Emerging Hemispheric Trends in Earth Radiation

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Introduction

- Numerous studies have shown that the Northern and Southern Hemispheres reflect nearly the same amount of incident solar irradiance on an annual average.
  - True even though most landmasses and atmospheric aerosols reside in the Northern Hemisphere

- Voigt et al. (2013) use CERES data to show that only 3% of partitionings of Earth into two random halves exhibit hemispheric symmetry within 0.1 Wm^{-2}.

- Do clouds naturally compensate for hemispheric asymmetries in non-cloud properties?

- This has been a topic of intrigue over the past 50+ years.

- Have there been any significant changes in albedo hemispheric symmetry during the CERES period?

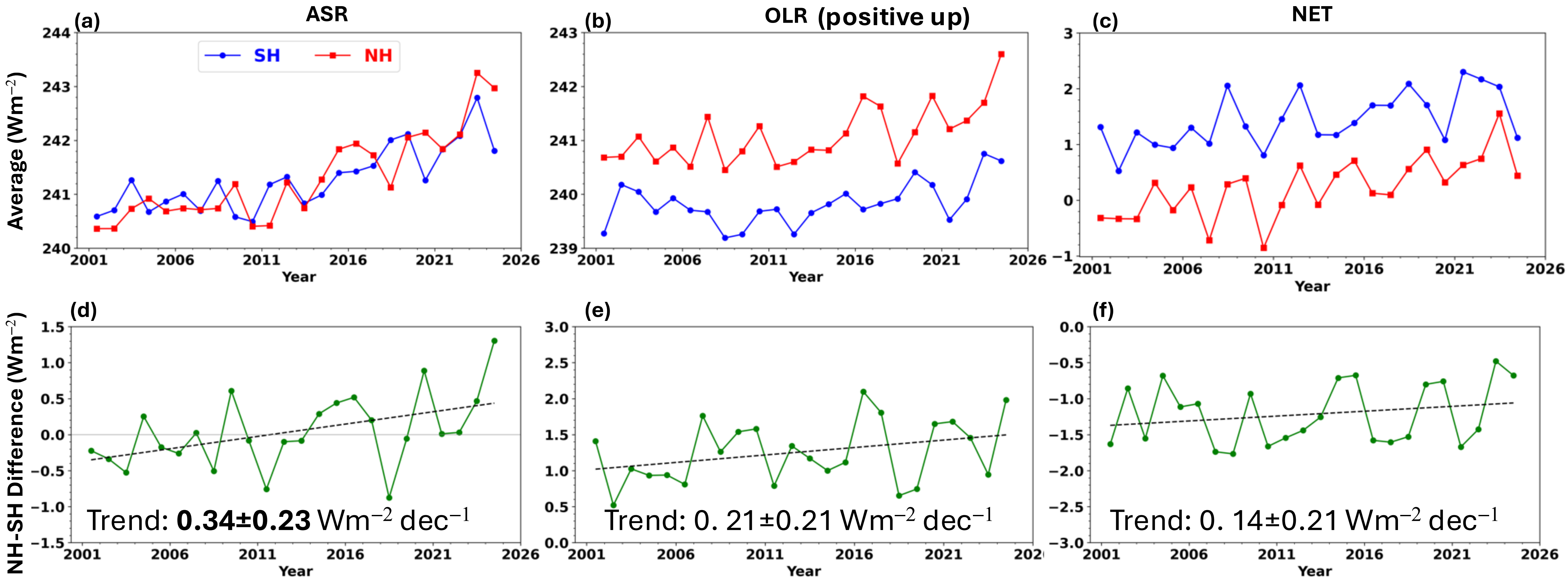
Data and Methods

- EBAF Ed4.2.1: 2001–2024

- Partial Radiative Perturbation Analysis (Thorsen et al., 2018)
  - Uses inputs to radiative transfer calculations in EBAF-SFC product
  - Provides contributions to regional monthly TOA flux anomalies from changes in:
    - Aerosol-radiation interactions
    - Surface albedo
    - Clouds
    - Temperature (surface and atmosphere)
    - Water vapor
    - Solar irradiance and trace gases (S+Tr)

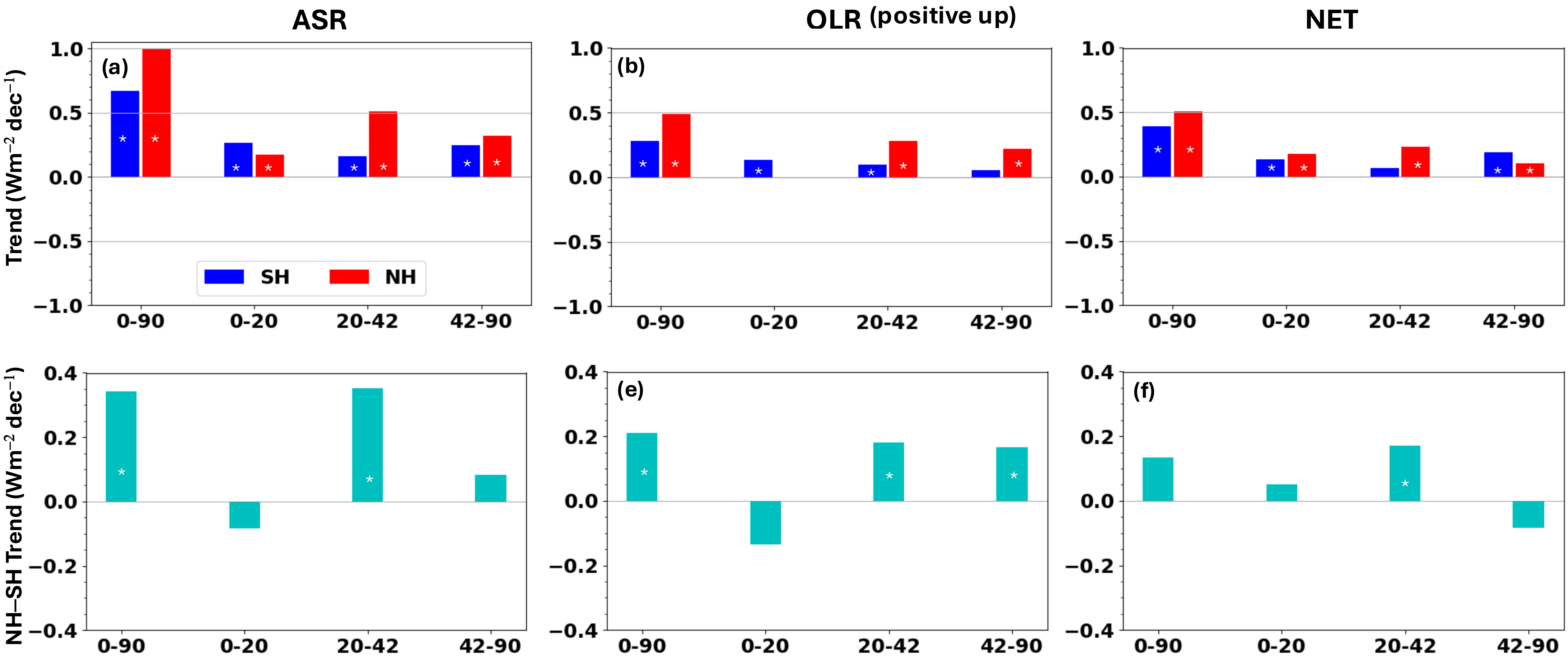
- Cloud radiative effect (CRE) from AMIP climate model simulations (Hodnebrog et al., 2021)
  - Multi-model mean climate model simulations for 2001-2019
  - CESM2, ICON-HAM, NorESM2, HadGEM3, GFDL

Annual Mean TOA Flux for Southern and Northern Hemispheres & NH–SH Differences (2001-2024)



- Positive trends in ASR and OLR for both SH and NH
    - ➢ NH is darkening faster than SH; OLR trend in NH > SH
- Weak NET trend in NH–SH difference due to compensation between ASR and OLR

Trends in ASR, OLR and NET for Tropics, Sub-Tropics, Extratropics (2001-2024)



- Hemispheric asymmetry in ASR trend primarily from marked ASR increase in NH sub-tropics (20-42°N)
- Hemispheric asymmetry in OLR trend primarily from NH subtropics and mid-high latitudes.

Attribution of CERES TOA Flux Trends Using Partial Radiative Perturbation (PRP) Method

(What are the contributions from individual variables to observed CERES TOA flux trends?)

(a) Non-Cloud Contributions:

The effect on the flux (δF) due to some perturbation Δx of variable *x* is:

$$\boxed{\delta F_{\Delta x} = F(x + \Delta x, y_1, \ldots, y_N) - F(x, y_1, \ldots, y_N)} \quad (1)$$

$x, y_1, \ldots, y_N$ = Gridded monthly mean input variables to radiative transfer model calculations

$\Delta x, \Delta y_1, \ldots, \Delta y_N$ = Gridded deseasonalized monthly mean anomalies of input variables

F = Fu-Liou radiative transfer model computed TOA flux

Input variables (non-cloud): Skin temperature, profiles of temperature and water vapor, surface albedo, aerosols, gases (ozone, carbon dioxide, methane, nitrous oxide, CFC-11, CFC-12, and HCFC-22) and incoming solar irradiance.

Source: Adjusted EBAF-SFC inputs.

- Inputs are “tuned” to force match between computed and observed EBAF clear-sky TOA fluxes

(b) Cloud Contributions:

$$\boxed{\delta F_{\Delta c} = \Delta CRE - \sum_{i} \left[\delta F_{\Delta x_i} - \delta F^{o}_{\Delta x_i} \right]} \qquad (2)$$

ΔCRE = Anomaly in cloud radiative effect (CRE) from EBAF Ed4.2.1 observations

$\delta F_{\Delta x_i}$ = All-sky flux perturbation due to anomaly in variable $\boldsymbol{x}_i$

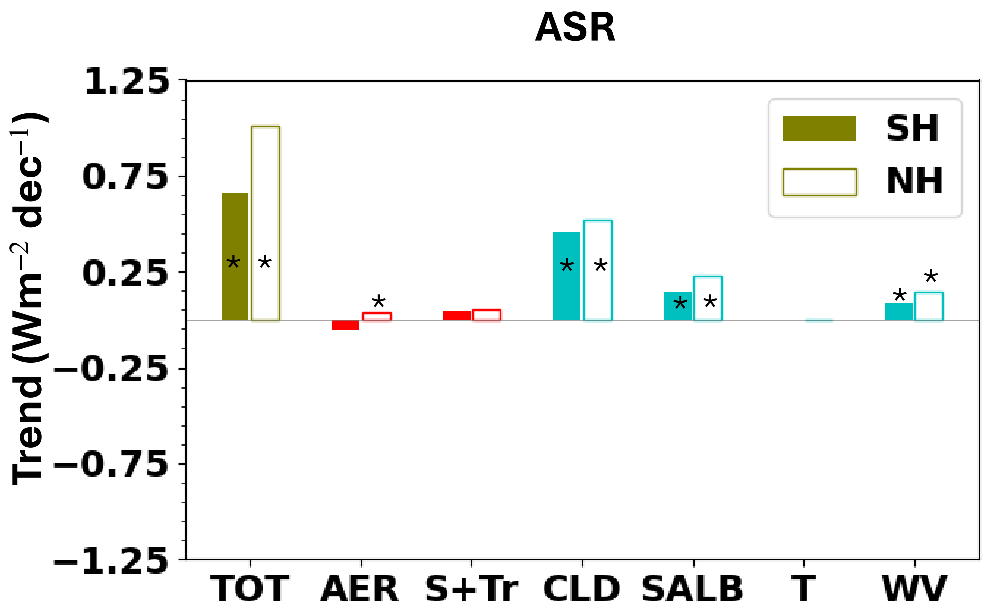
$\delta F^{o}_{\Delta x_i}$ = Clear-sky flux perturbation due to anomaly in variable $\boldsymbol{x}_i$

Perturbations (Δx_i) Considered

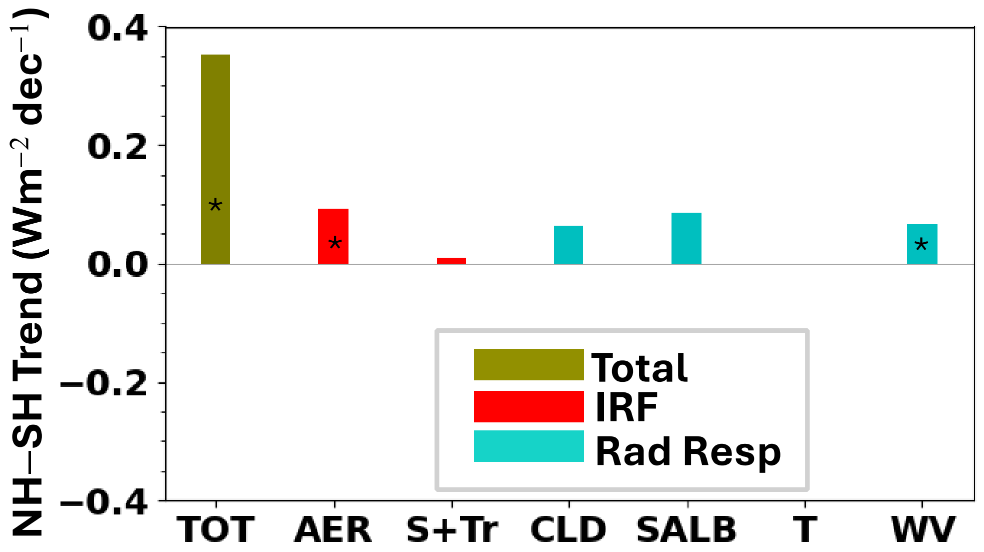
1) Skin Temperature and atmospheric temperature profile (T)
2) Water vapor profile (WV)
3) Surface albedo (SALB)
4) Aerosol-Radiation Interactions (AER)
5) Solar irradiance + Trace Gases (S+Tr)
6) Clouds (CLD)

Time Period: 01/2001– 12/2024

Attribution of TOA Flux Trends and Trend Differences Using PRP Method (2001-2024)

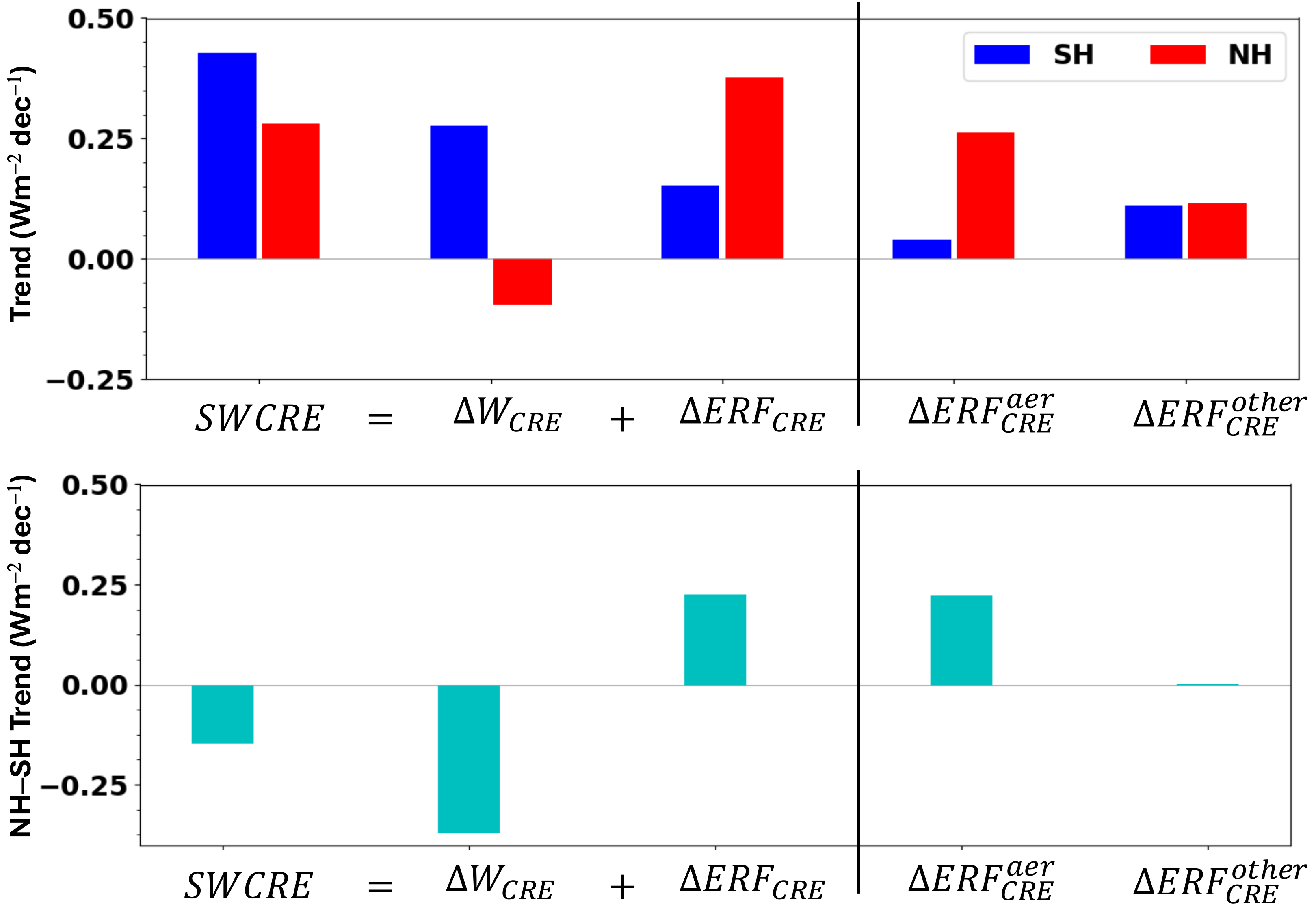


- Largest contributions to the SH and NH ASR trends are from changes in clouds, surface albedo, and water vapor



- Largest contributions to the NH–SH difference trend are from changes in aerosol-radiation interactions, surface albedo, water vapor and clouds
- Cloud contribution does not compensate for non-cloud NH–SH ASR difference trends
- Why?

Global Climate Model Simulations (AMIP) of SH, NH, and NH–SH Trends in SW CRE (2001-2019)

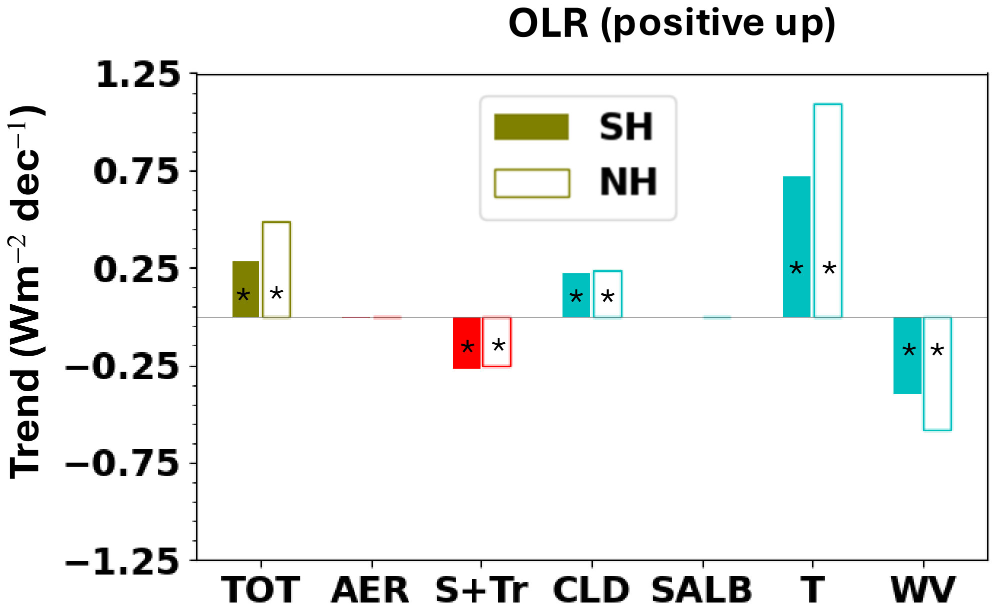


$\Delta W_{CRE} =$ Cloud feedback

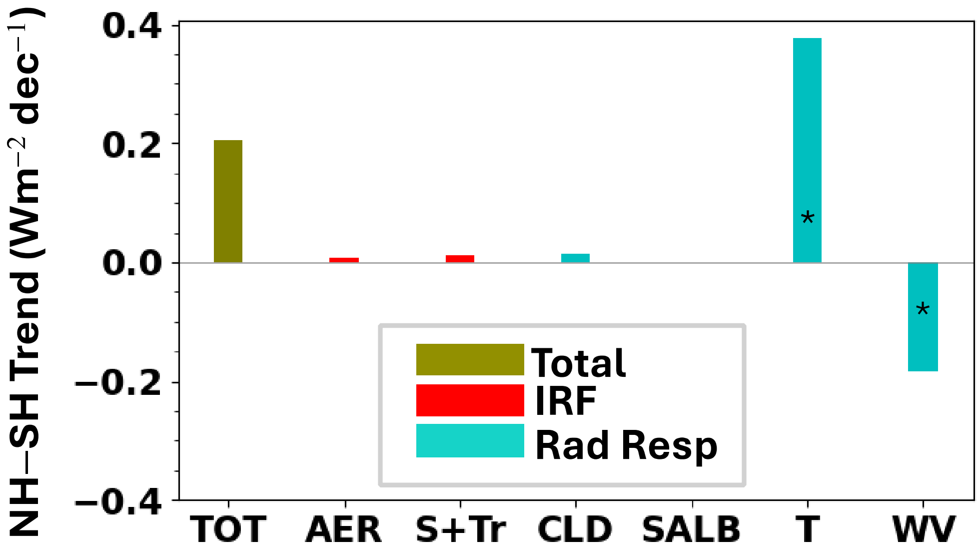
$\Delta ERF_{CRE} =$ Effective radiative forcing

- Compensation between NH–SH difference trends for cloud feedback and ERF explains weak hemispheric contrast in the cloud contribution

Attribution of TOA Flux Trends and Trend Differences Using PRP Method (2001-2024)

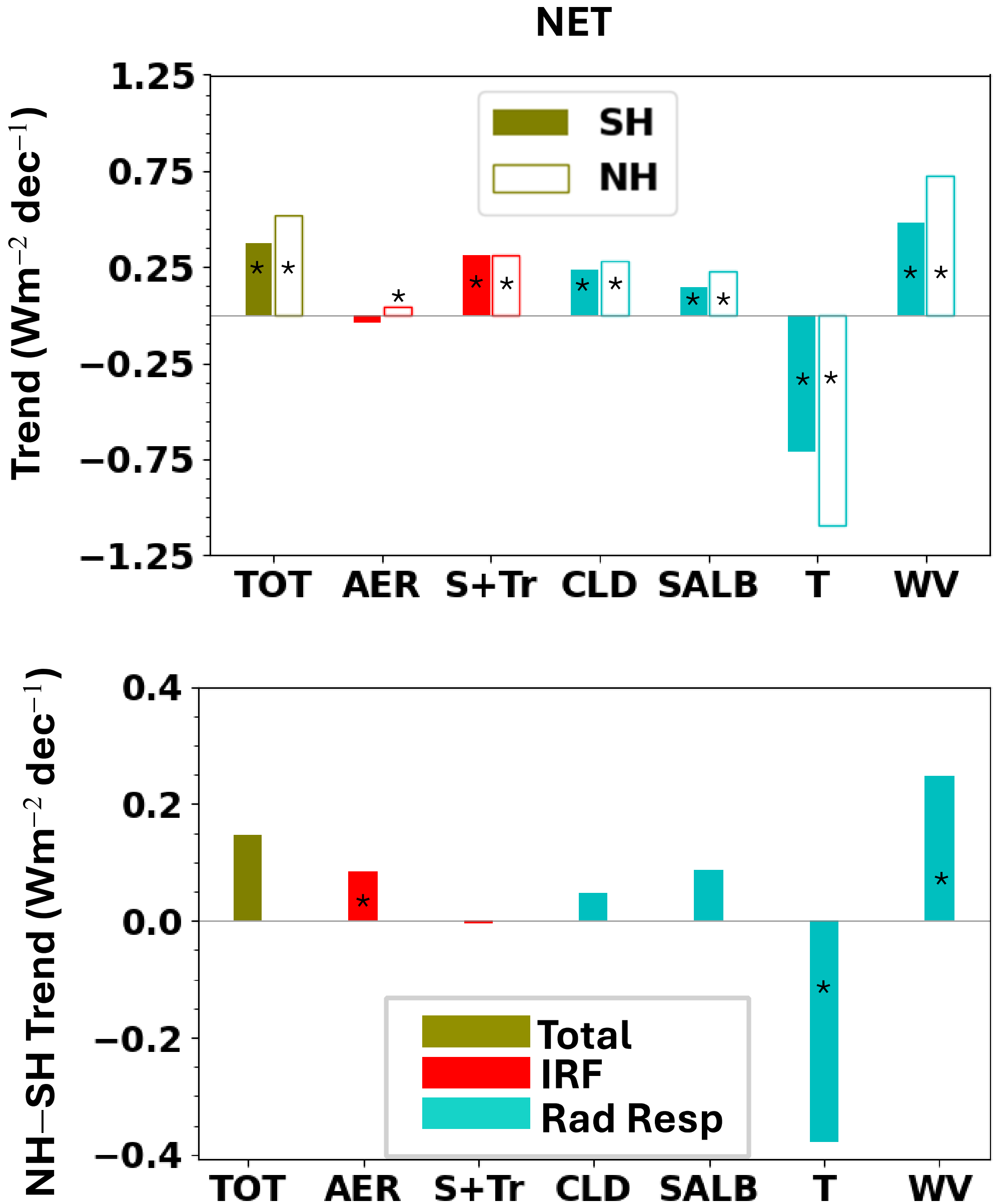


- Largest contributions to the SH and NH OLR trends are from temperature, water vapor, trace gases and clouds



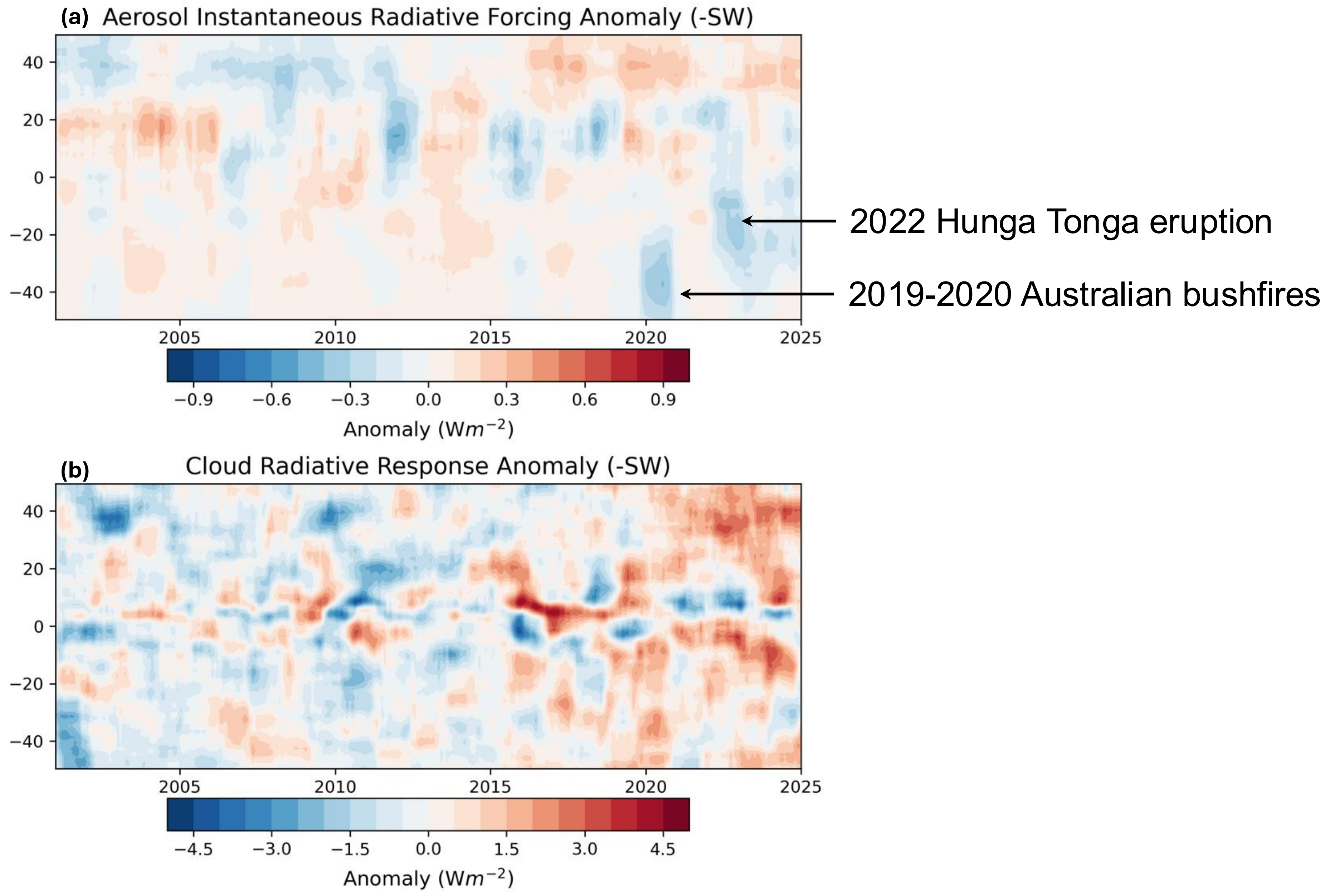
- Largest contributions to the NH–SH difference trend are from changes in temperature and water vapor.
- Trace gas and cloud contributions exhibit hemispheric symmetry.

Attribution of TOA Flux Trends and Trend Differences Using PRP Method (2001-2024)

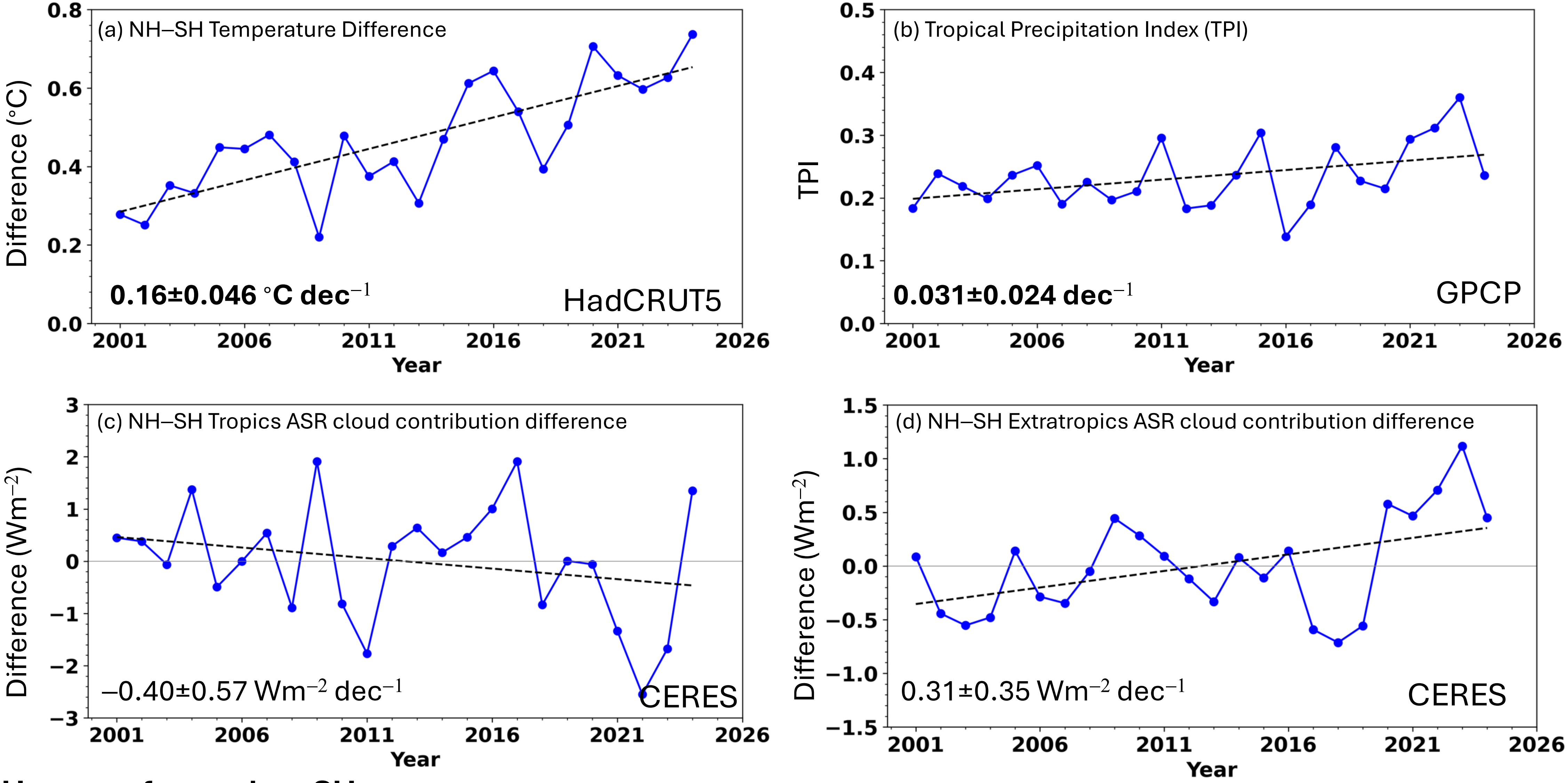


- Rad Resp terms largely cancel one another.
- Majority of the TOT NH–SH difference trend is associated with AER.

Zonal Mean Anomalies in Aerosol-Radiation Interactions and –SW Cloud Radiative Response (2001-2024)



Anomalies in Hemispheric Differences: Surface Temperature, Tropical Precipitation, ASR Cloud Contribution



- **NH warms faster than SH**
- **Progressively more precipitation and cloud in the NH tropics relative to SH tropics**
- **Progressively less cloud in NH extratropics than SH extratropics, cancelling NH–SH difference trend in tropics**

Conclusions

- **NH is getting darker and warmer relative to the SH**
  - ➢ The break in hemispheric symmetry albedo challenges the notion that clouds should naturally compensate for forced hemispheric asymmetries in non-cloud properties

- **Darkening of NH relative to SH is associated with aerosol-radiation interactions, surface albedo, and water vapor changes.**
  - ➢ Cloud changes also contribute, but the magnitude is relatively small
  - ➢ Climate model simulations suggest this may be due to compensation between cloud feedback (stronger in SH) and effective radiative forcing (stronger in NH)

- **Observed hemispheric trends from CERES consistent with expected tropical precipitation changes**
  - ➢ Positive trend in NH–SH tropical precipitation: ITCZ move towards warmer hemisphere
  - ➢ Reduced cloud reflection in NH extratropics relative to SH extratropics