Observational estimates of a short-term LW high cloud feedback

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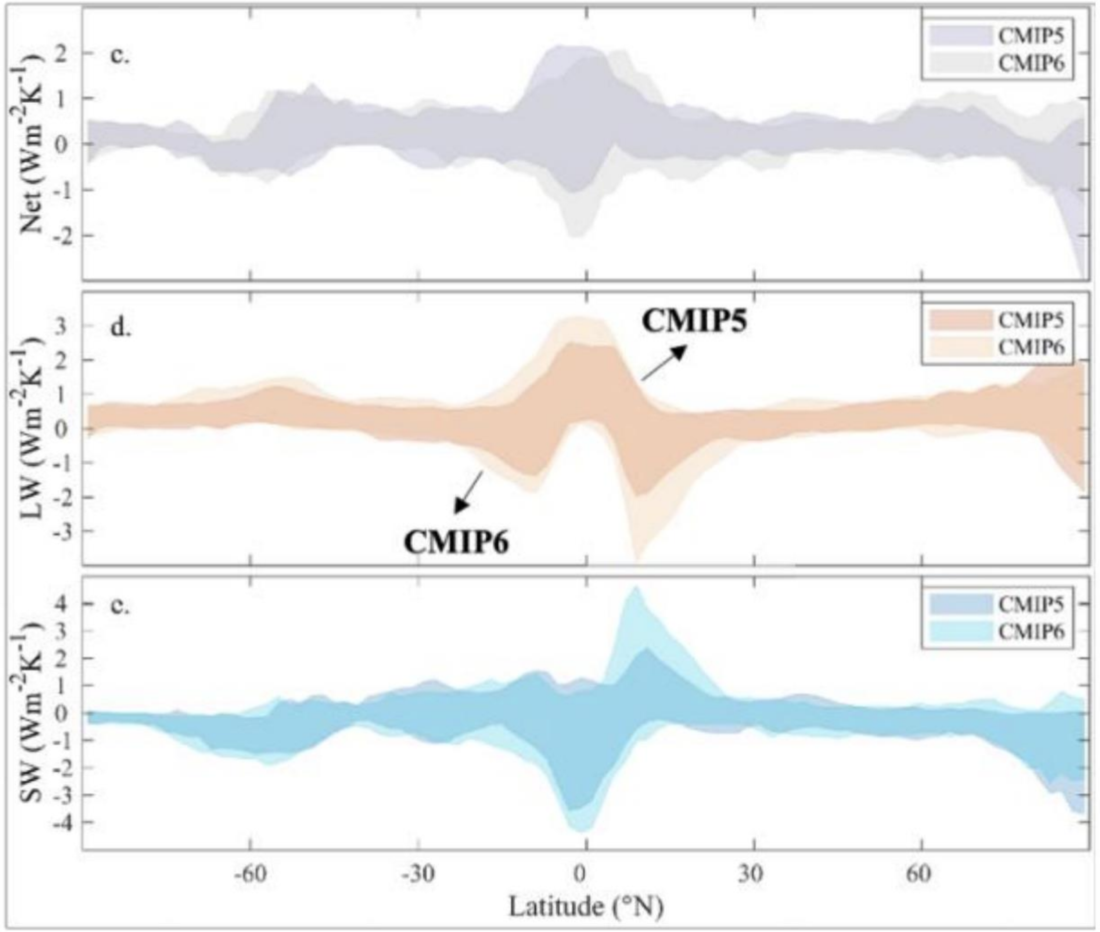
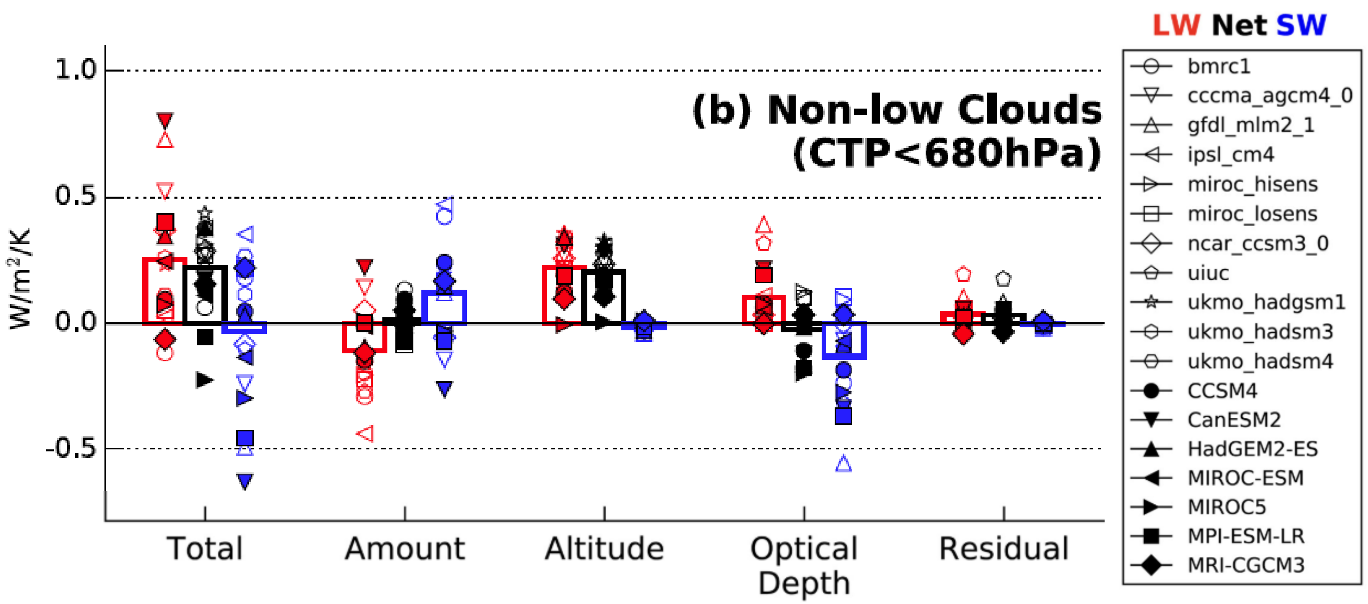
High cloud feedbacks remain largely uncertain in climate models

Large intermodal spread in high cloud feedbacks, which increased from CMIP5 to CMIP6



Courtesy of Greg Cesana

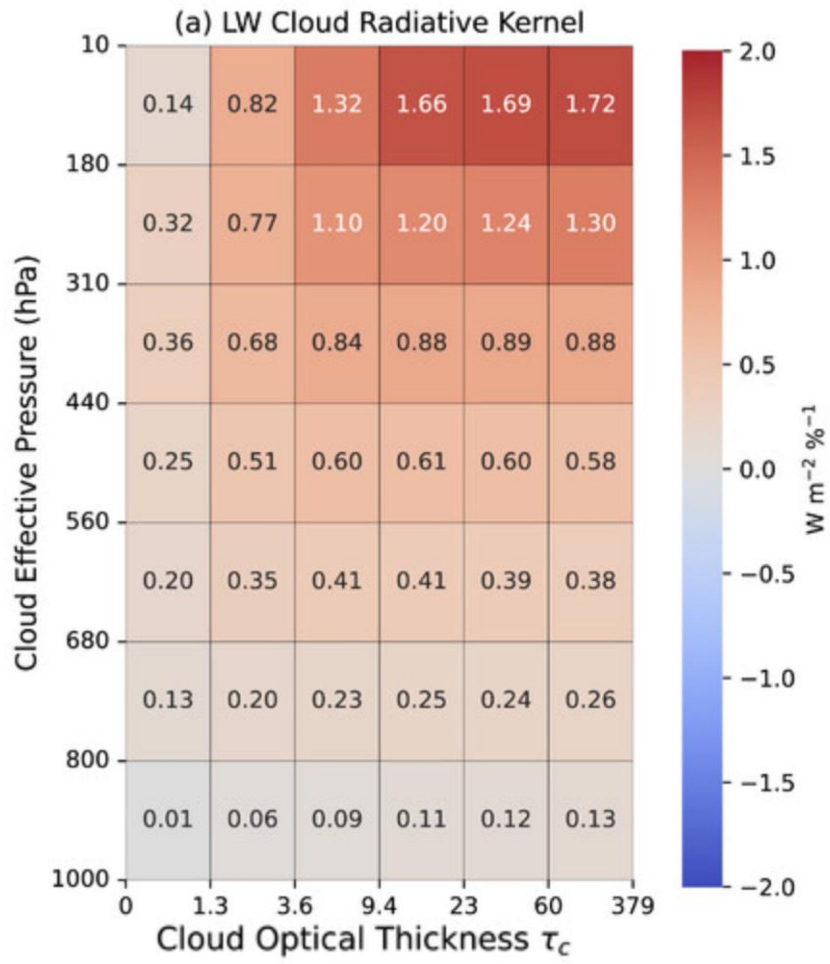


Zelinka et al. (2016)

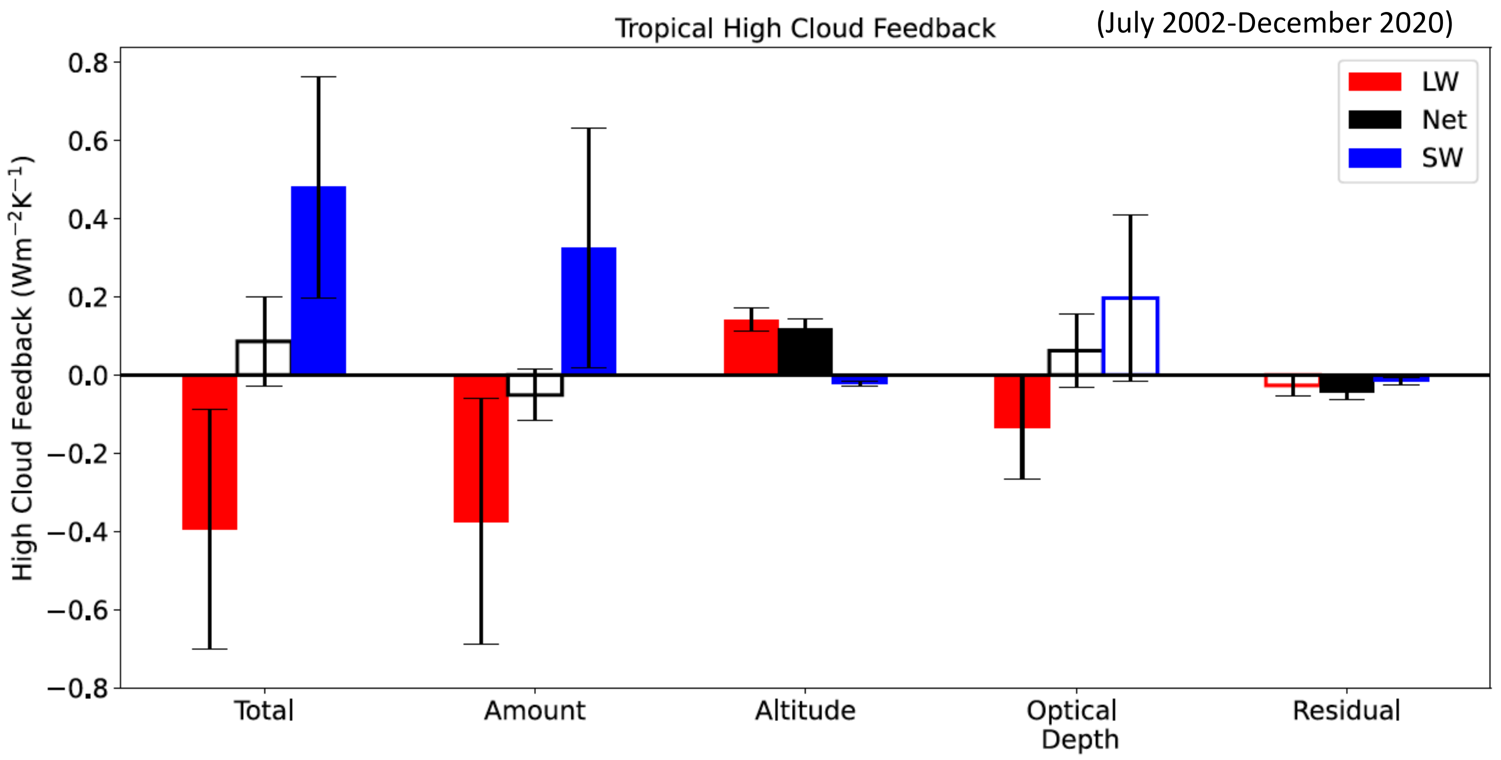
Need to observationally constrain high cloud feedbacks

Current observational estimates of high cloud feedbacks

CERES FluxByCldTyp (FBCT) Cloud Radiative Kernels (CRK) combines MODIS & CERES SSF observations



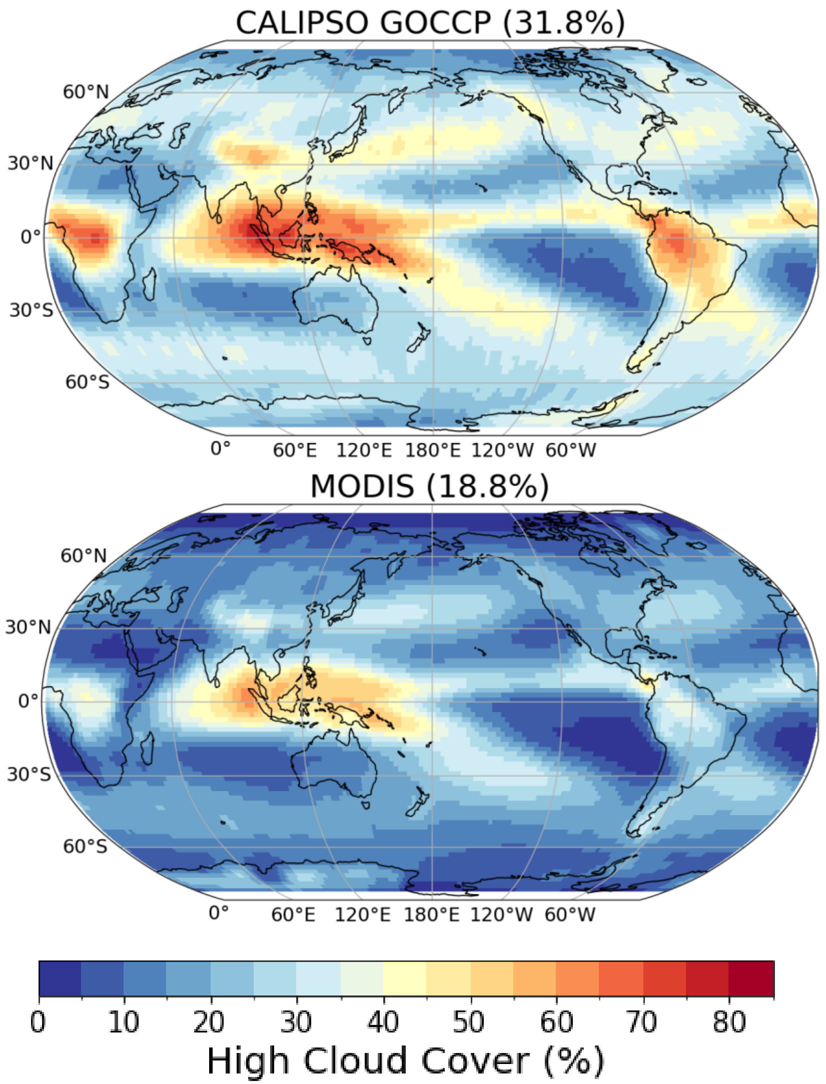
Sun et al. (2022)

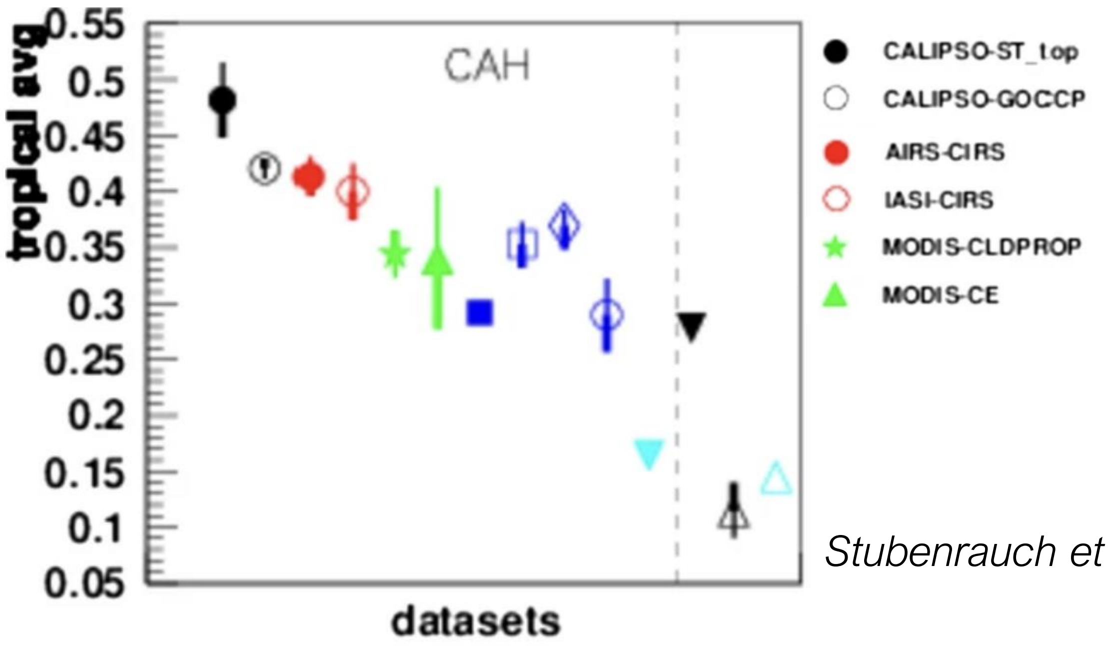


Raghuraman et al. (2024)

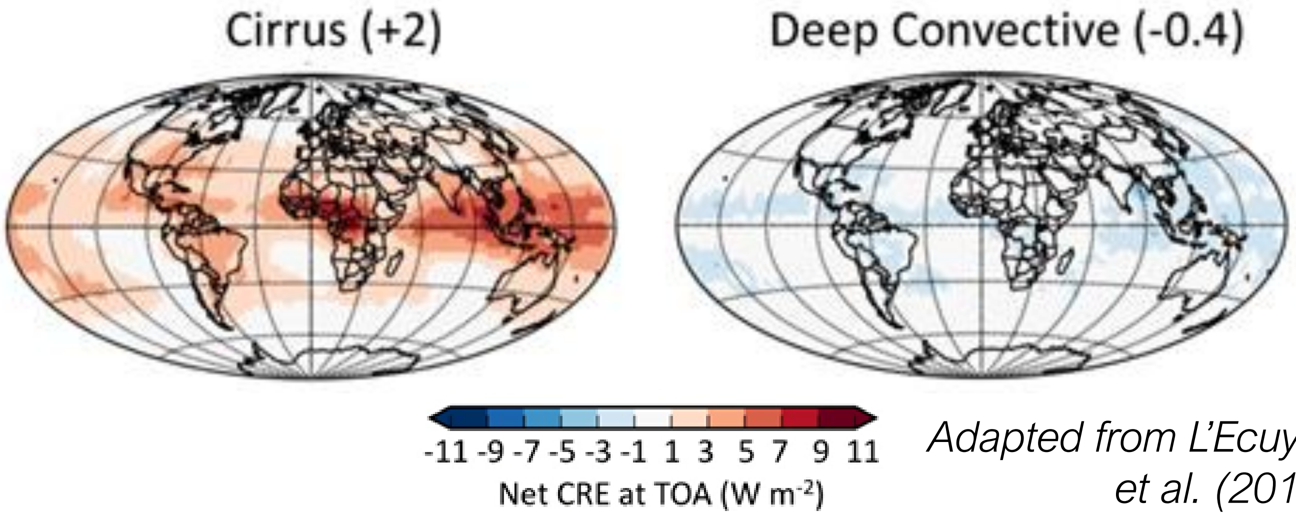
Most passive sensors underestimate thin cirrus clouds

Mean High Cloud Cover (2007-2018)





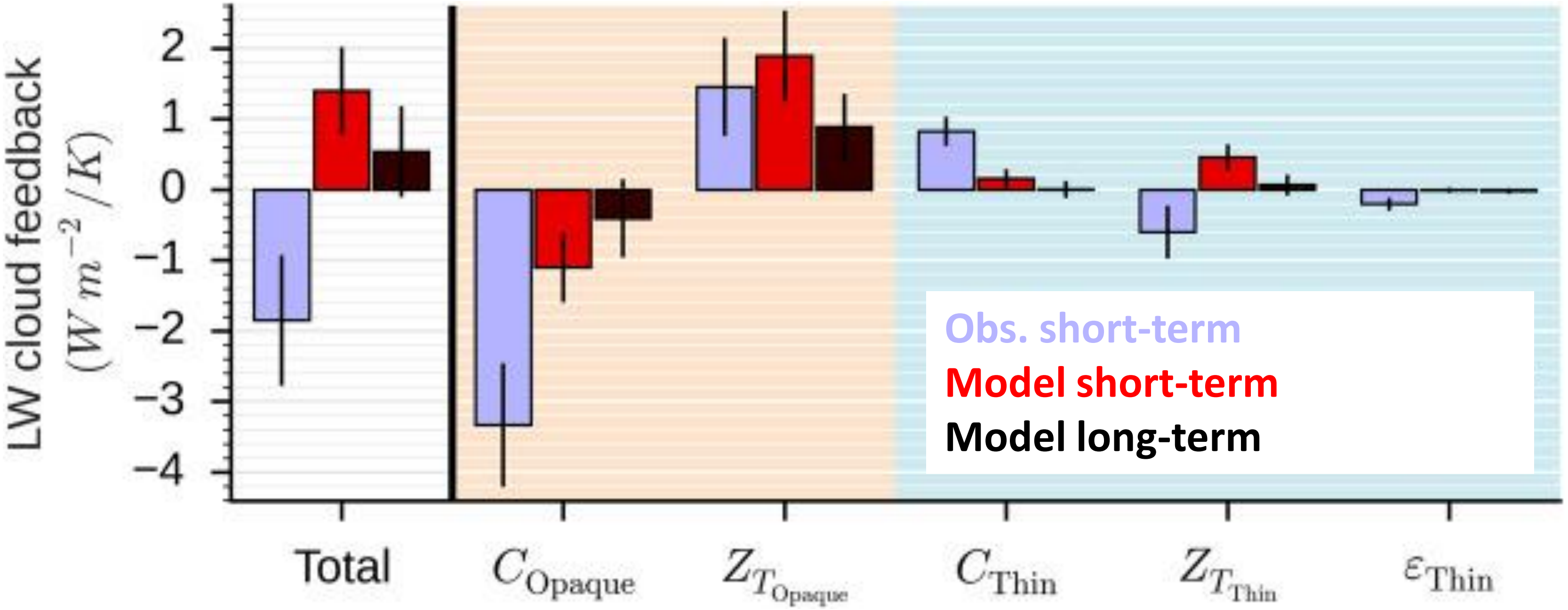
Stubenrauch et al. (2024)



Adapted from L'Ecuyer et al. (2019)

Estimating LW cloud feedbacks from CALIPSO GOCCP

Opposite sign in feedback between observations & models



Vaillant de Guélis et al. (2018)

- **Observations**: CALIPSO data (2008-2014)
- **Model simulation short-term** : LMDZ model+lidar simulator in present-day (AMIP) climate
- **Model simulation long-term:** present day (AMIP) and future (AMIP + 4K)

GOAL: Derive a short-term (interannual) LW high cloud feedback

A. What are the ingredients necessary for the computation?

B. Compute and compare the "inferred" feedback with active and passive observational data sets

   i. Decompose the feedback into different high cloud regimes

C. Ongoing:

   i. Constructing long-term feedback with Cloud Controlling Factors

   ii. Evaluating GISS ModelE3

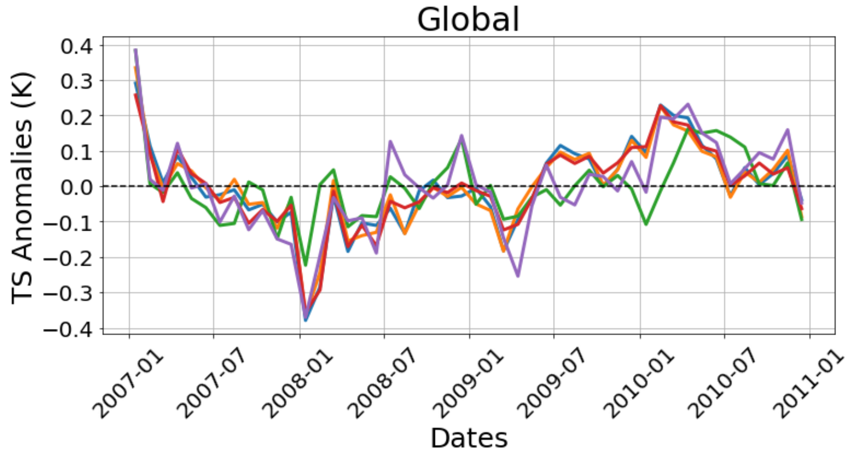
D. Summary

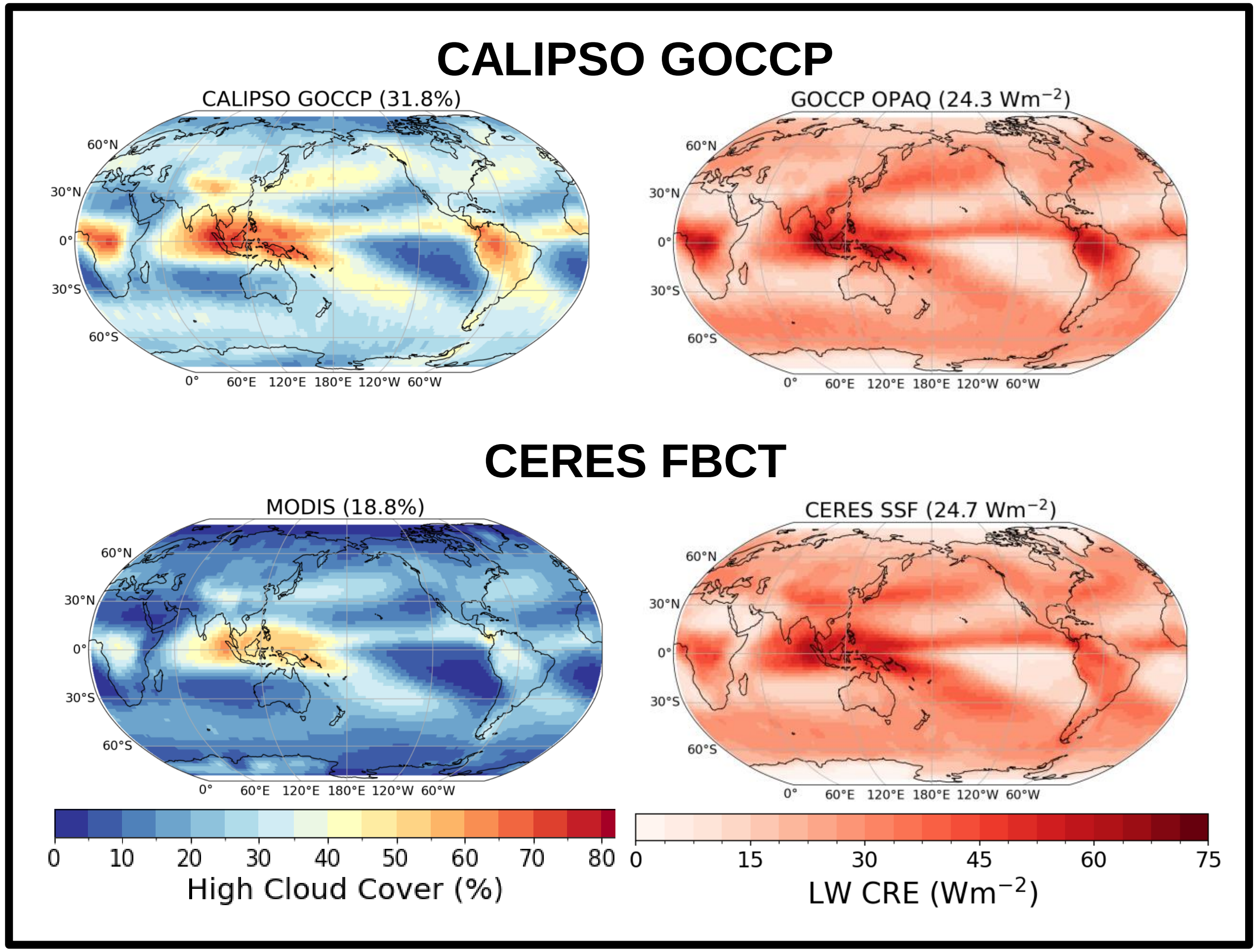
Data sets for LW high cloud feedback calculation

Data set & method requirements

- ✓Compatible with climate model output (i.e. gridded monthly means)
- ✓Combined clouds and TOA radiative fluxes
  - ✓Extract high clouds only
    - → High Cloud Cover (HCC)
  - ✓Isolate the changes in LW CRE *due to clouds only*

Surface temperature anomalies

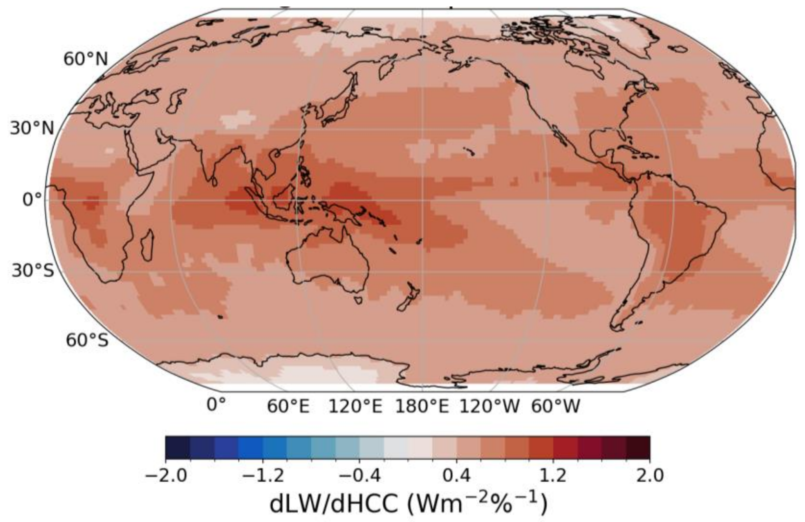




High cloud feedback from CALIPSO GOCCP

2°x 2° gridded monthly mean anomalies (2007-2018)

$$\underbrace{\frac{dCRE_{LW,CLD}}{dHCC}}_{\text{Sensitivity of }\Delta\text{CRE (from cloud changes) to }\Delta\text{HCC}}\frac{dHCC}{dT} \cong \frac{dCRE_{LW,HCC}}{dT}$$

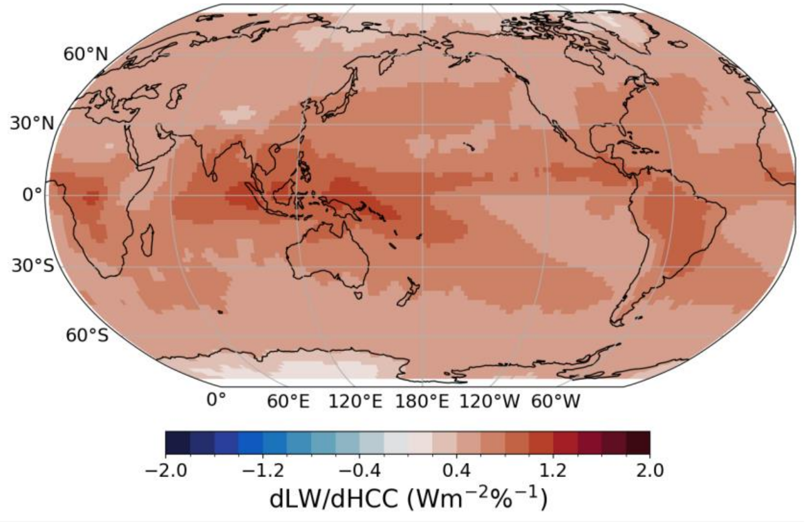


✓ LW CRE increases with increased high clouds

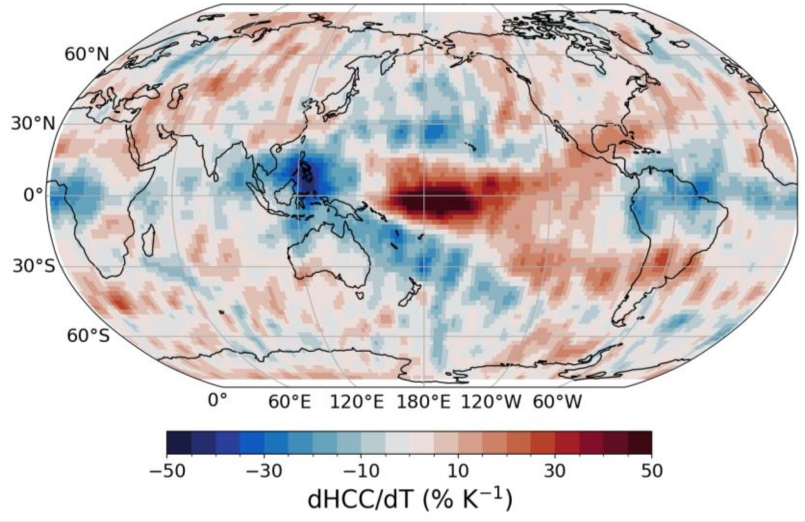
High cloud feedback from CALIPSO GOCCP

2°x 2° gridded monthly mean anomalies (2007-2018)

$$\frac{dCRE_{LW,CLD}}{dHCC}\underbrace{\frac{dHCC}{dT}}_{\text{Interannual variability of HCC}} \cong \frac{dCRE_{LW,HCC}}{dT}$$



✖



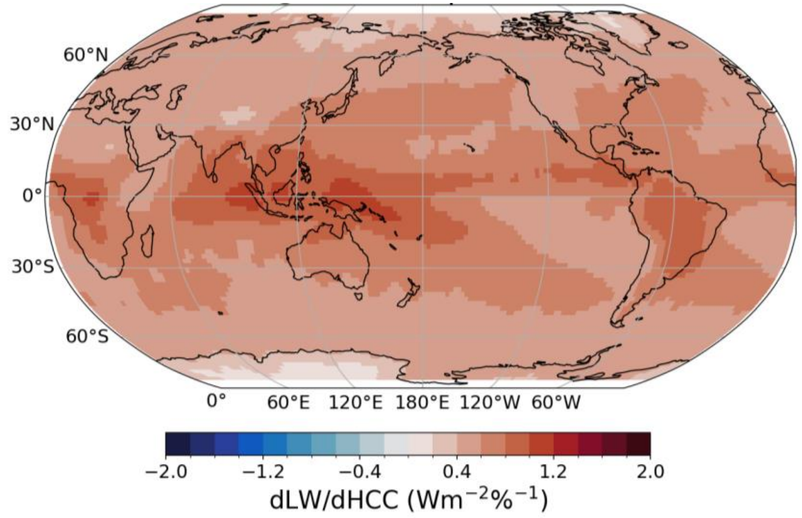
✓ Distinct El Niño signature

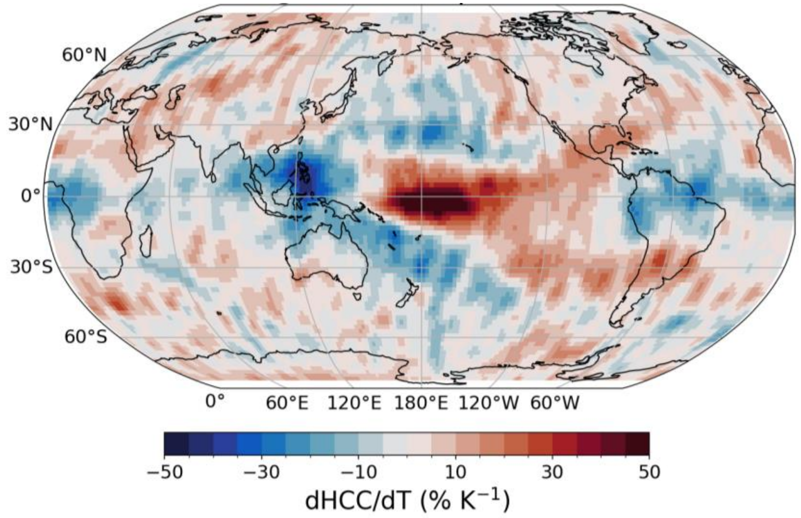
High cloud feedback from CALIPSO GOCCP

2°x 2° gridded monthly mean anomalies (2007-2018)

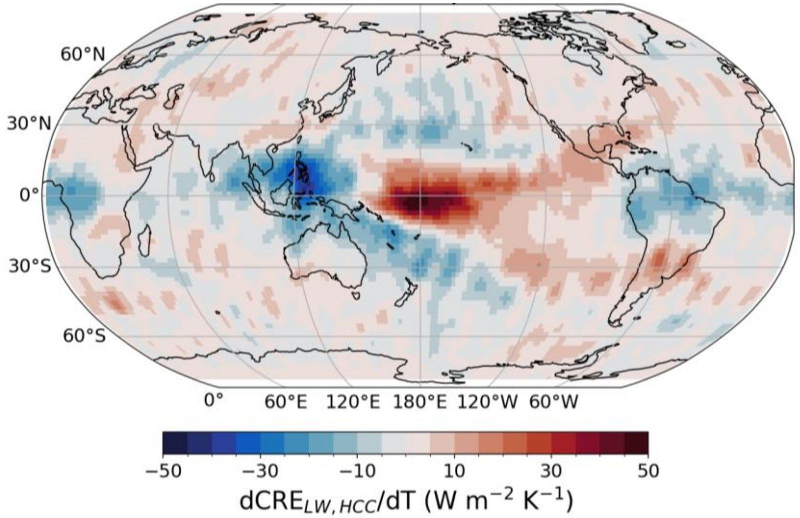
$$\frac{dCRE_{LW,CLD}}{dHCC}\,\frac{dHCC}{dT} \cong \underbrace{\frac{dCRE_{LW,HCC}}{dT}}_{\textbf{High cloud cover feedback } (\sim\lambda_{HCC})}$$

- ✓ Negative tropical mean (consistent with *Raghuraman et al. 2024*)
- ✓ Near-zero global mean

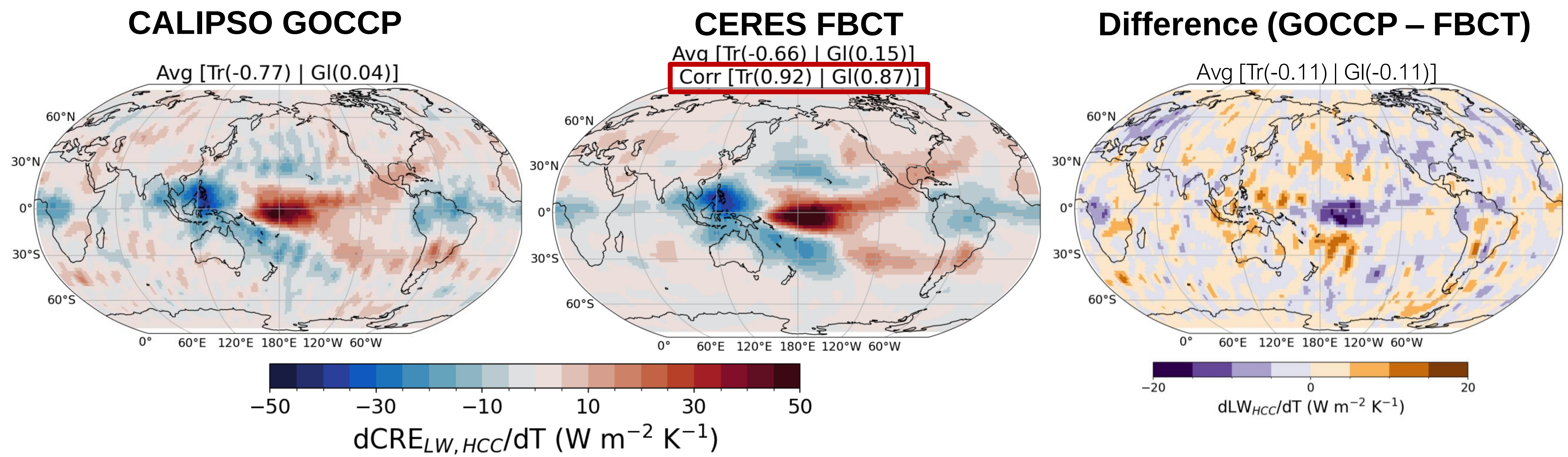




Avg [Tr(-0.77 ± 0.52) | Gl(0.04 ± 0.02)]



Comparing feedbacks between GOCCP and FBCT

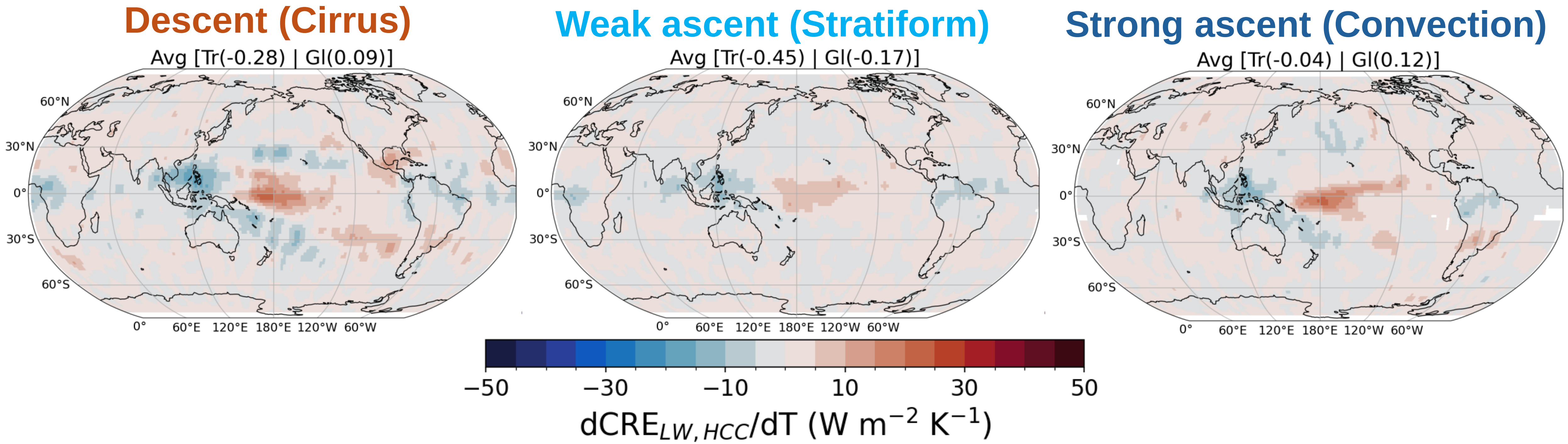


✓ High correlation, magnitudes differ between data sets

Decomposing feedback for different high cloud regimes

$$\frac{dCRE_{LW,CLD}}{dHCC}\sum_{regime}^{j}\frac{dHCC_{regime}}{dT}\cong\frac{dCRE_{LW,HCC}}{dT}$$

CALIPSO GOCCP (2007-2018)



✓ The **descent regime has largest contribution** to the global feedback due to how frequently subsidence occurs

Ongoing: High cloud controlling factors (CCFs)

CALIPSO GOCCP (2007-2010)

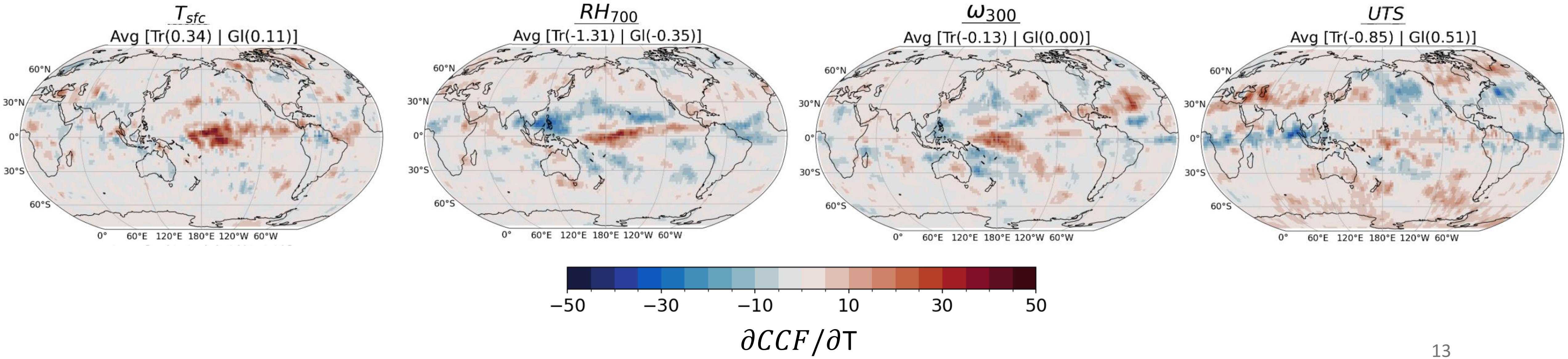
$$\frac{dCRE_{LW,CLD}}{dHCC}\sum_{i=1}\frac{\partial HCC}{\partial CCF_i}\underbrace{\frac{\partial CCF_i}{\partial T}}_{}\cong\frac{dCRE_{LW,HCC}}{dT}$$

CCF contribution to interannual variability of HCC

High CCFs from ERA5 (*Kemsley et al. 2024*):

- **Surface temperature** (T_{sfc})
- **Free Tropospheric Relative Humidity** (RH_{700})
- **Vertical velocity at 300 hPa** (ω_{300})
- **Upper Tropospheric Stability** (UTS)

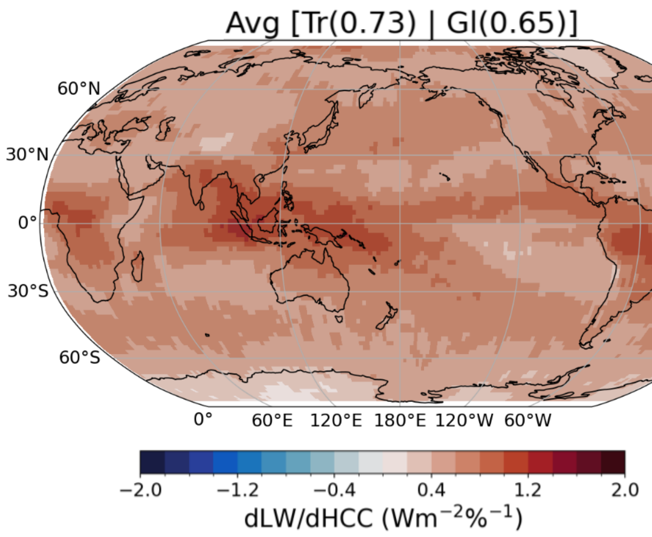
$$UTS = \theta_{200} - \theta_{500}$$



Ongoing: High cloud controlling factors (CCFs)

CALIPSO GOCCP (2007-2010)

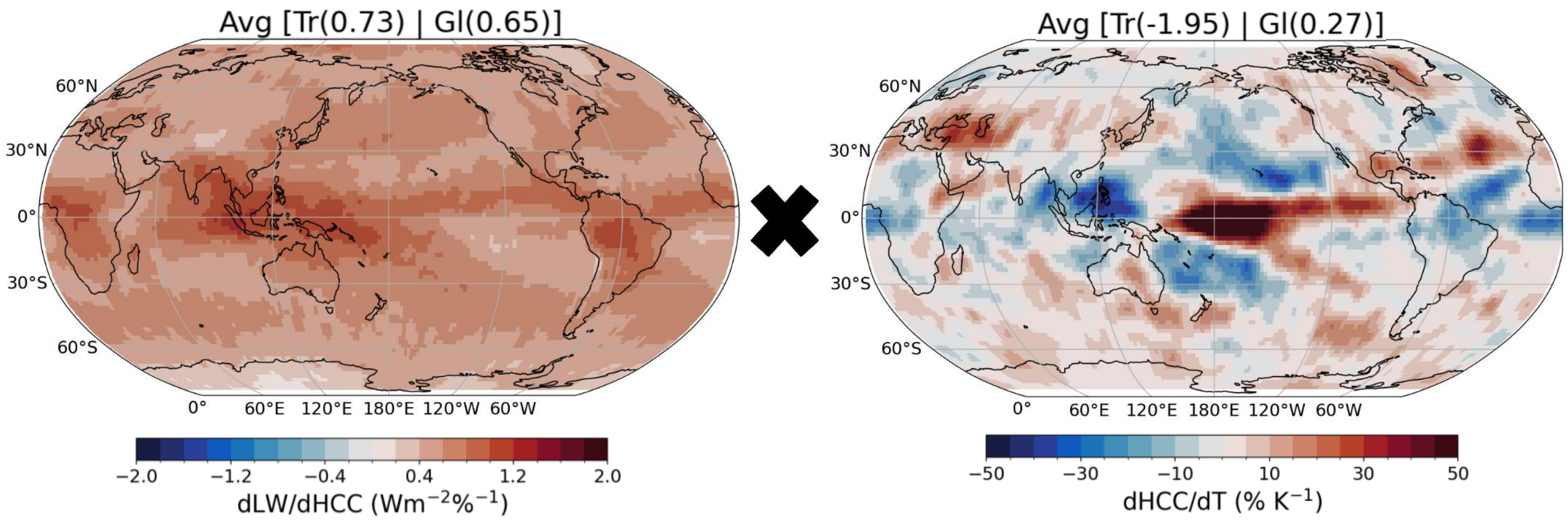
$$\boxed{\frac{dCRE_{LW,CLD}}{dHCC}} \sum_{i=1} \frac{\partial HCC}{\partial CCF_i} \frac{\partial CCF_i}{\partial T} \cong \frac{dCRE_{LW,HCC}}{dT}$$



Ongoing: High cloud controlling factors (CCFs)

CALIPSO GOCCP
(2007-2010)

$$\frac{dCRE_{LW,CLD}}{dHCC}\boxed{\sum_{i=1}\frac{\partial HCC}{\partial CCF_i}\frac{\partial CCF_i}{\partial T}} \cong \frac{dCRE_{LW,HCC}}{dT}$$

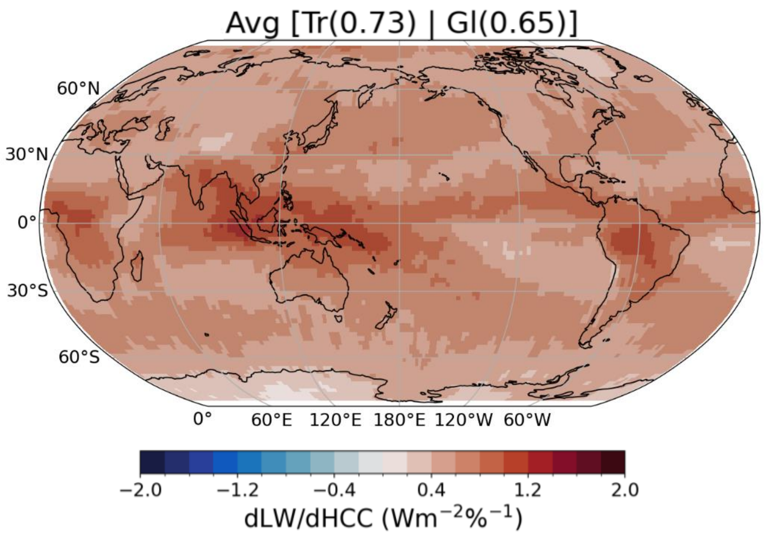


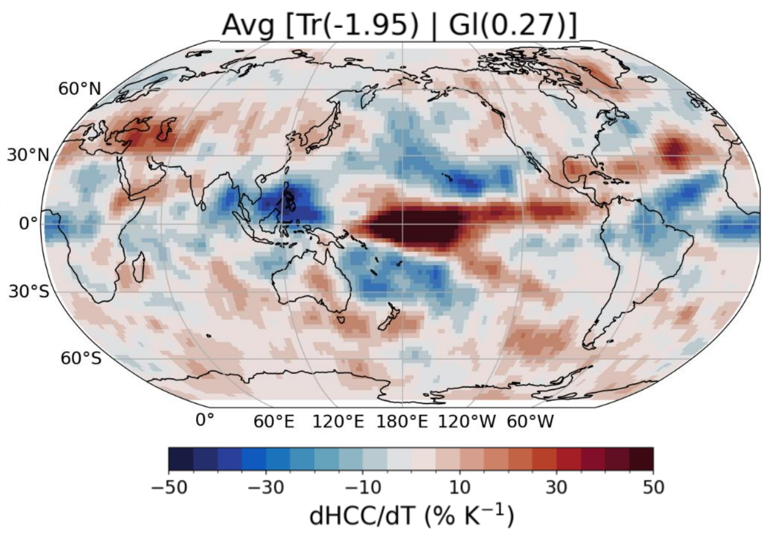
Ongoing: High cloud controlling factors (CCFs)

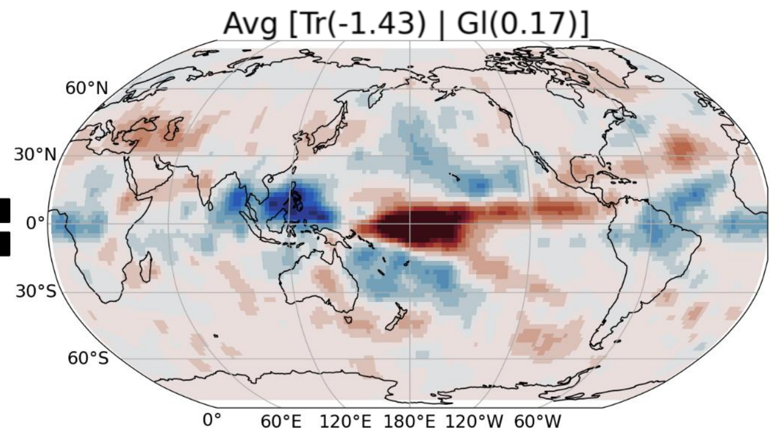
CALIPSO GOCCP (2007-2010)

$$\frac{dCRE_{LW,CLD}}{dHCC}\sum_{i=1}\frac{\partial HCC}{\partial CCF_i}\frac{\partial CCF_i}{\partial T} \cong \boxed{\frac{dCRE_{LW,HCC}}{dT}}$$

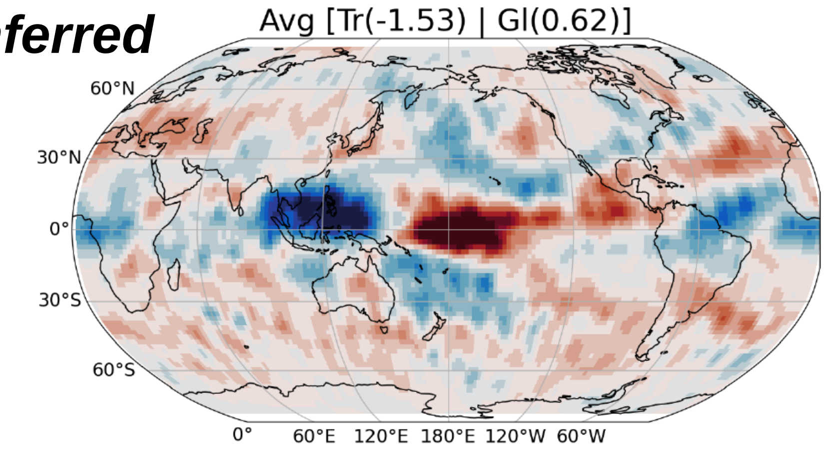
- ✓ High (88%) correlation between methods







Inferred



Difference between ***inferred*** and ***CCF*** approaches could emerge from:

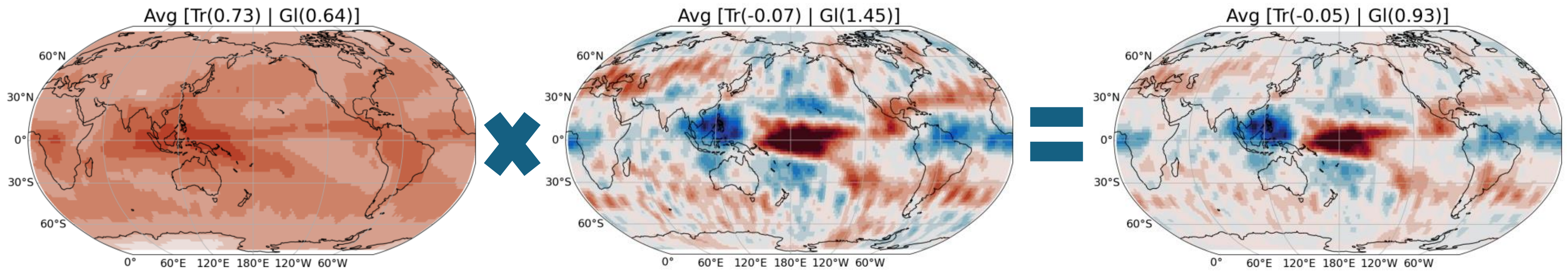
(1) Inaccuracies from reanalyses

(2) Potentially missing / covarying CCFs

Ongoing: Evaluating GISS ModelE3

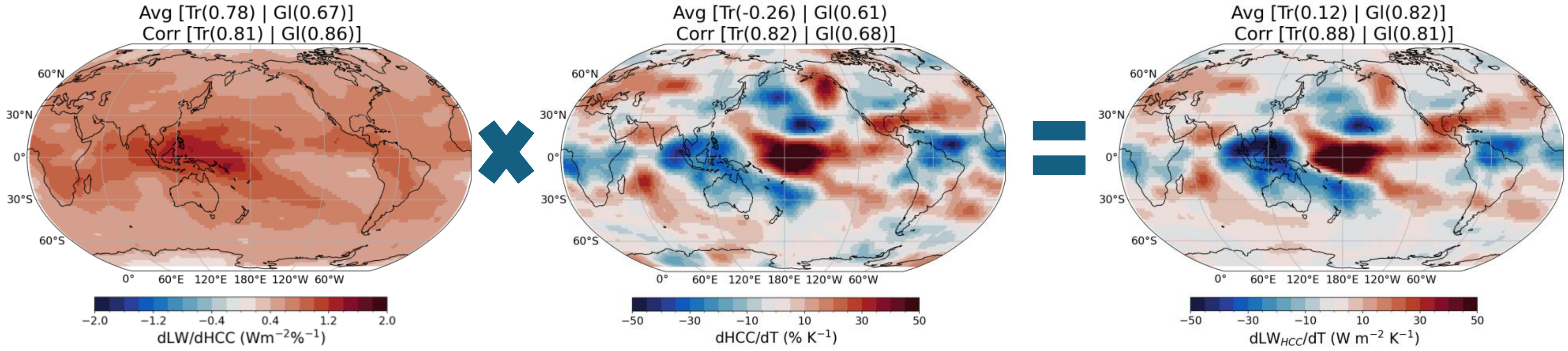
2°x 2° gridded monthly mean anomalies (2007-2014)

CALIPSO



E3-G-p101 (AMIP)

✓ 81% correlated



Sensitivity of LW to HCC is very similar between observations and E3

Summary & Future work

Contact: jap2335@columbia.edu

- Active-based remote sensing measurements well-represent the LW high cloud cover feedback
  - **Near-zero** global short-term LW high cloud cover feedback
- High thin clouds have an important impact on the feedback
- Important given how high clouds are biased in CMIP models
- Future work:
  1. Isolate cloud property contributions to feedback
  2. Explore covariance between high cloud controlling factors
  3. Evaluate multiple E3 model members / extrapolate to CMIP6 models

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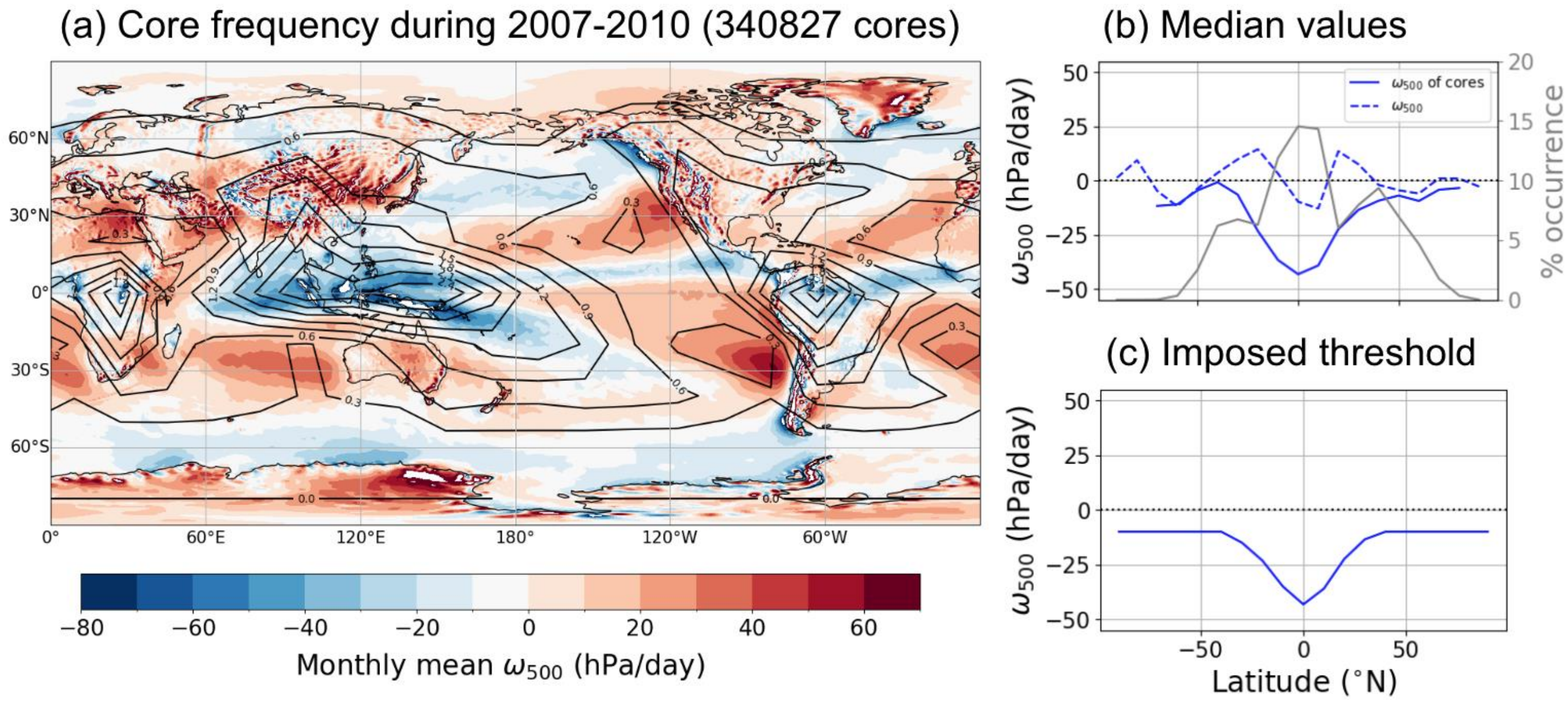
Extra slides



Convective cores from Convective Object Database (Pilewskie and L'Ecuyer, 2022)