



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

(manuscript submitted)

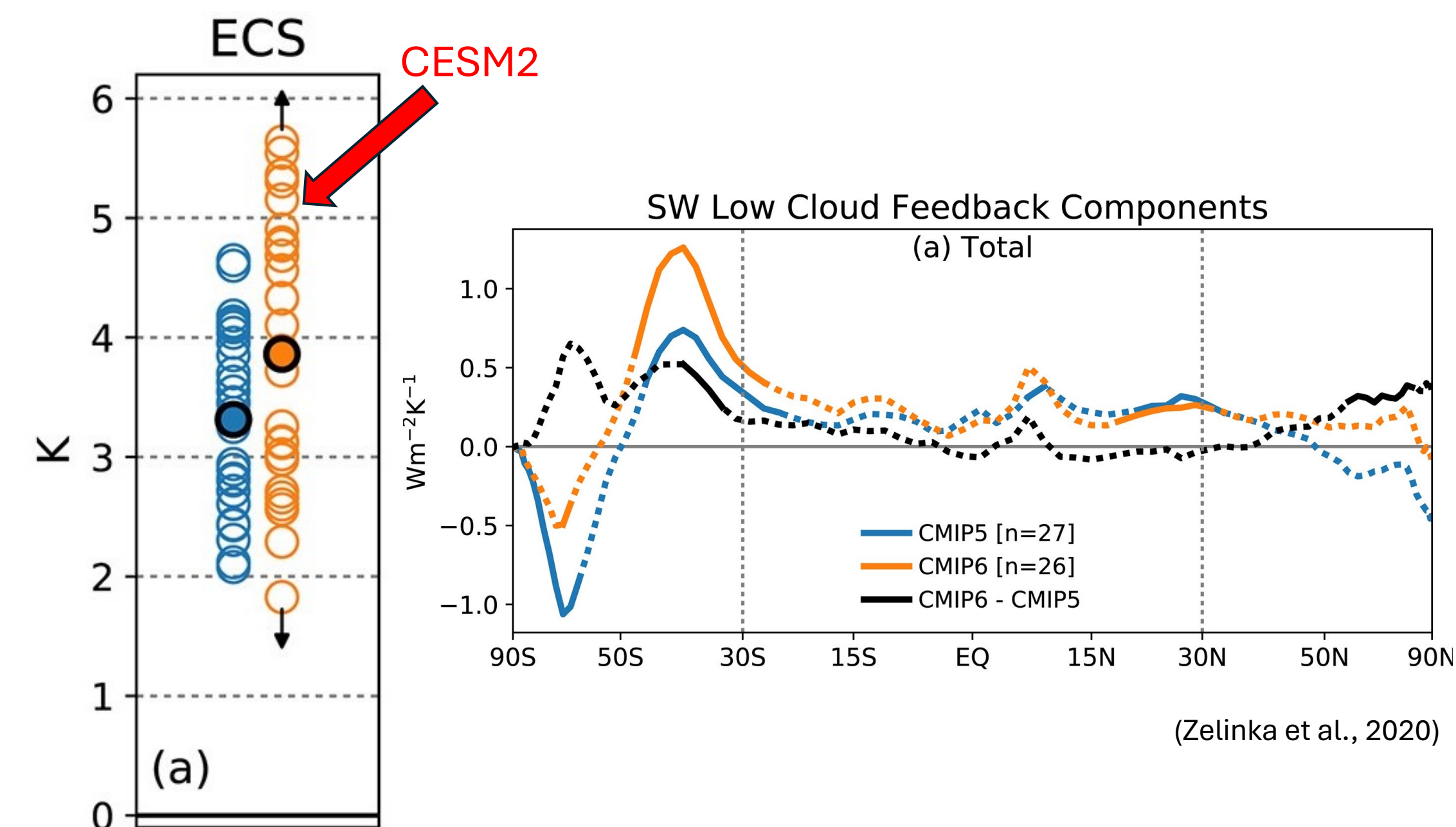
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## BACKGROUND & MOTIVATION

A positive shift in shortwave cloud feedback ( $SW_{CF}$ ) in several CMIP6 models has led to the emergence of high equilibrium climate sensitivity (ECS). CESM2 ECS is  $\sim 5K$ .



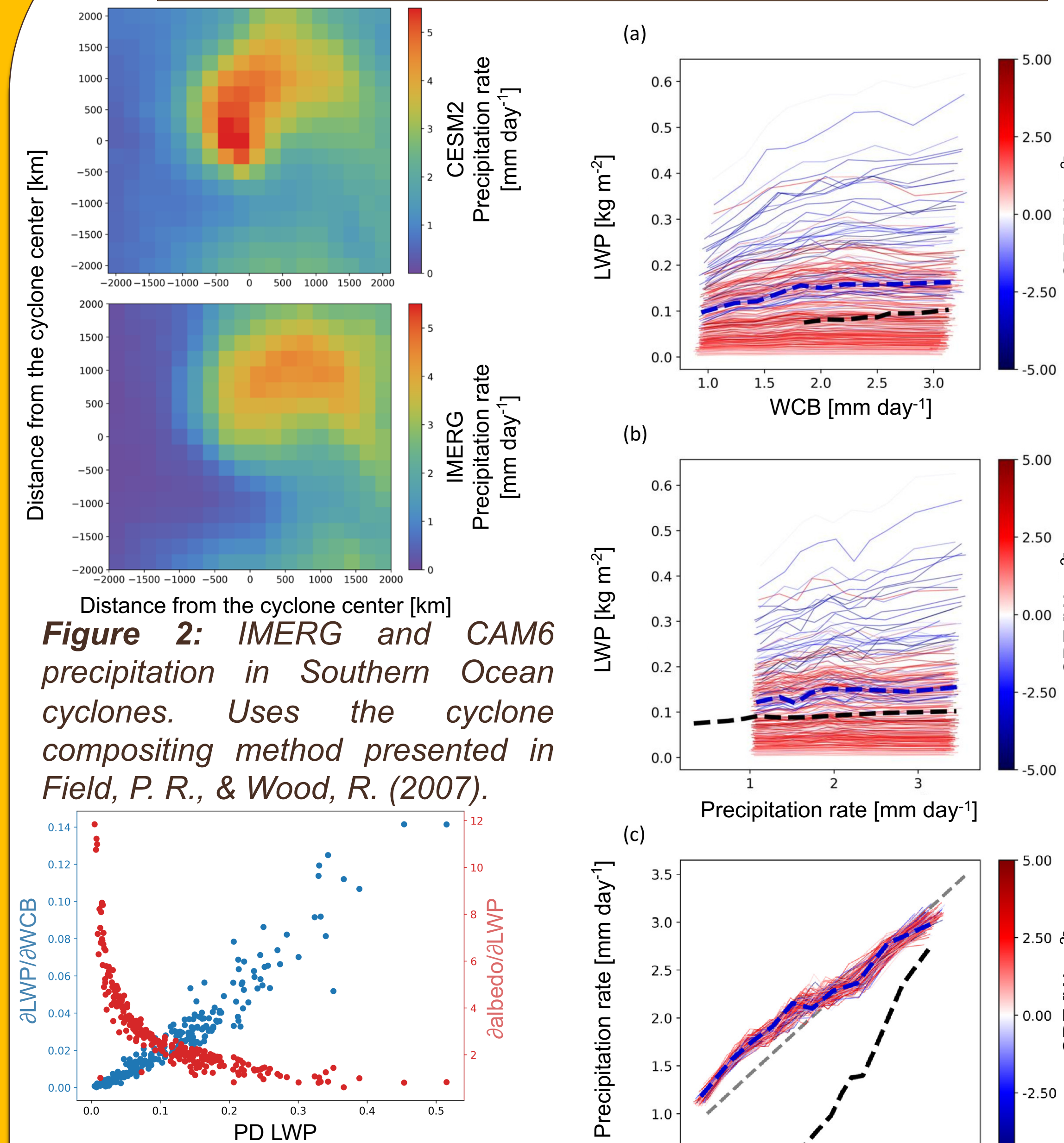
**Figure 1:** (a) Estimates of equilibrium climate sensitivity (ECS) from abrupt-4xCO<sub>2</sub> experiments. (b) Zonal mean short wave low cloud feedback

Can the very high ECS of CESM2 (atmospheric model: CAM6) be ruled out by observations?

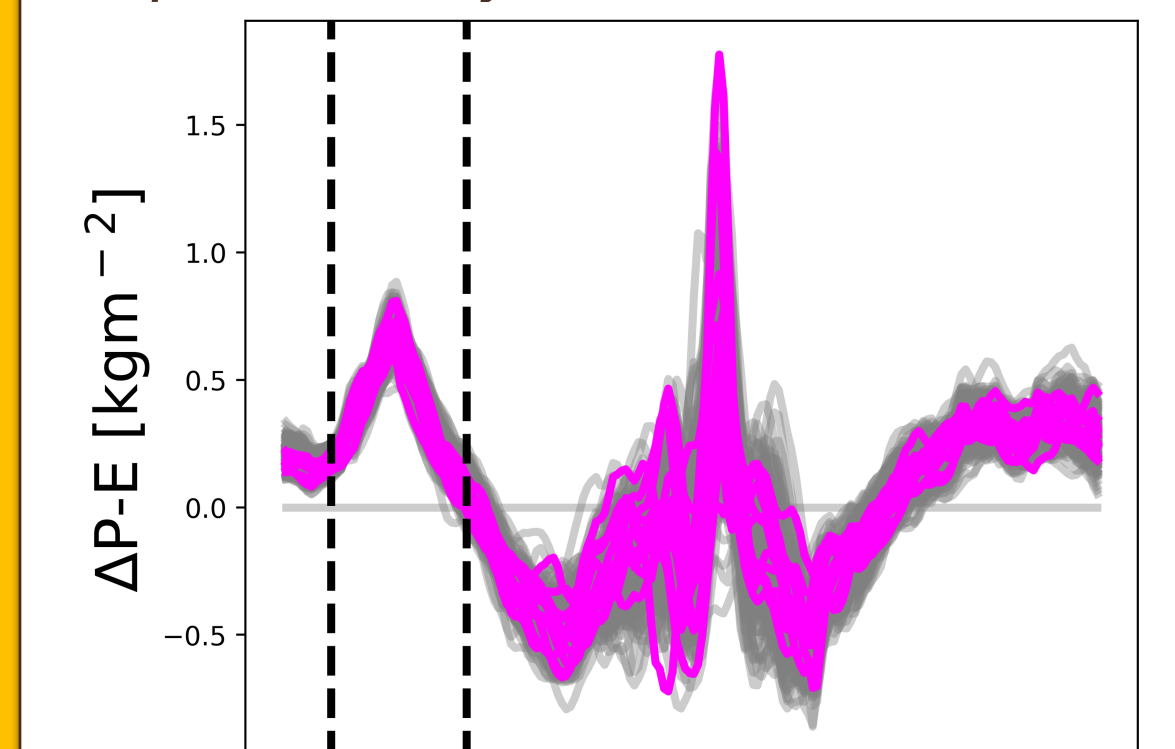
## DATA USED

- The sixth Community Atmosphere Model (CAM6) Perturbed Physics Ensemble (PPE) (Eidhammer et al., 2024).
  - Present Day
  - SST+4K
- Multi-Sensor Advanced Climatology of Liquid Water Path (MACLWP) (Elsaesser et al. 2017)
  - Daily average cloud liquid water path
  - Daily average total column water vapor
  - Daily average 10m wind speed
- Integrated Multi satellite Retrievals for GPM (IMERG)
  - V07 Final Run
  - Daily accumulated Merged microwave-only precipitation estimate.
- The second Modern-Era Retrospective Analysis for Research and Applications reanalysis (MERRA2)
  - Atmospheric state

## EC PRECIPITATION EFFICIENCY



**Figure 2:** IMERG and CAM6 precipitation in Southern Ocean cyclones. Uses the cyclone compositing method presented in Field, P. R., & Wood, R. (2007).

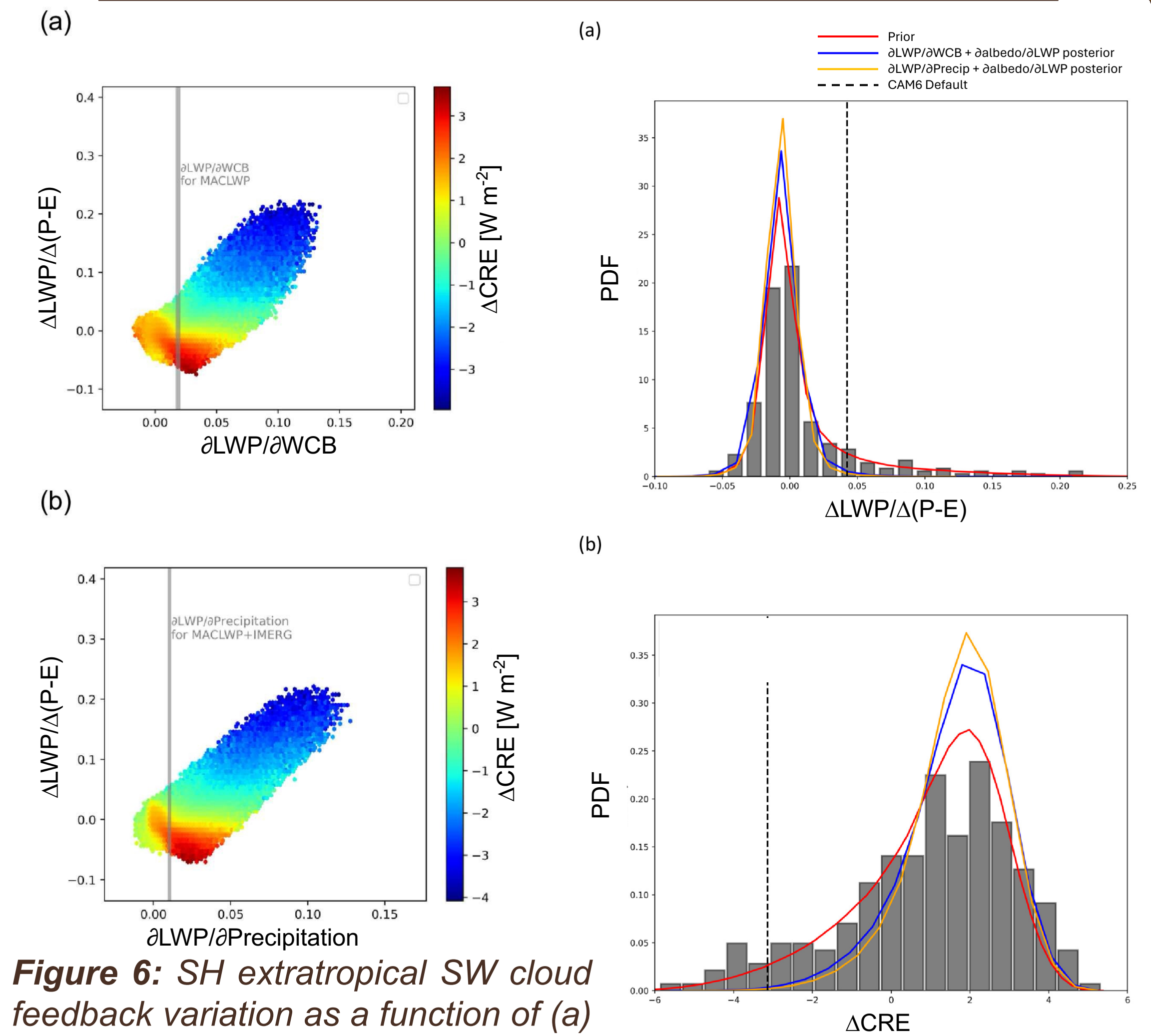


**Figure 4:** Sensitivity of LWP to WCB moisture convergence and albedo susceptibility as a function of present day LWP.

CAM6 simulate increasing extratropical cloudiness in response to enhanced moisture flux. In response to warming, extra tropics moistens. This behavior is consistent amongst the PPE ensembles irrespective of the parameter perturbations.

**Figure 3:** (a) Liquid water path (LWP) vs Warm conveyor belt moisture convergence (WCB) (b) LWP vs precipitation rate (c) Precipitation rate vs WCB for observations (black dashed line), CAM6 default model (blue dashed lines), and CAM6 PPE members (colored solid lines), colored by the  $\Delta CRE$  values. Grey dashed line on (c) shows the 1-1 relationship shown in Field & Wood (2007)

## FEEDBACK



**Figure 6:** SH extratropical SW cloud feedback variation as a function of (a) sensitivity of LWP to WCB and (b) sensitivity of LWP to precipitation, colored by the CRE response to warming. Observations are shown as a grey vertical line.

**Figure 7:** (a) CAM6 LWP response to warming and (b) CRE response to warming constrained by observations.

Gaussian process emulates within the observation uncertainty provides a constraint for the  $SW_{CF}$  and  $\Delta LWP/\Delta(P-E)$  in the CAM6 PPE.

95% confidence interval ranges in	When constrained by albedo susceptibility combined with:	
	$\partial LWP/\partial WCB$	$\partial LWP/\partial Precip$
$\Delta LWP/\Delta(P-E)$	64%	69%
$\Delta CRE$	27%	33%

## SUMMARY

- Clausius-Clapeyron drives enhanced moisture convergence to ECs as the climate warms.
- More extratropical cloudiness in ECs 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 cannot be ruled out by observed precipitation efficiency in ECs.