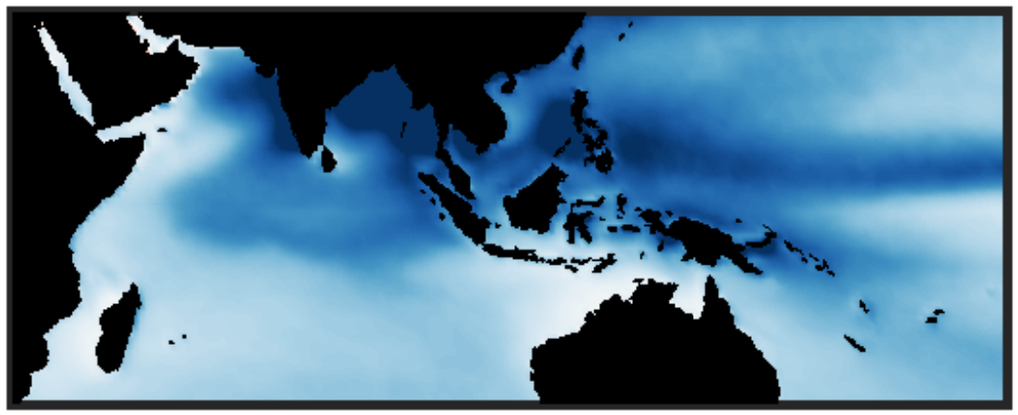
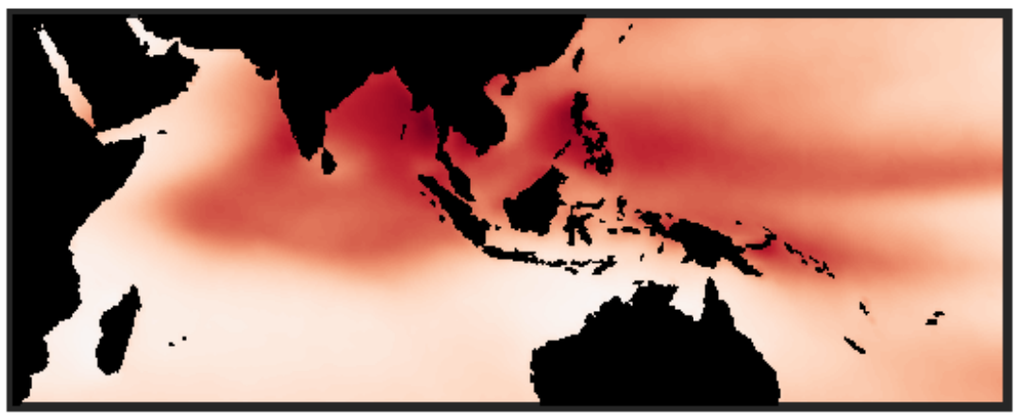
SW CRE



LW CRE



Net CRE

Is the Net CRE Constrained to be Uniform over the Tropical Warm Pools?

Casey Wall*
Dennis Hartmann
Joel Norris

*Scripps Institution of Oceanography

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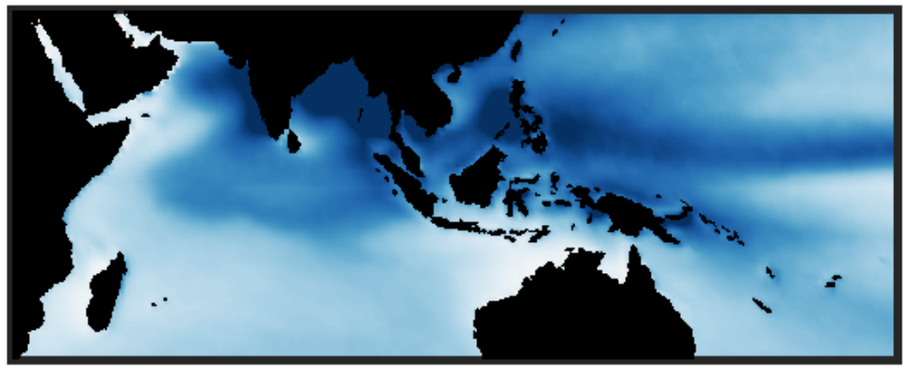
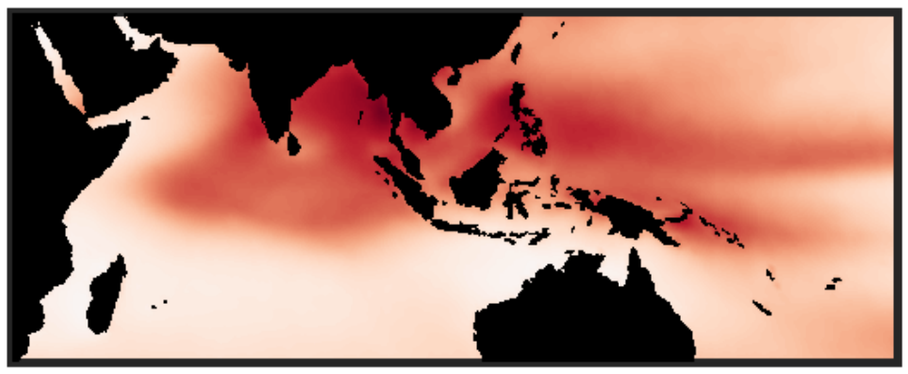
Cloud Radiative Effects — JJA Mean

SW CRE



LW CRE



Net CRE

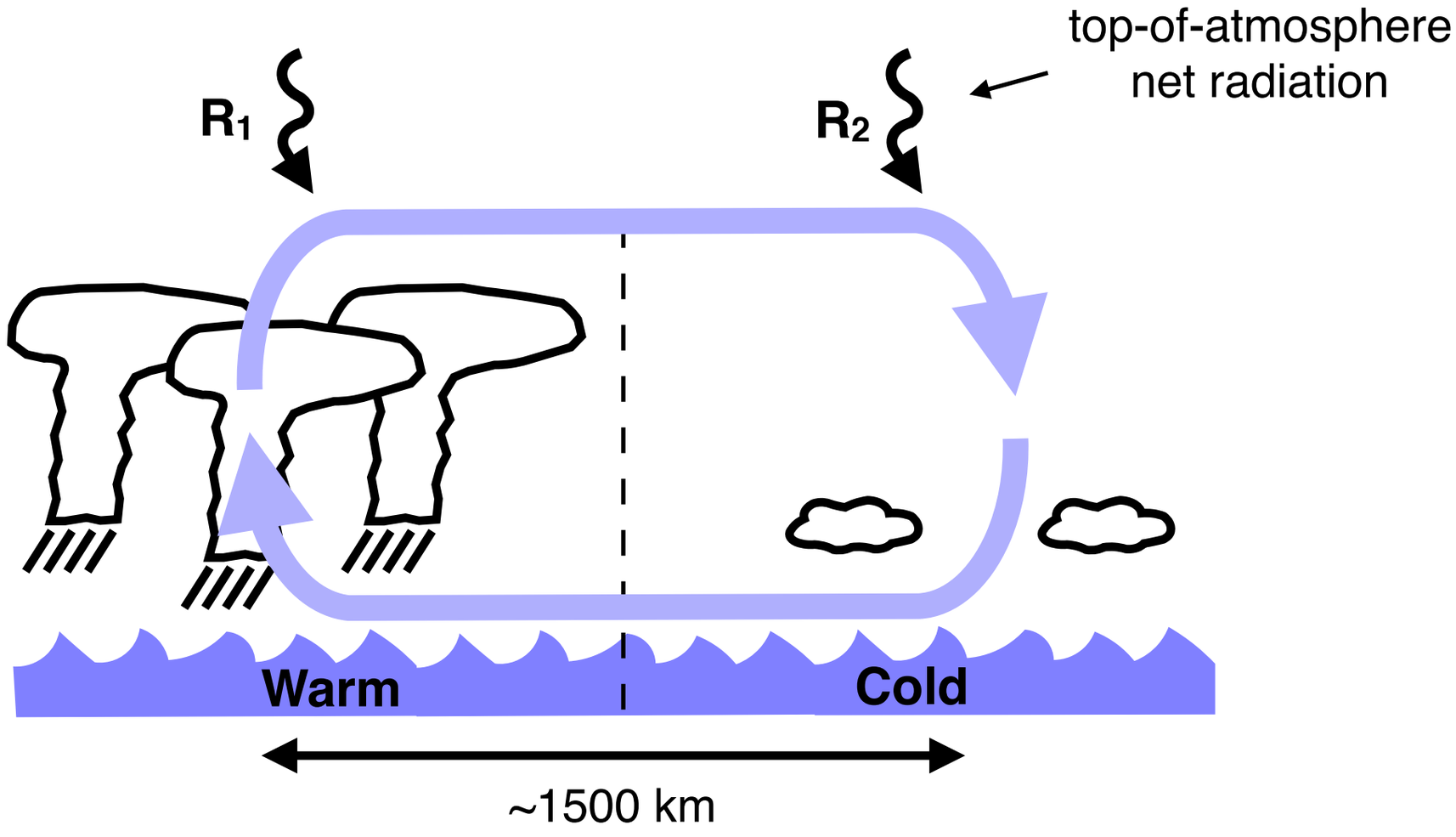
Why is net CRE about the same in convective and non-convective regions?

CRE (Wm^{-2})

-80 -40 0 40 80

data: CERES

Hypothesis
(Hartmann et al., 2001)



If the “cloud shading feedback” is strong, then $R_1 \approx R_2$.

Climate Model Experiments

Model Configuration

- Community Atmosphere Model v. 4 (CAM4)
- global RCE
- non-rotating aquaplanet with uniform insolation
- 5 m slab ocean
- daily output

Is this model useful for testing the hypothesis?

- conserves energy
- resolves motions with scale ~1500 km
- simulates cloud-shading feedback

Climate Model Experiments

Experimental Design

Control
(cloud shading feedback on)

save $SW_{\downarrow}$ at ocean surface for every time step

randomly permute $SW_{\downarrow}$ in time dimension

Random SW
(cloud shading feedback off)

model sees randomized $SW_{\downarrow}$ at ocean surface

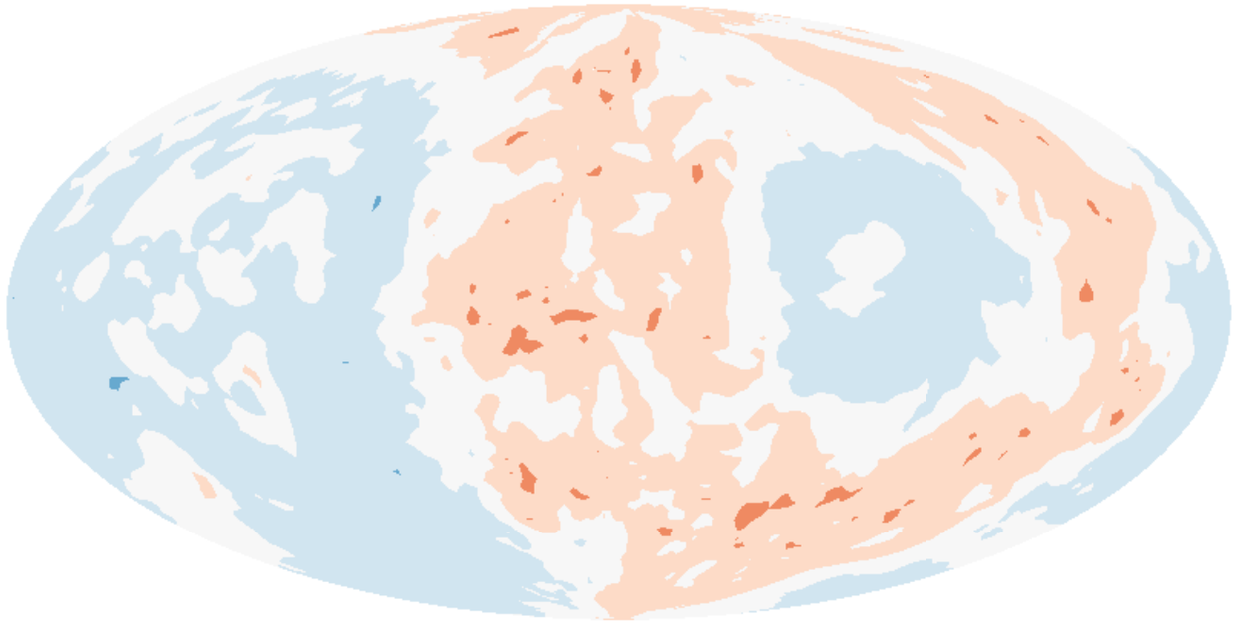
Hypothesis Testing

If the hypothesis is correct, then we will see:

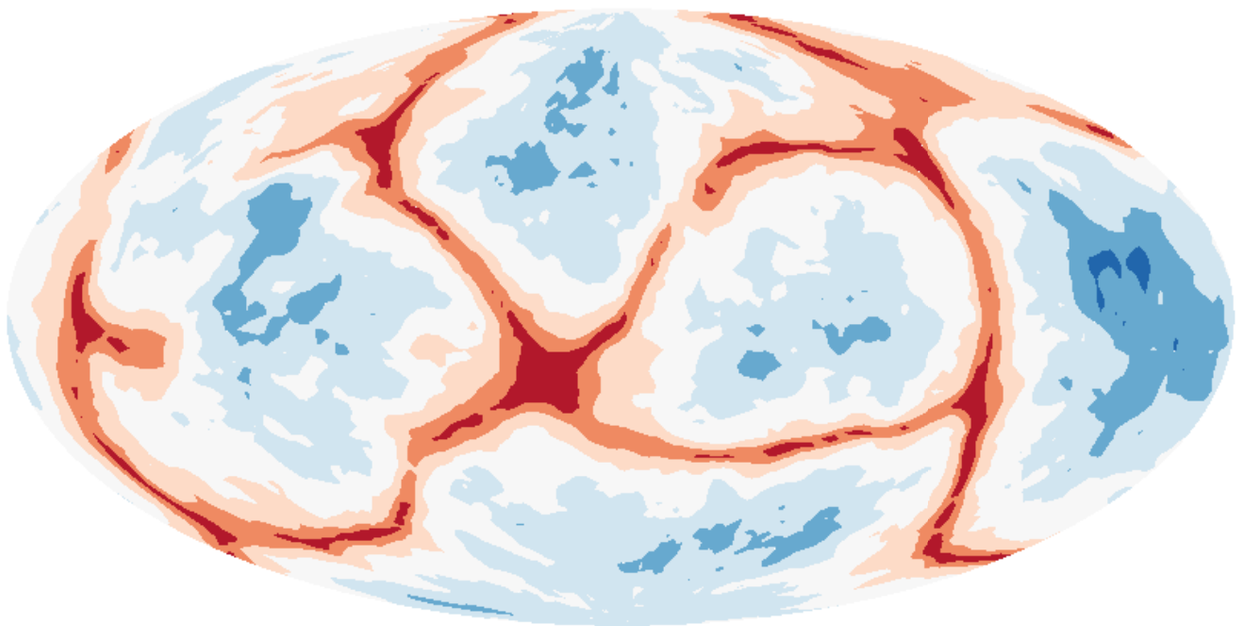
	Control (feedback on)	Random SW (feedback off)
SST gradients	small	large
energy transport	small	large
CRE contrast	small	large

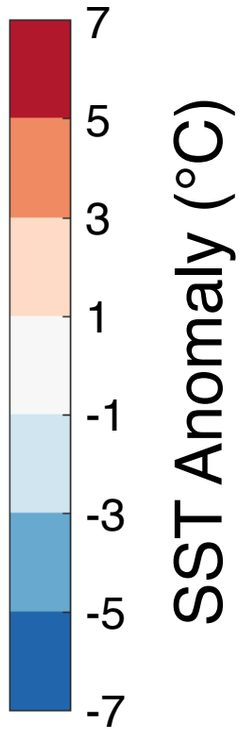
SST Gradients

Control
(feedback on)

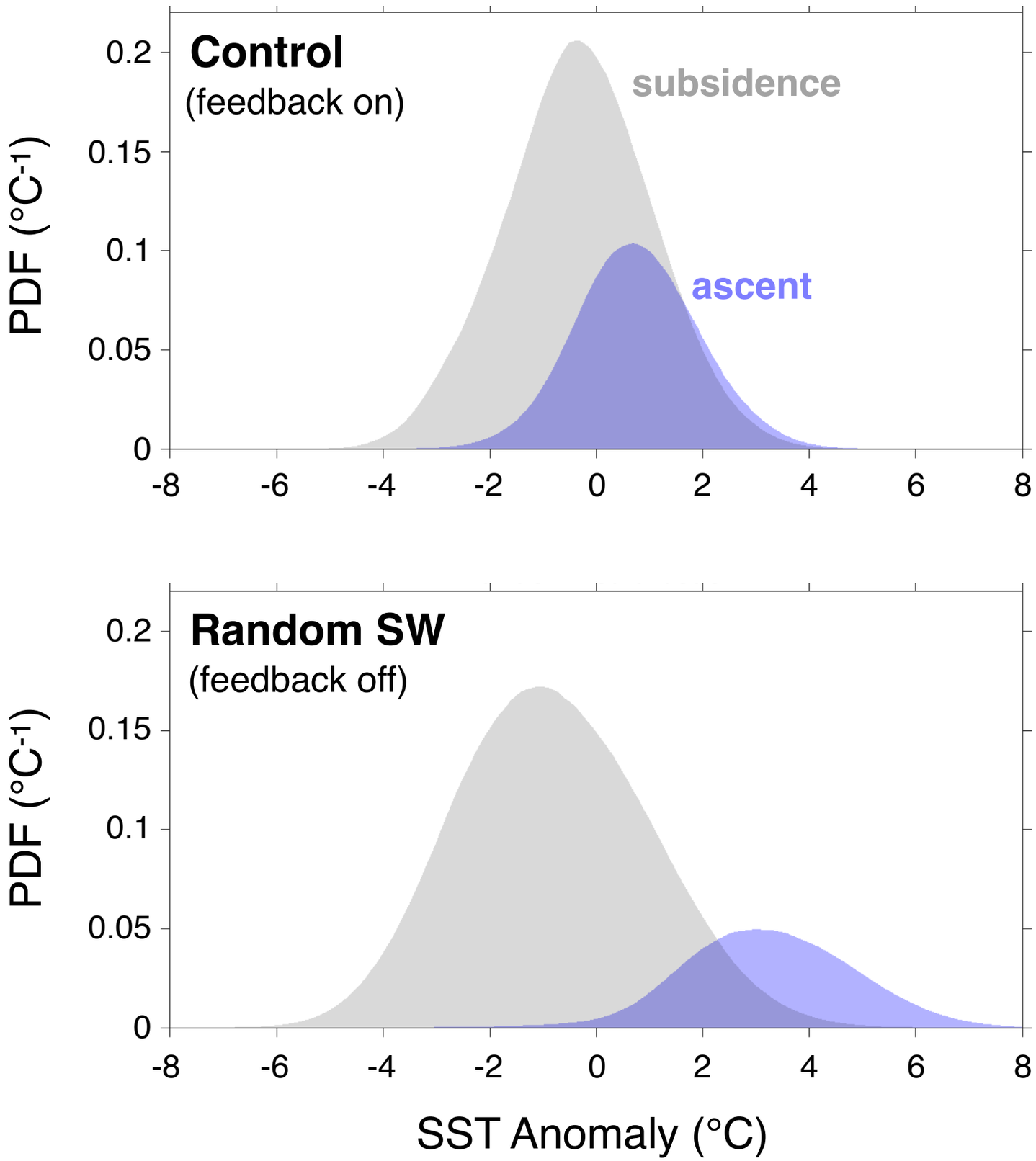


Random SW
(feedback off)

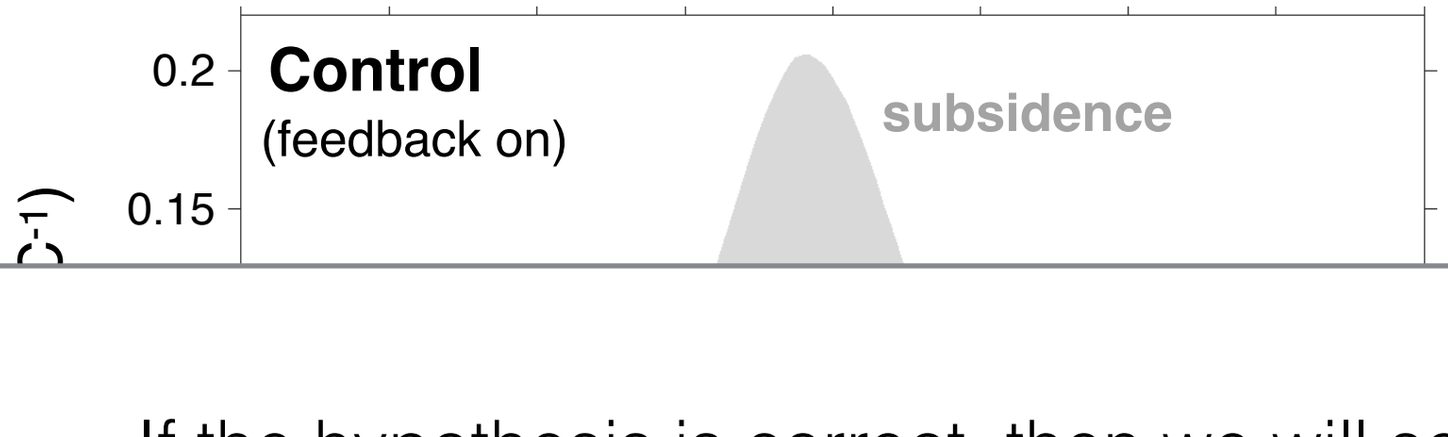




SST Gradients



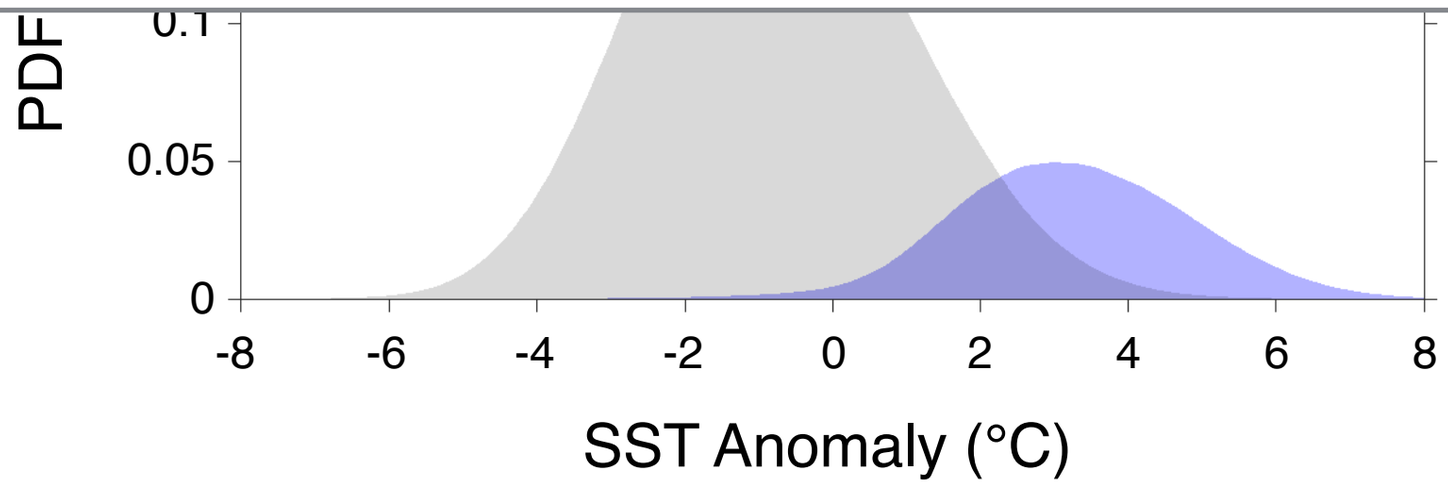
SST Gradients



If the hypothesis is correct, then we will see:

	Control	Random SW
SST gradients	small	large
energy transport	small	large
CRE contrast	small	large

✓



Horizontal Energy Transport

moist static energy

$$h = c_p T + Lq + gz$$

column moist static energy

$$H = \int_{p_0}^{p_t} h\Big(-\frac{dp}{g}\Big)$$

column moist static energy budget

$$\frac{\partial H}{\partial t} = SH + LH + R_{LW} + R_{SW} - D$$

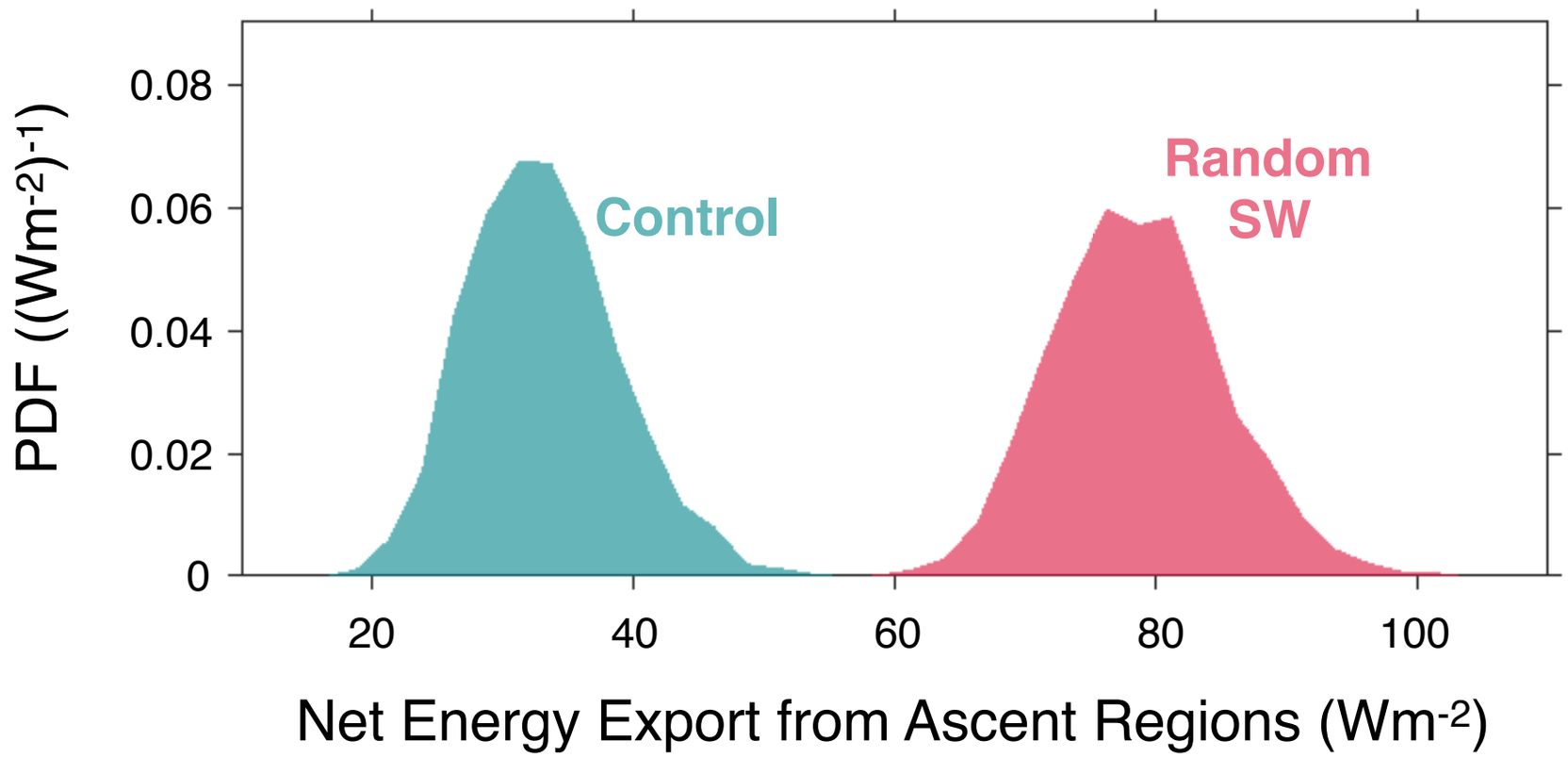
energy tendency

surface heat flux

column radiative heating

atmospheric energy transport

Horizontal Energy Transport



Horizontal Energy Transport

Horizontal Energy Transport

If the hypothesis is correct, then we will see:

	Control	Random SW	
SST gradients	small	large	✓
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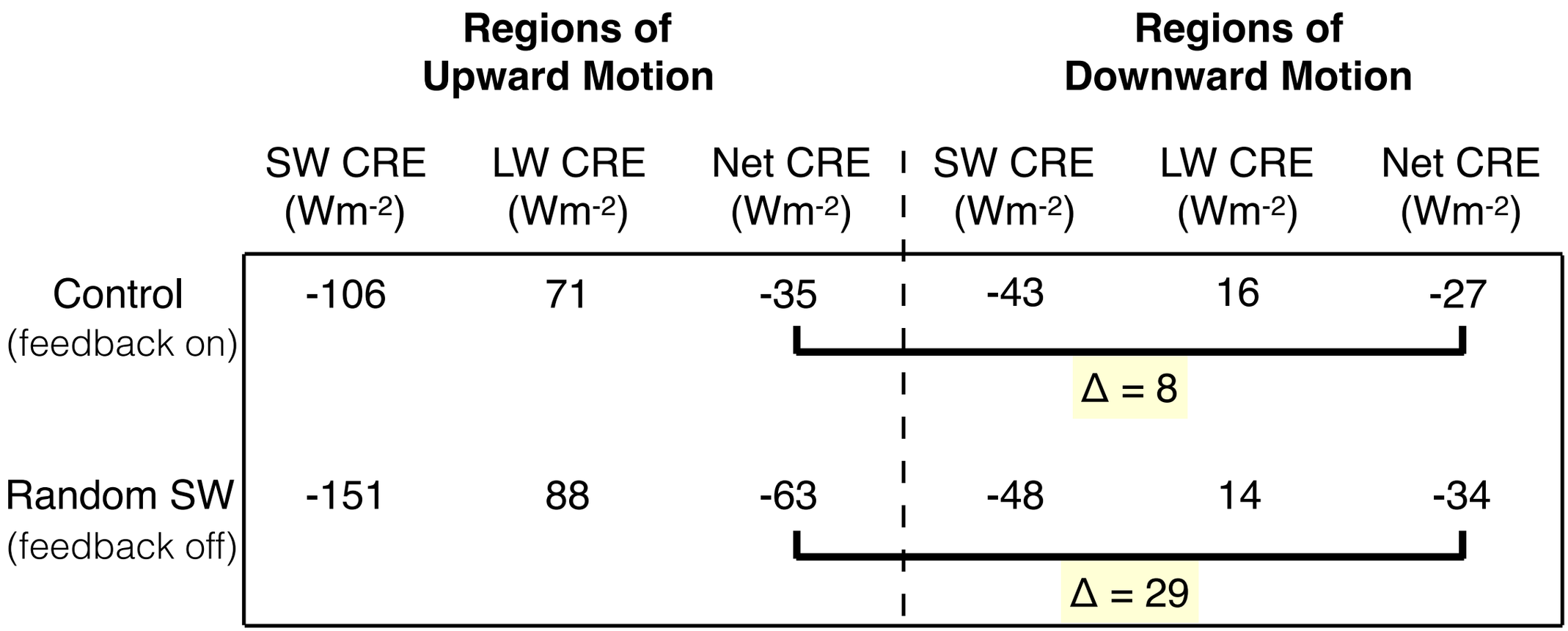
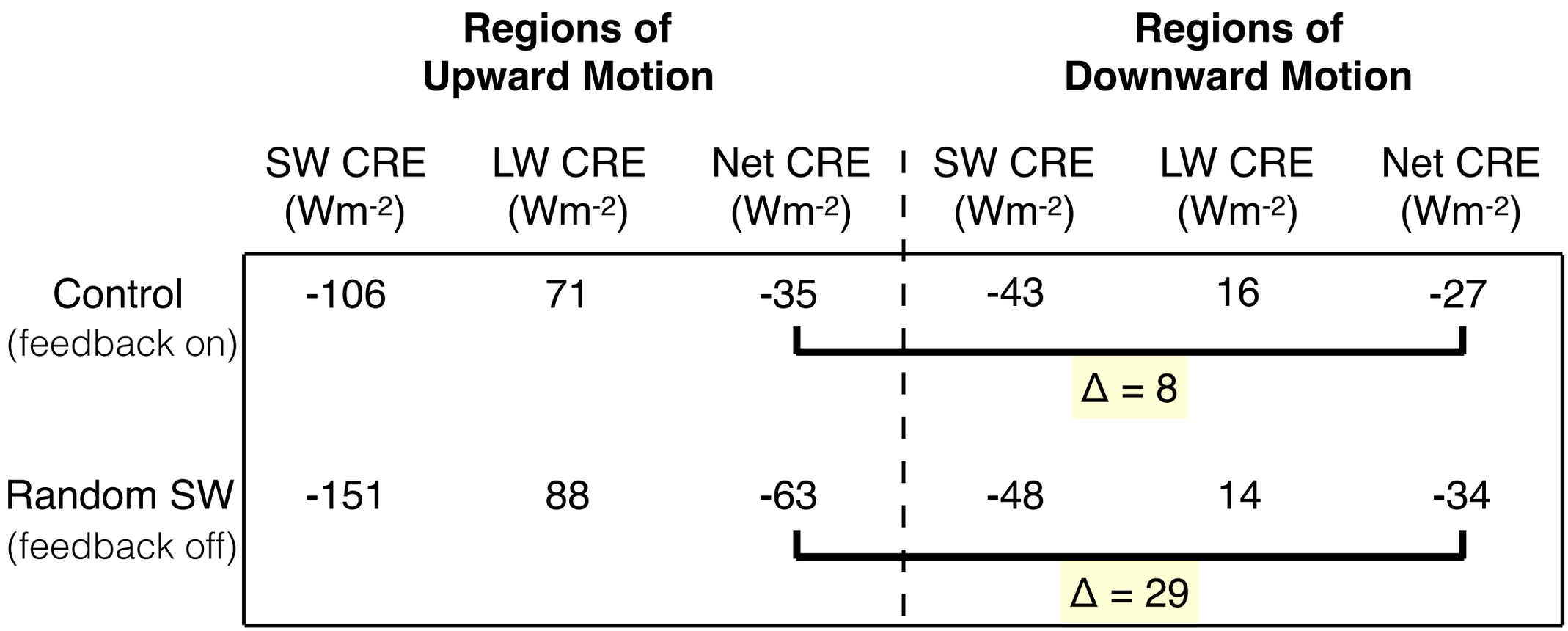
Cloud Radiative Effects



Cloud Radiative Effects



If the hypothesis is correct, then we will see:

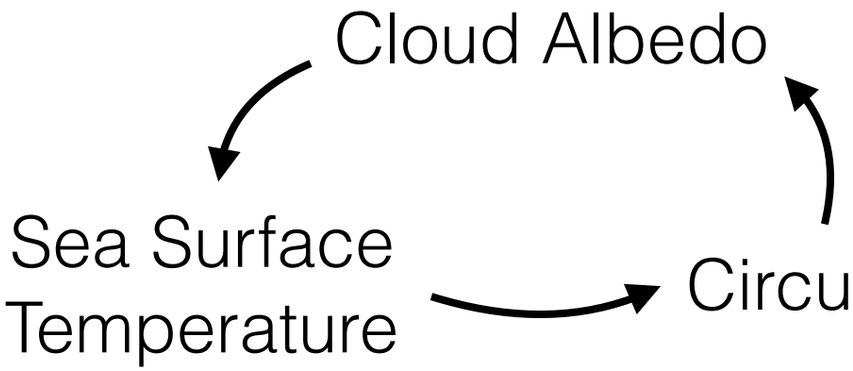
	Control	Random SW	
SST gradients	small	large	✓
energy transport	small	large	✓
CRE contrast	small	large	✓

Conclusion: Cloud shading feedback *causes* net CRE to be more uniform.

Summary

Question Why is net CRE nearly uniform over the tropical warm pools?

Hypothesis



This is a key mechanism for obtaining uniform net CRE over the warm pools [Hartmann et al., 2001].

Findings Modeling support for hypothesis

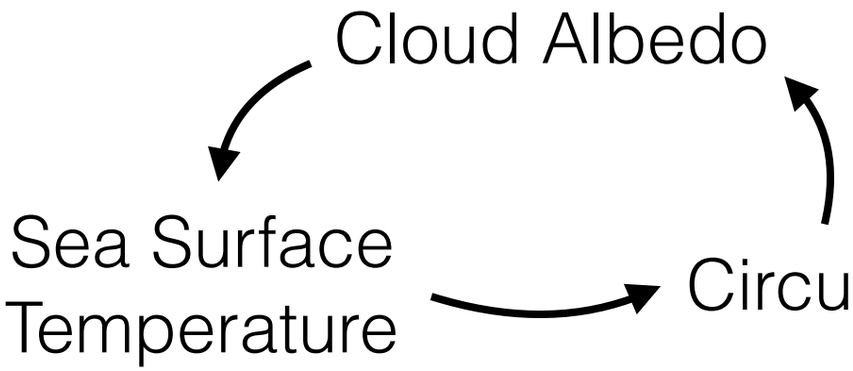
Open Questions

- Is this theory a complete explanation?
- Implications for cloud-climate feedbacks?

Summary

Question Why is net CRE nearly uniform over the tropical warm pools?

Hypothesis



This is a key mechanism for obtaining uniform net CRE over the warm pools [Hartmann et al., 2001].

Findings Modeling support for hypothesis

Reference Wall, Hartmann, & Norris (in press) Is the Net Cloud Radiative Effect Constrained to be Uniform over the Tropical Warm Pools? *Geophysical Research Letters*

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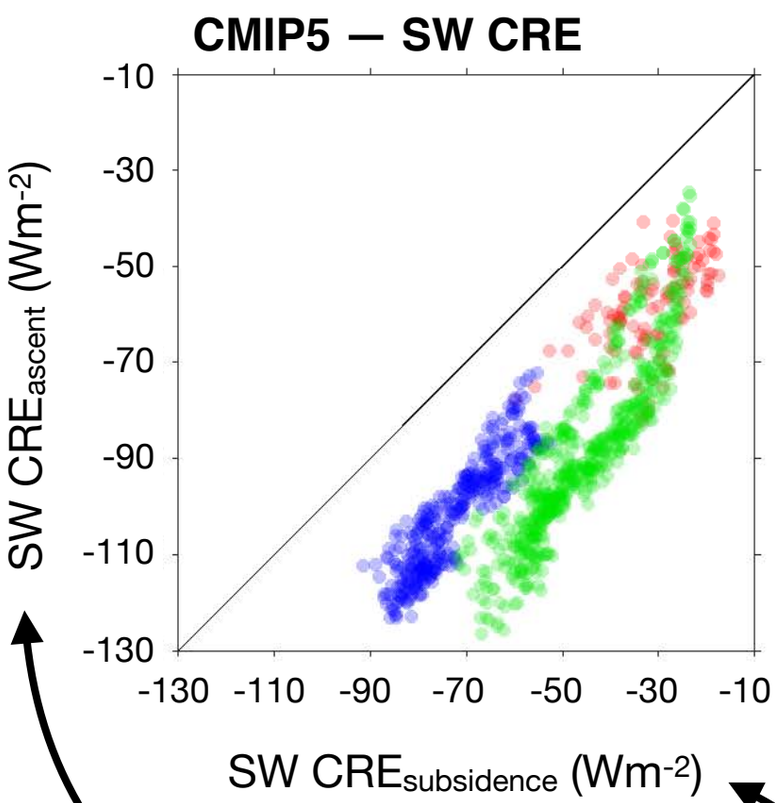
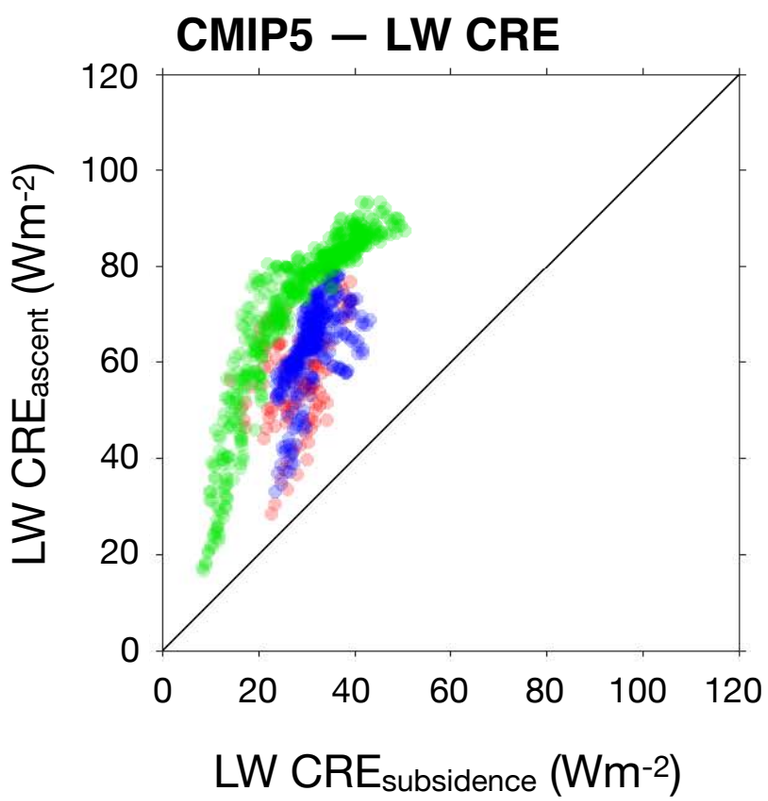
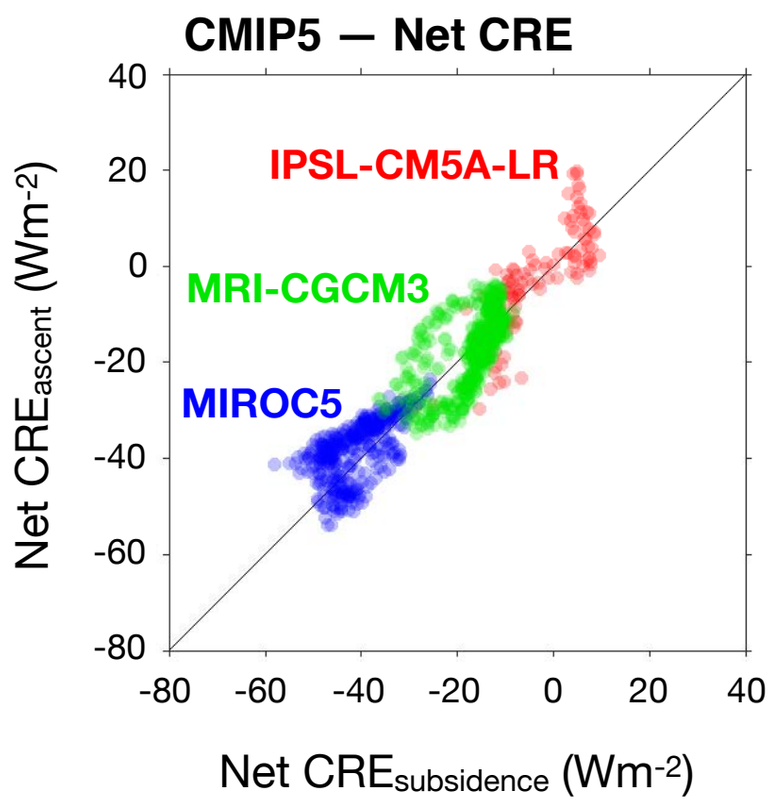
Extra Slides

A Note on Model Tuning: CRE in CMIP5 Models





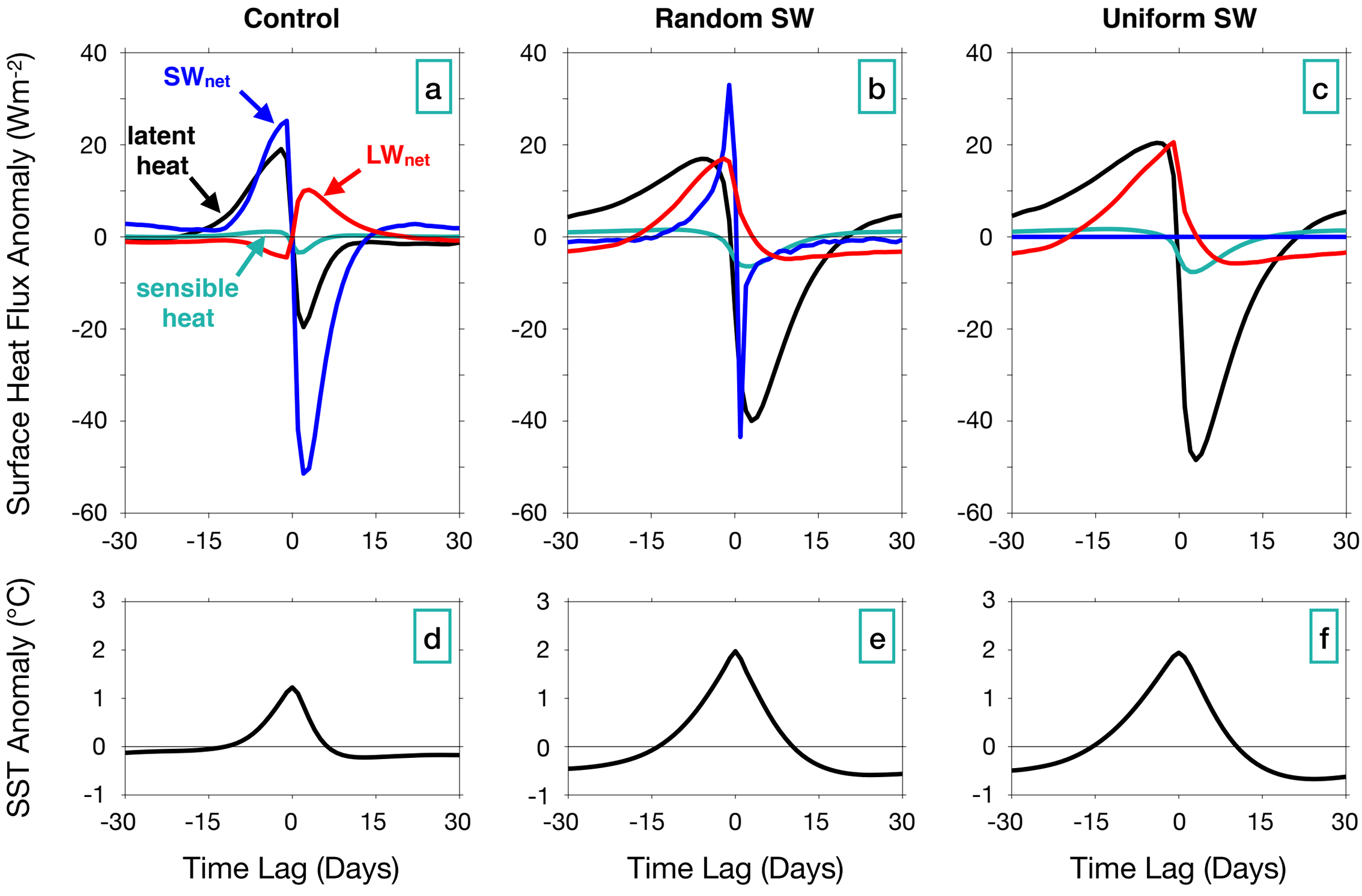


average over days with upward motion at 500 hPa

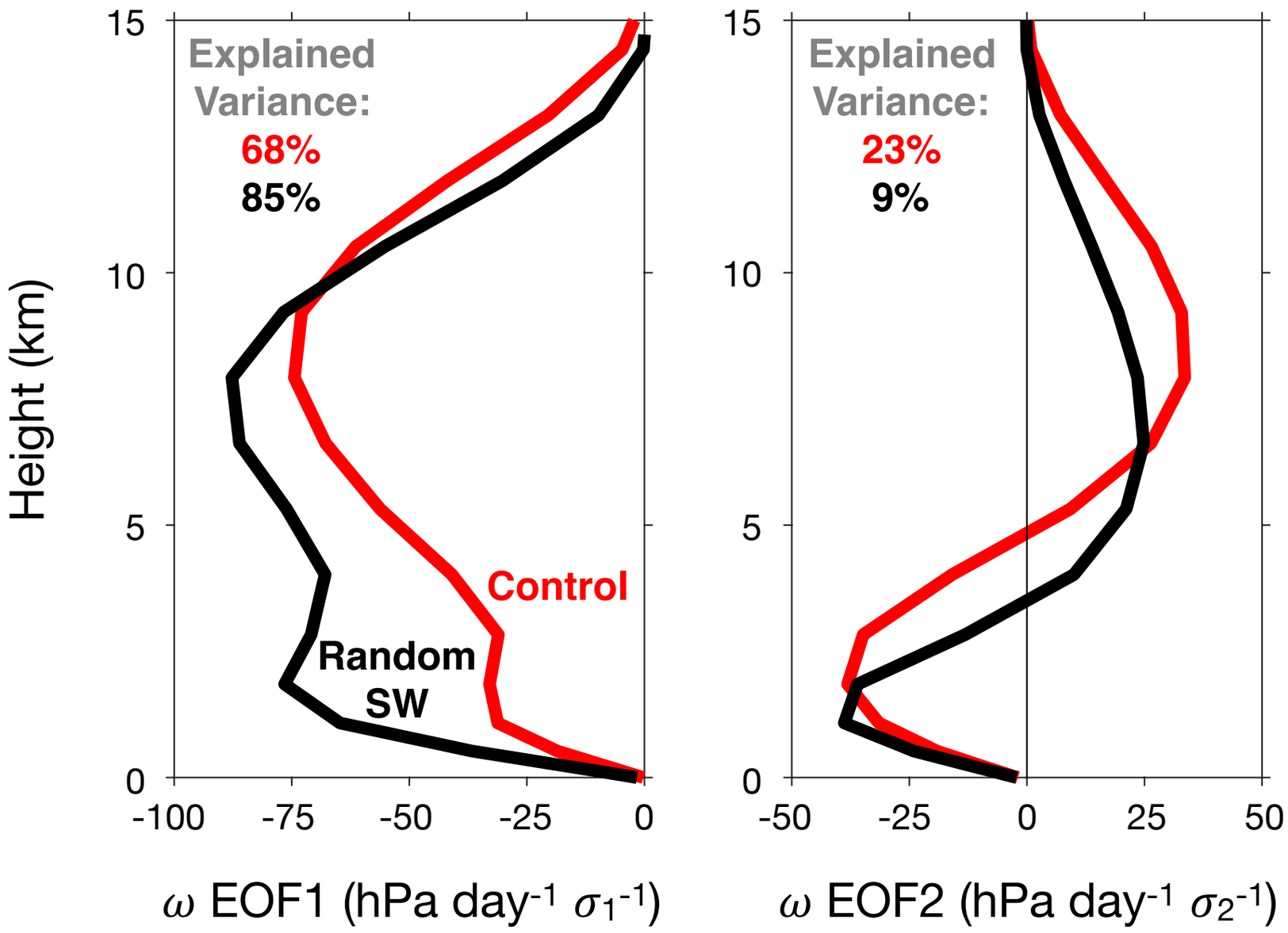
average over days with downward motion at 500 hPa

data:
CMIP5 fully-coupled historical runs (1979-2005)

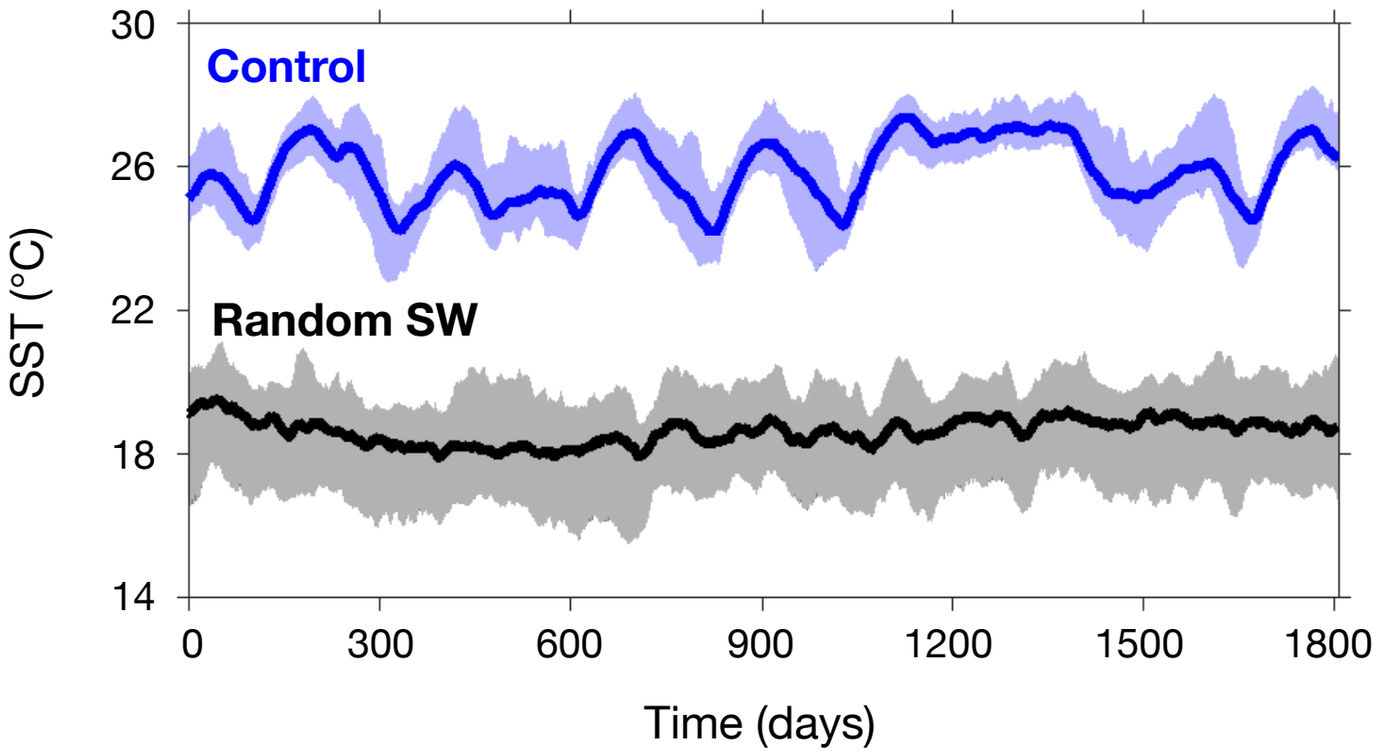
Surface Heat Budget



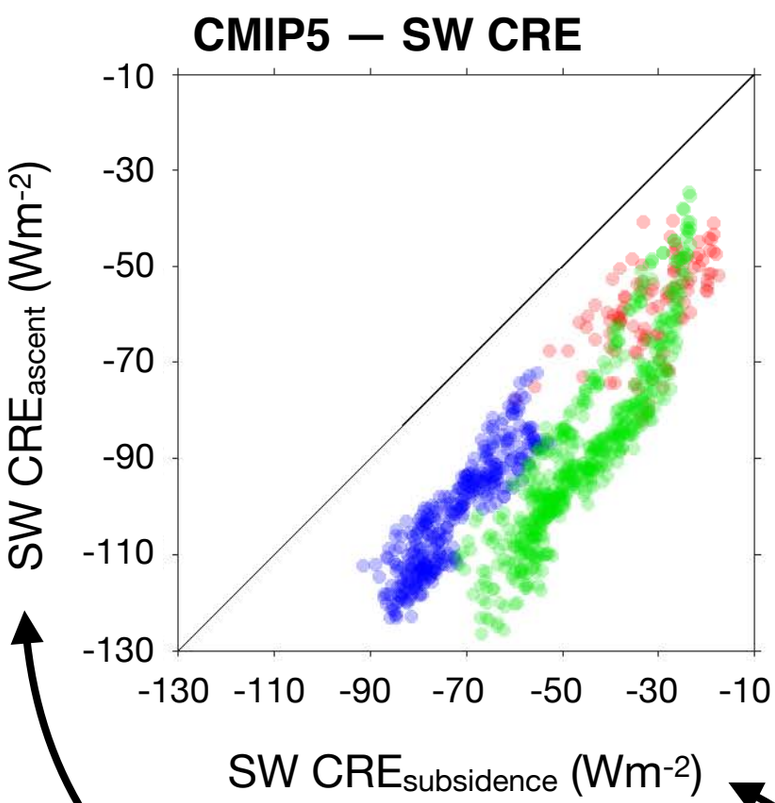
Modes of Vertical Motion in Tropic World

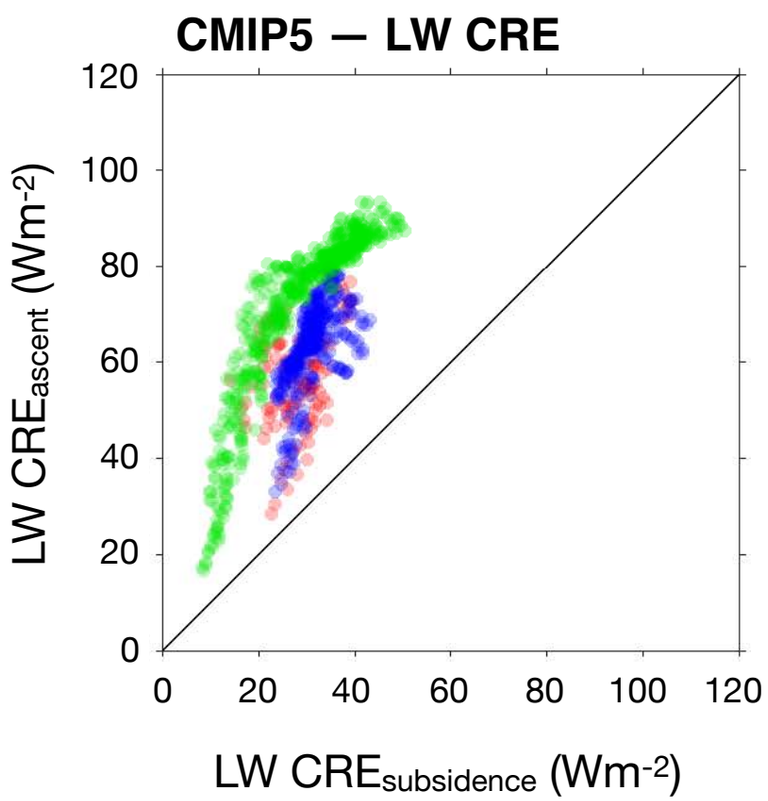


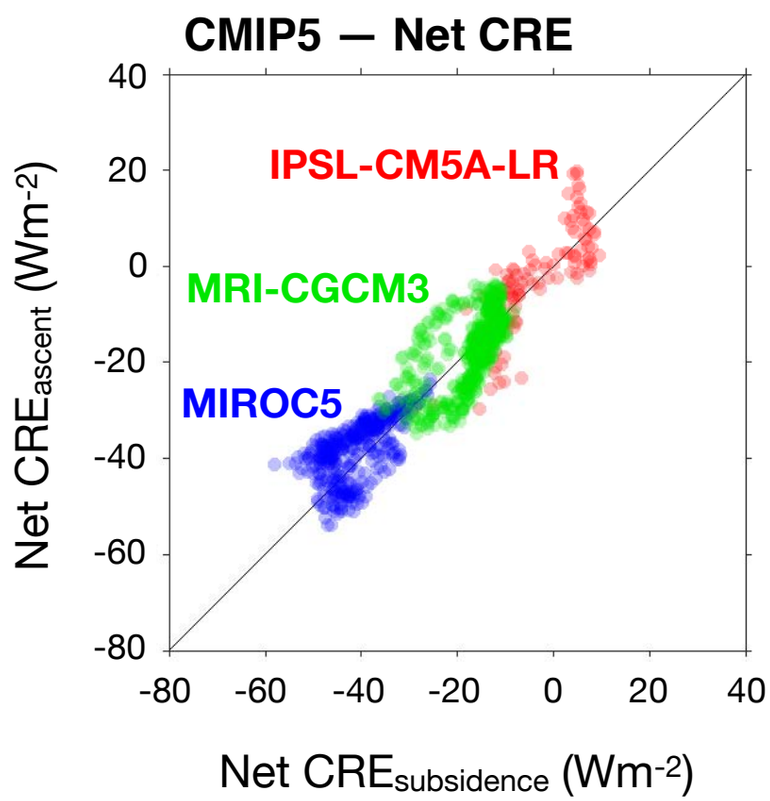
Global-mean SST in Tropic World Simulations



A Note on Model Tuning: CRE in CMIP5 Models







average over days with upward motion at 500 hPa

average over days with downward motion at 500 hPa

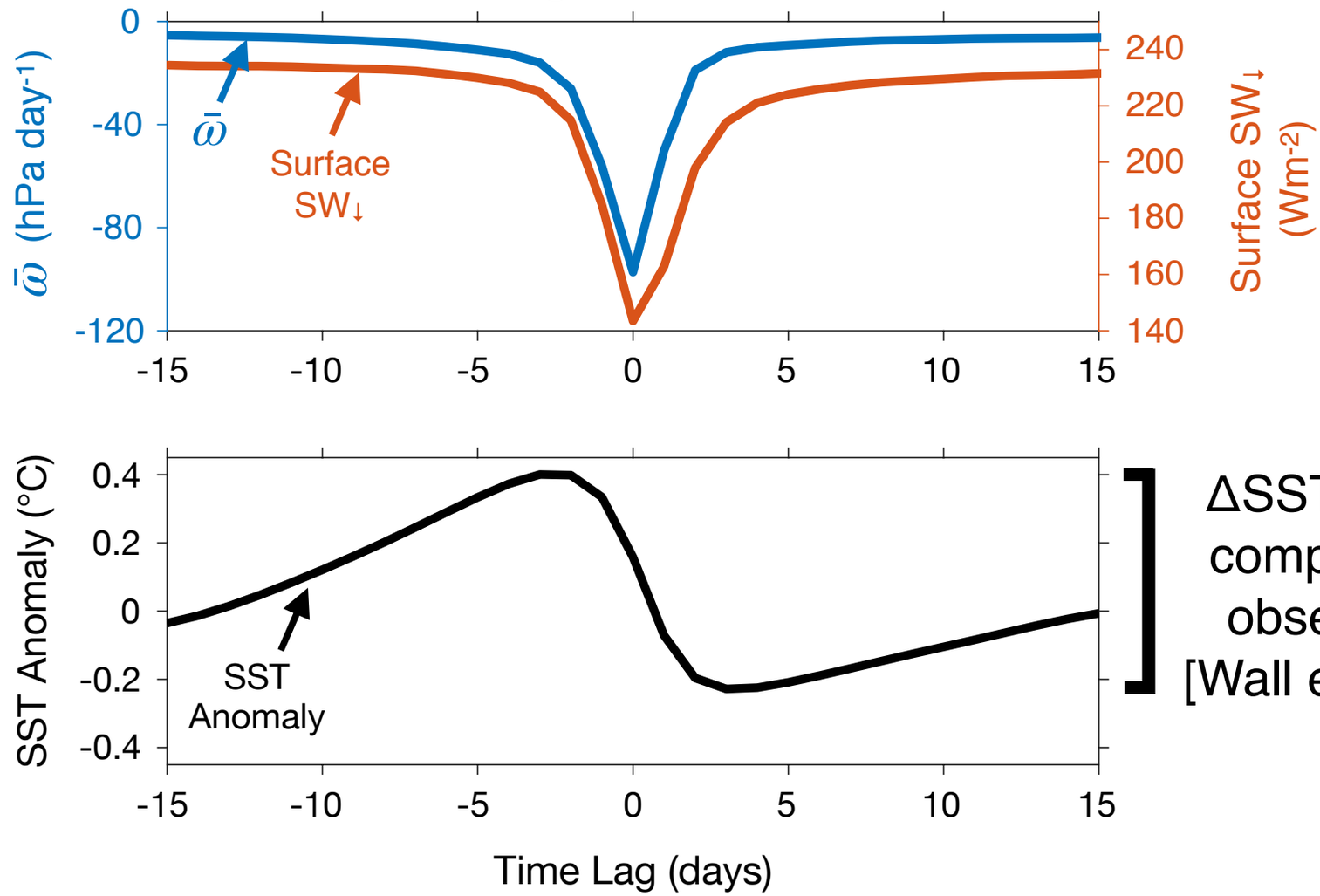
data:
CMIP5 fully-coupled historical runs (1979-2005)

Climate Model Experiments

Model Details

- CAM4 global RCE
- RCEMIP standard protocol
- aquaplanet
- 5 m slab ocean
- daily output

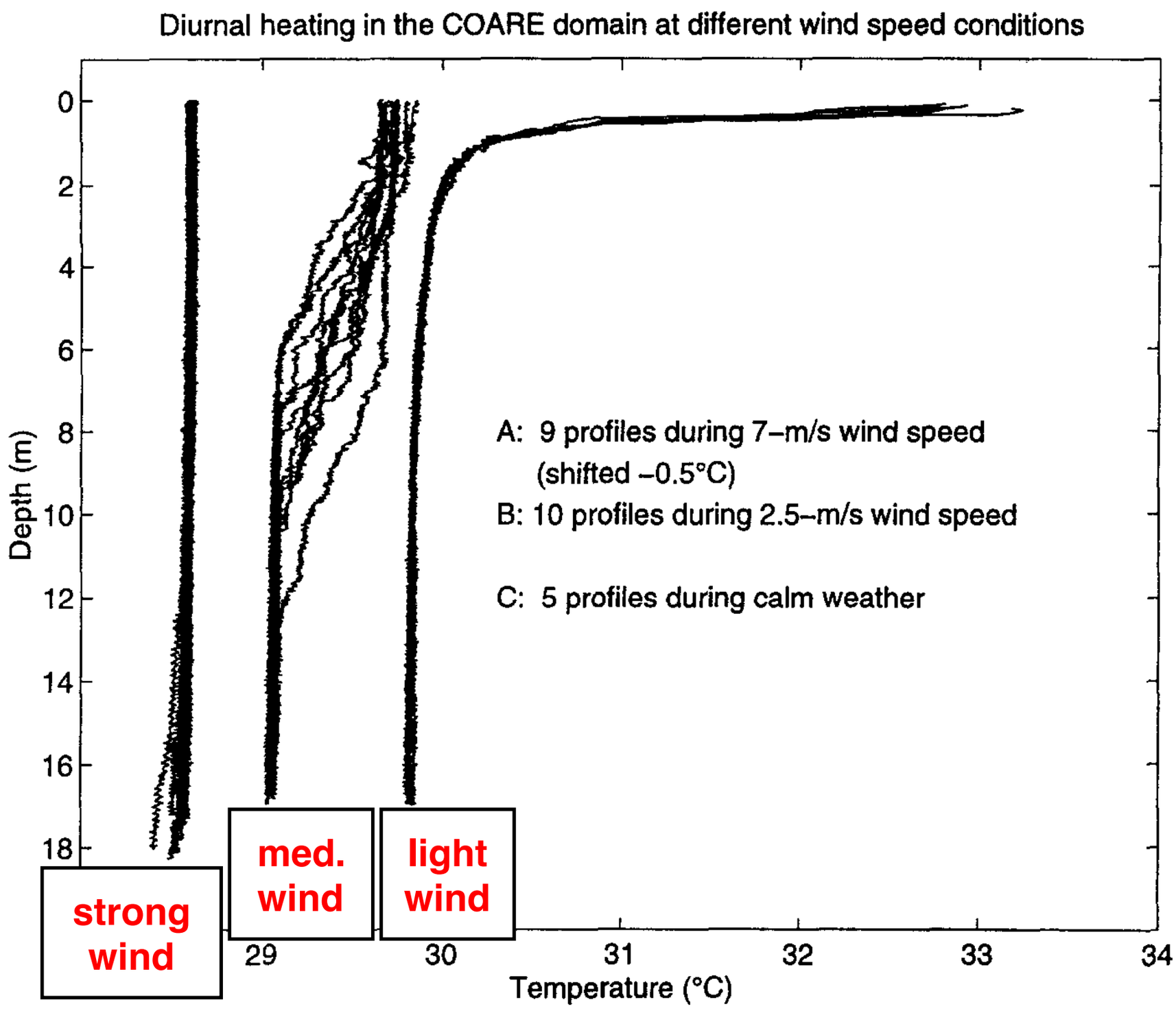
Cloud Shading Feedback in CAM4



ΔSST ≈ 0.6 °C comparable to observations [Wall et al. 2018]

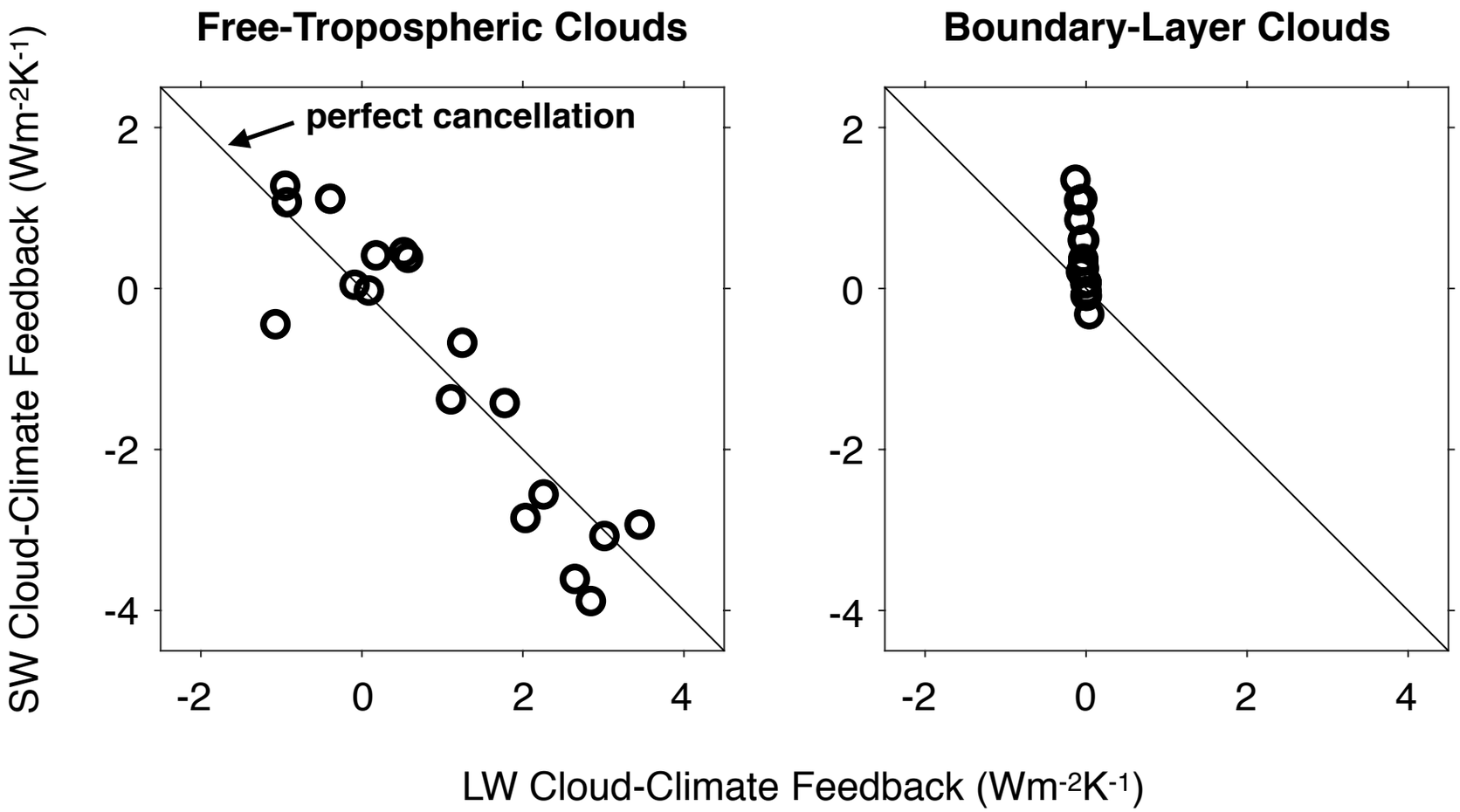
Other

Upper-Ocean Temperature in the West Pacific Warm Pool

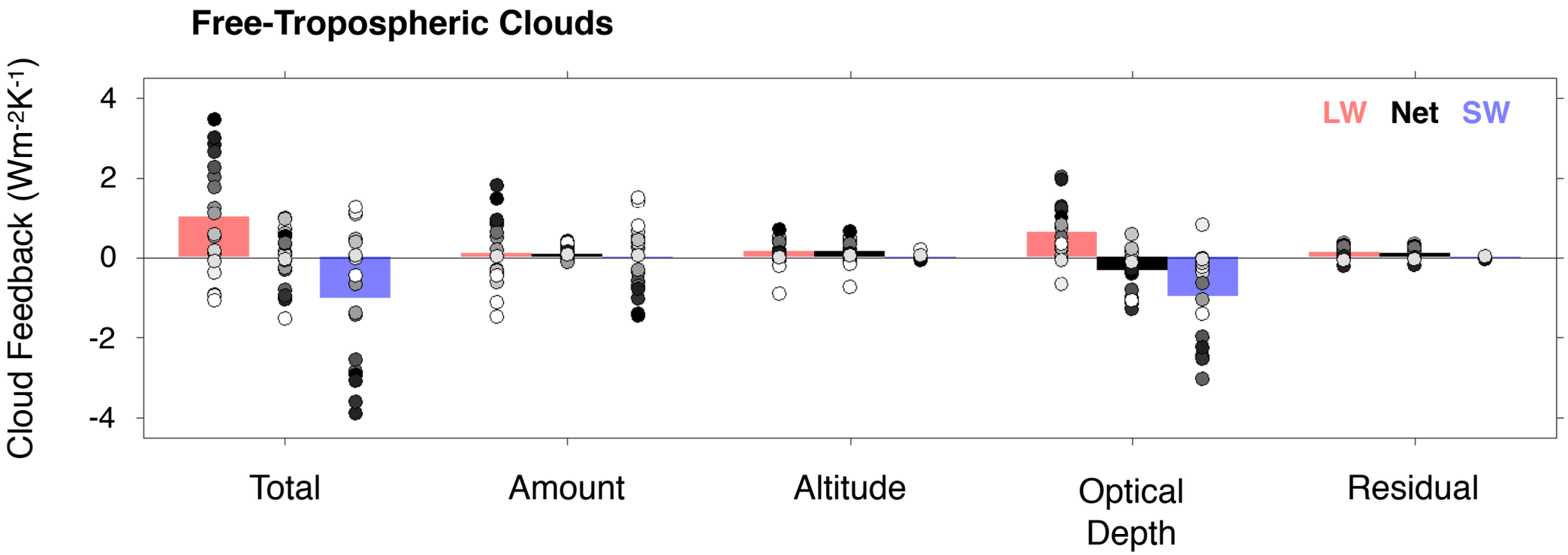


Future Research: Implications for Climate Change

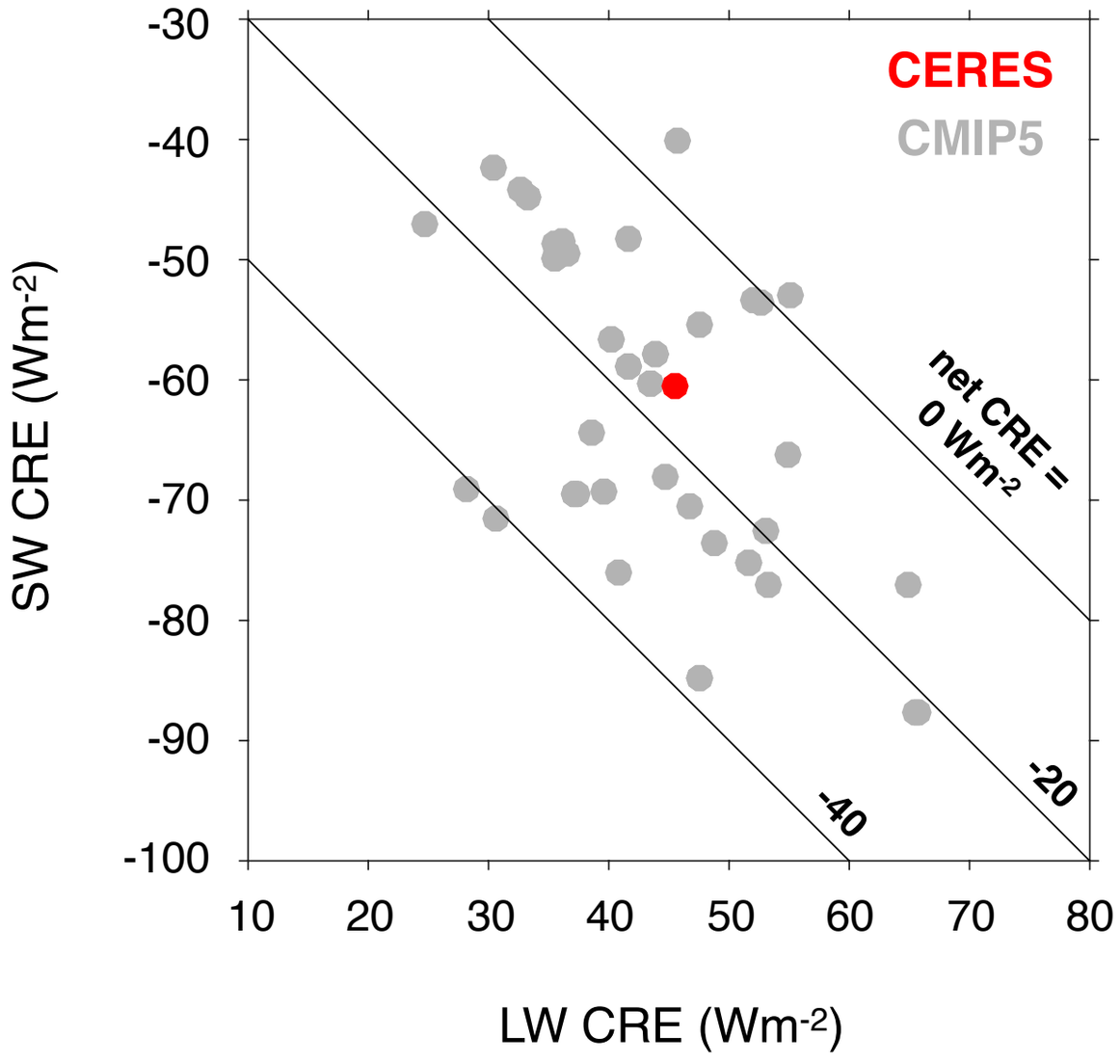
Cloud Feedbacks over the Tropical Western Pacific from CMIP5 Models



CMIP5 Cloud Feedbacks over the West Pacific Warm Pool

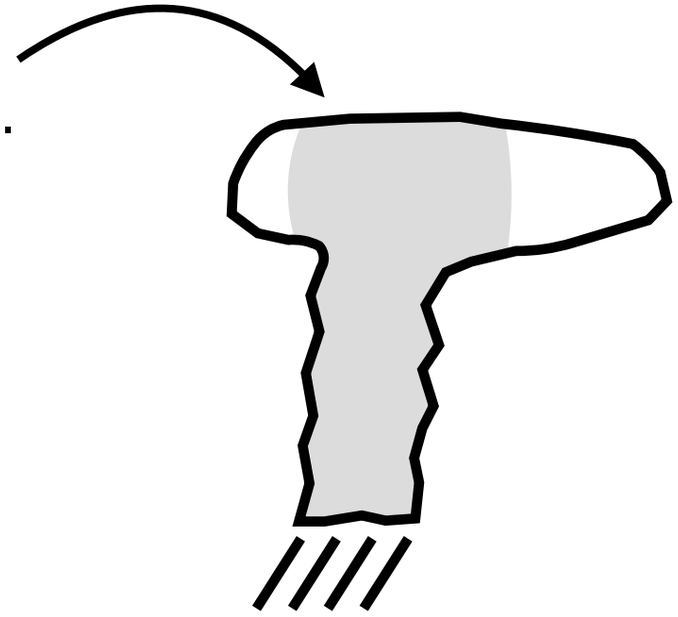


Climatology of CRE over the West Pacific Warm Pool in CMIP5 Fully-Coupled Simulations



The Coincidence Hypothesis
(Kiehl, 1994)

- The thick part of anvils determines the average CRE.
- These clouds are very thick, so their albedo and emissivity are fixed.
- Therefore
    1. SW CRE is determined only by insolation
    2. LW CRE is determined only by the tropopause temperature
    3. *Uniform net CRE is the result of a fortuitous coincidence*



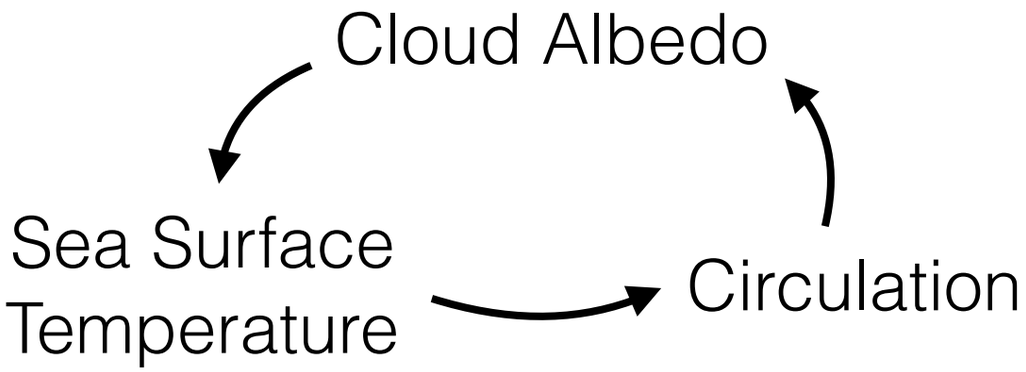
- Weak hypothesis: Life cycle of anvil clouds produces uniform net CRE [Hartmann et al., 2018].

Outline

Question

Why is net CRE about the same in convective and non-convective regions over the tropical warm pools?

Hypothesis

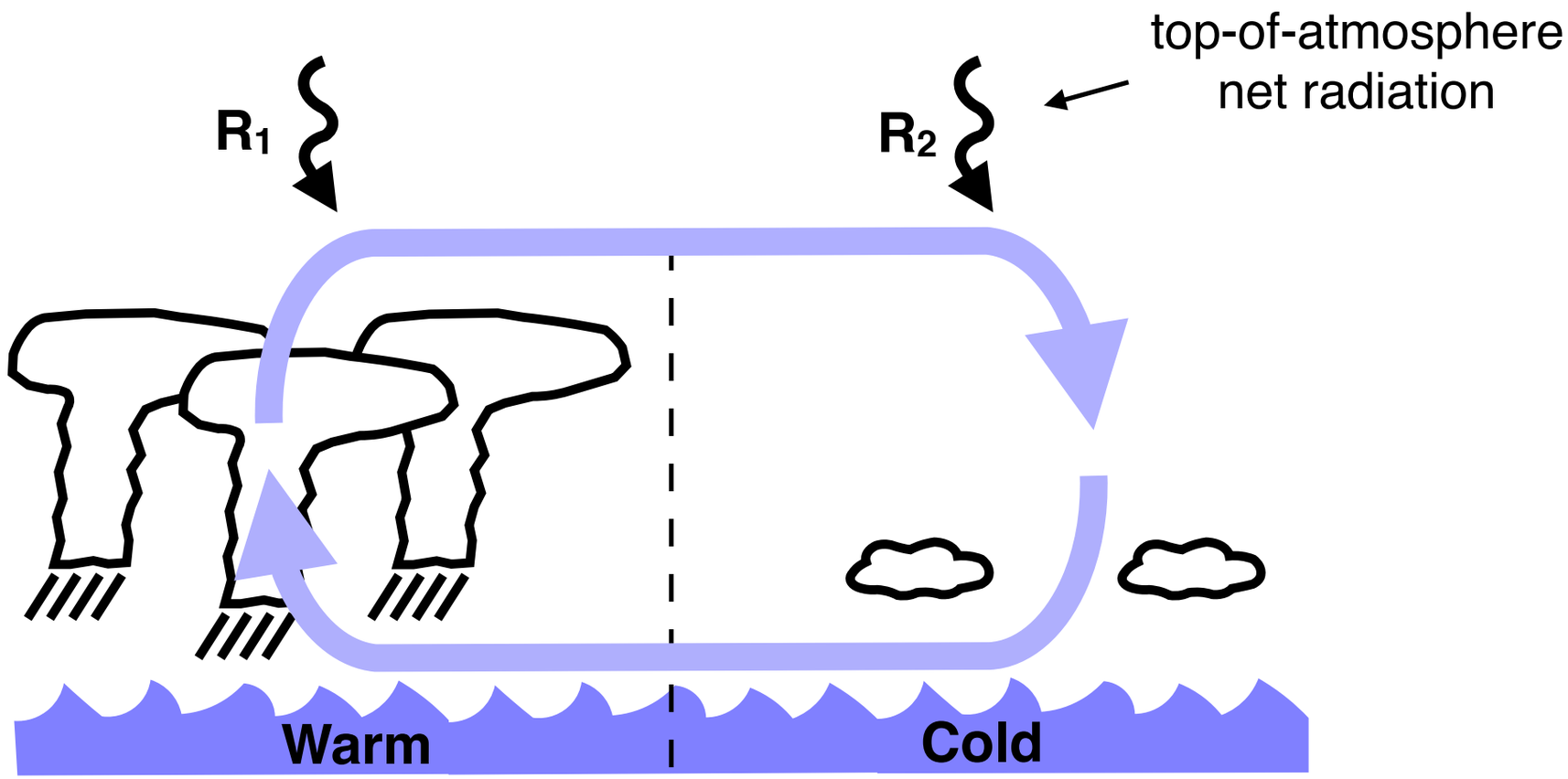


This is a key mechanism for producing uniform net CRE over the warm pools [Hartmann et al., 2001].

Objective

Test hypothesis with idealized GCM experiments

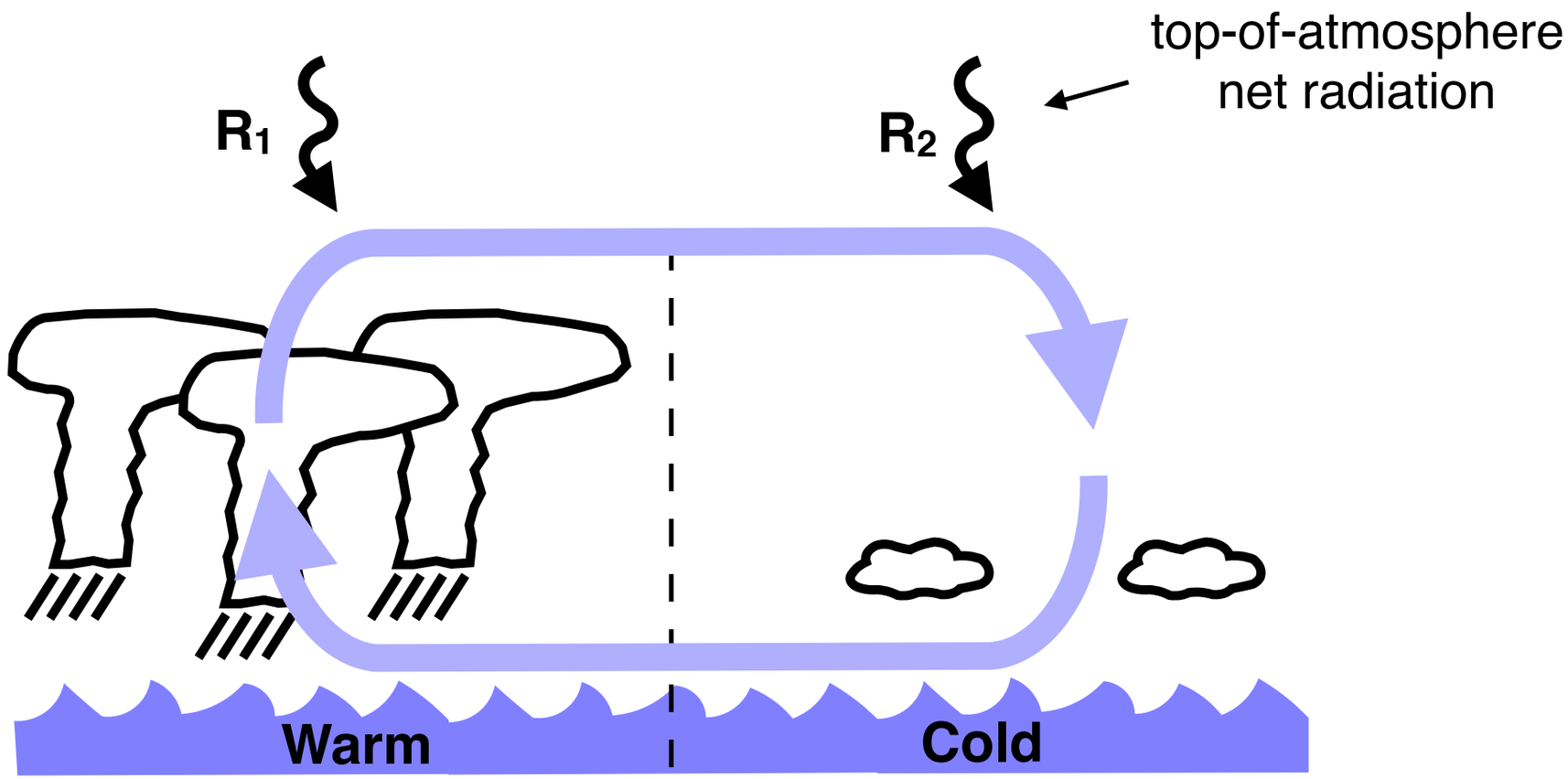
Hypothesis
(Hartmann et al., 2001)



Cloud shading feedback reduces SST gradient,
which reduces lateral heat transport,
which reduces the contrast in net radiation.

If the feedback is strong, then $R_1 \approx R_2$.

Hypothesis
(Hartmann et al., 2001)



Objective

Test hypothesis with idealized GCM experiments

Climate Model Experiments

Model Details

- CAM4
- global radiative-convective equilibrium configuration
- RCEMIP standard protocol
- aquaplanet
- 5 m slab ocean
- daily output

Is this model useful for testing the hypothesis?

- conserves energy
- resolves motions ~1500 km in scale
- simulates cloud shading feedback; SST fluctuations agree with observations [Wall et al., 2018]

Is the Net Cloud Radiative Effect Constrained to be Uniform over the Tropical Warm Pools?

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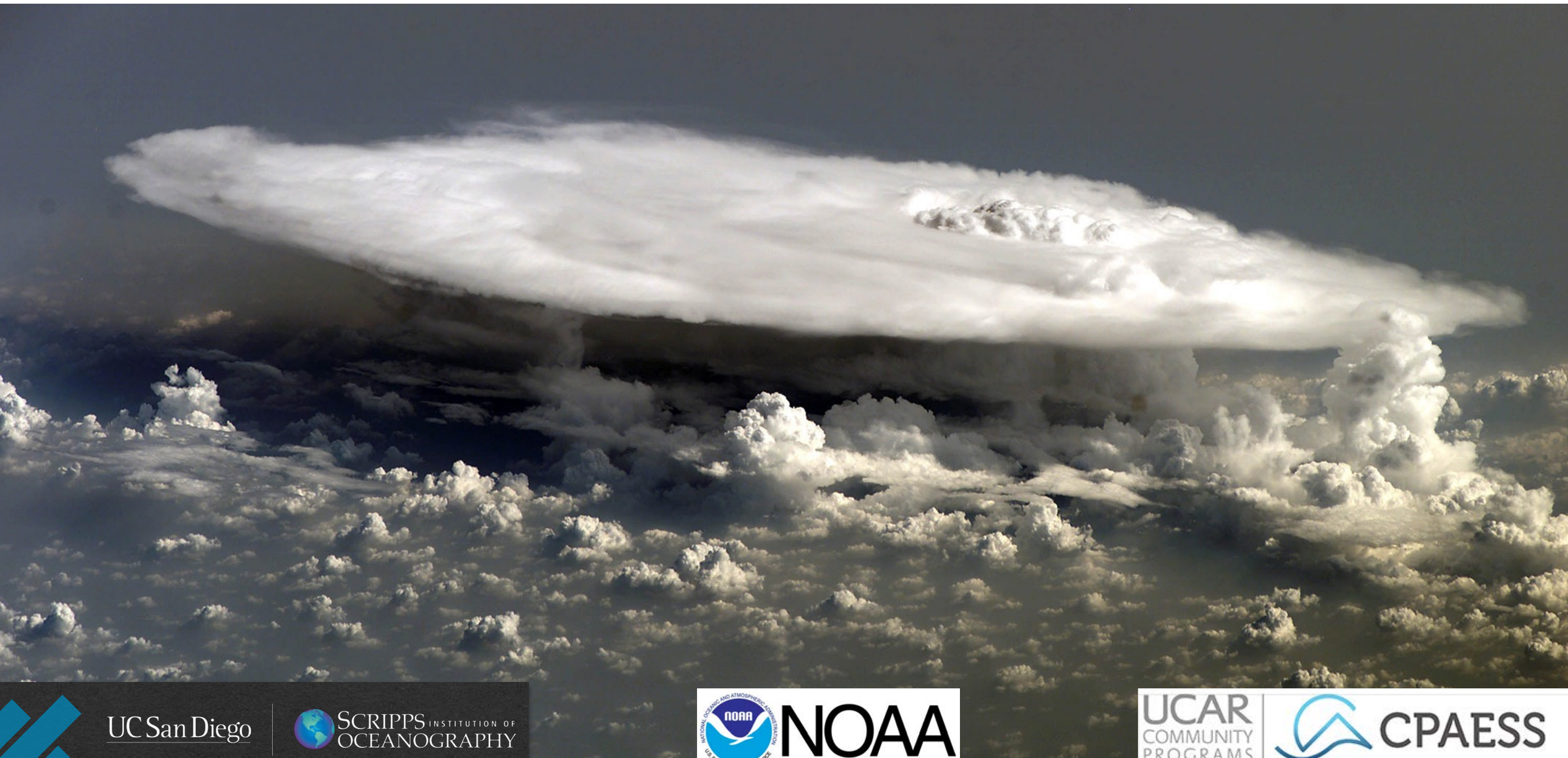

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Climate Model Experiments

Model Configuration:
CAM4 Global Radiative-Convective Equilibrium

- aquaplanet
- no rotation
- uniform insolation
- no aerosol effects
- 5 m slab ocean
- daily output

Experimental Design

Control
(cloud shading feedback on)

save $SW_{\downarrow}$ at ocean surface for every time step

randomly permute $SW_{\downarrow}$ in time dimension

Random SW
(cloud shading feedback off)

model sees randomized $SW_{\downarrow}$ at ocean surface

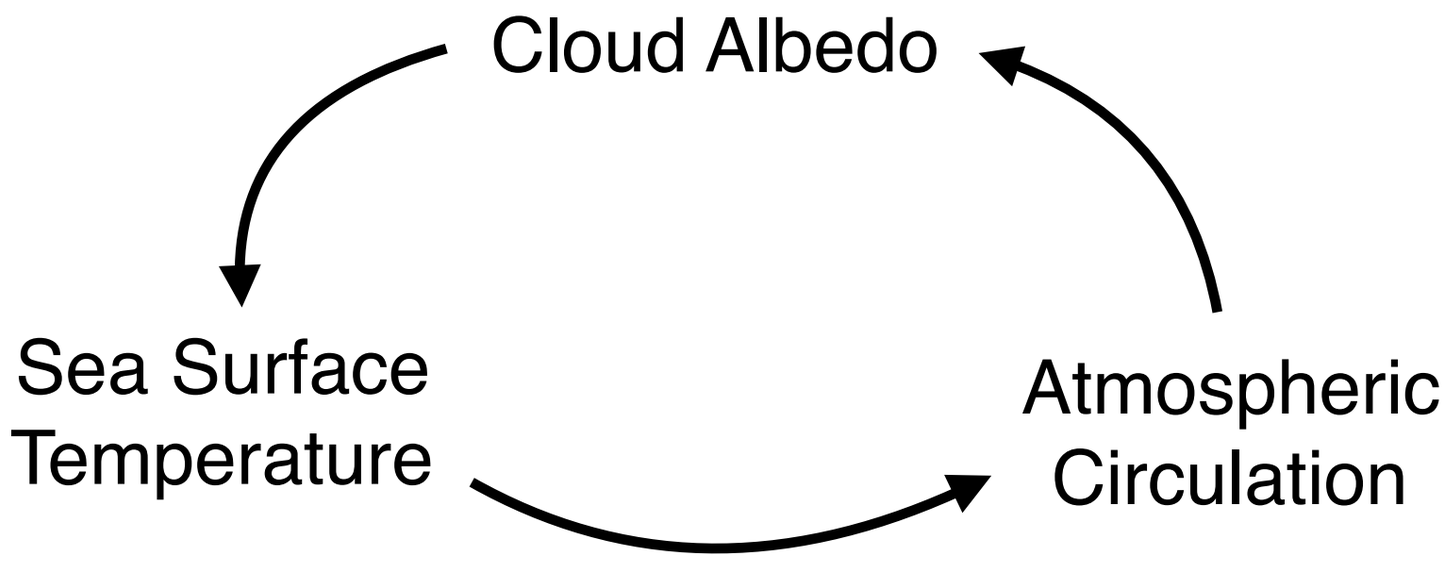
Hypothesis Testing

If the hypothesis is *correct*, then we will see:

	Control (feedback on)	**Random SW** (feedback off)
SST gradients	small	large
energy transport	small	large
CRE contrast	small	large

If the hypothesis is *incorrect*, then we will see:
Similar values in the two experiments

Hypothesis
(Hartmann et al., 2001)



“cloud shading feedback”