# Extratropical cloud feedback in the context of the hydrological cycle and large-scale circulation

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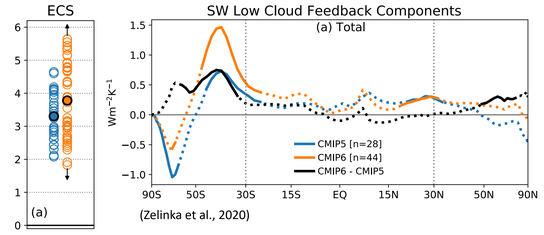
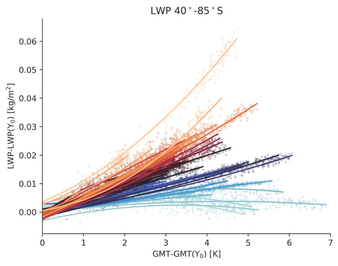
## Background

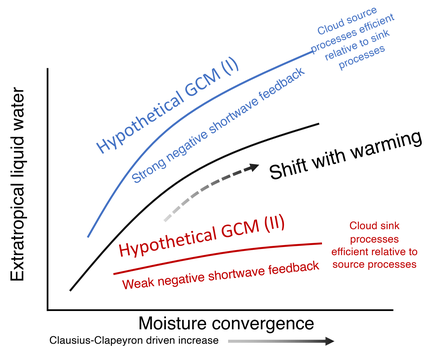


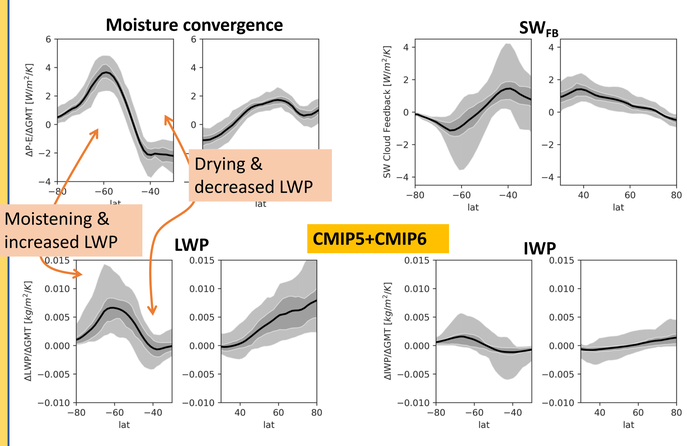

**Motivation:** Extratropical shortwave cloud feedback ($SW_{FB}$) is highly uncertain in GCMs. Qualitatively, $SW_{FB}$ transitions from positive in the subtropics to negative in the extratropics. In CMIP6 shifts towards more positive feedback in the extratropics has been linked to higher ECS. Out of 57 GCMs from CMIP6 and CMIP5 all GCMs monotonically increase liquid water path (LWP) in response to warming in abrupt4xco2. The exceptions are CESM2 and E3SM, which saturate LWP after initial warming-driven increases. *What governs the liquid cloud response in GCMs and what extratropical $SW_{FB}$ is the most consistent with observations?*




## Source-sink model of extratropical cloud feedback

**Steady state model:** We propose a new mechanism to explain part of the negative extratropical $SW_{FB}$ (in addition to existing mechanisms: stability, ice-to-liquid shifts, etc.). We consider the extratropics as being in steady state between converging moisture and precipitation. If a given GCM is inefficient at making precipitation, then it will have a strong relationship between converging moisture and cloud (it takes a lot more cloud to make the right amount of precipitation to balance the moisture convergence). Below, the change in moisture convergence (approximated as P-E), LWP, ice water path (IWP), and SWFB for 57 GCMs are summarized. Note the consistency between regions of moistening and increased LWP.



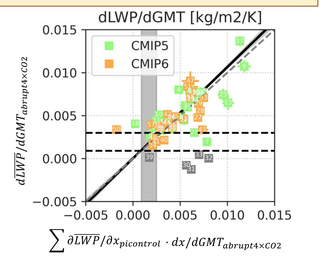




## Regional-mean cloud controlling factor (CCF) analysis

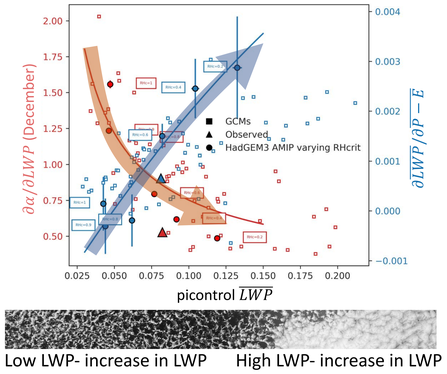
**Simple CCF:** First, we utilize a simple CCF model that only considers moisture convergence (P-E) and surface temperature (acting as a proxy for other processes).

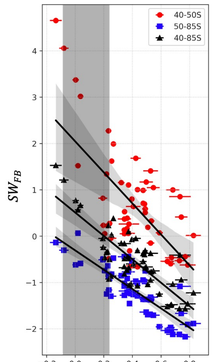
$$\overline{LWP} = a \cdot \overline{T_{skin}} + b \cdot \overline{P-E}$$

The 40-80°S region is averaged and the regression model is trained on monthly mean values from picontrol and used to predict LWP response in abrupt4xco2. The ability of the simple CCF model to predict change in LWP during abrupt4xco2 is good, except for CESM2 models and E3SM (shown at right in grey).




## Competition between radiative and cloud source efficiency




Low LWP- increase in LWP increases albedo a lot

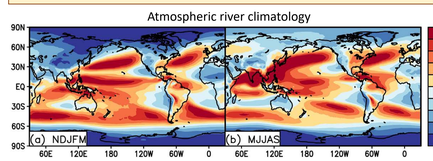
High LWP- increase in LWP increases albedo minimally

**Radiative efficiency:** Utilizing the prediction of LWP derived above, we seek to predict $SW_{FB}$ as the product of LWP changes (left term on the RHS) and the efficiency of LWP in altering albedo (right term on the RHS).

$$SW_{FB} \sim \frac{\Delta\overline{LWP}}{\Delta GMT} \cdot \frac{\partial\alpha}{\partial\ LWP}$$

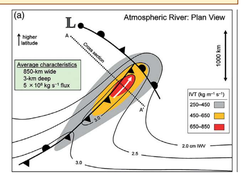
We find that the radiative efficiency anticorrelates with the sensitivity of cloud to moisture convergence (see CCF model in the previous panel) across GCMs. This makes sense- moisture convergence is fairly similar across GCMs. GCMs that have a lot more mean state cloud get less radiative bang for their buck in creating additional cloud. Thus, GCMs that are more efficient at making cloud less efficiency increase radiation when adding cloud. Using the simple equation above, the $SW_{FB}$ from GCMs can be predicted and constrained using observations of each term (top right).

## Atmospheric rivers: linking subtropics to extratropics



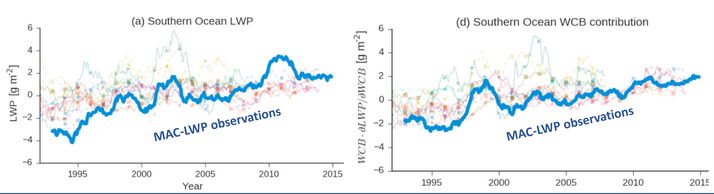

(Guan & Waliser, 2015)

85th percentile of IVT




(Gimeno et al., 2021)

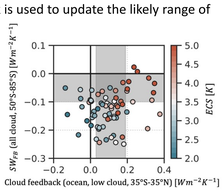
**Warming pattern and feedbacks:** One implication of this is that subtropical warming has a hand in setting extratropical cloud feedback via transient eddies/atmospheric rivers (ARs) and Clausius-Clapeyron. This can be understood from the perspective of the warm conveyor belt (WCB) in extratropical cyclones- the termination point of ARs. Previous work has shown steady decadal trends in observed Southern Ocean cyclones. This is driven by WCB moisture convergence- linking this trend to non-local moisture sources. This relates non-local subtropical warming to extratropical feedback.

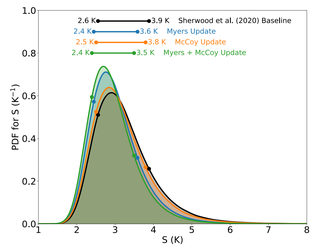



## Updates to ECS range based on WCRP framework

**ECS:** A natural question is how the weak, negative extratropical SWFB we infer affects the most likely range of ECS. We combine our estimate with estimated subtropical cloud feedback from Myers et al. (2021). The WCRP Bayesian framework is used to update the likely range of ECS.

The inferred range from this study is consistent with the range assumed in Sherwood et al. (2021) of +0.01 ± 0.06 $Wm^{-2}K^{-1}$ and the shift in ECS is small.



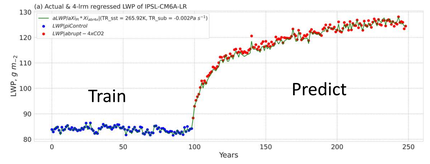



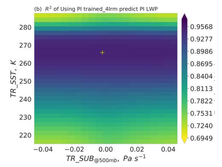

## Updated model results (Chuyan Tan)

**New CCF model:**

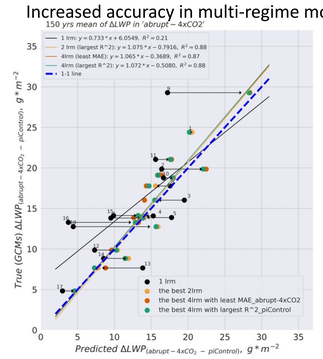
- Additional predictors: SST , P-E, LTS, $\omega_{500}$
- Use 5°x5° monthly boxes instead of 40-80°S region (P-E=$\nabla q$)
- Cold and warm clouds and subsidence and upsidence allowed to have different CCFs

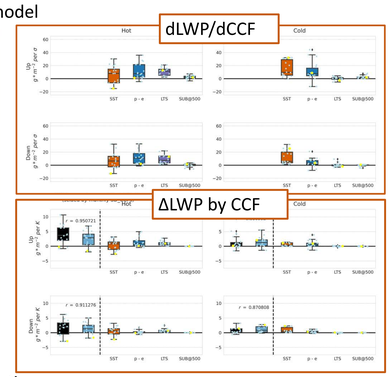
As before, train on picontrol, predict abrupt4xco2. Fairly accurate predictions of GCM behavior (better than before because CESM2 is better represented). P-E and SST still dominate in many models. CESM2 has minimal dependence on moisture convergence, but is heavily influenced by stability changes.



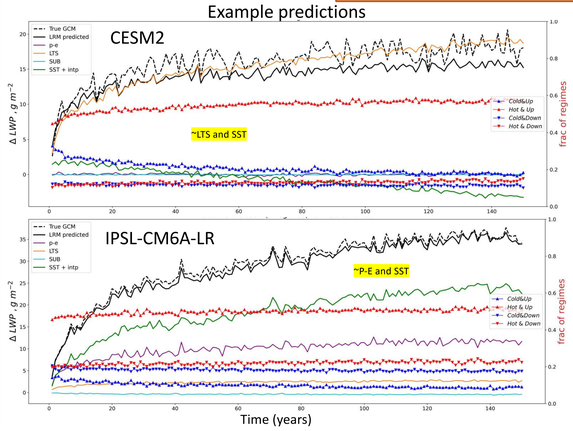




### Increased accuracy in multi-regime model




### Example predictions




**Contrasting the predictions from dissimilar models:** CESM2 is mostly dependent on LTS- and SST-driven changes and shows an expanding warm regime. IPSL-CM6A-LR is mostly dependent on moisture convergence and SST.