The circulation response to greenhouse gas forcings as a negative climate feedback

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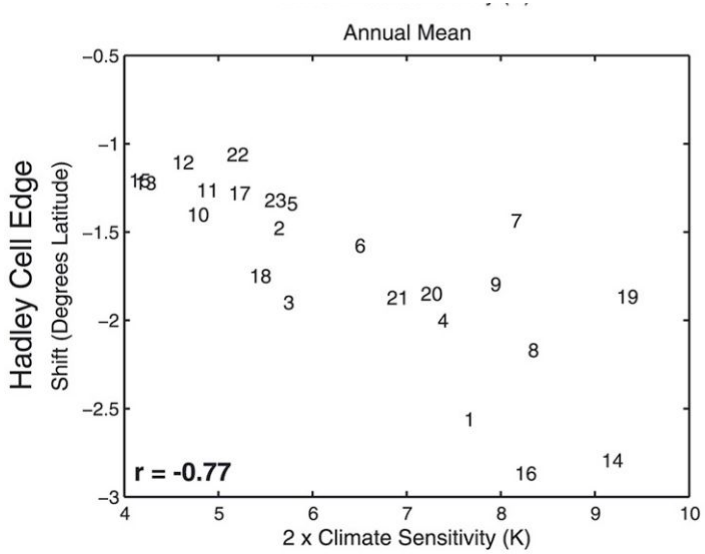
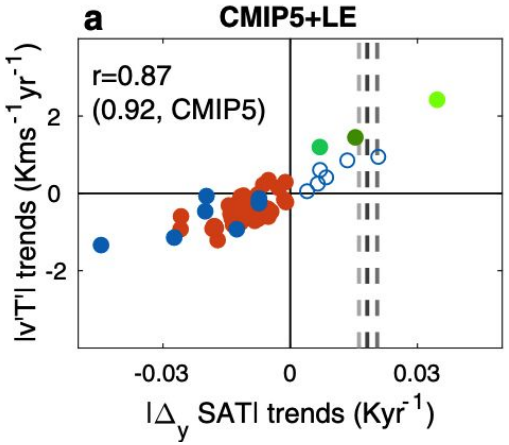
Connections between the circulate and climate sensitivity

- Dynamical sensitivity scales with climate sensitivity
  - Hadley cell expansion [Grise and Polvani 2016]
  - Midlatitude eddy heat flux [Chemke and Polvani 2020]
- Cloud response and cloud biases can be linked to the Hadley circulation [Tselioudis et al. 2016, Lipat et al. 2017]
- Can we explain *why*?
  - *Is the circulation a passive response, or an active feedback?*



From Grise and Polvani [2016], the correlation between shifts in the SH Hadley cell edge and climate sensitivity across CMIP5 models.

From Chemke and Polvani [2020], the correlation between eddy heat flux trends and trends in the meridional gradient of surface temperature.



Leveraging the nudging scheme to *uncouple* the circulation

Preindustrial emissions

Abrupt 4xCO2 emissions

Preindustrial control
U, V, T archived every timestep

4xCO2 response

Radiative-convective response

4xCO2
Freely evolving circulation

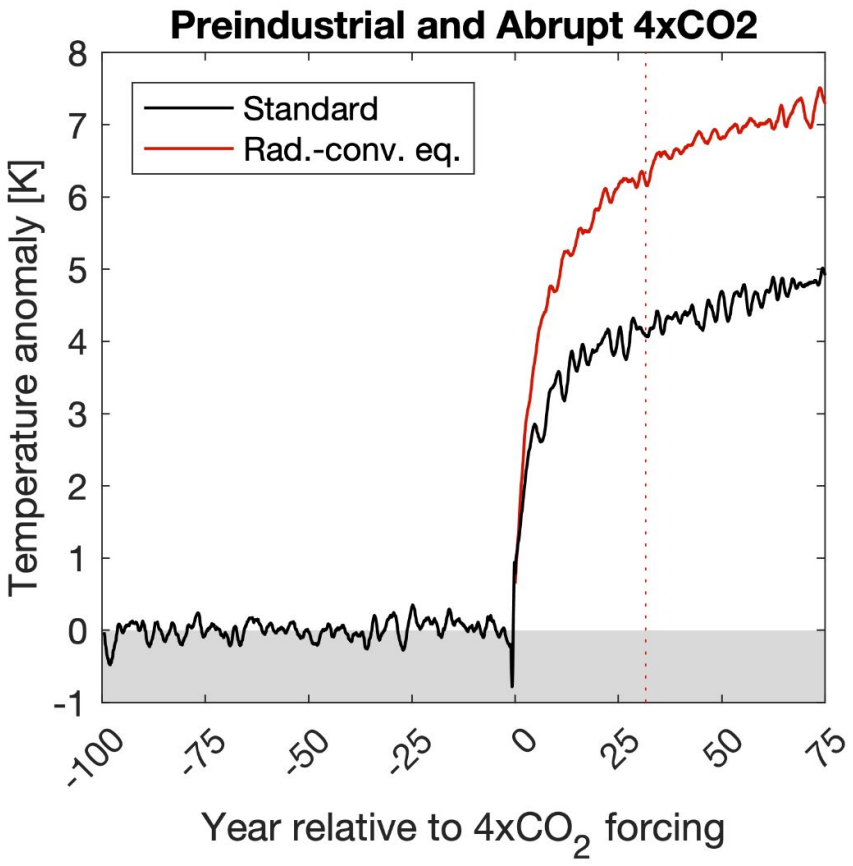
4xCO2
Eddy U,V,T and zonal-mean V nudged to PiC

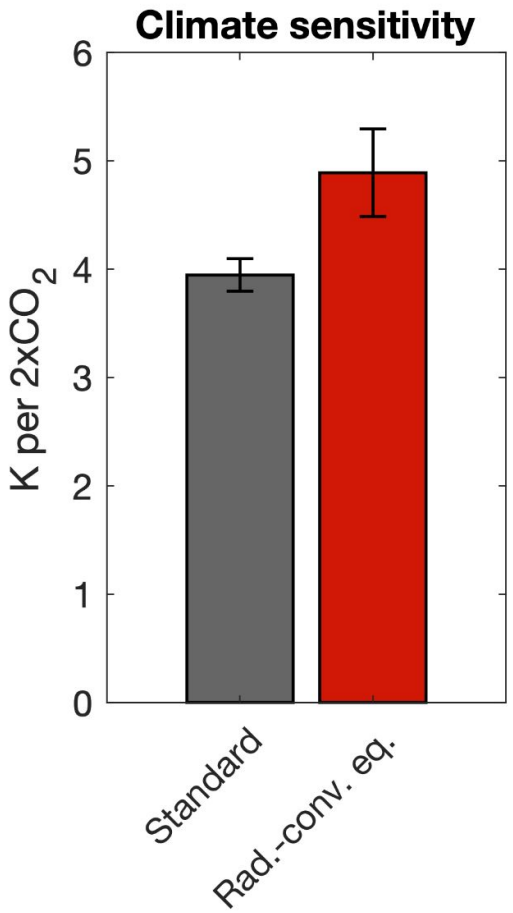
What the climate response looks like if the circulation doesn't change.

WACCM-FV 2 deg. with TSMLT chemistry, 70 vertical levels

Adaptation of approach used by Davis and Birner [2022] in an idealized aquaplanet model with gray radiation.

How does circulation change impact climate sensitivity?



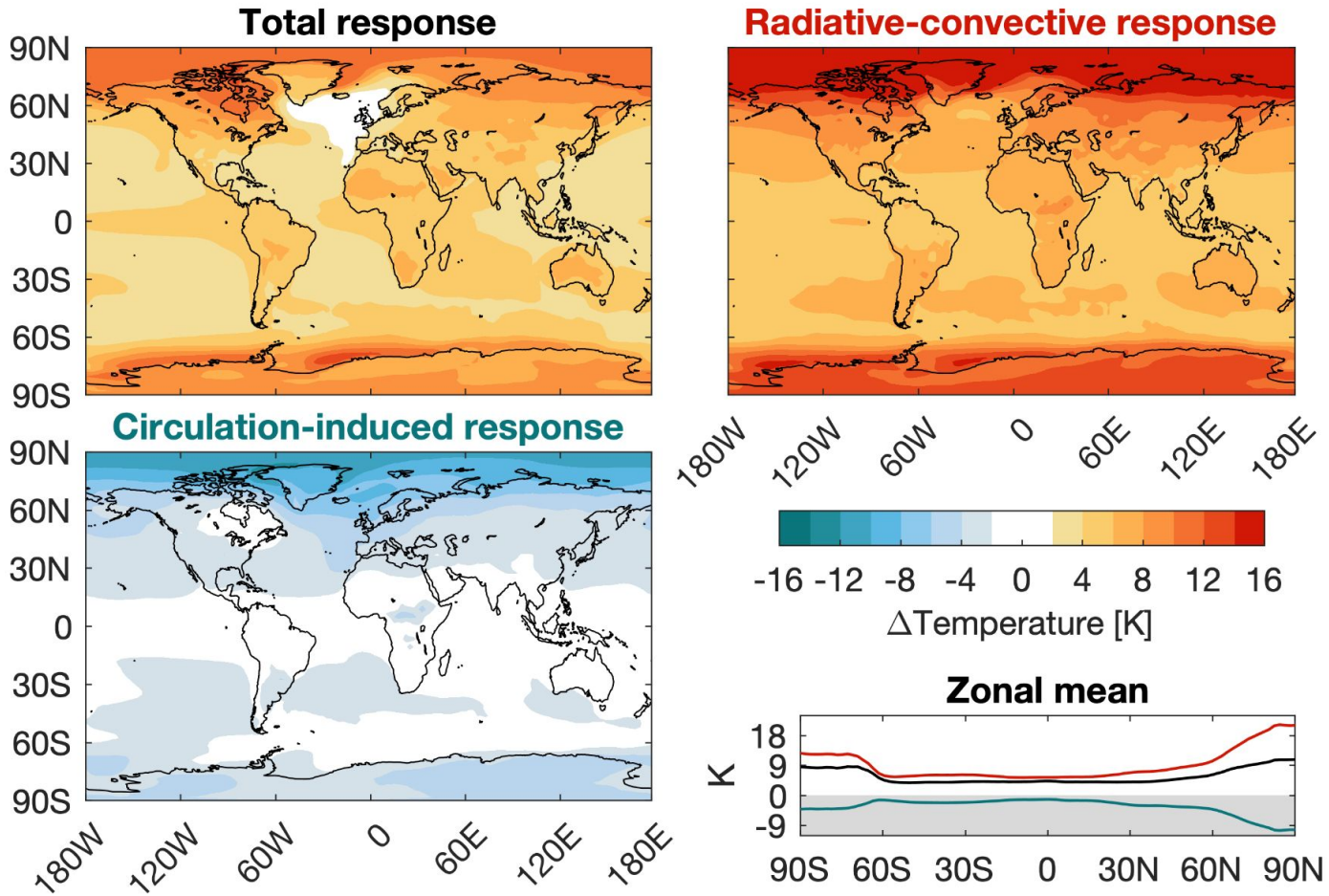


- Climate sensitivity increases by ~25% when circulation is constrained to PiC
- AMOC fully collapses in radiative-convective response, limit analysis to first 75 years of 4xCO2

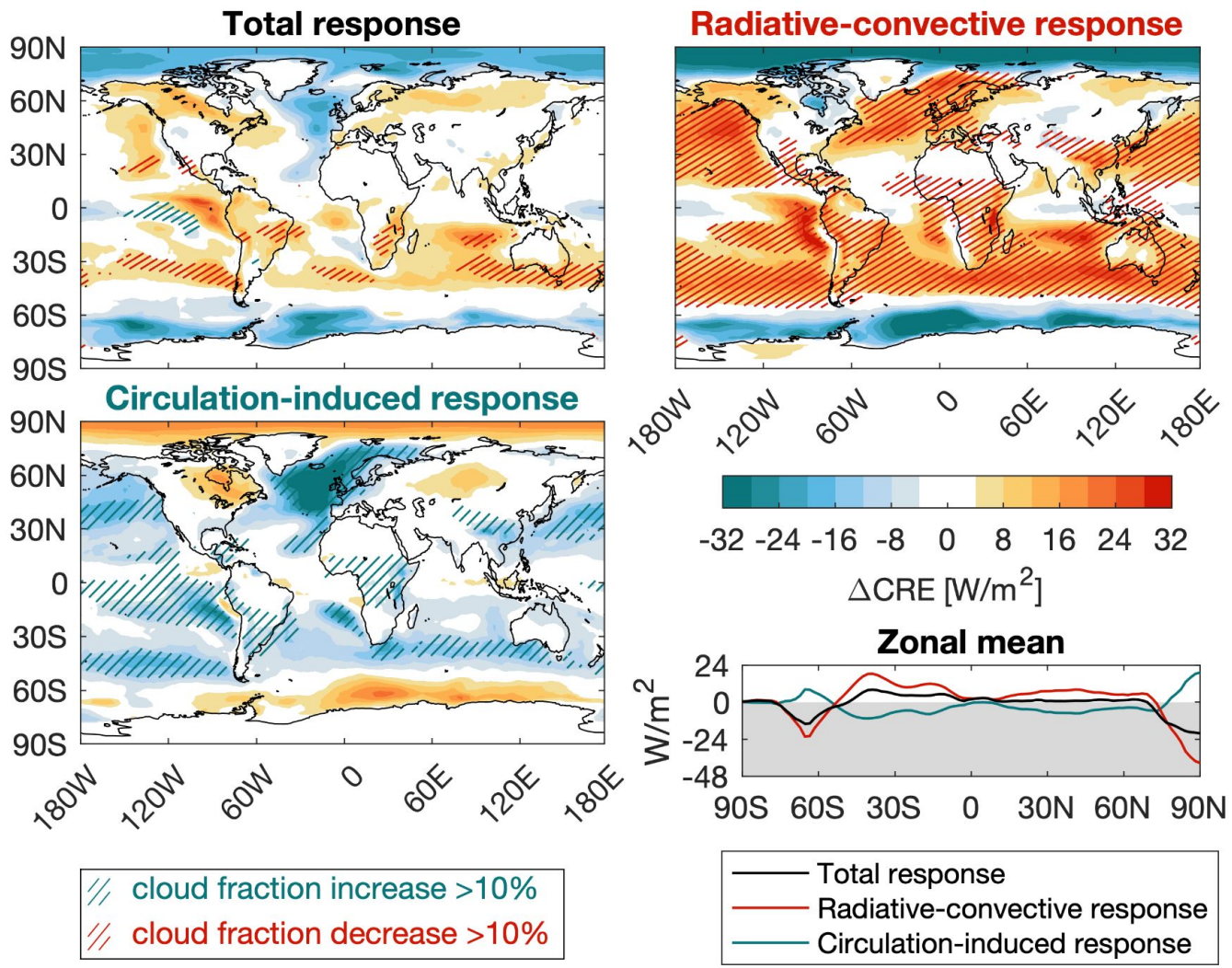
99% confidence intervals based on bootstrap resampling with replacement.

The circulation is a negative feedback - everywhere

- Radiative-convective response has 1.5-2x more polar amplification than 4xCO2 response
- Circulation-induced cooling is as large as 4xCO2 response at poles
- Circulation response *cools everywhere*
  - Damping process, i.e., feedback



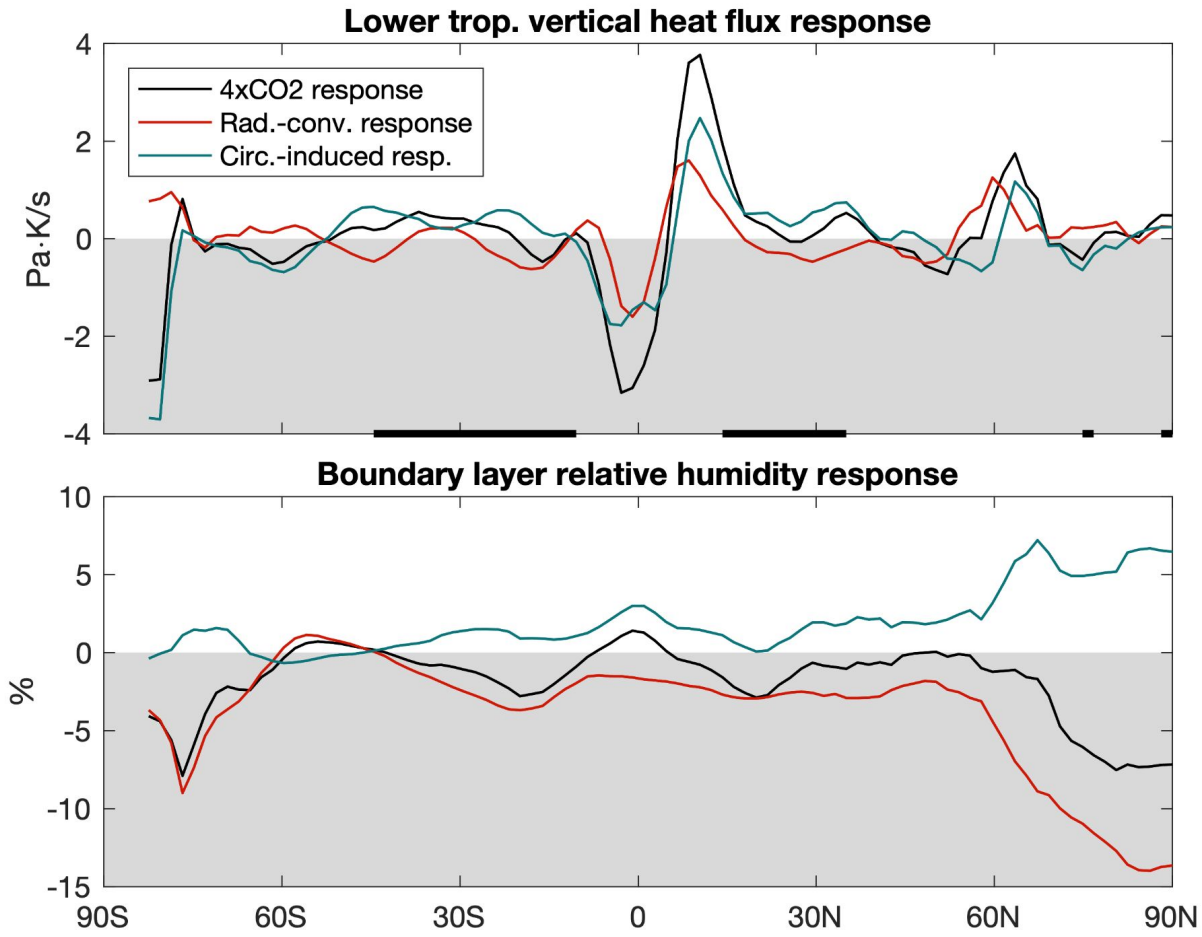
The feedback operates through clouds in the tropics and midlatitudes…



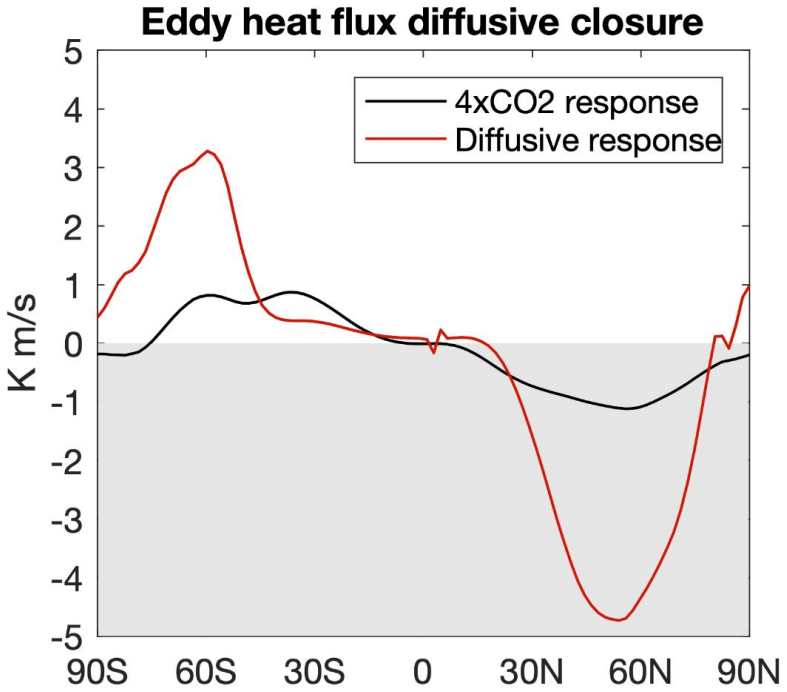
- The individual responses are more coherent than the coupled response
- Radiative-convective response wipes out tropical and midlatitude clouds
- Circulation rebuilds clouds
- At the poles, large CRE changes but minimal cloud changes; albedo and sea ice effects on clear-sky radiation

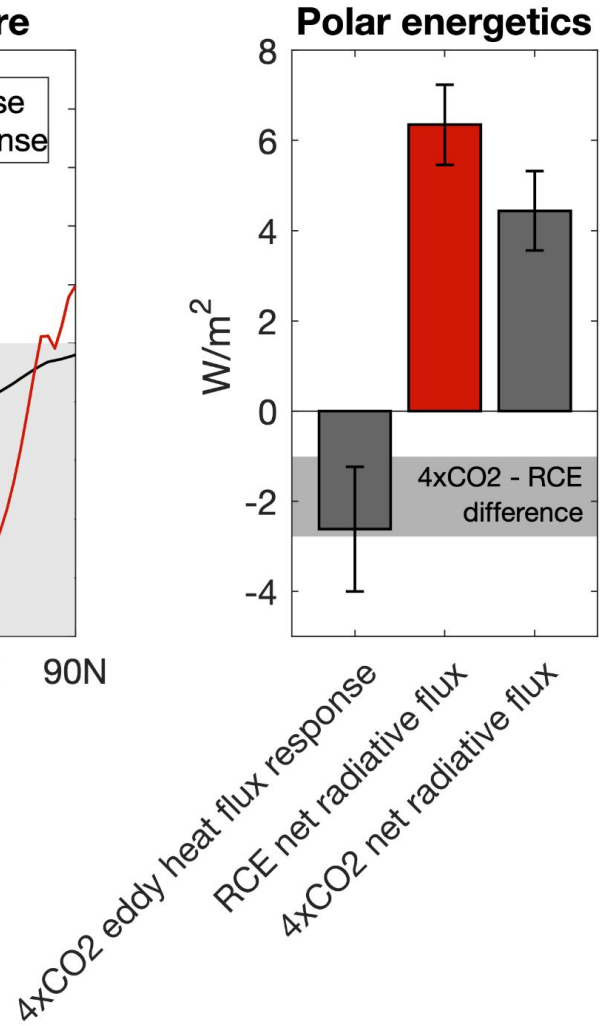
…limiting boundary layer drying by weakening subsidence…

- Radiative-convective response:
  - ↓ Vertical (downward) heat flux
  - ↓ Relative humidity
- Circulation-induced response:
  - ↑ Vertical (downward) heat flux
  - ↑ Relative humidity
- Vertical heat flux ~ boundary layer inversion strength for a given vertical velocity [Betts 1989]
  - The circulation response may help maintain the capping inversion and elevate relative humidity



…and operates through eddy heat fluxes at the poles.





- Hypothesis: radiative-convective polar warming weakens the meridional temperature gradient, weakens eddy heat flux
  - Train diffusivity on PiC, apply to radiative-convective temperature gradient
- Change in net radiative flux at the pole between the radiative-convective and coupled responses is consistent with the weakening of the eddy heat flux

Summary

- The circulation response to climate forcings is a negative feedback, damping the warming at all locations
  - The feedback seems to operate through meridional eddy fluxes (poles) and clouds (tropics and midlatitudes)
  - It could explain why dynamical sensitivity is connected to climate sensitivity and cloud responses
    - Some existing feedbacks are probably wrapped up the “circulation feedback”
- The individual responses appear more coherent and easier to understand than the total response
- While we generally think about climate feedbacks from a column/radiation perspective, that may be limiting, and due in part to the use of offline radiative transfer models
  - Feedbacks work in all dimensions, this framework may be able to address them more robustly