SST Patterns and TOA Radiation in the Instrumental Record Since 2000

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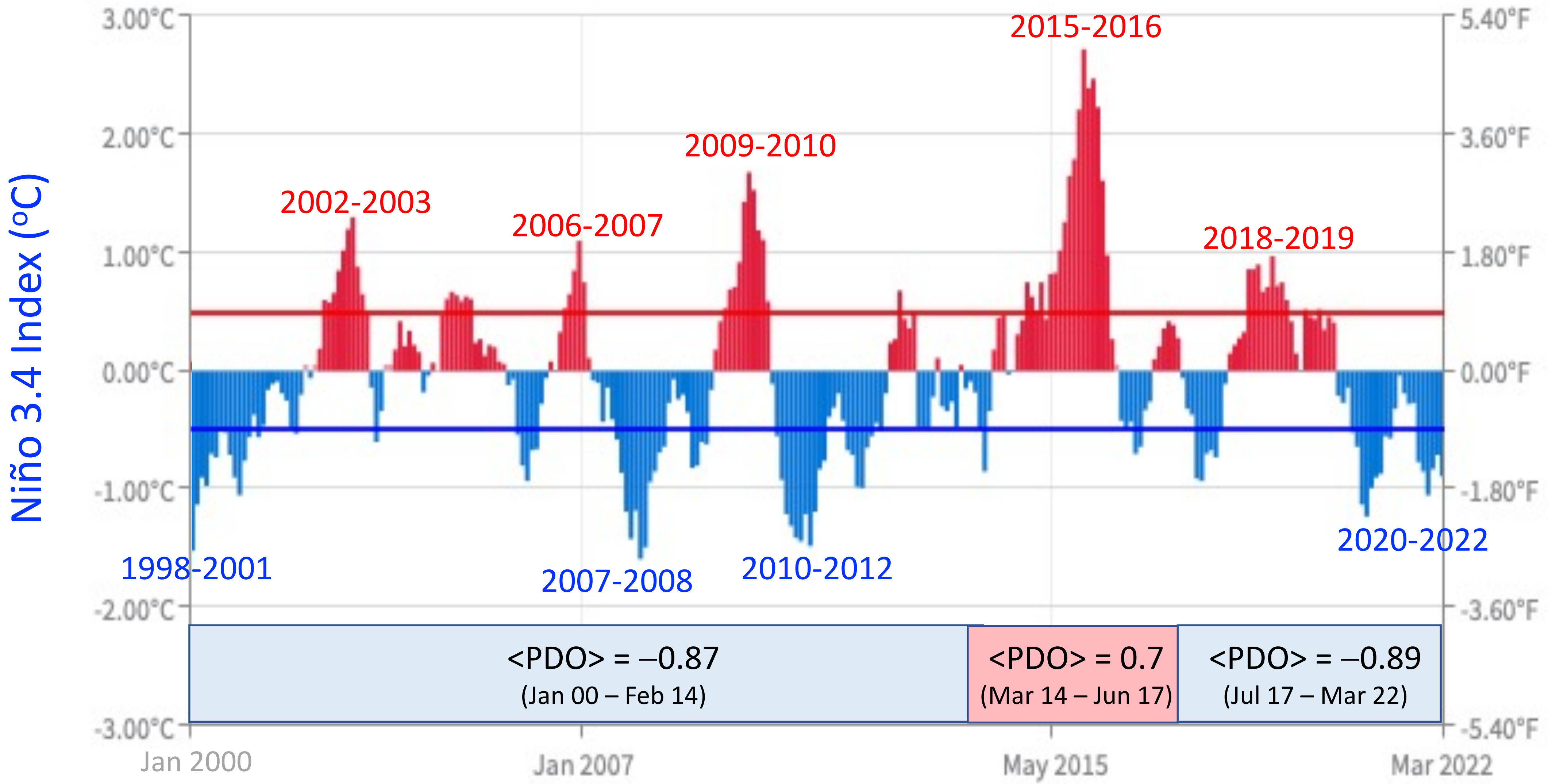
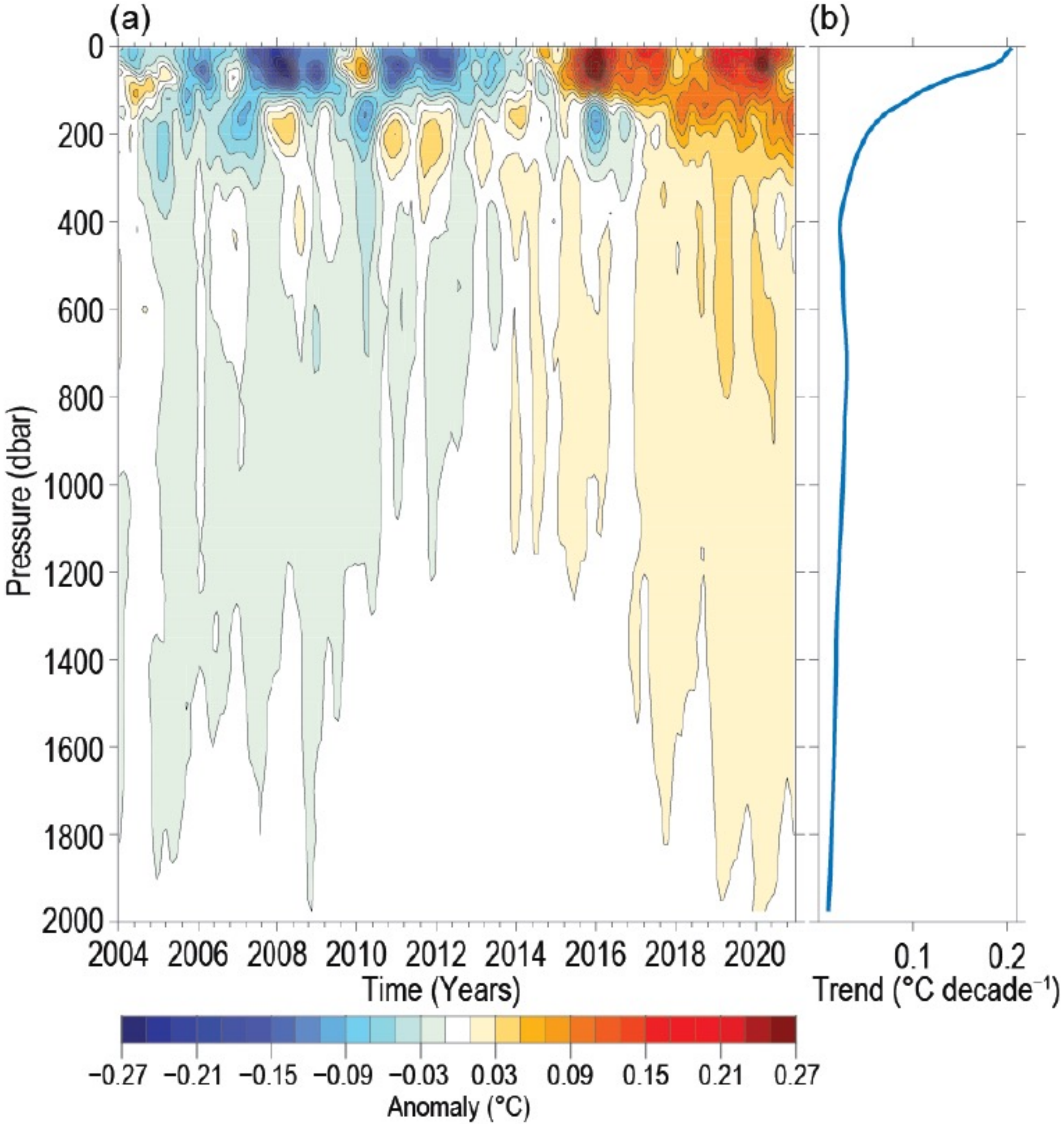
The Pattern Effect: Coupling of SST Patterns, Radiative Feedbacks, and Climate Sensitivity, Boulder, CO May 10-13, 2022

Niño 3.4 Index (ONI) Anomaly & PDO Index (01/2000 – 03/2022)

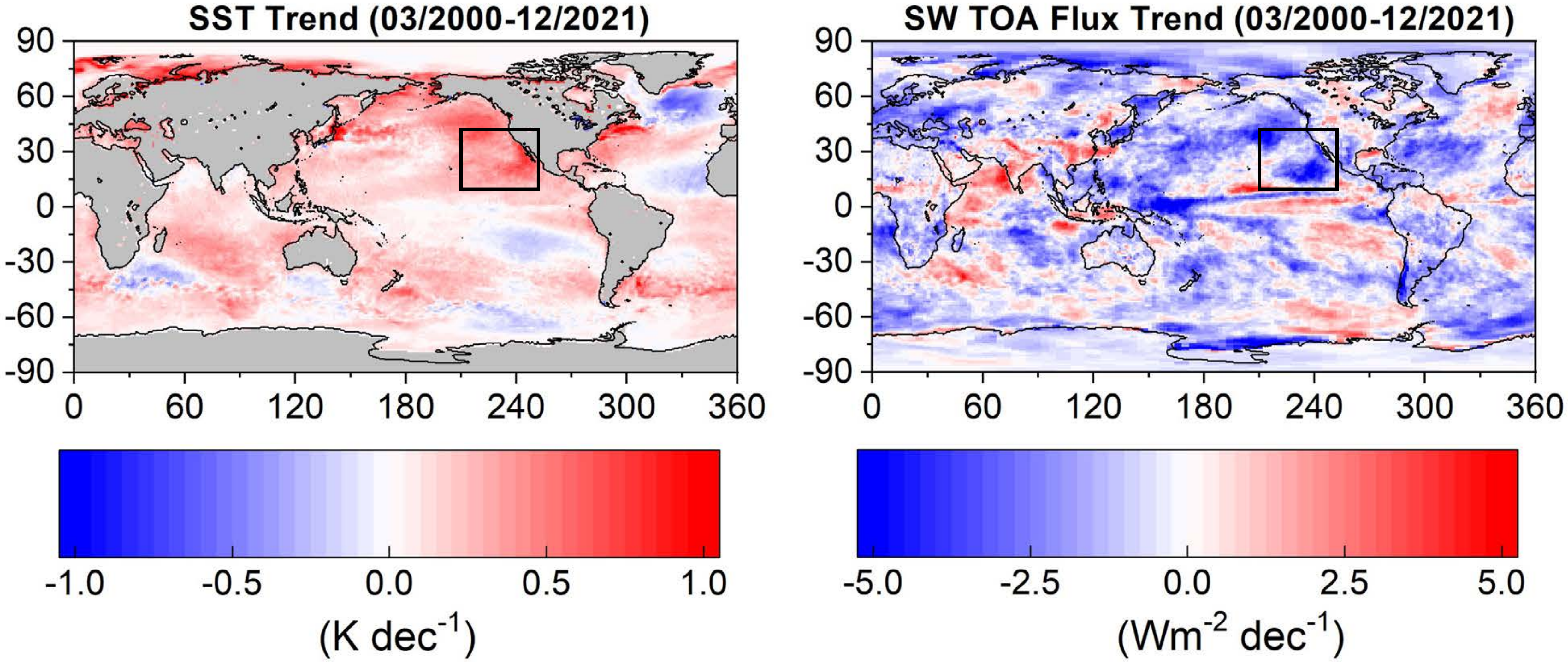


Near-Global (65S-80N) Ocean Temperature Anomalies (Argo)



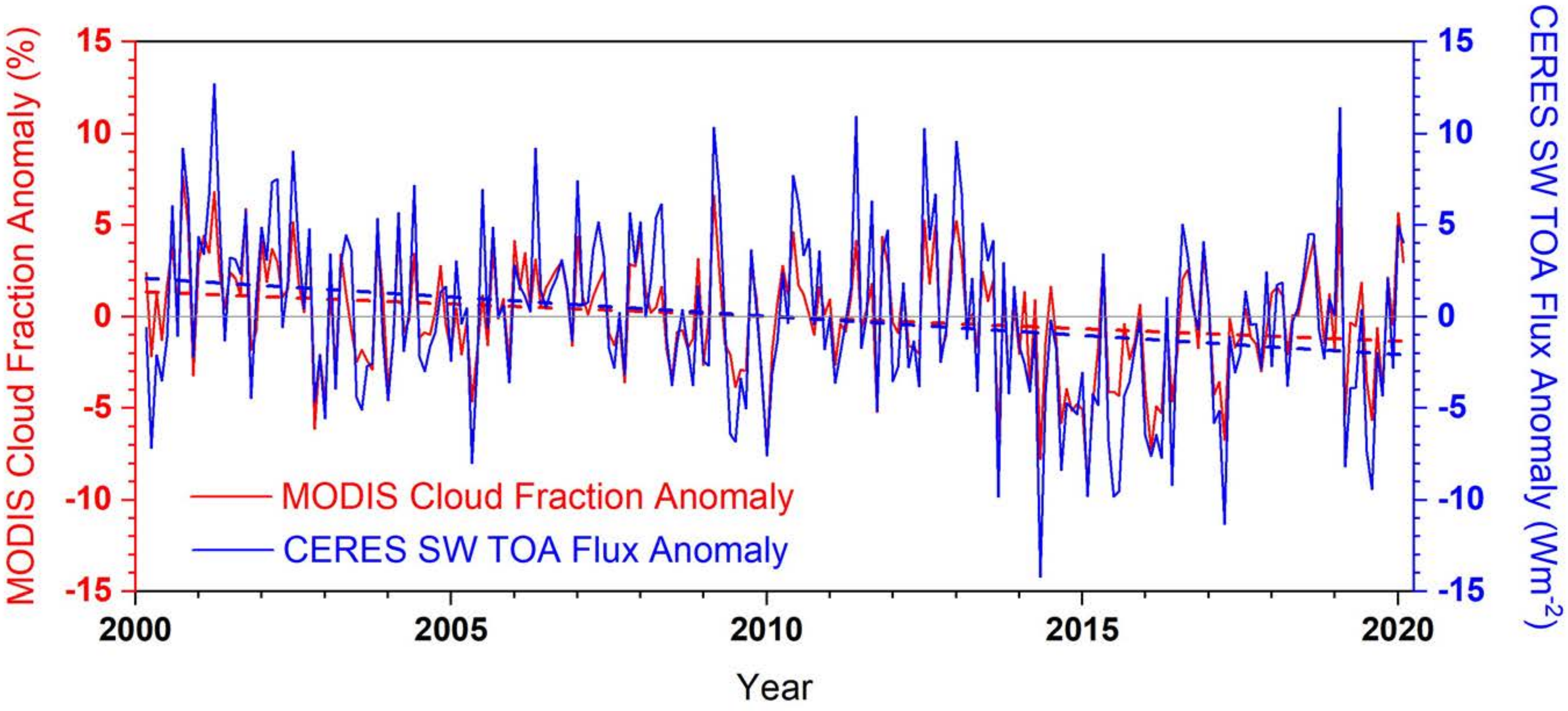
- Negative anomalies for 2004 – 2014
- Onset of positive anomalies coincides with change in sign of PDO index from negative to positive in 2014
- Positive anomalies persist even after PDO switches sign back to negative in mid-2017
- Near-surface trend exceeds 0.2 ^{o}C decade^{-1}

BAMS State of the Climate 2020



- SST trend shows strong warming over Northern Hemisphere Eastern Pacific Ocean
- Northeast Pacific experienced marine heatwaves ("blobs") in 2013-2015 and 2019-2020
- SW TOA flux trend pattern is closely linked to SST trend pattern (especially in regions with abundant low cloud)

MODIS Cloud Fraction and CERES SW TOA Flux Monthly Anomalies Over Eastern Pacific (10°-40°N, 150°-110°W) (March 2000 – February 2020)



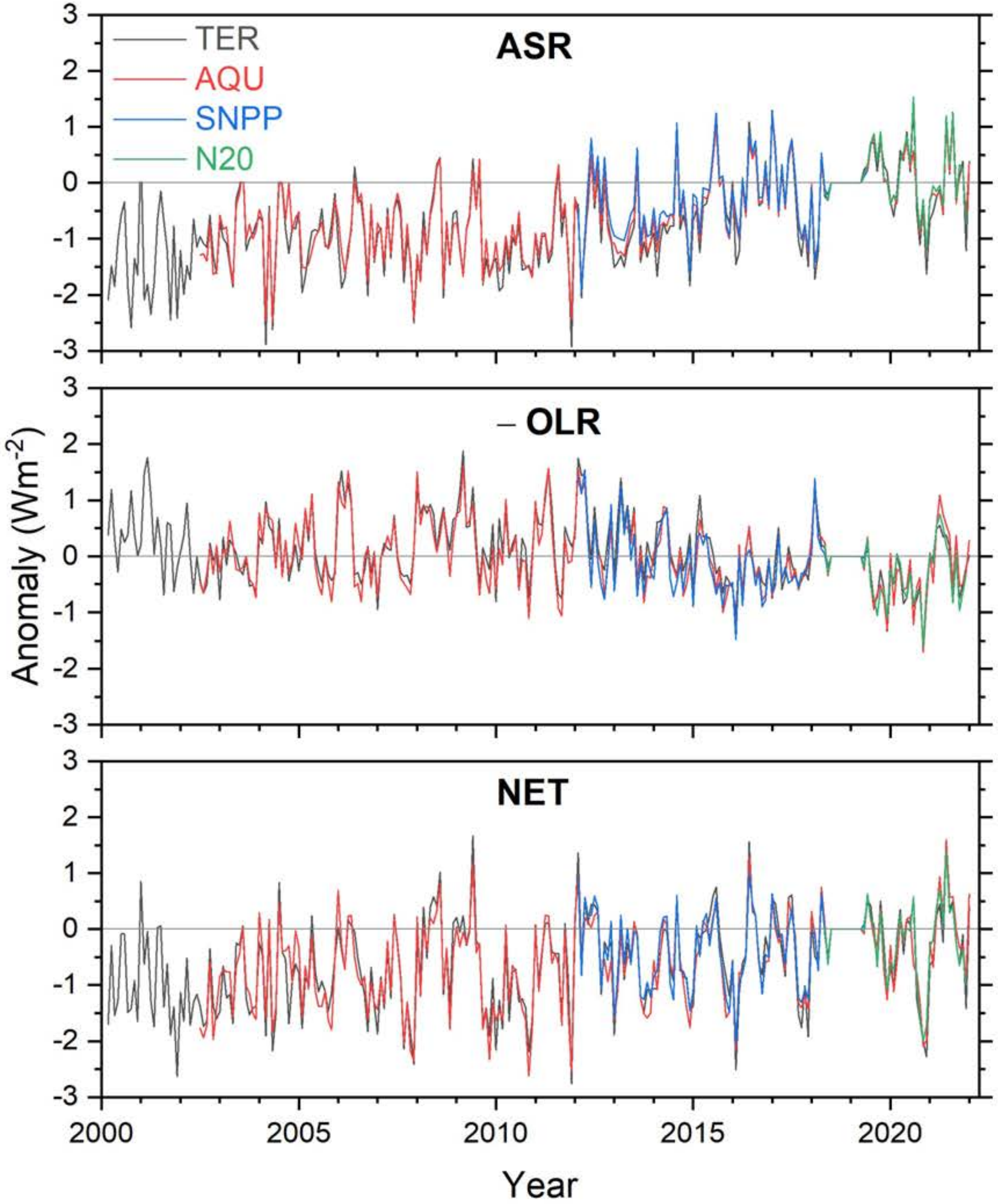
Trends

MODIS Cld frac: -1.4 ± 1.1 %/decade

CERES SW TOA: -2.1 ± 1.6 Wm^{-2}/decade

Loeb et al. JGR, 2022 (in press)

Global Mean All-Sky TOA Flux Anomalies (Relative to Climatology for 05/2018—06/2019)



EBAF Trends (03/2000-01/2022)

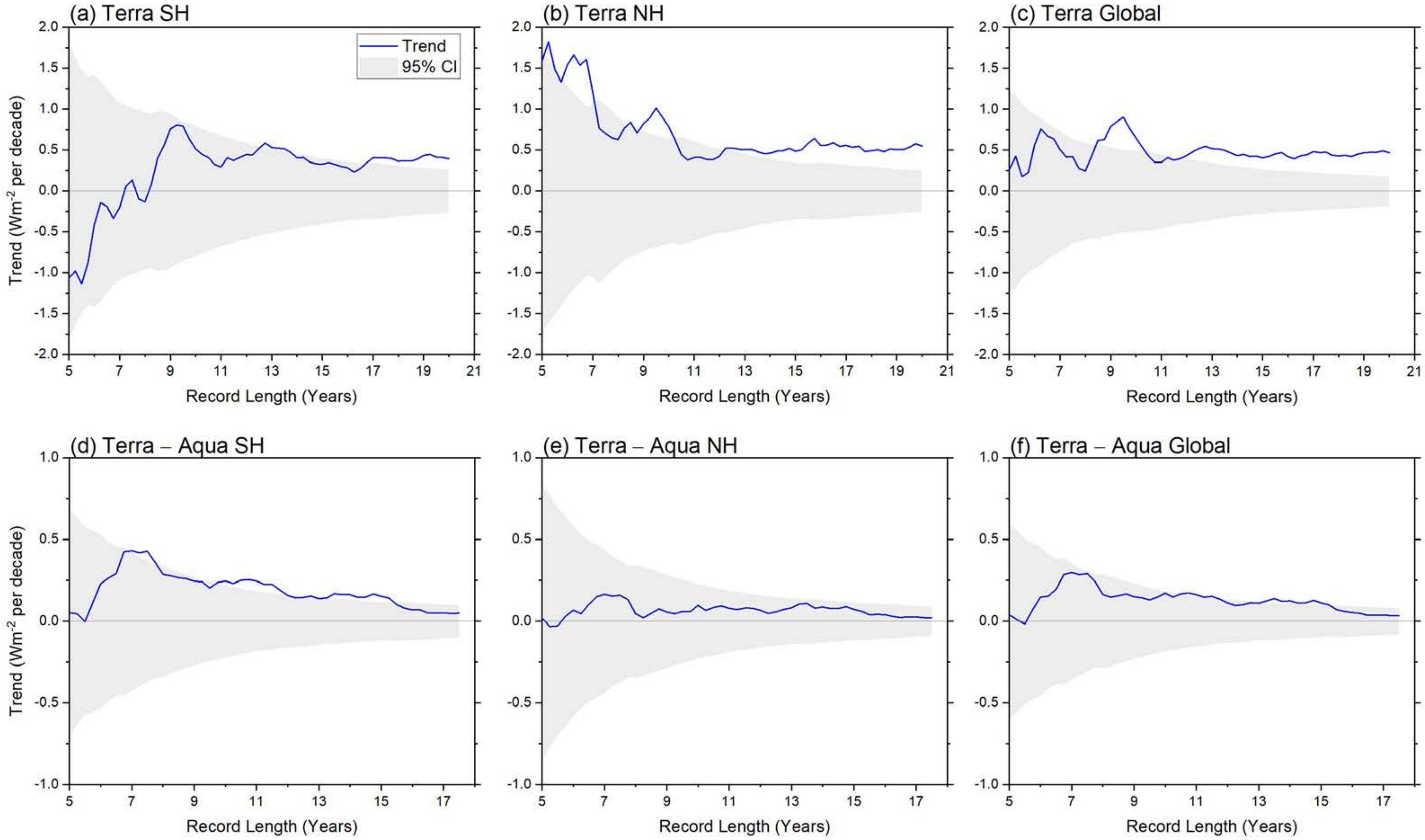
0.69 ± 0.20 Wm^{-2} per decade

-0.27 ± 0.21 Wm^{-2} per decade

0.42 ± 0.20 Wm^{-2} per decade

- **Earth's heating rate increased markedly since 2000:**
  - **Avg EEI (03/2000—02/2005): 0.44 Wm^{-2}**
  - **Avg EEI (02/2017—01/2022): 1.14 Wm^{-2}**

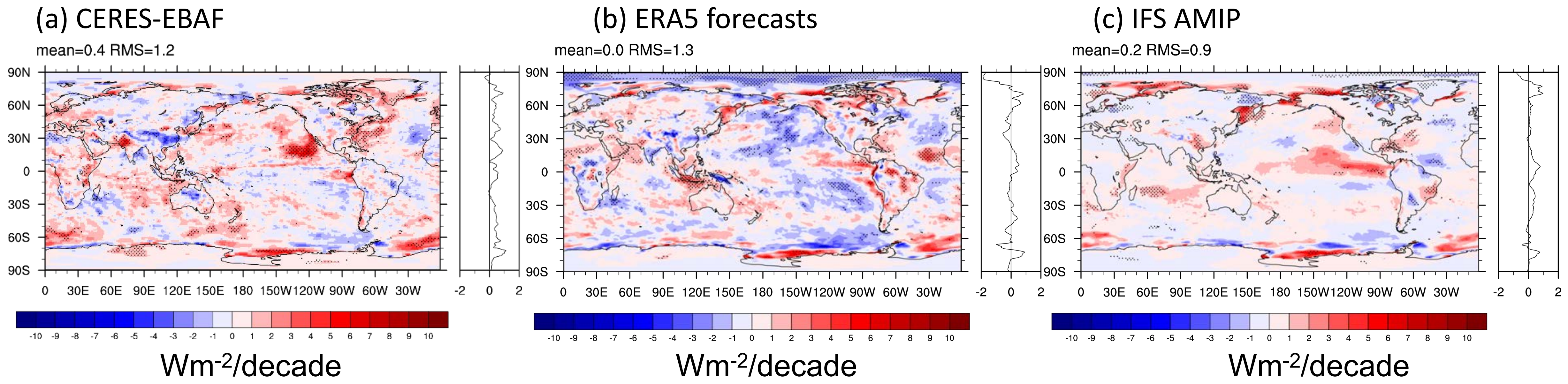
CERES Net TOA Flux Trends vs Record Length for CERES SSF1deg Terra (top) and Terra – Aqua (bottom)
(Start date is 03/2000 for Terra and 07/2002 for Terra – Aqua. Gray shading corresponds to 95% confidence interval.)



- Terra & Aqua net TOA flux trends are consistent to < 0.1 Wm^{-2} per decade for the full period

Loeb et al. JGR, 2022 (in press)

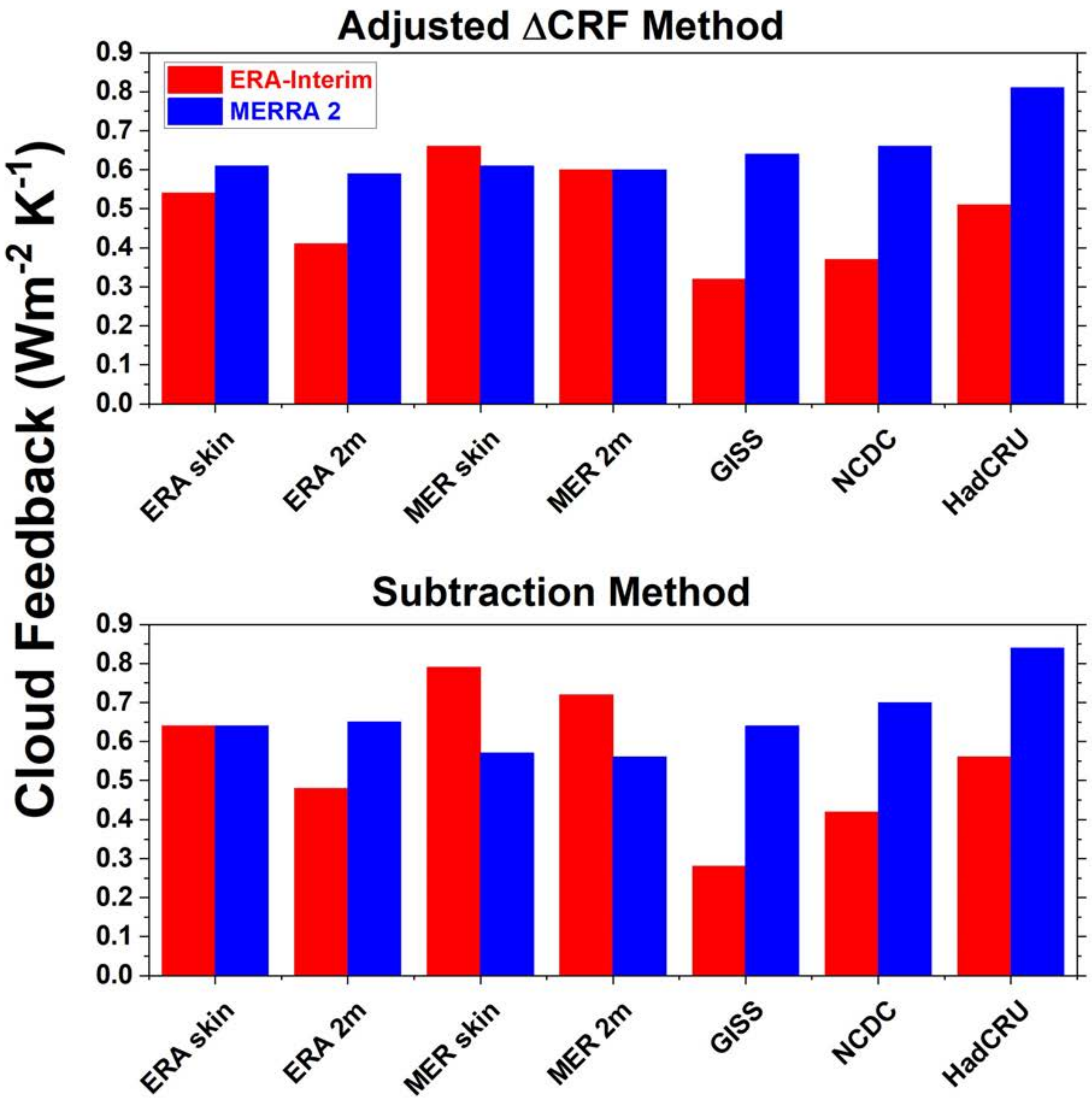
Trends in TOA Net Flux Anomalies: ERA5 vs CERES (03/2000-02/2020)



Loeb et al. JGR, 2022 (in press)

Cloud Feedback Sensitivity to Temperature and Reanalysis Dataset Used

- Cloud feedback using CERES SSF1deg all-sky TOA Flux for 03/2000-06/2011, 7 ΔT_s datasets, and 2 reanalyses (ERA-Interim and MERRA 2).



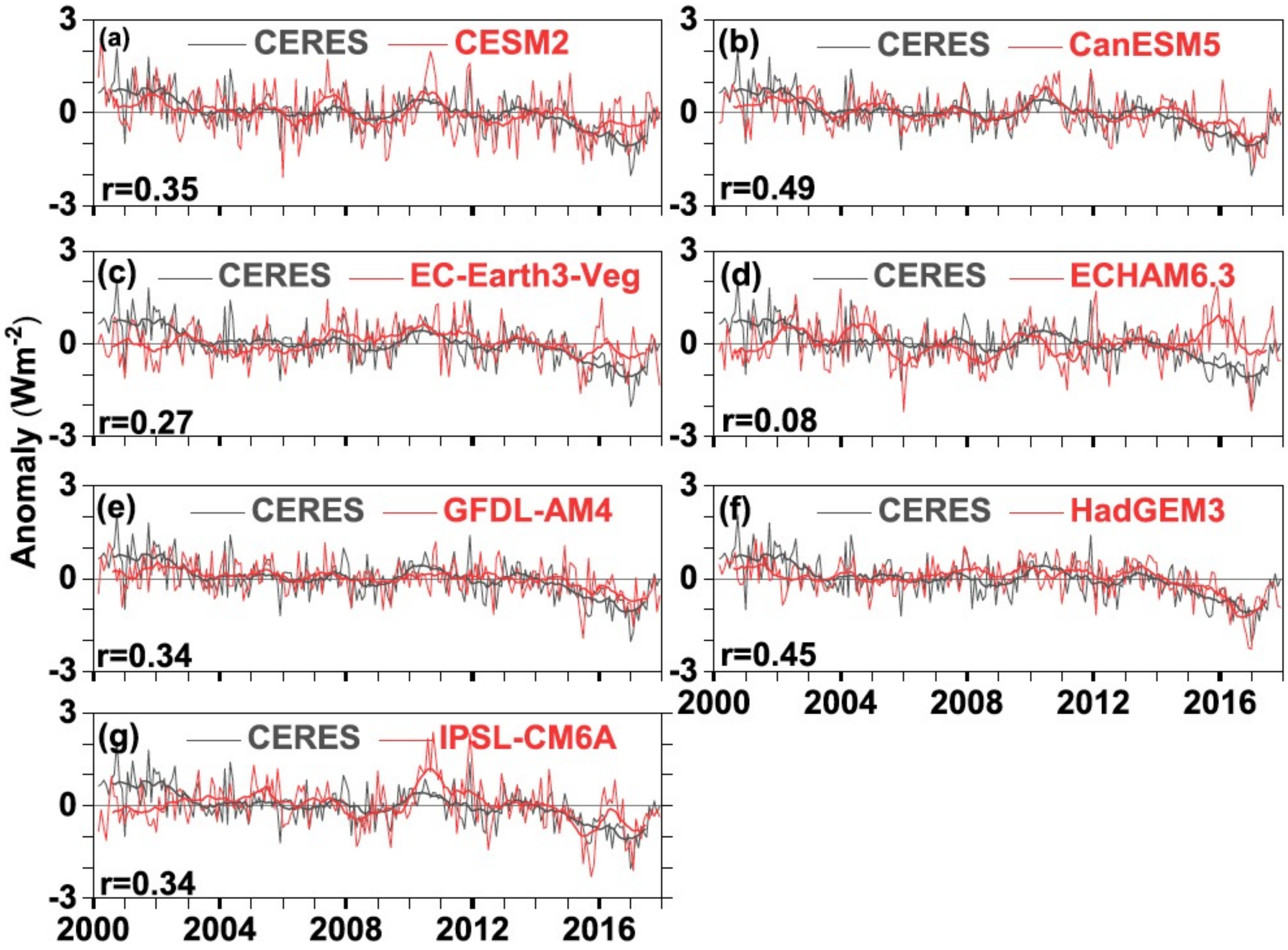
	ERA-Interim	MERRA 2
Mean	0.49	0.65
Stdev	0.13	0.08

	ERA-Interim	MERRA 2
Mean	0.56	0.66
Stdev	0.18	0.09

(Dessler and Loeb, 2013)

Model–Observation Comparisons

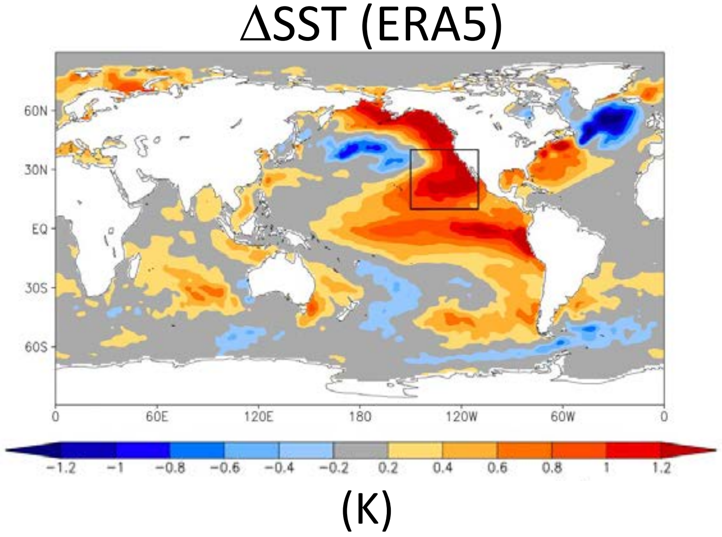
Anomalies in Global Mean TOA Reflected SW Flux: CERES vs CMIP6 AMIP Simulations (March 2000 – December 2017)

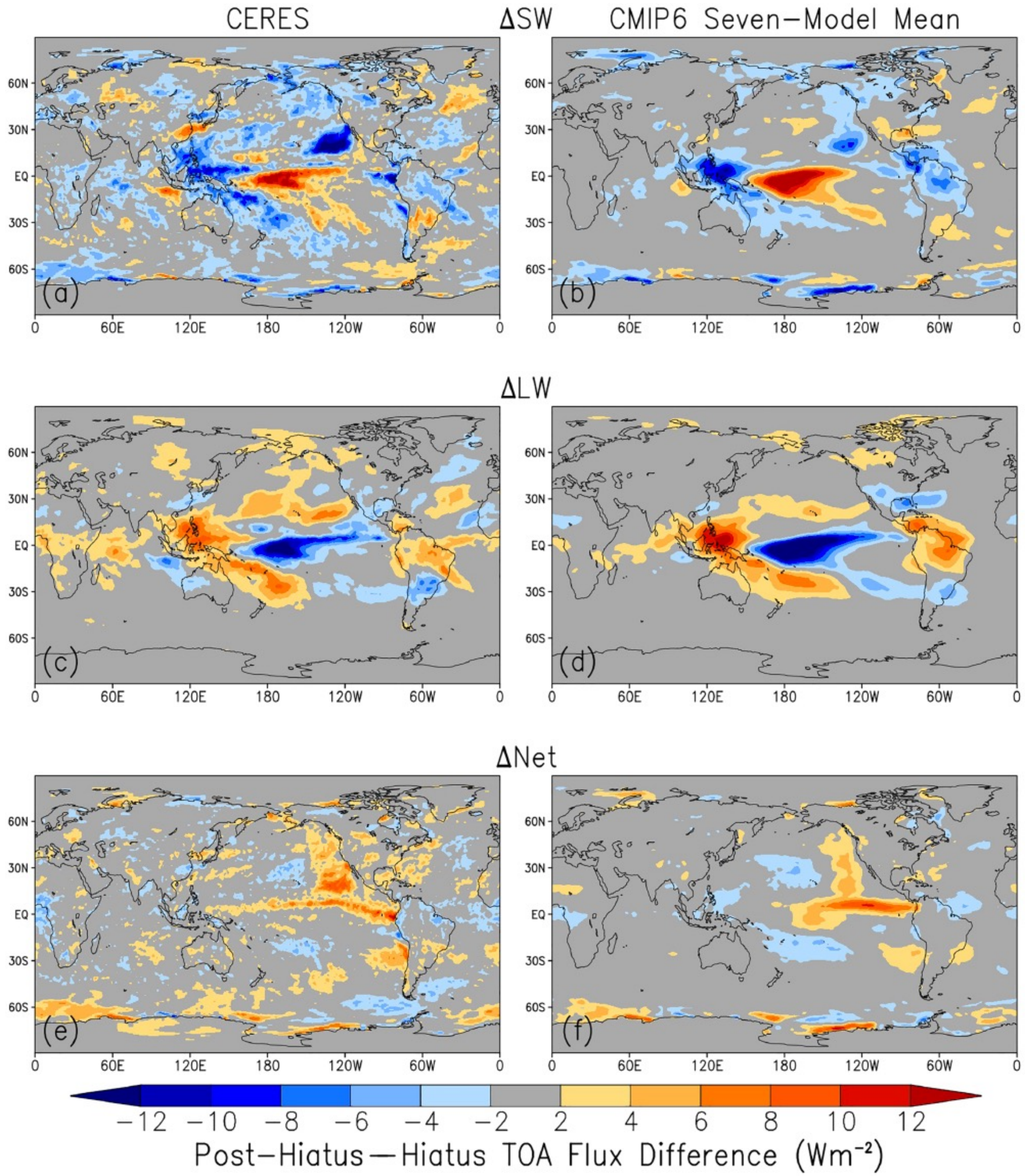


- Several of the CMIP6 models capture observed variability when provided forcing and observed SSTs and sea-ice boundary conditions.

Loeb et al. GRL, 2020

Post-Hiatus (July 2014–June 2017) minus Hiatus (July 2000–June 2014) Differences





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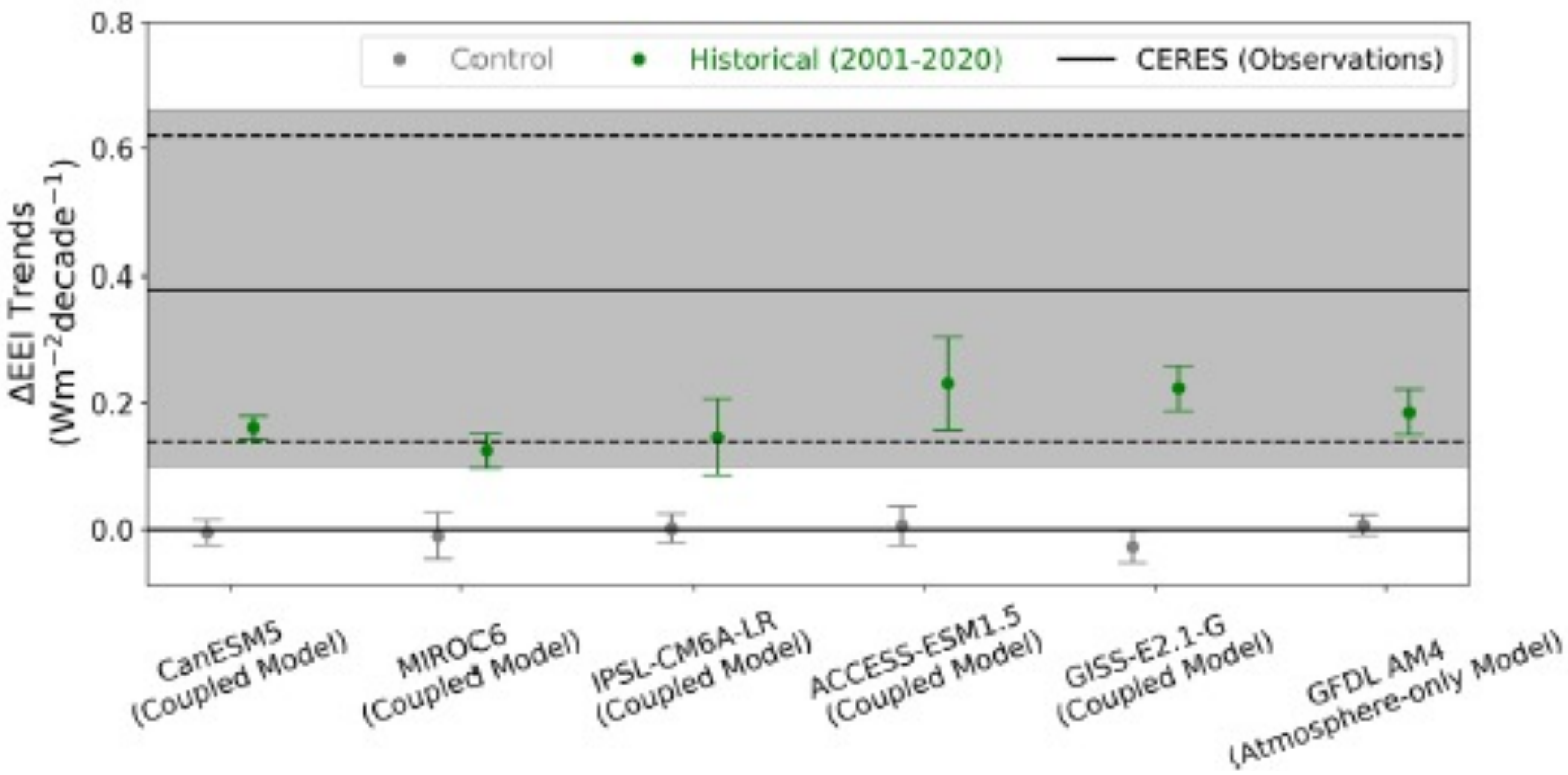
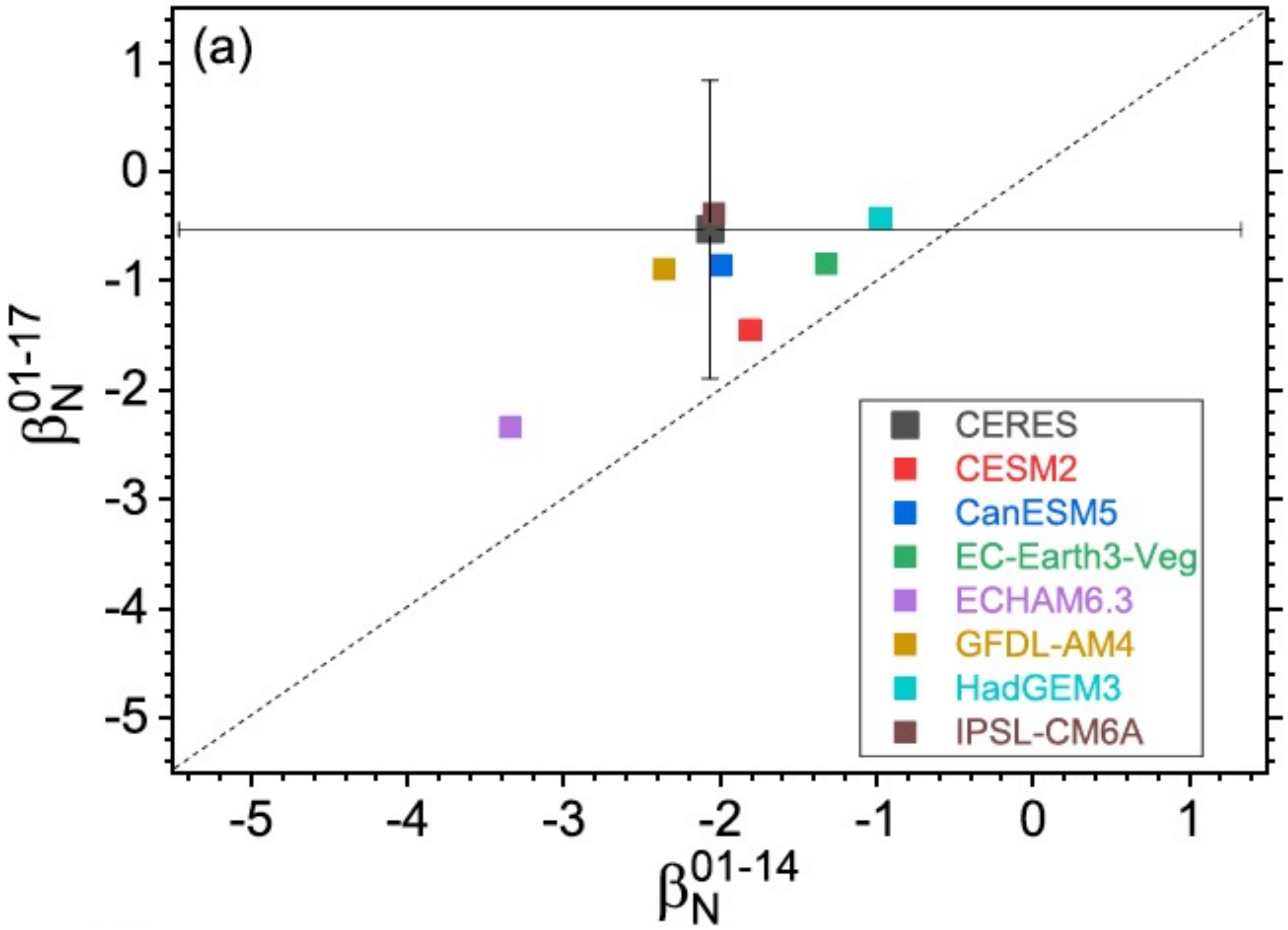
Global Mean Trend in Earth's Energy Imbalance (2001-2020): GCMs vs CERES



- The CERES EEI trend is exceptionally unlikely (<1% probability) to be explained by internal variability alone.
- Model simulations only fall within observational uncertainty when anthropogenic radiative forcing and the associated climate response are accounted for.
- Model EEI trends are in the lower range of the observed 95% confidence interval (dashed lines).

(Raghuraman et al., Nat. Comm., 2021)

CERES Radiative Restoring Coefficient (β_N)



β_N = Slope of regression fit:

$(\delta N - \delta F)$ vs δT_s

δN = Net flux anomaly

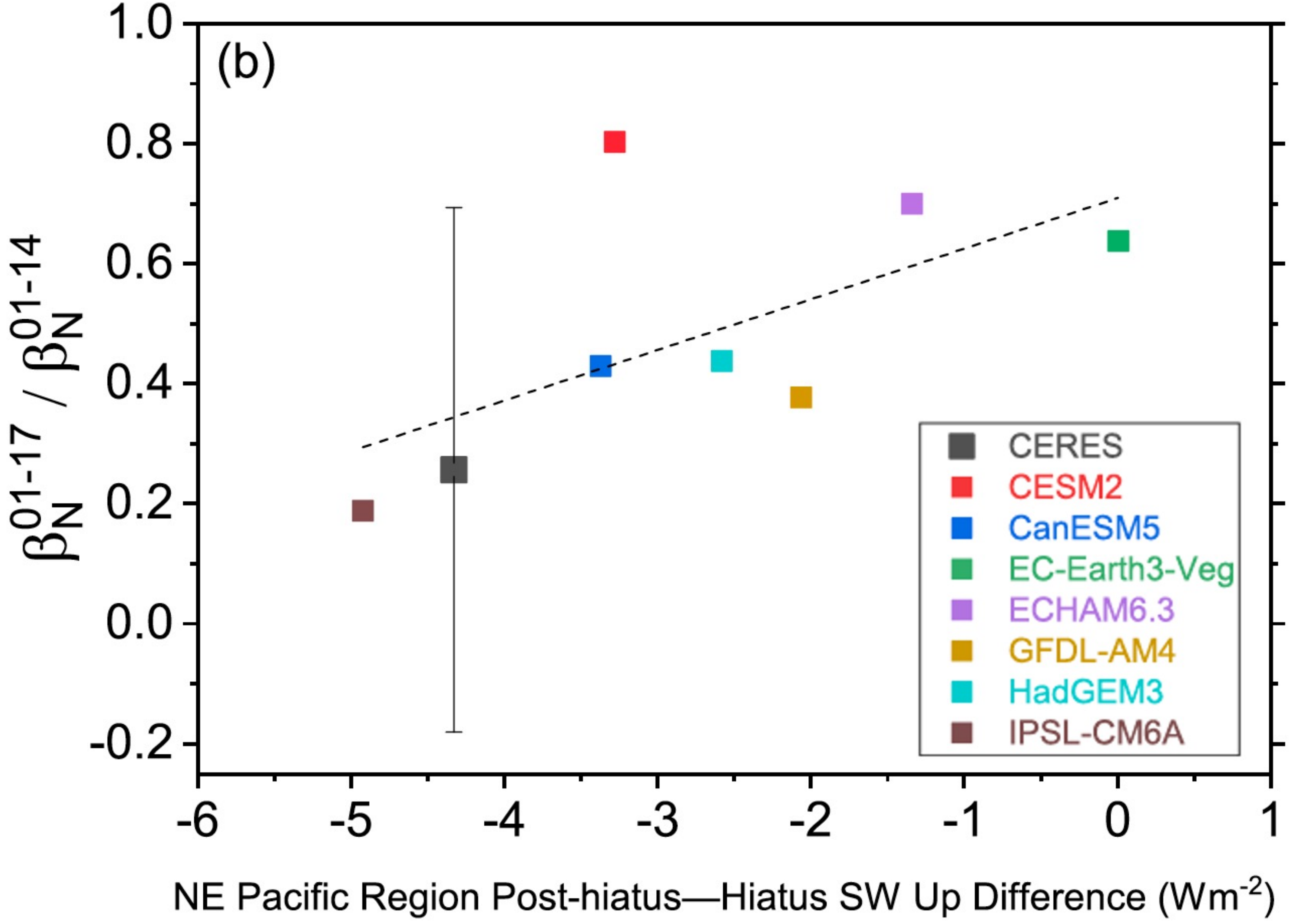
δF = Effective radiative forcing anomaly

δT_s = Surface Temperature anomaly

- β_N becomes dramatically less stabilizing when the three post-hiatus years are included, changing from –2.1 to –0.53 $Wm^{-2}\ K^{-1}$ due to a strong SW cloud feedback during the post-hiatus period.

Loeb et al. GRL, 2020

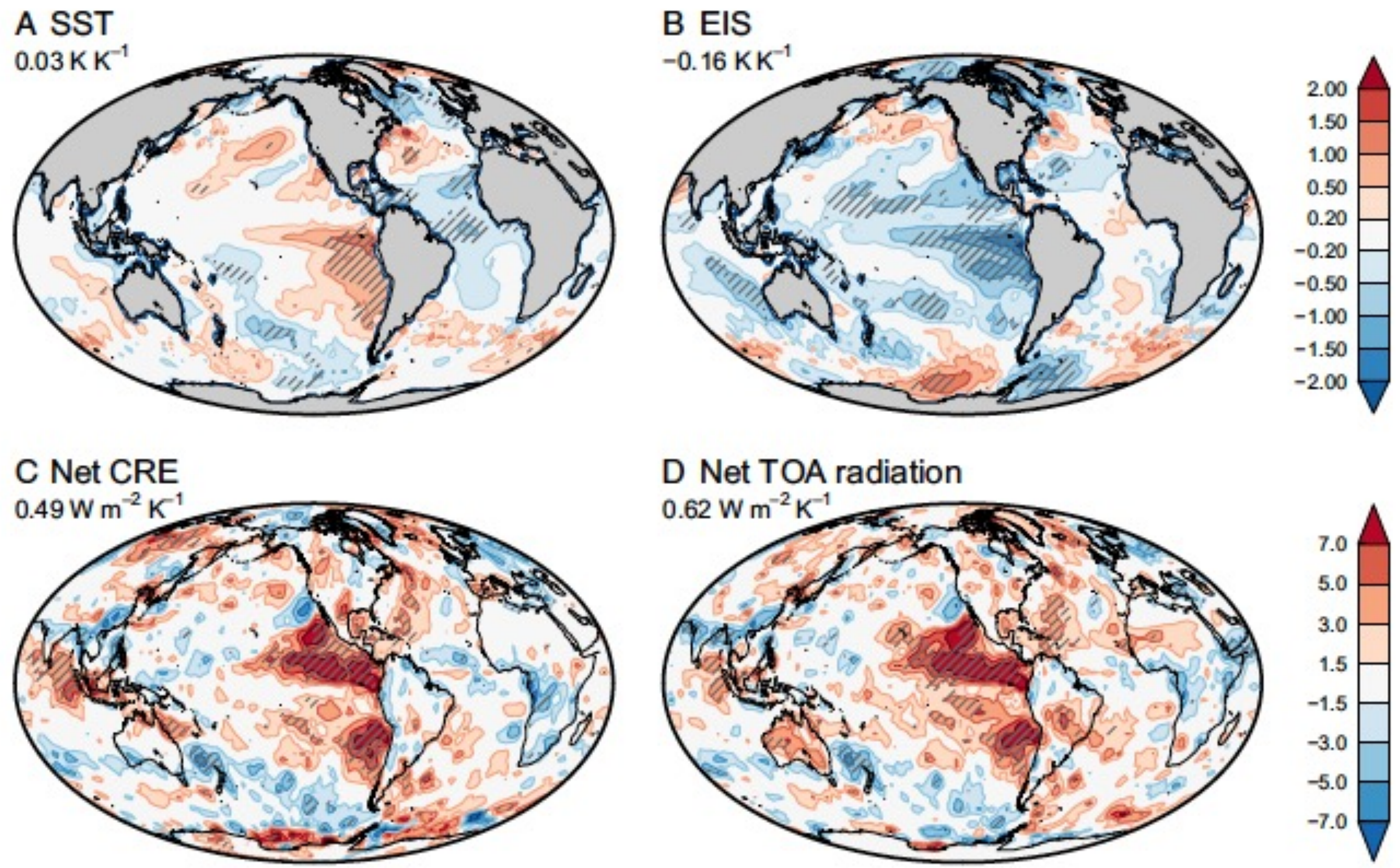
Quantifying the Pattern Effect: β_N(2001-2017) / β_N(2001-2014)



- Most models have a β_N ratio that is too large, indicating too weak a pattern effect, and a SW response in EP that is too weak.
- For this period, a model's ability to represent changes in the relationship between global mean net flux and surface temperature depends upon how well it represents SW flux changes in the EP.

Loeb et al. GRL, 2020

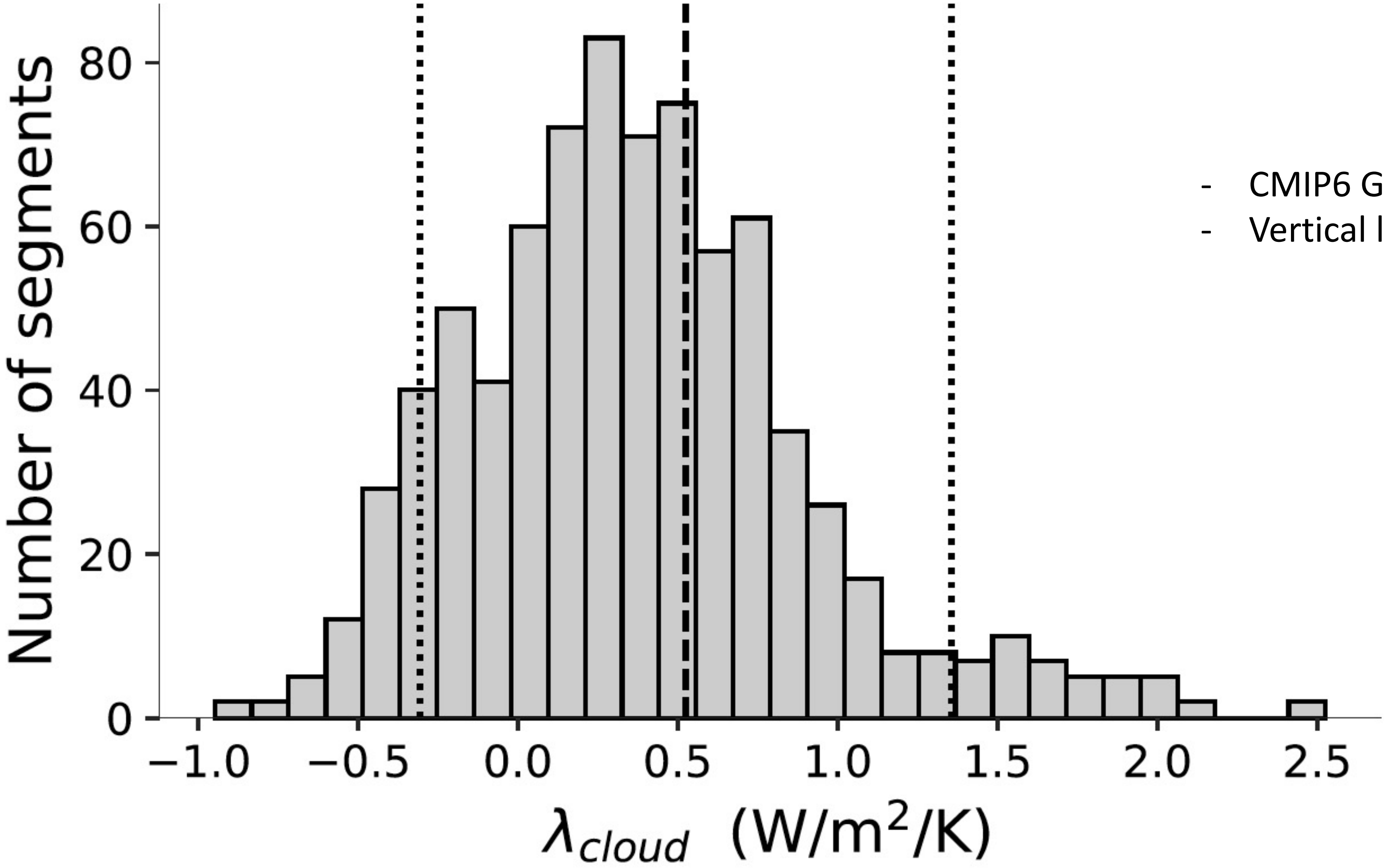
Observed Regressions of SST, EIS, Net CRE & Net TOA Radiation Anomalies against Global Mean EIS Anomalies (December 2000 – November 2016)



- EIS decrease in Eastern Pacific (EP) associated with positive SST anomalies, positive CRE and NET TOA anomalies.
- Observational results qualitatively support the notion that decreasing tropospheric stability promotes a decrease in radiative cooling to space through changes in clouds and tropospheric lapse rate, consistent with the evolution toward higher effective climate sensitivity in CO_2-forced climate model experiments.

Ceppi and Gregory, PNAS, 2017

Distribution of Cloud Feedback Values for 20-year Segments in CMIP6 Control Runs vs CERES

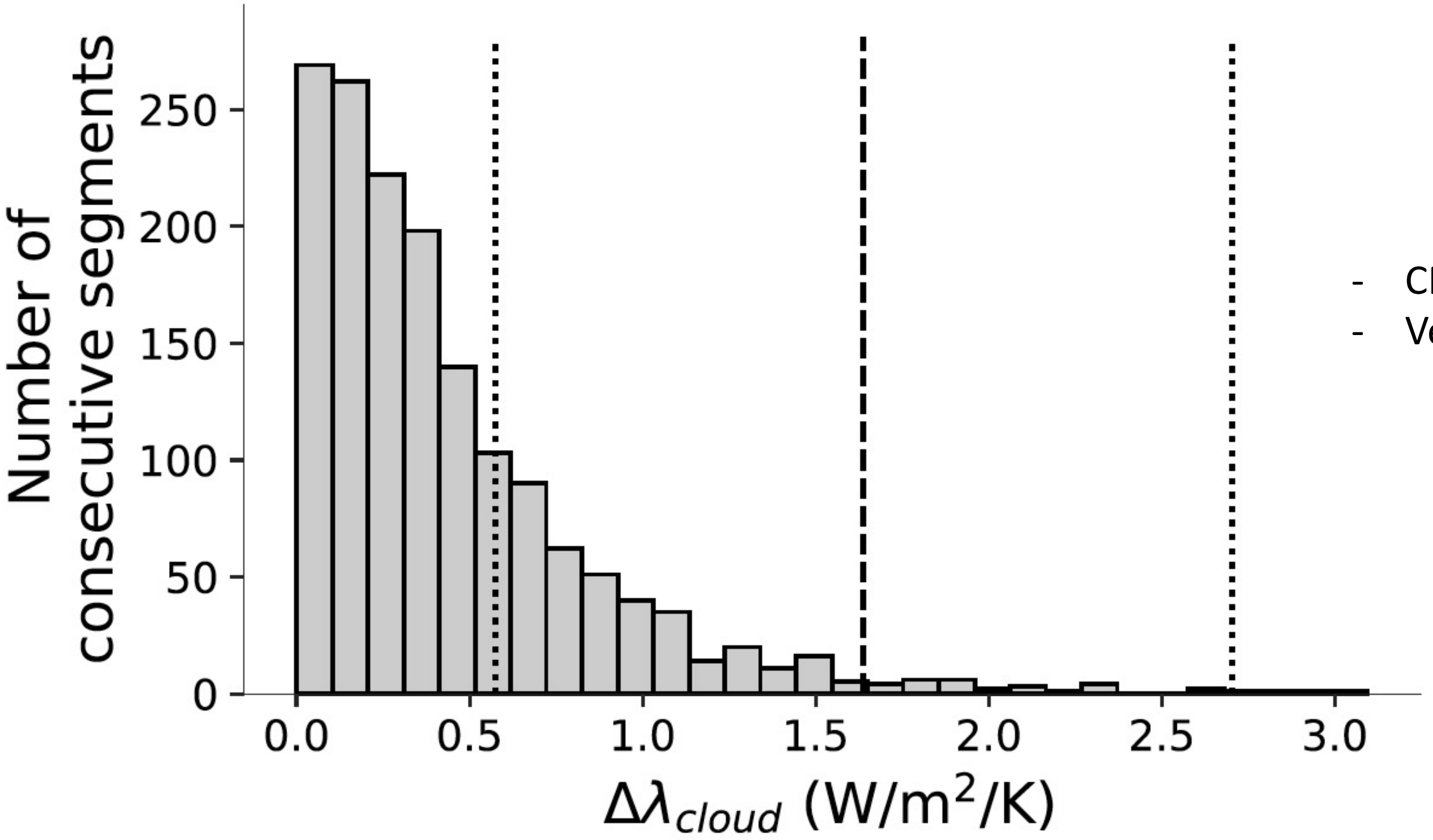


- CMIP6 GCM PI Control Runs from 26 models
- Vertical lines correspond to Observed 90% CI

- 85% of 20-year model segments have values of λ_{cloud} within the uncertainty range of CERES data

Chao, Muller & Dessler, GRL, 2022

Radiative Pattern Effect: Distribution of 1570 Consecutive 10-Year λ_{cloud} Differences from CMIP6 Models



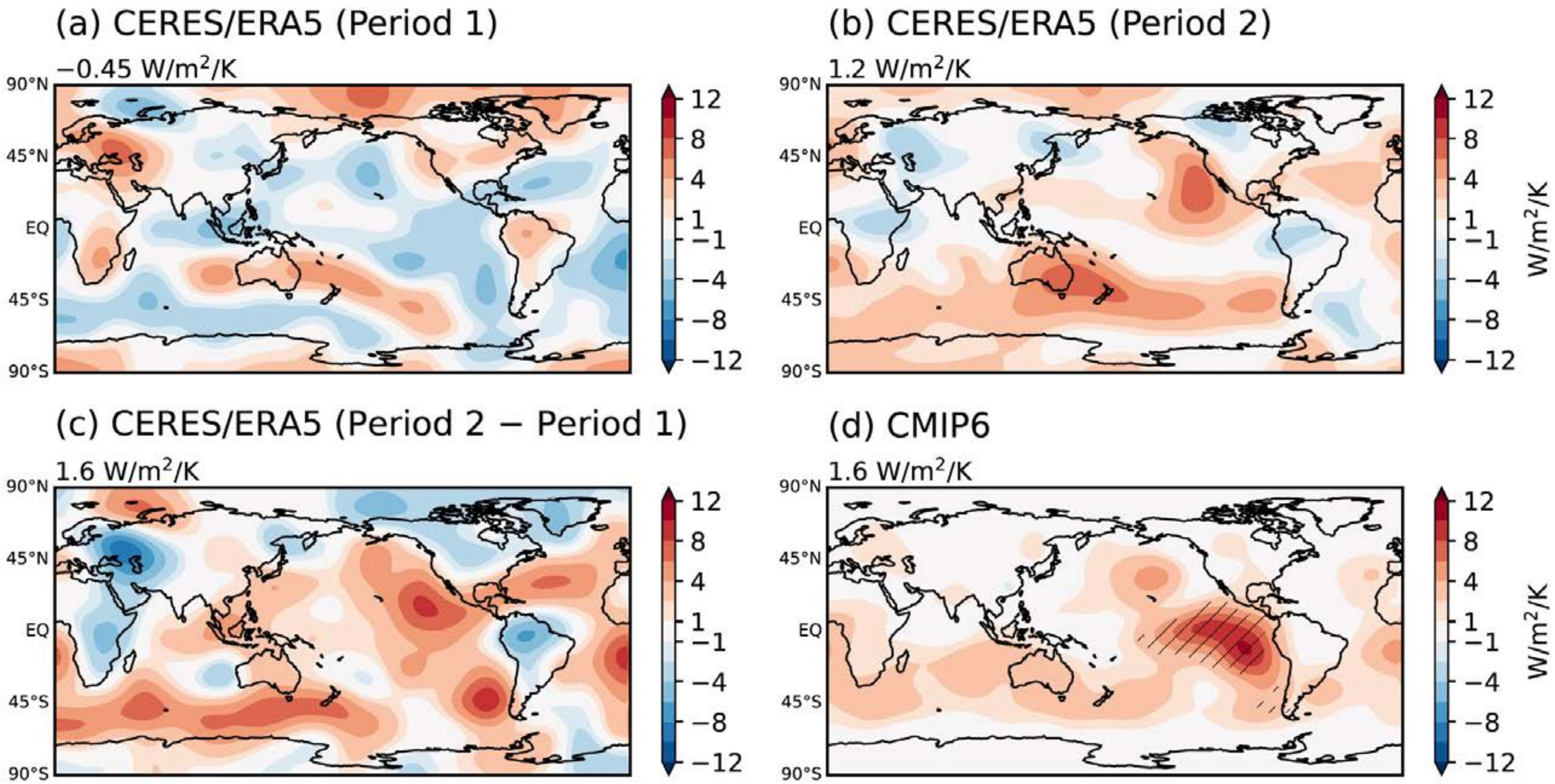
- CMIP6 GCM PI Control Runs from 26 models
- Vertical lines correspond to Observed 90% CI

- 27% of $\Delta\lambda_{cloud}$ values fall within the uncertainty range of the observations, mostly at the lower end of the range.
- Only two percent of the model estimates exceed the best estimate of $\Delta\lambda_{cloud}$ from CERES sub-periods.

=> CERES period was either exceptional or couple models do poor job at representing radiative pattern effect.

Chao, Muller & Dessler, GRL, 2022

Spatial Pattern of λ_{cloud}: CERES/ERA5 vs CMIP6



- Period 1: 03/2000 – 07/2020
- Period 2: 08/2010 – 12/2020
- CMIP6 10-year segments have global average $\Delta\lambda_{cloud}$ within 90% confidence interval of obs.
- Hatching denotes regions where 66% of consecutive segments have same sign as observations.

- Positive changes in cloud feedback over the East Pacific are robust, but magnitudes differ appreciably.

Chao, Muller & Dessler, GRL, 2022

Discussion

- Why is the observed trend in EEI since 2000 so large (0.42 ± 0.20 Wm^{-2} per decade)?
  - Forced climate model simulations just barely exceed the lower bound of the 95% confidence interval in the observed trend.
  - Is the unforced pattern effect responsible for the large observed trend? Is this effect underestimated in GCMs?

- Besides ENSO and PDO, what other factors impact SST and TOA radiation patterns?

- How can observations best be used to assess the realism of SST and ERB pattern changes in coupled atmosphere-ocean GCMs?

- If a climate model performs poorly when compared with observations, can we trust the model's projections of long-term warming?