CONTRIBUTIONS OF DIFFERENT CLOUD TYPES TO FEEDBACKS & RAPID ADJUSTMENTS IN CMIP5

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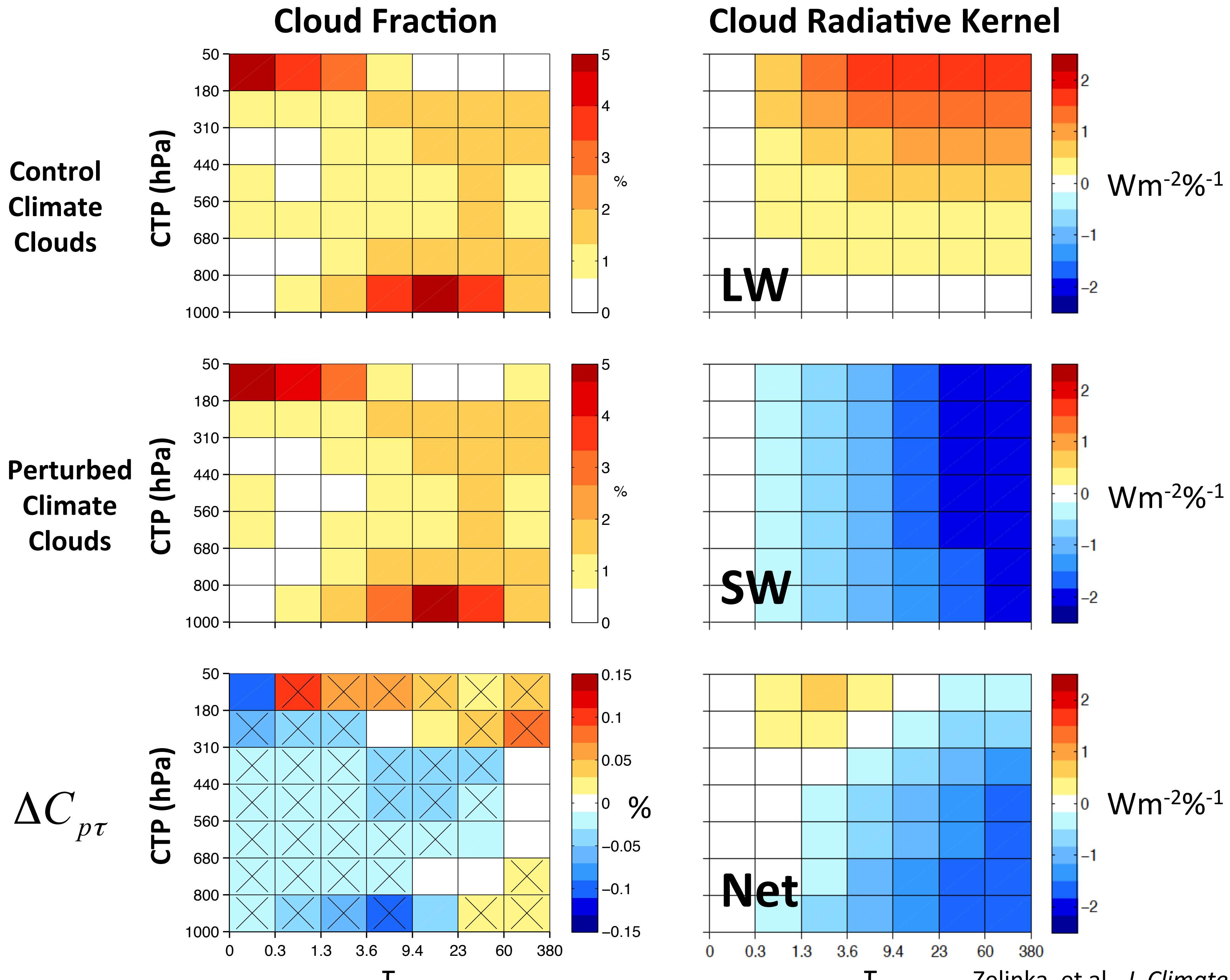
Calculating Cloud Feedbacks & Rapid Adjustments

- Method 1: Gregory analysis
  - Multiply Δclouds by their radiative impact (cloud radiative kernels)
  - Plot this product as function of T_{sfc}
    - Slope = cloud feedback
    - Y-intercept = rapid cloud adjustment

- Method 2: sstClim4xCO2 runs (Hansen-style experiments)
  - SSTs held fixed while CO_2 is quadrupled
  - Gives another estimate of the rapid adjustment

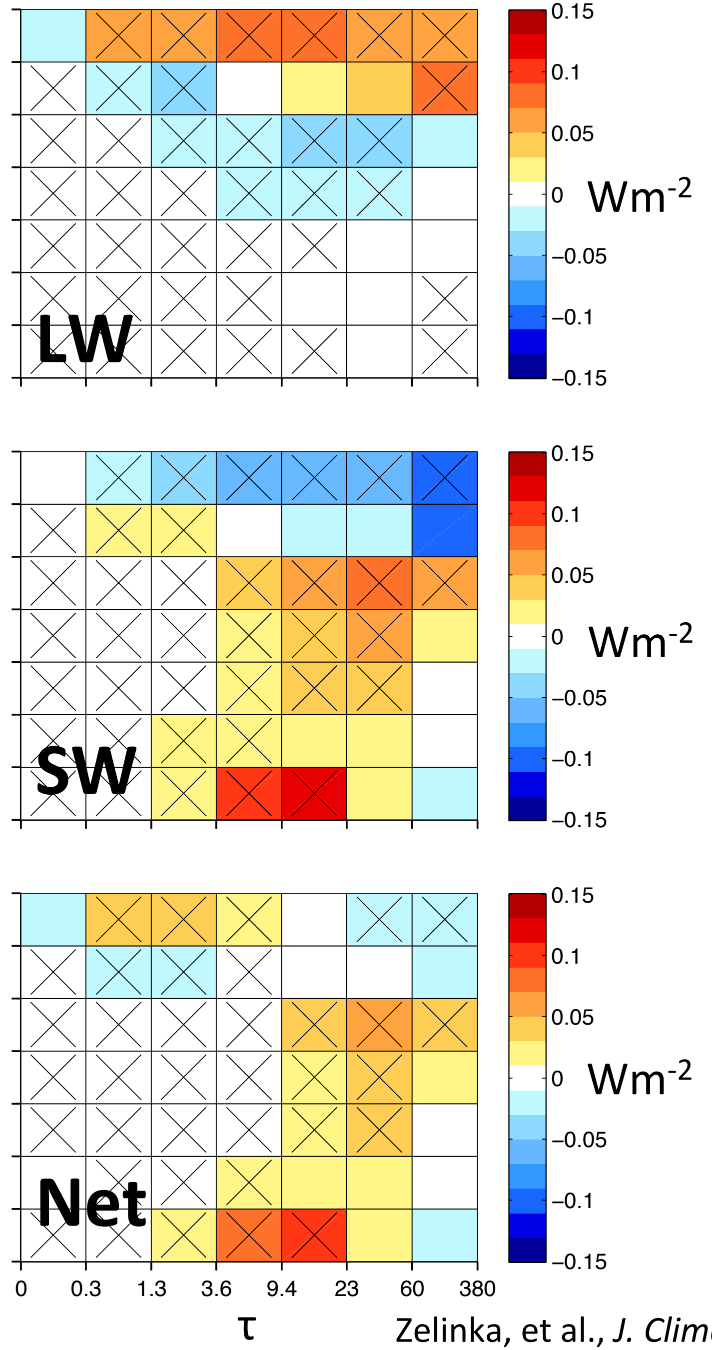


Zelinka, et al., *J. Climate* (2012a)

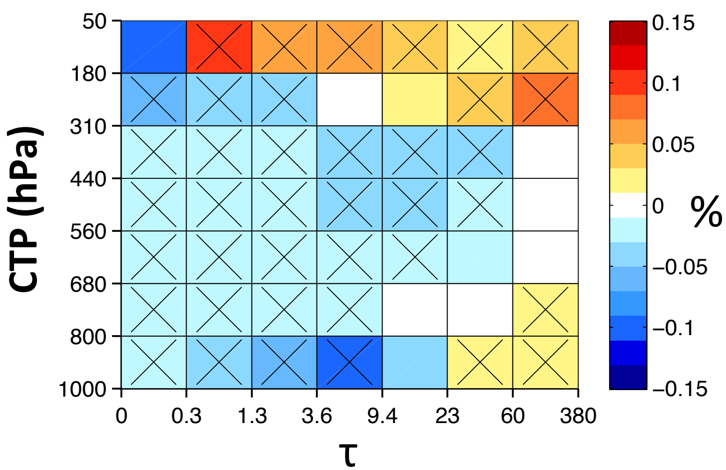
Cloud-Induced Rad. Anomalies

$$\Delta R_C = \sum_{p=1}^{P}\sum_{\tau=1}^{T}(K_{p\tau} \times \Delta C_{p\tau})$$

Plot ΔR_C against ΔT_S
→ slope = feedback



$\Delta C_{p\tau}$



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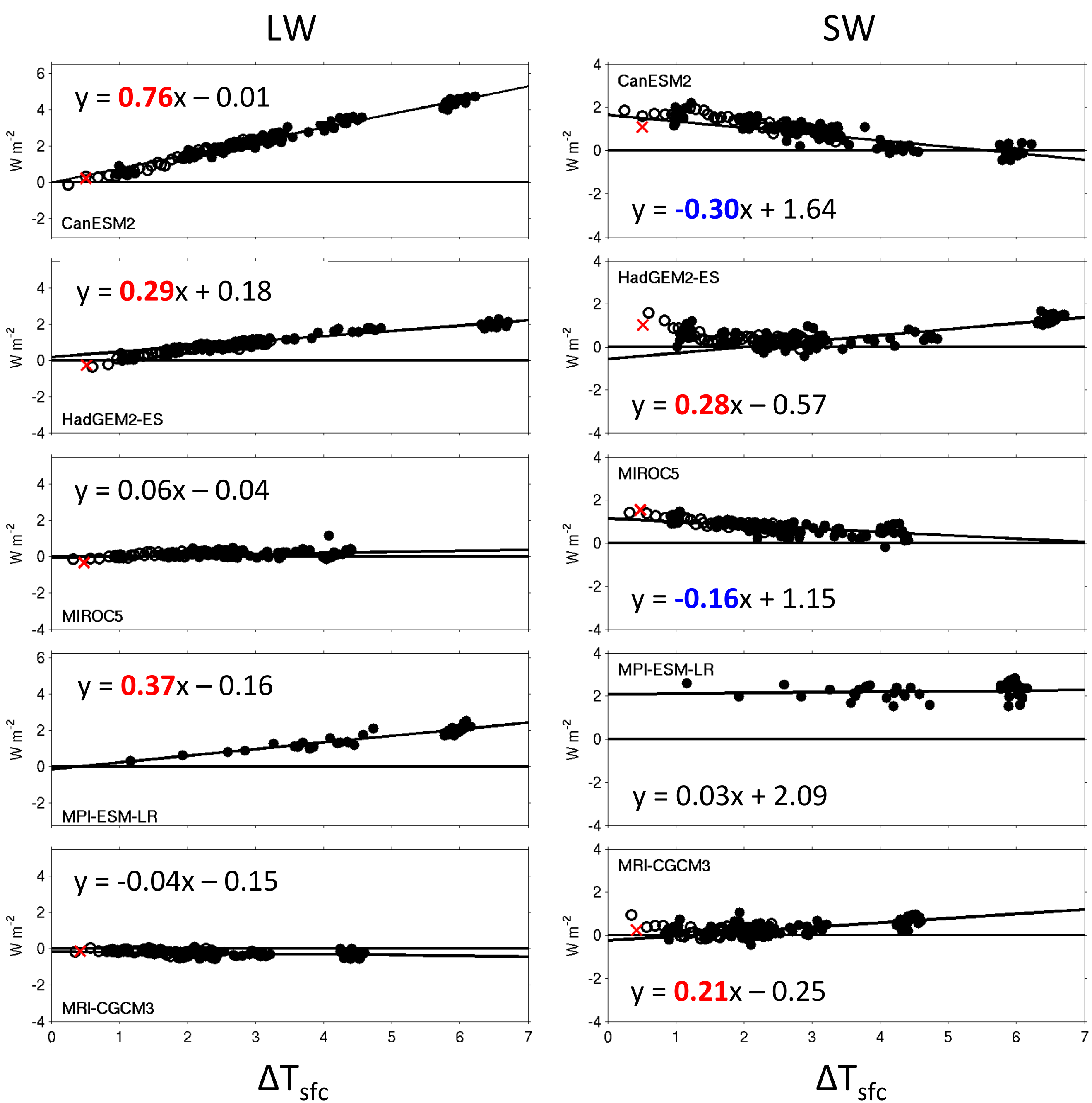


- Cloud-induced radiation anomalies

  (Positive = heating)

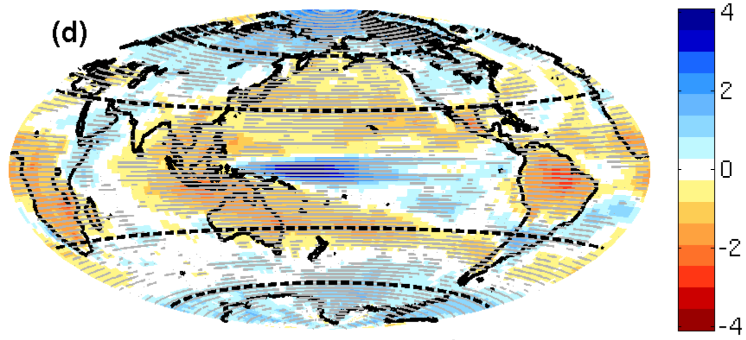
Zelinka et al., *J. Climate* (in press)

What happens to clouds as the planet warms in climate models?

Implied Feedback

Clouds go away

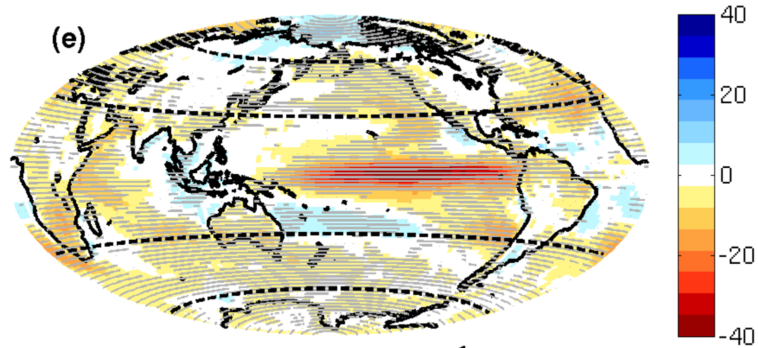
Δ Total Cloud Frac.: -0.10 % K^{-1}



POSITIVE

Clouds rise

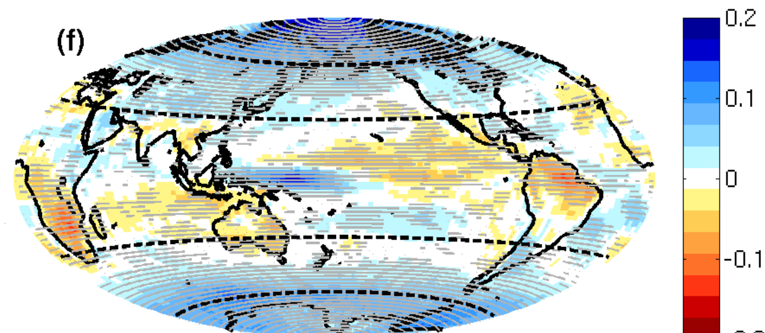
Δ CTP: -3.76 hPa K^{-1}



POSITIVE

Cold clouds get brighter

Δτ: 2.0 % K^{-1}



NEGATIVE

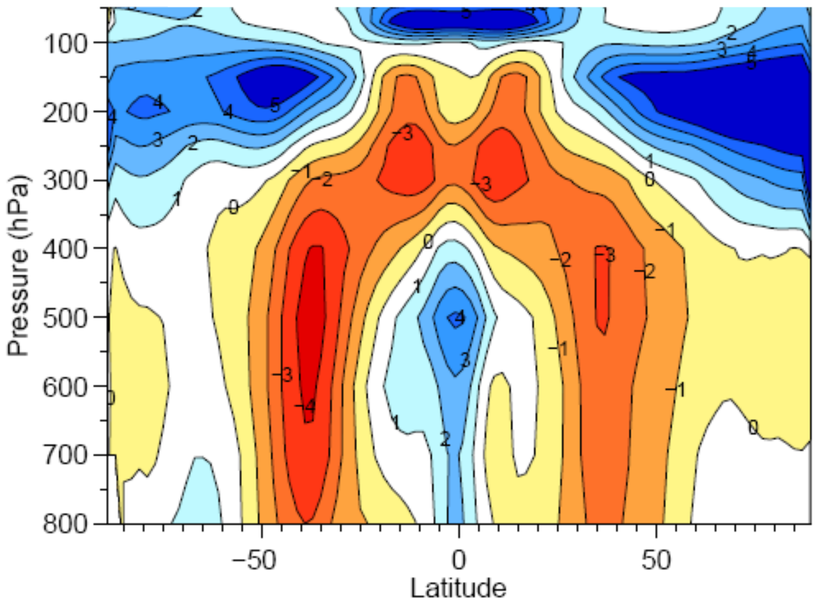
....but the devil is in the details...

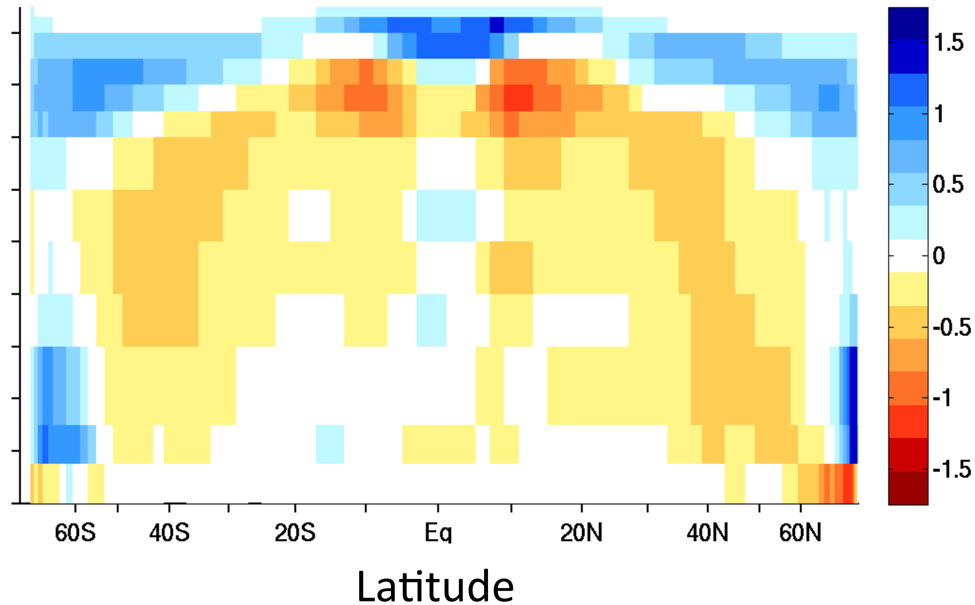
Zelinka, et al., *J. Climate* (in press)

T_{sfc}-Mediated Cloud Changes

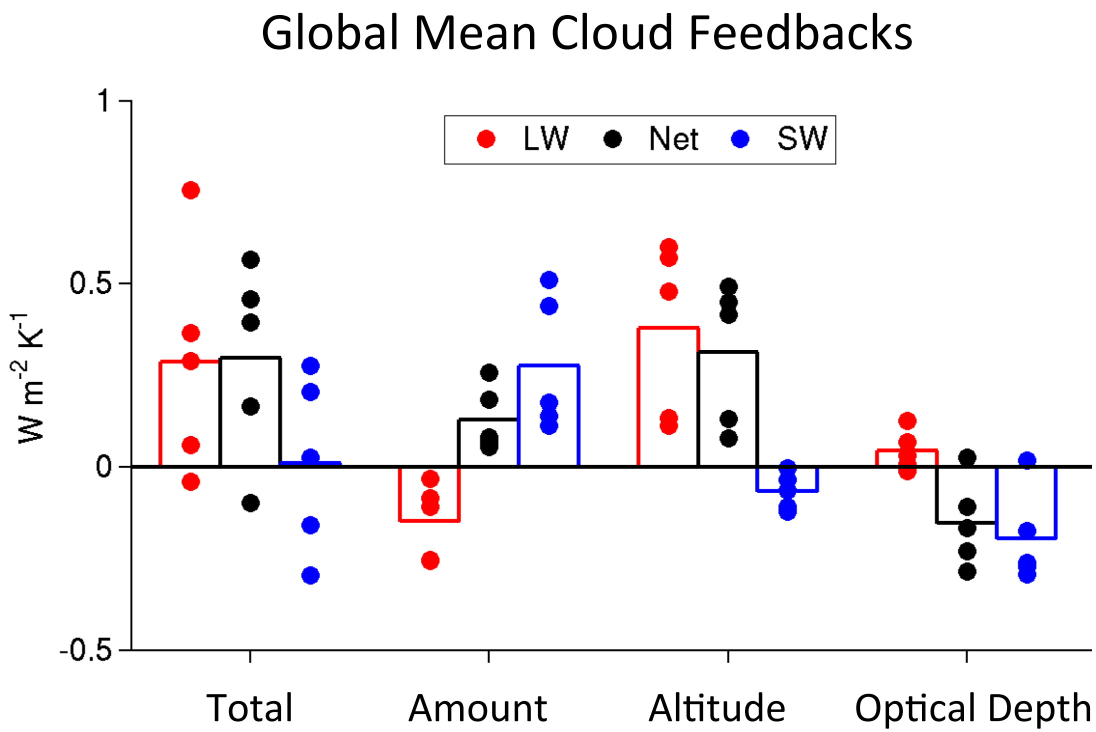
ΔRH (%, absolute)

SRES A2: 2090s minus 2000s





Zelinka, et al., *J. Climate* (in press)



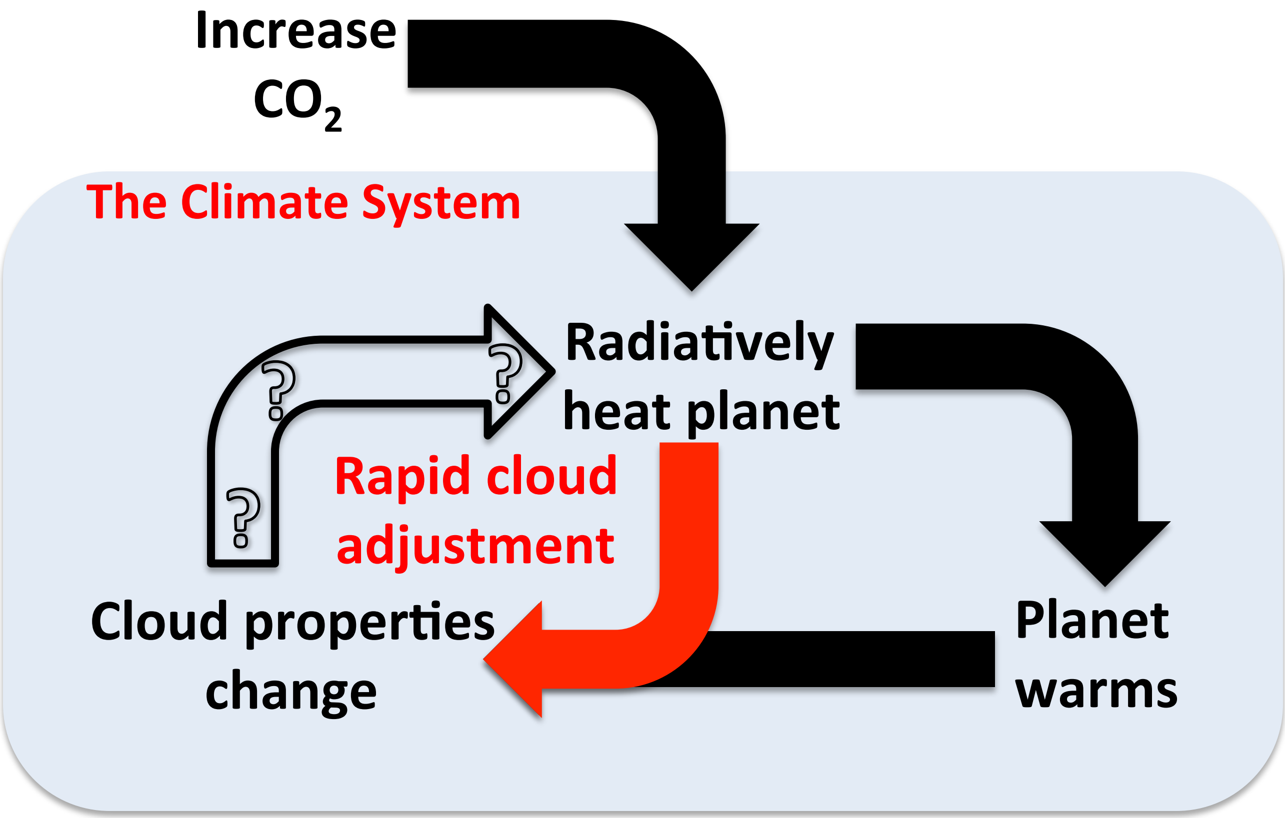
As the planet warms, clouds become **fewer, higher**, and **thicker**
→ The SW cloud feedback is small because fewer oppose thicker

The net cloud amount and altitude feedbacks are **robustly positive**

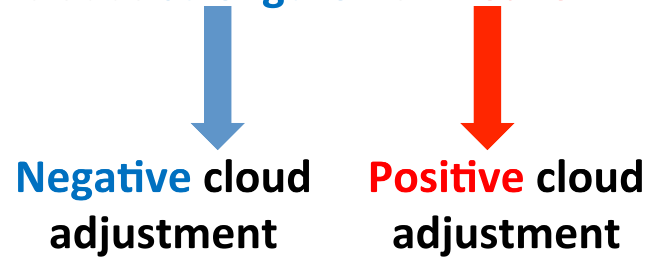
As in CMIP3, biggest inter-model spread in **net** comes from low clouds,
but biggest inter-model spread in **LW** and **SW** comes from high clouds

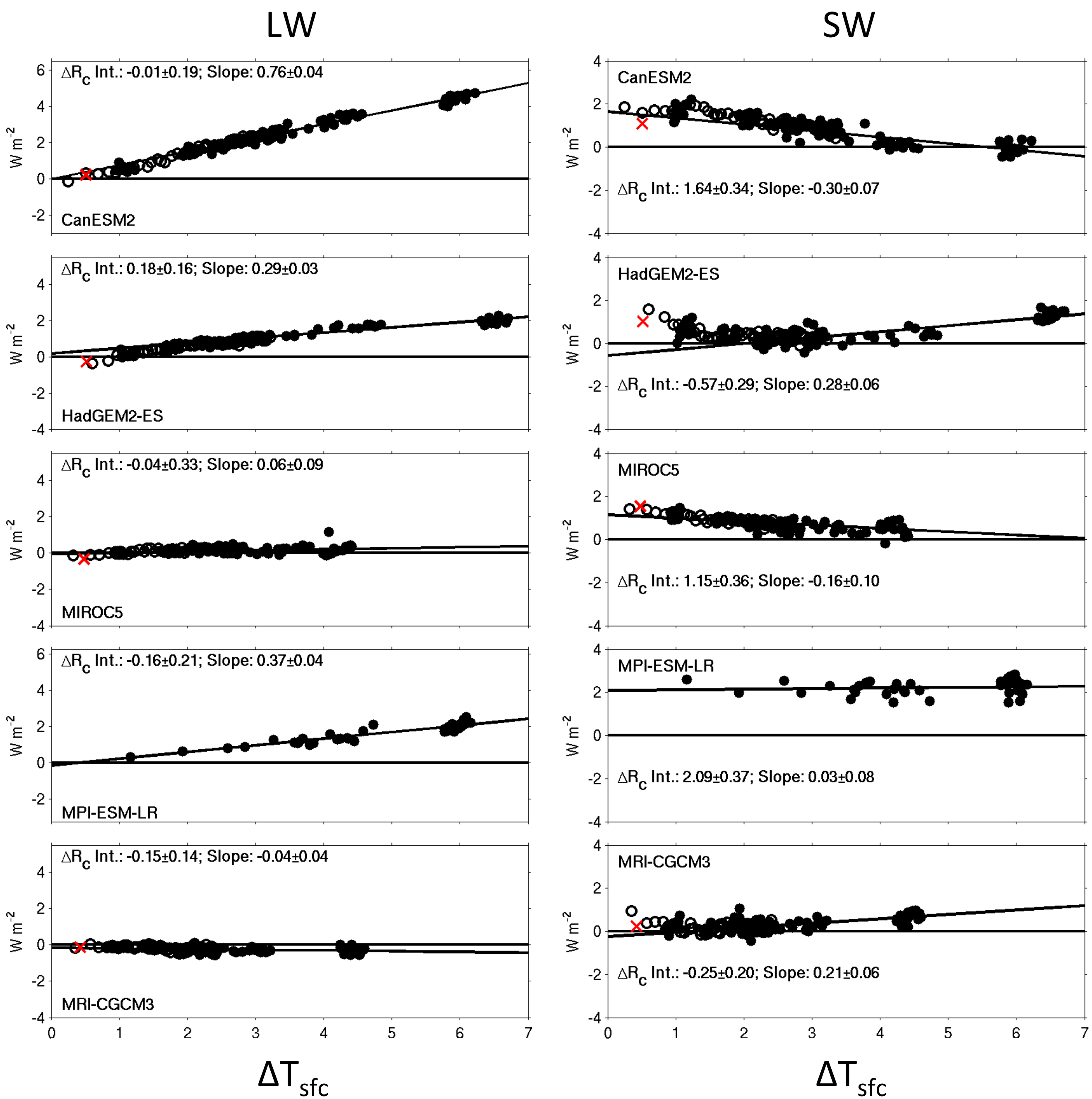
Zelinka, et al., *J. Climate* (in press)

Cloud Feedback + Adjustment



Immediately upon increase of CO_2, does the cooling effect of clouds **strengthen** or **weaken**?





- Cloud-induced radiation anomalies

x Radiation anomalies from fixed SST runs with 4xCO_2 imposed

(Positive = heating)

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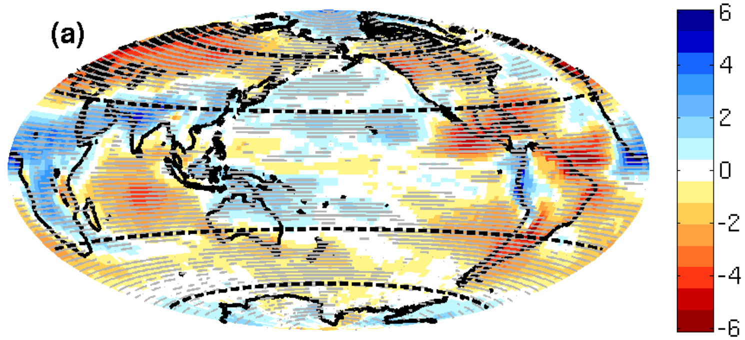
What happens to clouds immediately upon quadrupling CO_2?

Implied Radiative Impact

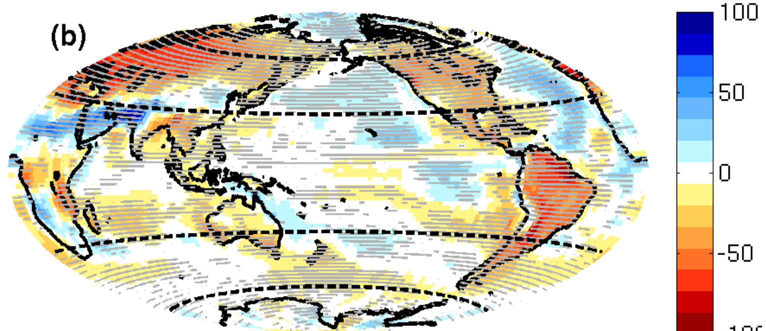
Δ Total Cloud Frac.: -0.50 %



Clouds go away

POSITIVE

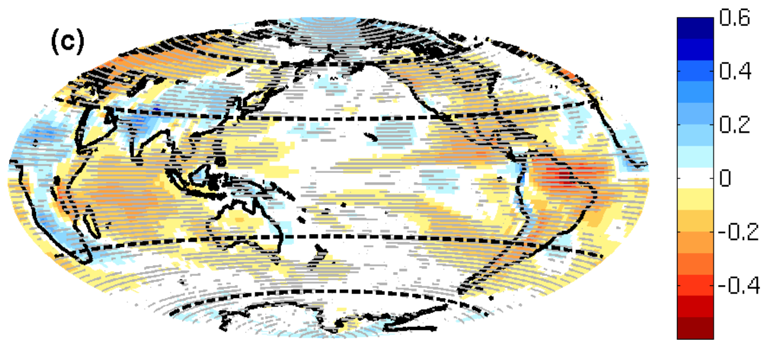
Δ CTP: -8.30 hPa



Clouds rise (esp. over land)

POSITIVE

Δτ: -4 %

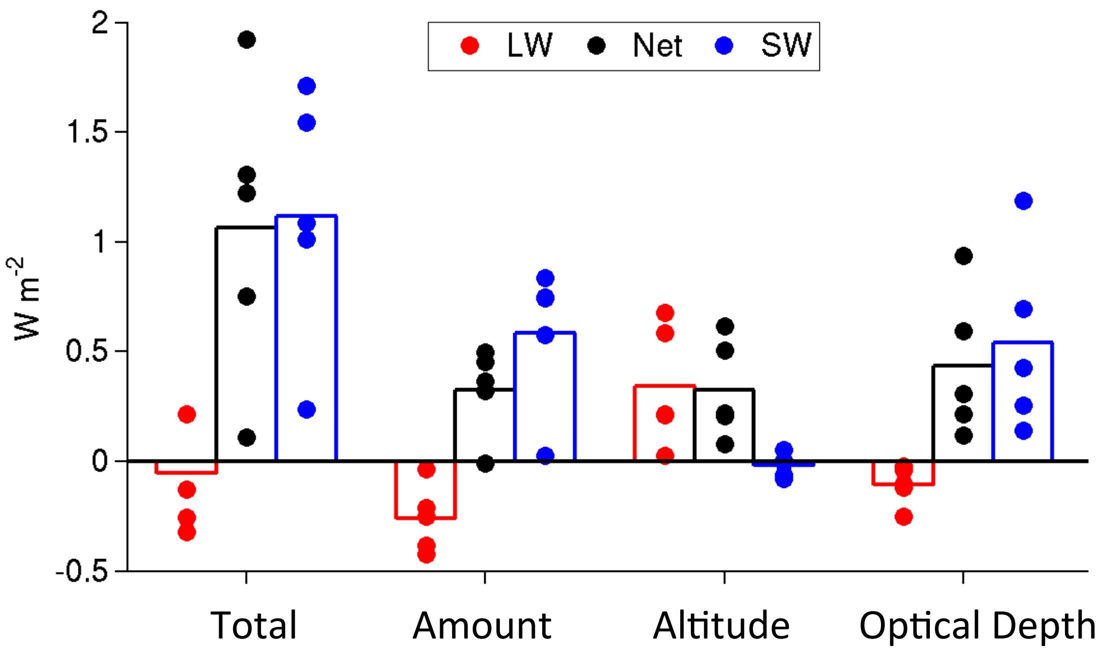


Clouds get darker

POSITIVE

Zelinka, et al., *J. Climate* (in press)

Global Mean Rapid Cloud Adjustments

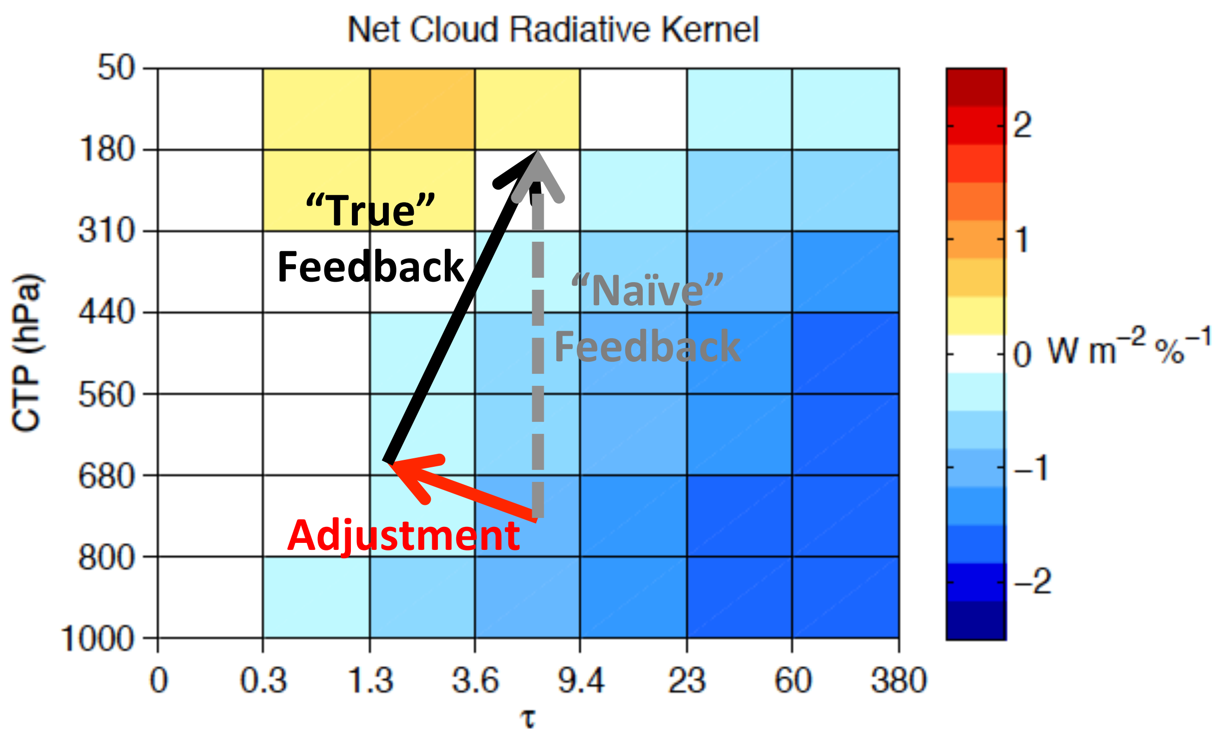


Immediately upon CO_2 quadrupling, clouds become **fewer, higher**, and **thinner**
→ the LW cloud adjustment is small because fewer/thinner oppose higher

Thinner & fewer act together to bring about a big reduction in reflected SW.

Zelinka, et al., *J. Climate* (in press)

Importance of properly accounting for rapid adjustments



* Here we are considering only altitude and optical depth feedbacks

Conclusions

- Upon 4xCO_2, clouds rapidly become **fewer, higher, and thinner**, each contributing equally to a **+1.1 W m^{-2} net cloud radiative adjustment**
  - Rapid reductions in mid-level clouds and optically thick clouds are especially important in reducing planetary albedo in every model.

- As the planet warms, clouds become **fewer, higher, and thicker**, and global mean **net cloud feedback is positive in all but one model**
  - As in CMIP3, **low** cloud changes are the largest contributor to the mean and spread in **net cloud feedback**, but **high** cloud changes are the largest contributor to inter-model spread in **LW** and **SW cloud feedbacks**.

- Accounting for rapid adjustments **reduces the ensemble mean net cloud feedback by 0.14 W m^{-2} K^{-1}** (to 0.30 W m^{-2} K^{-1})
  - Due to combination of smaller positive cloud amount & altitude feedbacks and a larger negative optical depth feedback.

Zelinka, et al., *J. Climate* (in press)