Framework for an Earth Radiation Budget Satellite Mission: An Imperative to Track and Understand Earth's Energy Imbalance

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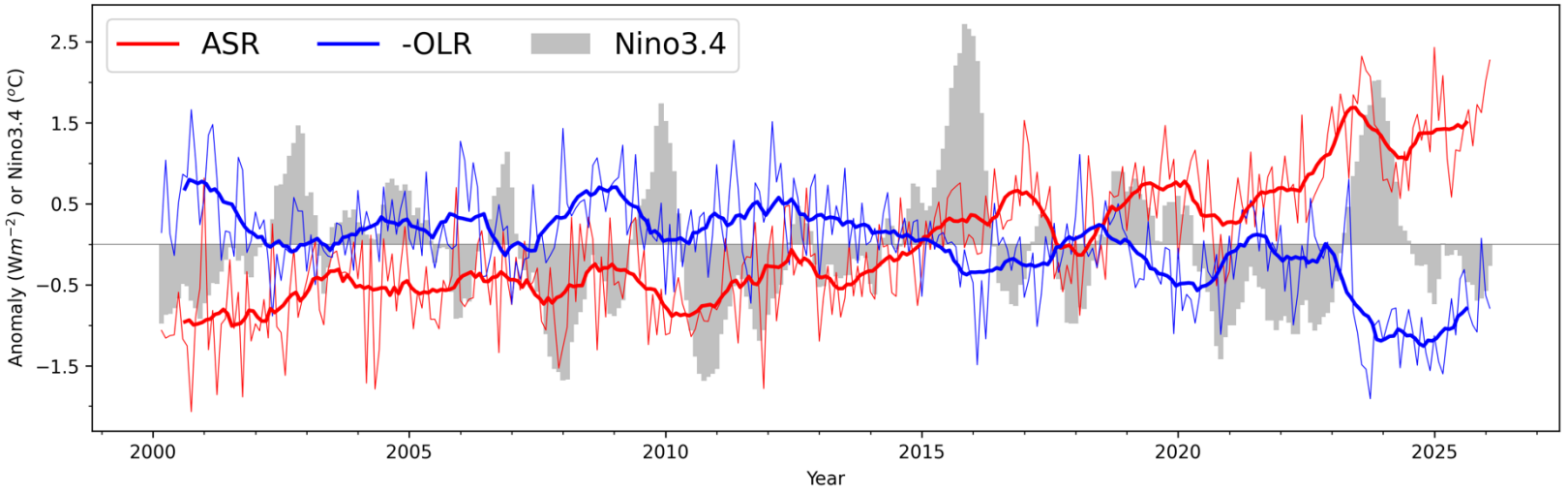
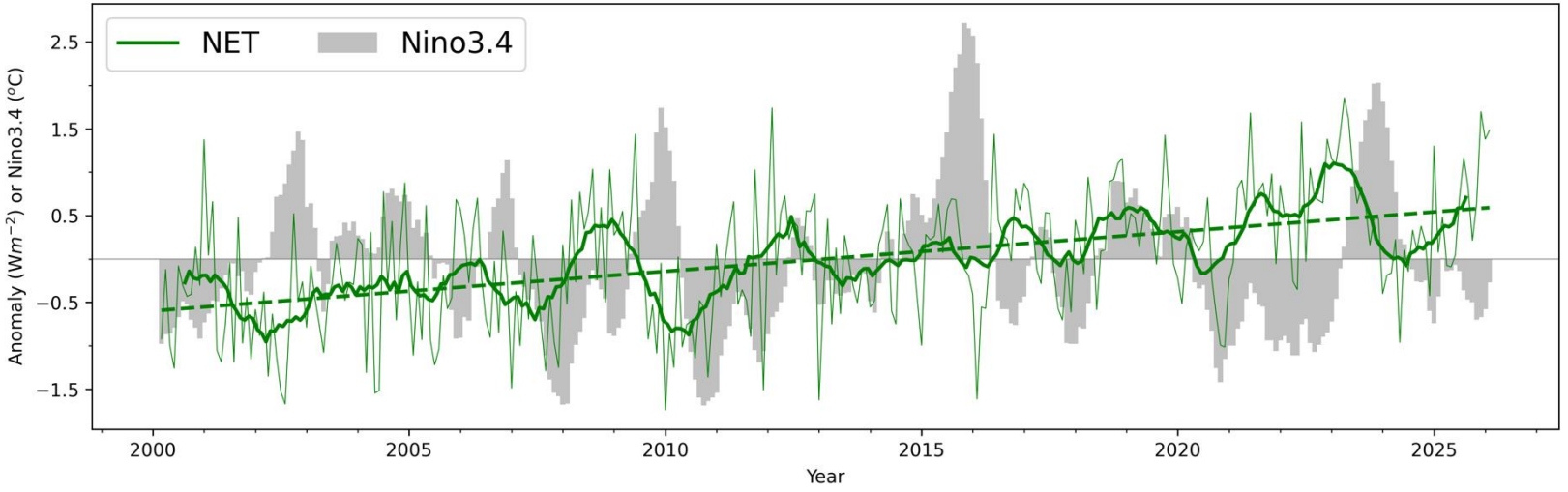
2nd GEWEX Earth's Energy Imbalance Assessment Workshop, June 1-5, 2026, Pasadena, CA

Global Mean All-Sky TOA Flux Anomalies (CERES EBAF Ed4.2.1; 03/2000–02/2026)





Trends (Wm^{-2} per decade; 2.5-97.5% CI)

ASR: 0.89 ± 0.22

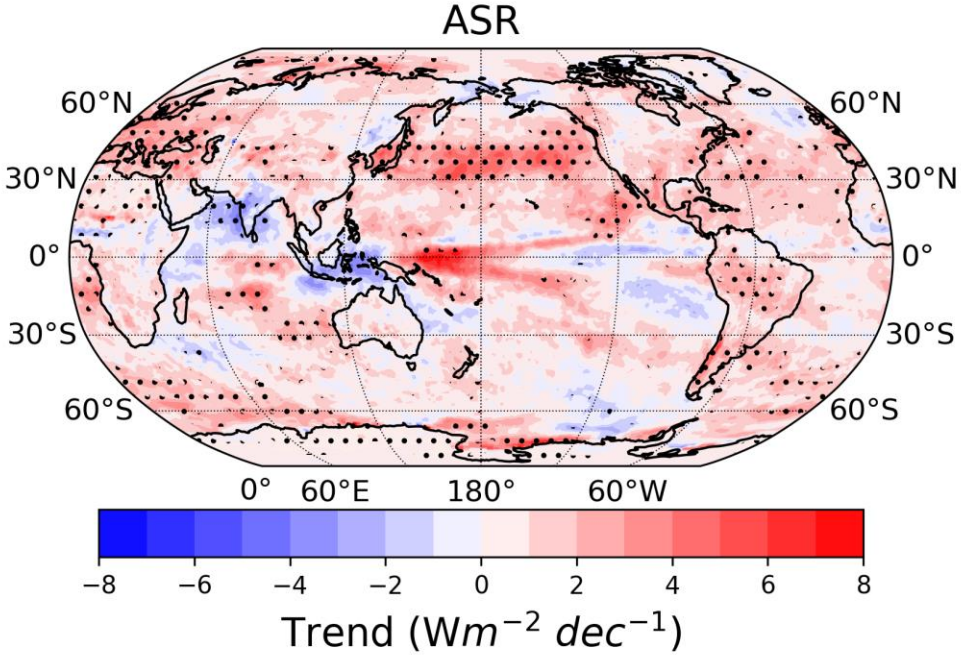
–OLR: –0.44 ± 0.23

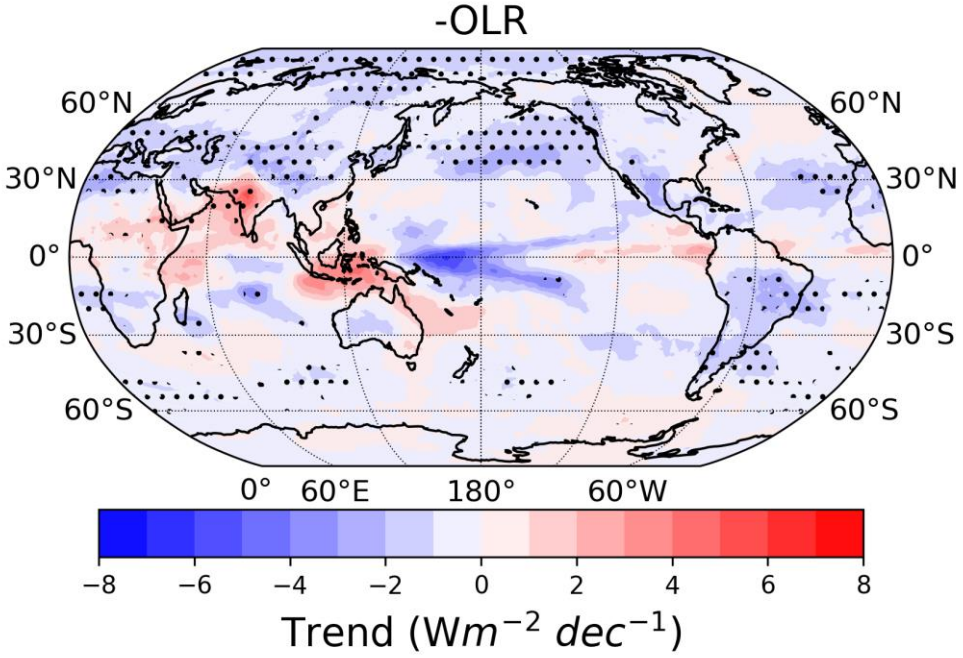
NET: 0.46 ± 0.16

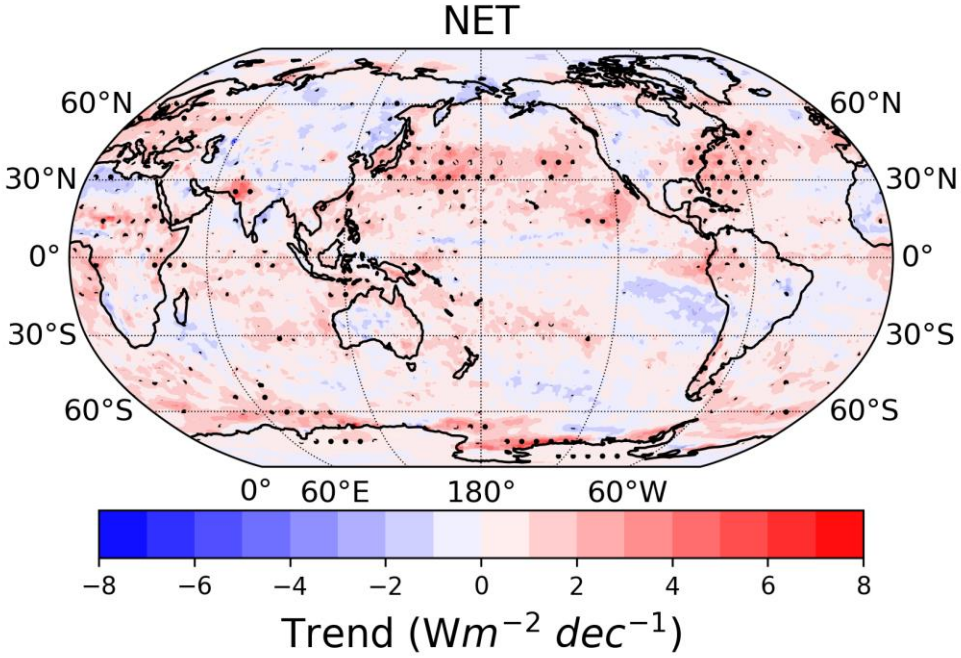
Units: Wm^{-2}	Solar Irradiance	ASR	–OLR	NET
03/2000-02/2010	340.14	240.73	–240.20	0.53
03/2016-02/2026	340.23	242.12	–240.87	1.25
Difference	0.090	1.39	–0.67	0.72

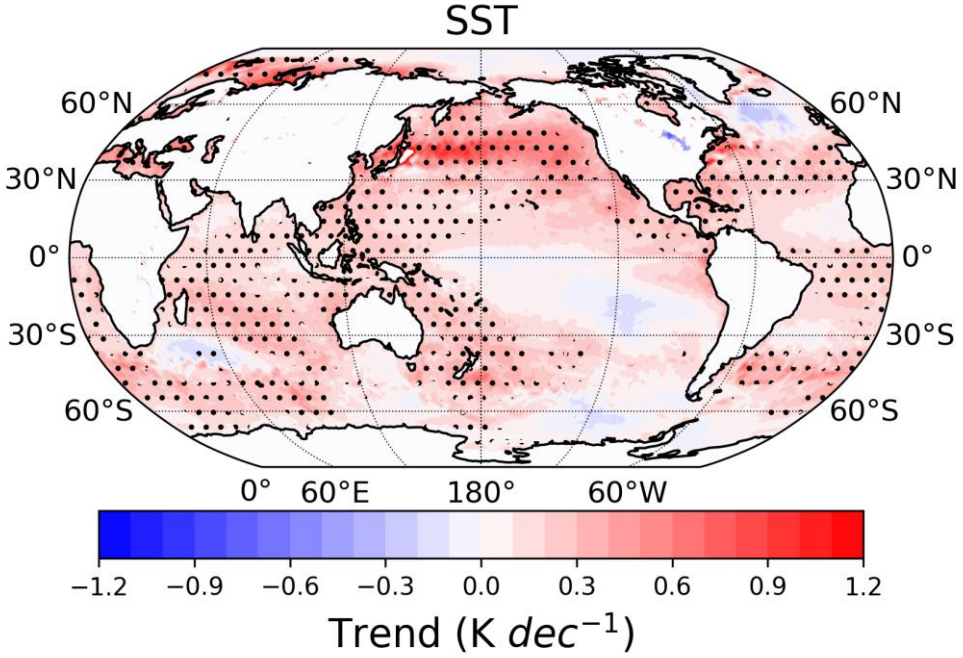
Doubling in EEI!

Trends in TOA Radiation and SST (03/2000–02/2026)

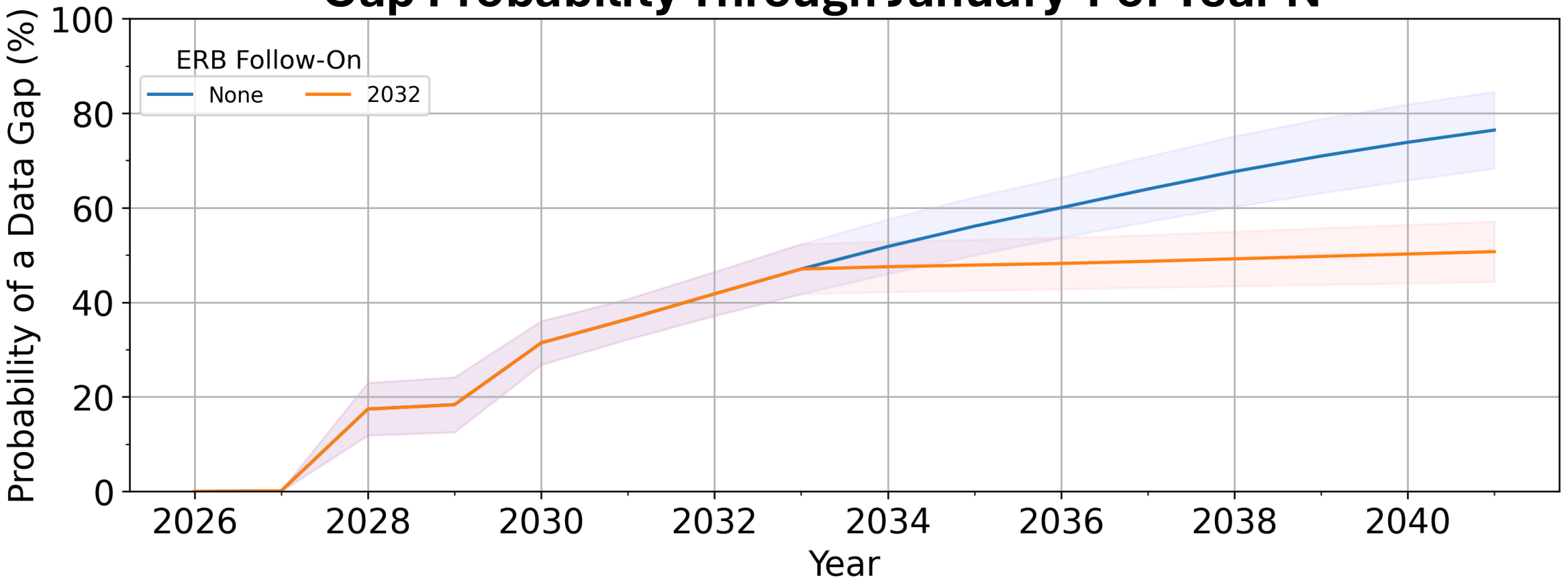






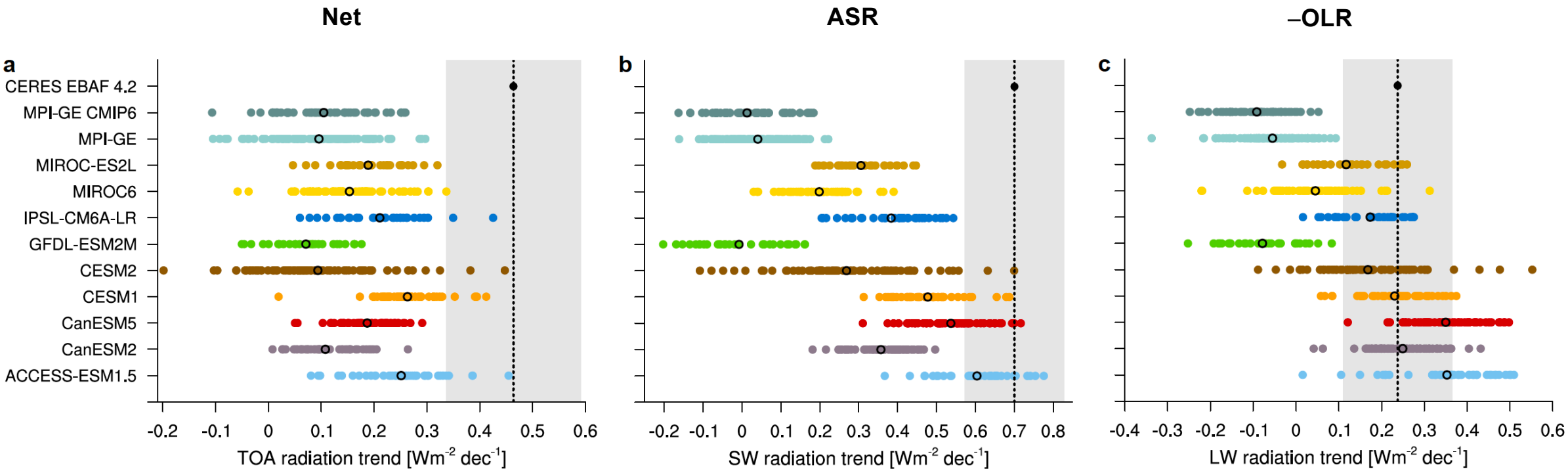


Gap Probability Through January 1 of Year N



Mission	Start	End
Terra	12/1999	02/2027
Aqua	05/2002	09/2027
S-NPP	10/2011	12/2026
NOAA-20	11/2017	06/2029
Libera	09/2027	-
ERB Follow-On	06/2032	-

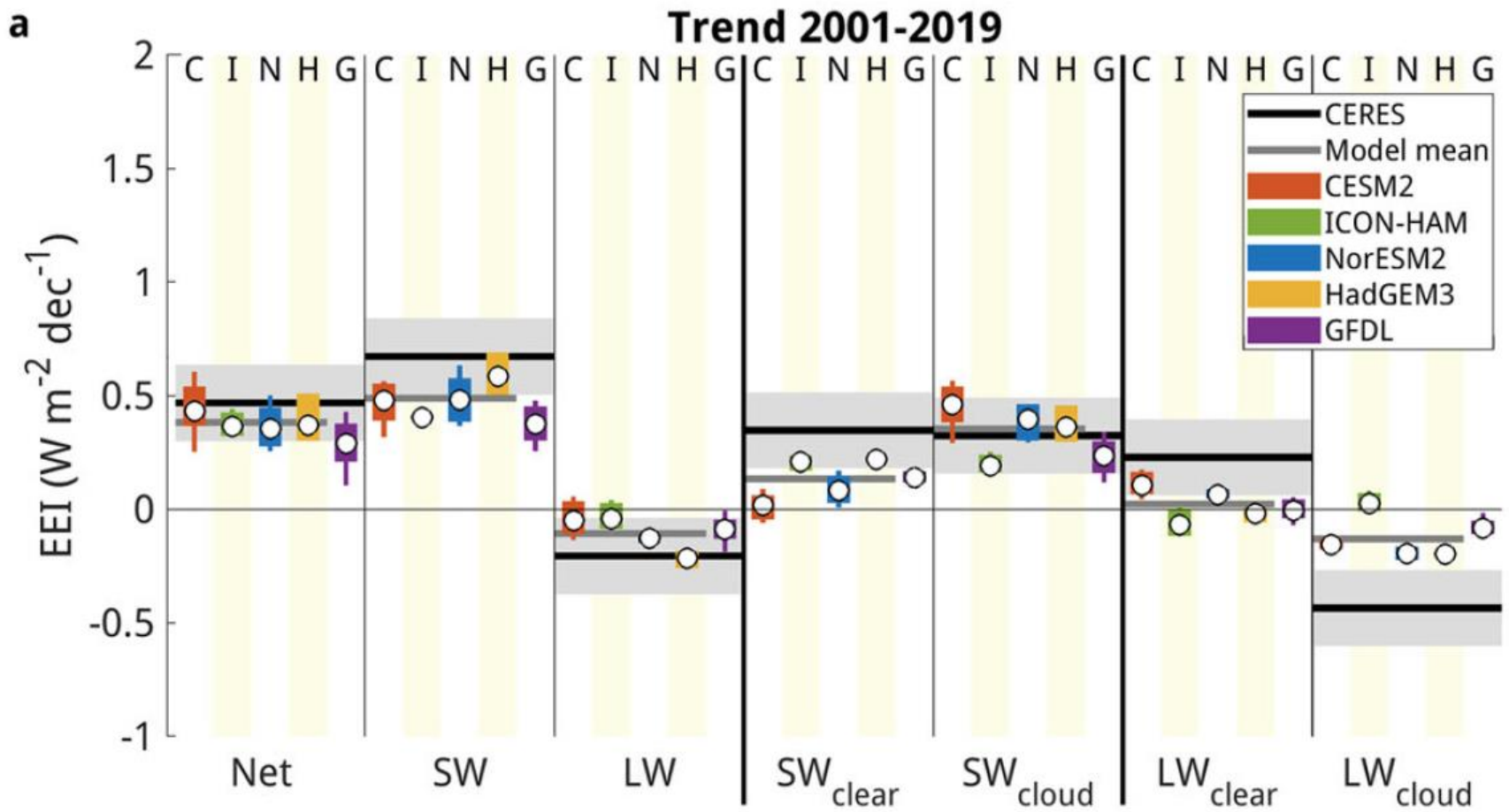
Observed and Coupled Model Trends in Global Mean TOA Radiation (2001–2022)



- Coupled model simulations systematically underestimate the observed Net TOA radiation trend.
- Primarily reason is due to model underestimation of ASR trend.

Olonscheck and Rugenstein, GRL (2024)

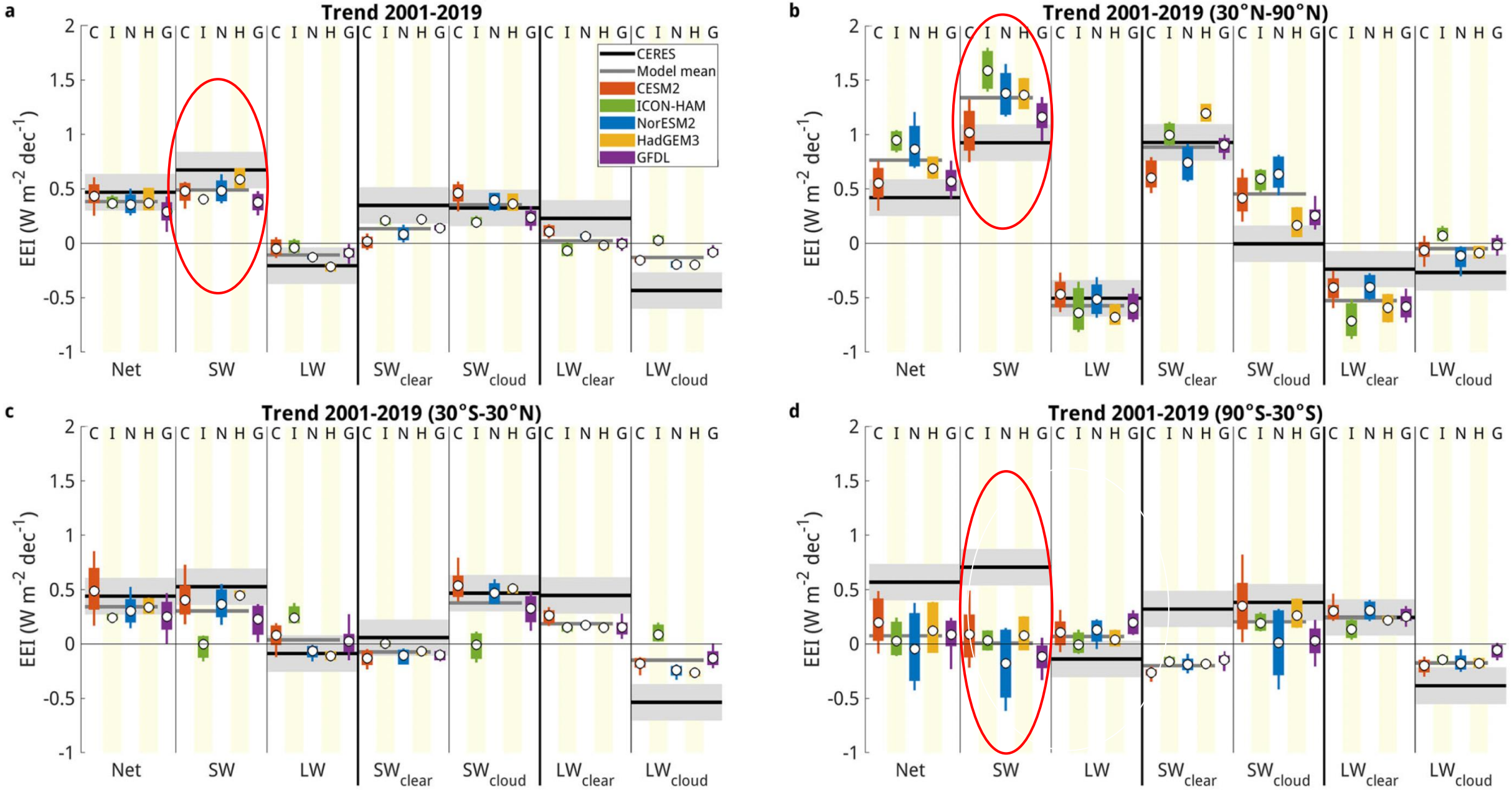
Observed and AMIP Trends in Global Mean TOA Radiation (2001–2019)



- AMIP simulations come closer to observations but still underestimate Net and ASR TOA radiation trends.

Hodnebrog et al., Comm Earth & Env (2024)

Observed and AMIP Trends in Regional Mean TOA Radiation (2001–2019)

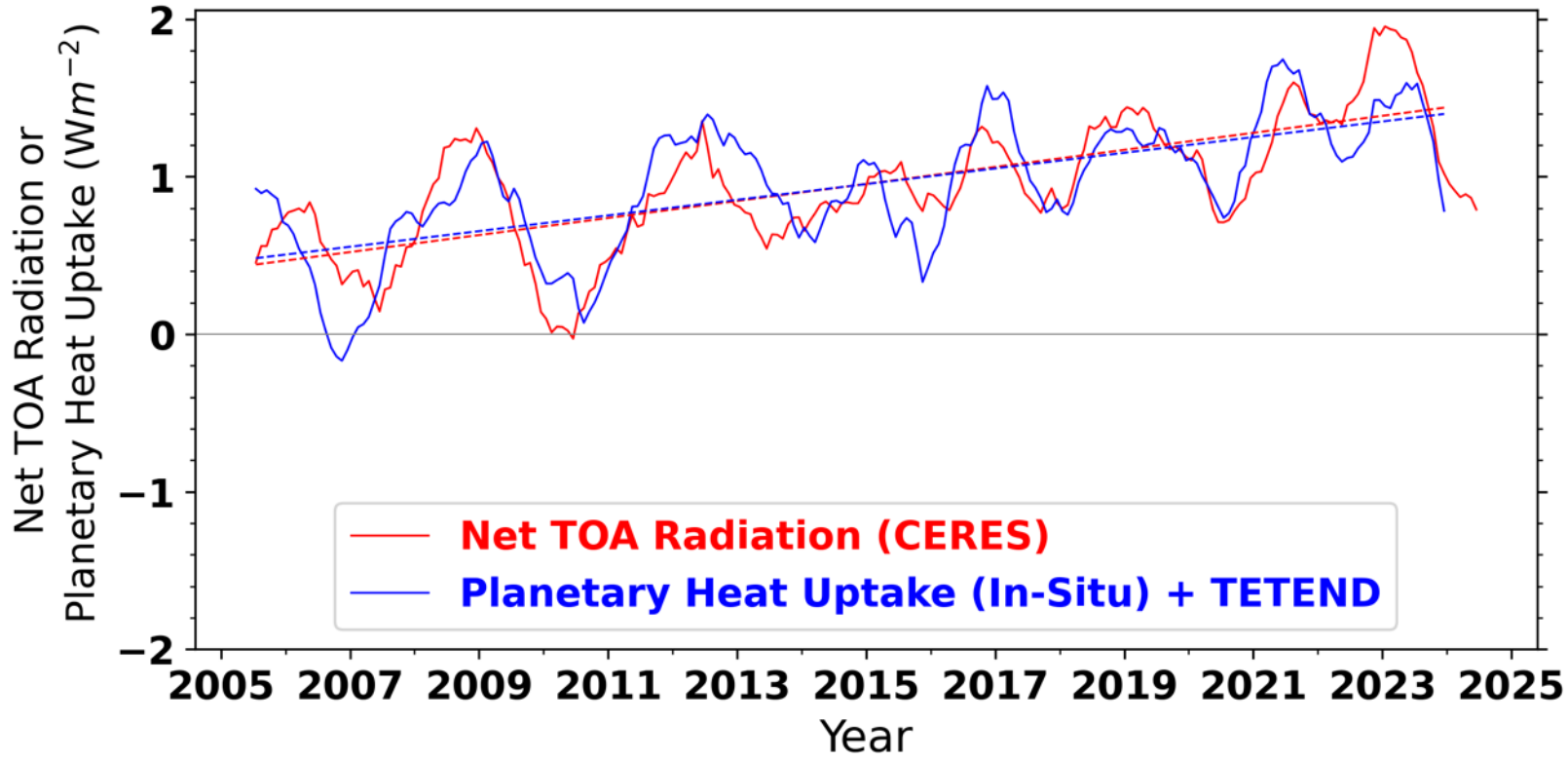


Hodnebrog et al., Comm Earth & Env (2024)

Can we trust the CERES Trends?

Annual Mean Net TOA Radiation & In-Situ Planetary Heat Uptake

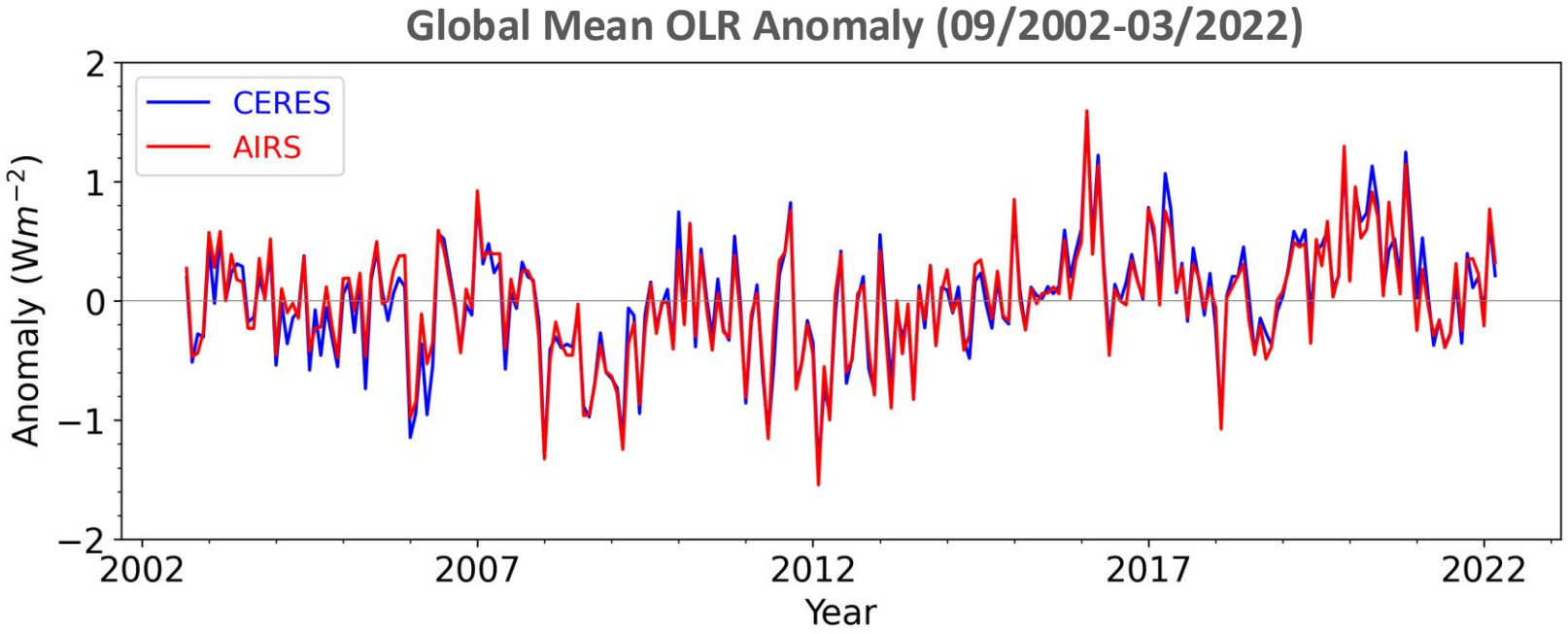
(CERES 02/2005-12/2024; In situ: 02/2005-06/2024)

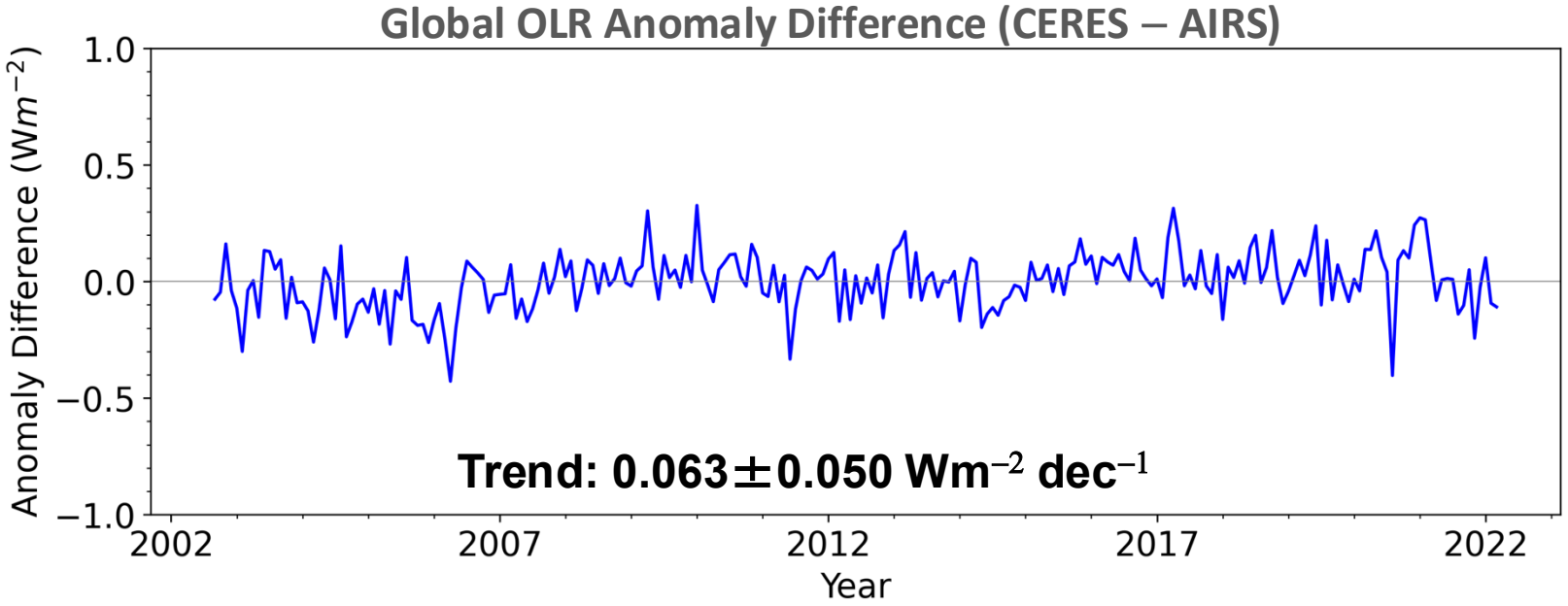


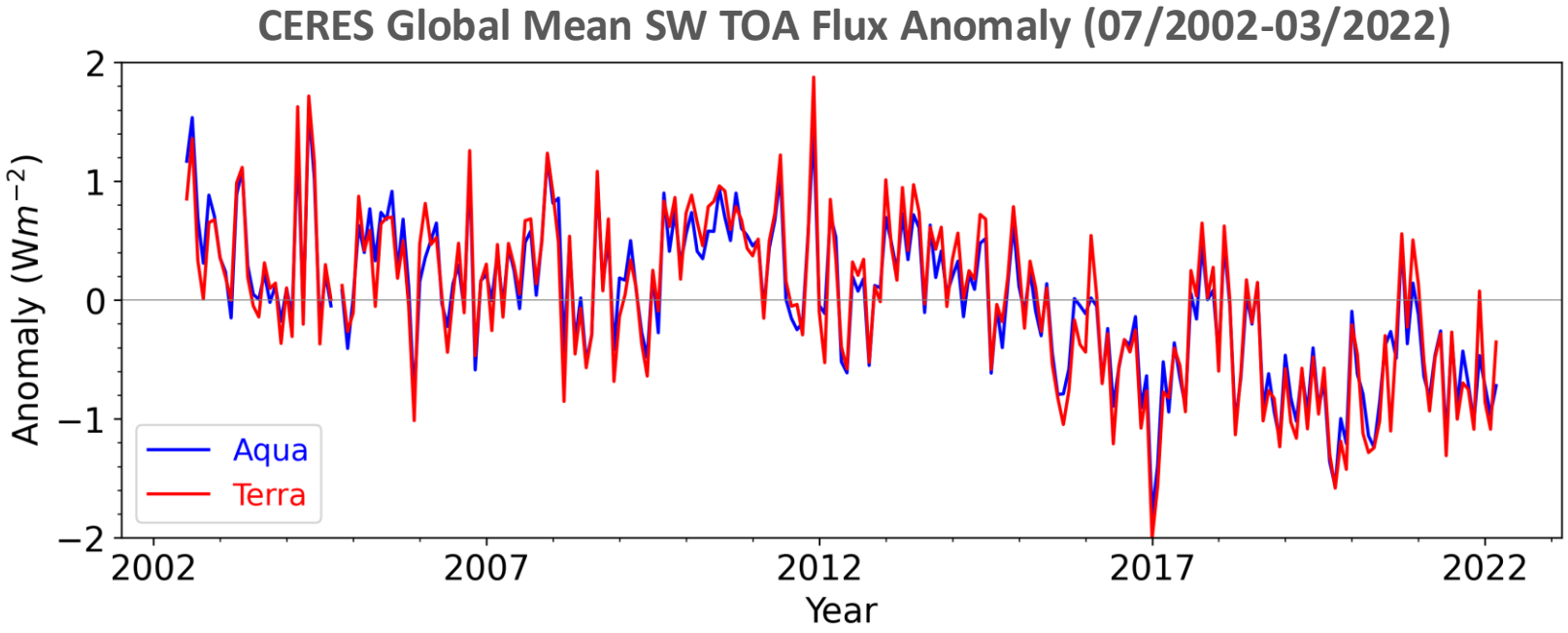
Ocean: RFROM21 (Lyman & Johnson, 2023)

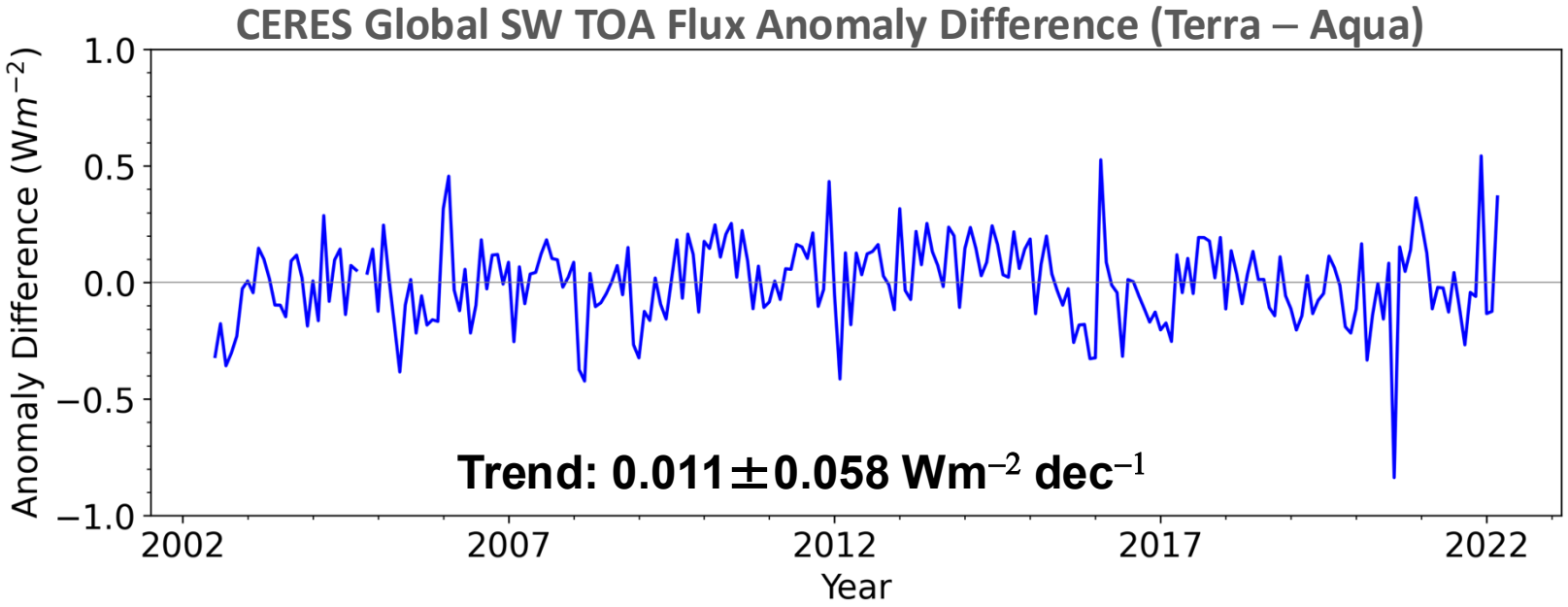
TETEND: ERA-5 (Mayer et al., 2021)

	Trend (Wm^{-2} dec^{-1}) 02/2005-06/2024
CERES EBAF Ed4.2	0.54 ± 0.27
In-Situ	0.50 ± 0.27
Difference	**0.04 ± 0.21**
R	0.82


Global Mean OLR Anomaly (09/2002-03/2022)
CERES
AIRS
Anomaly (Wm^{-2})
2
1
0
−1
−2
2002
2007
2012
2017
2022
Year

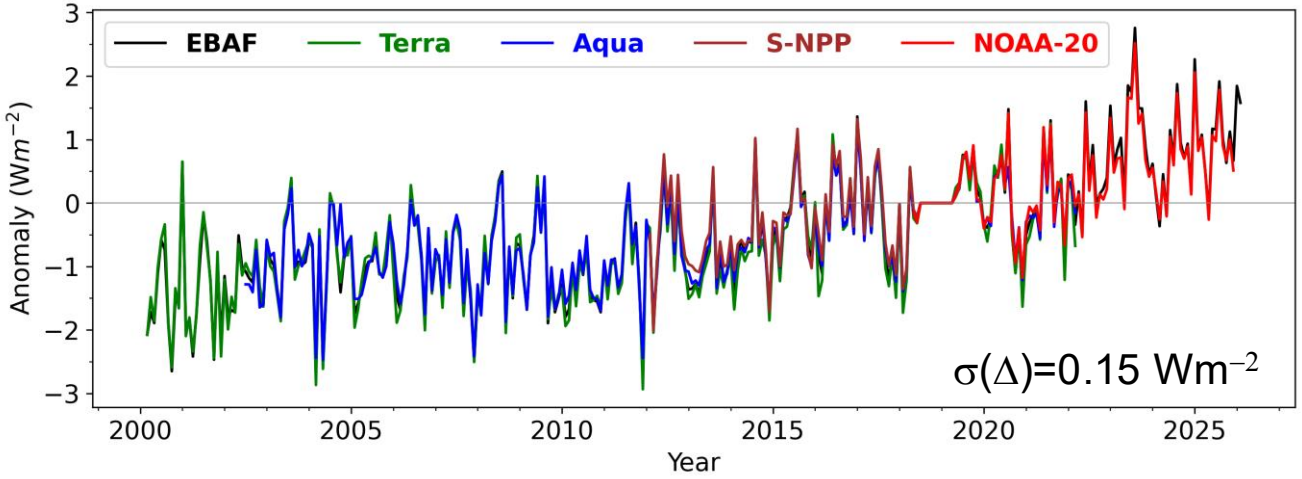

Global OLR Anomaly Difference (CERES − AIRS)
Anomaly Difference (Wm^{-2})
1.0
0.5
0.0
−0.5
−1.0
2002
2007
2012
2017
2022
Year
Trend: 0.063±0.050 Wm^{-2} dec^{-1}


CERES Global Mean SW TOA Flux Anomaly (07/2002-03/2022)
Anomaly (Wm^{-2})
2
1
0
−1
−2
Aqua
Terra
2002
2007
2012
2017
2022
Year

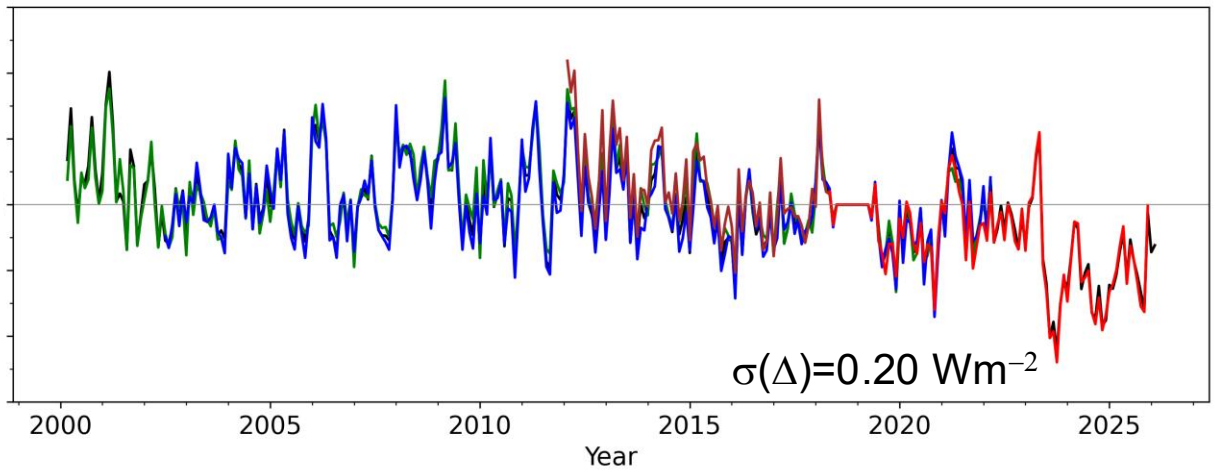

CERES Global SW TOA Flux Anomaly Difference (Terra – Aqua)
Anomaly Difference (Wm^{-2})
1.0
0.5
0.0
−0.5
−1.0
Trend: 0.011±0.058 Wm^{-2} dec^{-1}
2002
2007
2012
2017
2022
Year

CERES Global Mean TOA Flux Anomalies
(May 2018-June 2019 Climatology)

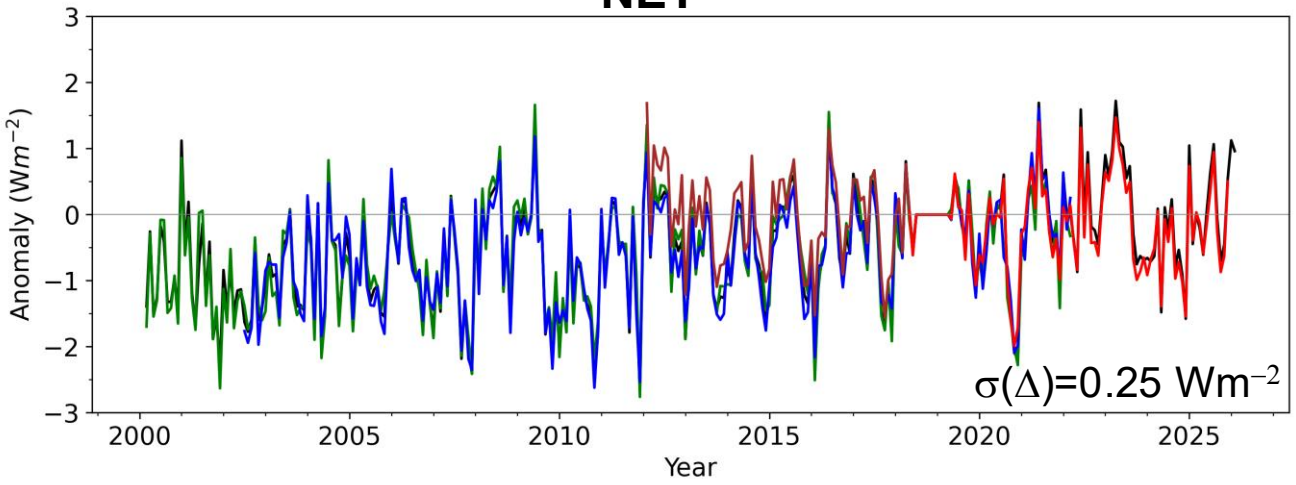
ASR



–OLR



NET



Framework for an Earth Radiation Budget Satellite Mission

Scenario: You are offered $$$ to fly one or more satellites to address pressing EEI science.

- What would such a mission look like?
- How would you prioritize what instruments to fly?

Earth Radiation Budget Mission

- Solar irradiance instrument (TSI and SSI)
  - Continues the continuous four-decade long record

- Two broadband+imager pairs
  - Continues the CERES+Libera Climate Data Record
  - Placed in 10:30 am and 1:30 pm orbits like Terra and Aqua
  - Smallsats to reduce cost and enable a more flexible launch schedule
  - Increased spatial resolution to improve cloud radiative studies (can be degraded to CERES FOV scale)

- Visible/near-infrared and infrared spectrometers
  - Enables understanding of how different reflecting surfaces and media contribute to the total spectrally integrated energy reflected to space
  - Provides spectral context for trends observed in broadband radiation. Also useful in model evaluation.
  - Provides constraints for surface radiation budget calculations that use ancillary input from multiple sources (Kato et al., 2025)
  - Improved aerosol and cloud retrievals (especially when VIS spectrometer combined with polarimeter)

- Multi-angle multi-channel VIS/NIR polarimeter
  - Retrievals of aerosol optical properties and cloud microphysics (especially when combined with VIS spectrometer)