Assessing Radiation Biases in GFDL AM4 due to Prescribed SST/SIC Datasets: Comparison to CERES Products

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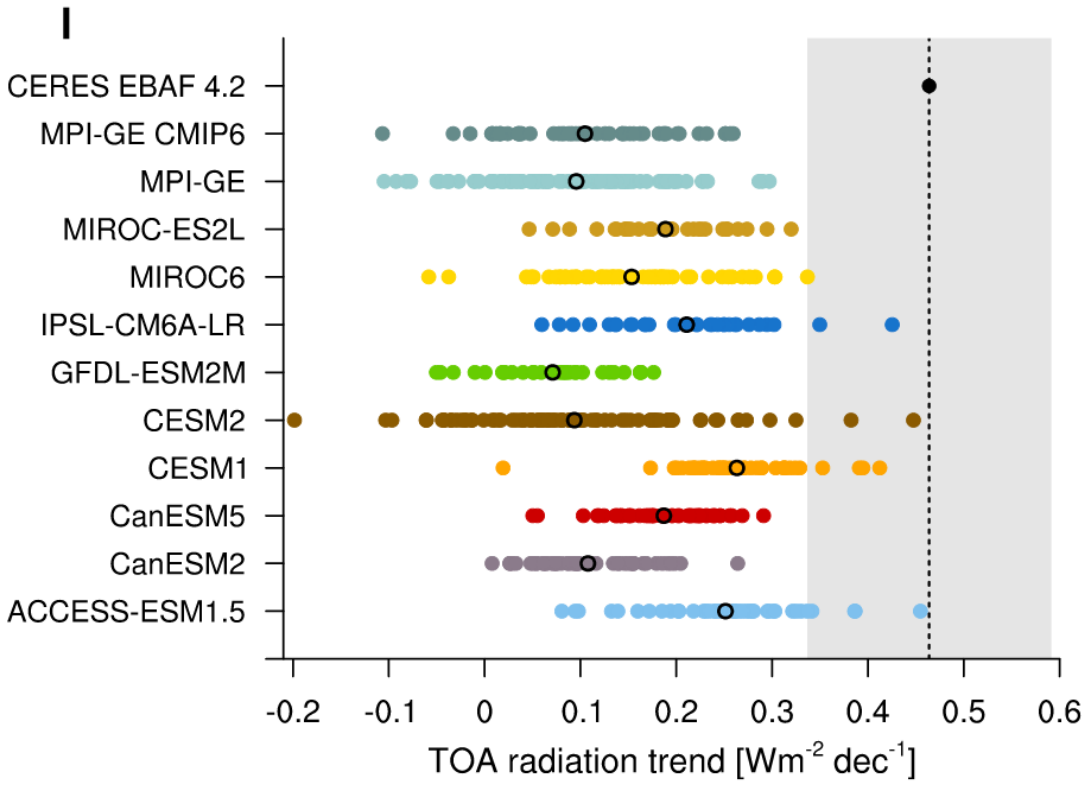
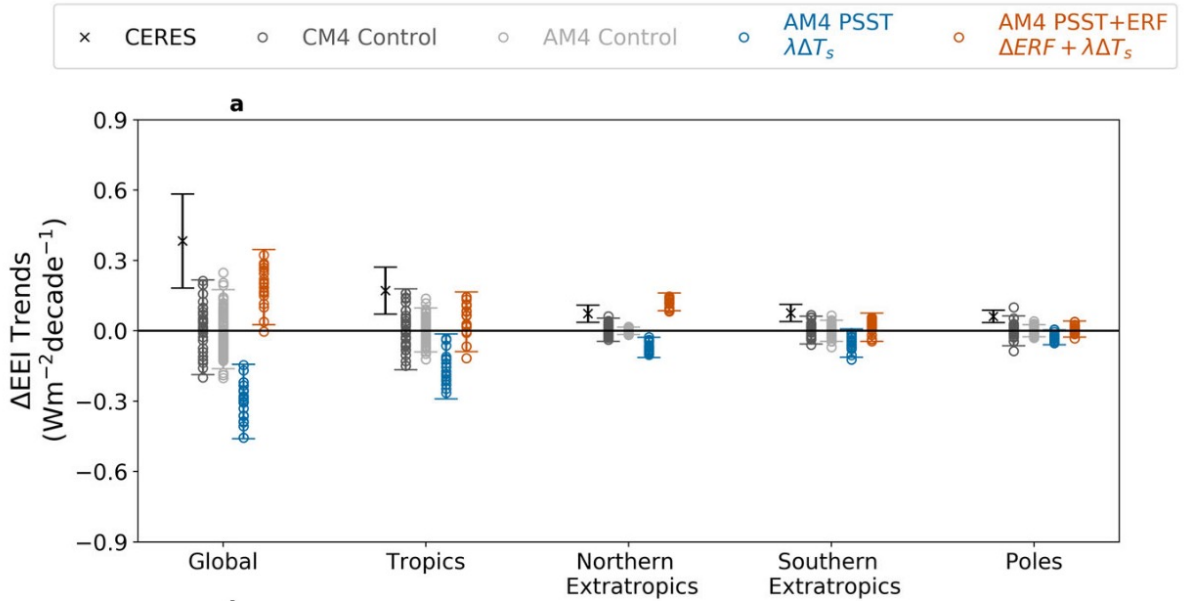
Earth radiation budget: obs. vs models

Both coupled model runs and AMIP runs underestimate TOA radiation trends compared to CERES



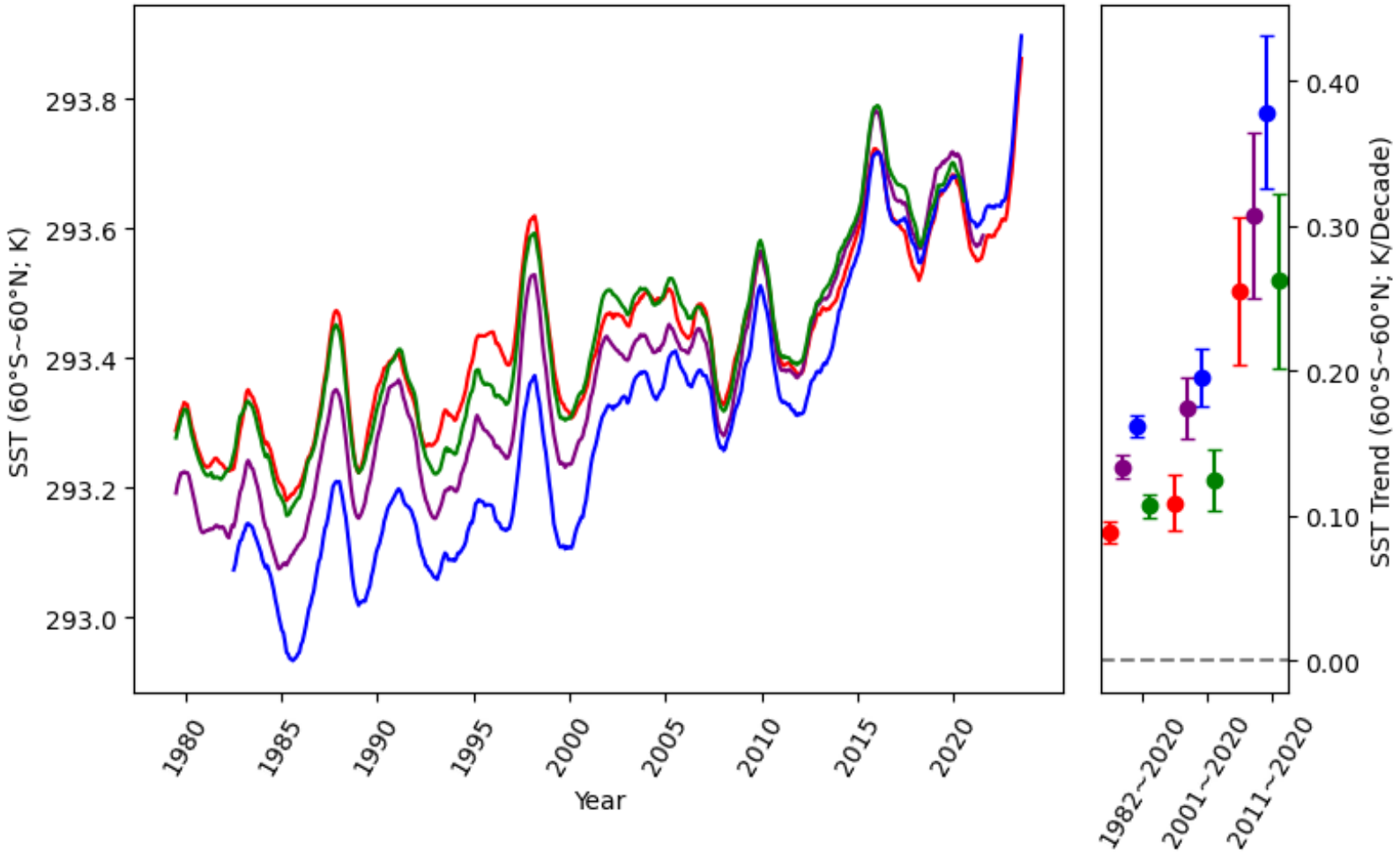
(Olonscheck and Rugenstein, 2024)



PSST: prescribed SST run based on a combination of the PCMDI and the NOAA OI SST V2 dataset

(Raghuraman et al., 2021)

Differences between SST products



Processed SST in model simulations (1979~2023)

all datasets processed by PCMDI procedures

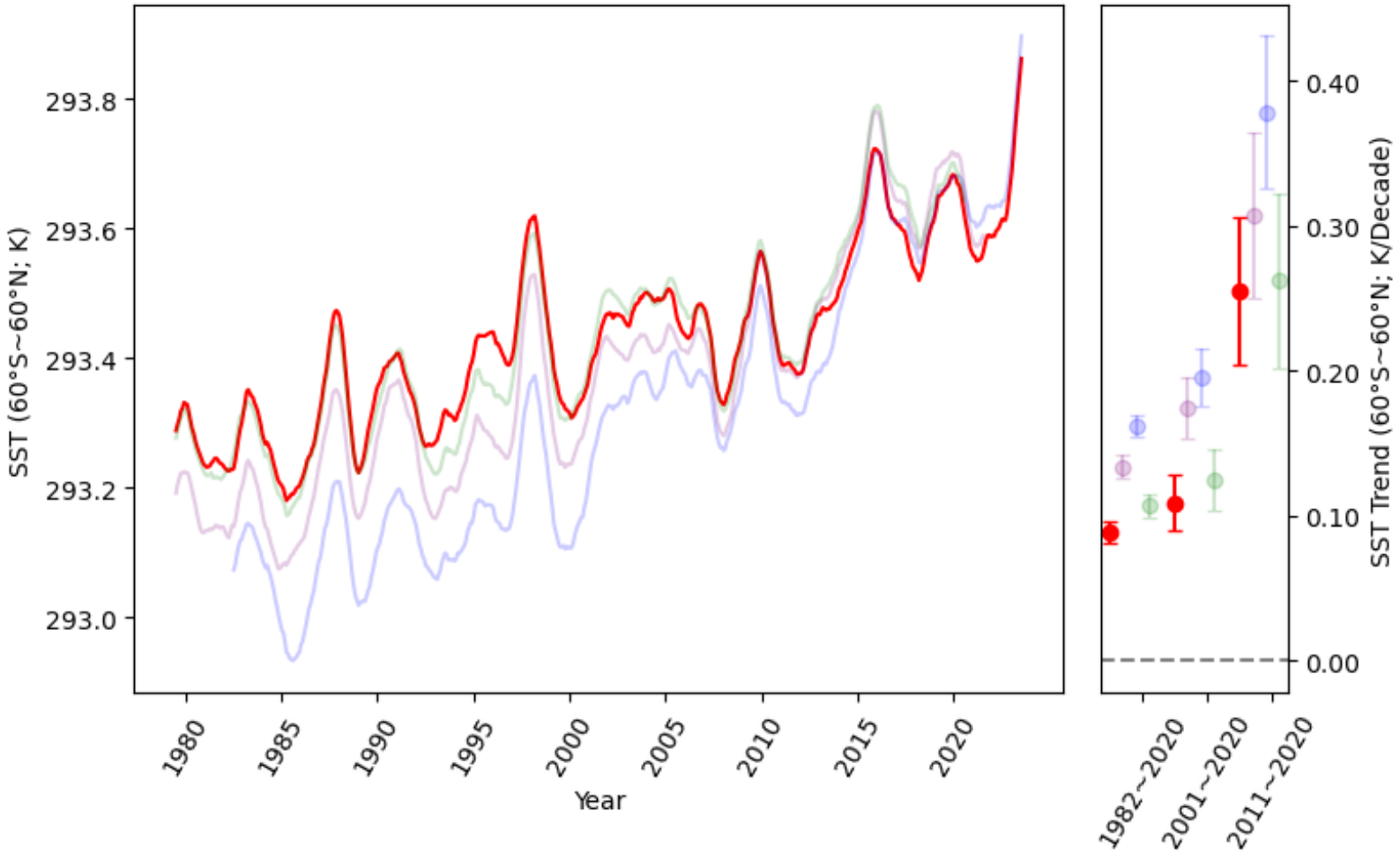
HadISST 1.1

HadISST 2.4.0.0

PCMDI-AMIP 1.1.18

NOAA OISST High-Res V2.1

Differences between SST products



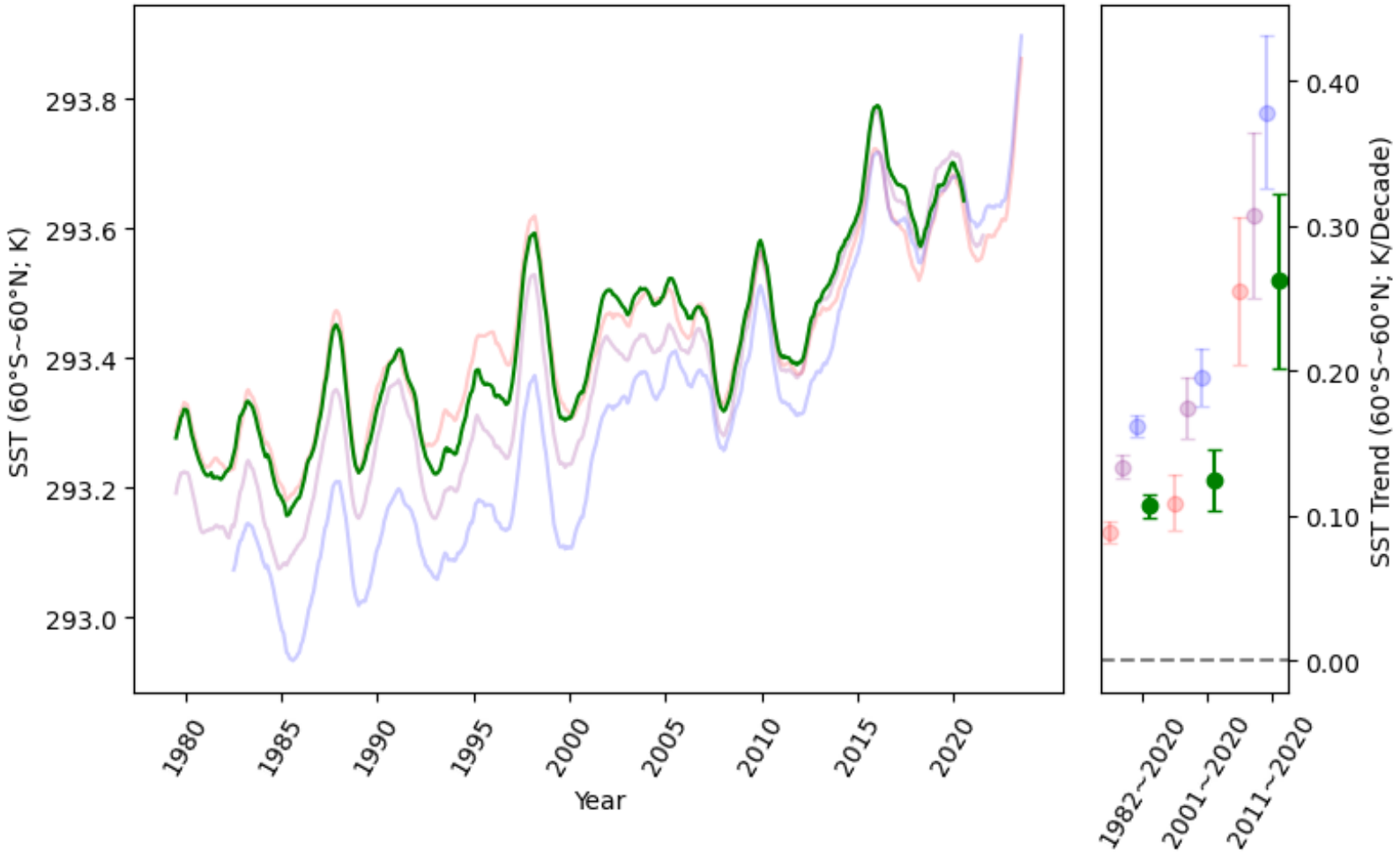
HadISST 1.1

- Rayner et al. (2003)
- 1870~present day monthly; 1º lat-lon
- MDB + COADS + AVHRR (1982~)
- Reduced space optimal interpolation method

Widely used for prescribing AMIP runs

Weakest warming among datasets studied

Differences between SST products



PCMDI-AMIP 1.1.18

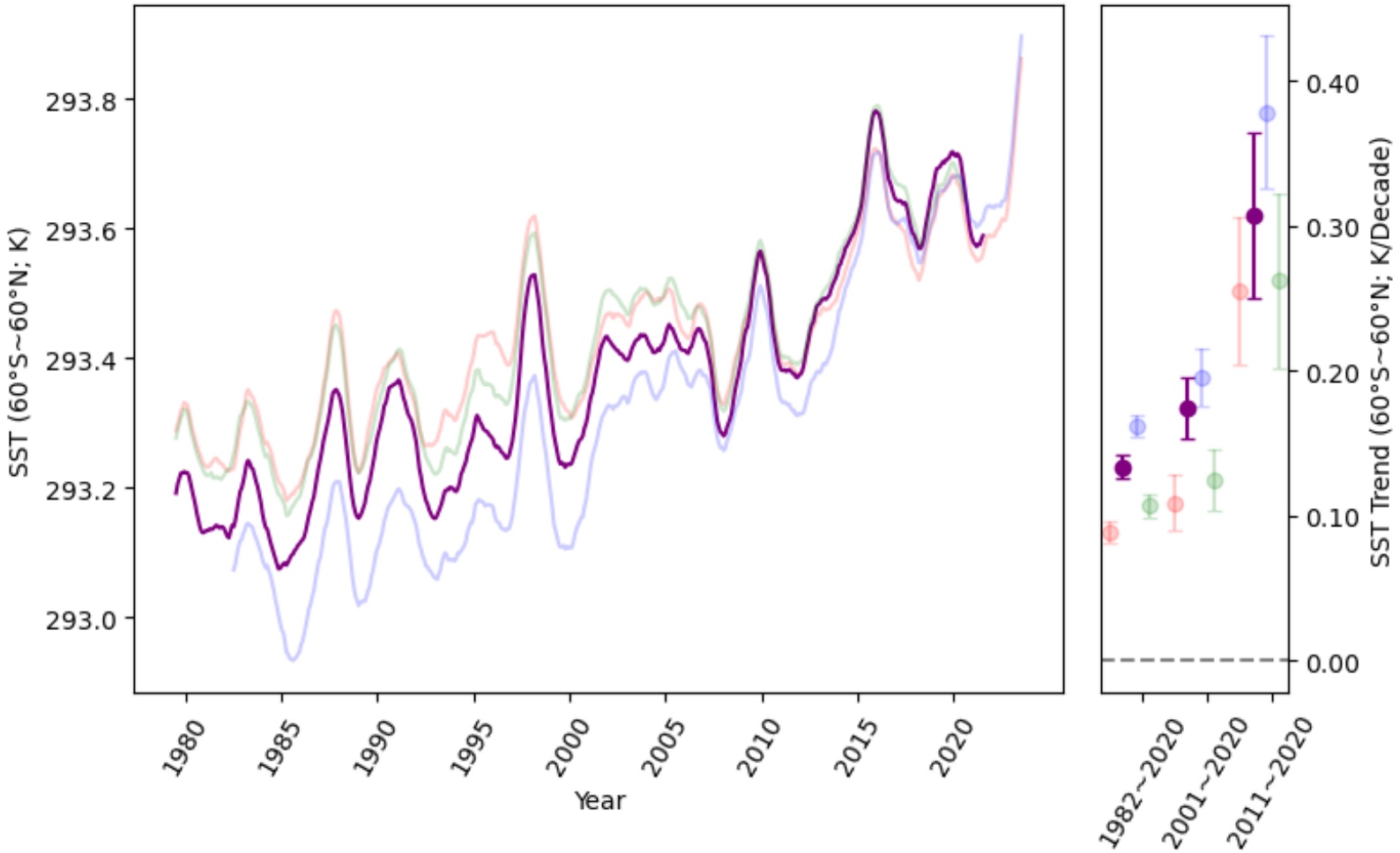
- Taylor et al. (2000)
- 1870~2021 monthly; 1º lat-lon
- HadISST1 before Nov 1981 and NOAA OIv2.0 after then
- Optimized temporal interpolation

Version 1.1.19 will be used in CMIP7 experiments

(very similar series compared to 1.1.18 with an additional year)

Similar warming rate with HadISST 1.1

Differences between SST products



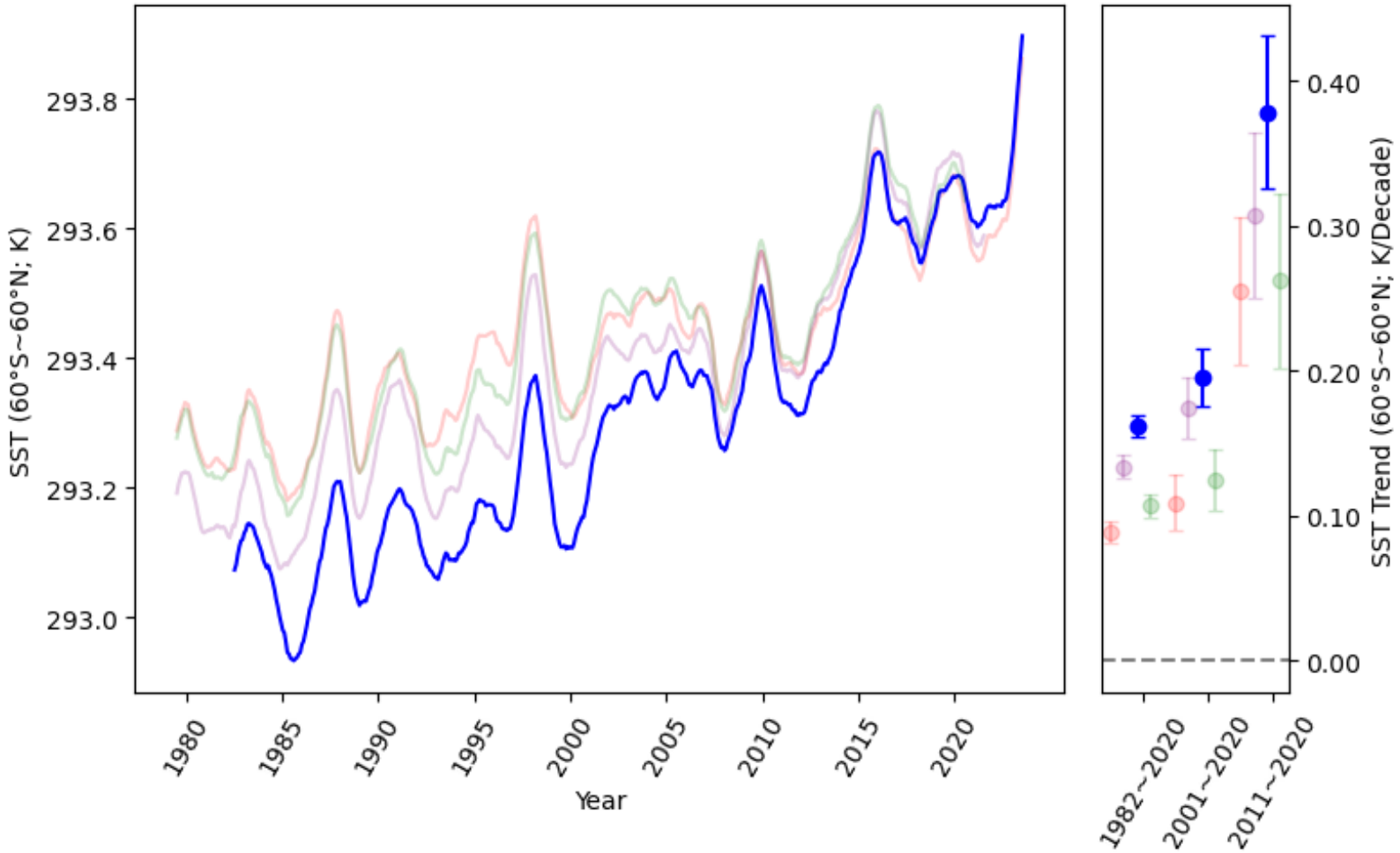
HadISST 2.4.0.0

- No documentation yet
- 1850~2021 monthly; 1° lat-lon

Recommended for CERESMIP experiments

Significantly faster warming than HadISST1 and PCMDI-AMIP

Differences between SST products



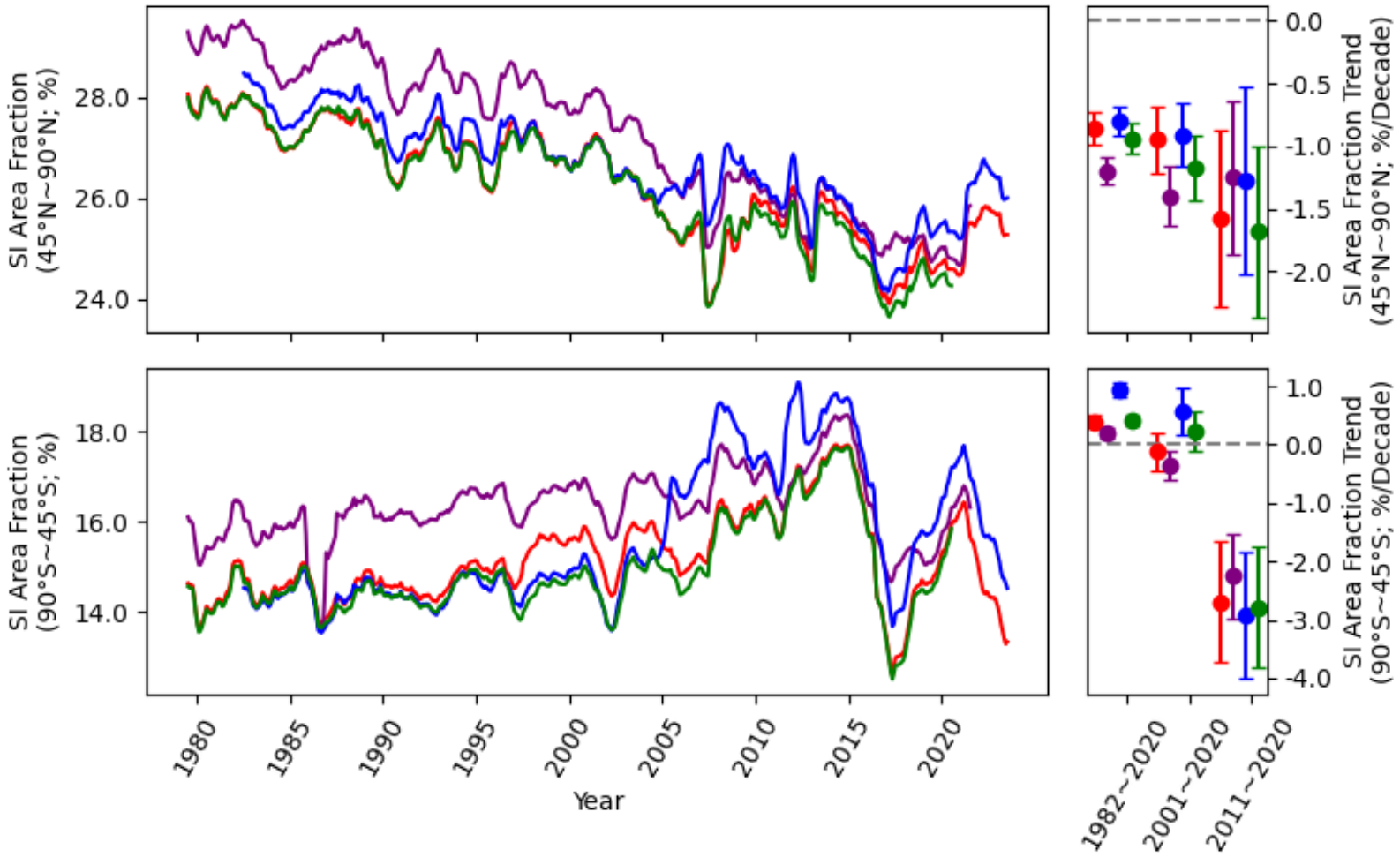
NOAA OISST High-Res V2.1

- Reynolds et al. (2007)
- 1981/9~present day monthly; 0.25º lat-lon
- AVHRR corrected by ships and buoys
- Too-cold bias after Jan 2016 addressed from V2.0 to V2.1

Highest resolution, but strongest warming

~2x warming rate (0.164 ± 0.008 K/decade) compared to HadISST 1.1 (0.089 ± 0.008 K/decade)

Differences between SIC products



Processed sea ice area fraction in model simulations (1979~2023)

all datasets processed by PCMDI procedures

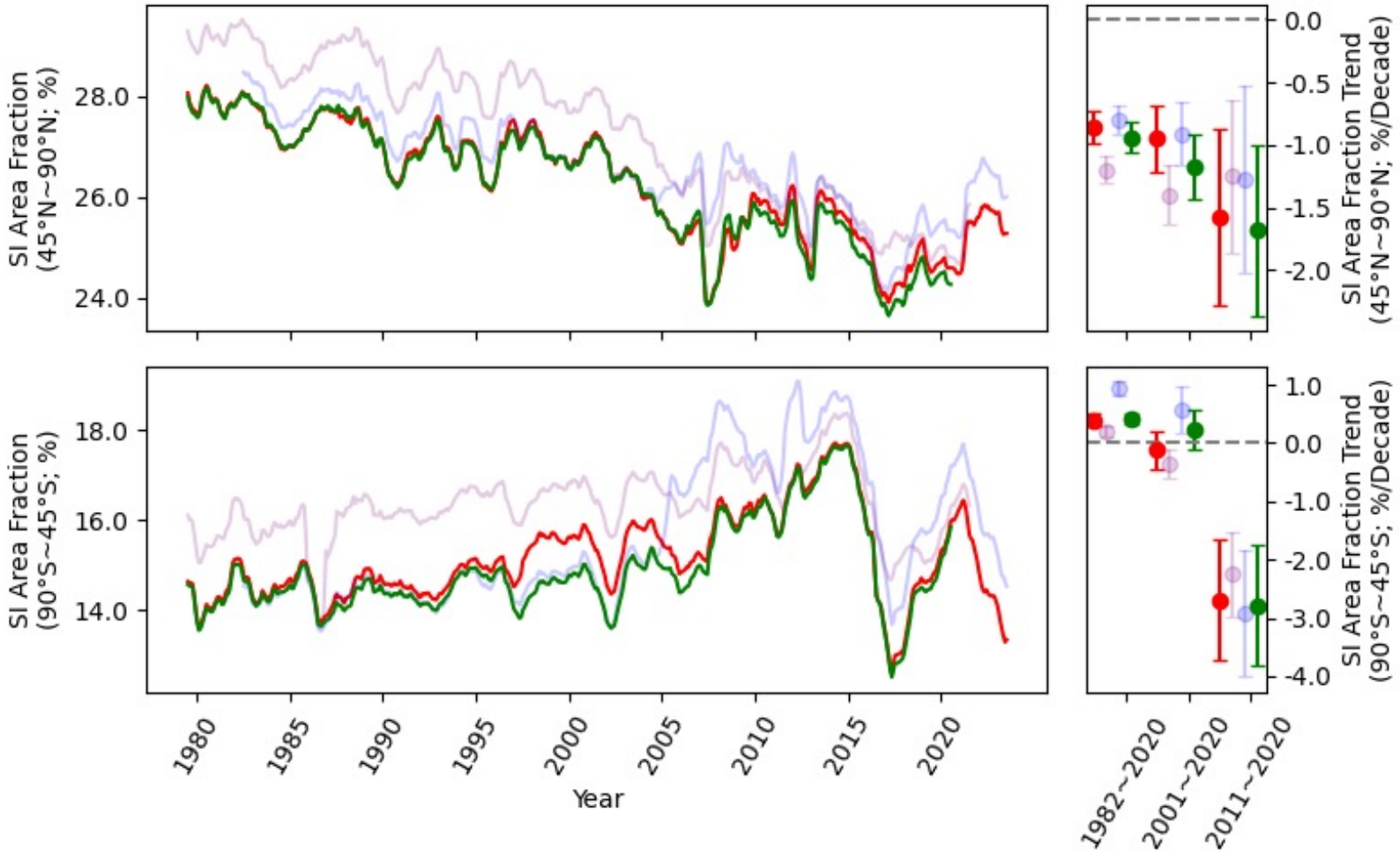
HadISST 1.1

HadISST 2.2.1.0

PCMDI-AMIP 1.1.18

NOAA OISST High-Res V2.1

Differences between SIC products



HadISST 1.1

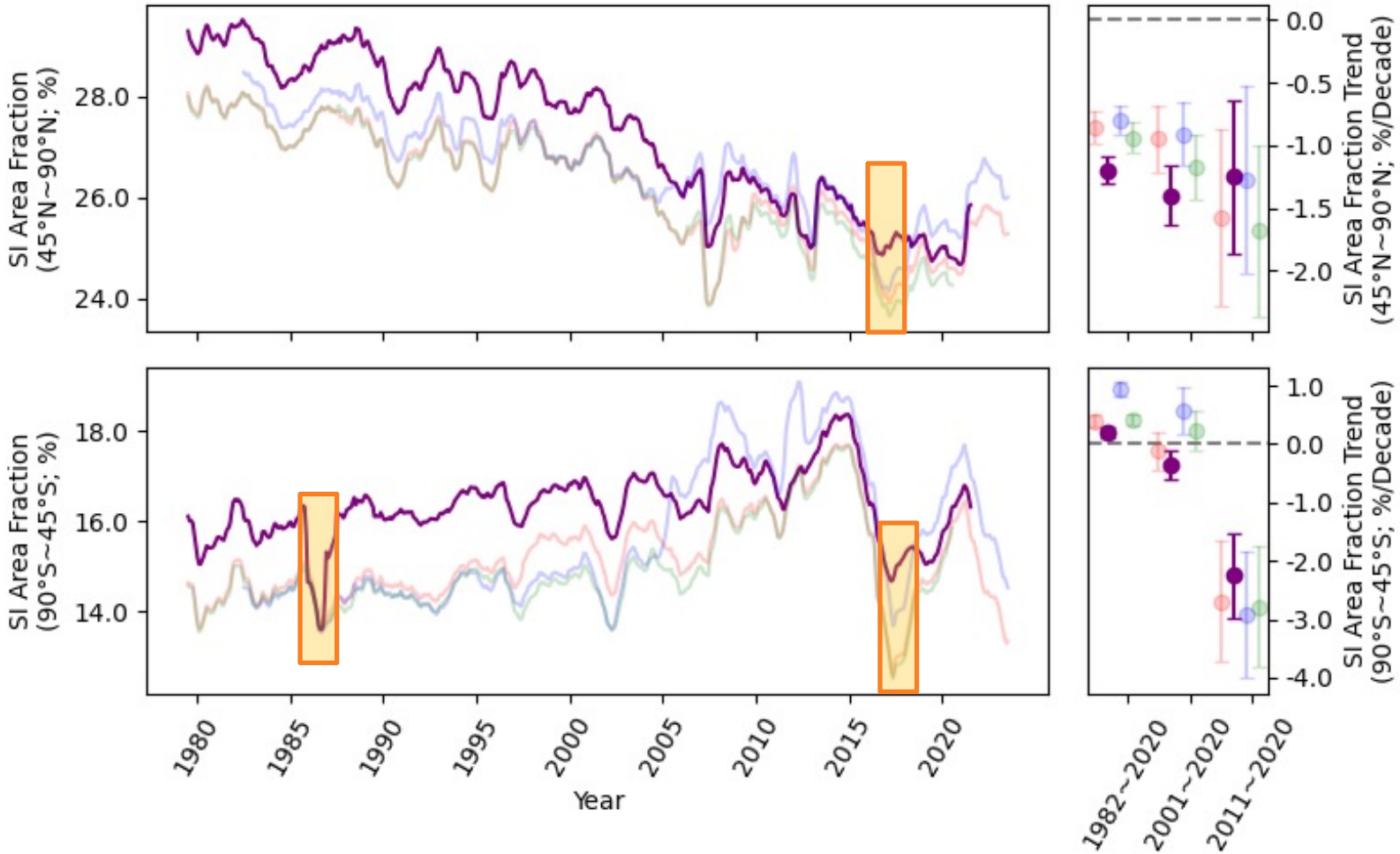
PCMDI-AMIP 1.1.18

Similar SH sea ice trend

Relatively large differences after 2010 in the Arctic region and 1995~2005 in the Antarctic region

(note that PCMDI uses HadISST1 before Nov 1981 and NOAA OIv2.0 after then)

Differences between SIC products



HadISST 2.2.1.0

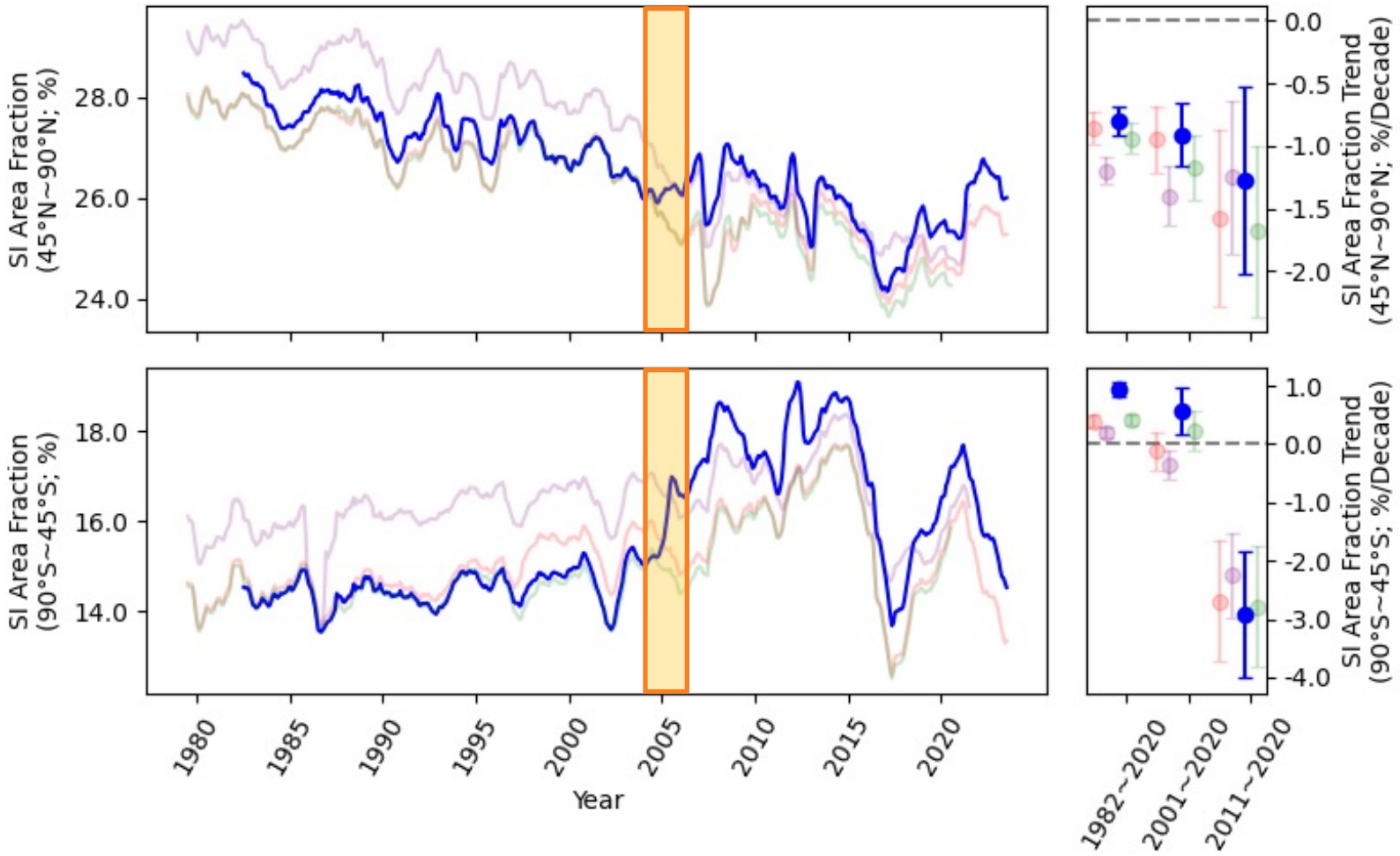
More sea ice before 2005 => more downward trend

Significant sea ice loss in both hemispheres over 2001~2020

Unable to catch the sea ice minimum around 2018

Strange SH sea ice minimum in 1986, closing the gap between products

Differences between SIC products



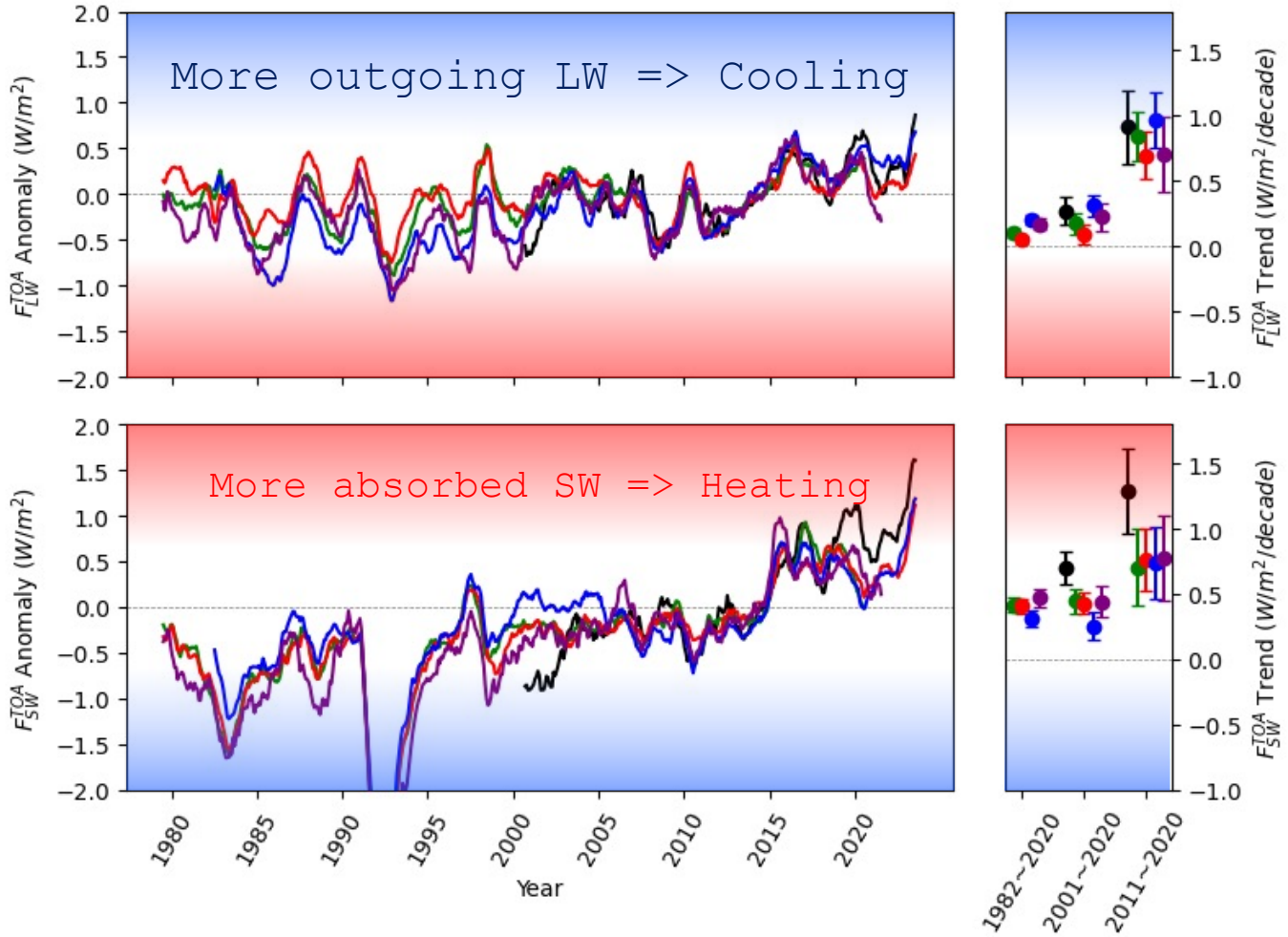
NOAA OISST High-Res V2.1

Abnormal sea ice increase around 2005

(note the effect of 12-month moving average)

Coincident with sea ice data source transition from NASA to NCEP

Time series of TOA radiative fluxes



TOA LW (upper) and SW (lower) fluxes and trends (1979~2023)

CERES EBAF Ed4.2

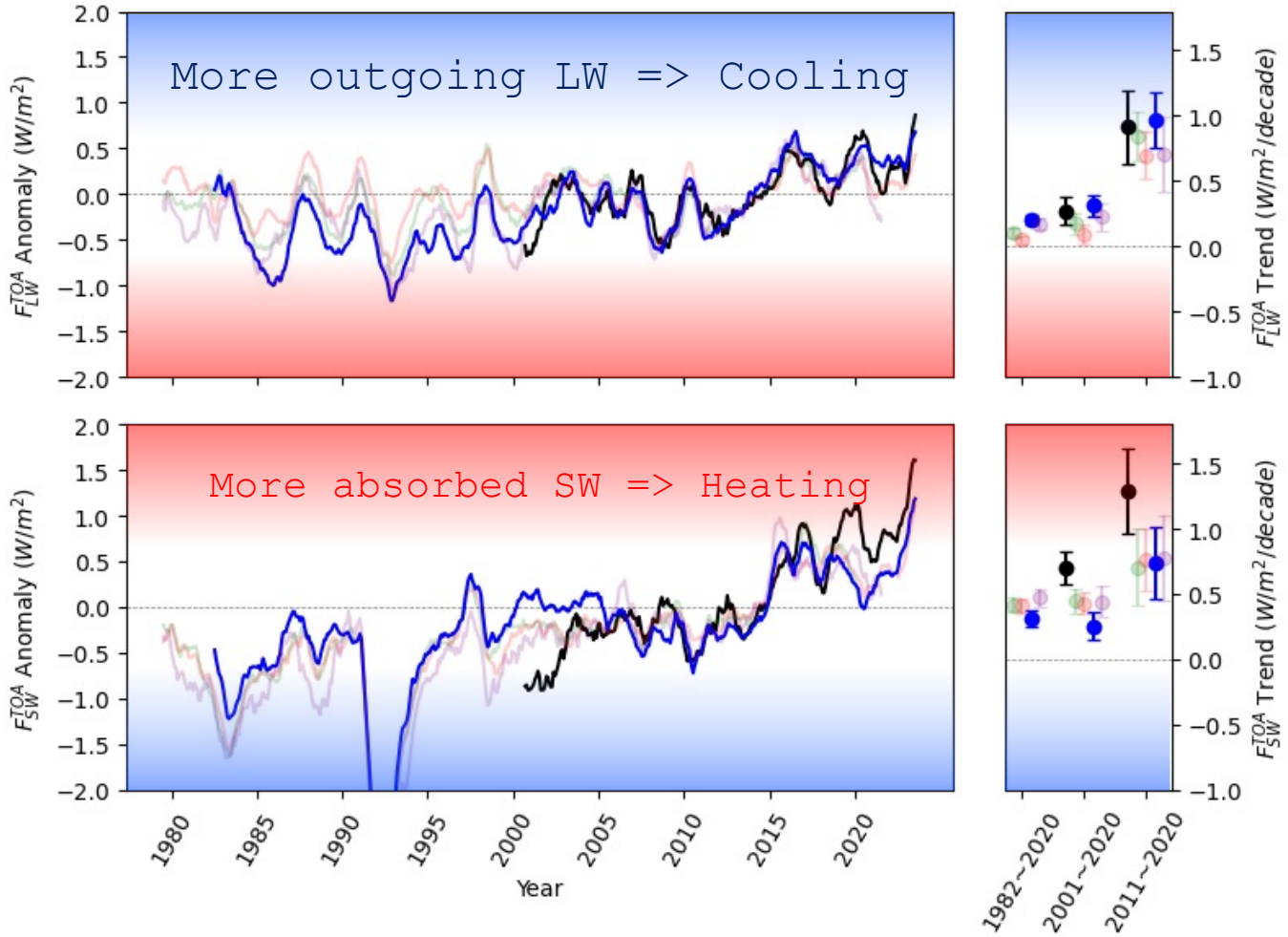
AM4 HadISST 1

AM4 HadISST 2

AM4 PCMDI

AM4 NOAA OISST

Time series of TOA radiative fluxes



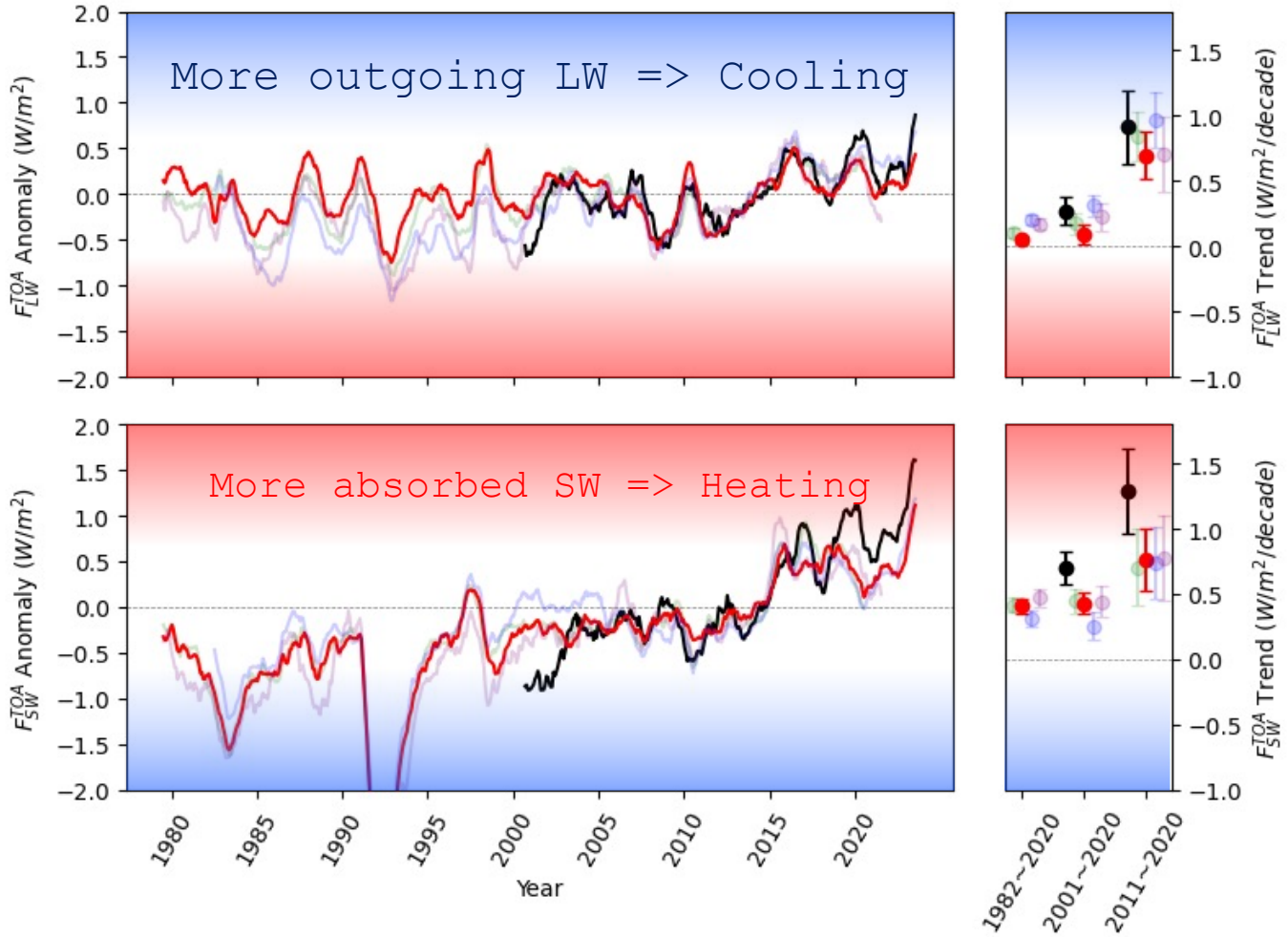
CERES EBAF Ed4.2

AM4 NOAA OISST

Strongest OLR trend consistent with CERES due to strong SST increase

Weakest ASR trend due to more sea ice reflecting solar radiation

Time series of TOA radiative fluxes



CERES EBAF Ed4.2

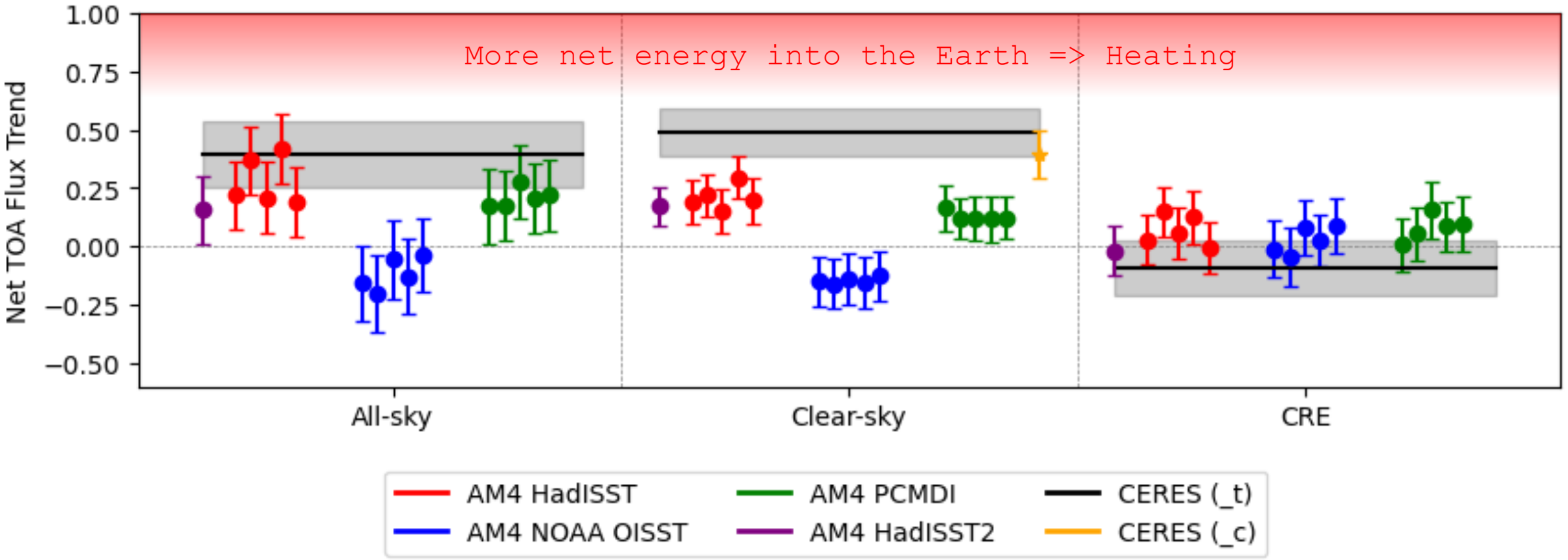
AM4 HadISST 1

Weakest OLR trend due to weak SST increase

ASR trend still ~1/2 of the CERES trend, despite less sea ice fraction relative to other products

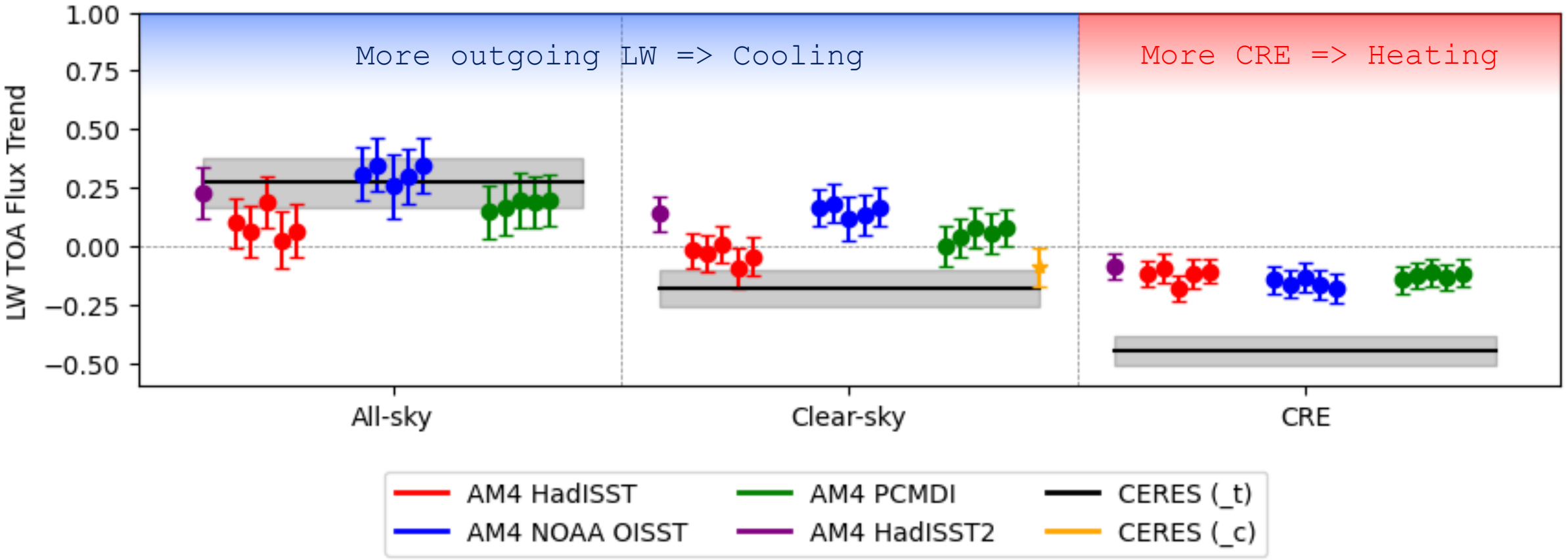
Comparison of broadband net flux trends

(2001~2020)



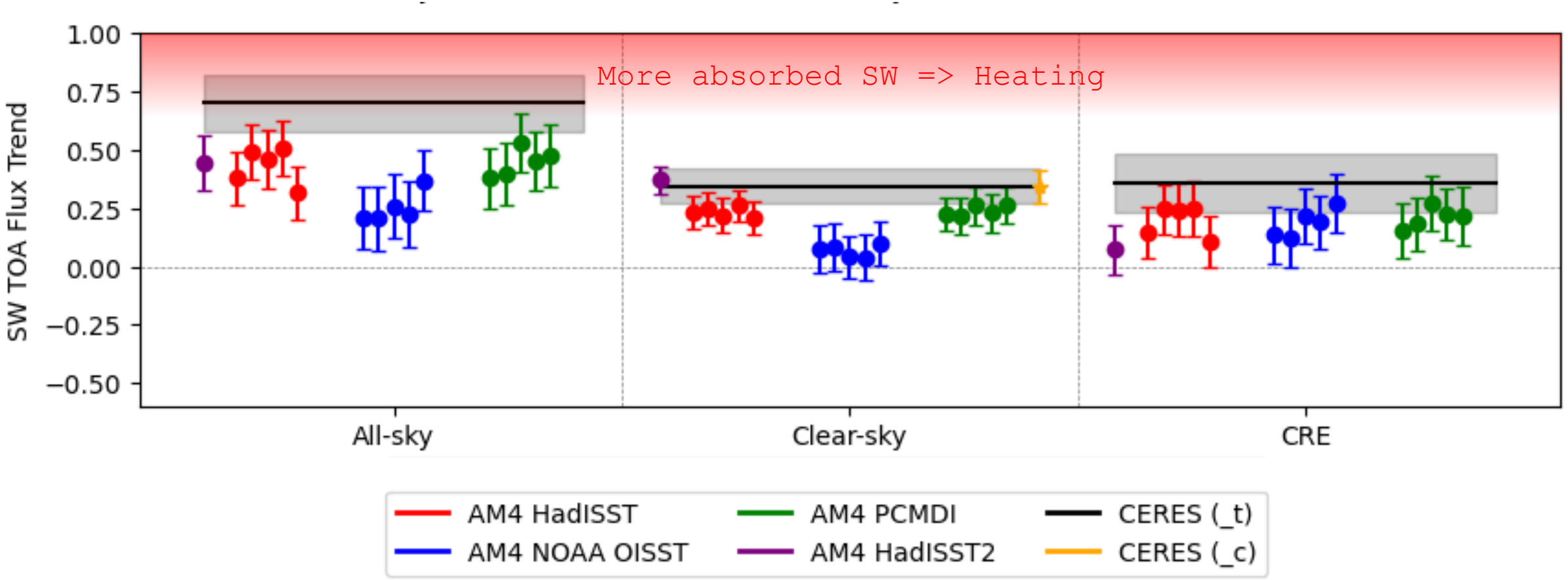
Comparison of broadband LW flux trends

(2001~2020)

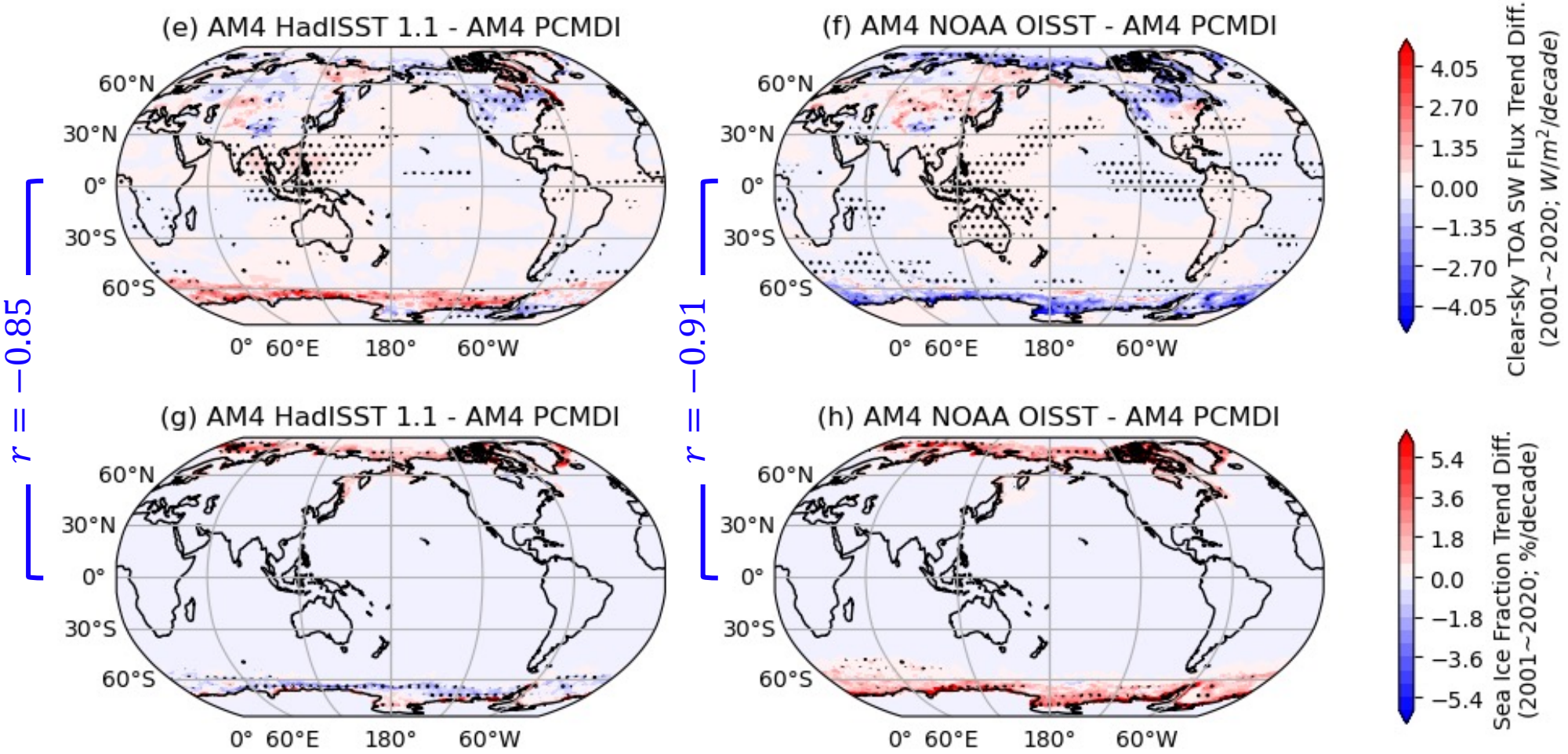


Comparison of broadband SW flux trends

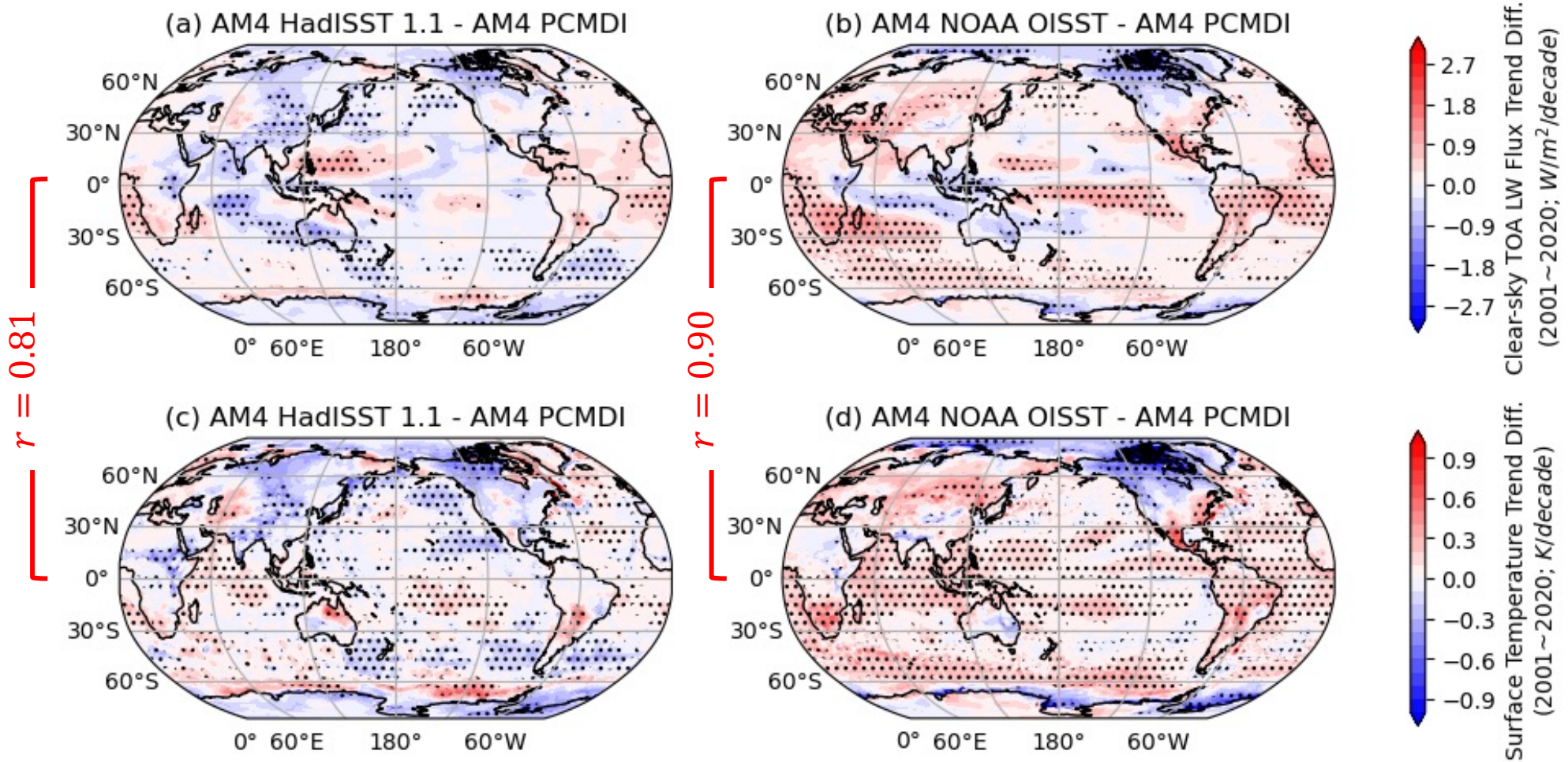
(2001~2020)



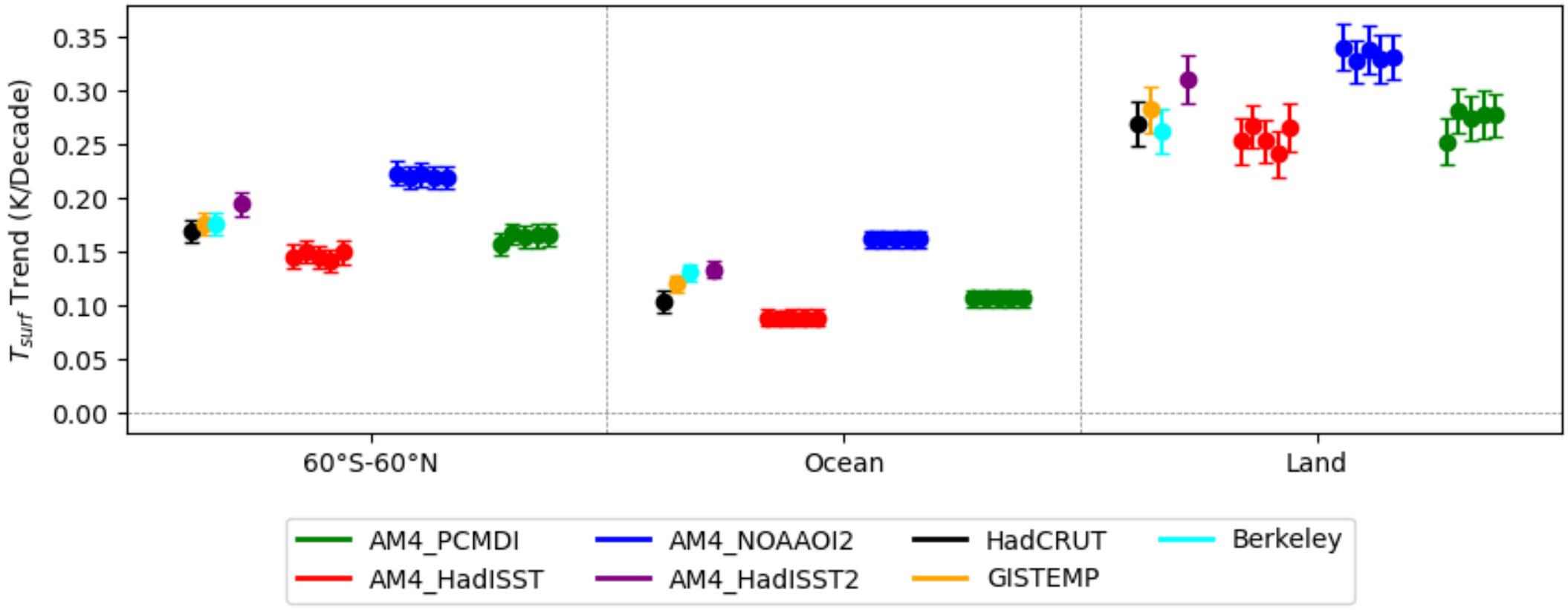
Clear-sky SW flux correlated to SI trends



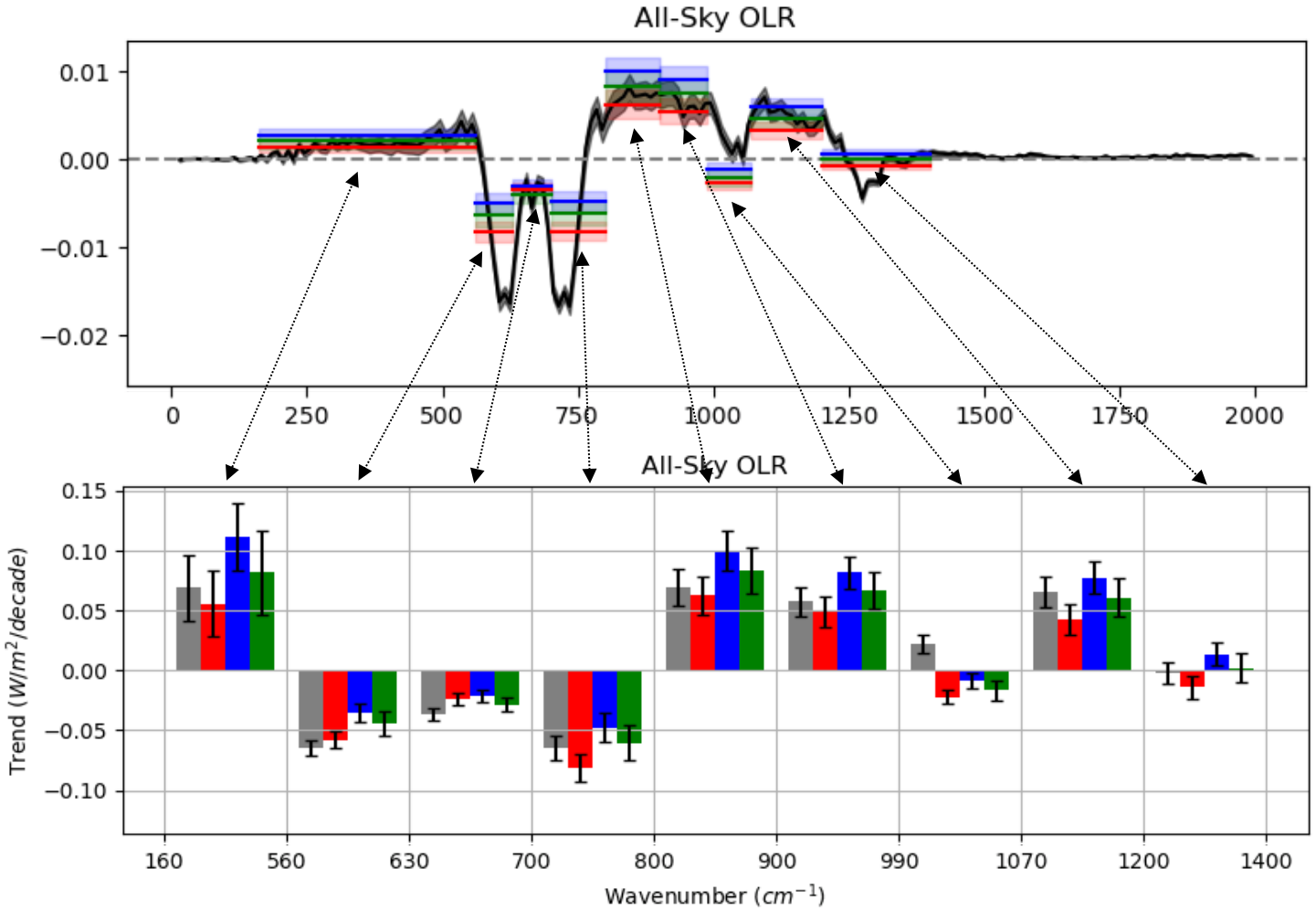
Clear-sky LW flux correlated to T_{surf} trends



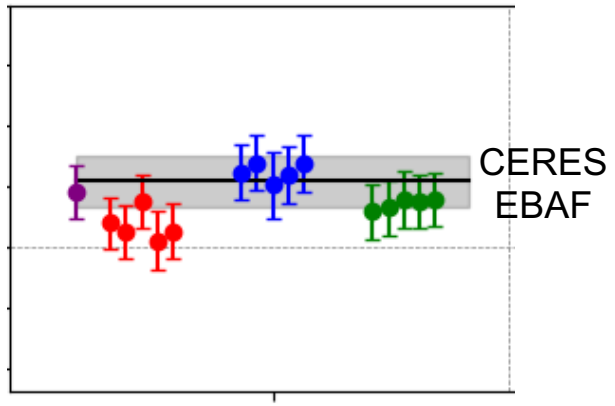
Global surface temperature datasets



Comparison to AIRS Spectral OLR



Broadband all-sky OLR for reference



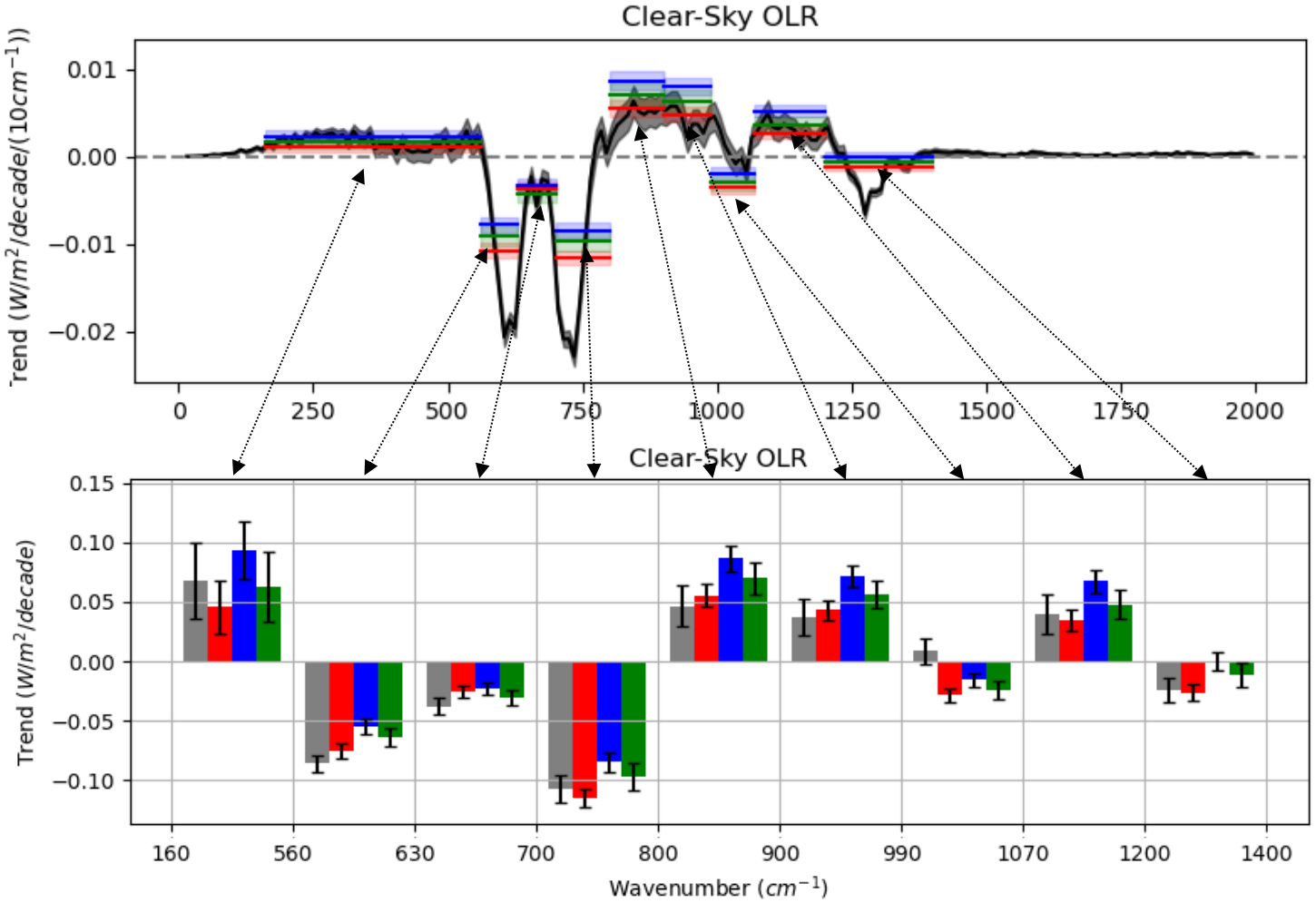
AIRS L3 OLR

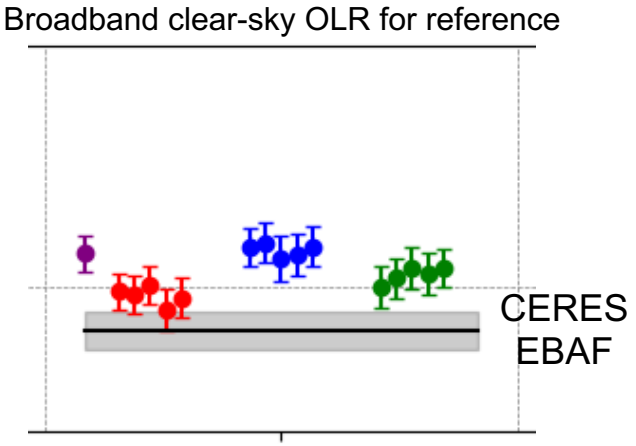
AM4 HadISST 1

AM4 PCMDI

AM4 NOAA OISST

Comparison to AIRS Spectral OLR





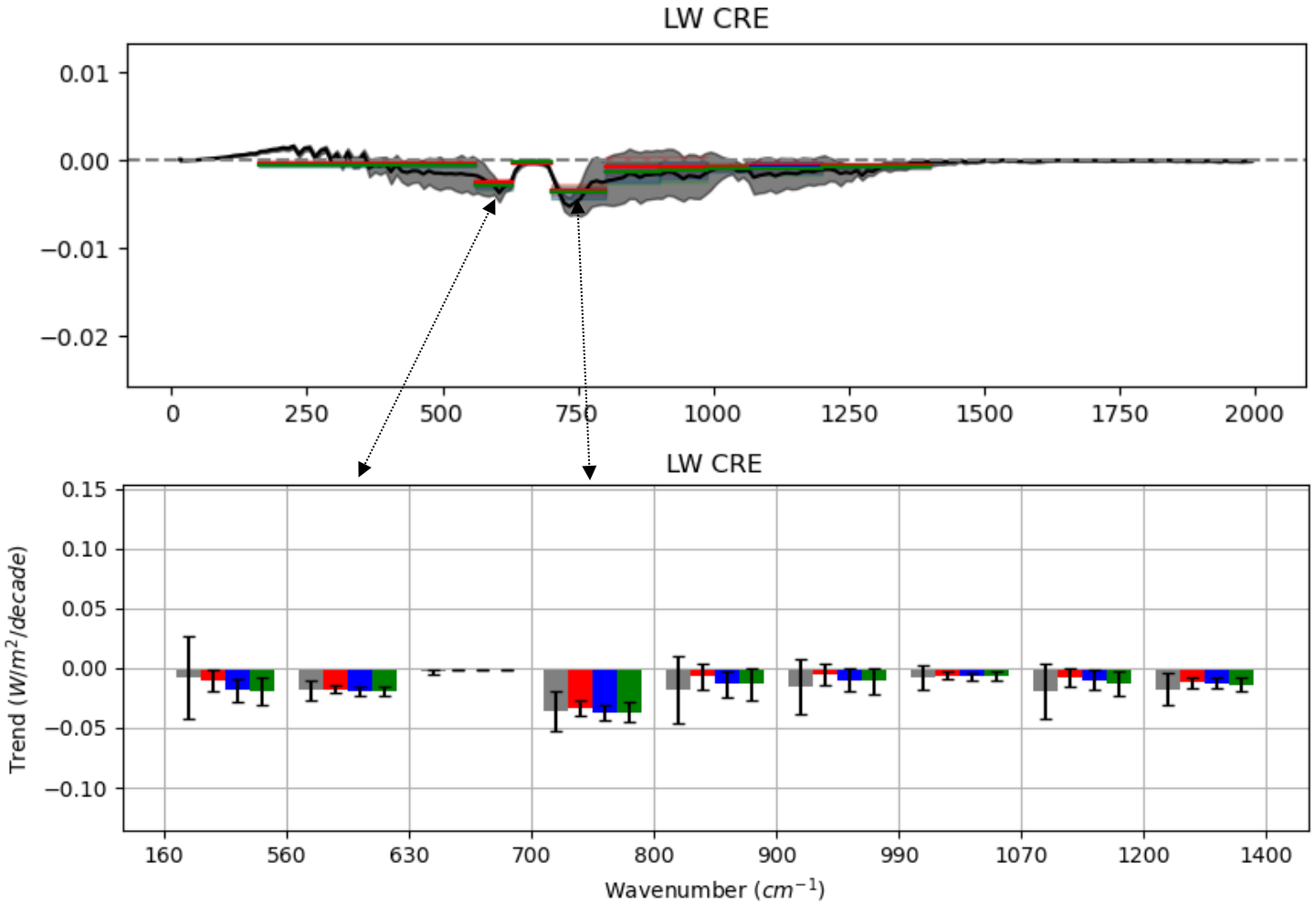
AIRS L3 OLR

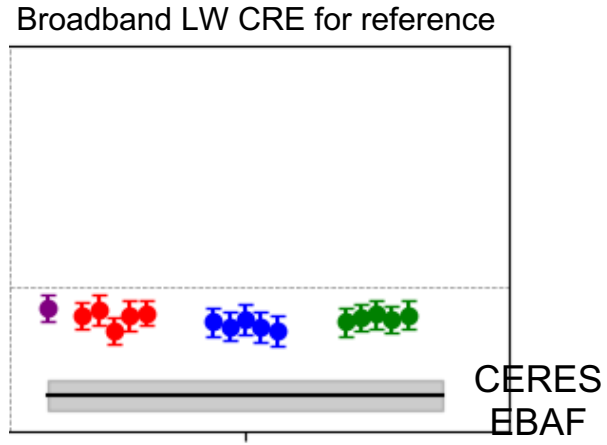
AM4 HadISST 1

AM4 PCMDI

AM4 NOAA OISST

Comparison to AIRS Spectral OLR





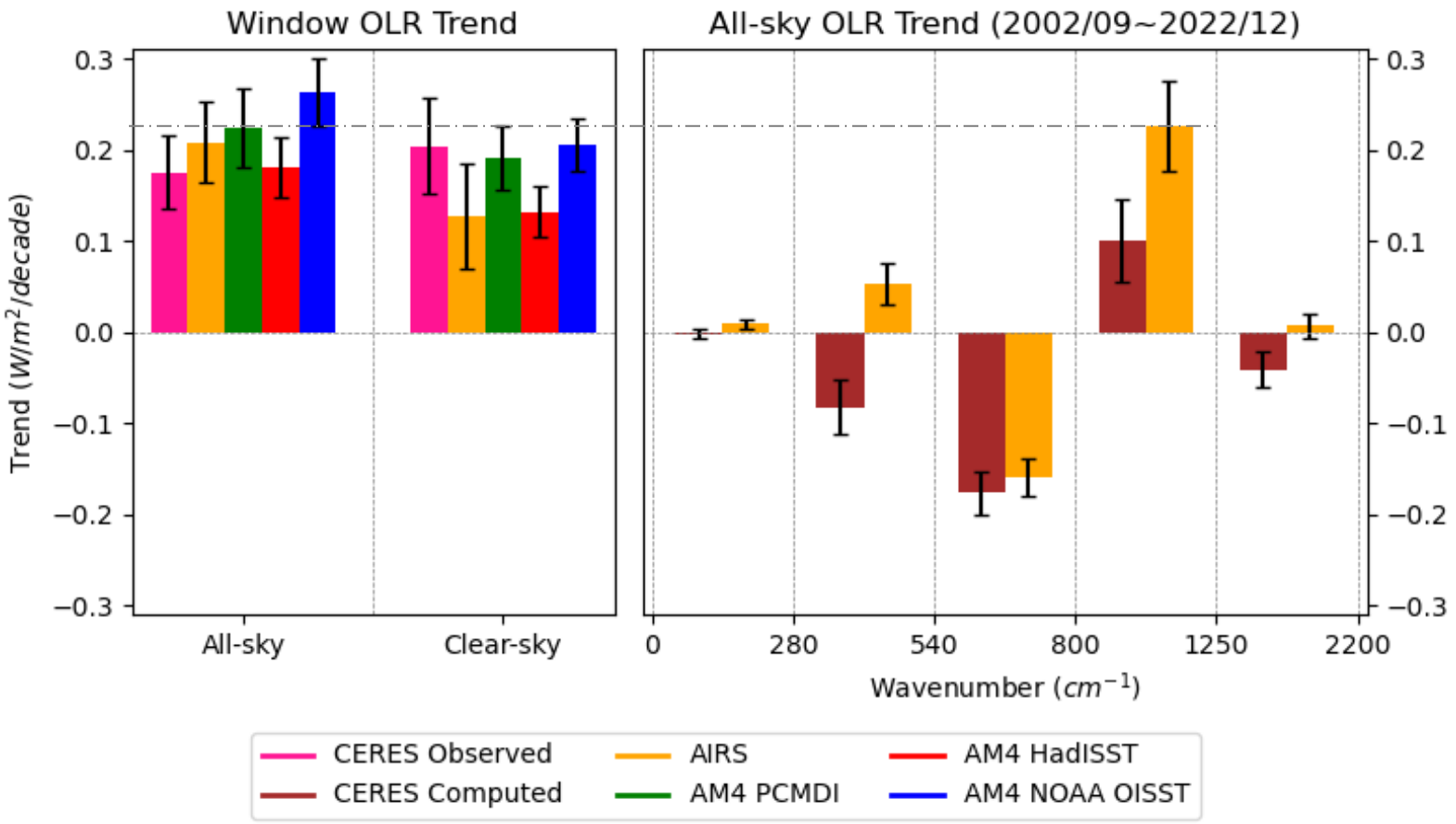
AIRS L3 OLR

AM4 HadISST 1

AM4 PCMDI

AM4 NOAA OISST

Spectral fluxes from CERES?



CERES SYN1deg Obs.

CERES SYN1deg Cmp.

AIRS L3 OLR

AM4 HadISST 1

AM4 PCMDI

AM4 NOAA OISST

Take-home Messages

- Strikingly different trends in the last four decades in different SST and sea ice products
  - ✓ SST: NOAA OISST V2.1 > HadISST 2.4.0.0 > PCMDI v1.1.18 ≈ HadISST 1.1
  - ✓ Sea ice: abrupt increase in NOAA OISST V2.1 in 2004, abrupt decrease in HadISST 2.2.1.0 in 2004
- Clear-sky outgoing LW flux positively correlated to SST trends, clear-sky absorbed SW flux negatively correlated to sea ice trends, resulting in differences in AMIP simulations when prescribed by different SST / sea ice products
  - ✓ AM4 NOAA OISST has the most consistent all-sky OLR trend with CERES, but for the wrong reason (too positive clear-sky OLR trend and weakly negative LWCRE trend); all model simulations struggle to reproduce negative LWCRE trend in CERES.
  - ✓ AM4 HadISST 2 has the most consistent clear-sky ASR trend with CERES; all model simulations fail to reproduce SWCRE trend.
  - ✓ For net flux trend, AM4 NOAA OISST reports negative net flux trend due to strongly positive OLR trend and weakly positive ASR trend; AM4 HadISST has the most consistent trend with CERES.

Take-home Messages

- Comparison to global surface temperature dataset favors AM4 HadISST and AM4 PCMDI simulations
  - ✓ Spread of SST in SST analysis datasets is larger than the spread of surface temperature over ocean in global surface temperature datasets.
  - ✓ AM4 NOAA OISST produces too warm surface temperature over both ocean and land.
- Comparison to AIRS spectral OLR favors AM4 HadISST simulation.
  - ✓ AM4 HadISST has the best consistency with AIRS spectral OLR product except in ozone band; compensating errors in atmospheric window band in AM4 PCMDI simulation.
  - ✓ Model LWCRE trends are very close to the AIRS ones, while they are too weak compared to CERES product (which is right?).
  - ✓ CERES provides computed spectral fluxes that could be helpful in further diagnosing the problem, but it has drifting issues before 2005 and after 2016.
  - ✓ Diagnosis of spectral SW trend?
- The importance of cross-checking multiple variables from multiple datasets and identifying compensating errors when comparing model and obs.

Thank you

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References

- Huang, B., Liu, C., Banzon, V., Freeman, E., Graham, G., Hankins, B., Smith, T., & Zhang, H. (2021). Improvements of the Daily Optimum Interpolation Sea Surface Temperature (DOISST) Version 2.1. *Journal of Climate*, *34*(8), 2923–2939. https://doi.org/10.1175/jcli-d-20-0166.1
- Huang, X., Chen, X., Potter, G. L., Oreopoulos, L., Cole, J. N. S., Lee, D., & Loeb, N. G. (2014). A Global Climatology of Outgoing Longwave Spectral Cloud Radiative Effect and Associated Effective Cloud Properties. Journal of Climate, 27(19), 7475-7492. https://doi.org/10.1175/JCLI-D-13-00663.1
- Huang, X., Loeb, N. G., & Yang, W. (2010). Spectrally resolved fluxes derived from collocated AIRS and CERES measurements and their application in model evaluation: 2. Cloudy sky and band-by-band cloud radiative forcing over the tropical oceans. Journal of Geophysical Research Atmospheres, 115(D21). https://doi.org/10.1029/2010jd013932
- Huang, X., Yang, W., Loeb, N. G., & Ramaswamy, V. (2008). Spectrally resolved fluxes derived from collocated AIRS and CERES measurements and their application in model evaluation: Clear sky over the tropical oceans. Journal of Geophysical Research Atmospheres, 113(D9). https://doi.org/10.1029/2007jd009219
- Loeb, N. G., Doelling, D. R., Wang, H., Su, W., Nguyen, C., Corbett, J. G., Liang, L., Mitrescu, C., Rose, F. G., & Kato, S. (2018). Clouds and the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) Top-of-Atmosphere (TOA) Edition-4.0 Data Product. *Journal of Climate*, *31*(2), 895-918. https://doi.org/10.1175/JCLI-D-17-0208.1
- Olonscheck, D., & Rugenstein, M. (2024). Coupled climate models systematically underestimate radiation response to surface warming. *Geophysical Research Letters*, *51*(6). https://doi.org/10.1029/2023gl106909

References

- Raghuraman, S. P., Paynter, D., & Ramaswamy, V. (2021). Anthropogenic forcing and response yield observed positive trend in Earth's energy imbalance. *Nature Communications*, *12*(1). https://doi.org/10.1038/s41467-021-24544-4
- Rayner, N. A., D. E. Parker, E. B. Horton, C. K. Folland, L. V. Alexander, D. P. Rowell, E. C. Kent, and A. Kaplan (2003), Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century, *J. Geophys. Res.*, 108, 4407, https://doi.org/10.1029/2002JD002670
- Reynolds, R. W., Smith, T. M., Liu, C., Chelton, D. B., Casey, K. S., & Schlax, M. G. (2007). Daily High-Resolution-Blended analyses for sea surface temperature. *Journal of Climate*, *20*(22), 5473–5496. https://doi.org/10.1175/2007jcli1824.1
- Schmidt, G. A., Andrews, T., Bauer, S. E., Durack, P. J., Loeb, N. G., Ramaswamy, V., Arnold, N. P., Bosilovich, M. G., Cole, J., Horowitz, L. W., Johnson, G. C., Lyman, J. M., Medeiros, B., Michibata, T., Olonscheck, D., Paynter, D., Raghuraman, S. P., Schulz, M., Takasuka, D., ... Ziehn, T. (2023). CERESMIP: a climate modeling protocol to investigate recent trends in the Earth's Energy Imbalance. *Frontiers in Climate*, *5*. https://doi.org/10.3389/fclim.2023.1202161
- Taylor, K. E., Williamson, D., & Zwiers, F. (2000). The sea surface temperature and sea ice concentration boundary conditions for AMIP II simulations. PCMDI Report 60, Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory, 25 pp.

References

- Zhao, M., Golaz, J.-C., Held, I. M., Guo, H., Balaji, V., Benson, R., et al. (2018a). The GFDL global atmosphere and land model AM4.0/LM4.0: 1. Simulation characteristics with prescribed SSTs. Journal of Advances in Modeling Earth Systems, 10, 691–734. https://doi.org/10.1002/2017MS001208
- Zhao, M., Golaz, J.-C., Held, I. M., Guo, H., Balaji, V., Benson, R., et al. (2018b). The GFDL global atmosphere and land model AM4.0/LM4.0: 2. Model description, sensitivity studies, and tuning strategies. Journal of Advances in Modeling Earth Systems, 10, 735–769. https://doi.org/10.1002/2017MS001209