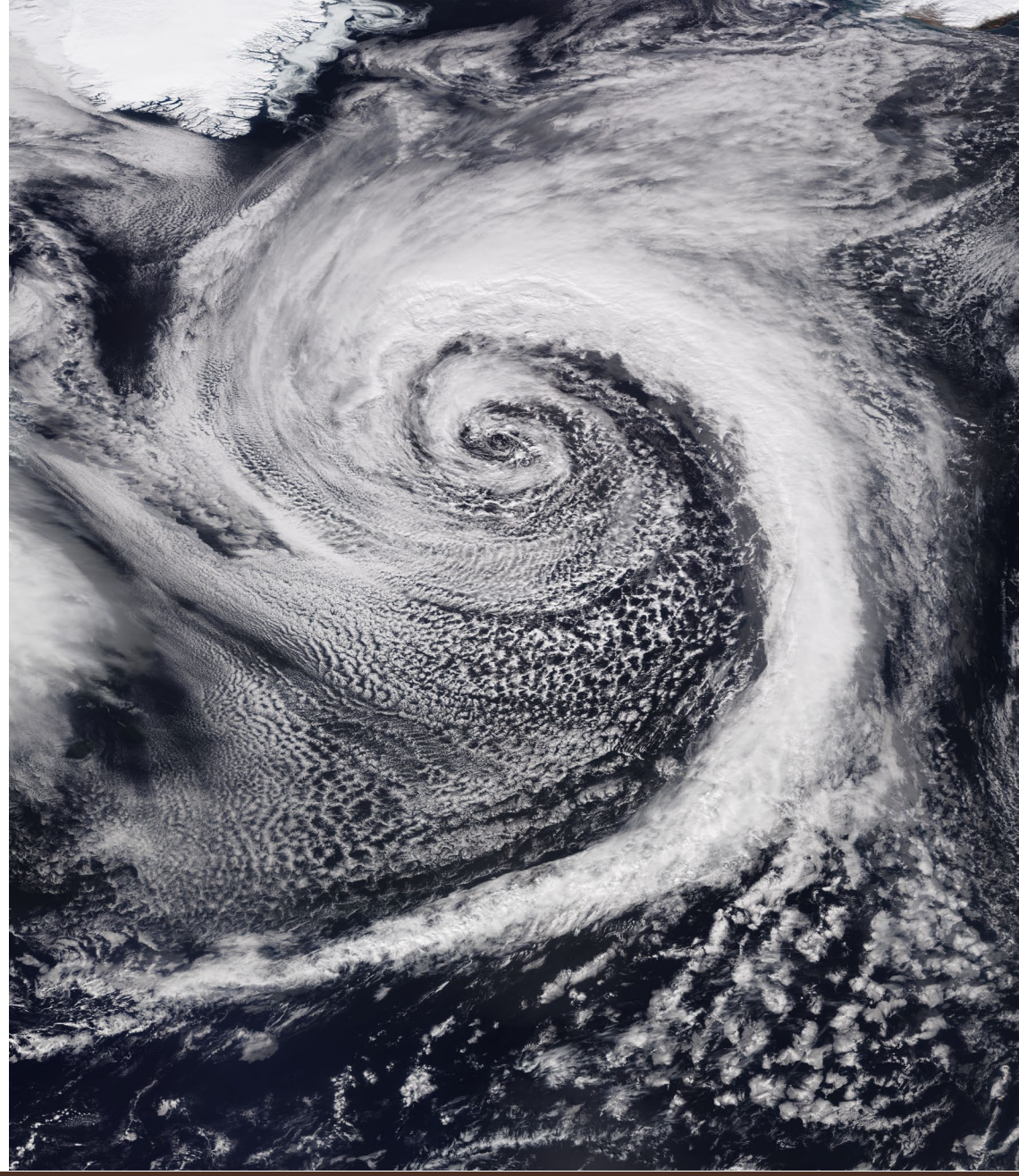
# Climate Model Extratropical Cloud Feedback Constrained by Cloud Sources and Sinks in Cyclones

Werapitiya et al. 2024 (JCLI, in prep)



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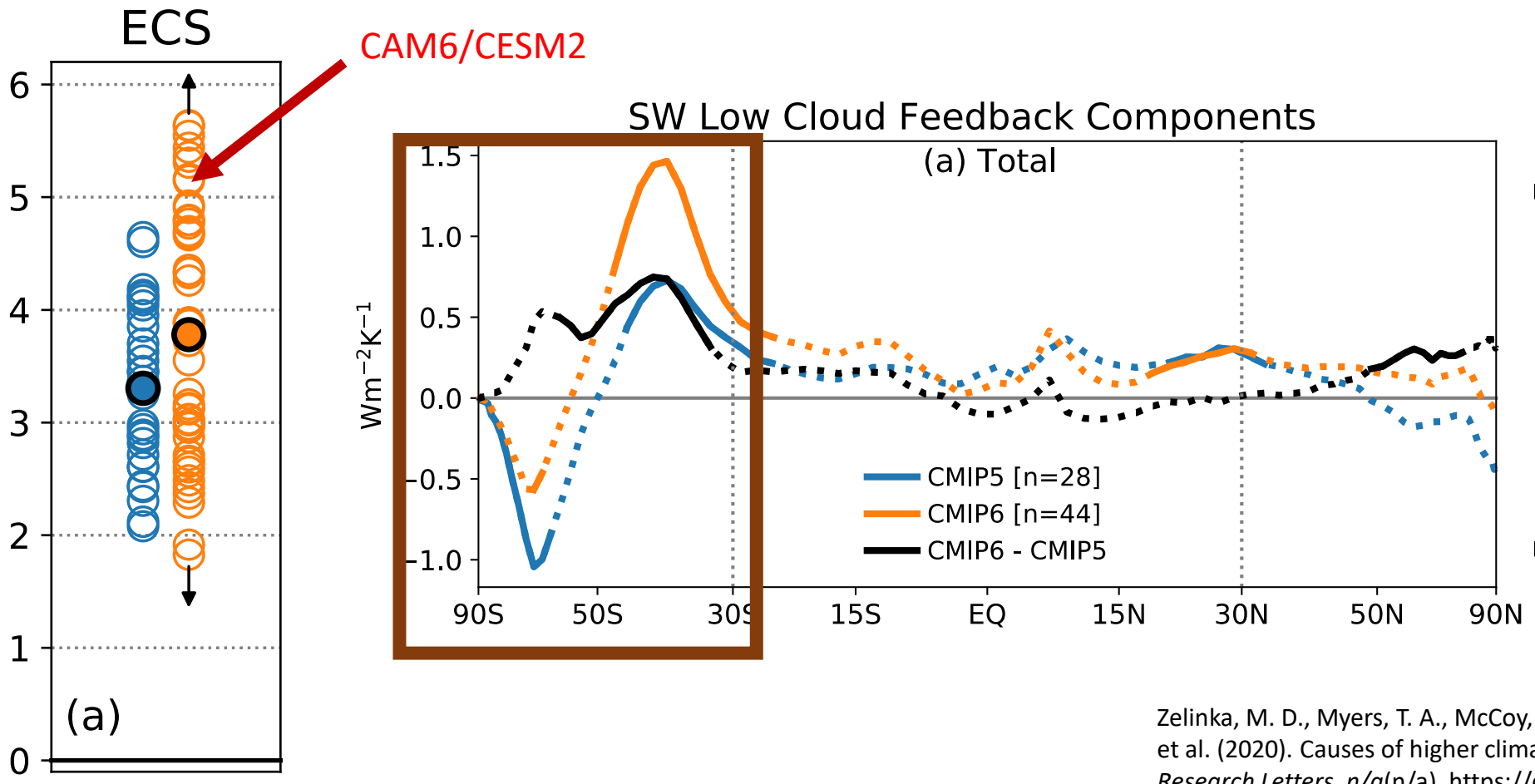
# Motivation




- CMIP6 GCMs had more positive extratropical cloud feedback.
- High Equilibrium Climate Sensitivity (ECS) (>4.5K) models emerged.
- CAM6 show ~5K ECS.

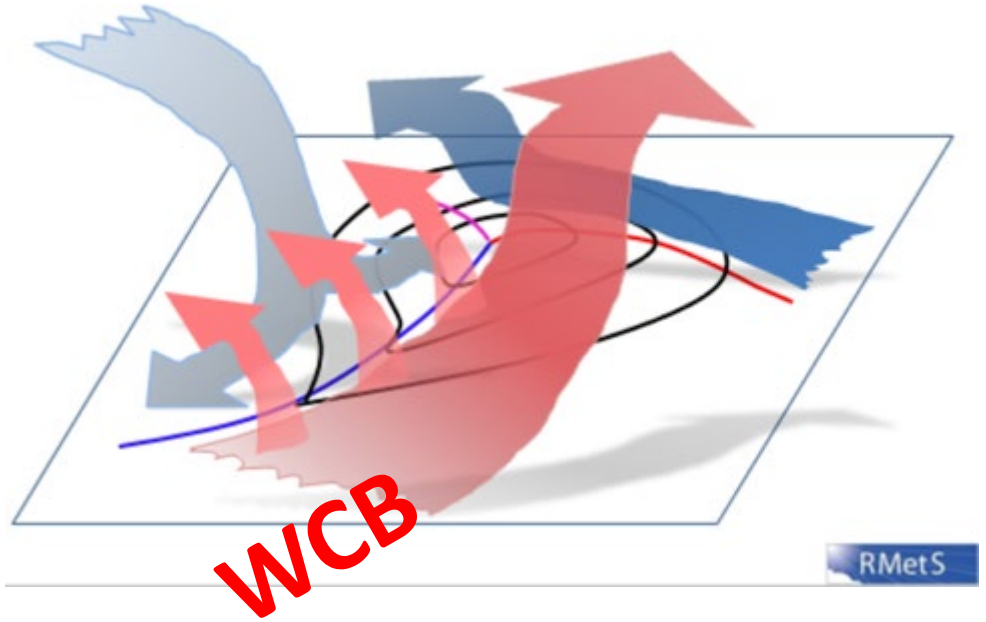

Zelinka, M. D., Myers, T. A., McCoy, D. T., Po-Chedley, S., Caldwell, P. M., Ceppi, P., et al. (2020). Causes of higher climate sensitivity in CMIP6 models. *Geophysical Research Letters*, *n/a*(n/a). https://doi.org/10.1029/2019GL085782

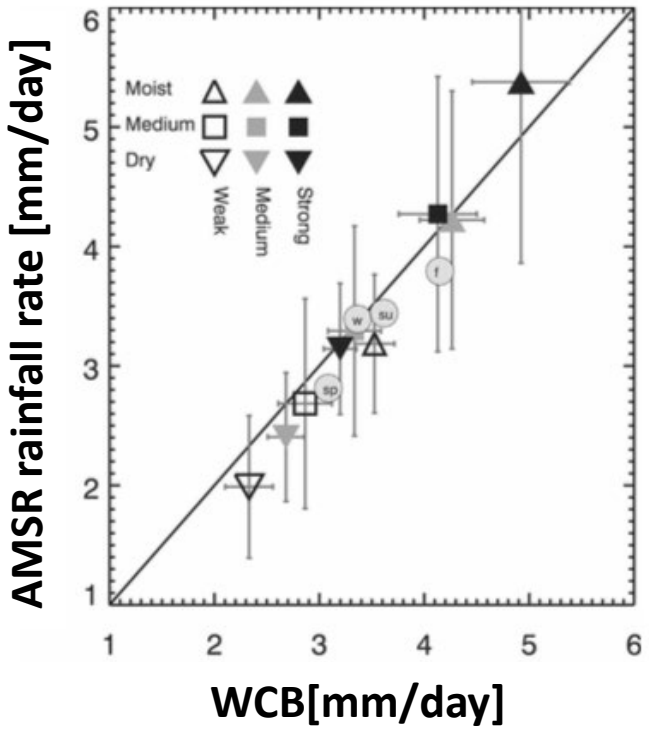
# What controls extratropical cyclones?

- Warm conveyor belt moisture convergence (WCB) is a good predictor of rain rate in observations where

$$\mathbf{WCB} = \boldsymbol{WS_{10m}} \times \mathbf{WVP} \times \mathrm{const}$$

*(quantities are cyclone-mean, e.g. within 2000km of cyclone center)*



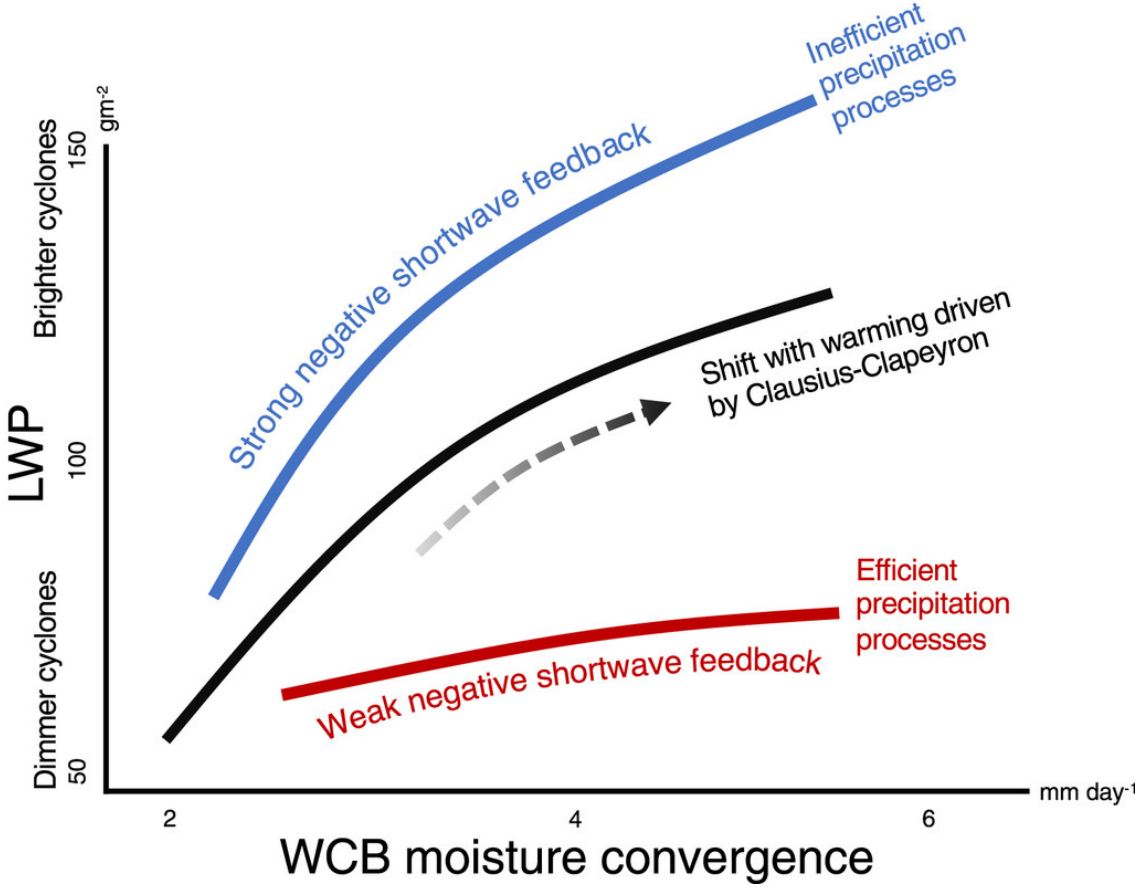




Field, P. R., & Wood, R. (2007). Precipitation and Cloud Structure in Midlatitude Cyclones. *Journal of Climate*, *20*(2), 233–254. https://doi.org/10.1175/JCLI3998.1

# Moisture convergence driven cloud feedback

- GCM simulate increasing extratropical cloudiness in response to enhanced moisture flux.

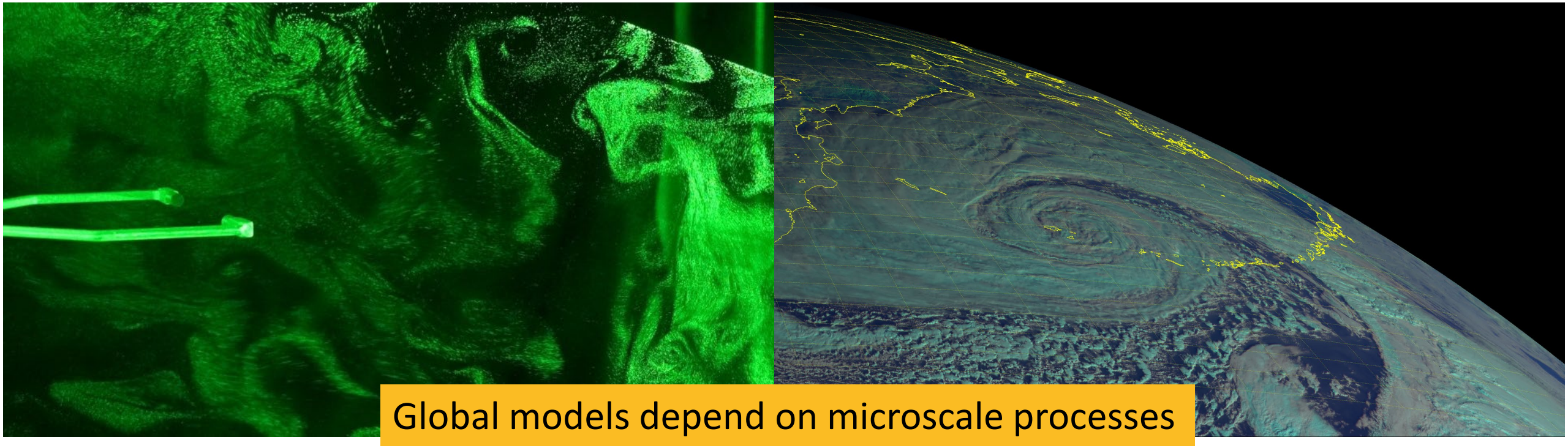
Cyclone-mean LWP




$$\mathbf{WCB} = \boldsymbol{WS_{10m}} \times \mathbf{WVP} \times \text{const}$$

$\mathbf{WVP} \propto \boldsymbol{T}$ Clausius-Clapeyron

# Why a perturbed parameter ensemble (PPE)?



Global models depend on microscale processes

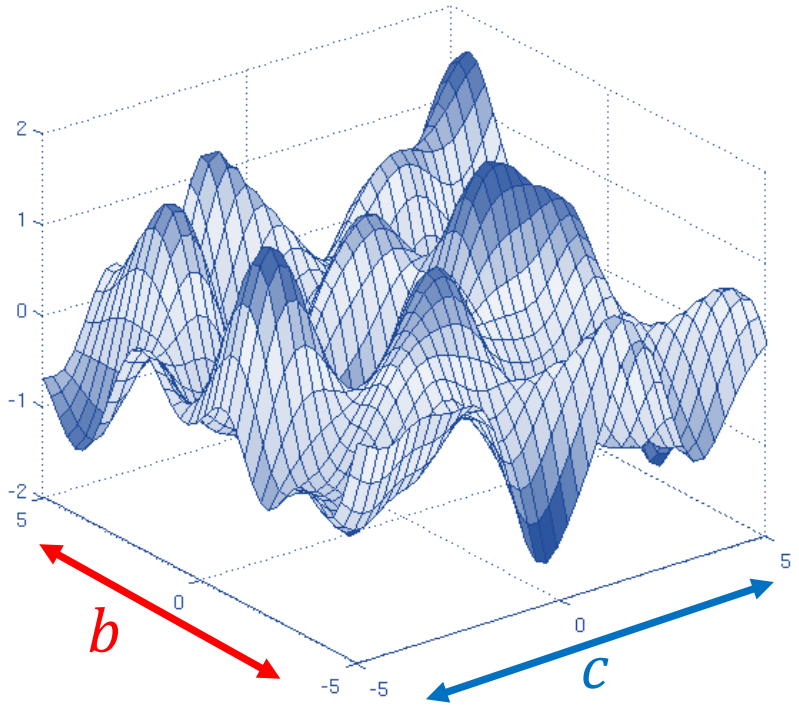
µm ⟷ km

# Perturbed parameter ensemble (PPE)

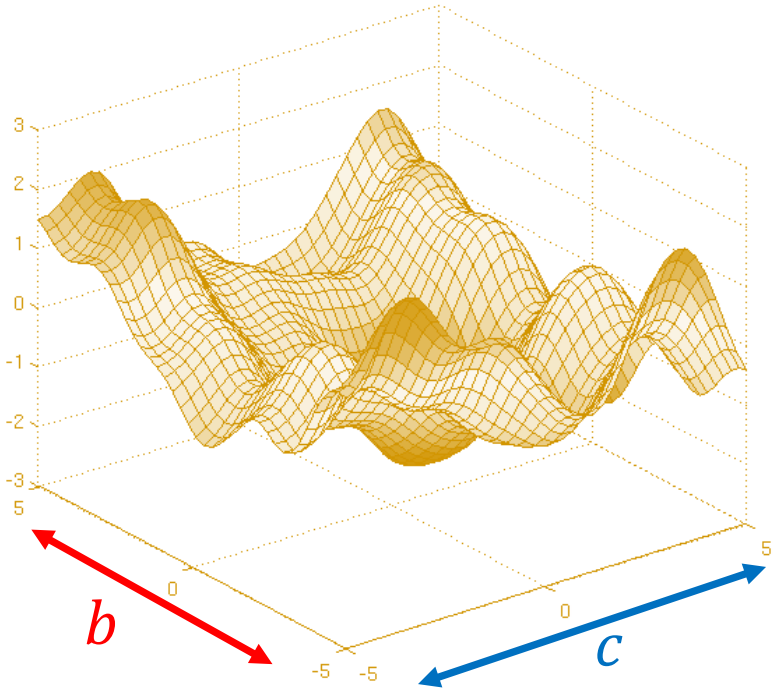
- Imagine a model with a single parameterization:

$$\dot{q}_c = a \cdot q_c^b \cdot N^c$$

An observable (e.g. cloud fraction)




An unobservable (e.g. aerosol forcing)




https://www.cs.toronto.edu/~duvenaud/cookbook/

# CAM6 Perturbed Physics Ensemble (PPE)

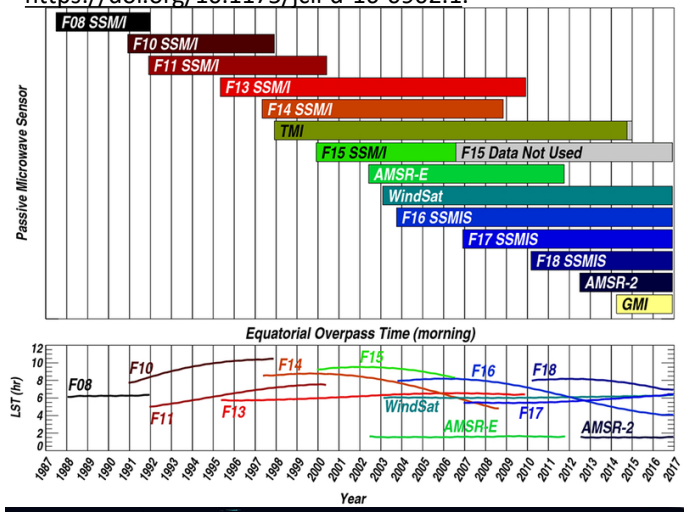
- CAM6 - The sixth Community Atmosphere Model
- 45 parameters
  - Cloud Microphysics(11), Turbulence(11), Aerosols(9), Deep Convection(12)
- 262 parameter sets for simulations, selected using *Latin Hypercube Sampling*
- With fixed SST and ice
- Development was led by Trude Eidhammer, Andrew Gettelman at NCAR and Daniel McCoy, Ci Song at UWyo.

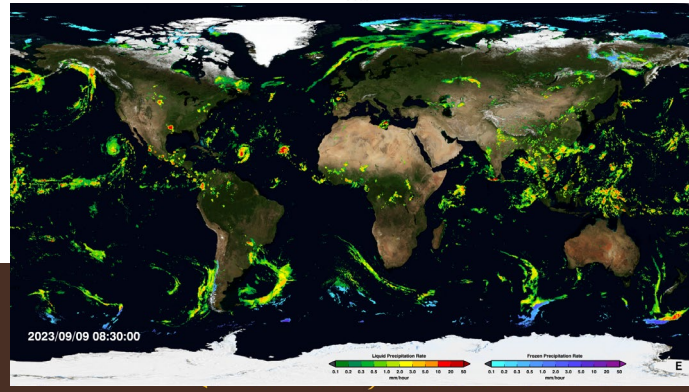
Eidhammer, T., A. Gettelman, K. Thayer-Calder, D. Watson-Parris, G. Elsaesser, H. Morrison, M. van Lier-Walqui, C. Song, and D. McCoy. "An Extensible Perturbed Parameter Ensemble (PPE) for the Community Atmosphere Model Version 6." *EGUsphere* 2024 (January 15, 2024): 1–27. https://doi.org/10.5194/egusphere-2023-2165.

# Observations

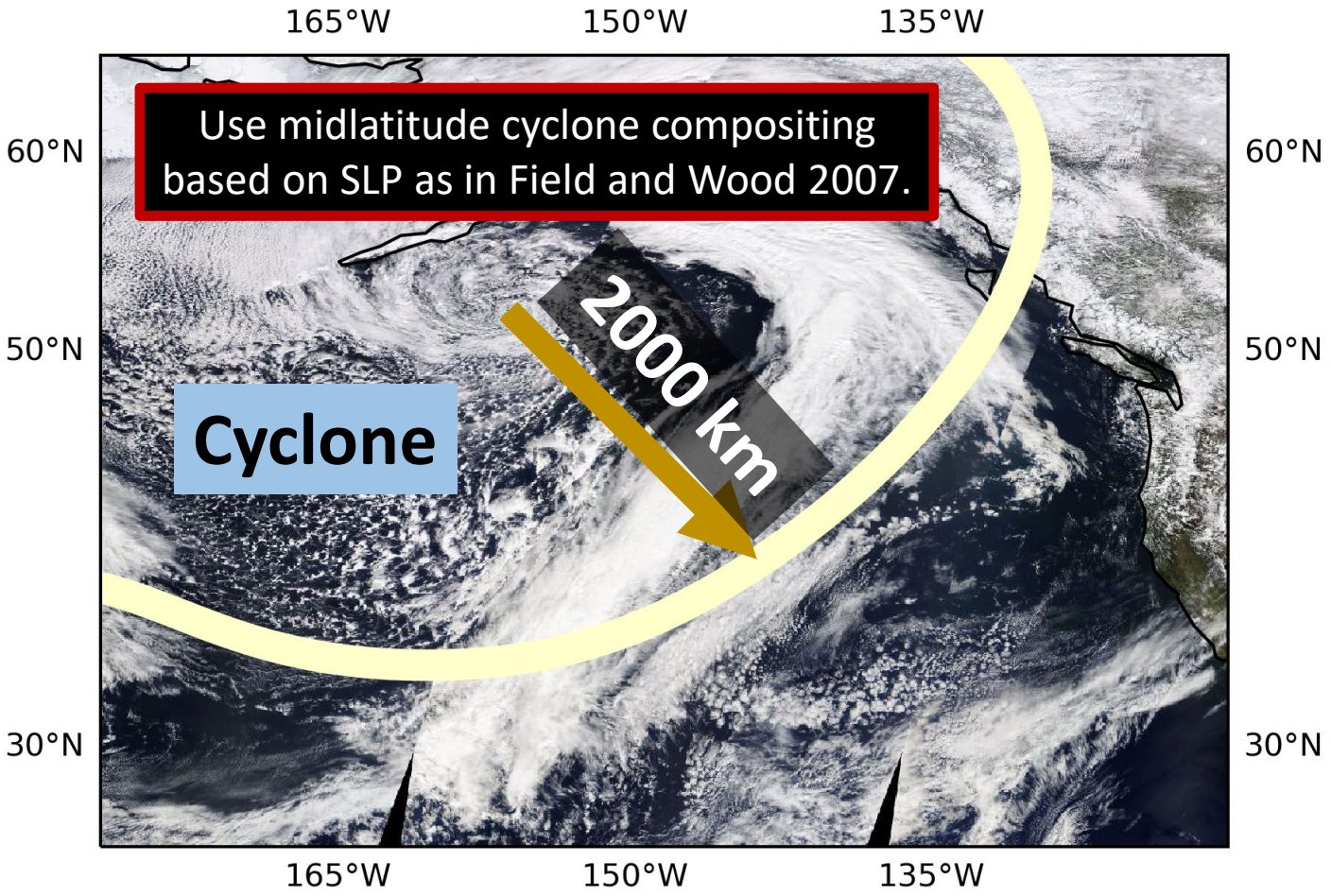
- Multi-Sensor Advanced Climatology of Liquid Water Path (MAC-LWP) – microwave radiometer based measurements
  - Variables: Daily Average Cloud Liquid Water Path, Daily Average Total Column Water Vapor, Daily Average 10-m Surface Wind Speed
- Integrated Multi-satellitE Retrievals for GPM (IMERG) Final V07 Daily product – microwave product
  - Variables: Daily accumulated Merged microwave-only precipitation estimate.
- The second Modern-Era Retrospective analysis for Research and Applications reanalysis (MERRA-2)
  - Atmospheric state

Elsaesser, G. S., Christopher W. O'Dell, Matthew D. Lebsock, Ralf Bennartz, Thomas J. Greenwald, and Frank J. Wentz. "The Multi-Sensor Advanced Climatology of Liquid Water Path (MAC-LWP)." *Journal of Climate* 0, no. 0 (2017): null. https://doi.org/10.1175/jcli-d-16-0902.1.



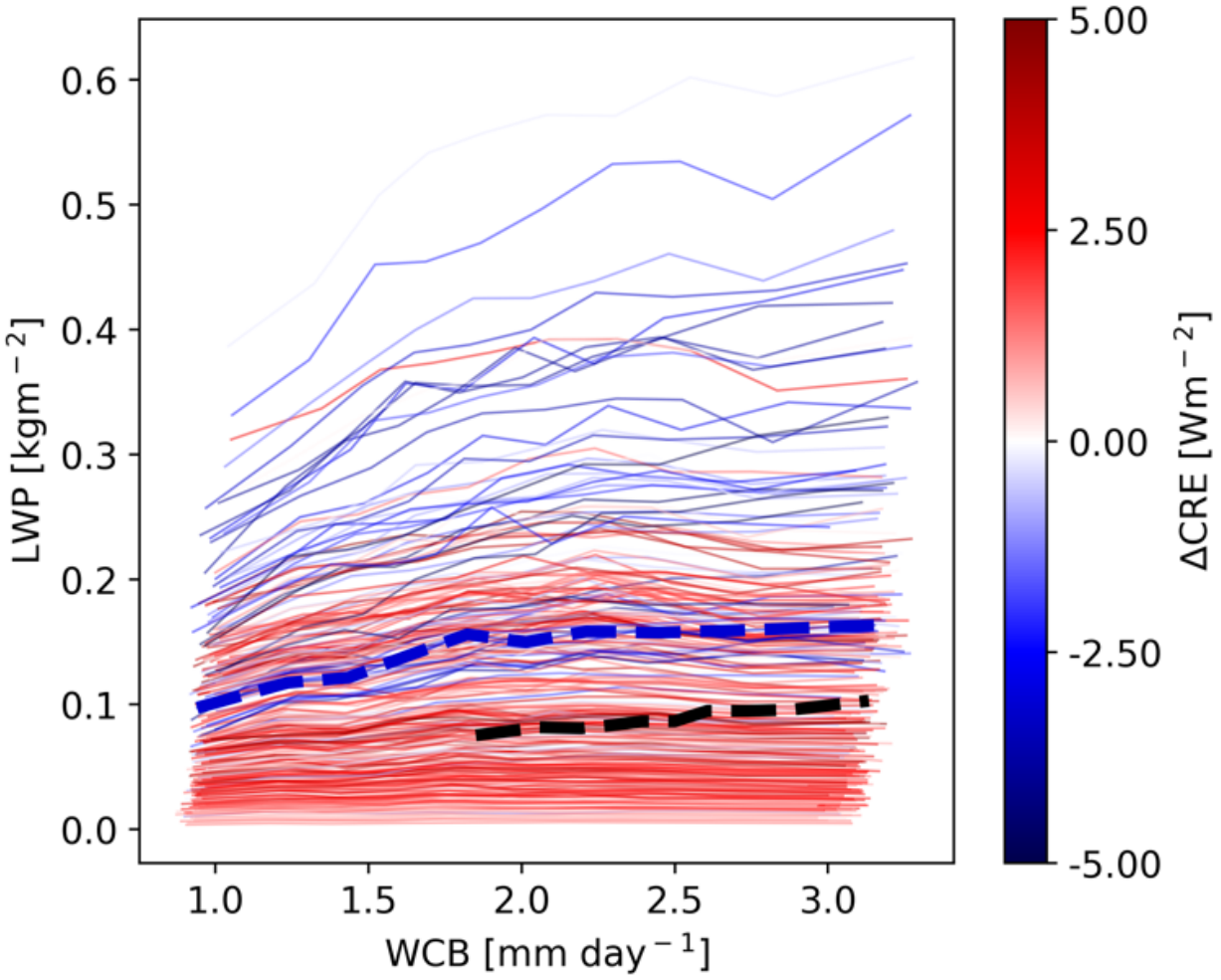



# Find extratropical cyclones




- Cyclone composites over oceans in the region 50°S-70°S
- cyclone centers using SLP
- Each composite is 4000km across

# More Clouds (LWP) with more Warm Conveyor Belt Moisture Convergence (WCB)



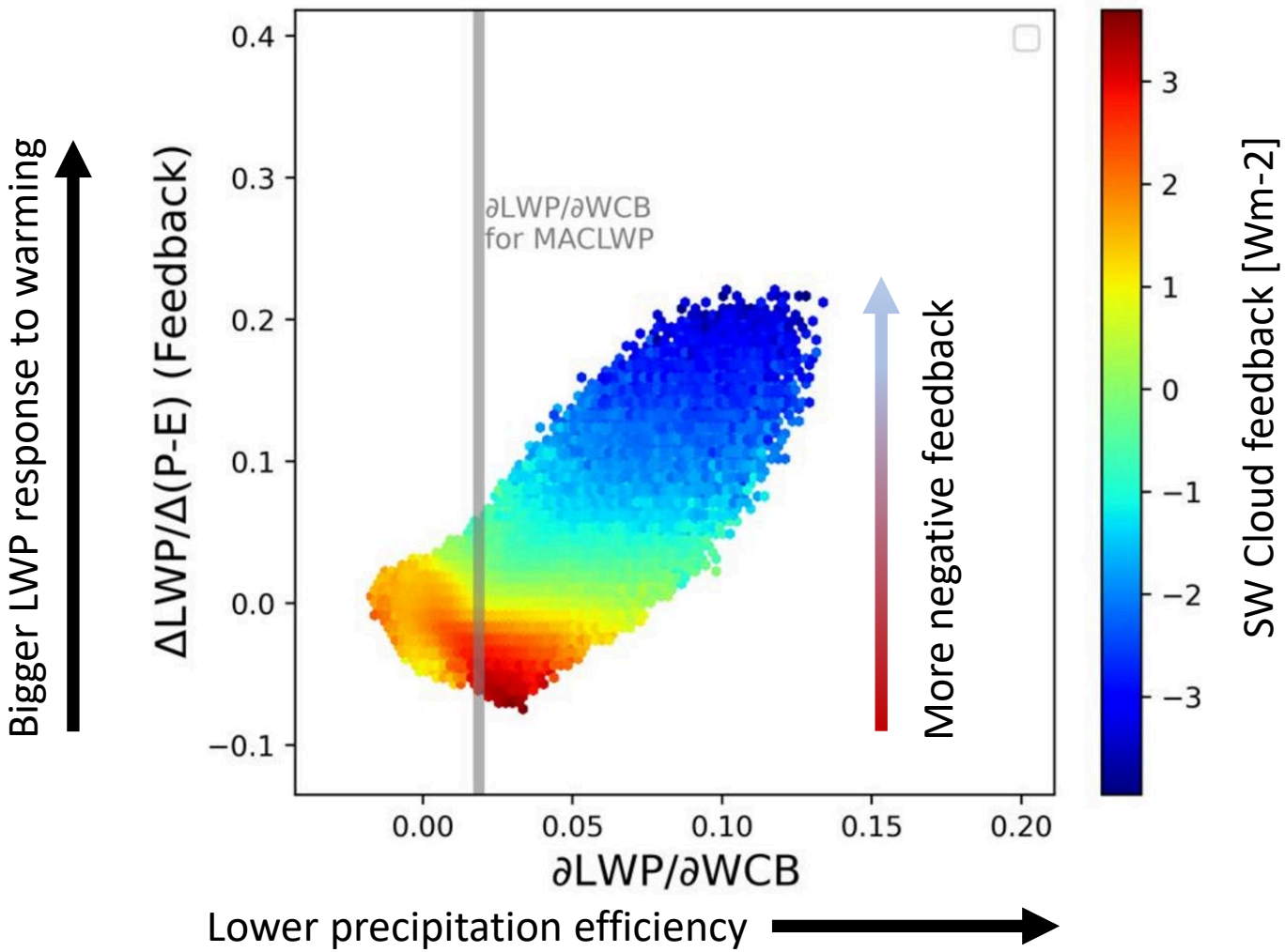

Observations: black dashed line

CAM6 default model: blue dashed lines

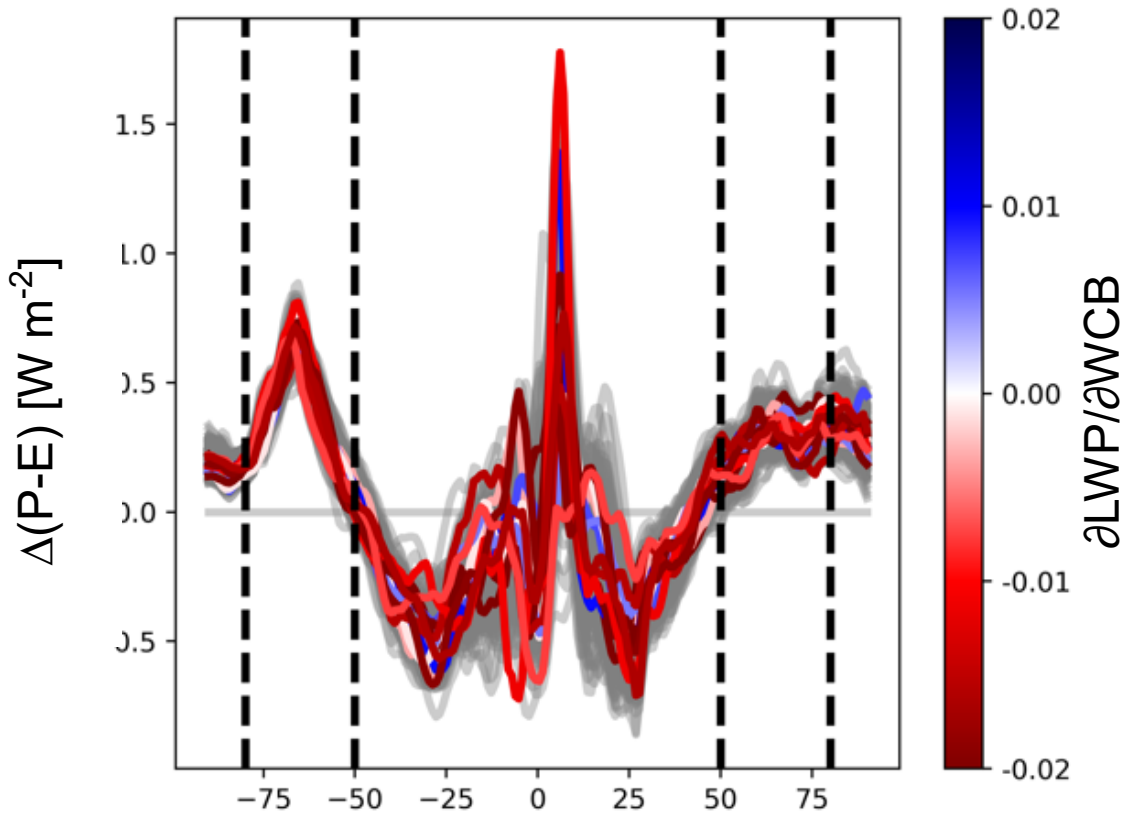
CAM6 PPE members: colored solid lines colored by the ΔCRE values

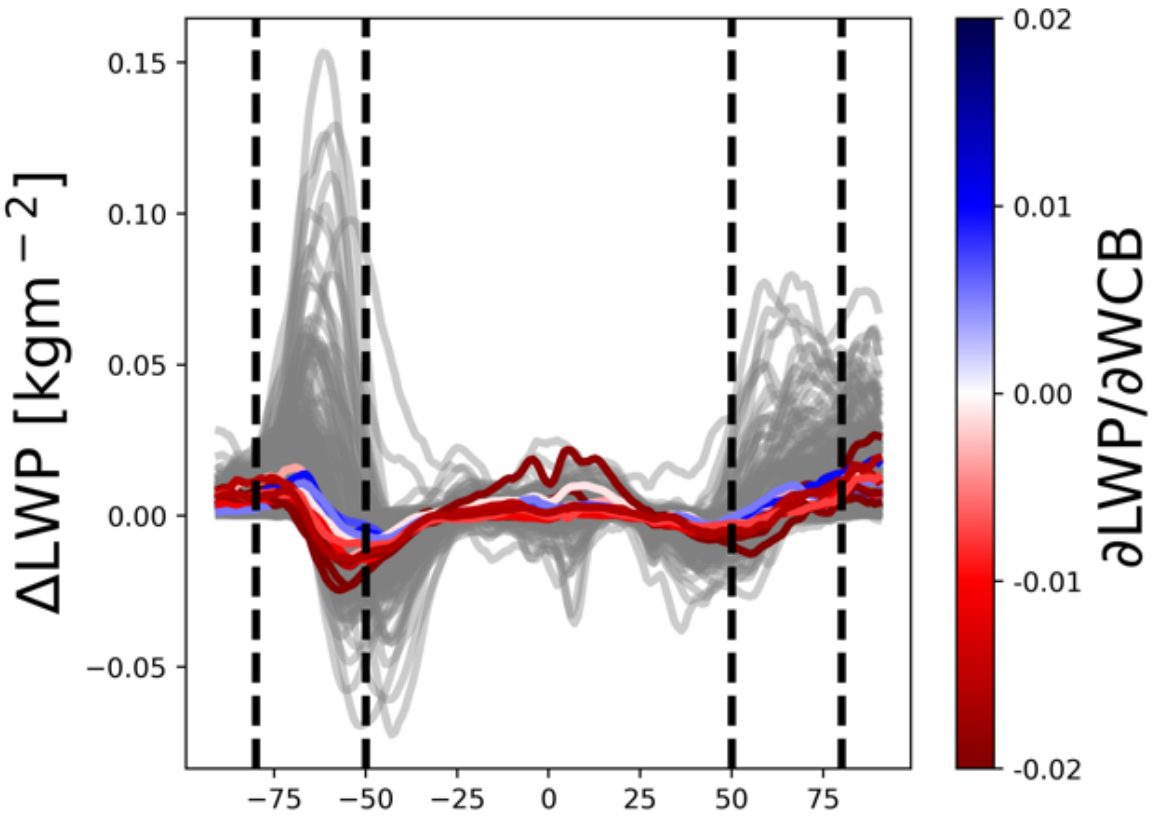
- **Clausius-Clapeyron drives enhanced moisture convergence to ECs as the climate warms.**
- **More extratropical cloudiness in ECs in response to warming.**

# Extratropical cloud feedback



# Zonal mean plots of response to warming

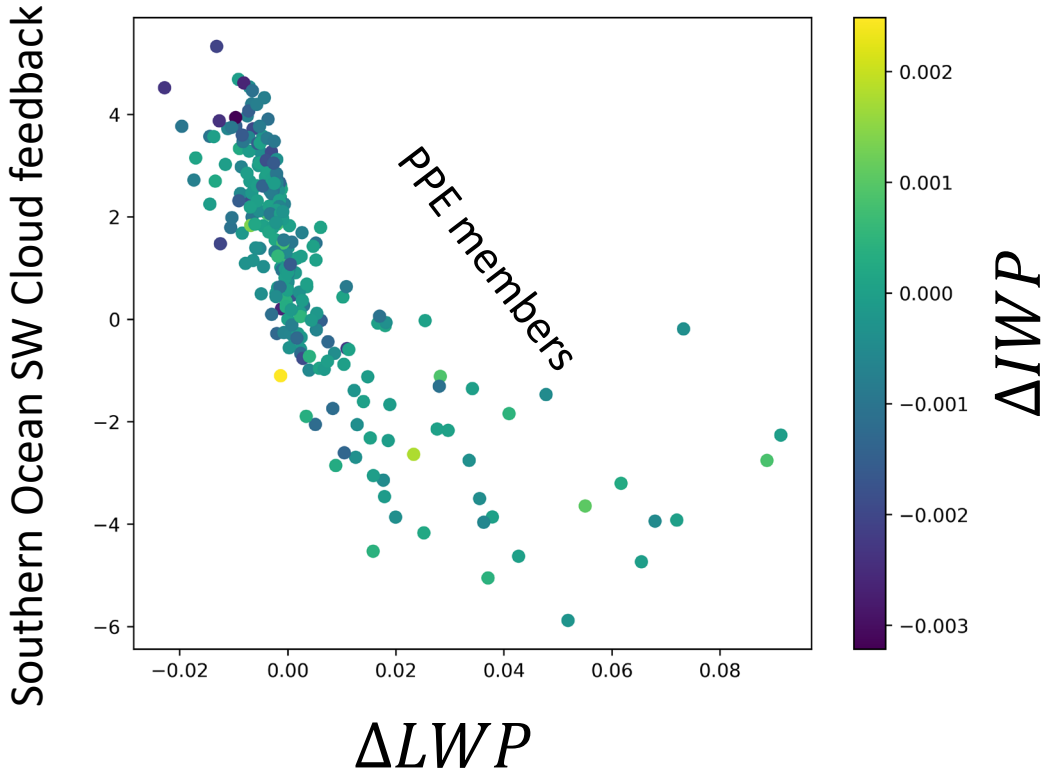


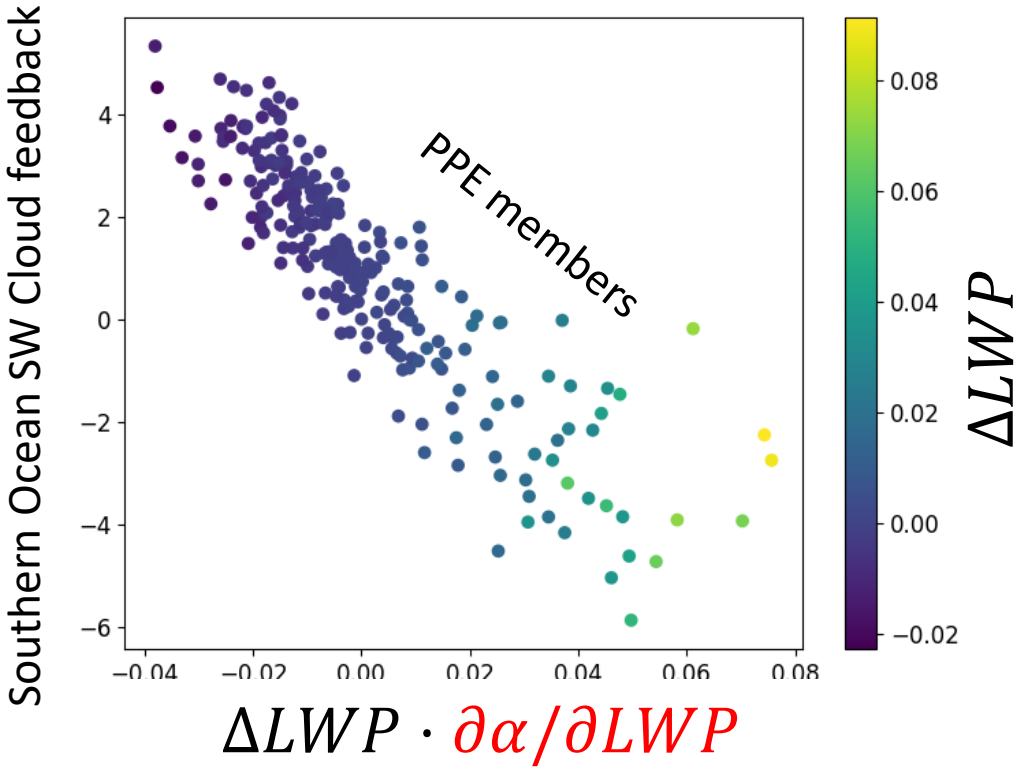




Colored lines are for PPE members constrained by observations.

- **In response to warming, subtropics dries and extratropics moistens.**

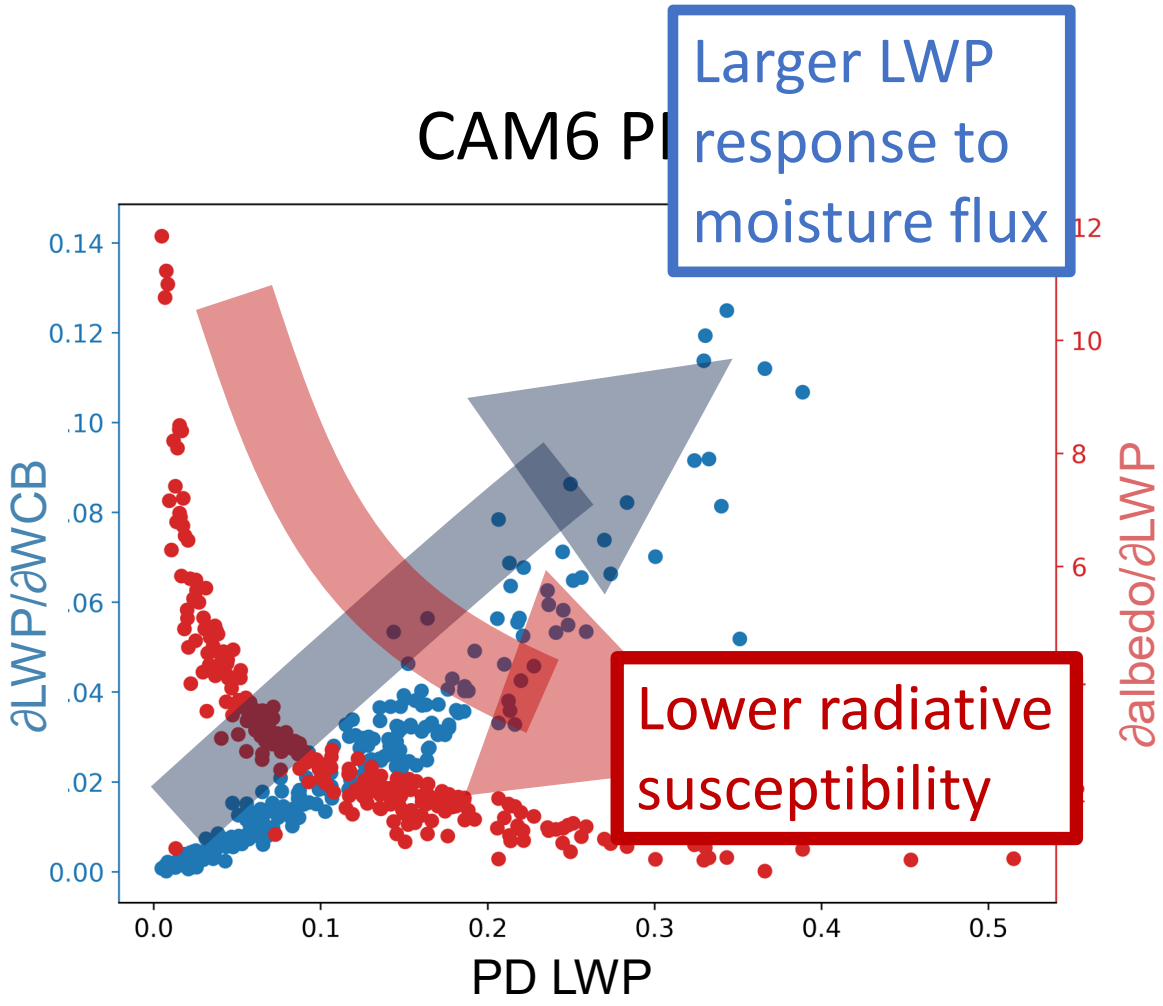
# Radiative feedback



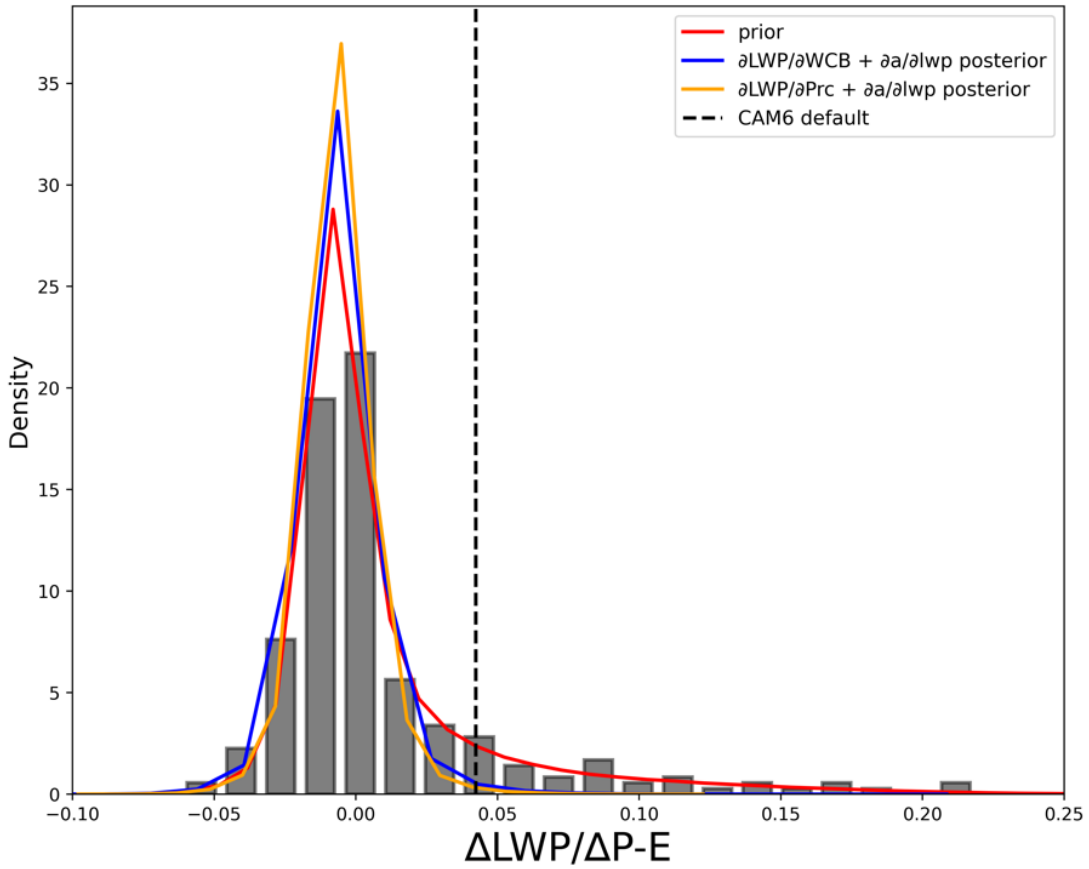

- Change in cloud properties scaled by albedo susceptibility is linear in cloud feedback.

# Moisture Removal and Radiative Efficiency

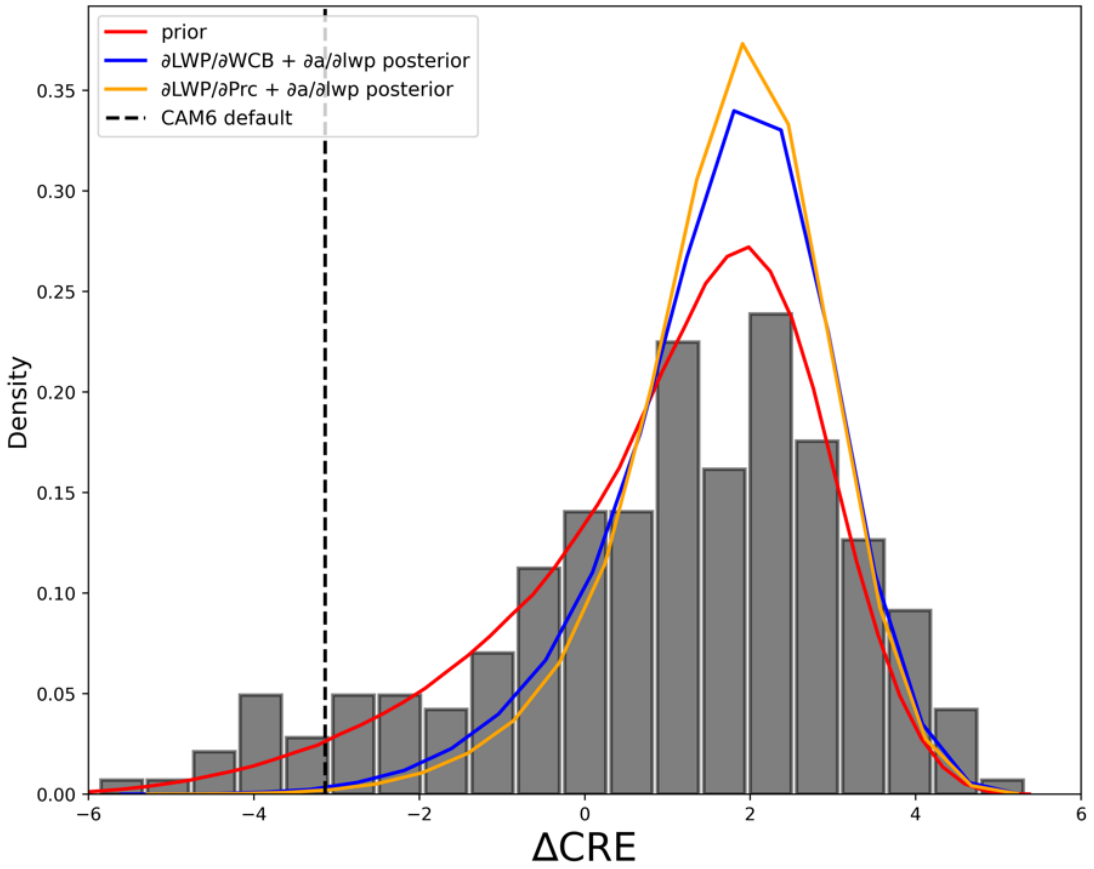



Strong sensitivities of LWP to WCB in EC are compensated by weak sensitivities of albedo to LWP.

# CAM6 is Constrained by Observations




| Constrained by ∂LWP/∂WCB | Constrained by ∂LWP/∂Precip |
|---|---|
| 64% | 69% |




| Constrained by ∂LWP/∂WCB | Constrained by ∂LWP/∂Precip |
|---|---|
| 27% | 33% |

# Take Home!

- Clausius-Clapeyron drives enhanced moisture convergence to EC as the climate warms.
- More extratropical cloudiness in EC in response to warming.
- Response of LWP to warming-driven moisture convergence ($\Delta$LWP/$\Delta$P-E) is constrained in the CAM6 PPE.
- Observations suggest a weaker $\Delta$LWP/$\Delta$P-E.
- CAM6 PPE $SW_{CF}$ is constrained by observations.
- More positive Southern ocean $SW_{CF}$ suggested by observations.
- CESM2's high ECS appears to be consistent with observational constraints on the Southern Ocean.

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THANK YOU!