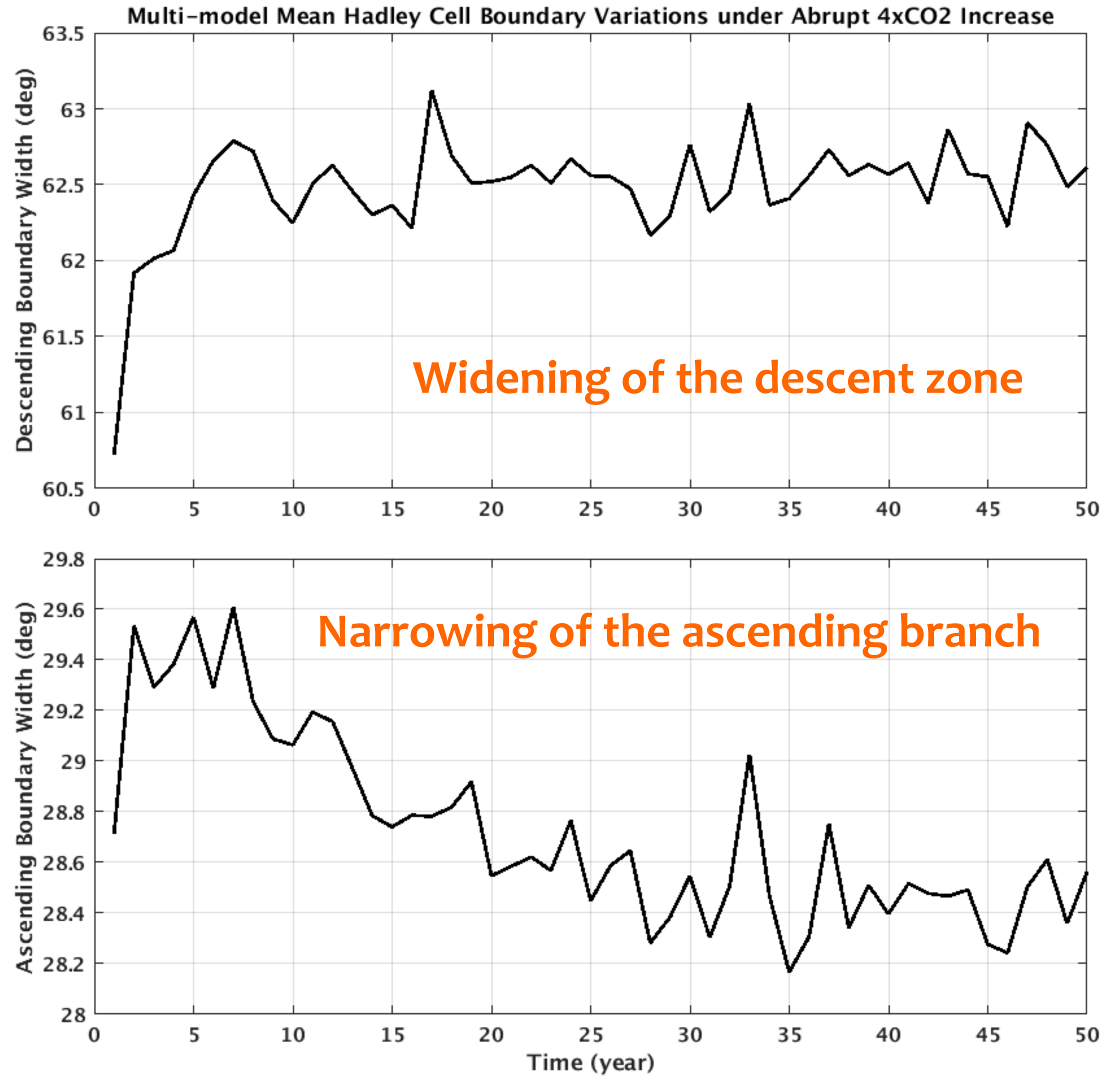


- Moist Static Energy (MSE) advection by the mean circulation and MSE divergence by transient eddies tend to narrow the ITCZ, while changes in net energy input to the atmosphere and the gross moist stability tend to widen the ITCZ.
- The narrowing tendency arises because the meridional MSE gradient strengthens with warming

Byrne and Schneider (2016, GRL)

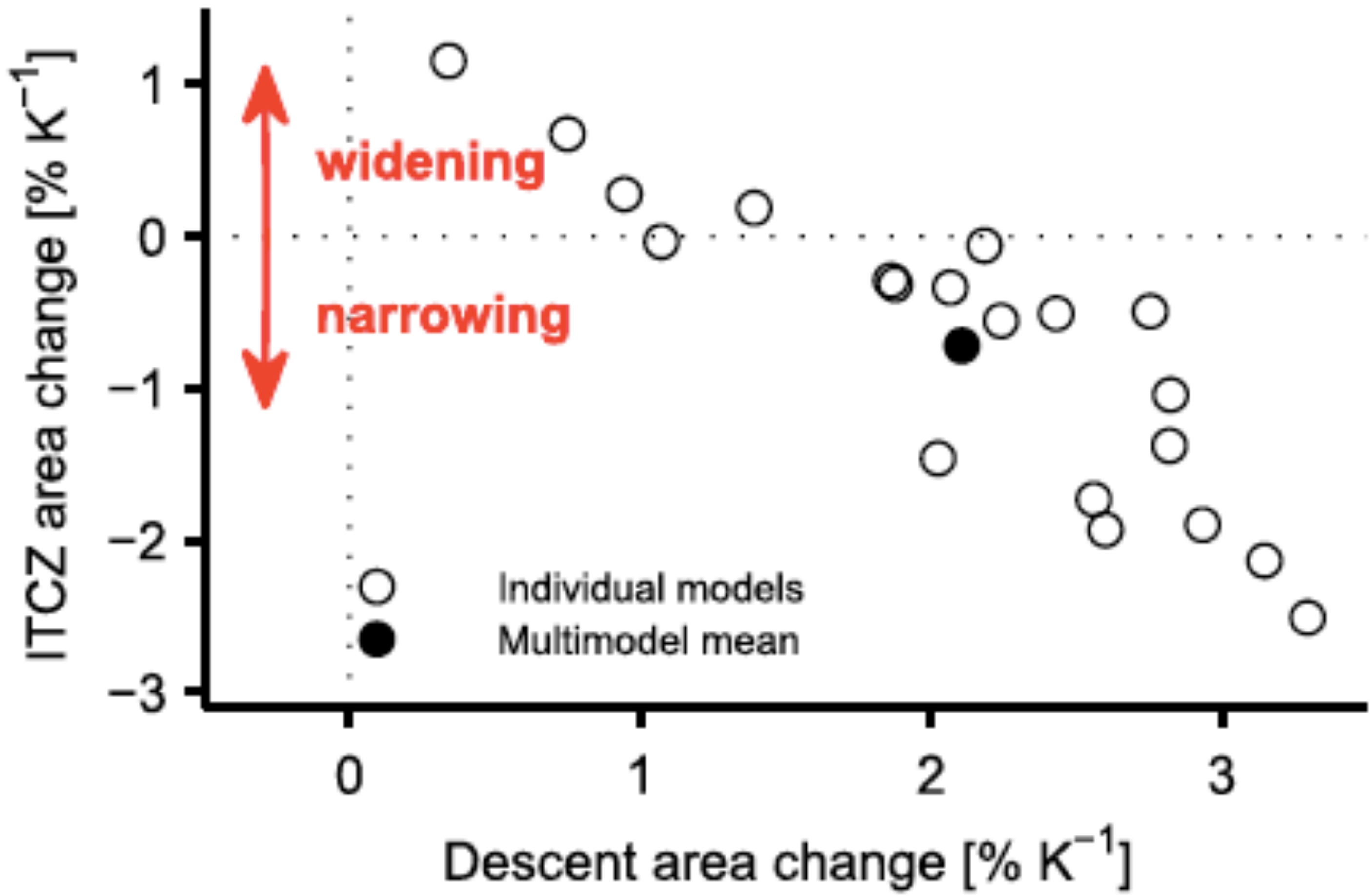
Time Evolution of the Width of the Hadley Circulation

Poleward edge of descent zone (where $\Psi_{500} = 0$)



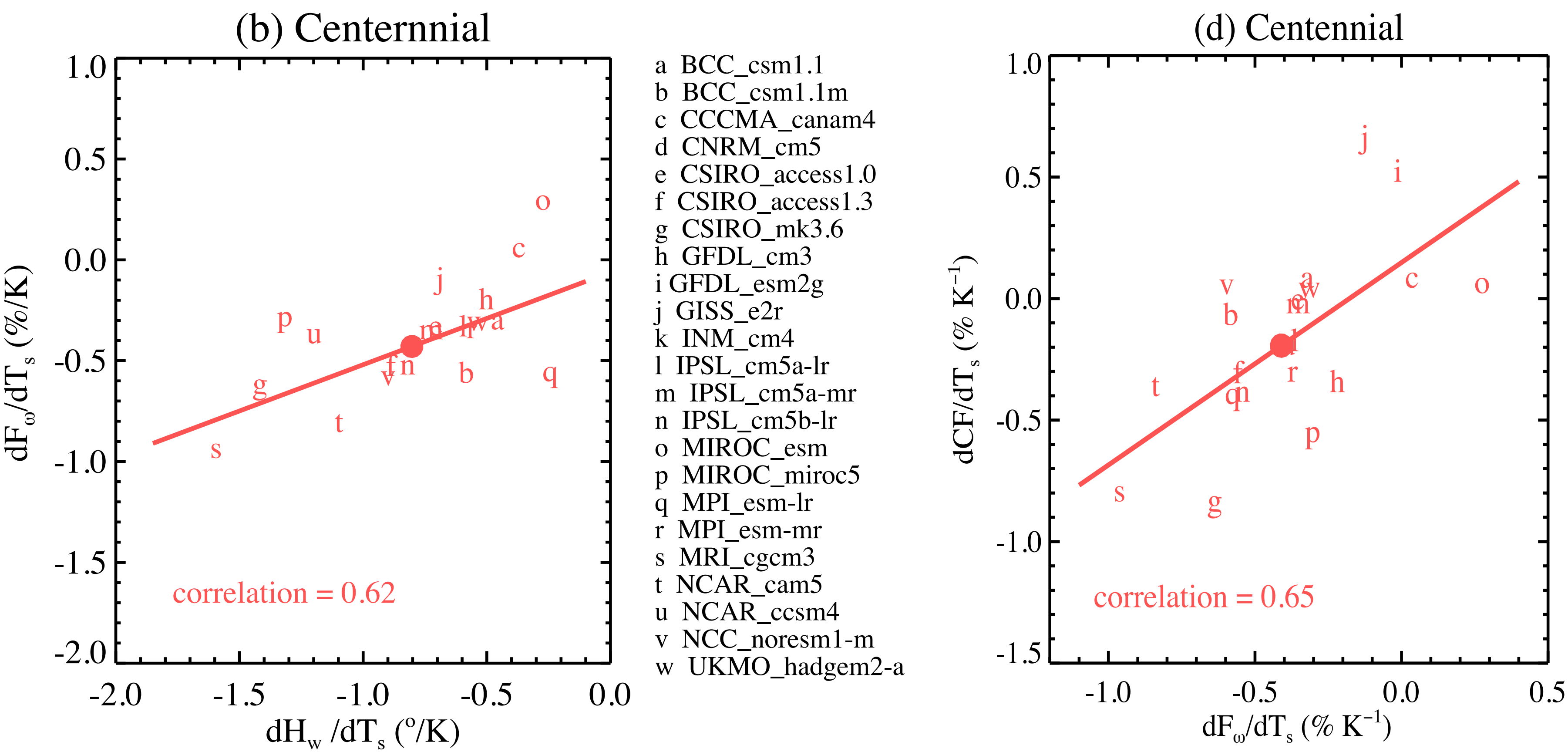
Width of ascending zone (where $\omega_{500} < 0$)

Widening and Narrowing Occur Simultaneously



Byrne and Schneider (2016, GRL)

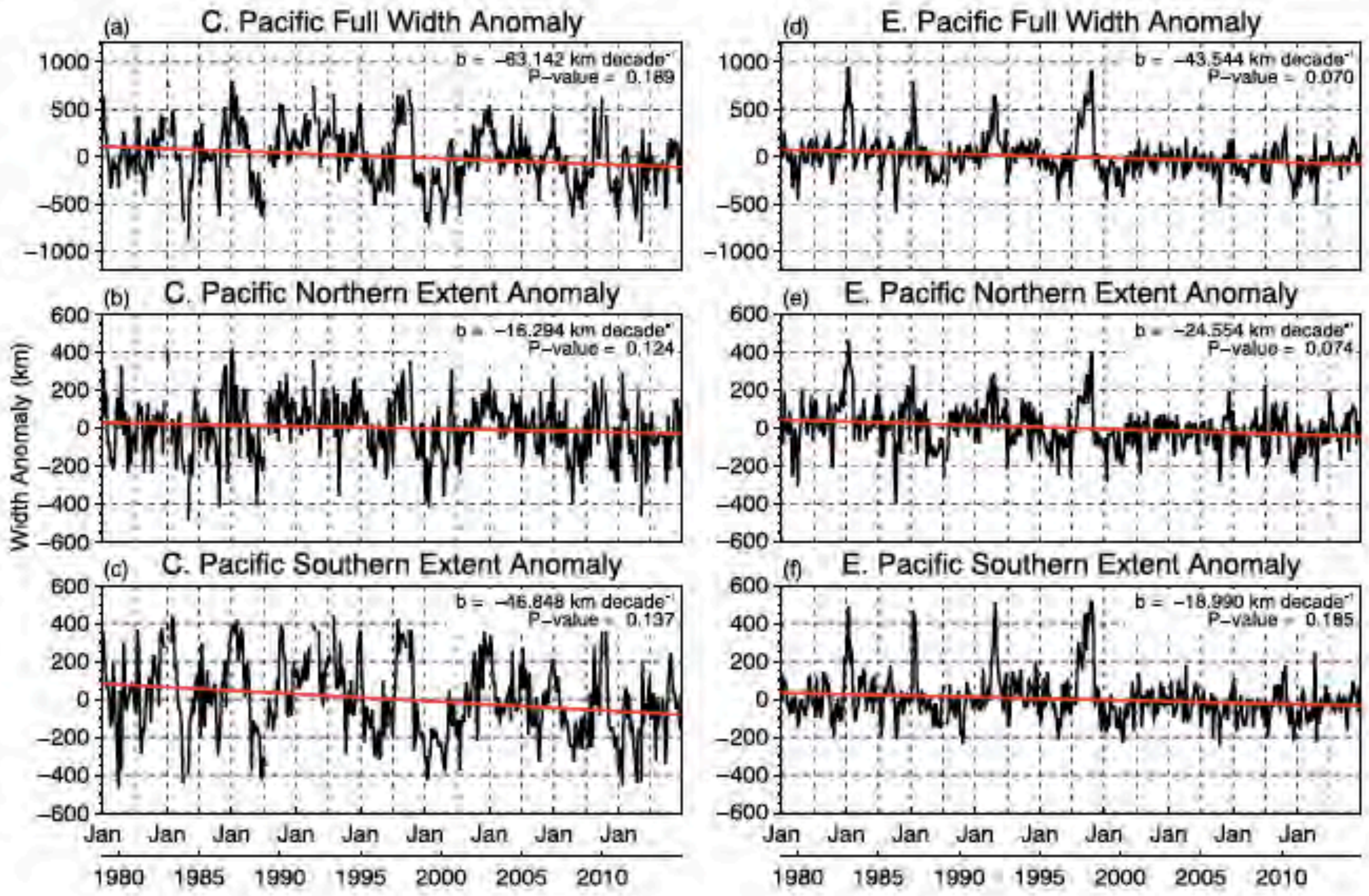
Tightening of Hadley Ascent and High Cloud Shrinkage



- H_w: the width of the ascending branch of the Hadley Circulation
- F_ω: the fractional of tropical ascending area
- CF: the tropical-mean high cloud fraction

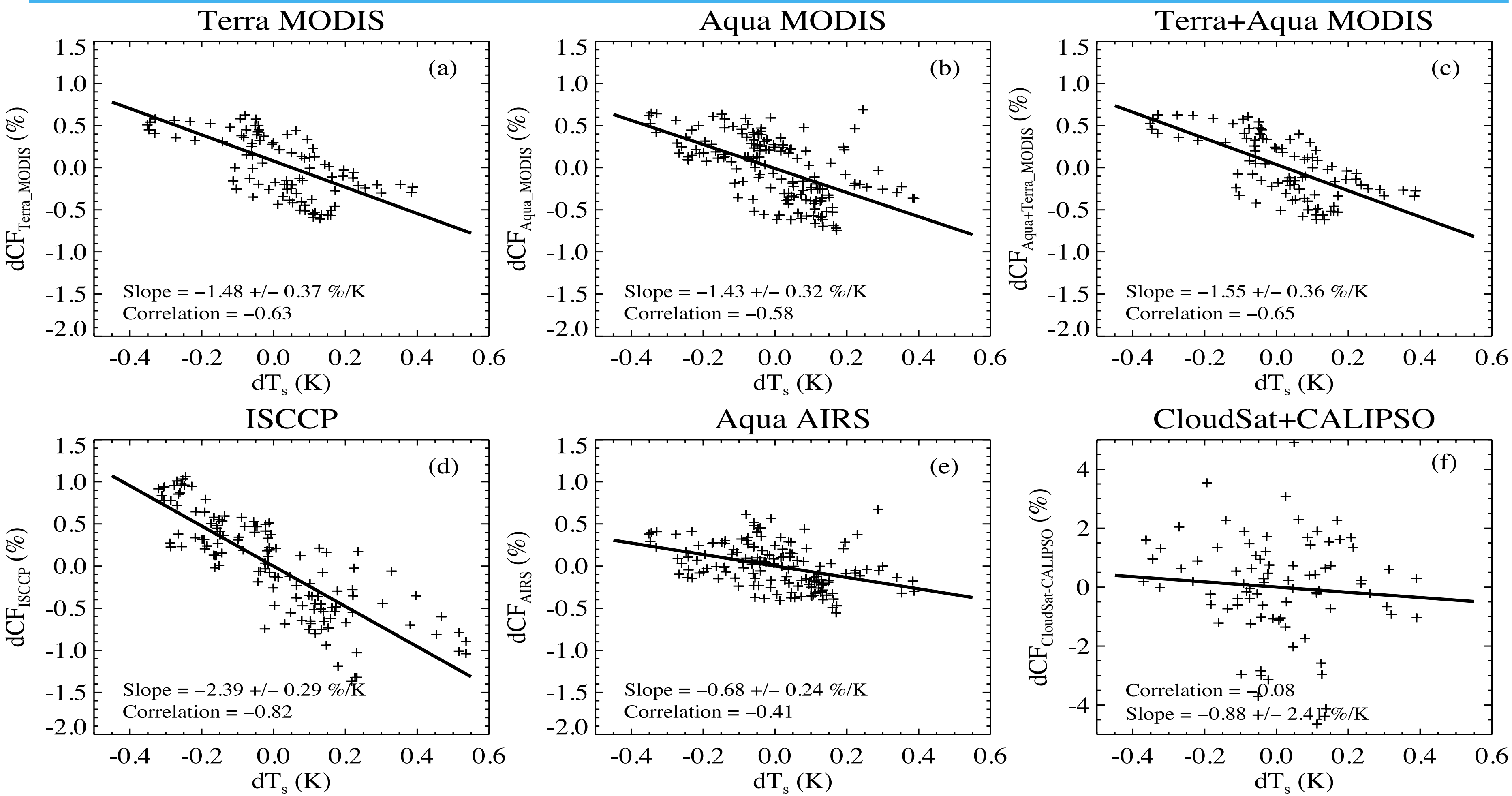
Su et al. (2017, Nature Comm. in press)

Observed Narrowing of the ITCZ



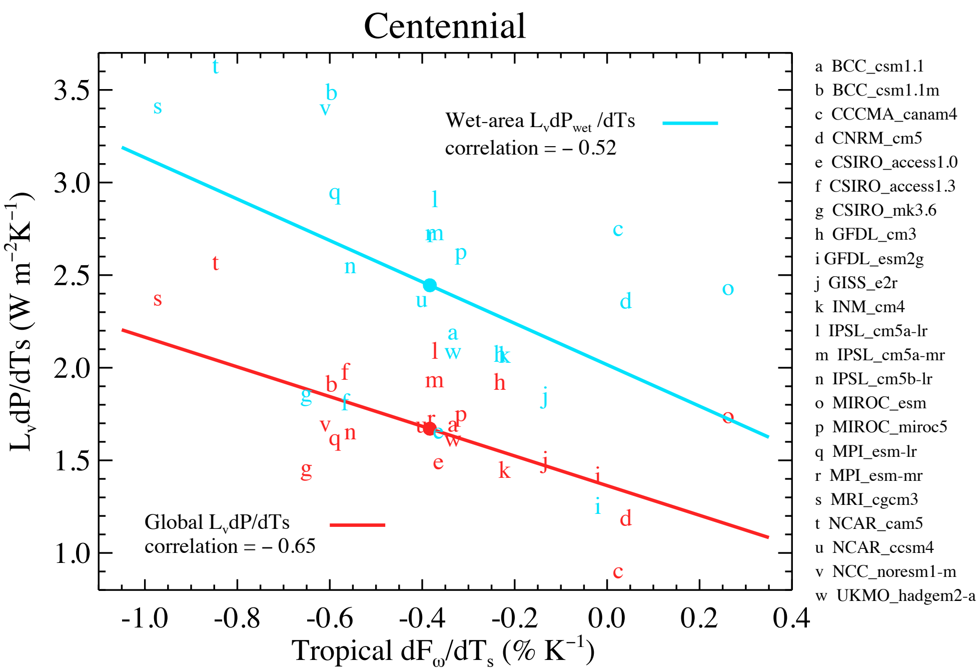
Wodzicki and Rapp (2016, JGR)

Satellite Observed "Iris Effect"

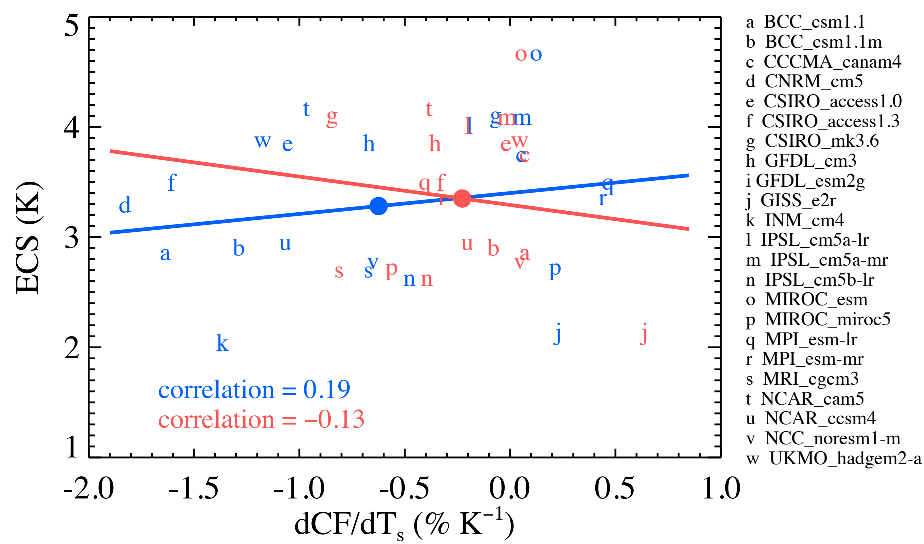


Su et al. (2017, Nature Comm. in press)

Relation with Hydrological Sensitivity and Climate Sensitivity



- The tightening of Hadley ascent drives the inter-model spread in global-mean precipitation change per unit surface warming



- The “iris effect” is not a dominant factor that drives the inter-model spread in climate sensitivity

Su et al. (2017, Nature Comm. in press)

Conclusions

- Satellite observations suggest high cloud fraction tends to decrease when surface temperature increases – "apparent iris effect".

- We suggest that the tightening of the ascending branch of the Hadley Circulation is an important process that contributes to the decrease of tropical-mean high cloud fraction.

- We find that the high cloud sensitivity to surface temperature is a primary source for the inter-model spread in the longwave radiative feedback and hydrological sensitivity.

- However, the "iris effect" is not a dominant factor that contributes to the inter-model spread in climate sensitivity.