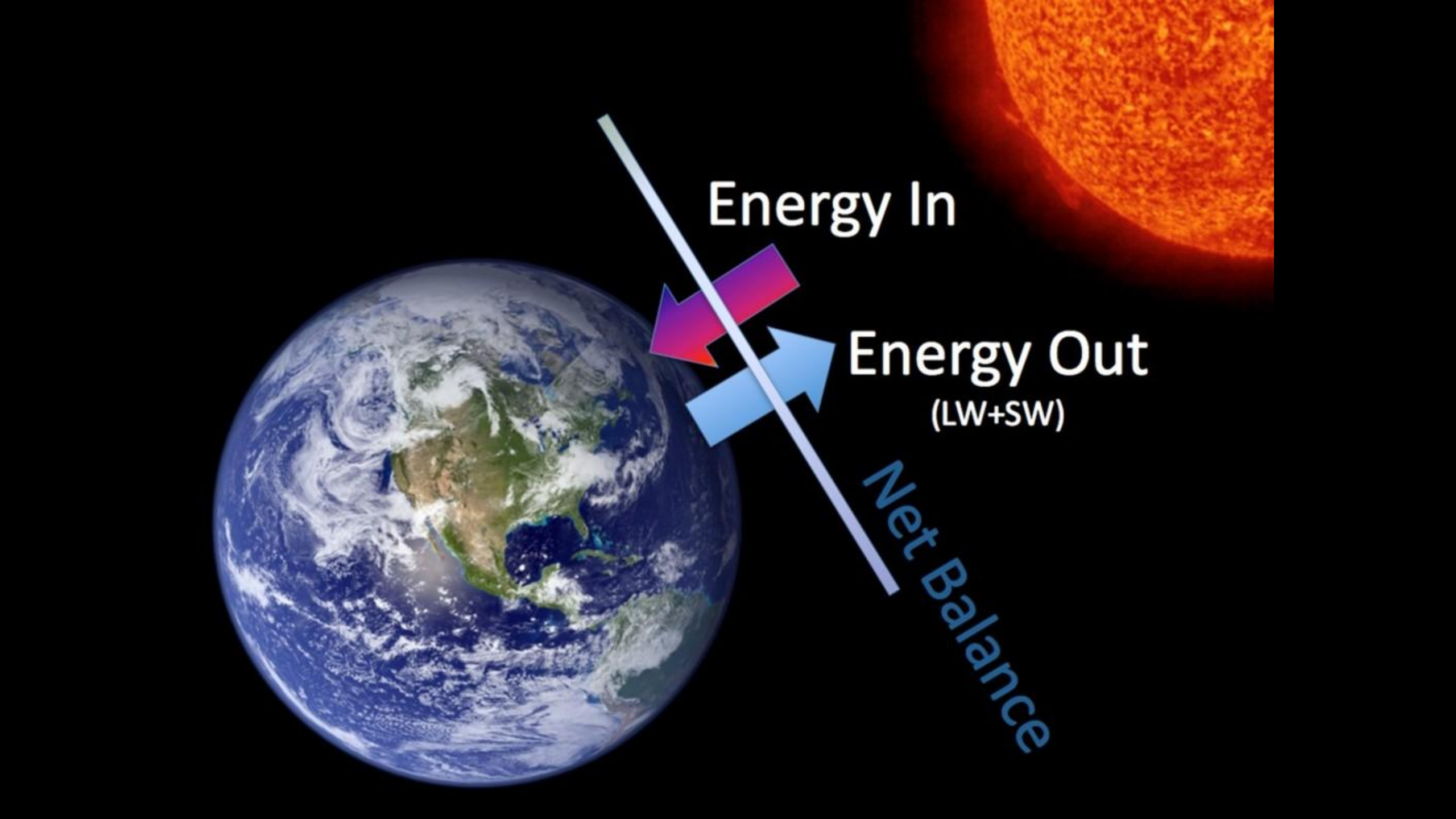
Connecting Atmospheric Composition to Earth's Radiation Budget for Climate Monitoring

Ryan Kramer

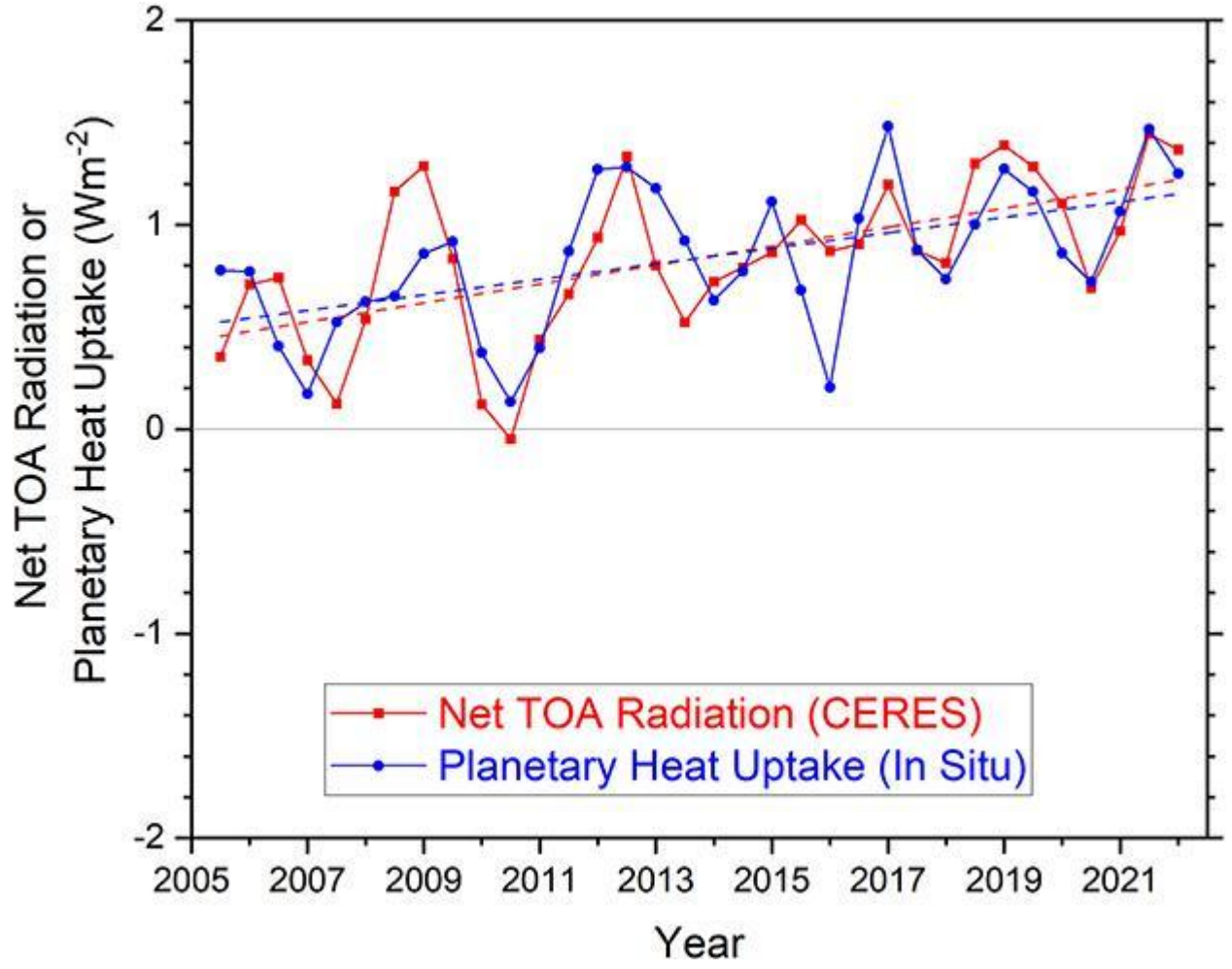
NOAA/Geophysical Fluid Dynamics Laboratory

NOAA GEOxo ACX Science Team Meeting – May 9, 2024

Collaborators: Lazaros Oreopoulos, Haozhe He, Brian Soden, David Paynter, Jing Feng, Ray Menzel, Gunnar Myhre, Keith Shine, Chris Smith, Daeho Jin, Nadir Jeevangee, Dongmin Lee and others!


Energy In
Energy Out
(LW+SW)
Net Balance

Observed Increase in Earth's Energy Imbalance



Schmidt et al. 2023
Loeb et al. 2021

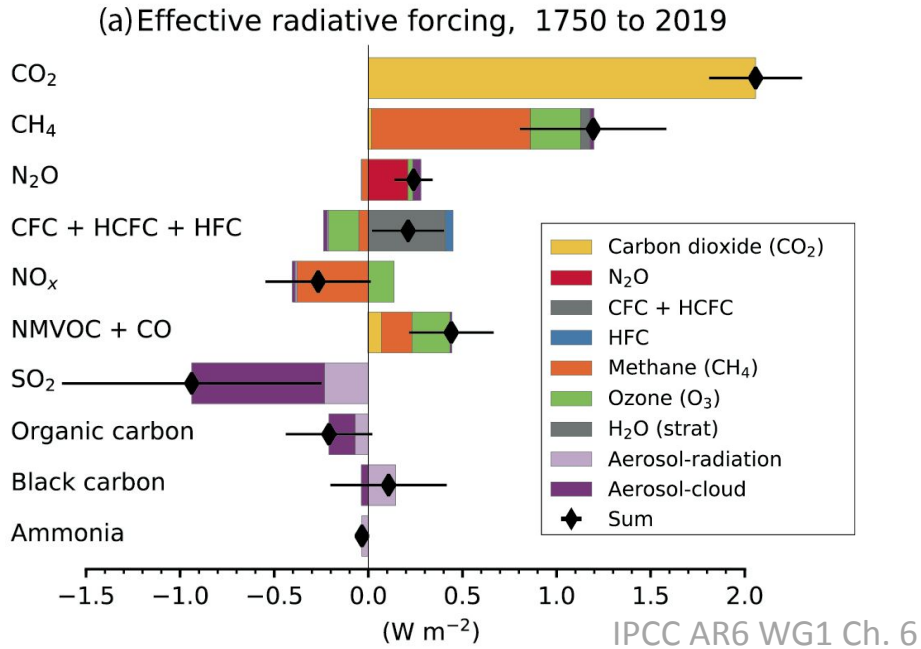
Energy Balance Equation

$$\Delta N = \Delta F + \lambda \Delta T_s$$

Total Radiative Imbalance

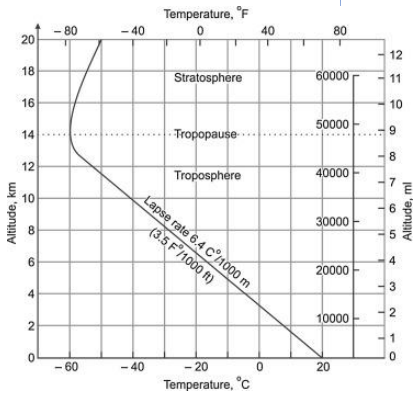
Radiative Forcing

Radiative Responses

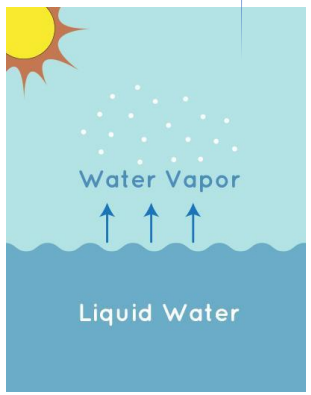


IPCC AR6 WG1 Ch. 6

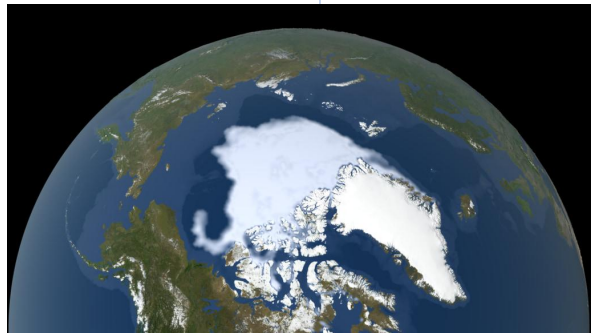
Temperature



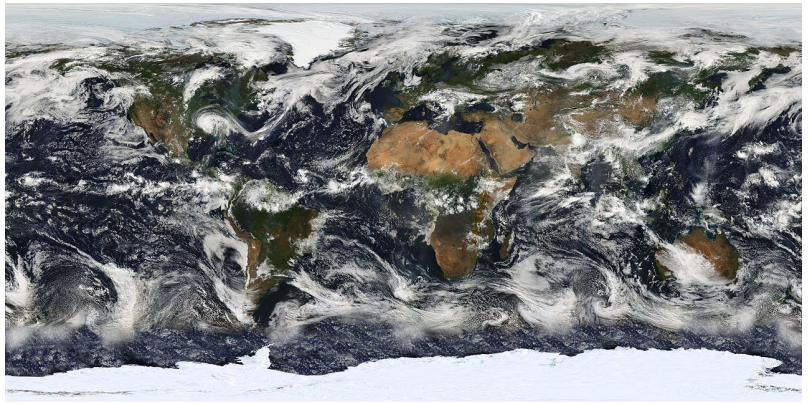
Water Vapor



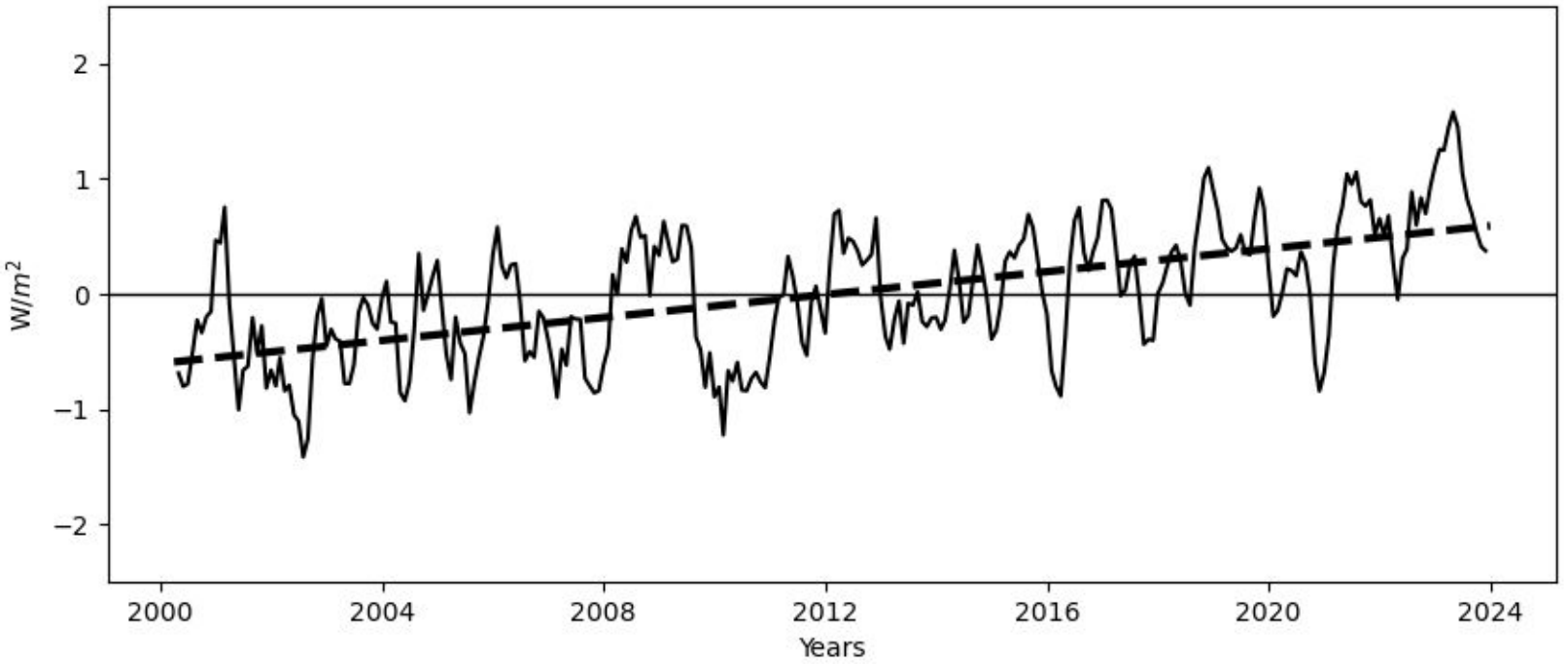
Surface Albedo



Cloud

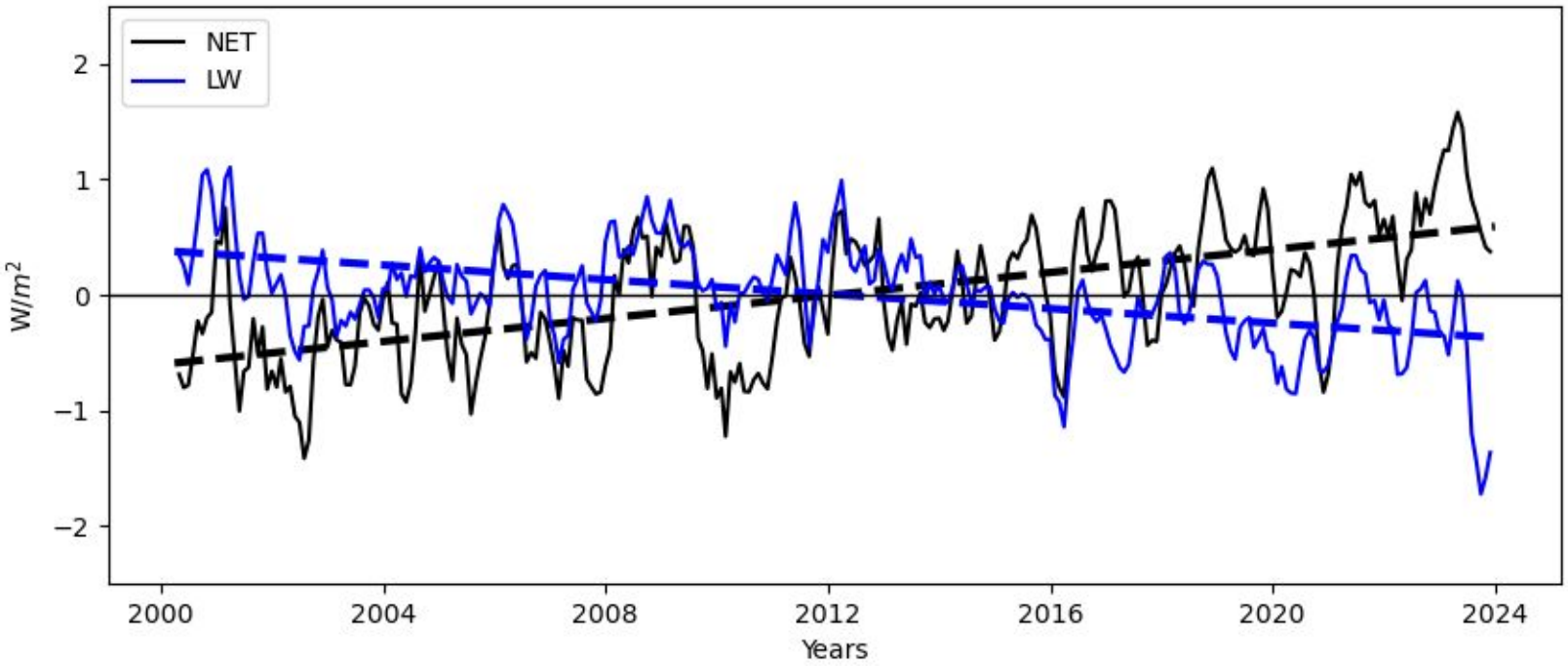


Top-of-Atmosphere
CERES Radiative Flux Anomalies



0.50 +/- 0.11 W/m^2/dec

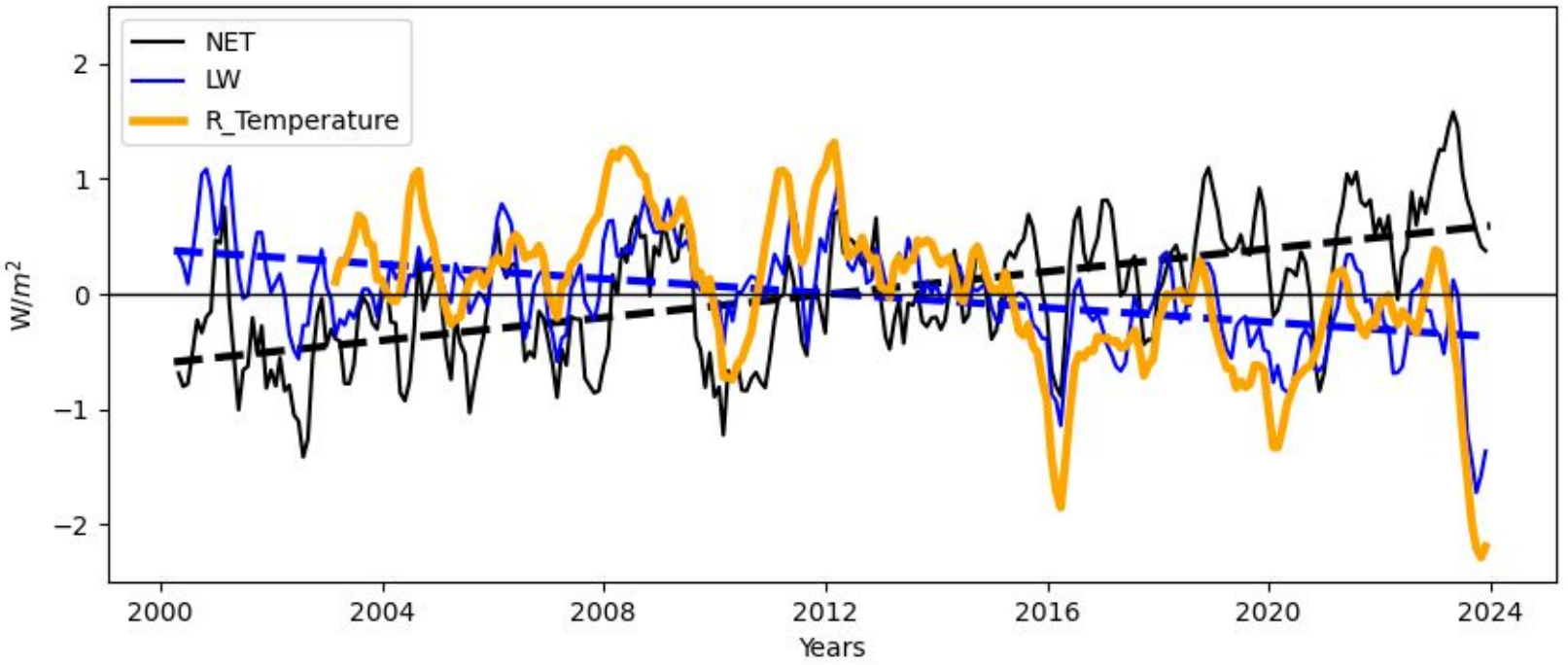
Top-of-Atmosphere
CERES Radiative Flux Anomalies



0.50 +/- 0.11 W/m^2/dec

-0.32 +/- 0.08 W/m^2/dec

Top-of-Atmosphere
CERES Radiative Flux Anomalies

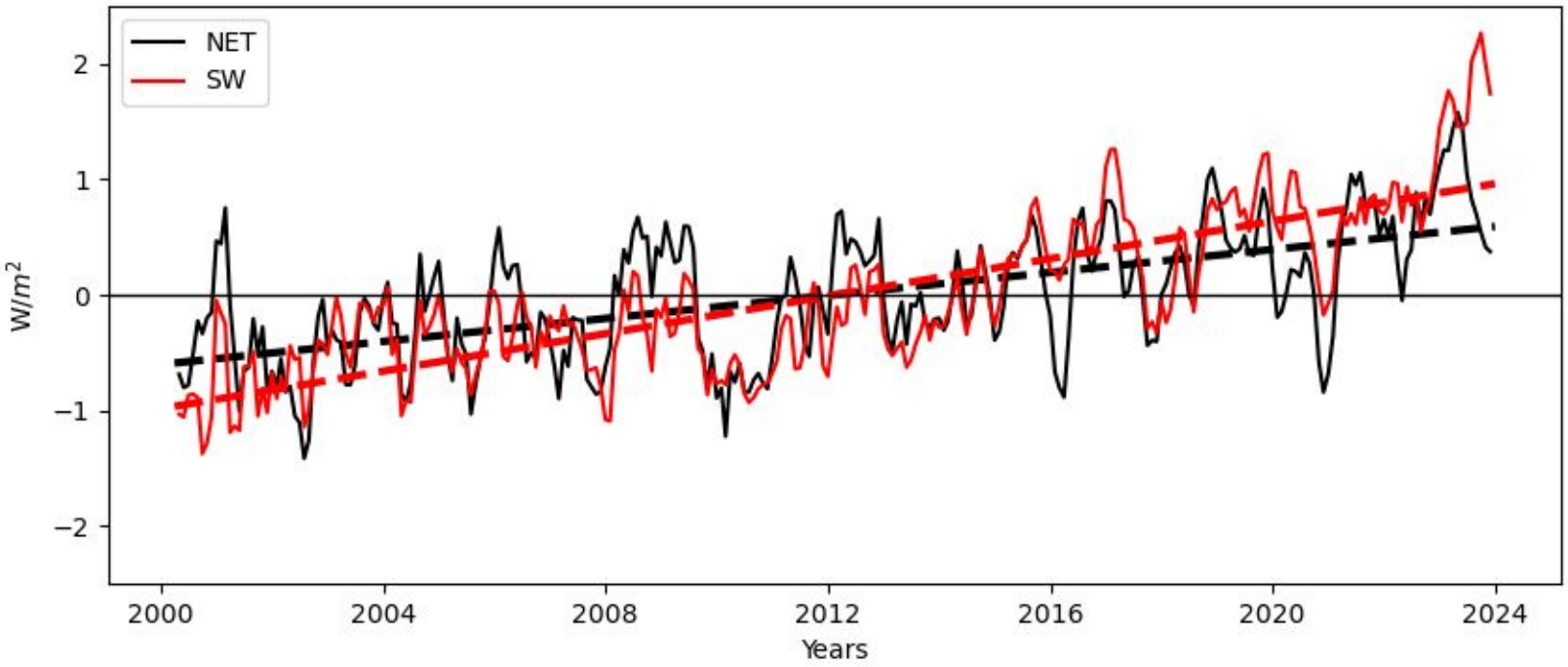


0.50 +/- 0.11 W/m^2/dec

-0.32 +/- 0.08 W/m^2/dec

-0.61 +/- 0.12 W/m^2/dec

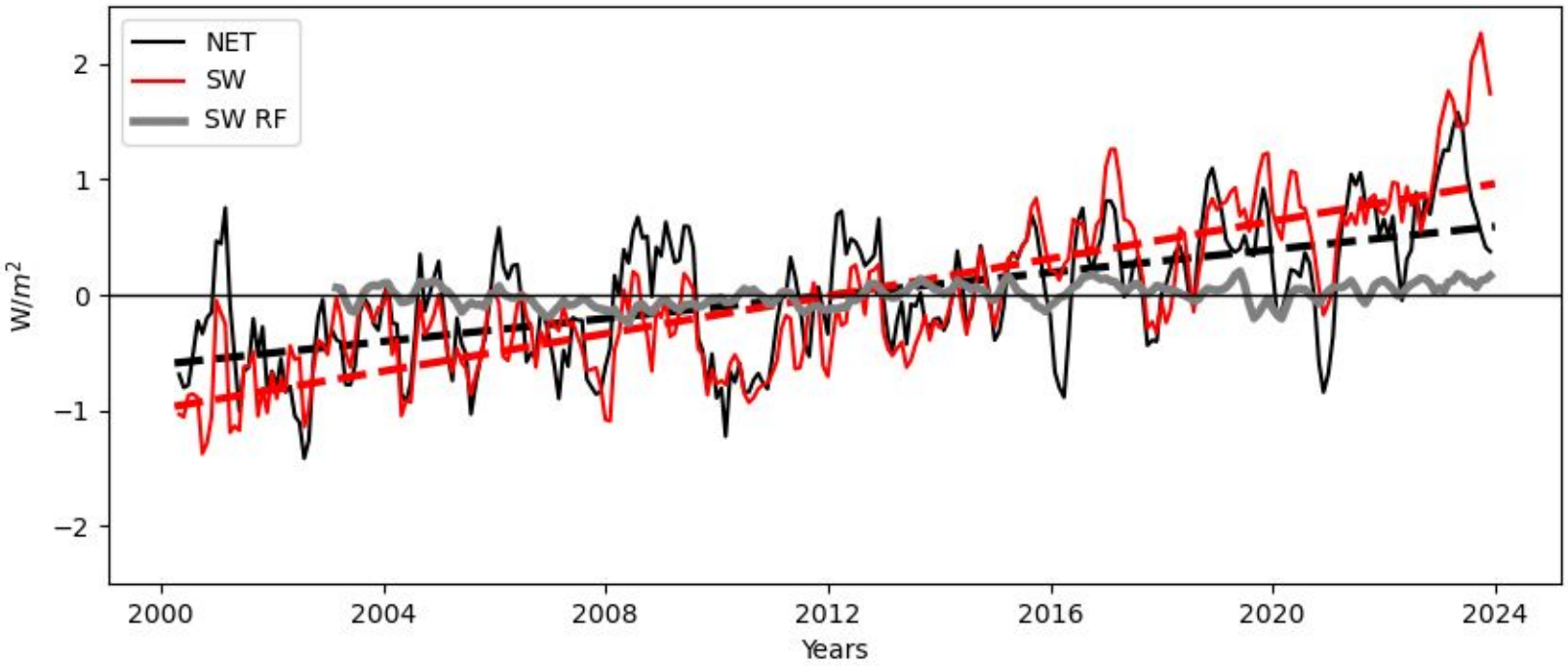
Top-of-Atmosphere
CERES Radiative Flux Anomalies



0.81 +/- 0.10 W/m^2/dec

0.50 +/- 0.11 W/m^2/dec

Top-of-Atmosphere
CERES Radiative Flux Anomalies

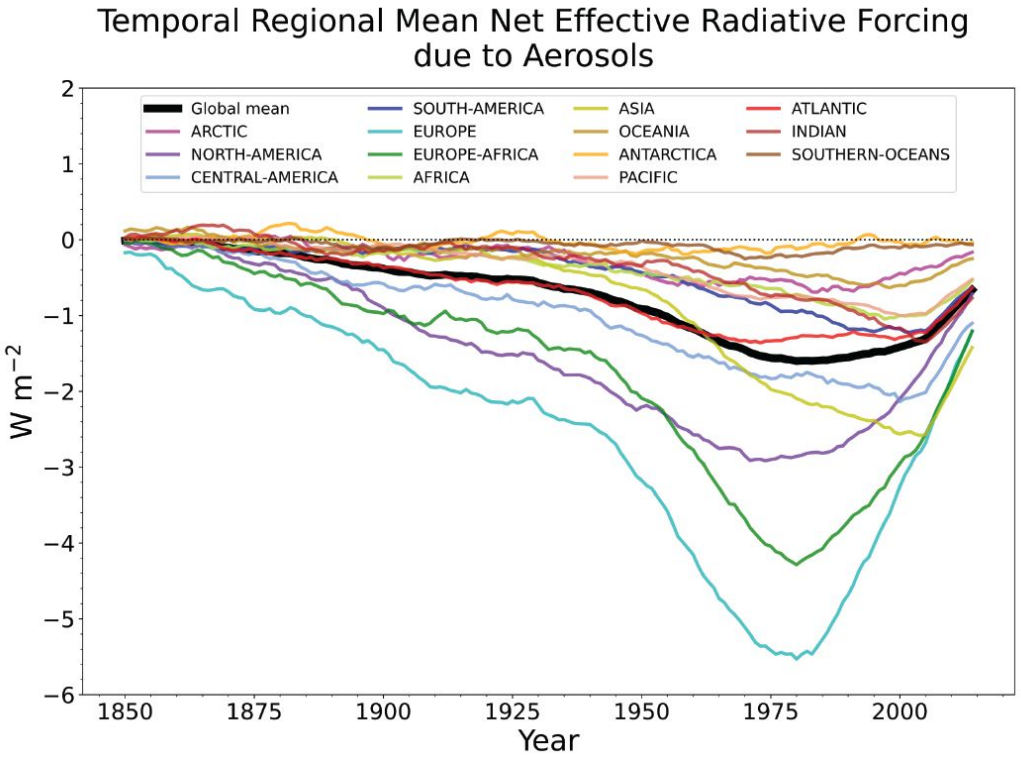


0.81 +/- 0.10 W/m^2/dec

0.50 +/- 0.11 W/m^2/dec

0.06 +/- 0.002 W/m^2/dec

Reversal of Global Aerosol Forcing Trends



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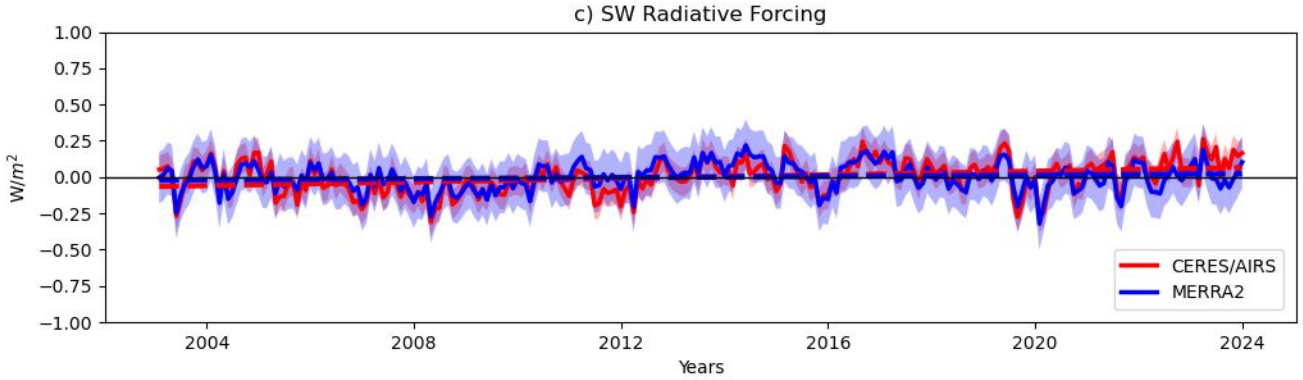
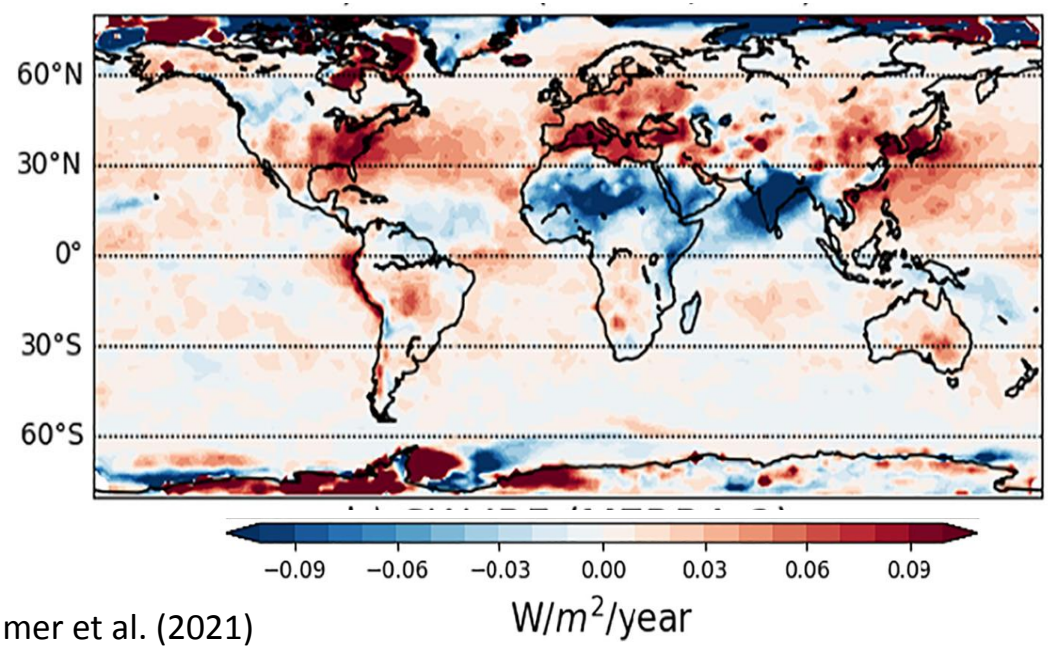


Trend = 0.06 +/- 0.002 W/m^2/dec

Local Trends in Shortwave Radiative Forcing

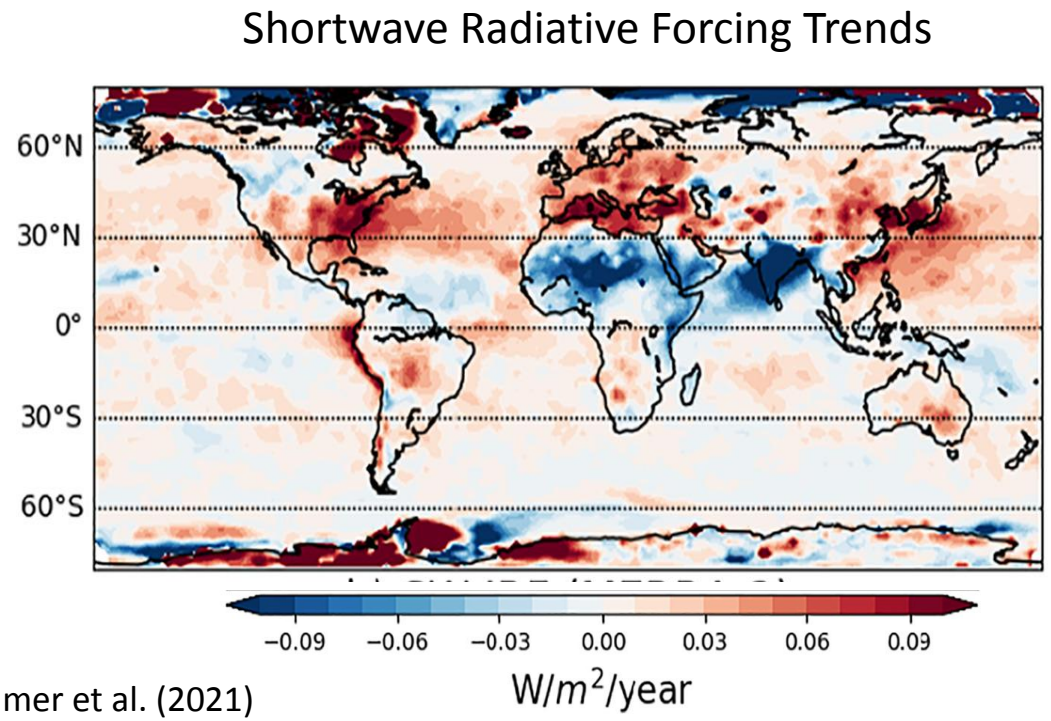
Shortwave Radiative Forcing Trends



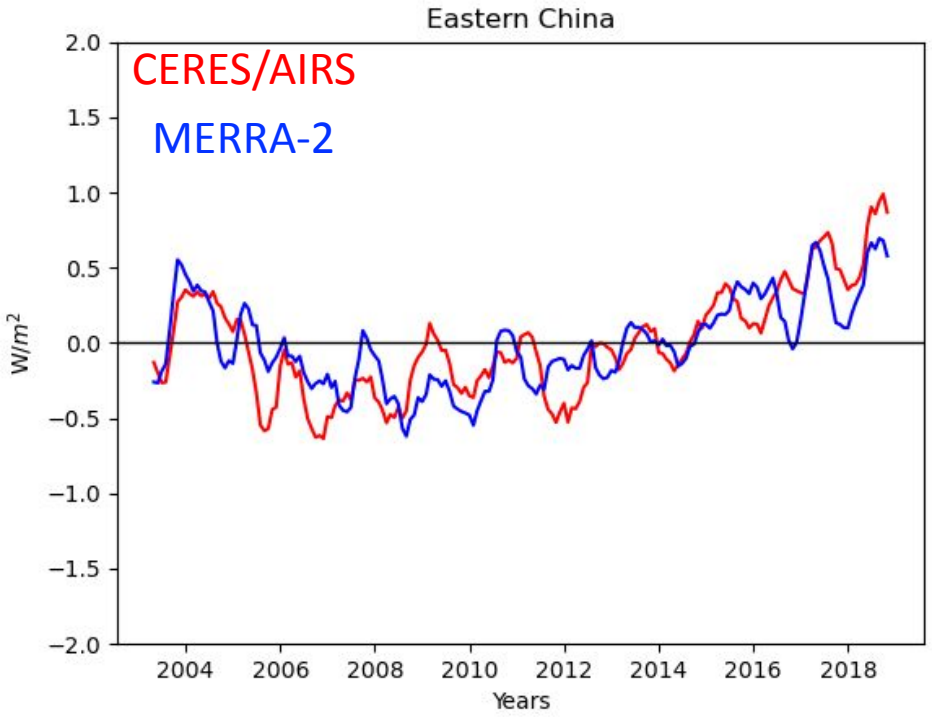
Kramer et al. (2021)

Red = Radiative Heating **and** **Blue = Radiative Cooling**

Local Trends in Shortwave Radiative Forcing

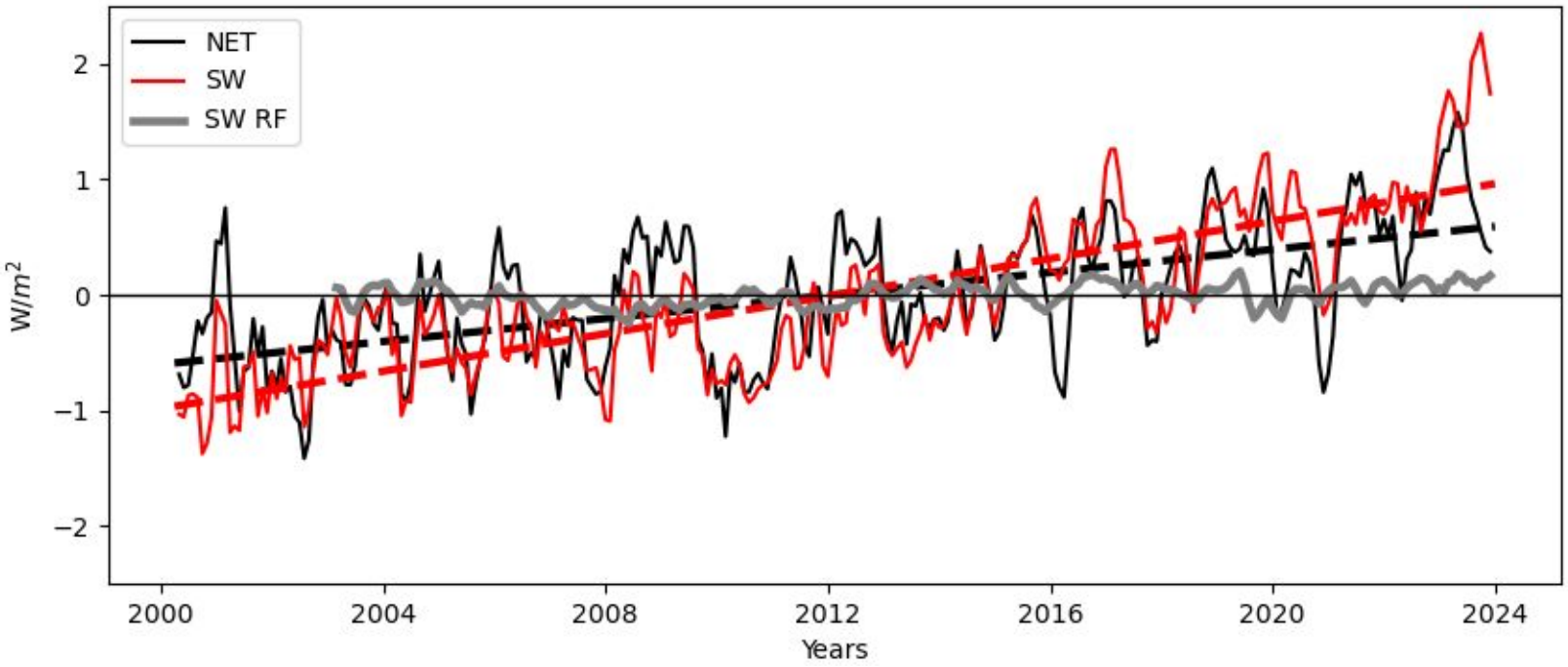


Kramer et al. (2021)



Red = Radiative Heating and Blue = Radiative Cooling

Top-of-Atmosphere
CERES Radiative Flux Anomalies

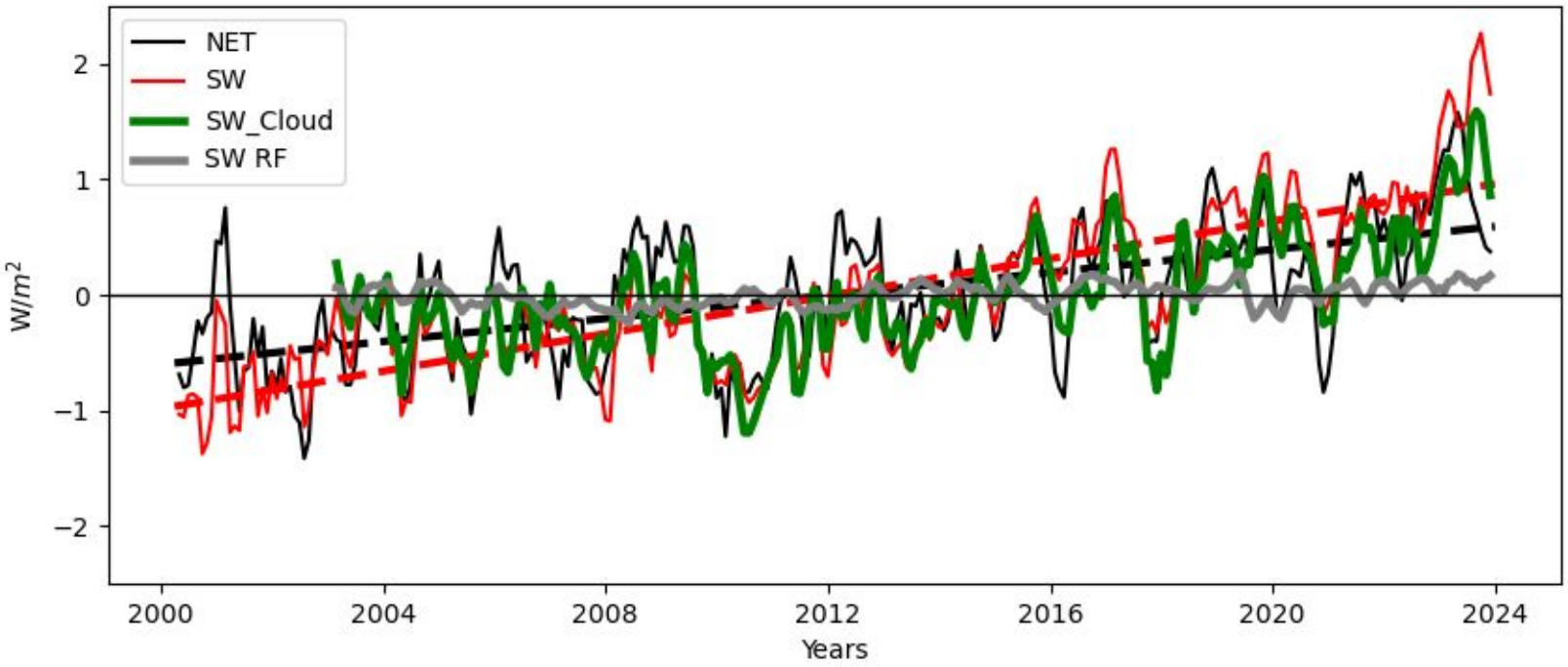


0.81 +/- 0.10 W/m^2/dec

0.50 +/- 0.11 W/m^2/dec

0.06 +/- 0.002 W/m^2/dec

Top-of-Atmosphere
CERES Radiative Flux Anomalies



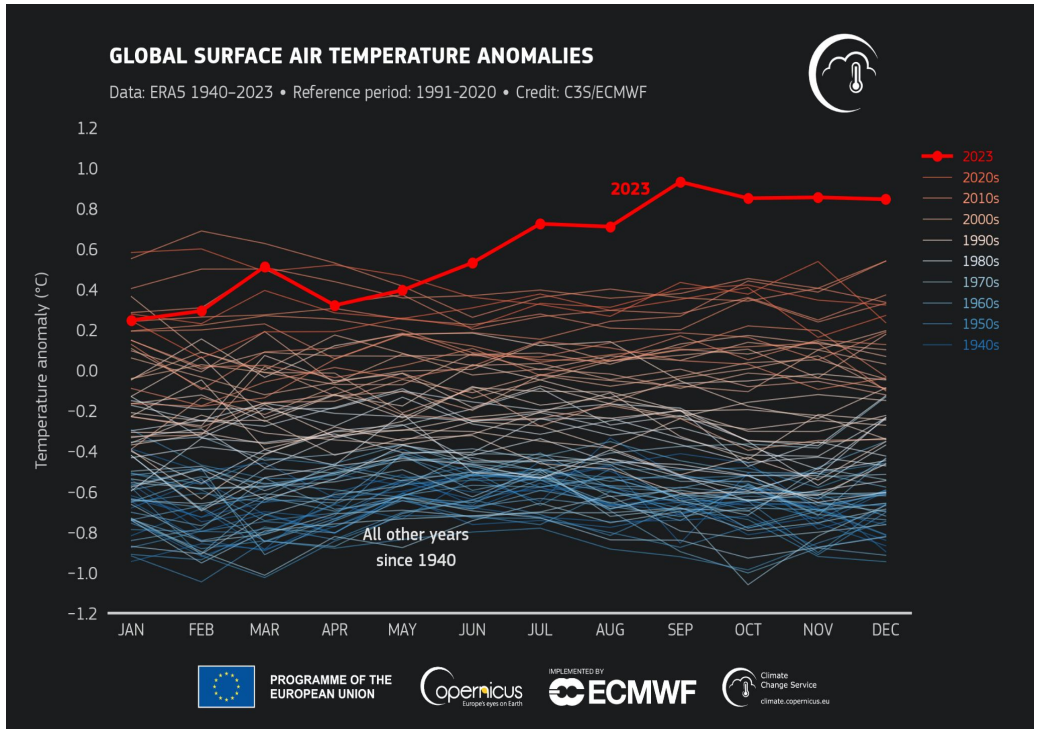
0.81 +/- 0.10 W/m^2/dec
0.52 +/- 0.10 W/m^2/dec
0.50 +/- 0.11 W/m^2/dec

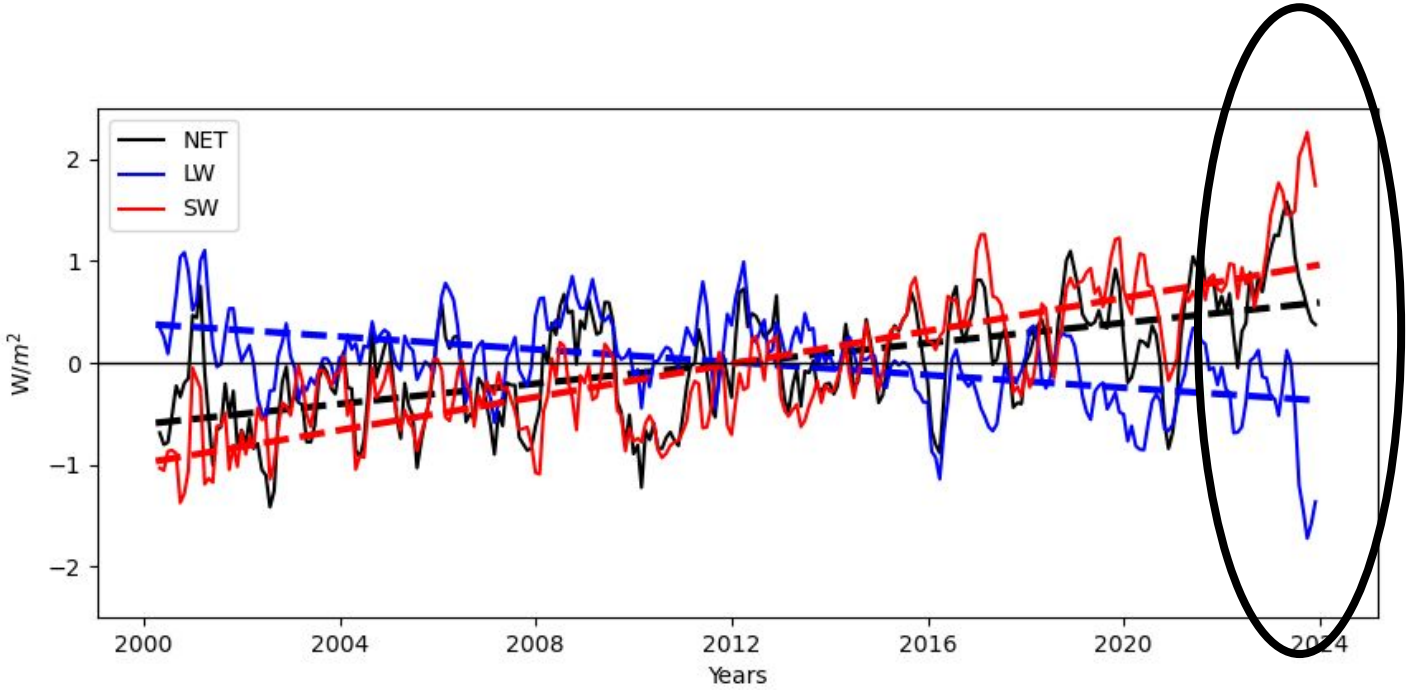
0.06 +/- 0.002 W/m^2/dec

Aerosol-Cloud Radiative Forcing

Raghuraman et al. 2023

Record-Breaking 2023

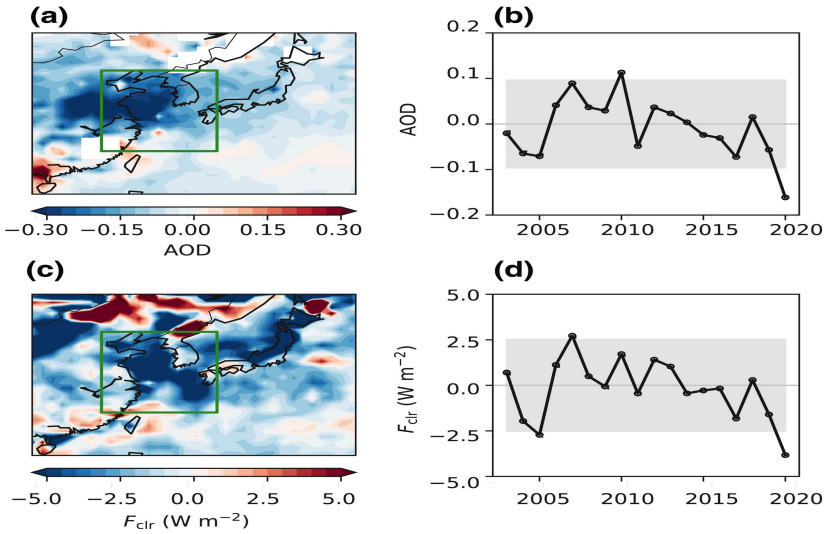




EU/Copernicus

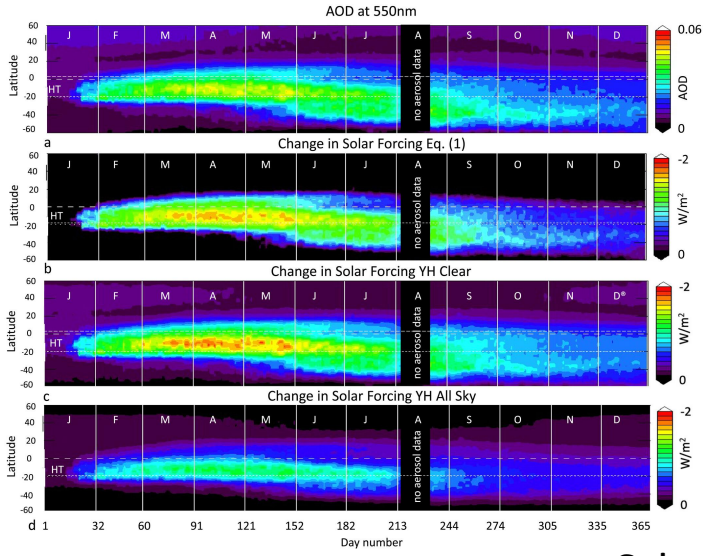
Event-Based Monitoring of the Energy Budget

COVID-19



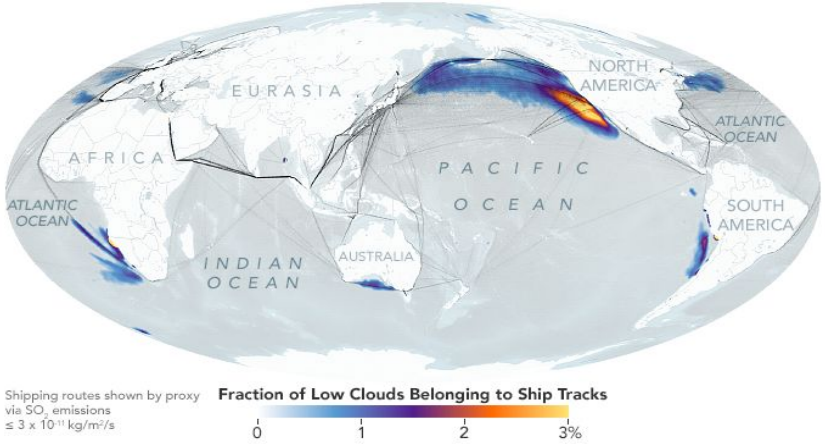
Ming et al. 2021

Honga-Tonga



Schoeberl et al. 2023

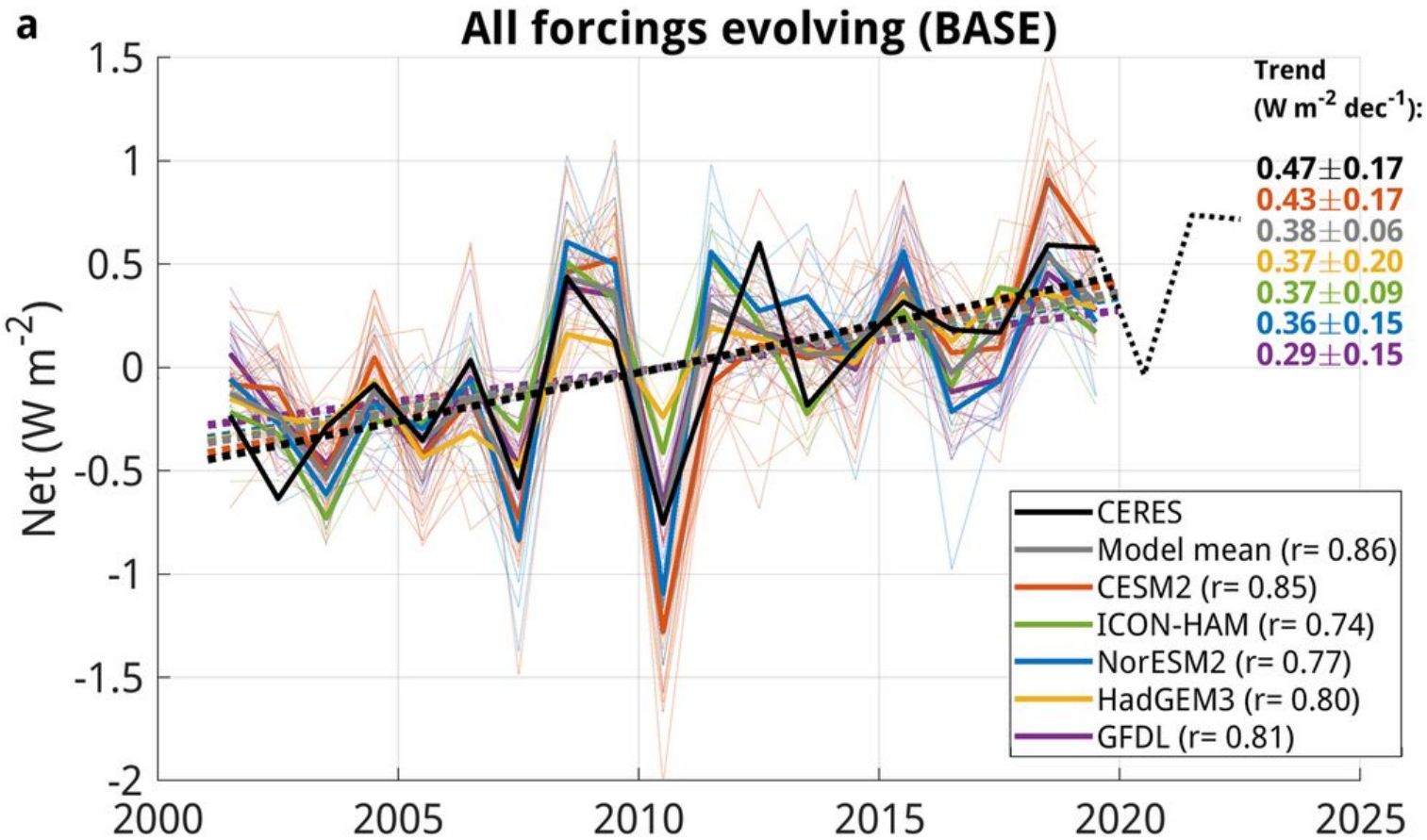
Ship-Tracks

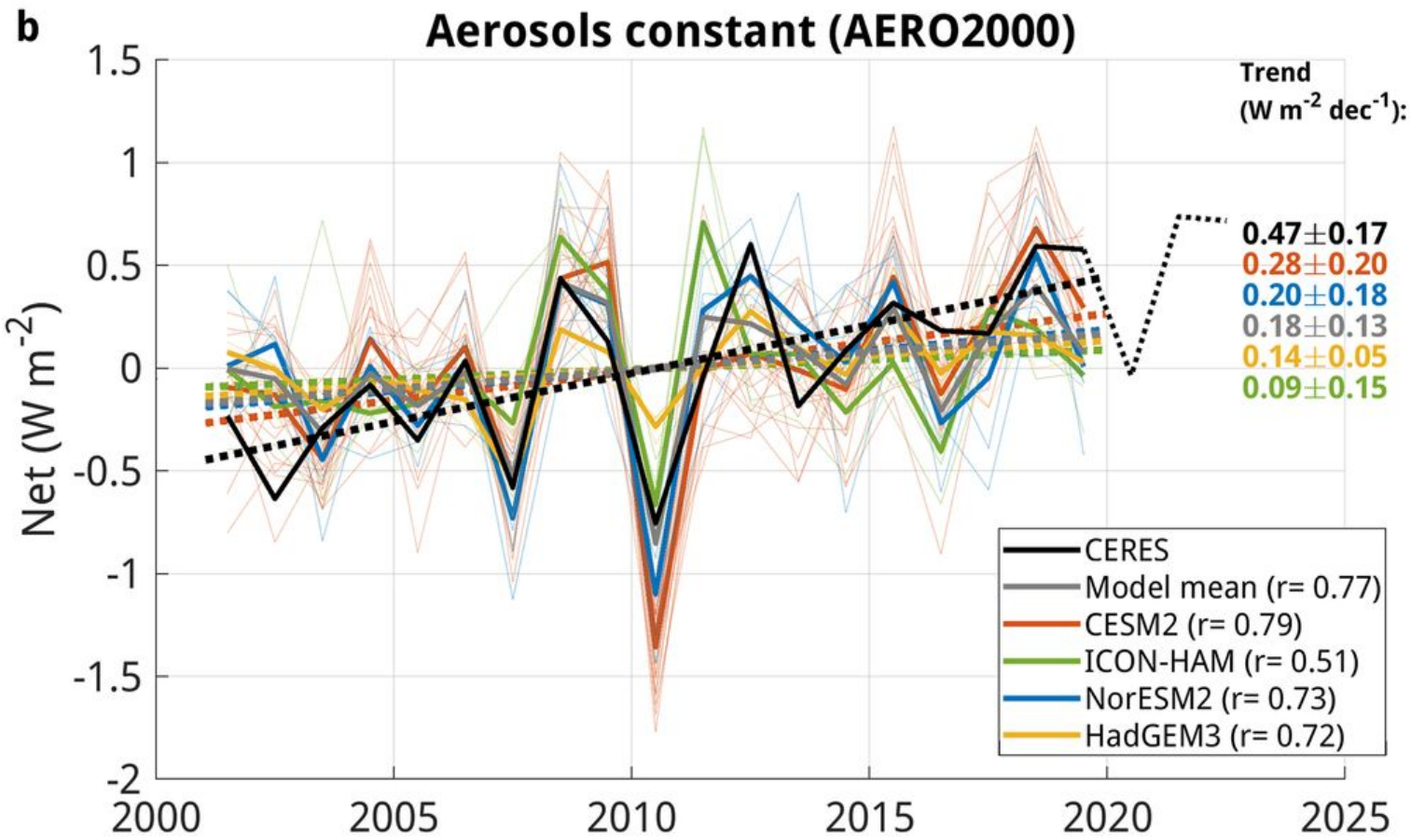


NASA/Earth Observatory

Conclusions

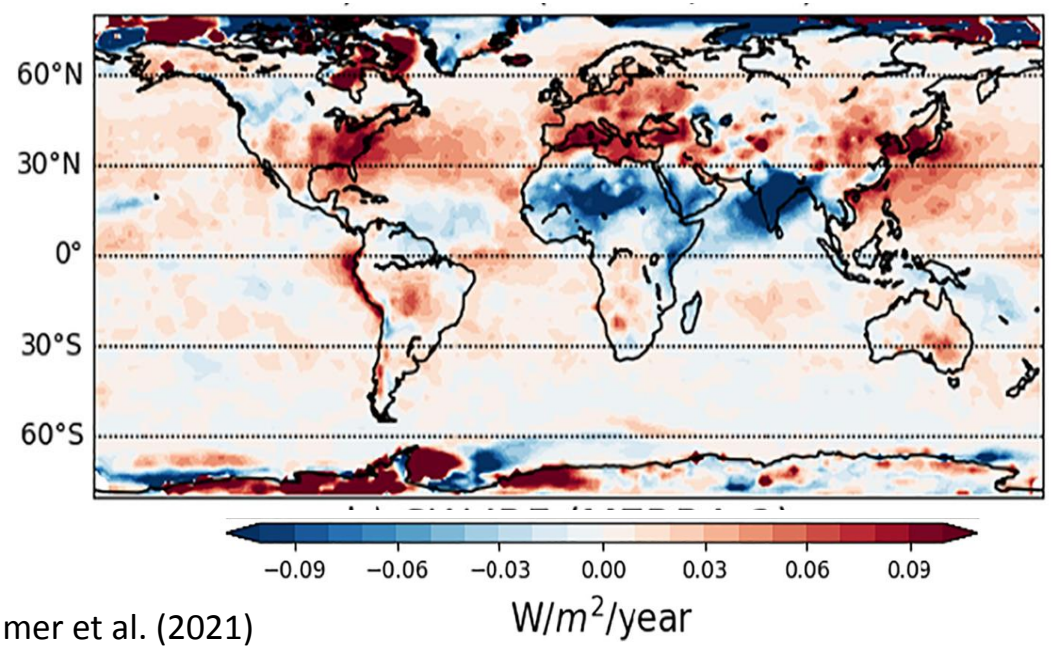
- Considerable growth in Earth's radiative energy imbalance as observed from space
  - Largely being driven by increasing Shortwave absorption with strong global and regional contributions from changing aerosol emissions
- Evidence suggests aerosol reductions are now a net heating effect on global climate
- Increasing role for "real time" detection and attribution of Radiation Budget Changes associated with individual climate events


a
All forcings evolving (BASE)
Net (W m-2)
1.5
1
0.5
0
-0.5
-1
-1.5
-2
2000
2005
2010
2015
2020
2025
Trend
(W m-2 dec-1):
0.47±0.17
0.43±0.17
0.38±0.06
0.37±0.20
0.37±0.09
0.36±0.15
0.29±0.15
CERES
Model mean (r= 0.86)
CESM2 (r= 0.85)
ICON-HAM (r= 0.74)
NorESM2 (r= 0.77)
HadGEM3 (r= 0.80)
GFDL (r= 0.81)

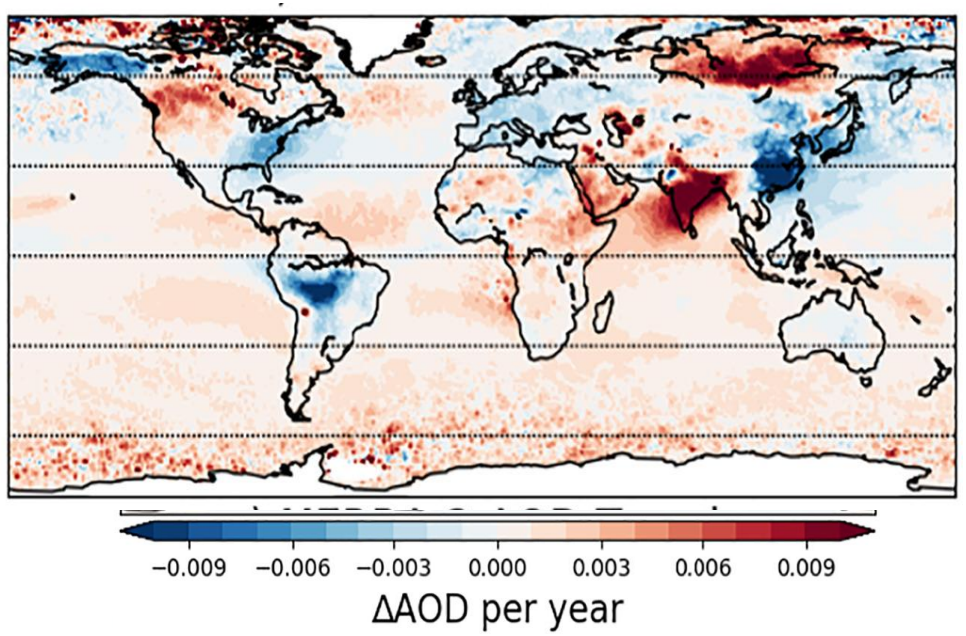

b
Aerosols constant (AERO2000)
Net (W m-2)
1.5
1
0.5
0
-0.5
-1
-1.5
-2
2000
2005
2010
2015
2020
2025
Trend
(W m-2 dec-1):
0.47±0.17
0.28±0.20
0.20±0.18
0.18±0.13
0.14±0.05
0.09±0.15
CERES
Model mean (r= 0.77)
CESM2 (r= 0.79)
ICON-HAM (r= 0.51)
NorESM2 (r= 0.73)
HadGEM3 (r= 0.72)

Local Trends in Shortwave Radiative Forcing

Shortwave Radiative Forcing Trends



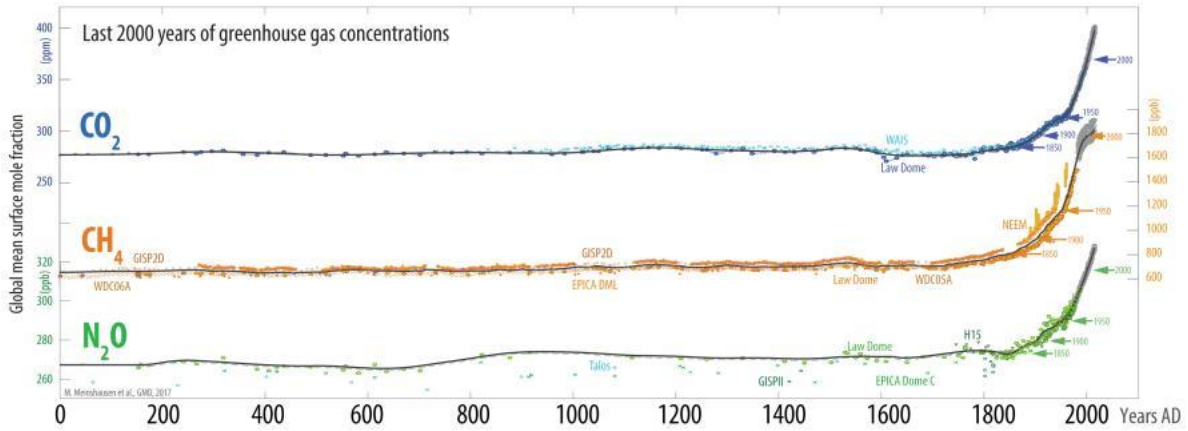
MODIS Aerosol Optical Depth Trends



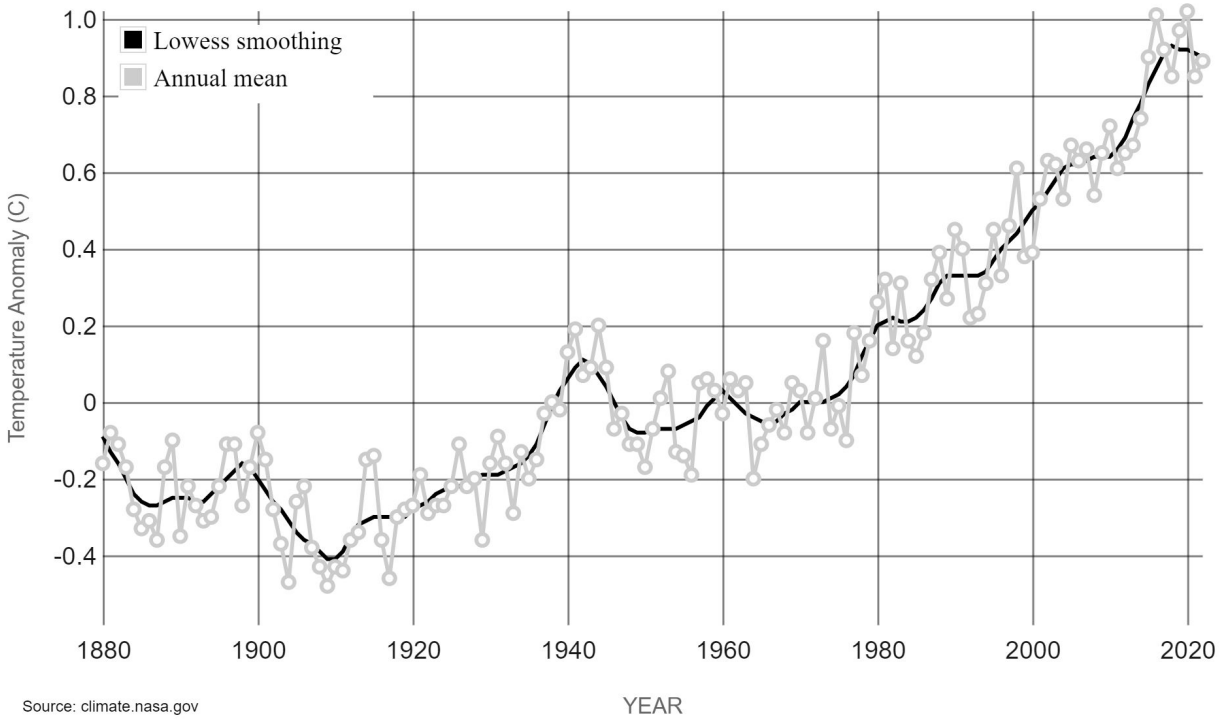
Kramer et al. (2021)

Red = Radiative Heating **and** **Blue = Radiative Cooling**

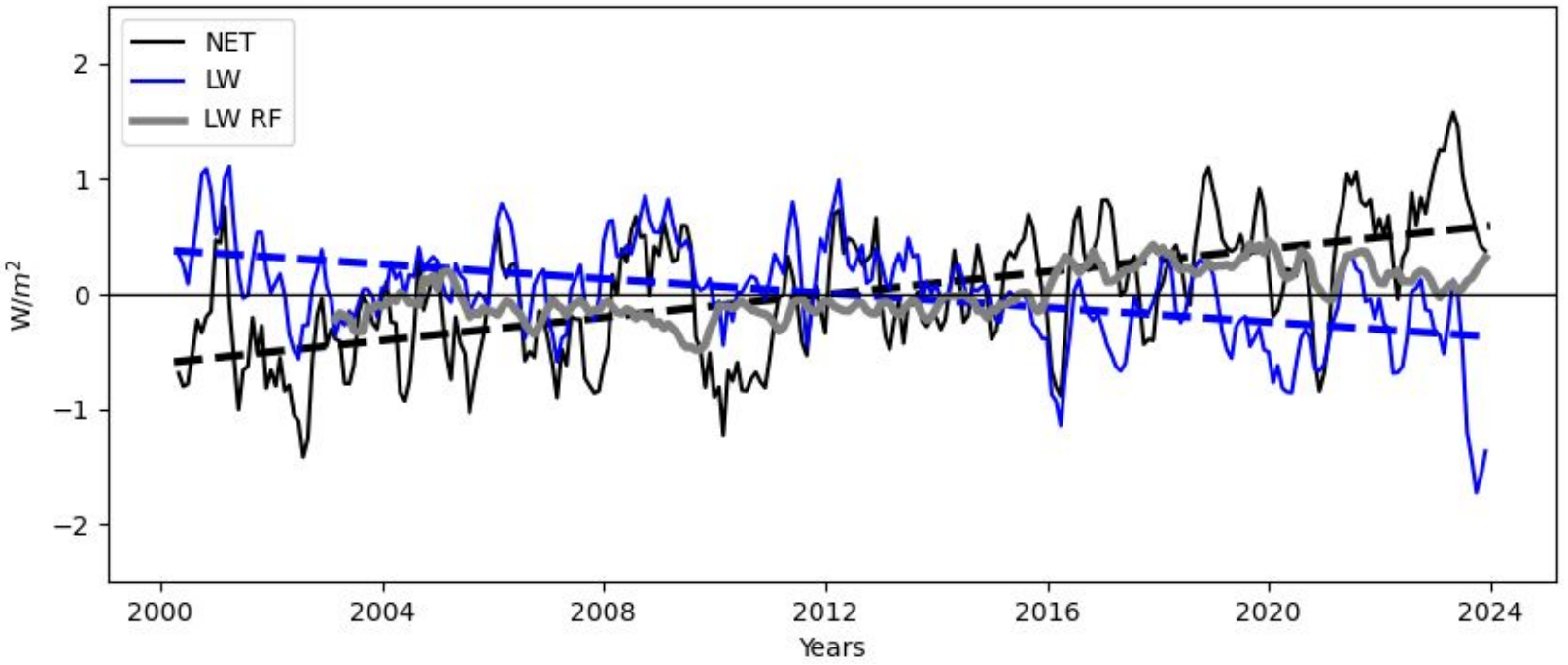
Connecting Changing Atmospheric Composition to Rising Temperatures



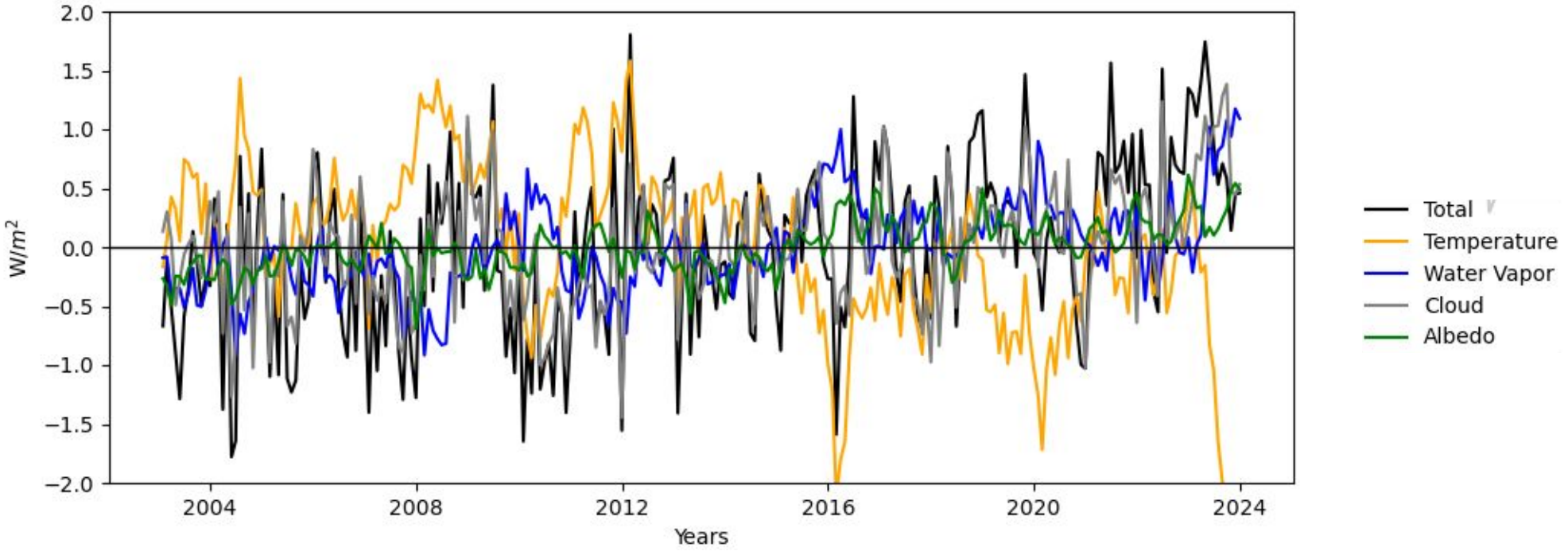
Meinhausen et al. (2017)



Top-of-Atmosphere
CERES Radiative Flux Anomalies

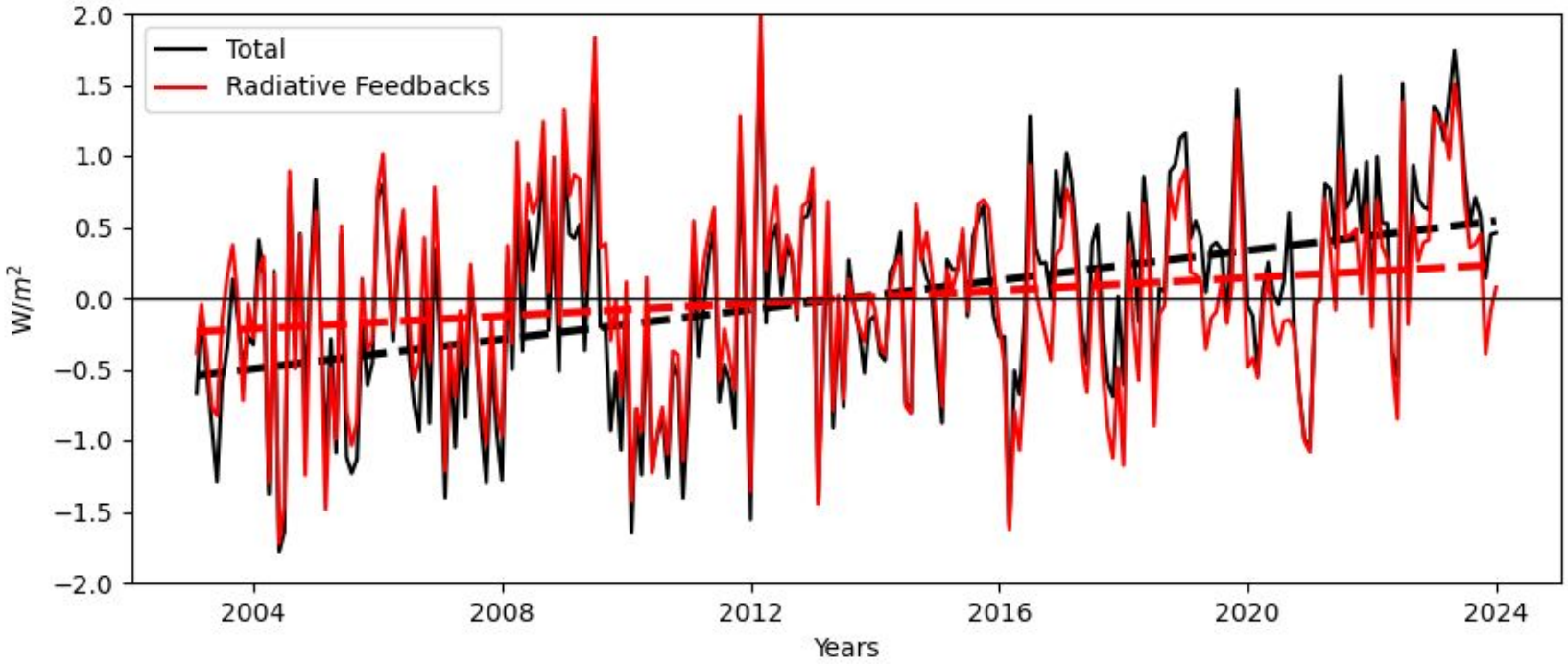


Top-of-Atmosphere
CERES Net Radiative Flux Anomalies



Longwave (LW) + Shortwave (SW)

Top-of-Atmosphere
CERES Net Radiative Flux Anomalies

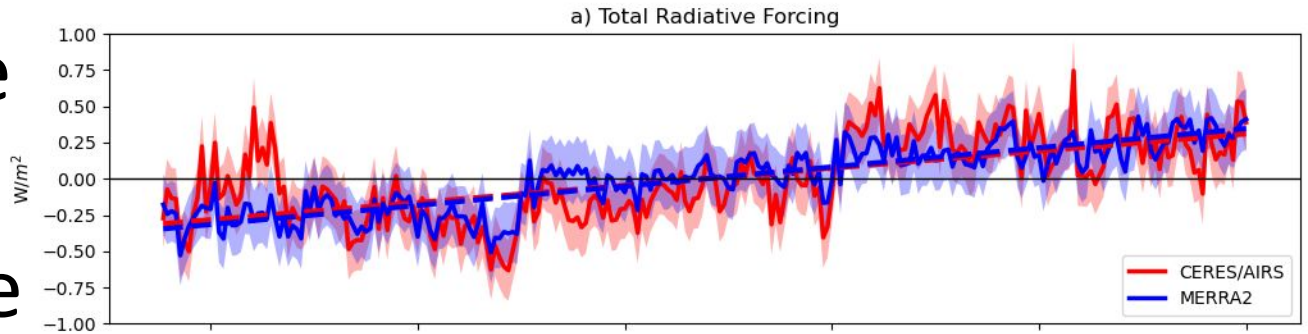


0.22 +/- 0.15 W/m^2/dec

Longwave (LW) + Shortwave (SW)

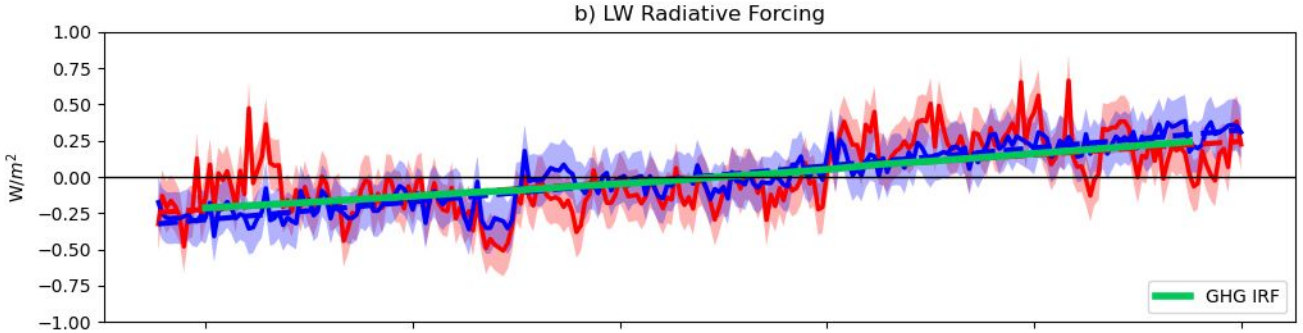
Observed Radiative Forcing

Longwave + Shortwave



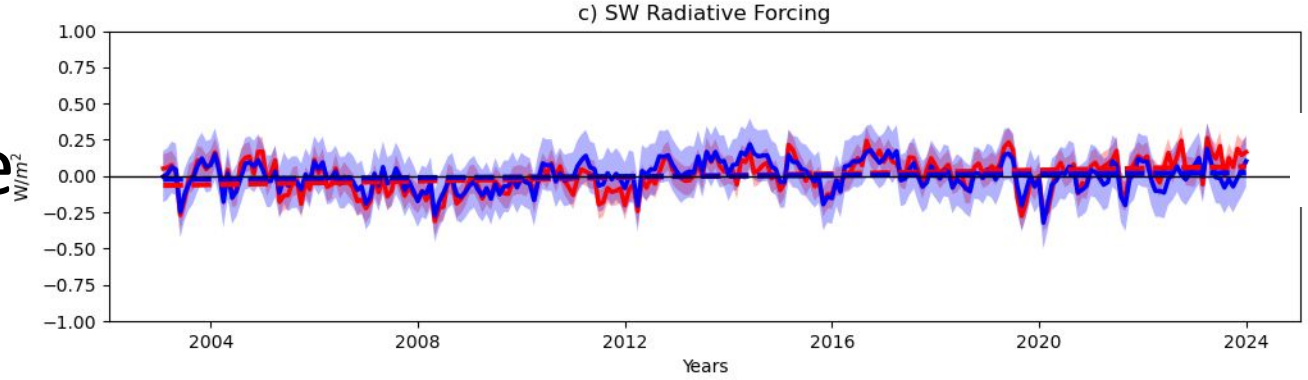
0.29 +/- 0.05 W/m^2/dec

Longwave



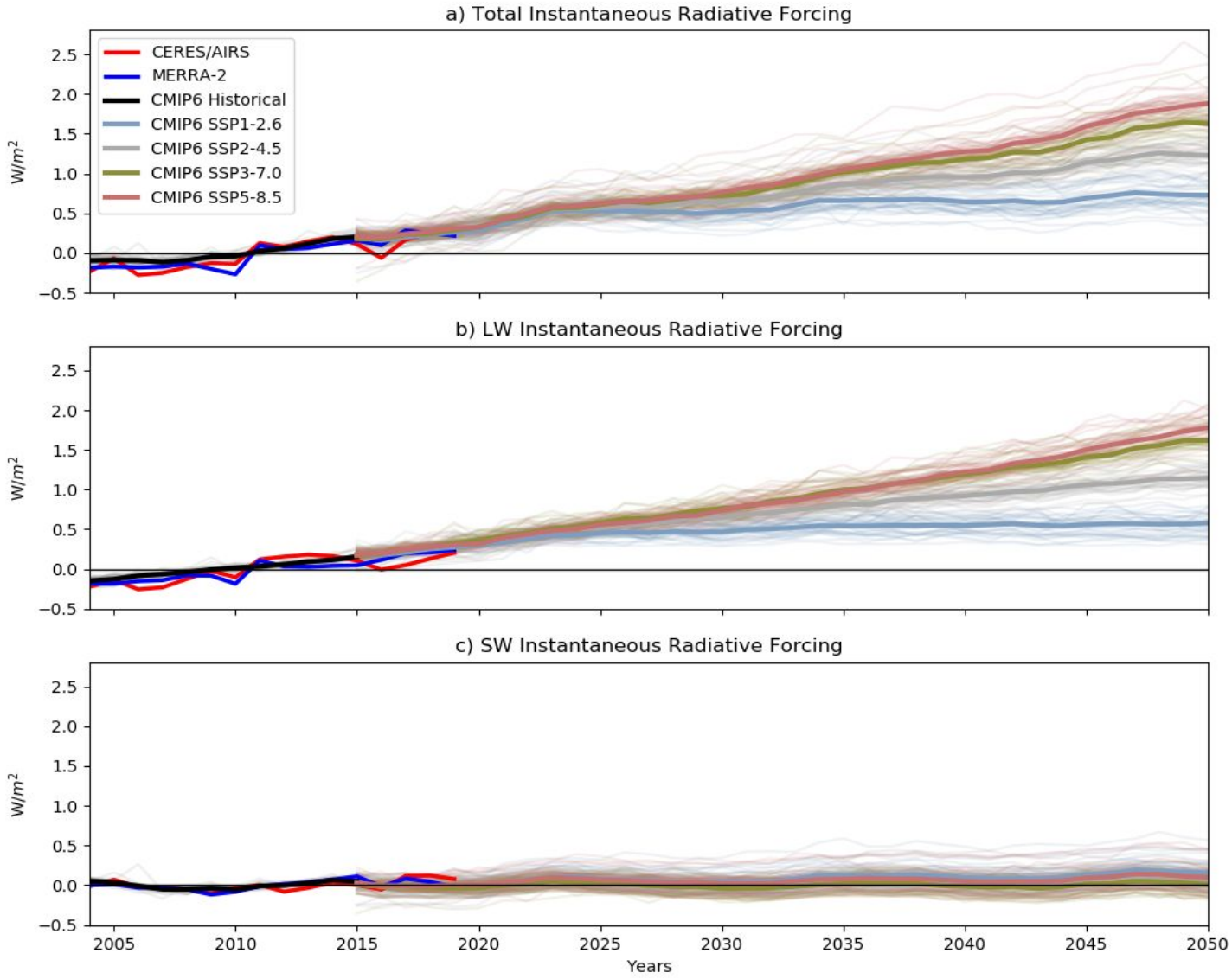
0.23 +/- 0.04 W/m^2/dec

Shortwave

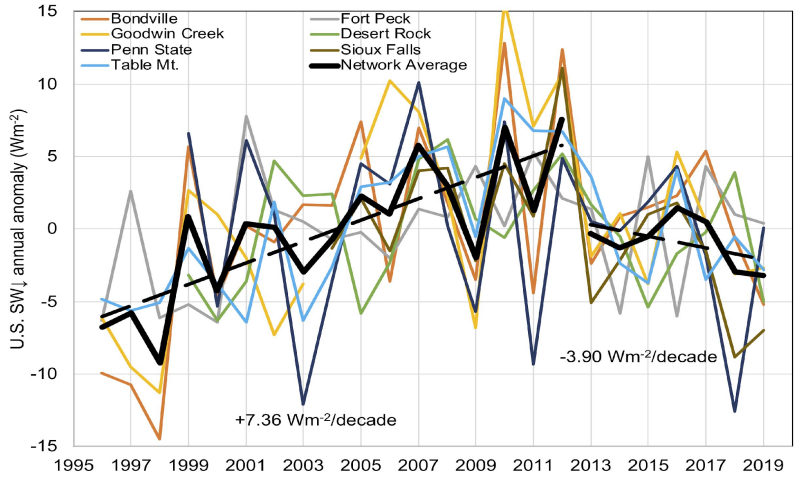


0.06 +/- 0.003 W/m^2/dec

Tracking our Impact on the Climate



Why measure radiative fluxes? Solar radiation (sunlight) drives weather and climate. The net radiation from **incoming and outgoing shortwave and longwave radiation** at the surface provides the energy for SE, LE, and GH, and subsequent turbulence, vertical mixing, and cloud formation, with feedbacks on the radiative fluxes.



Long-record allows correlation between decadal trends in shortwave radiation seen across the U.S. and connection with SST. (Augustine & Hodges, 2021)

SURFRAD Network provides high quality observations in radiative fluxes, clouds, aerosols, and land changes