Tropical Deep Convecting Clouds

Catherine Stauffer

MS Seminar

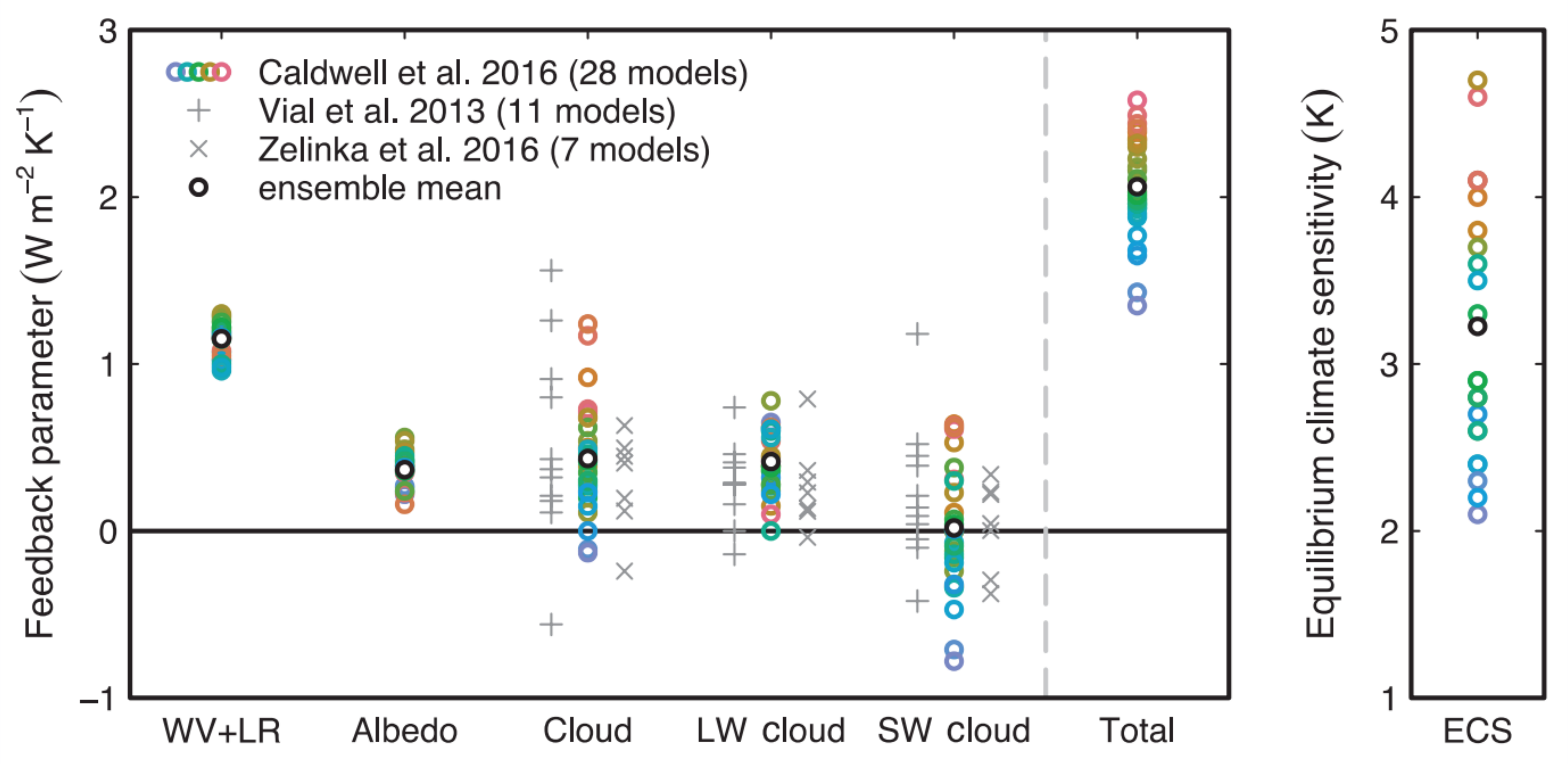


Figure 1. Ceppi et al. (2017)

Radiative-Convective Equilibrium Model Intercomparison Project (RCEMIP; Wing et al, 2018)

- Idealized simulations of RCE

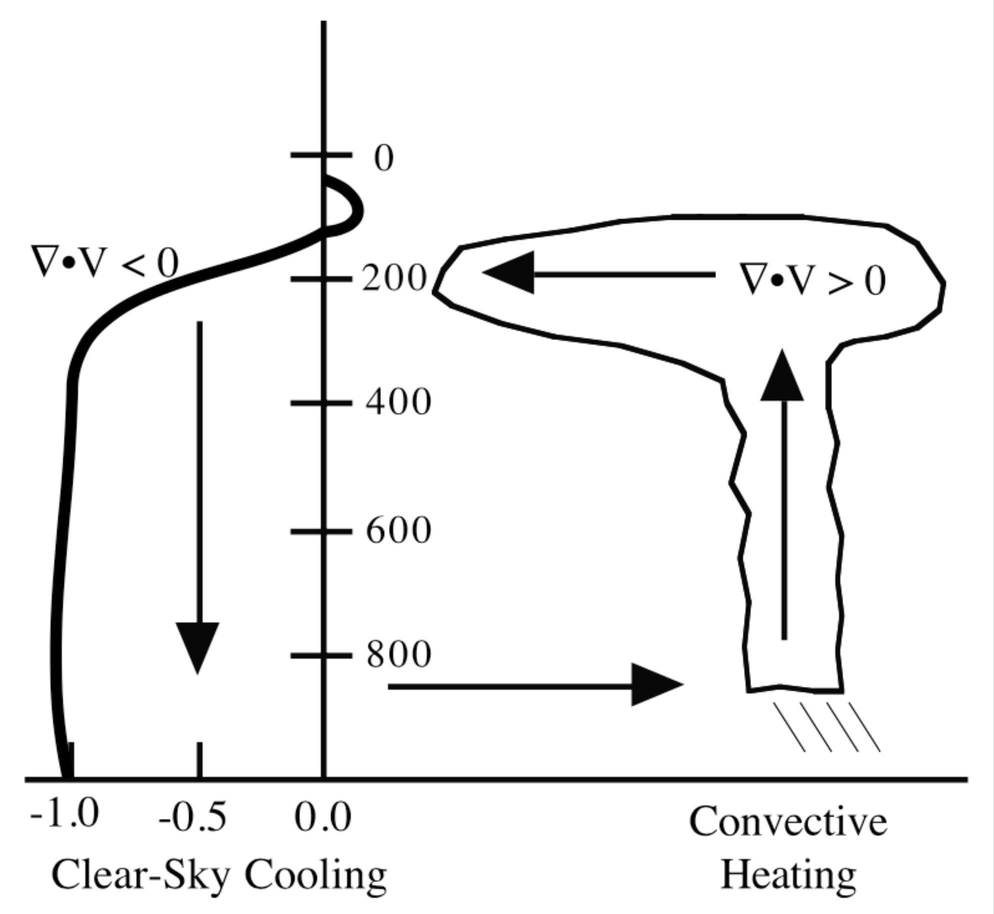
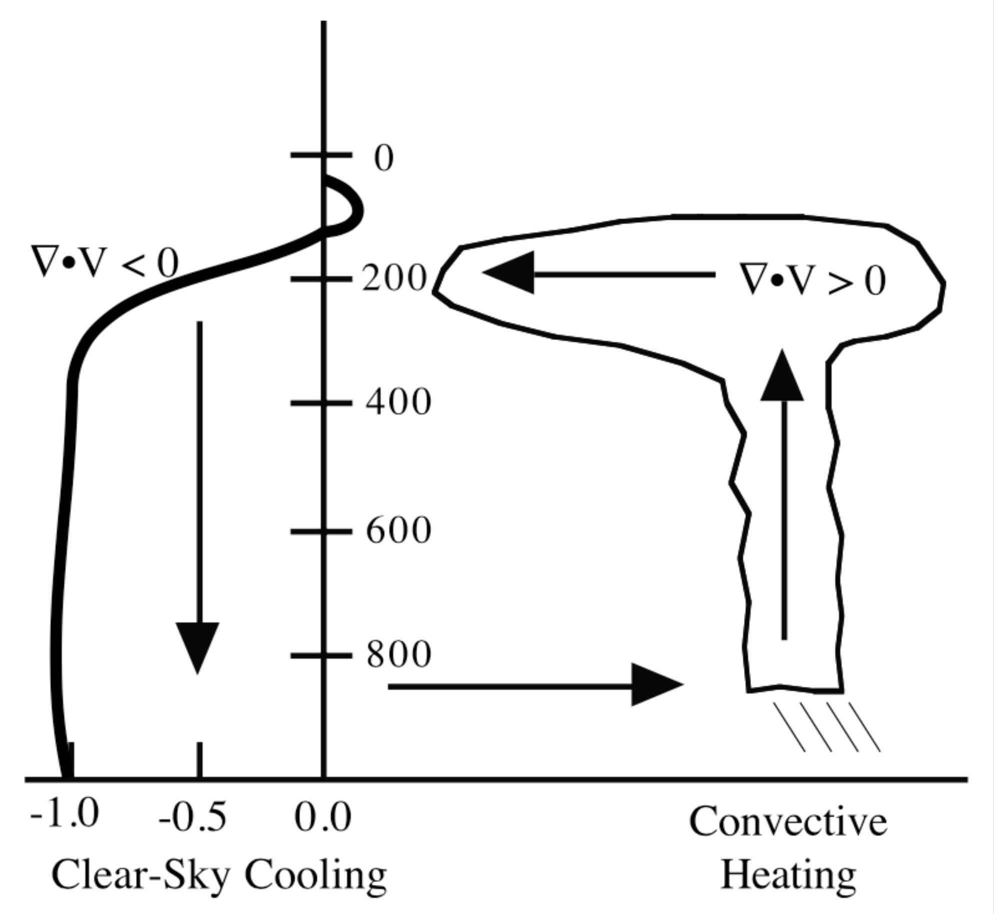


Figure 1. Hartmann and Larson (2002)

Radiative-Convective Equilibrium Model Intercomparison Project (RCEMIP; Wing et al, 2018)

- Idealized simulations of RCE
- 3 SSTs, 2 domains
- Hierarchy of models
  - CRMs, GCMs, GCRMs, LES, SCMs



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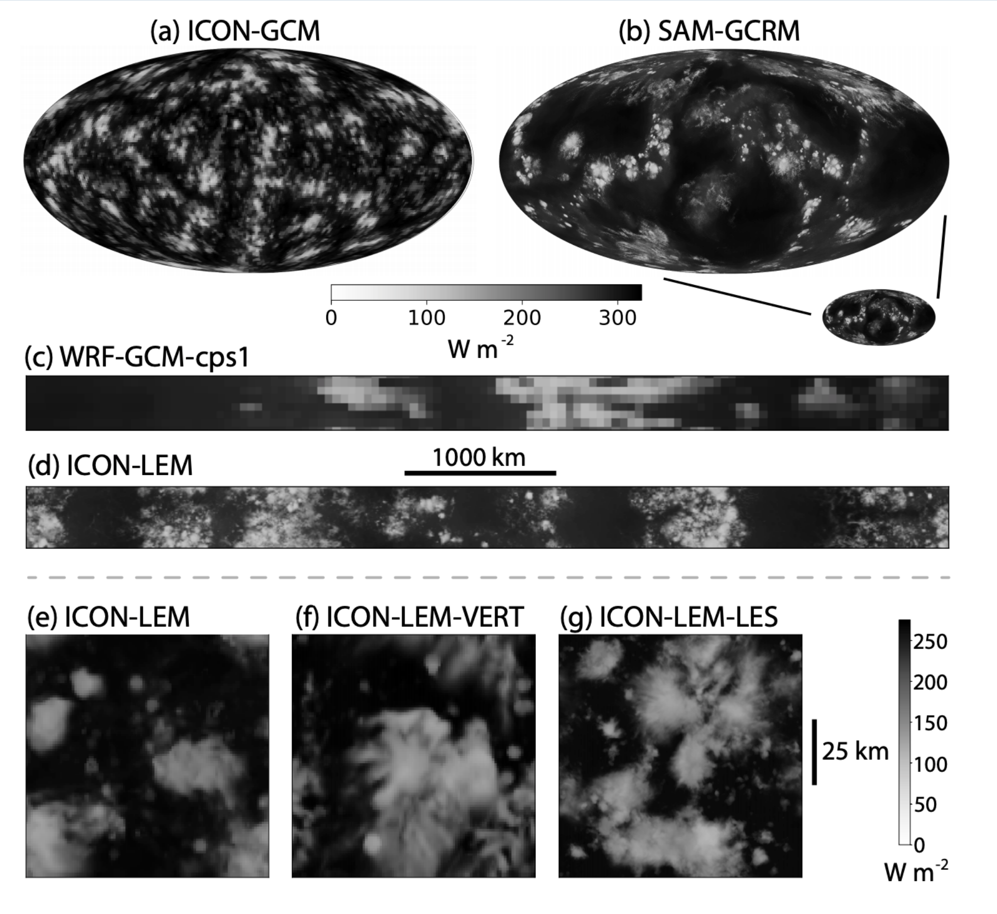


Becker and Wing (2020)

Radiative-Convective Equilibrium Model Intercomparison Project (RCEMIP; Wing et al, 2018)

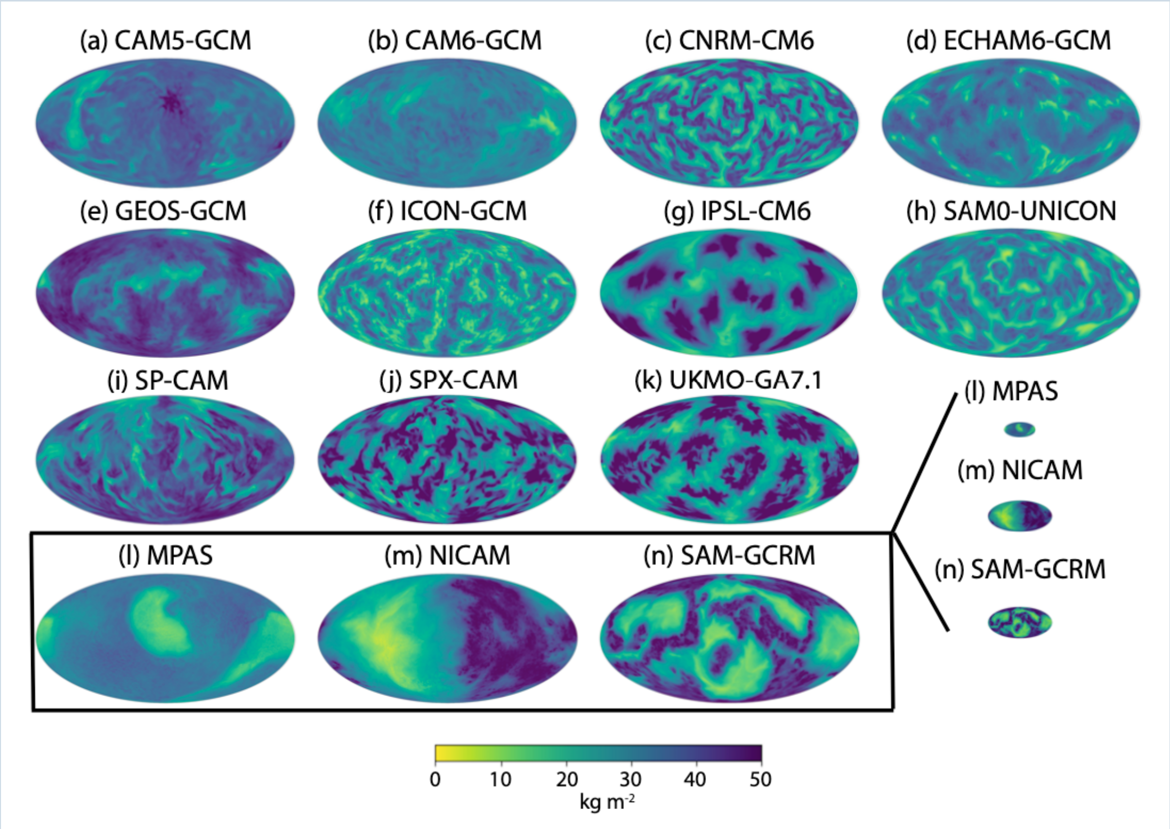
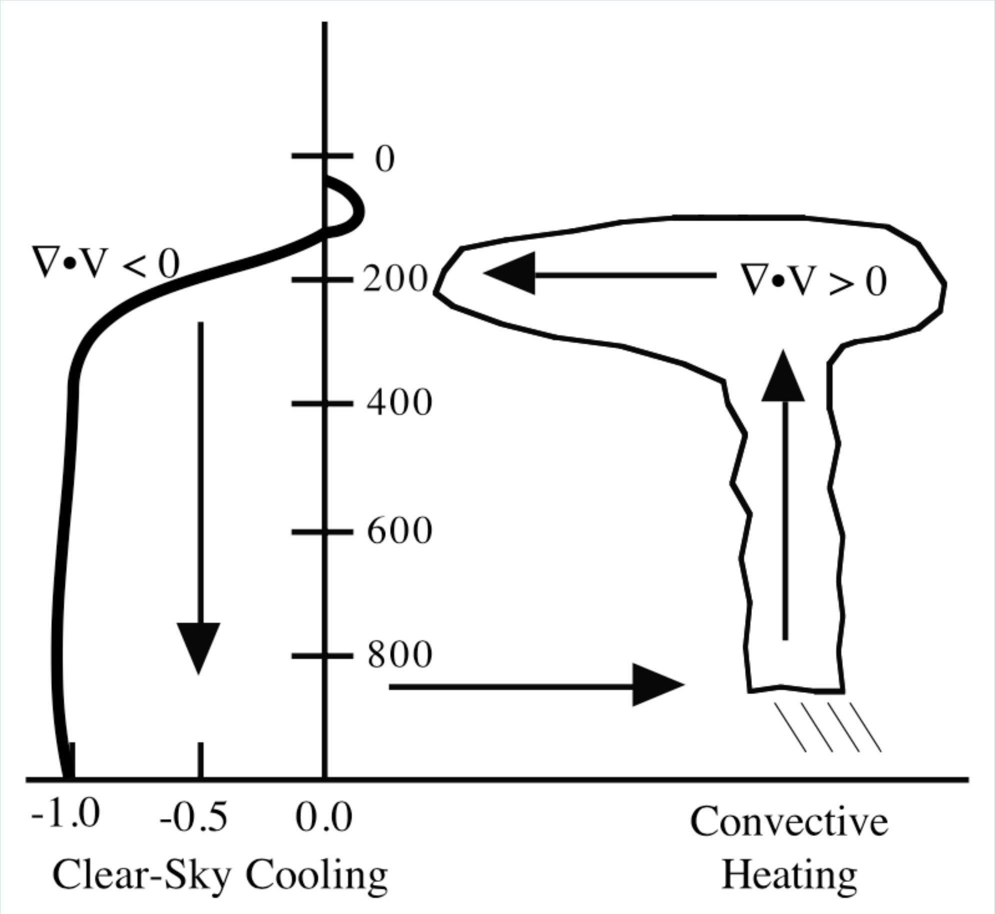


Figure S4. Wing et al. (2020)
(precipitable water)



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RCEMIP

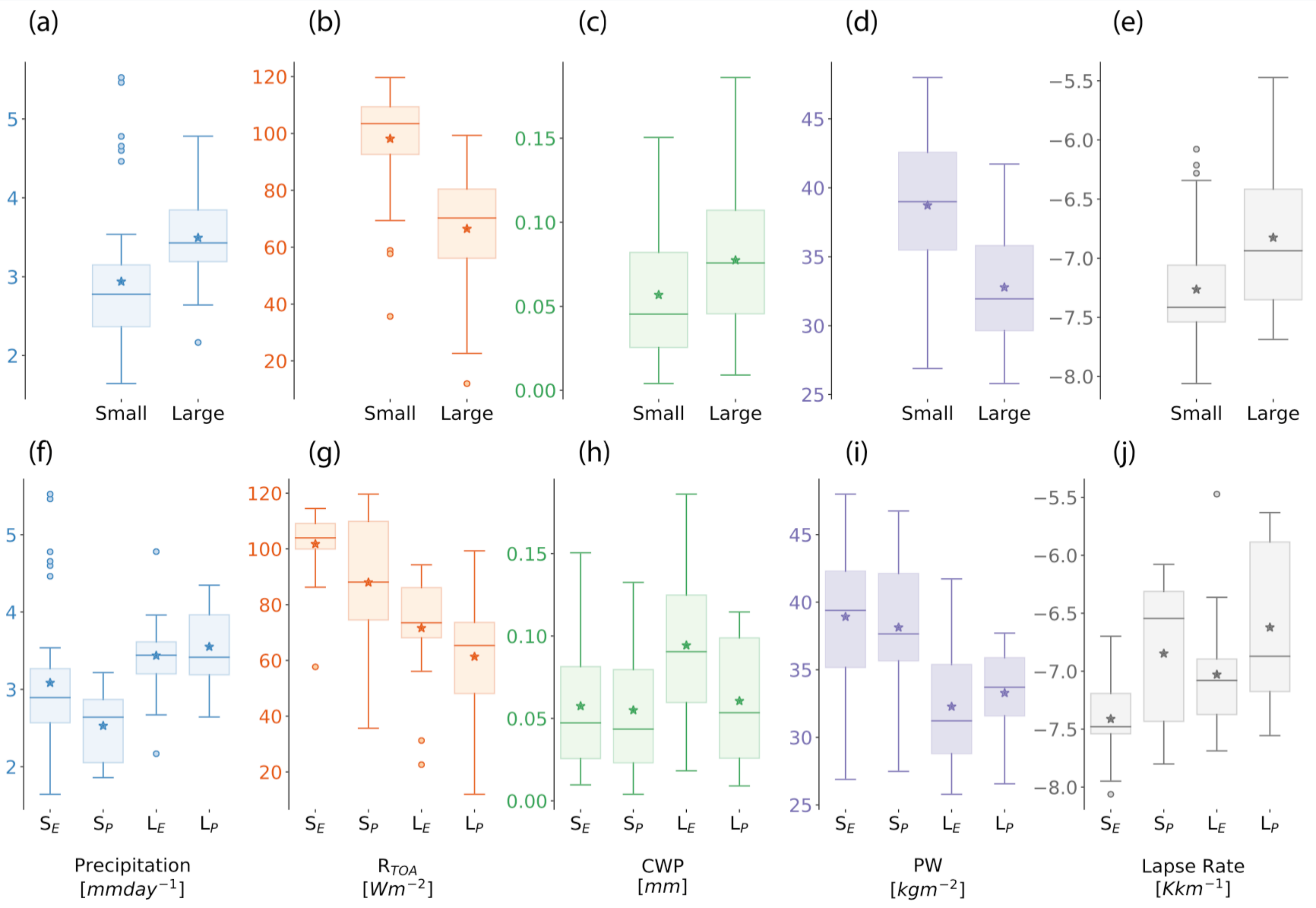


Figure 11. Wing et al. (2020)

FAT, PHAT, FAP, FiTT

Hypotheses on the behavior of cloud top properties

FAT: Fixed Anvil Temperature

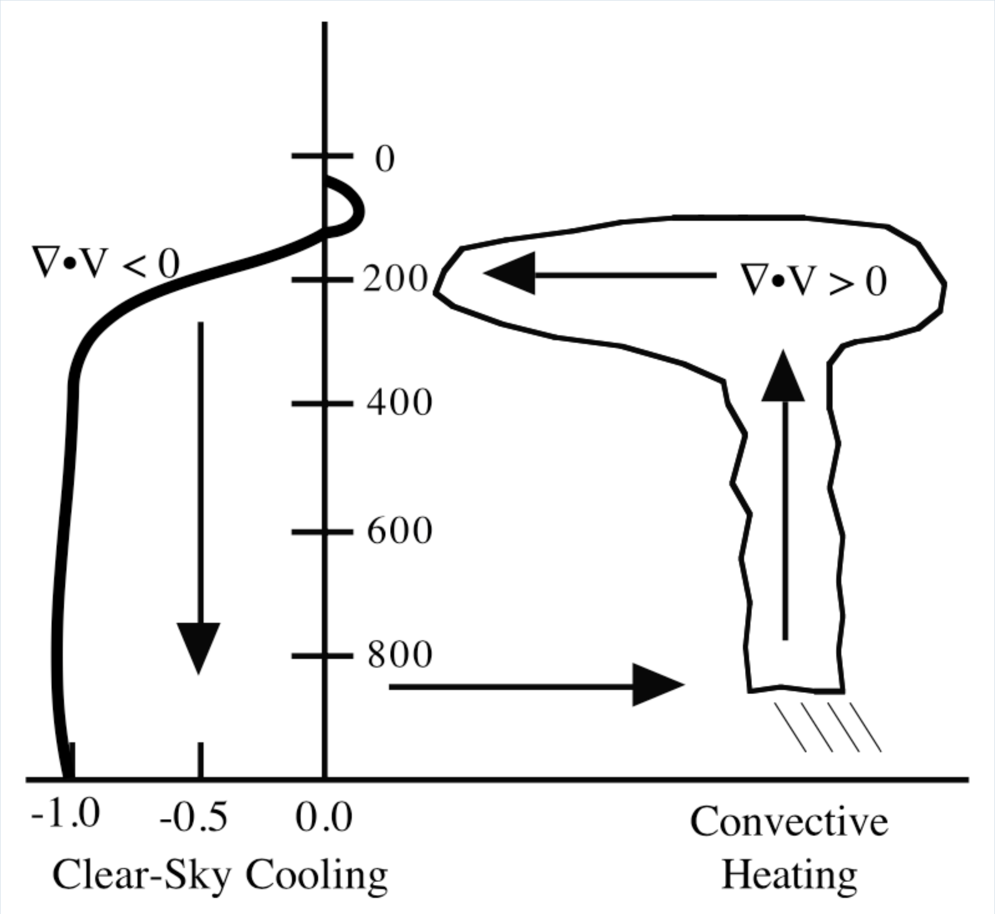


Figure 1. Hartmann and Larson (2002)

- The temperature where water vapor becomes an inefficient emitter of radiation
- The level where this occurs is the level of the anvil cloud

PHAT: Proportionally Higher Anvil Temperature

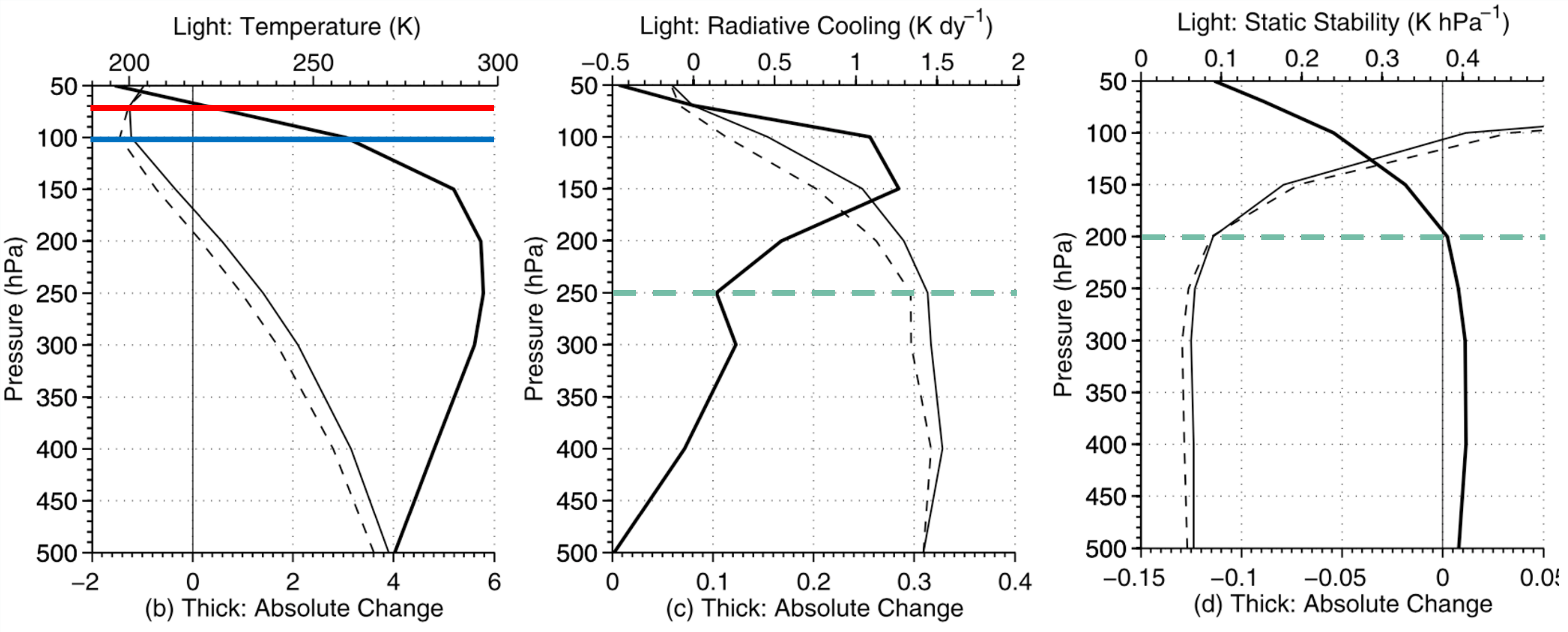


Figure 3b,c,d. Zelinka and Hartmann (2010)

Impact of anvil response on LW Cloud feedback

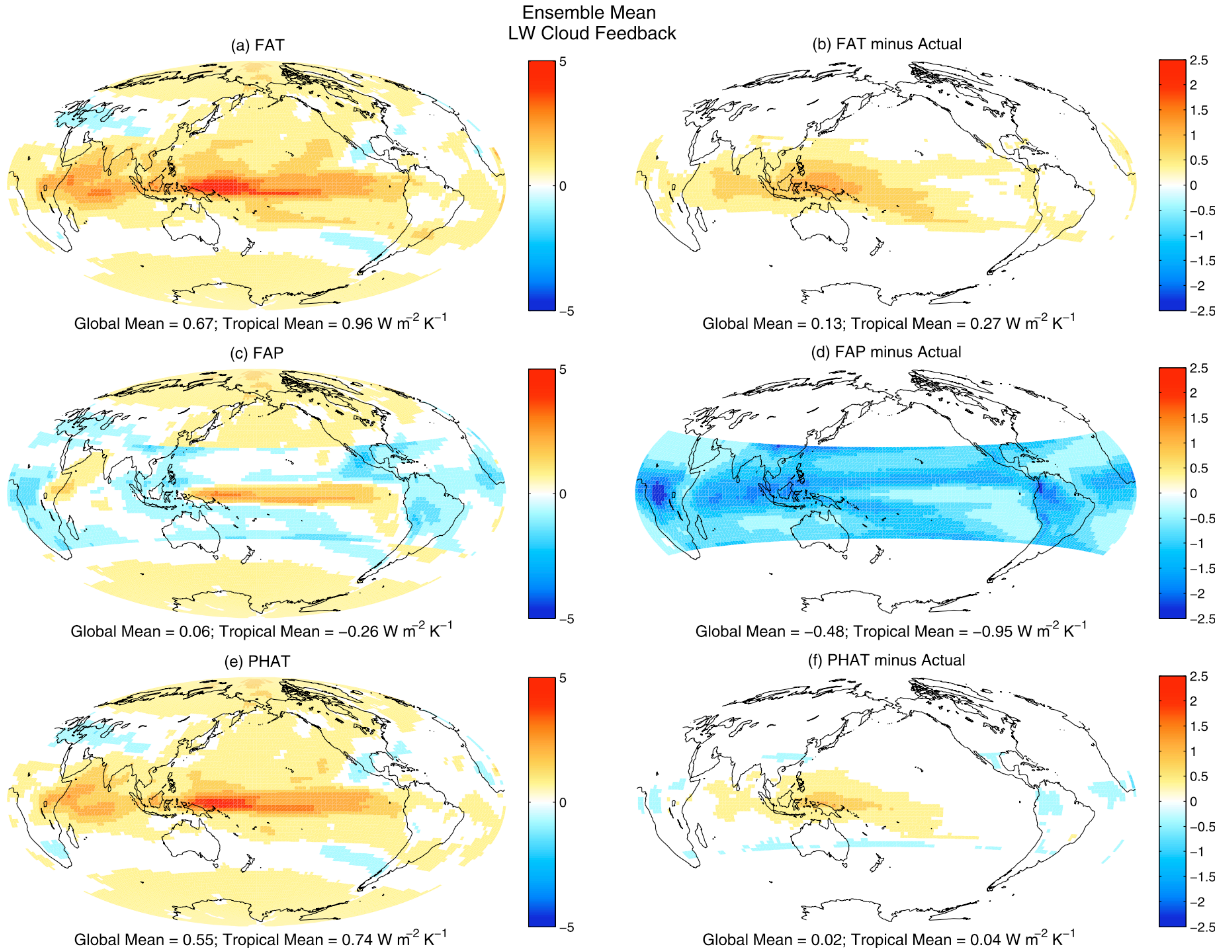


Figure 11. Zelinka and Hartmann (2010)

- Decadal means from 2000-2010 and 2090-2100 from the IPCC CFMIP SRES A2 scenario simulations

Impact of anvil response on LW Cloud feedback

$$\Delta LWCF = \Delta f_{tot}(OLR_{clr} - OLR_{cld}) + f_{tot}\Delta OLR_{clr} - f_{tot}\Delta OLR_{cld} + C$$

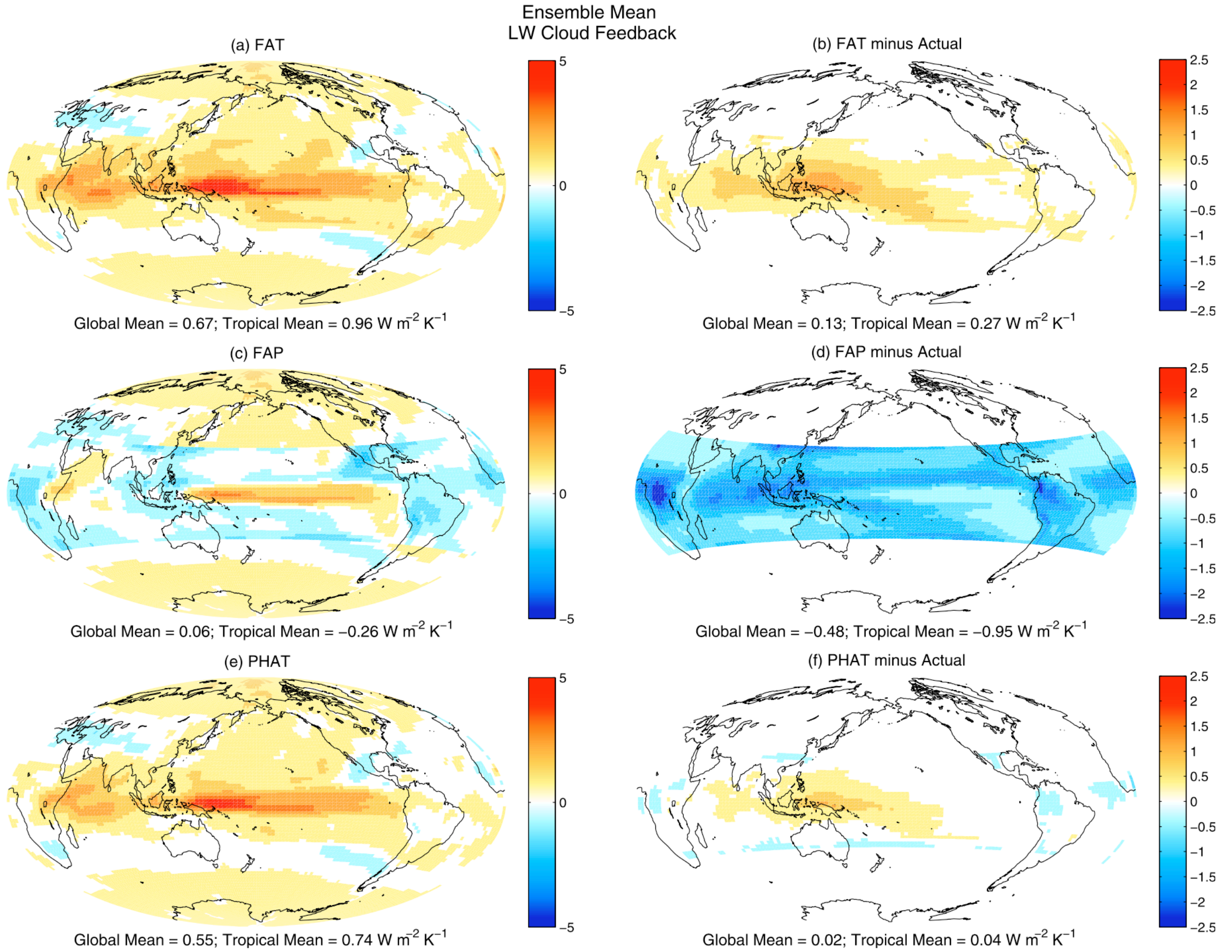


Figure 11. Zelinka and Hartmann (2010)

- f: cloud fraction, hi: high cloud, clr: clear sky, C: covariance
- $f_{tot} = f_{hi} + f_{low}$
- assumes $OLR_{hi} = \sigma T_{hi}^4$ and $OLR_{low} = OLR_{clr}$

Impact of anvil response on LW Cloud feedback

$$\Delta LWCF = \Delta f_{hi}(OLR_{clr} - OLR_{hi}) - f_{hi}\Delta OLR_{hi} + f_{hi}\Delta OLR_{clr} + C$$

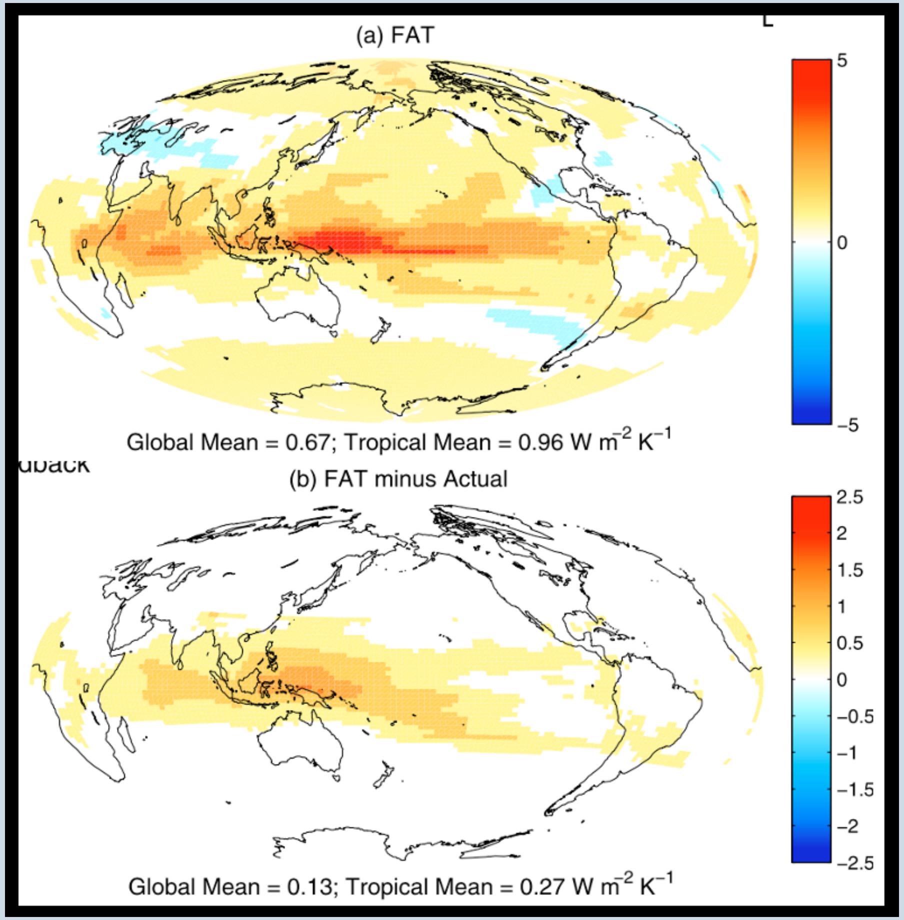


Figure 11. Zelinka and Hartmann (2010)

- FAT
  - $\Delta LWCF_{FAT}: \Delta OLR_{hi} = 0$; T_{hi} is fixed
  - feedback greater than actual

Impact of anvil response on LW Cloud feedback

$$\Delta LWCF = \Delta f_{hi}(OLR_{clr} - OLR_{hi}) - f_{hi}\Delta OLR_{hi} + f_{hi}\Delta OLR_{clr} + C$$

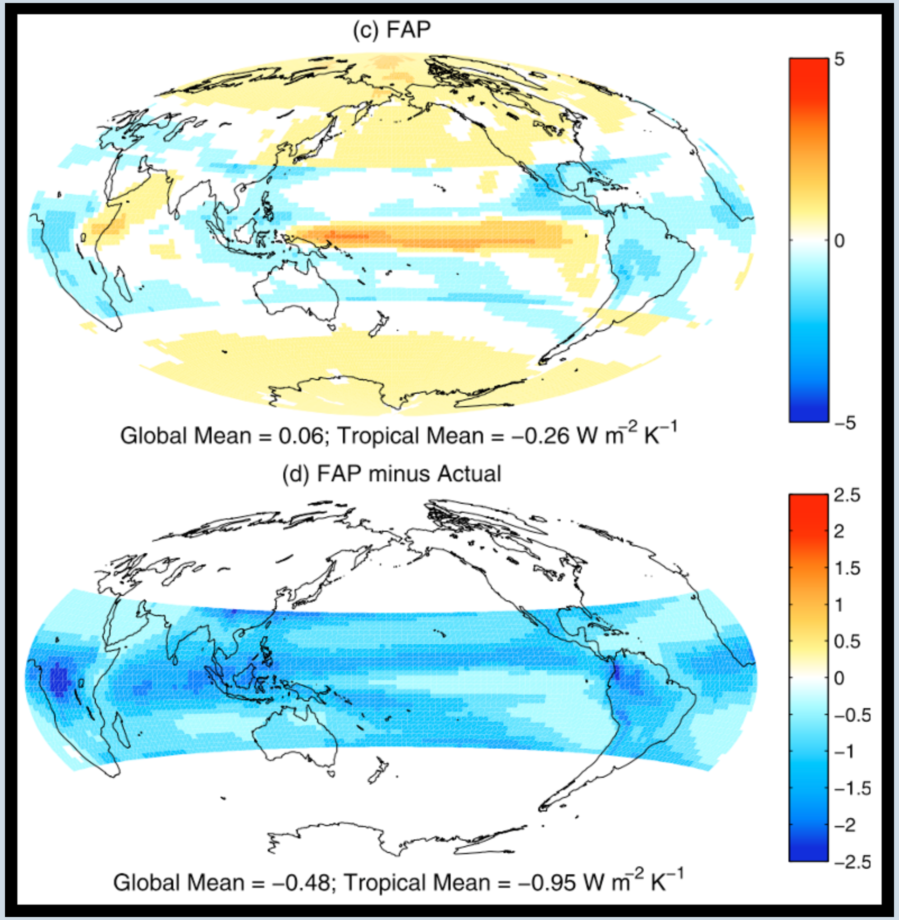


Figure 11. Zelinka and Hartmann (2010)

- FAP
  - $\Delta LWCF_{FAP}$: $\Delta OLR_{hi} = \Delta OLR_{hi}^{FAP}$; assumes clouds remain at the initial high cloud-weighted pressure
  - OLR drastically altered from major increase in temp
  - negative longwave cloud feedback

Impact of anvil response on LW Cloud feedback

$$\Delta LWCF = \Delta f_{hi}(OLR_{clr} - OLR_{hi}) - f_{hi}\Delta OLR_{hi} + f_{hi}\Delta OLR_{clr} + C$$

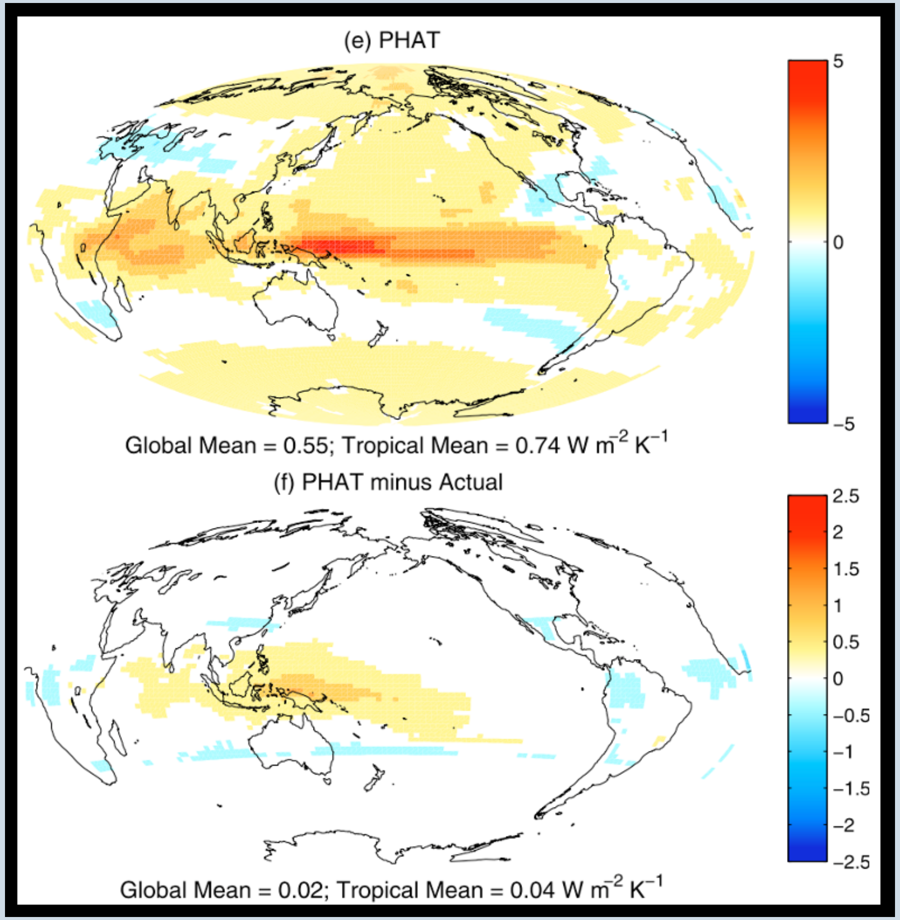


Figure 11. Zelinka and Hartmann (2010)

- PHAT
  - $\Delta LWCF_{PHAT}$: ΔOLR_{hi} = ΔOLR_{hi}^{PHAT}; the change T_{hi} is the same as the tropical mean upper-tropospheric clear-sky diabatic convergence-weighted temperature
  - Clouds only slightly warm so feedback is still positive

PHAT: Proportionally Higher Anvil Temperature

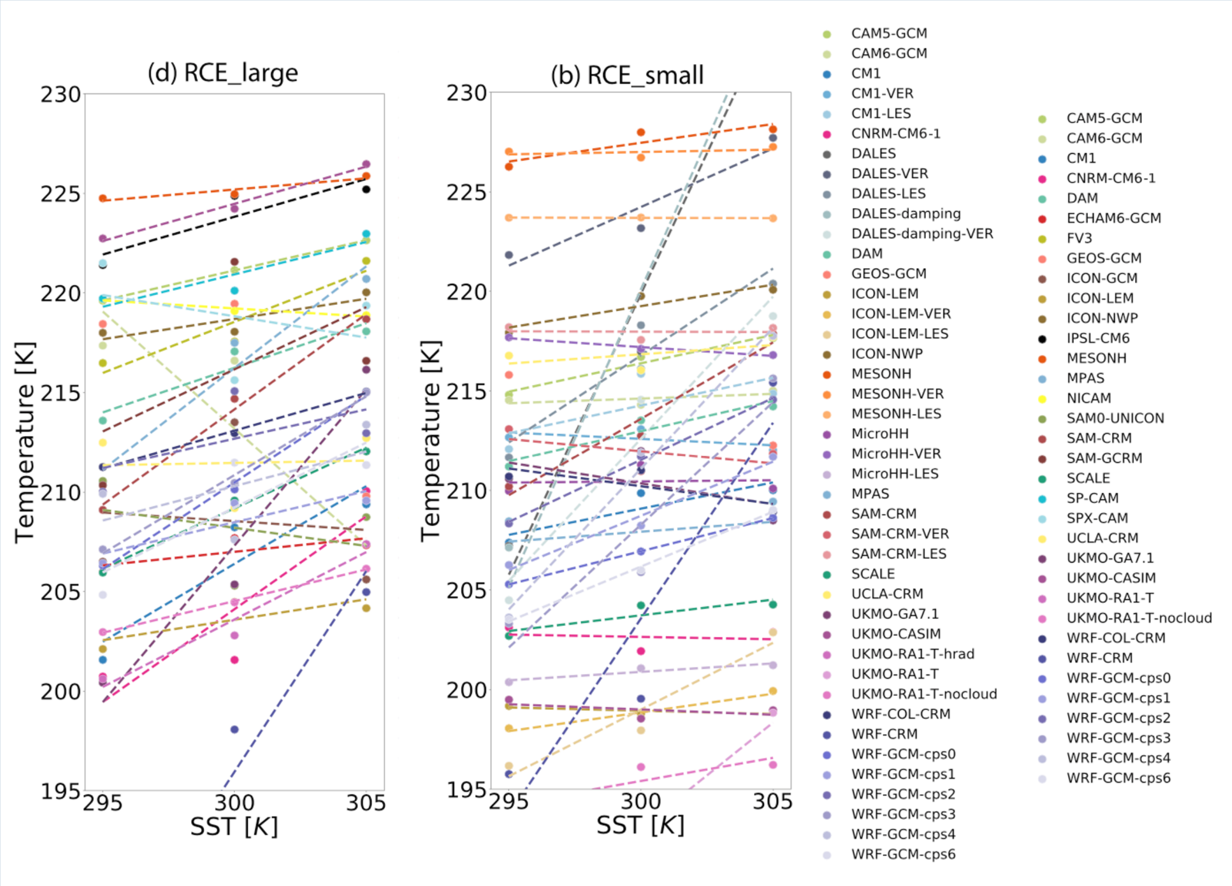


Figure 14b,d. Wing et al. (2020)

- RCEMIP has a PHAT response of ~4.4K across the 10K SST range

PHAT: Proportionally Higher Anvil Temperature

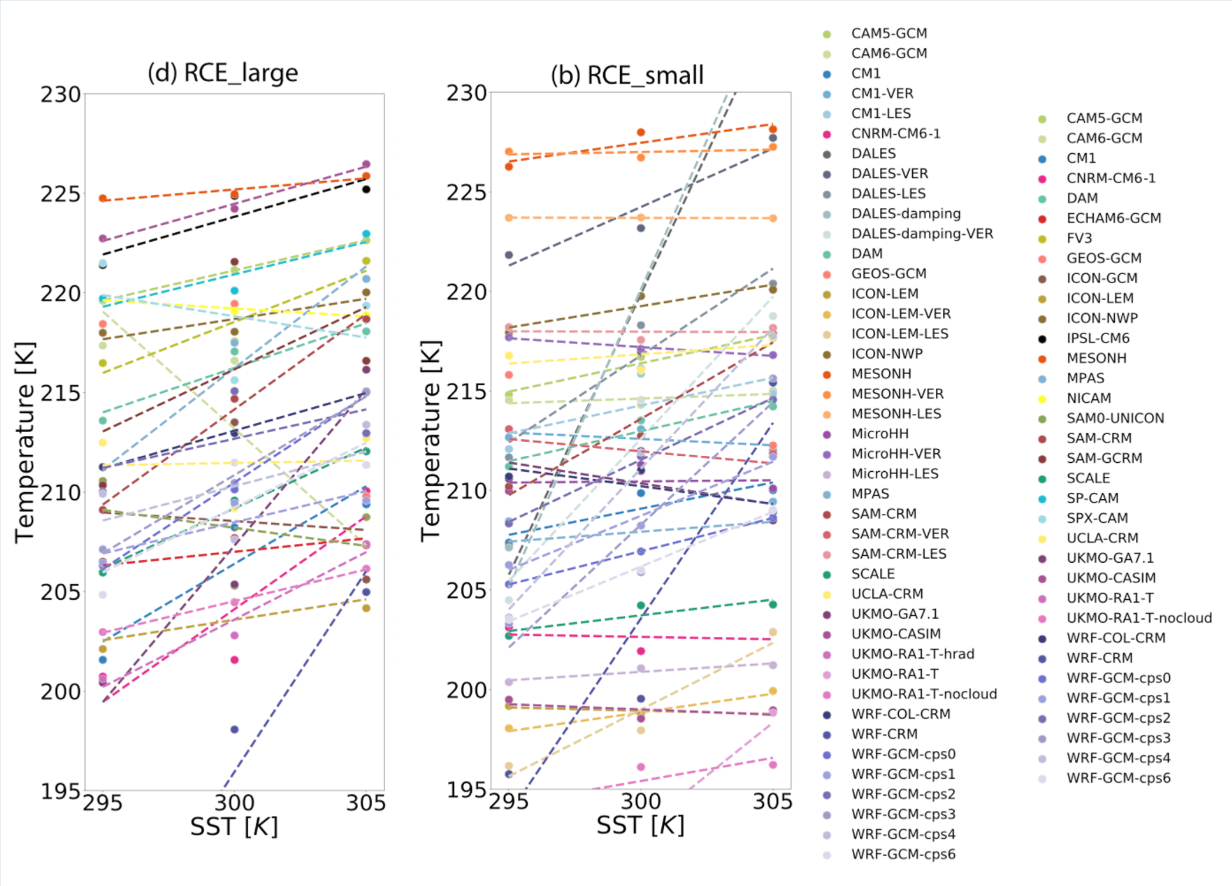


Figure 14b,d. Wing et al. (2020)

- RCEMIP has a PHAT response of ~4.4K across the 10K SST range
- Decreasing anvil temperature
  - 25% of small domain decrease
  - <20% large domain decrease
  - May need to reconsider method for cloud fraction and/or anvil diagnostic

Formation on anvils

- Traditional method
  - Detrainment out from region of mass divergence

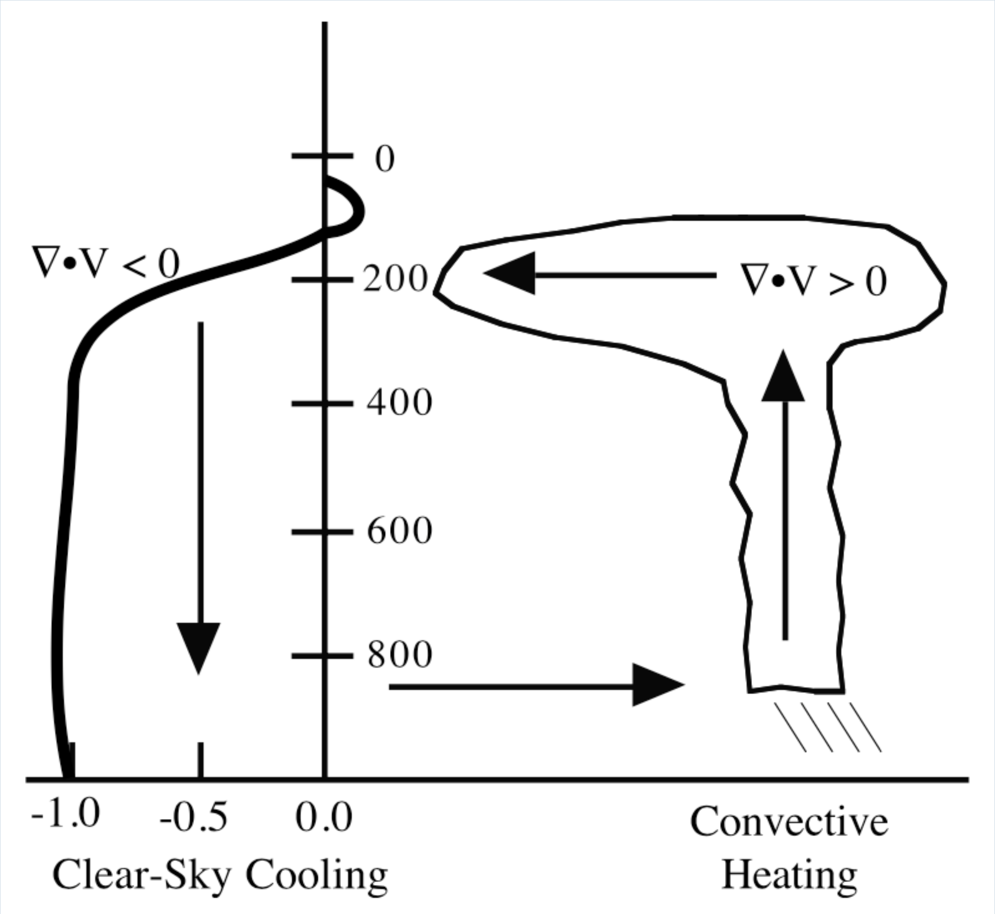


Figure 1. Hartmann and Larson (2002)

Formation on anvils

- Seeley et al. (2019) proposal
  - Long lifetime of cloud condensate
  - Cloud decay by evaporation hindered by small specific humidity in the **cold upper troposphere**

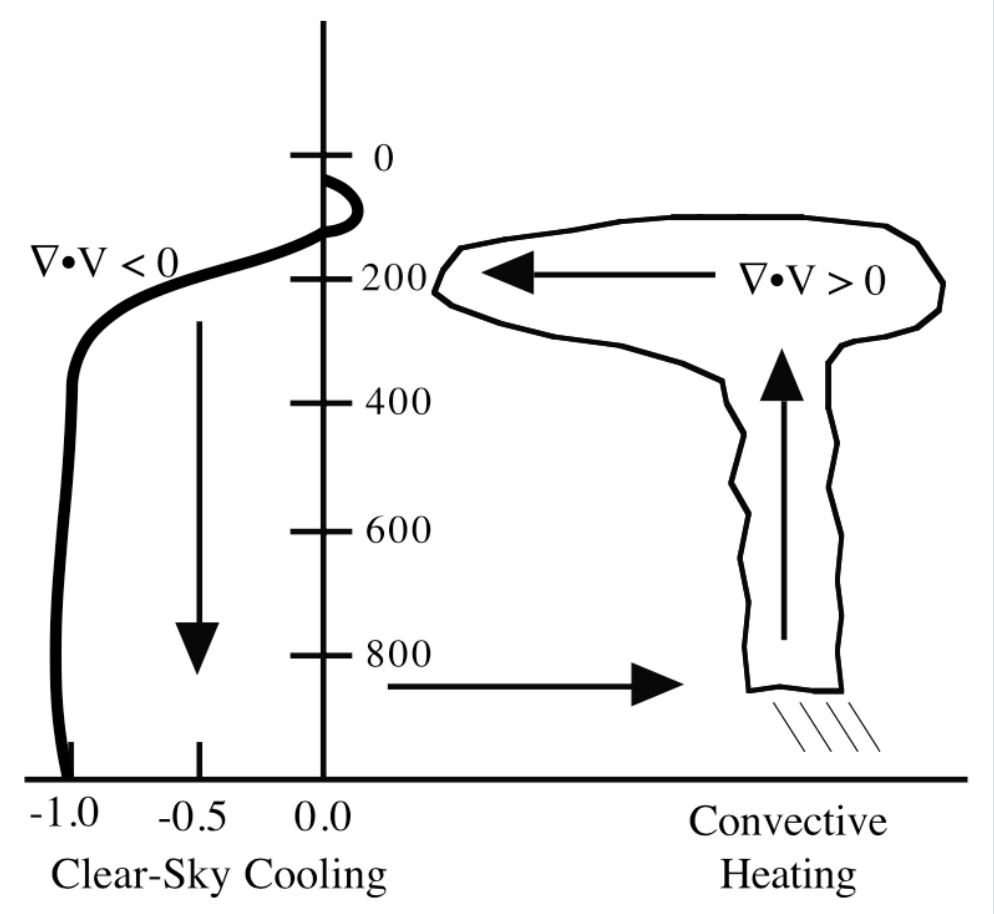


Figure 1. Hartmann and Larson (2002)

FiTT: Fixed Tropopause Temperature

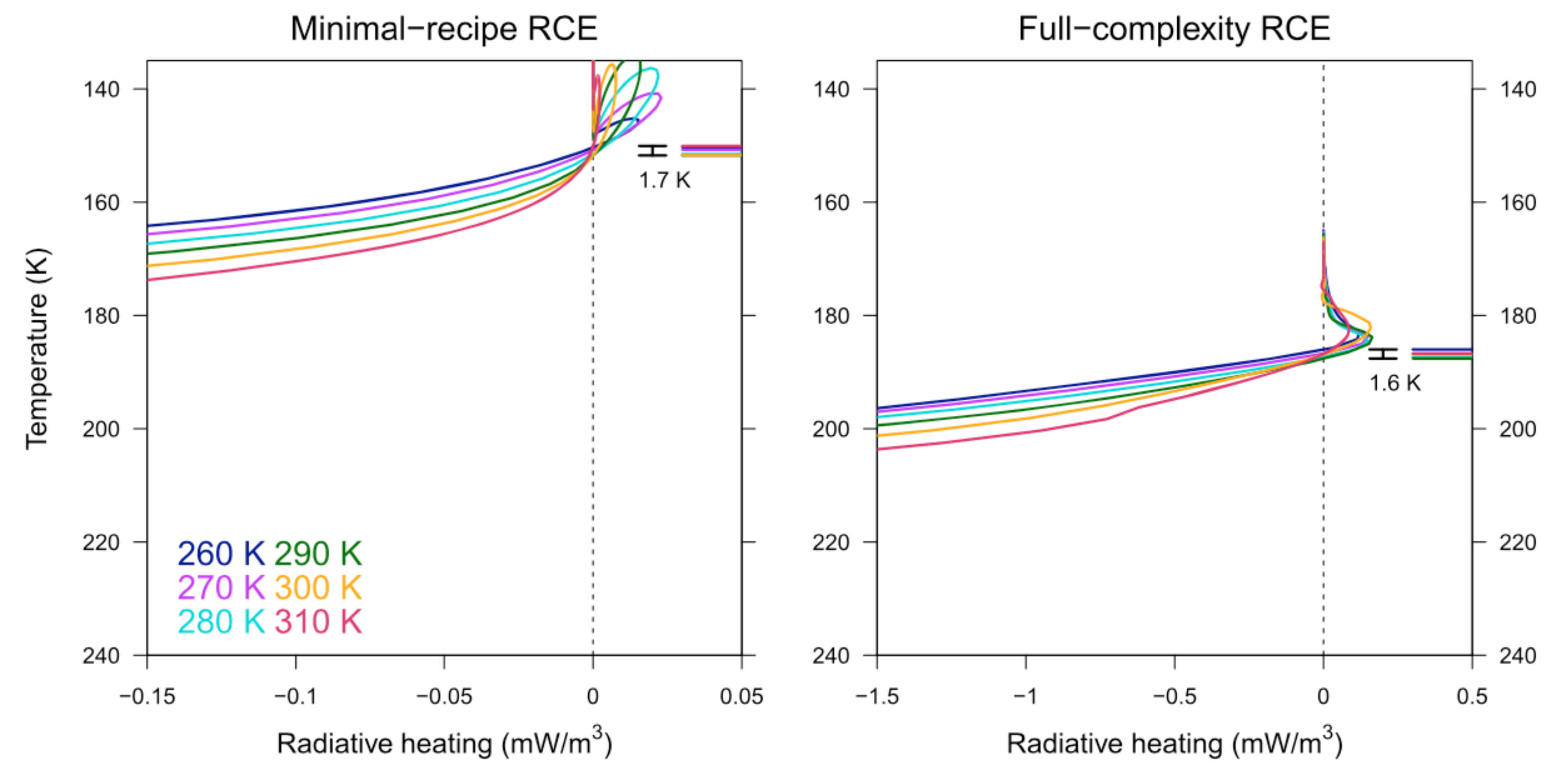


Figure 5. Seeley et al. (2019b)

Cloud Changes in RCEMIP

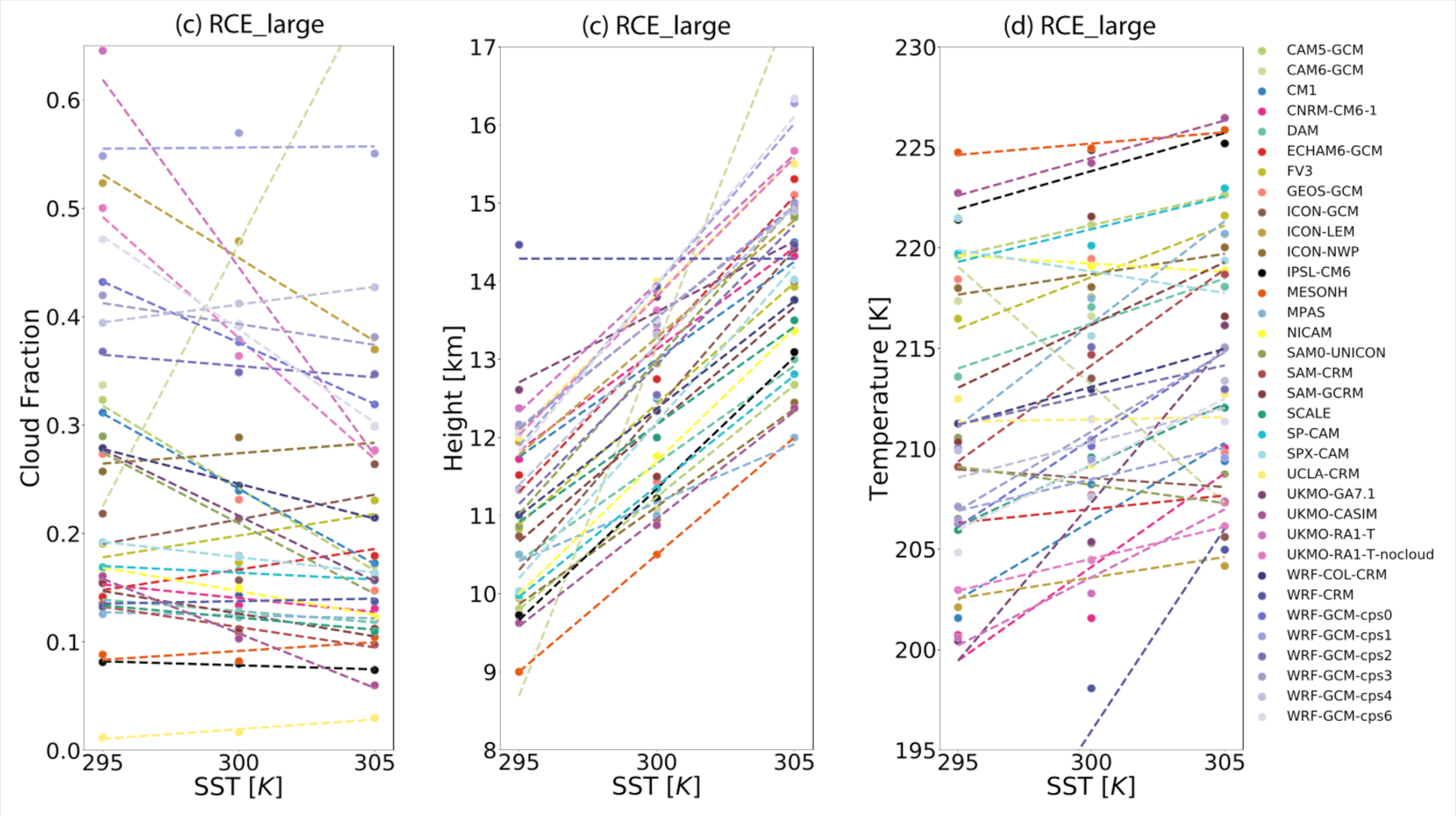


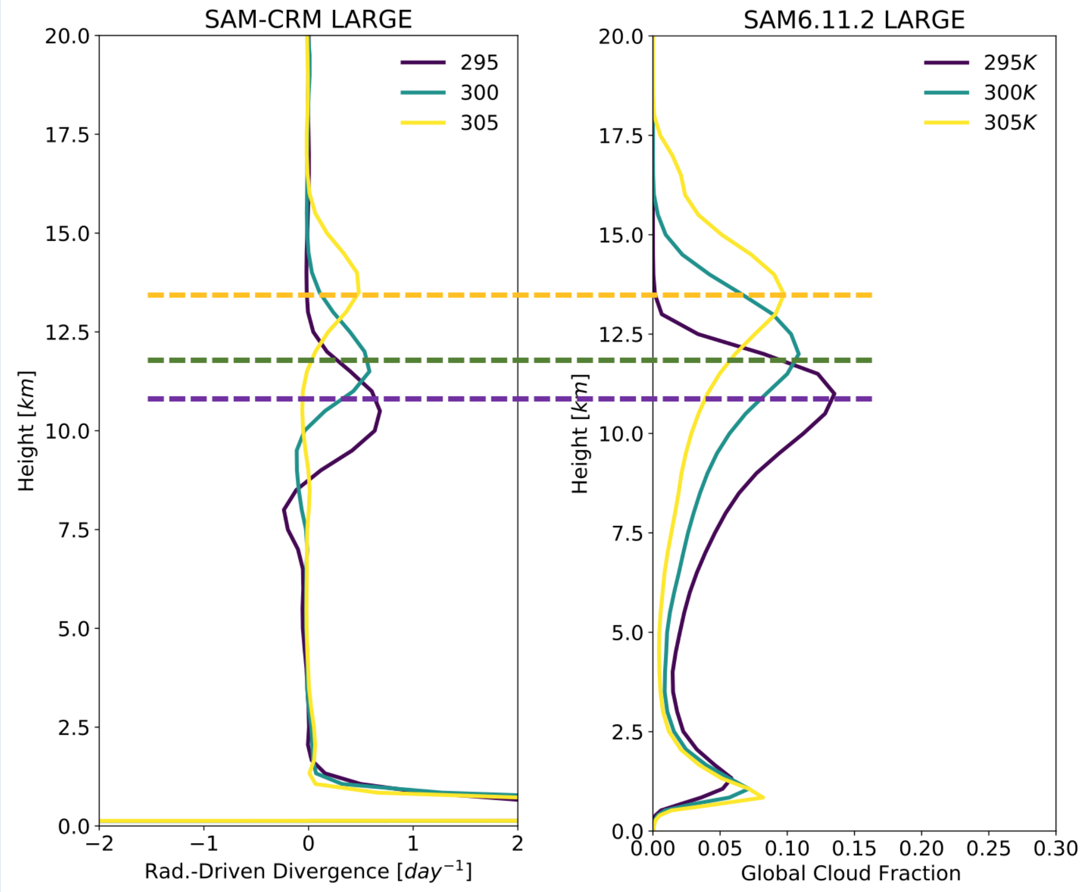
Figure 14c-d,15. Wing et al. (2020)

- Cloud fraction
  - Generally decreases with SST
- Height
  - Increase of 0.2-0.3 kmK−1 (on average)
- Temperature
  - Increase of 4.4KK-1

Radiatively-Driven Divergence

Radiatively-driven divergence

- $R_D = \frac{\partial \omega}{\partial P}$
- $\omega = -\frac{Q_r}{S}$
- $S = -\frac{T}{\Theta}\frac{\partial \Theta}{\partial P} = \left(\frac{R_D}{c_{pd}}\right)\frac{T}{P}(1-\gamma)$
- Height of the peak in R_D approximately corresponds to the height of the anvil



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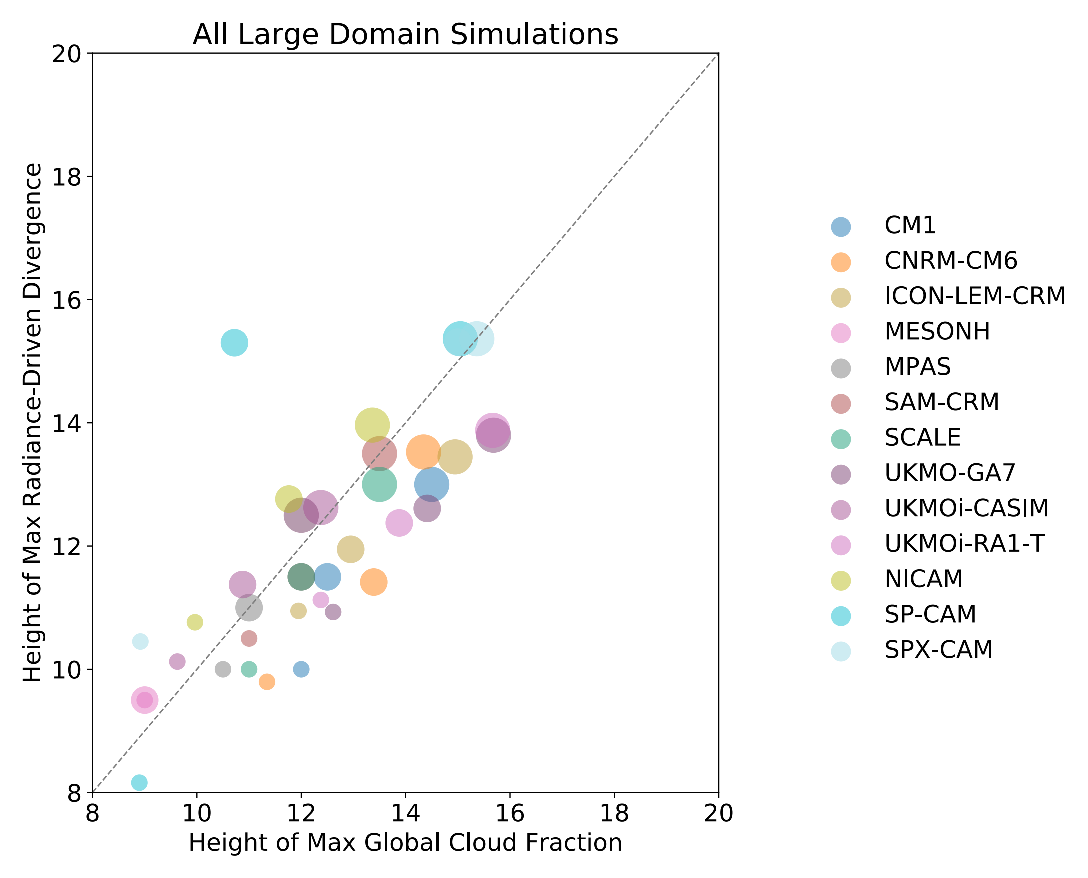


Anvil vs Divergence

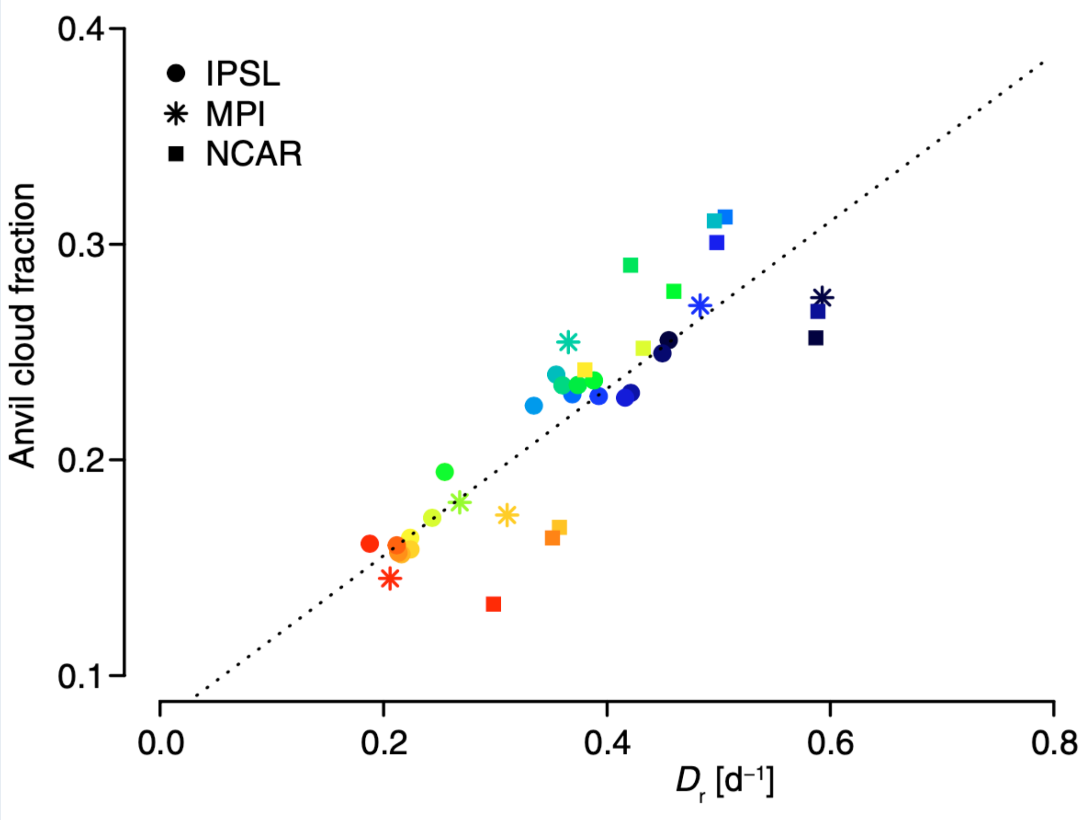


Figure 3. Bony et al. (2016)

- Decrease nearly together with warming
- Independent of whether convection aggregates

Anvil vs Divergence

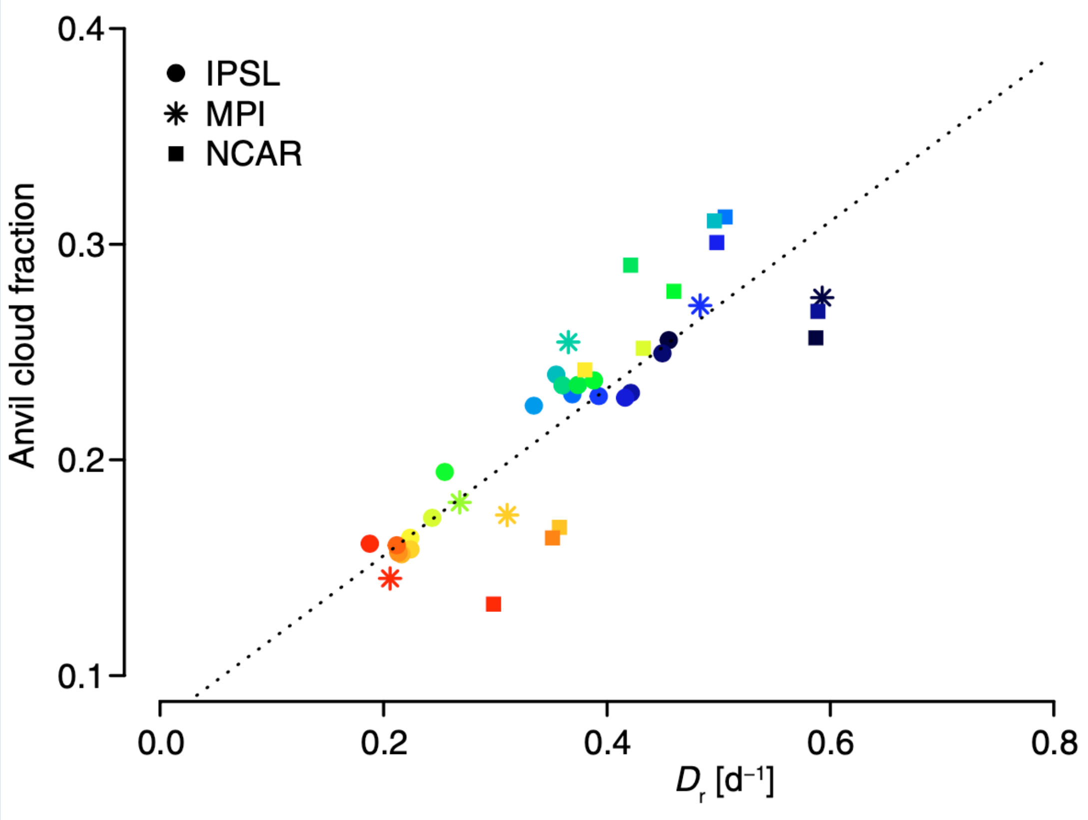
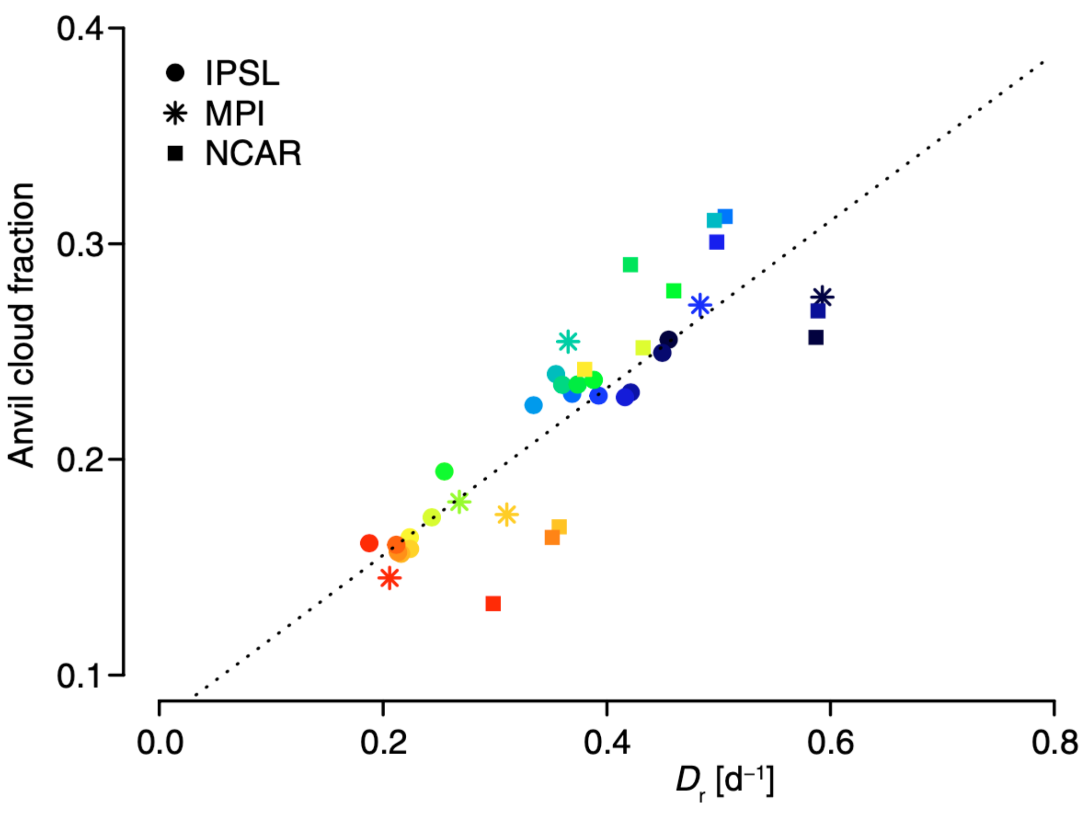


Figure 3. Bony et al. (2016)

- Decrease nearly together with warming
- Independent of whether convection aggregates
- With warming, isotherms:
  - Decrease in pressure
  - Increase in static stability

Anvil vs Divergence



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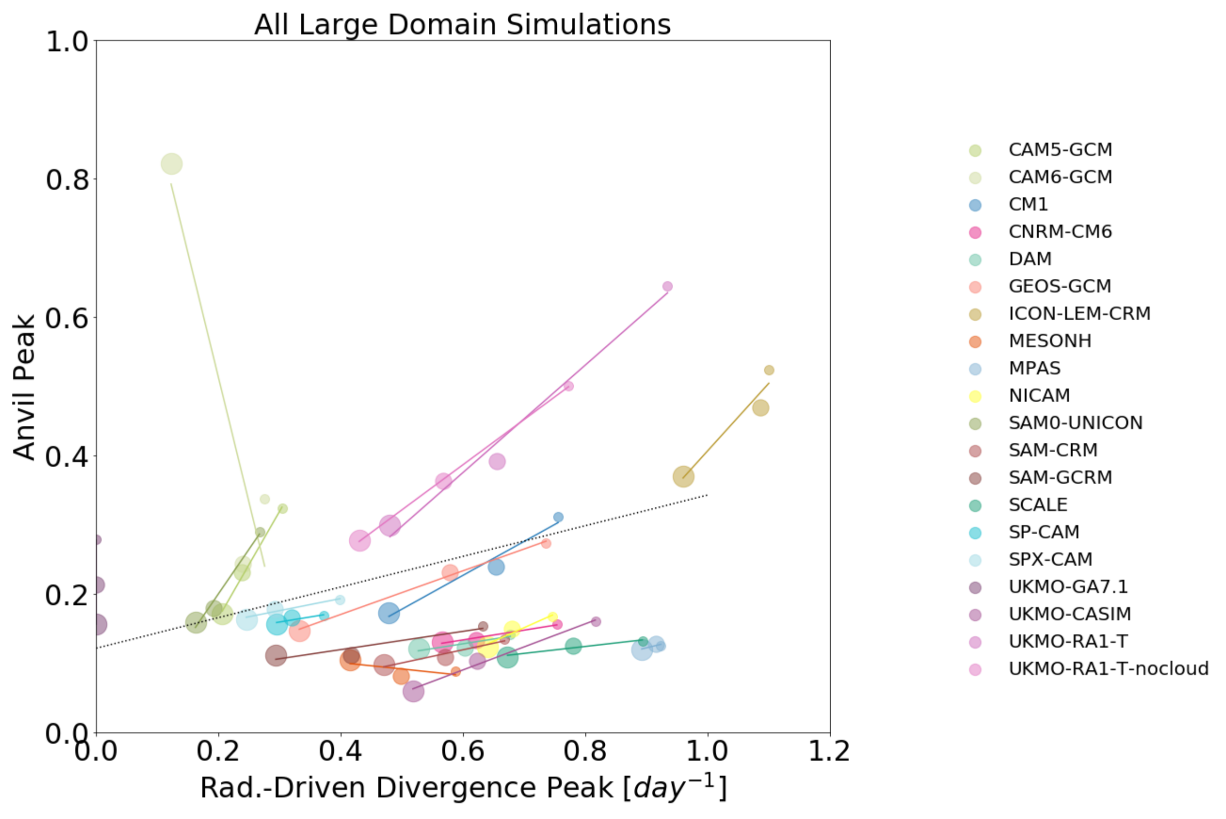


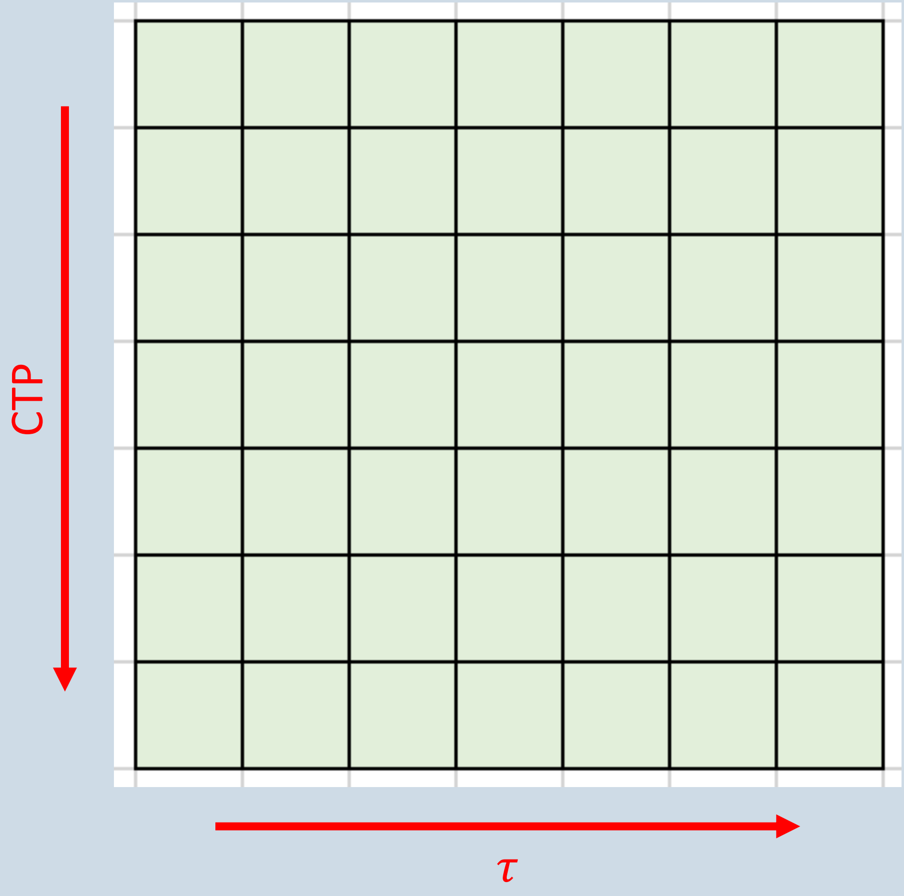
Partitioning Cloud Feedbacks

Radiative kernels

- Tool used to test sensitivity of radiative fluxes to perturbations of radiative properties
- Typically perturb the radiative properties of temperature and specific humidity
- Kernels typically viewed in terms of height and latitude

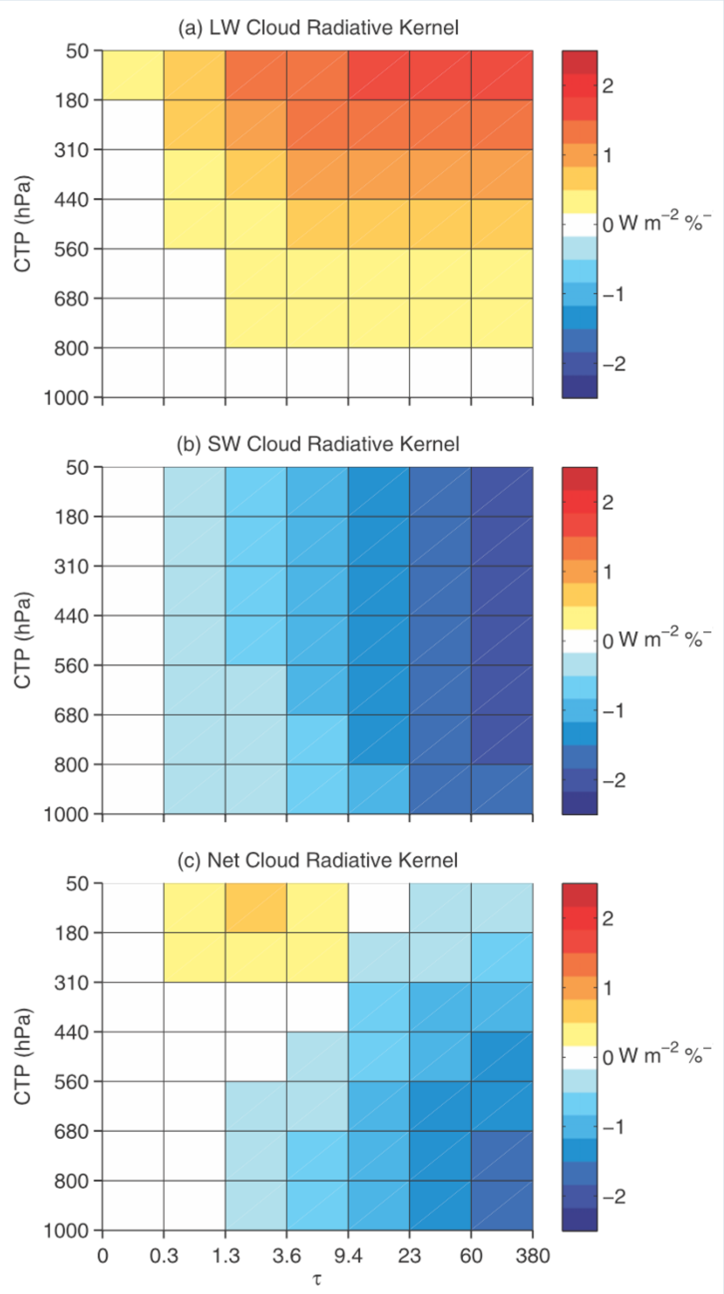
Radiative Kernels in Zelinka et al. (2019a)

- **Perturbs**: cloud fraction
- **Phase space**: optical depth versus cloud top phase space
- **Purpose**: estimate cloud feedbacks



Radiative Kernels in Zelinka et al. (2019a)

- Decreased OLR, increased SW reflection



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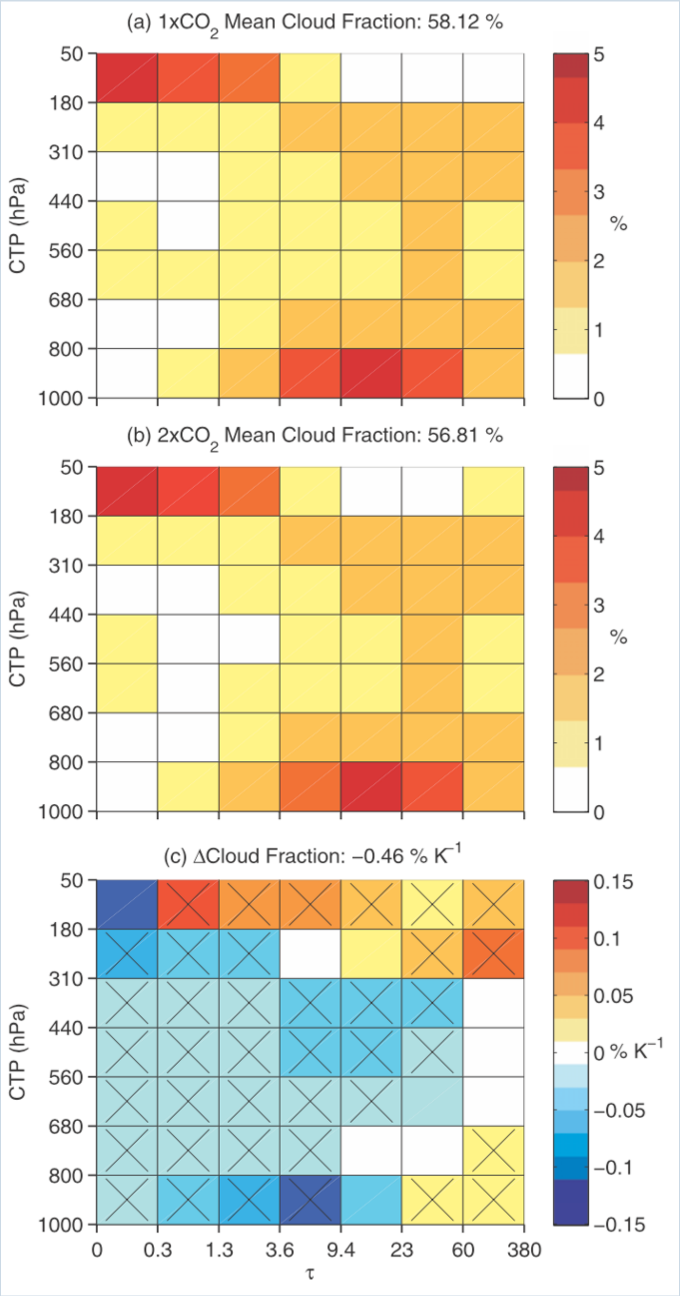
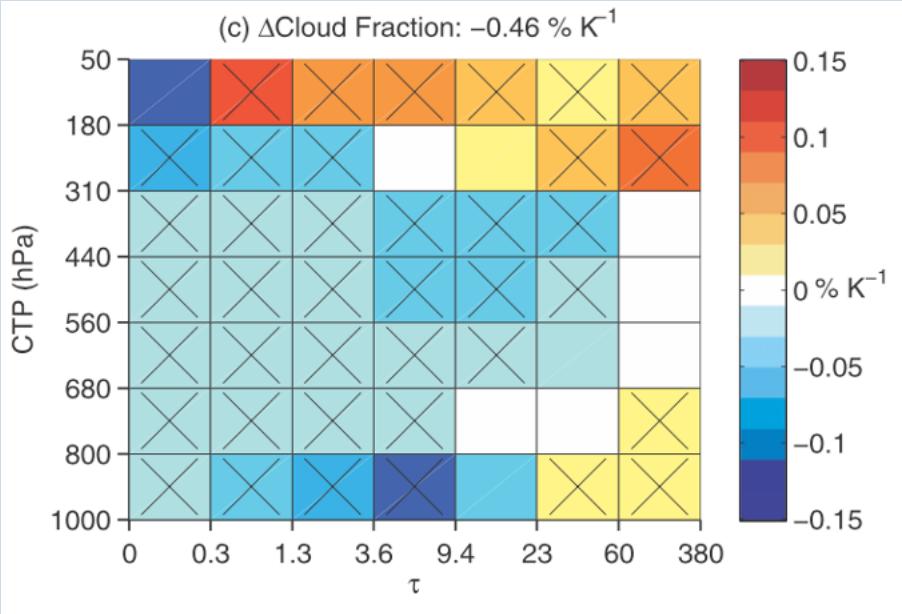


Radiative Kernels in Zelinka et al. (2019a)

- Decreased OLR, increased SW reflection
- Multiply the radiative kernels by the change in cloud fraction between the two climates



Radiative Kernels in Zelinka et al. (2019a)

- Decreased OLR, increased SW reflection
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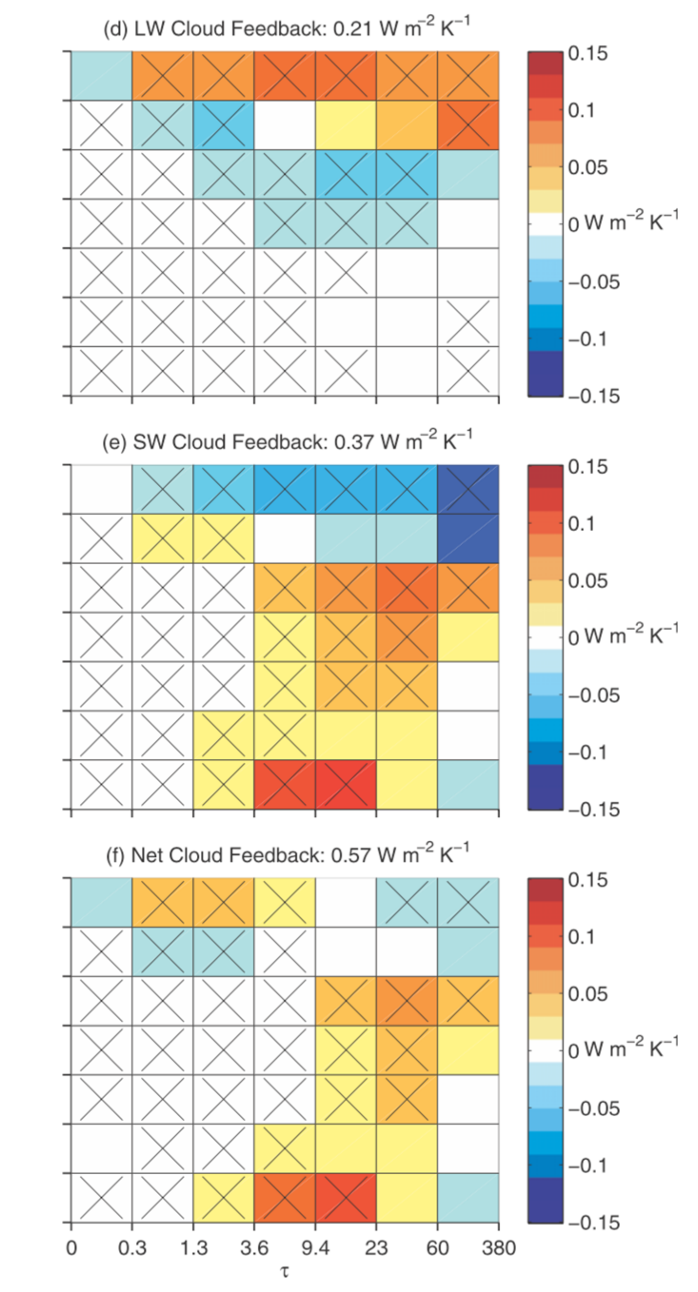
- Impact of cloud types on the radiative feedbacks



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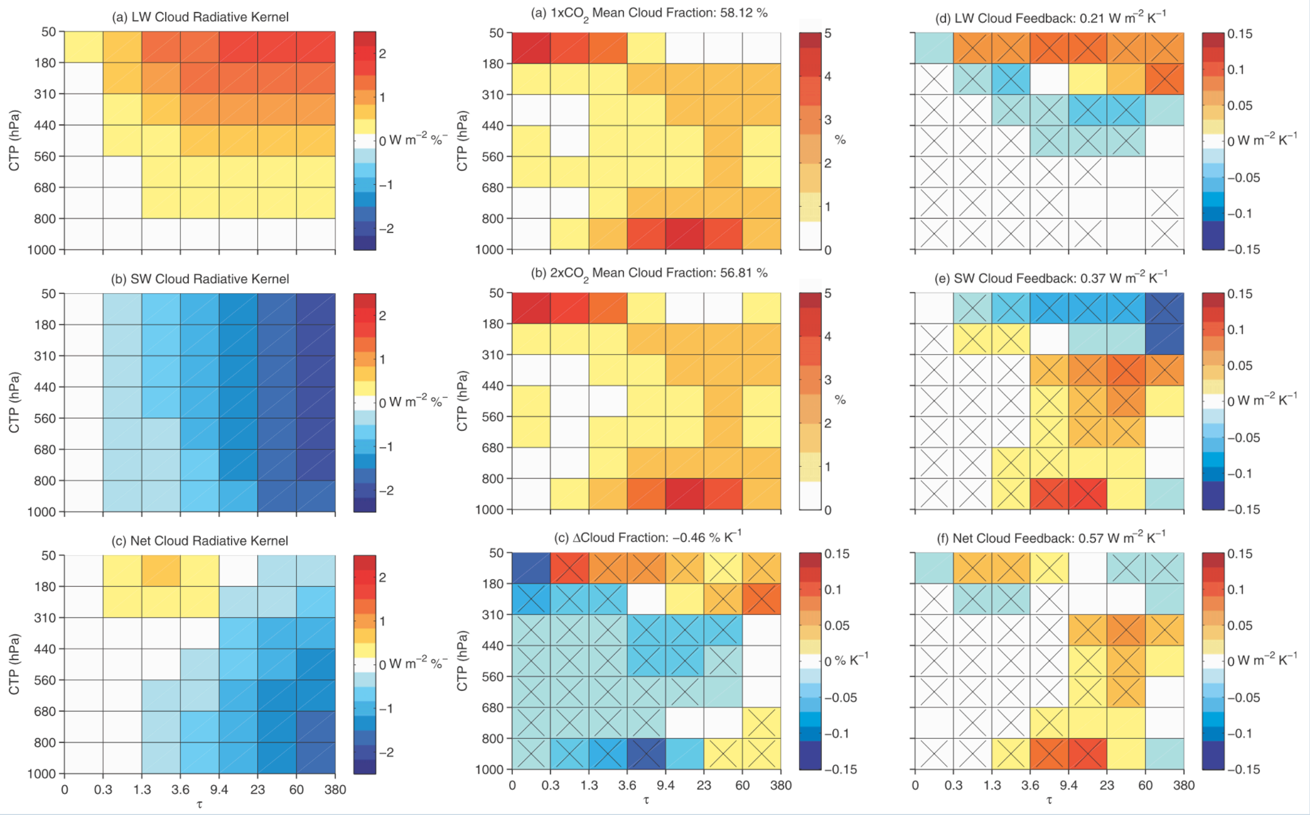
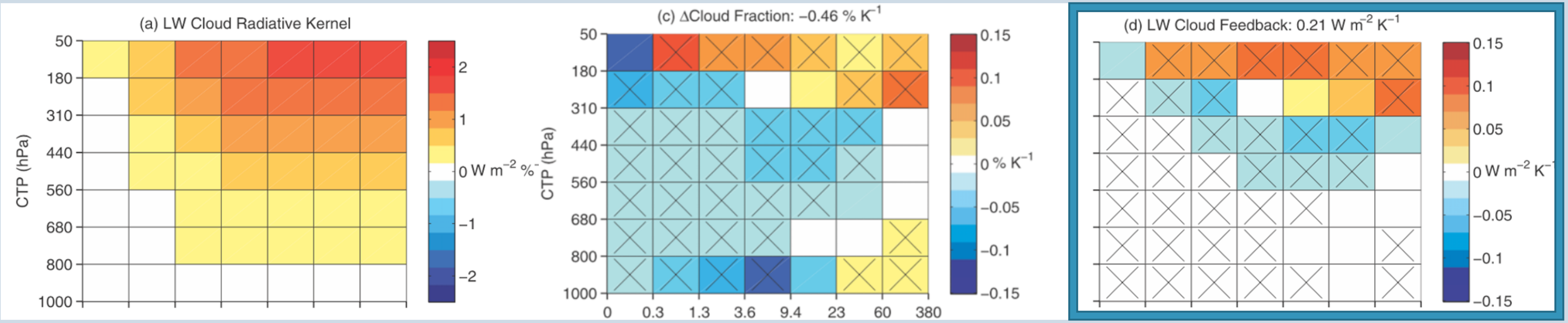
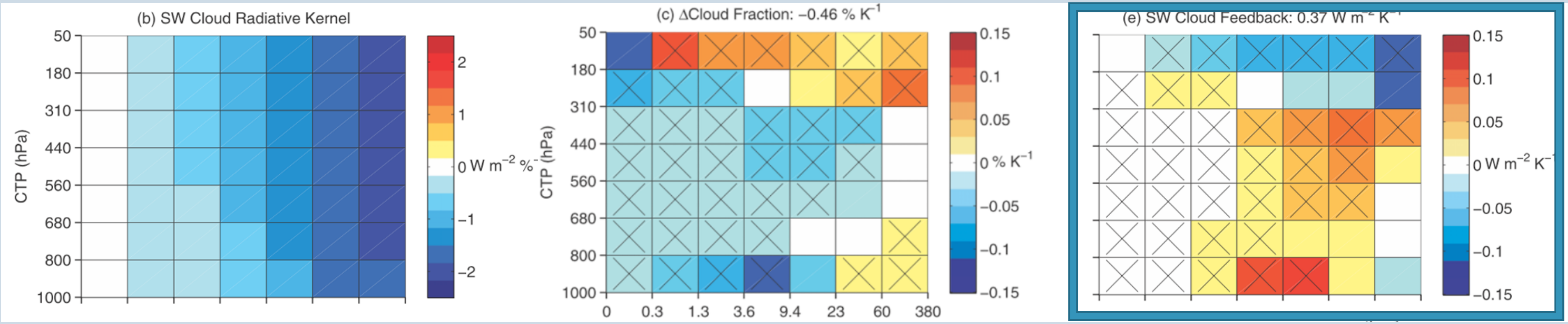


LW Cloud Feedback



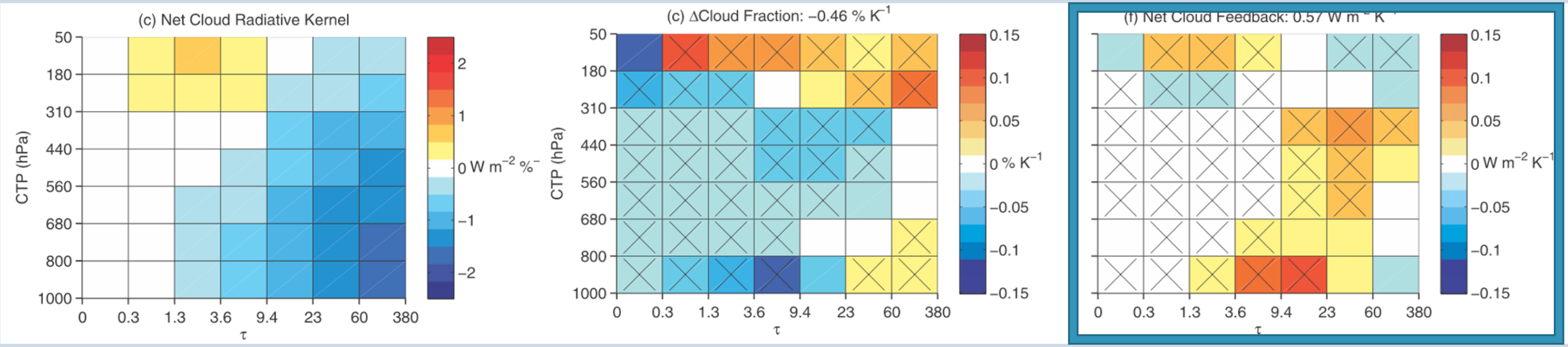
- high altitude increases in cloud fraction → positive LW feedback

SW cloud feedback



- increases in high cloud fraction → negative SW feedback
- decreases in low cloud fraction → positive SW feedback
- strong feedback concentrated at higher thicknesses.

Net Cloud Feedback



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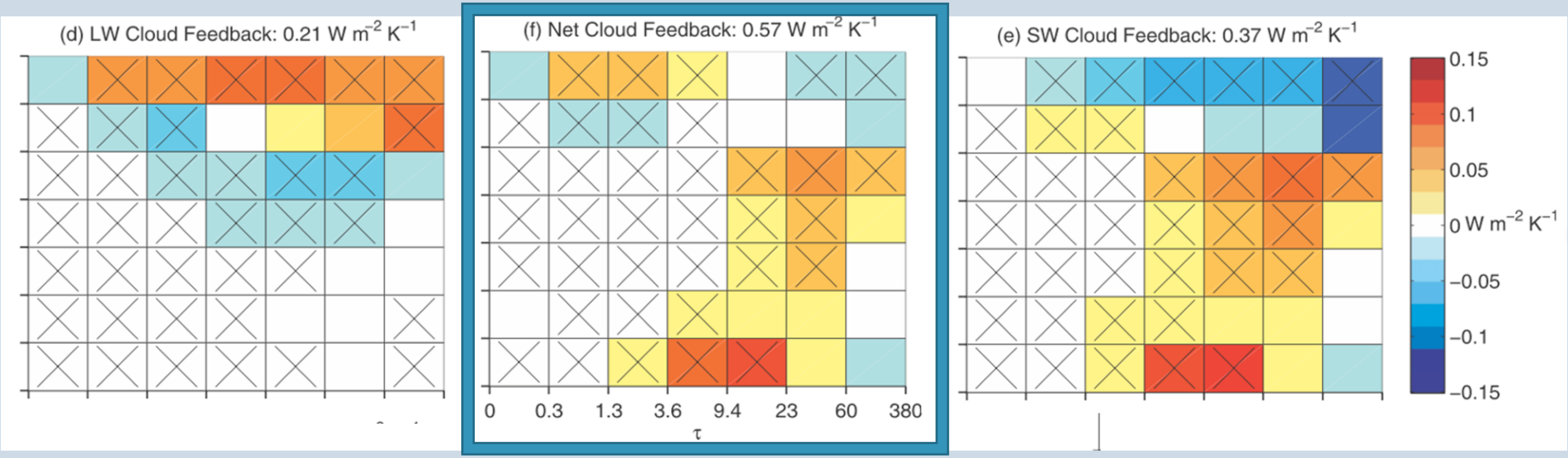
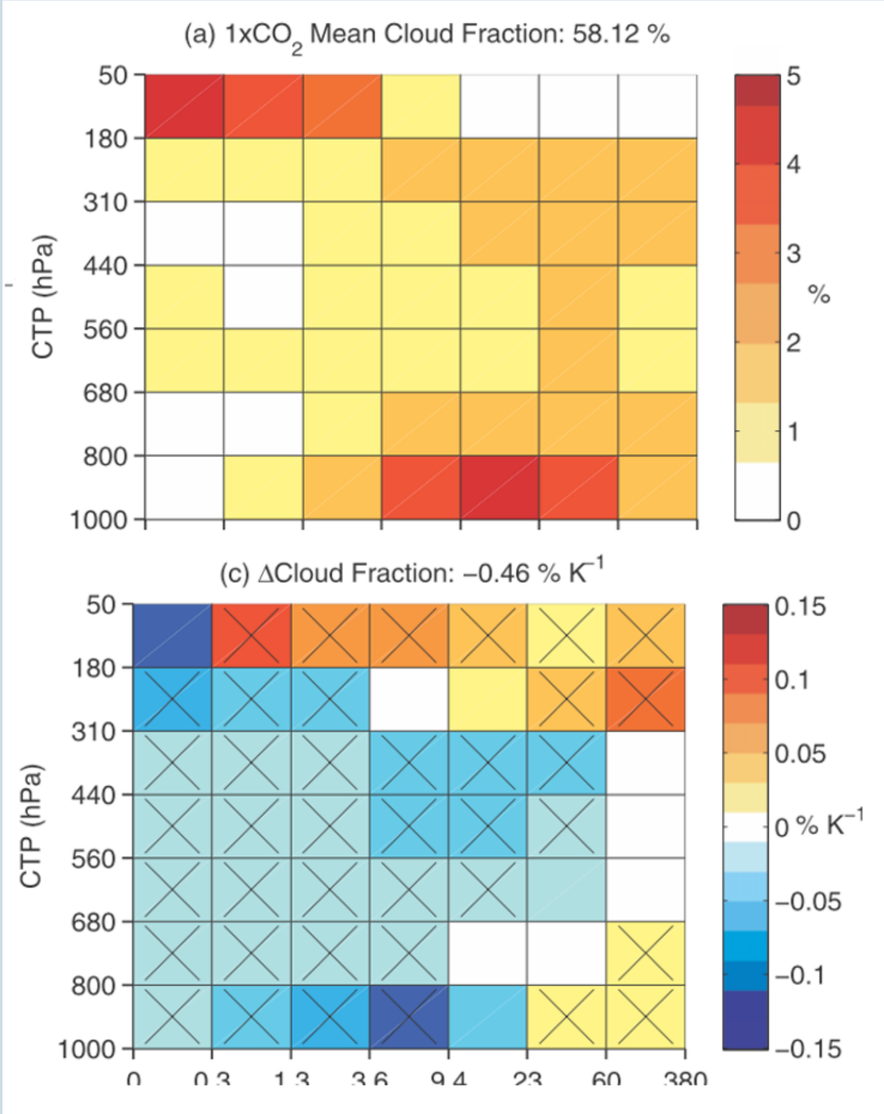


- low-levels: dominated by positive SW feedback
- upper-levels: SW dominates for thick clouds; LW feedback dominates for the thinner clouds.

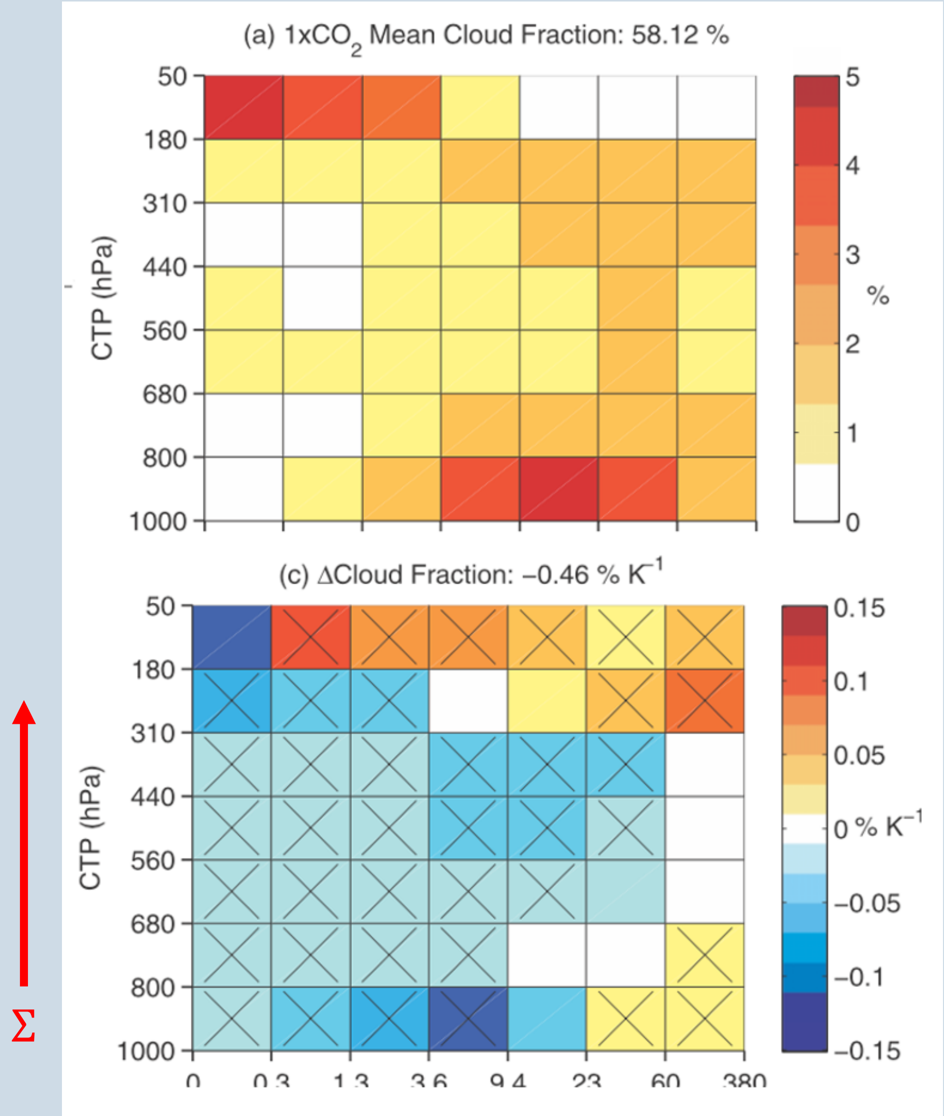
Cloud amount feedback

- $\Delta \boldsymbol{C}_{prop} = \left(\frac{\Delta C_{tot}}{C_{tot}}\right) \times \boldsymbol{C}$



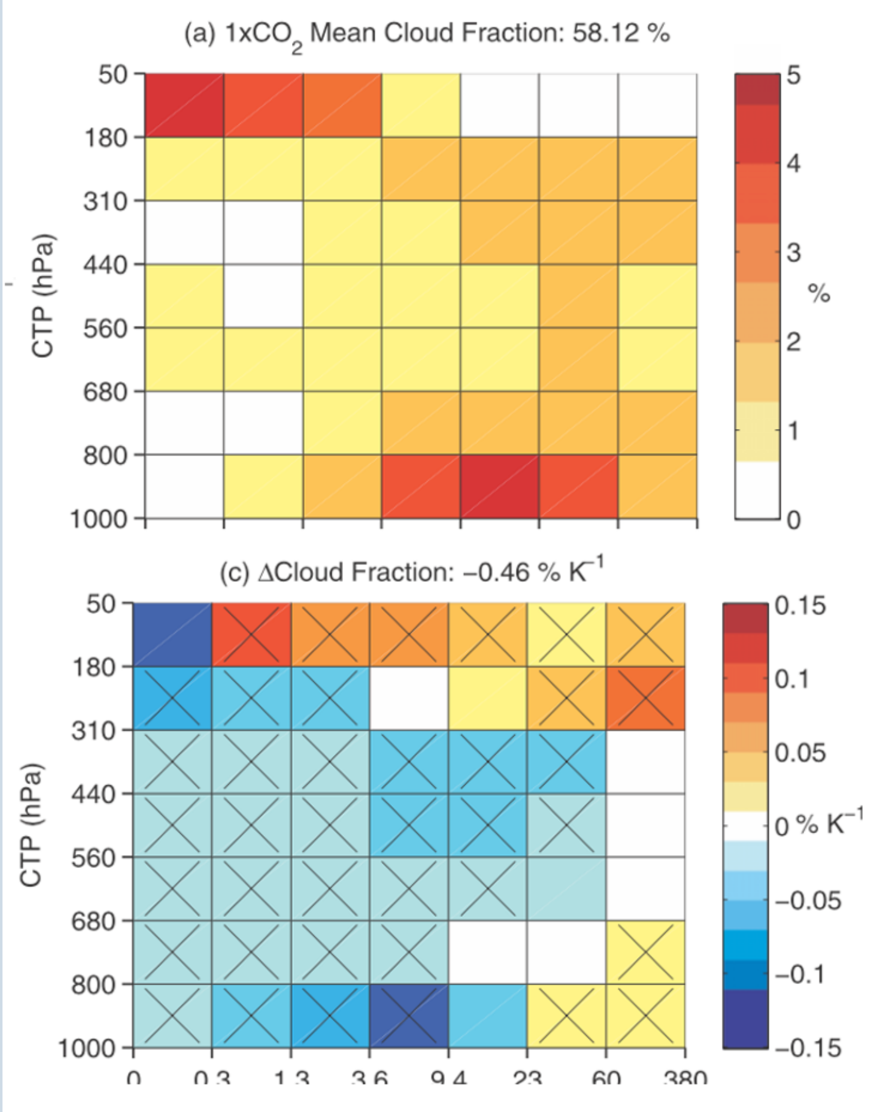
Cloud altitude feedback

- $\Delta \boldsymbol{C}_{\Delta p} = \Delta \boldsymbol{C} - \frac{1}{P} \sum_{p=1}^{P} \Delta \boldsymbol{C}$



Optical Thickness feedback

- $\Delta \boldsymbol{C}_{\Delta\tau} = \Delta \boldsymbol{C} - \frac{1}{T}\sum_{\tau=1}^{T} \Delta \boldsymbol{C}$



Σ

Net cloud feedback and its components

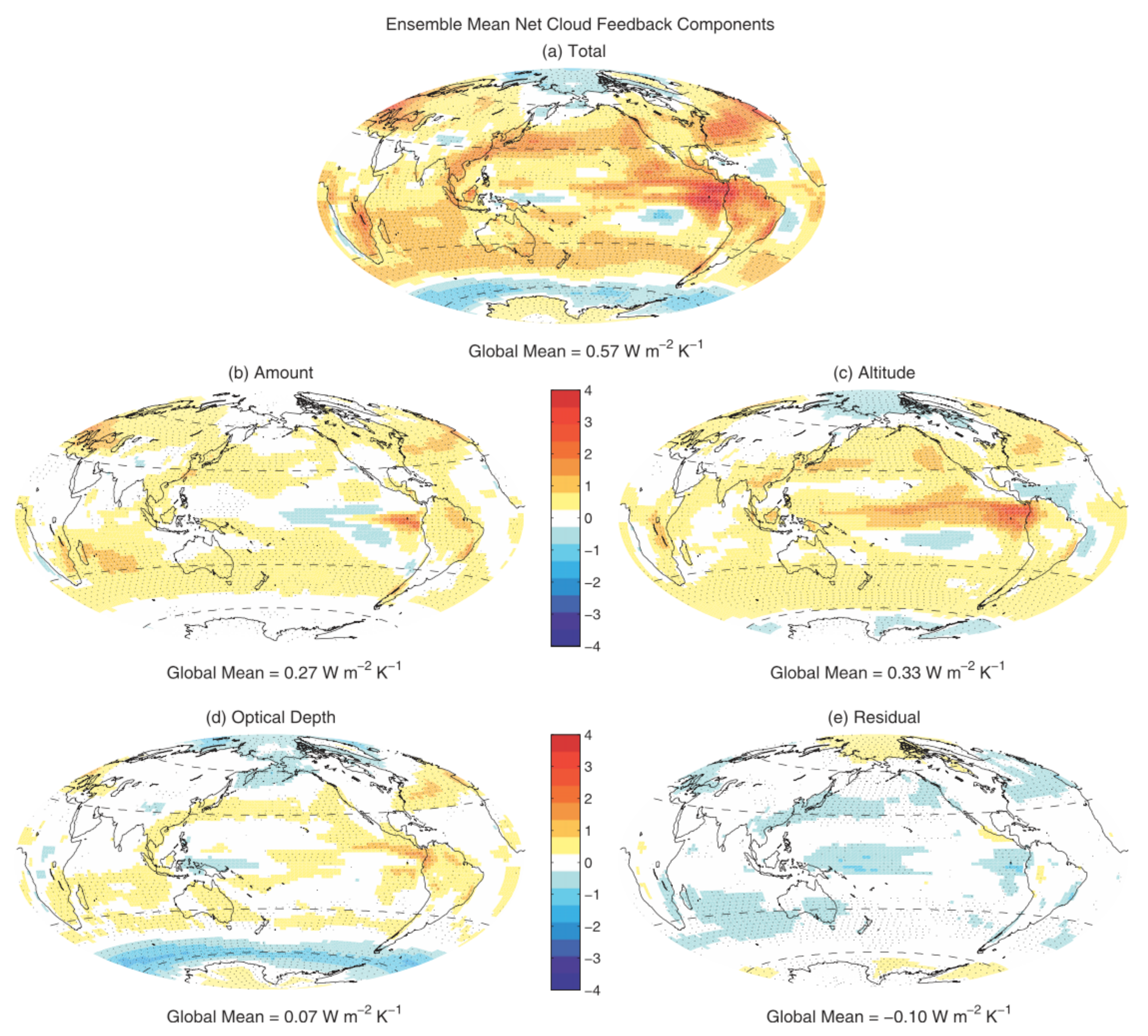


Figure 5. Zelinka et al. (2012b)

LW cloud feedback and its components

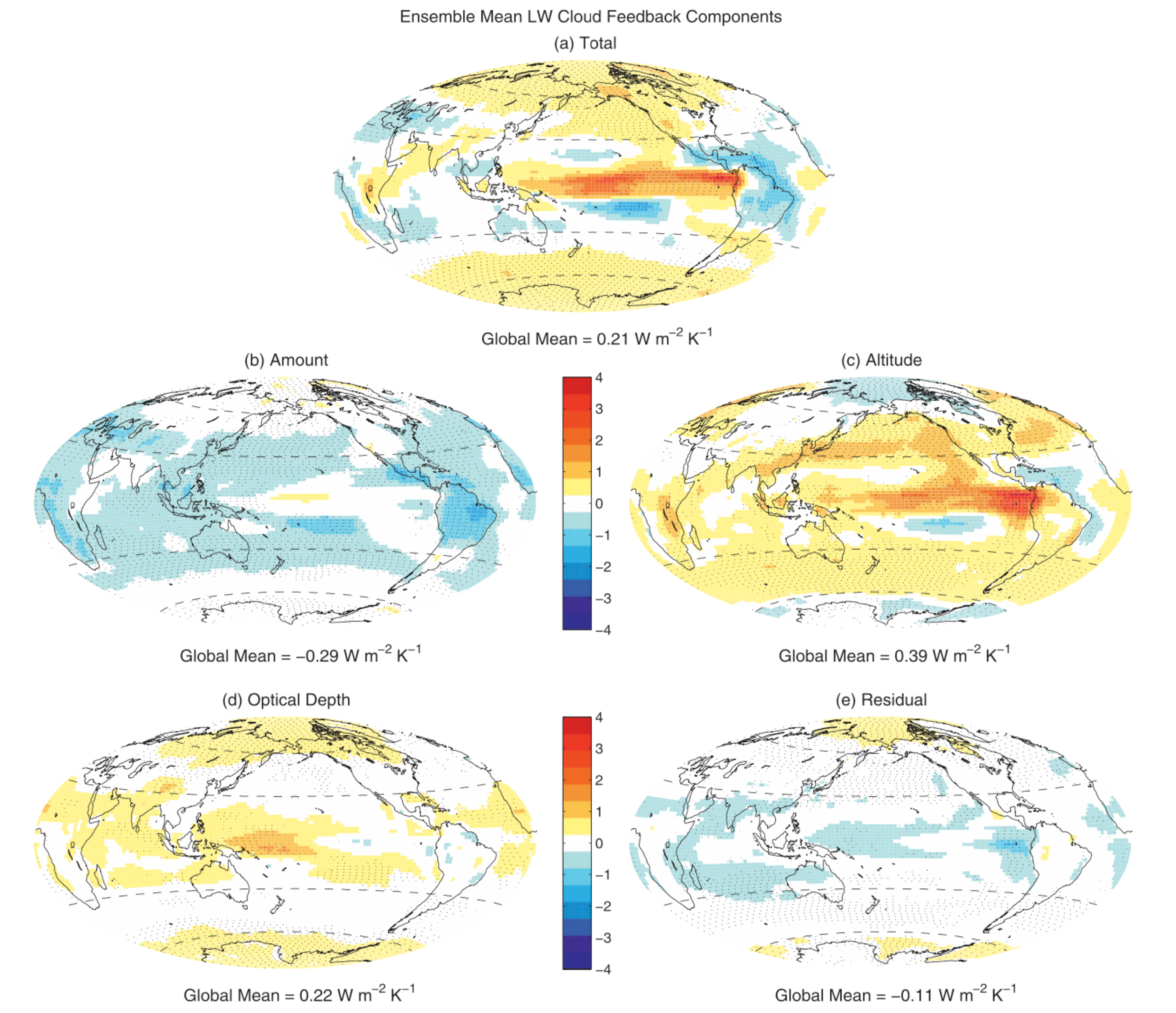


Figure 3. Zelinka et al. (2012b)

SW cloud feedback and its components

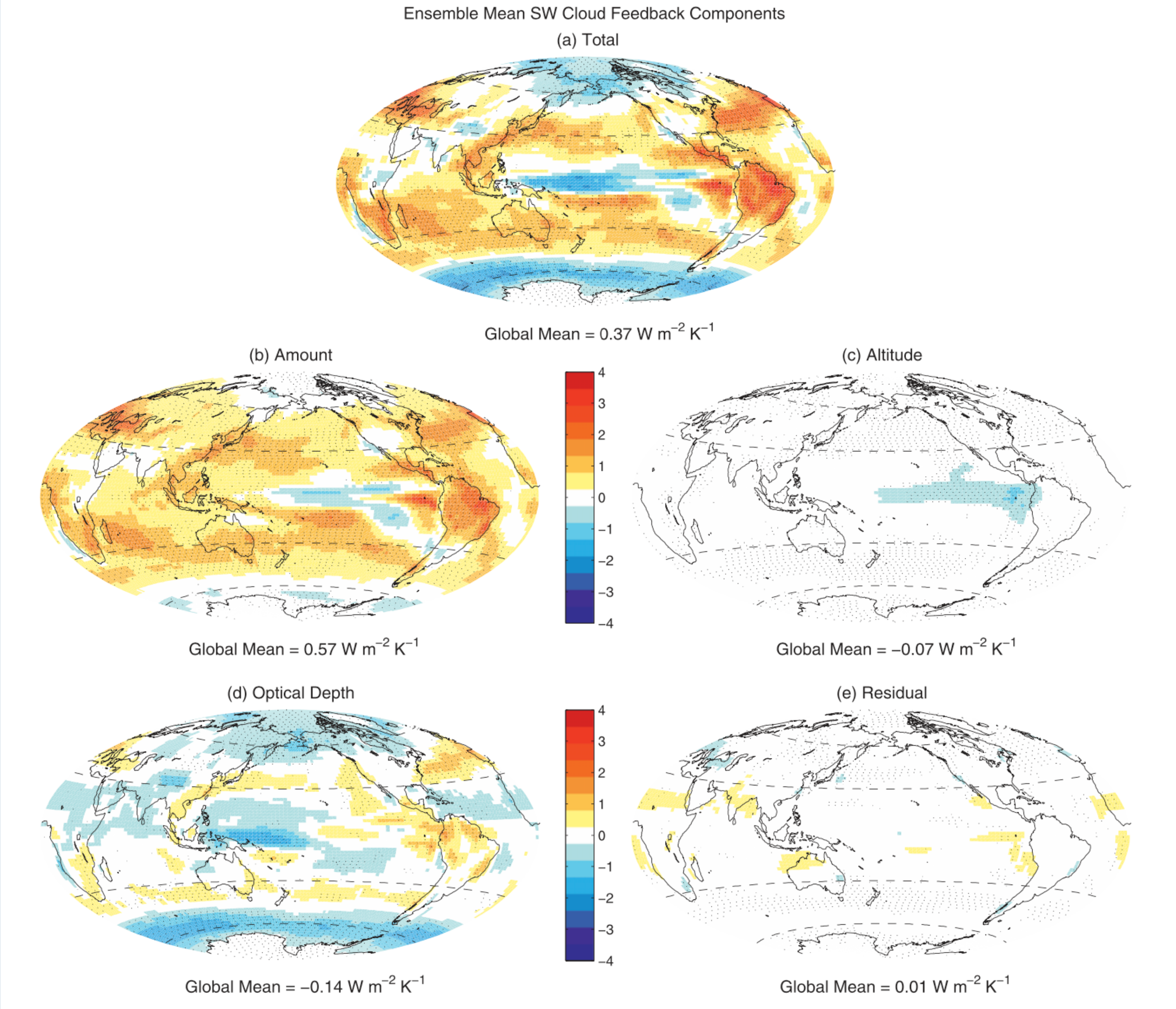


Figure 4. Zelinka et al. (2012b)

Tropical deep convecting clouds

Tropical deep convecting clouds

- There are three main hypotheses and a rising fourth describing the behavior of anvils with warming SSTs

Tropical deep convecting clouds

- There are three main hypotheses and a rising fourth describing the behavior of anvils with warming SSTs
    - Fixed Anvil Temperature

Tropical deep convecting clouds

- There are three main hypotheses and a rising fourth describing the behavior of anvils with warming SSTs
  - Fixed Anvil Temperature
  - Proportionally Higher Anvil Temperature

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  - Fixed Anvil Temperature
  - Proportionally Higher Anvil Temperature
  - Fixed Anvil Pressure

Tropical deep convecting clouds

- There are three main hypotheses and a rising fourth describing the behavior of anvils with warming SSTs
  - Fixed Anvil Temperature
  - Proportionally Higher Anvil Temperature
  - Fixed Anvil Pressure
  - Fixed Tropopause Temperature

Tropical deep convecting clouds

- There are three main hypotheses and a rising fourth describing the behavior of anvils with warming SSTs
  - Fixed Anvil Temperature
  - **Proportionally Higher Anvil Temperature**
  - Fixed Anvil Pressure
  - Fixed Tropopause Temperature

Tropical deep convecting clouds

- There are three main hypotheses and a rising fourth describing the behavior of anvils with warming SSTs
- An environment of increased static stability allows for the necessary condition for decreased pressure, increased temperature, and decreased coverage of anvil clouds

Tropical deep convecting clouds

- There are three main hypotheses and a rising fourth describing the behavior of anvils with warming SSTs
- An environment of increased static stability allows for the necessary condition for decreased pressure, increased temperature, and decreased coverage of anvil clouds
- Net cloud feedbacks are dominated by the positive SW cloud feedback in the low-levels with the upper-level dominated by SW cloud feedbacks for thick clouds and LW cloud feedbacks for thin clouds