Department of Meteorology

University of Reading

TRUTHS potential contributions in atmospheric modelling and understanding changes in Earth's radiation budget

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TRUTHS for Climate Workshop 27-28 June 2024

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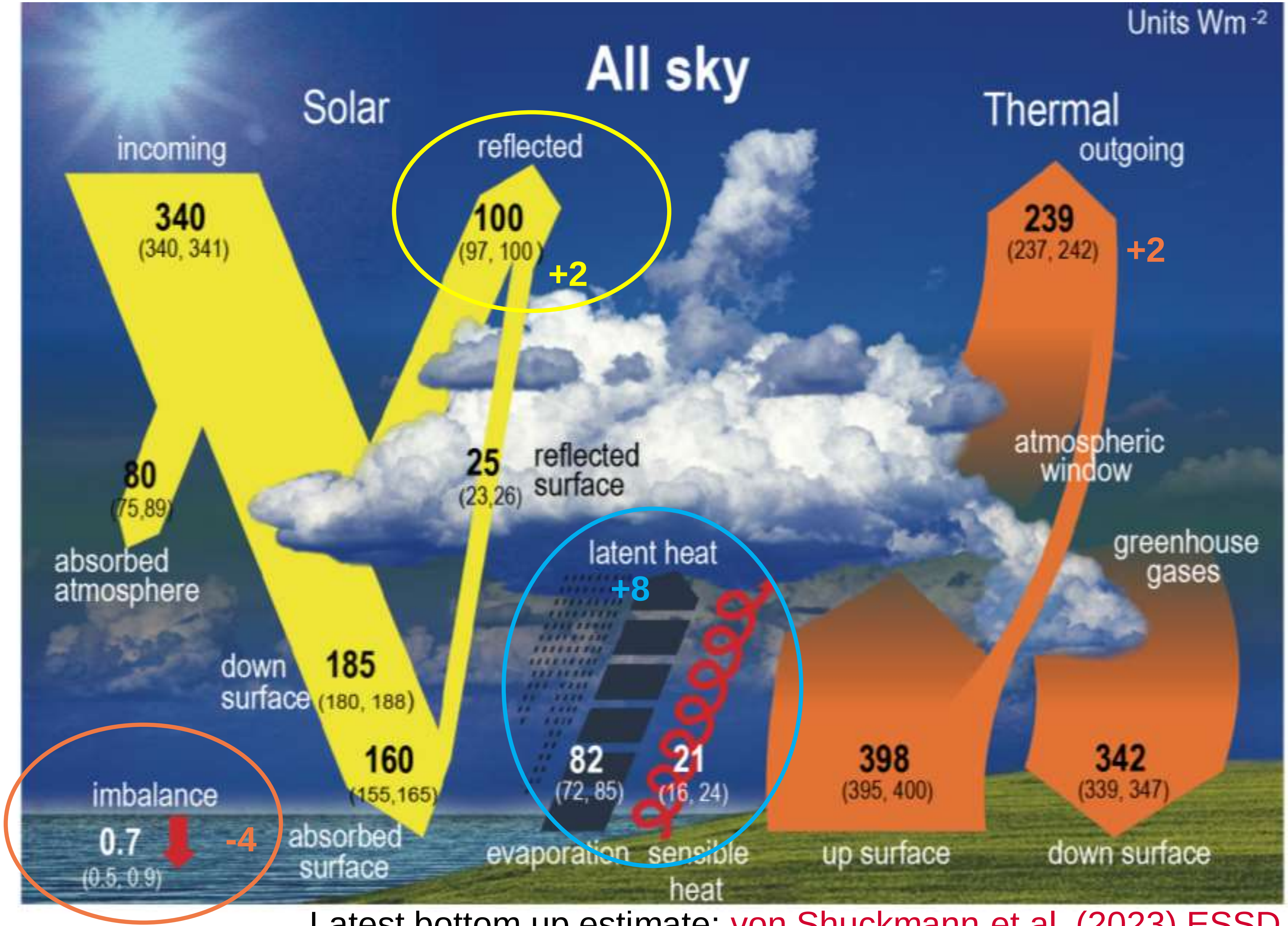


Latest bottom up estimate: [von Shuckmann et al. (2023) ESSD]

SPOT THE IMBALANCE…

← Earth's present day energy budget

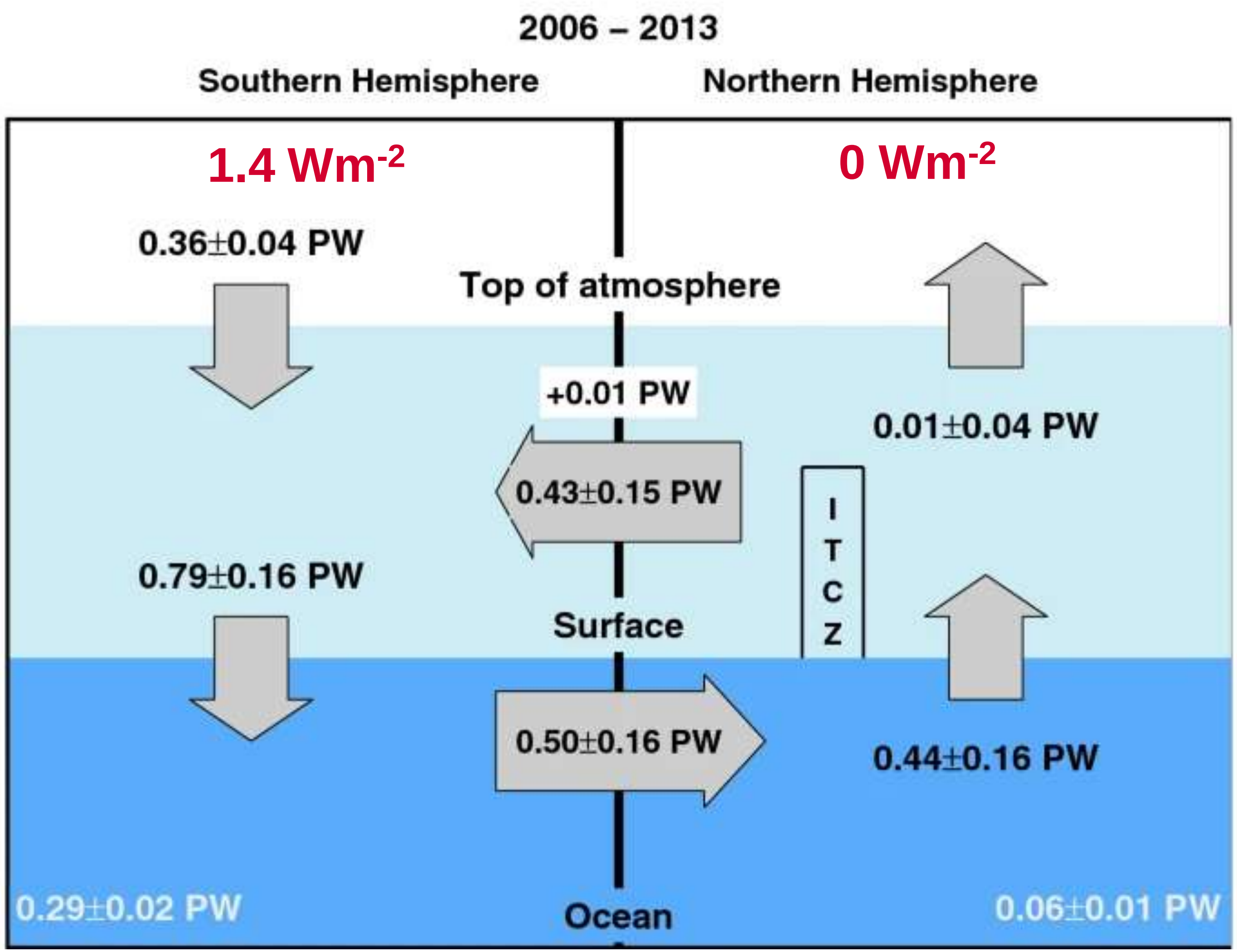
Forster et al. (2021) Chapter 7 of IPCC report, [Figure 7.2]

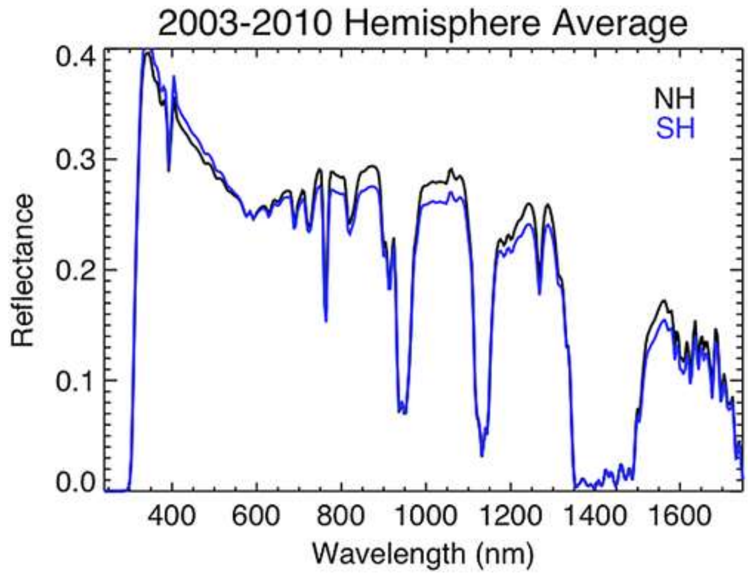
CERES adjusts reflected shortwave to force small imbalance to agree with Argo ocean heating

e.g. [Loeb et al. (2018) J. Clim]

→ Energy – water cycle uncertainty e.g. [Stephens et al. (2012) Nature Geosci.]

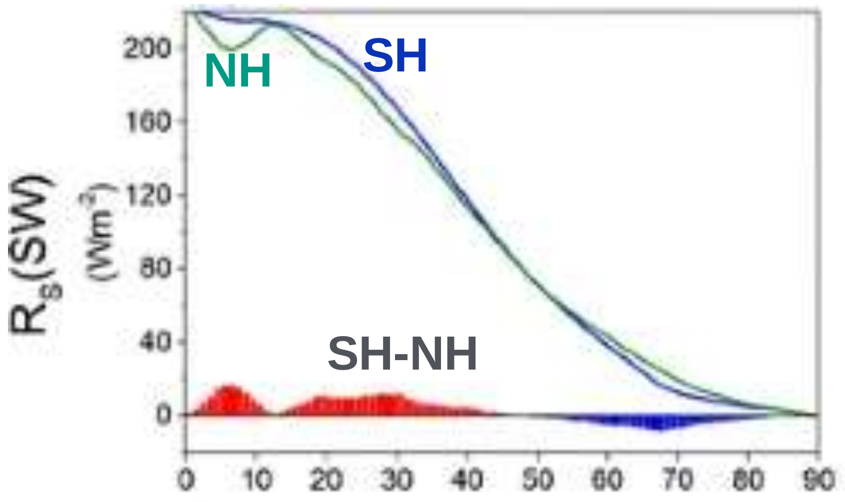
HEMISPHERIC IMBALANCE





[Stephens et al. (2015) Rev. Geophys.]

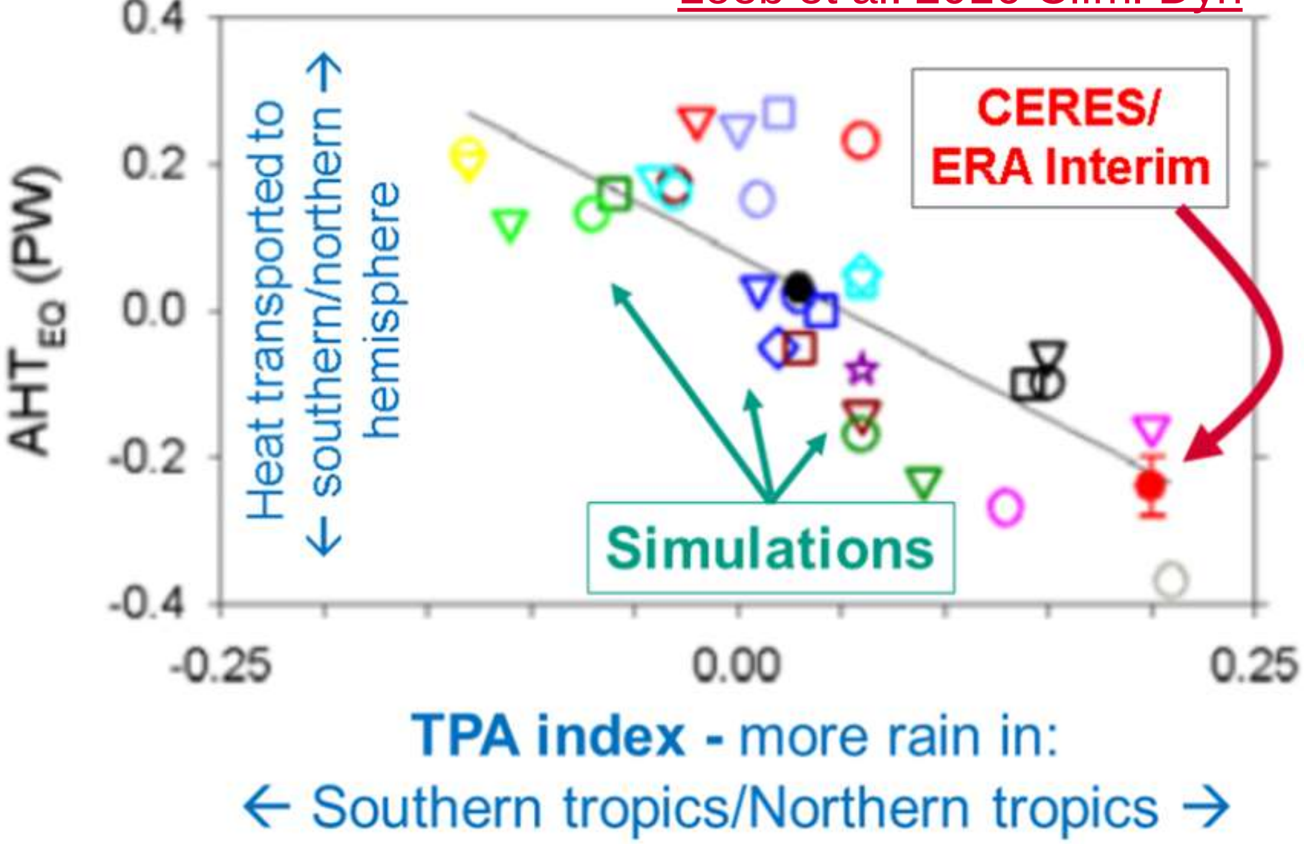
Surface shortwave with latitude



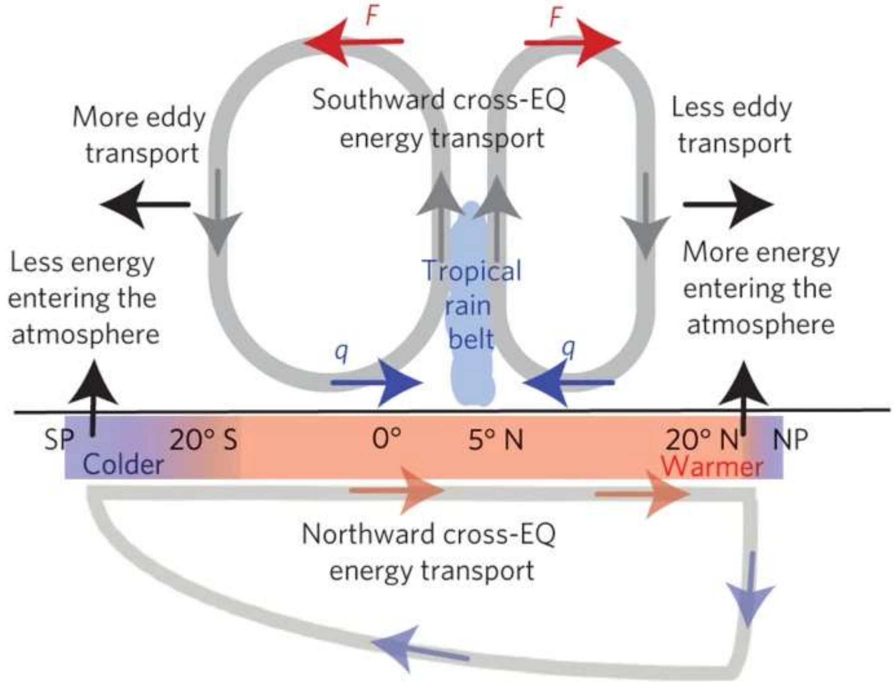
Liu et al. (2020) Clim. Dyn.; Loeb et al. 2016 Clim. Dyn

HEMISPHERIC IMBALANCE & PRECIPITATION

Loeb et al. 2016 Clim. Dyn



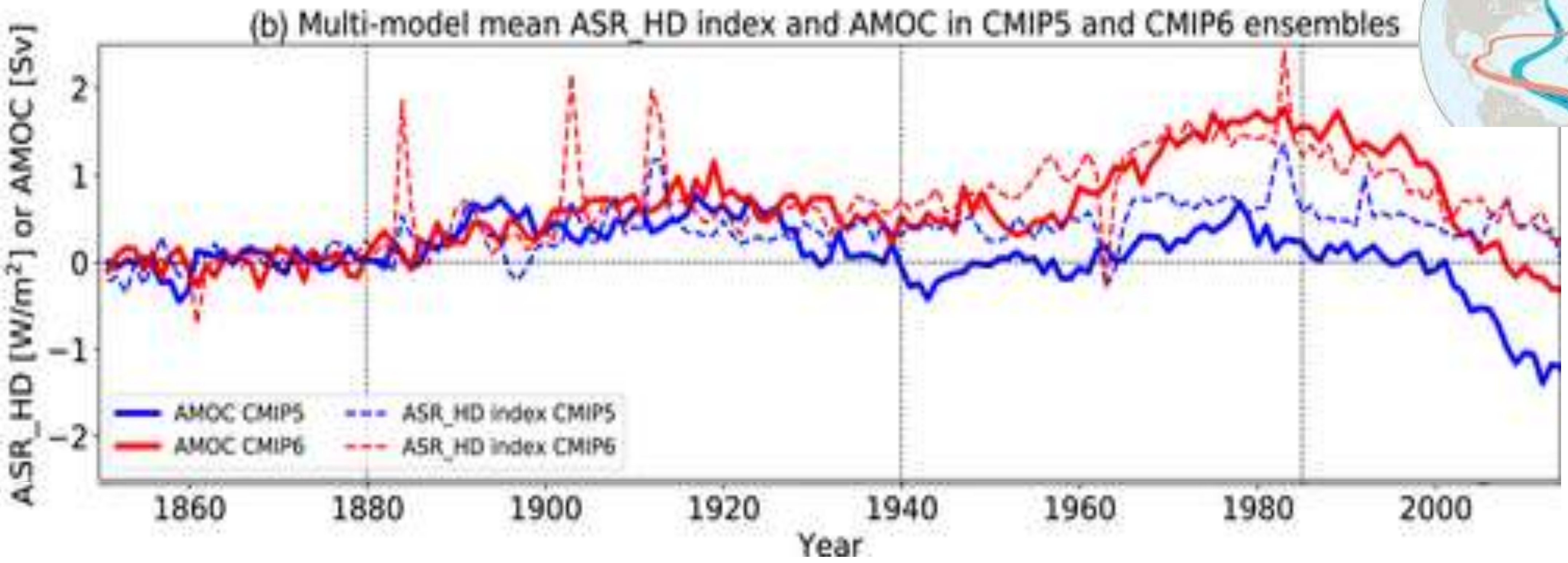
Estimated cross equatorial atmospheric heat transport in peta Watts (AHT_{EQ}) against an index of tropical precipitation asymmetry (TPA) between hemispheres in simulations and observations



Frierson et al. (2013) Nature Geosci.

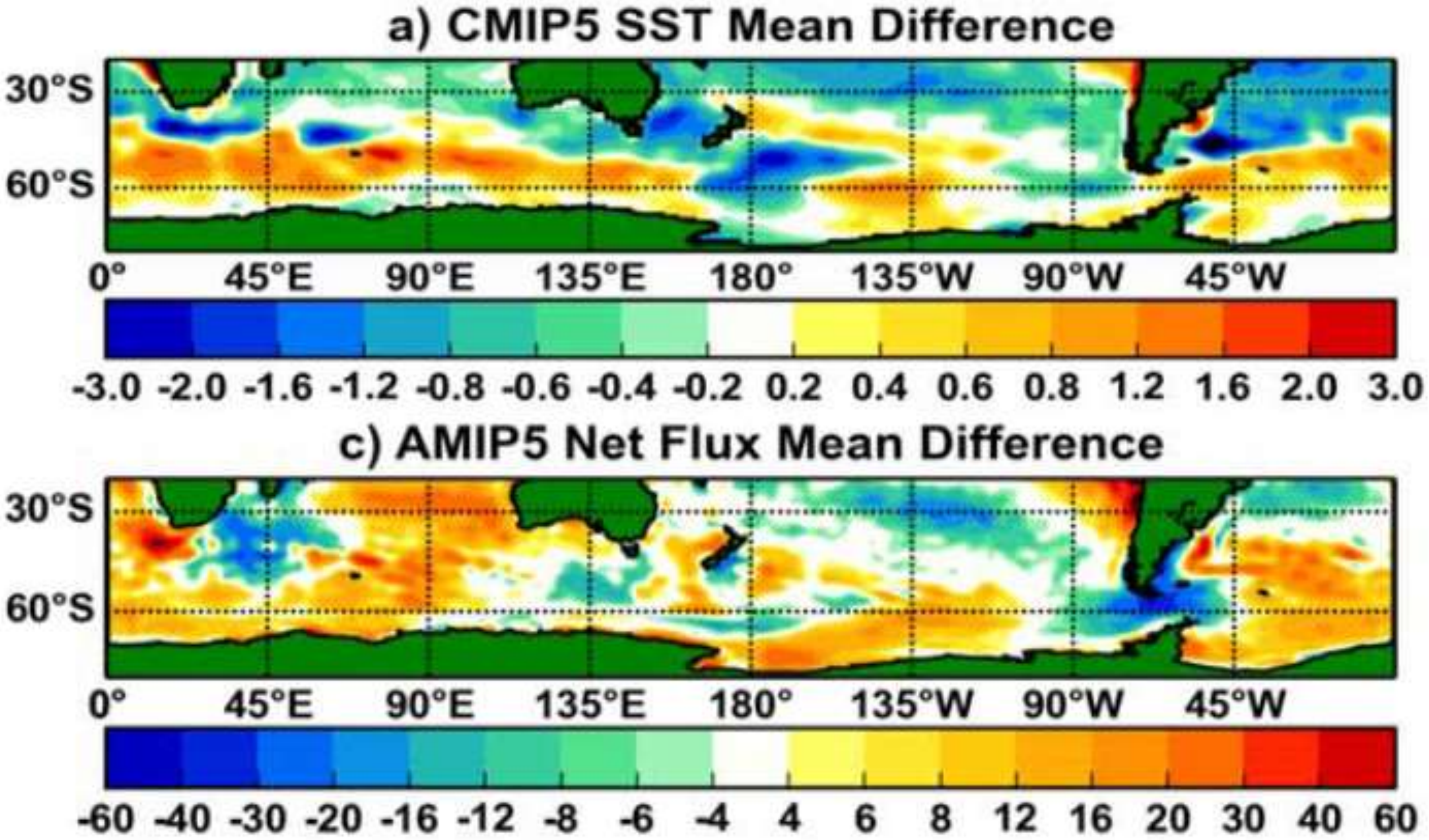
Zhang et al. (2023) Adv.Atmos.Sci.; Pearce & Bodas-Salcedo (2023) J. Clim; Rugenstein & Hakuba (2023) GRL; Diamond et al. (2022) Comm. Earth Env.; Jonsson & Bender (2022) J. Clim. …

HEMISPHERIC SHORTWAVE DIFFERENCE & OCEAN CIRCULATION



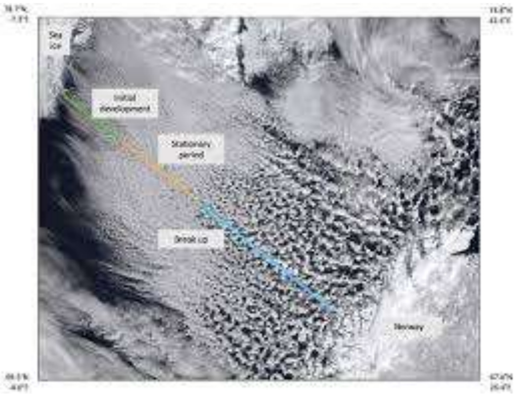
Menary et al. (2021) GRL

INTRANSIGENT SYSTEMATIC BIASES

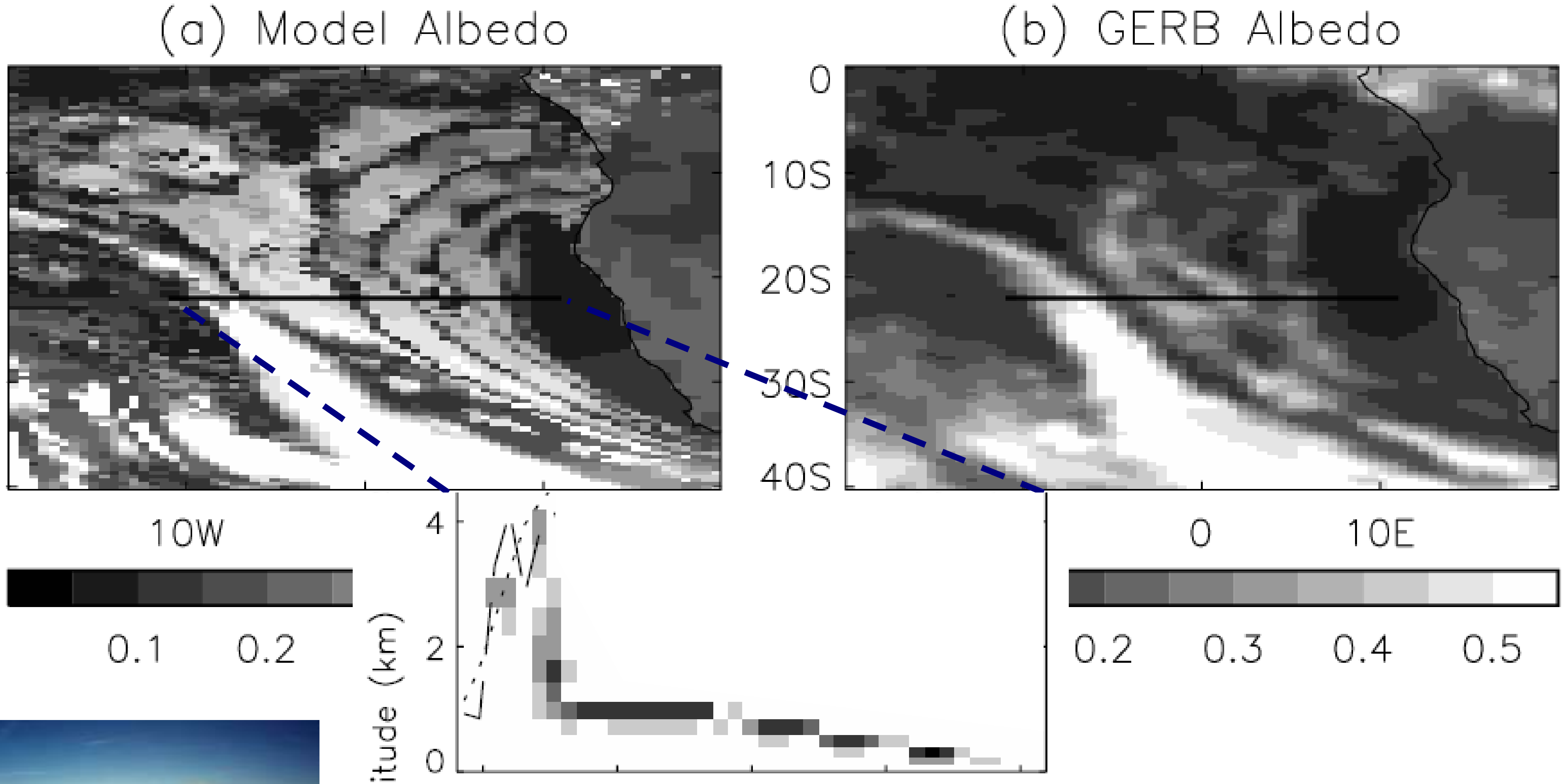


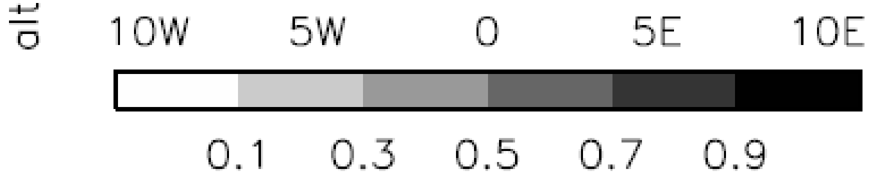
- Subtle contrasts in reflection of sunlight crucial in understanding & addressing systematic biases in climate models

Hyder et al. (2018) *Nature Comms*



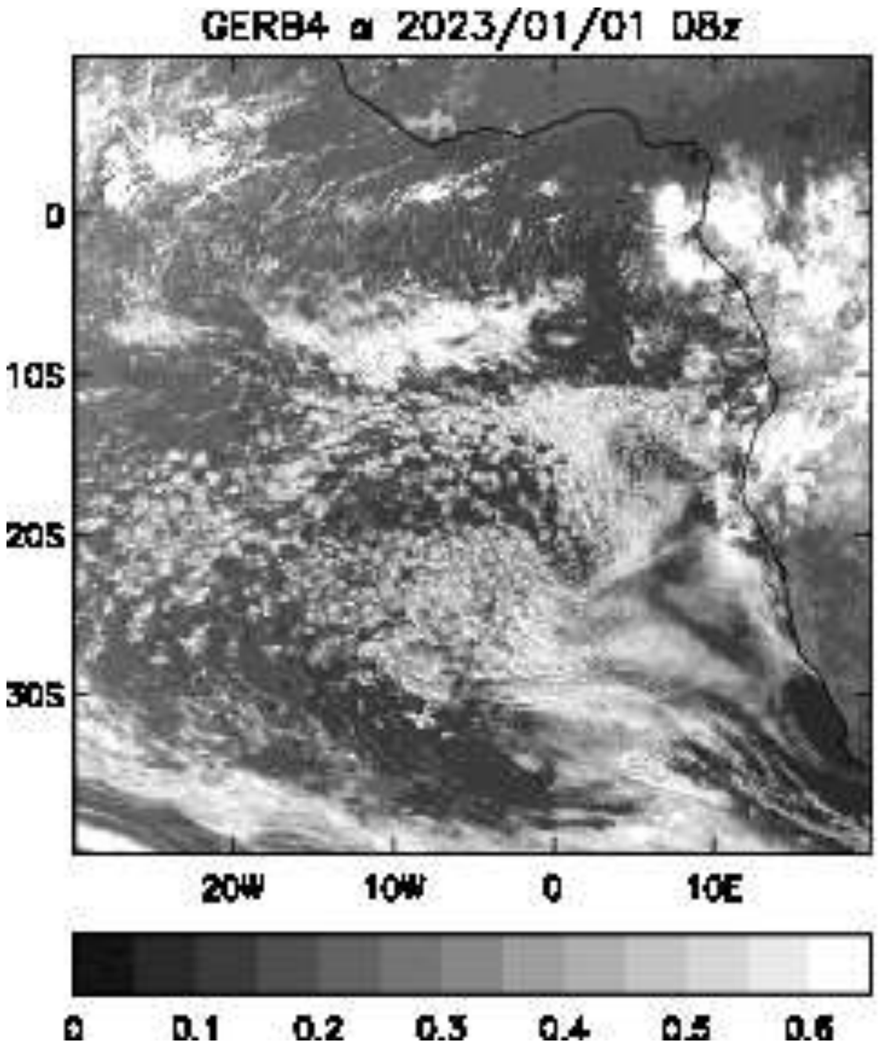
ANCIENT HISTORY

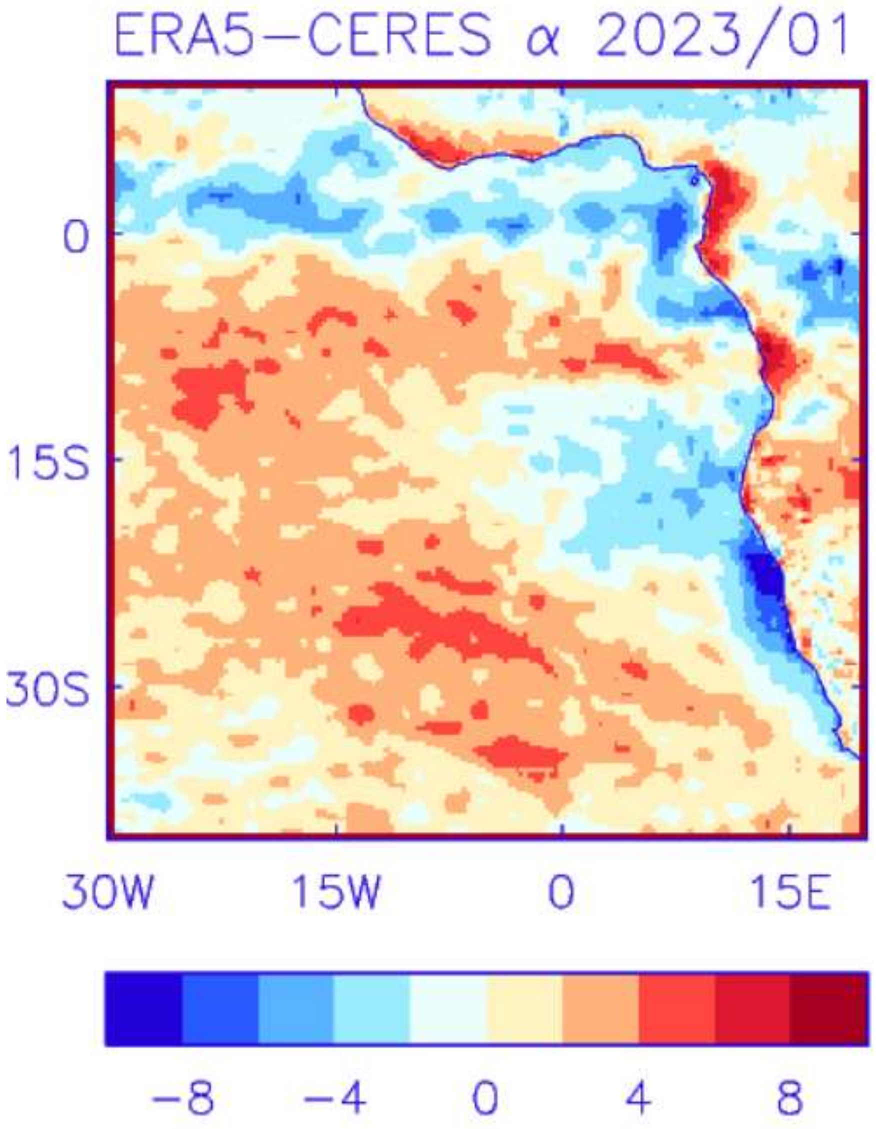


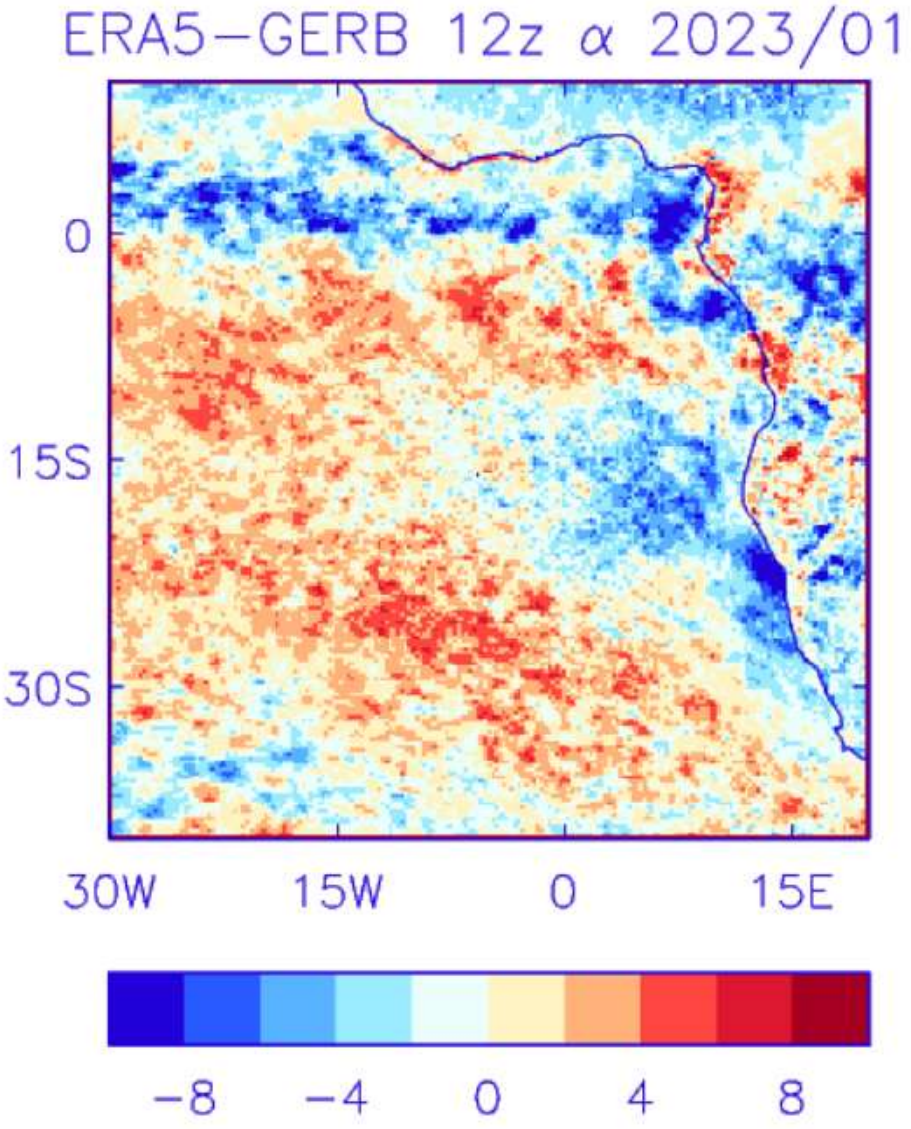


Allan et al. (2007) QJRMetS

GERB4 VS ERA5 HOURLY

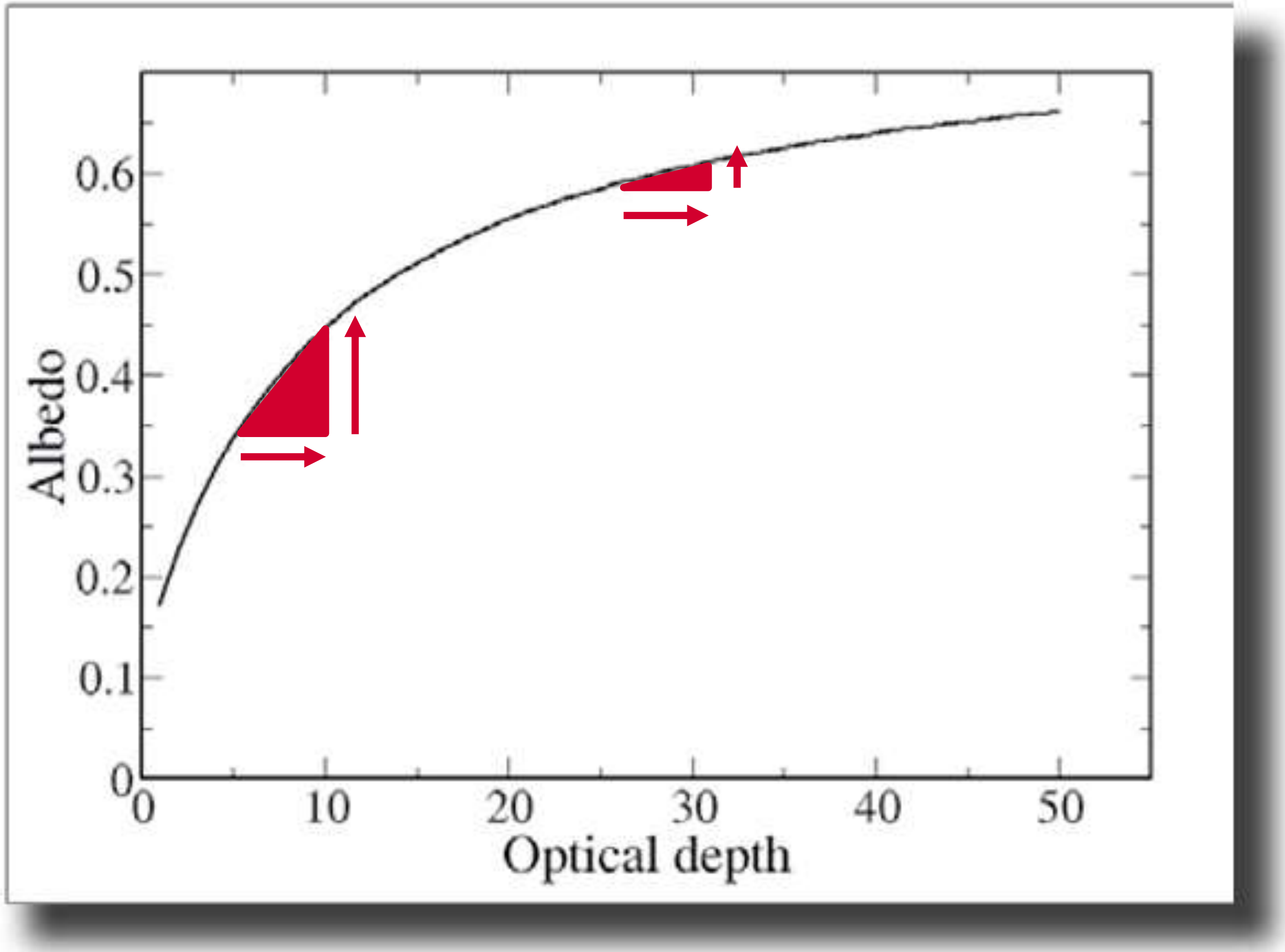






- ERA5 minus observations (% albedo)
- Monthly daily mean (CERES)
- Monthly 12-13z mean (GERB4)

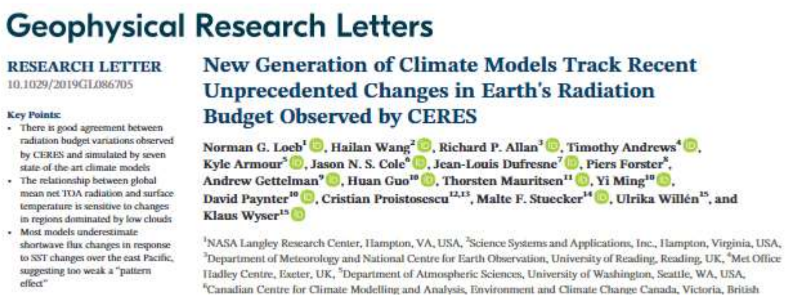
OPTICAL DEPTH FEEDBACKS



Calculated relationship between cloud albedo and optical depth based on a simple radiation model where vertically incident sunlight is assumed.

- Sensitivity of cloud albedo to cloud optical depth changes increases rapidly for dimmer clouds

HAVE CLOUDS BEEN DISSOLVING?


Geophysical Research Letters

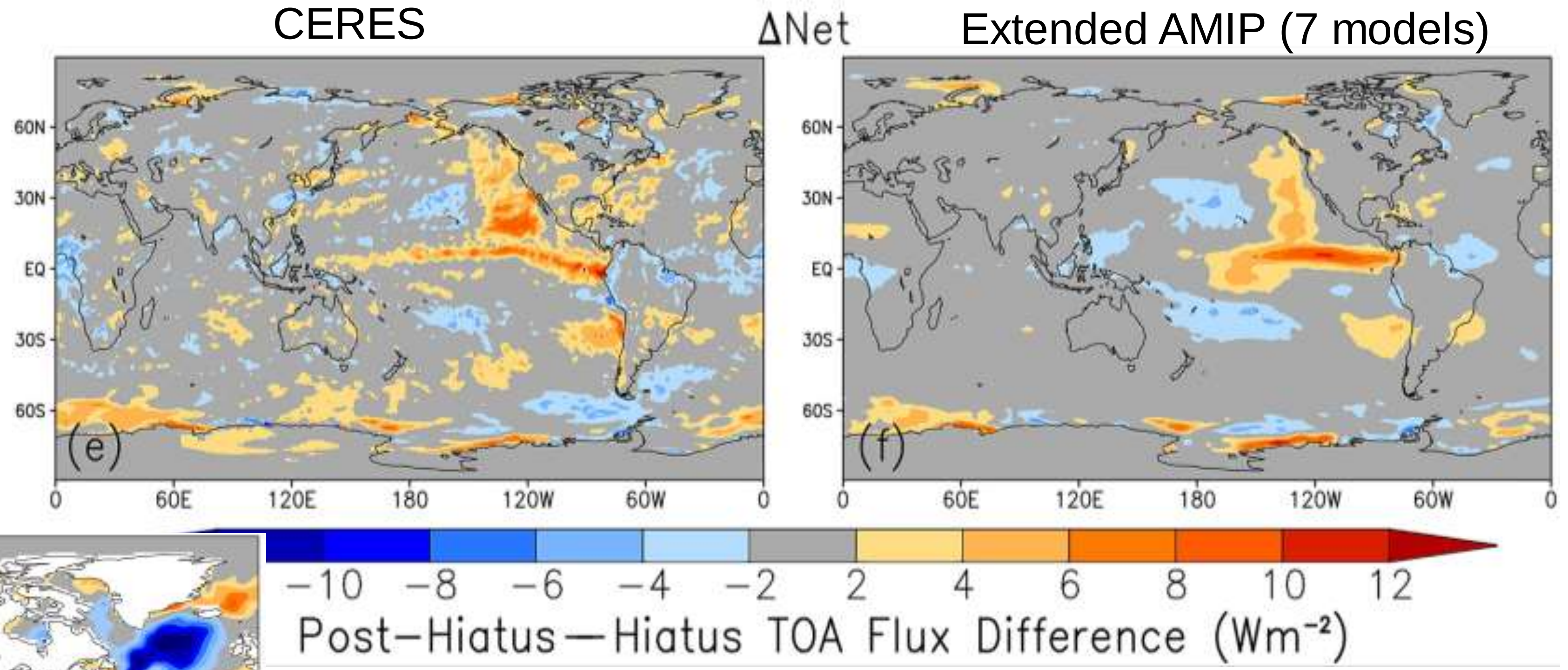
RESEARCH LETTER
10.1029/2019GL086705

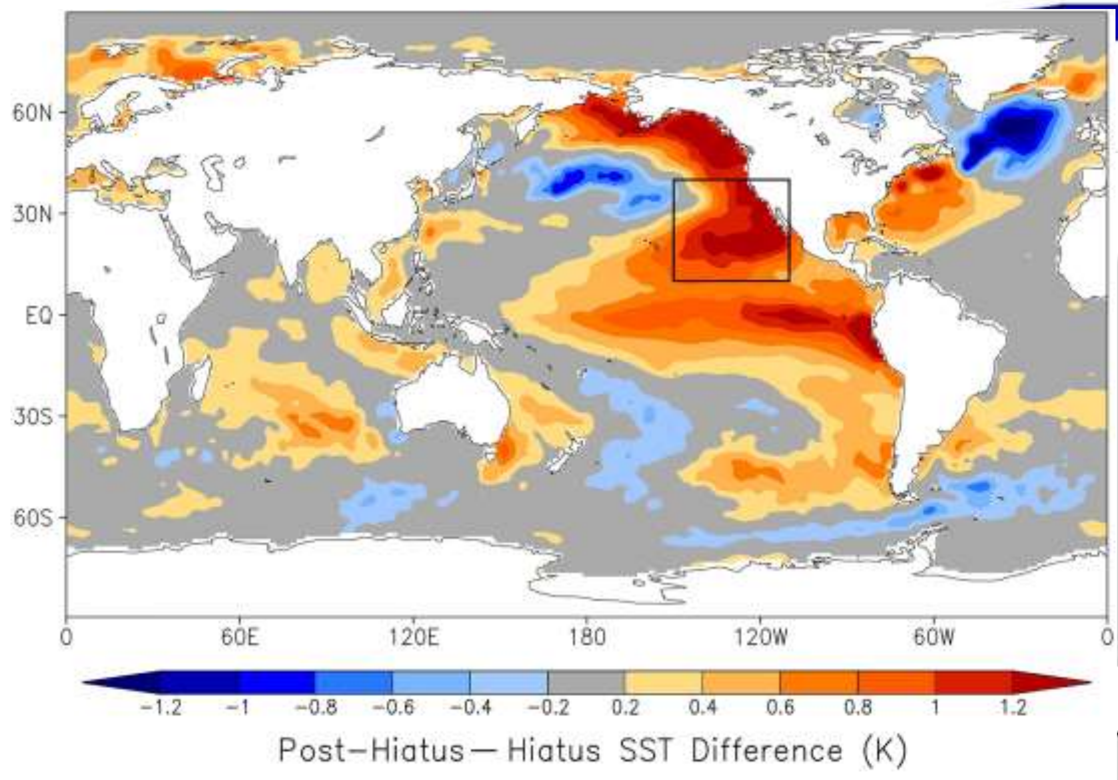
Key Points:
- There is good agreement between radiation budget variations observed by CERES and simulated by seven state-of-the-art climate models
- The relationship between global mean net TOA radiation and surface temperature is sensitive to changes in regions dominated by low clouds
- Most models underestimate shortwave flux changes in response to SST changes over the east Pacific, suggesting too weak a "pattern effect"

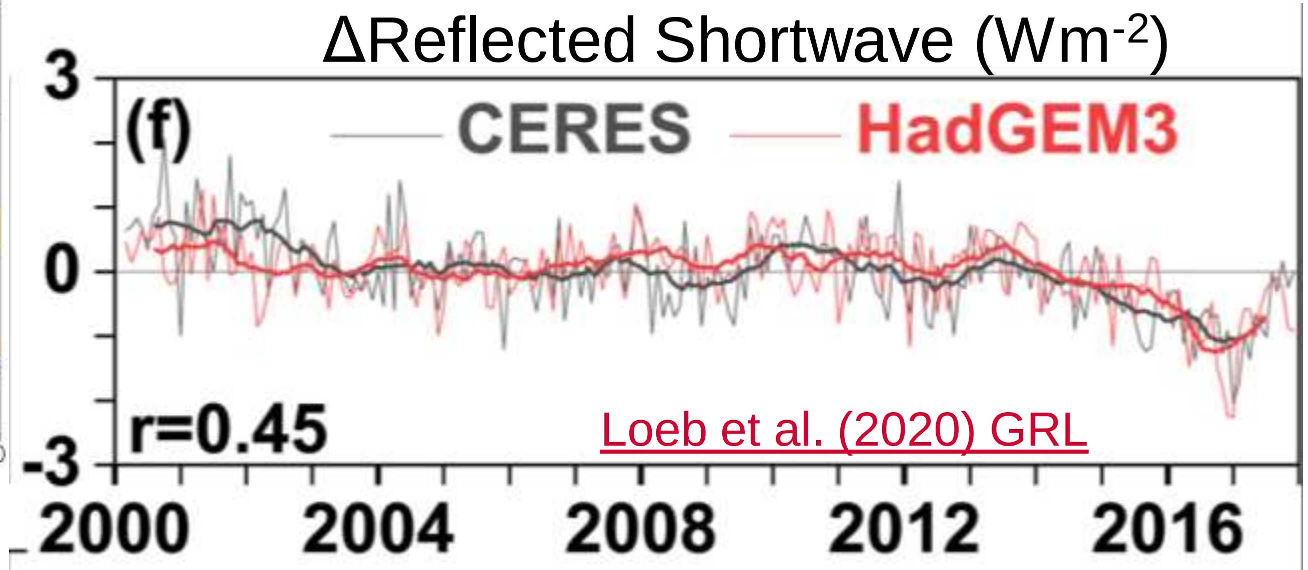
New Generation of Climate Models Track Recent Unprecedented Changes in Earth's Radiation Budget Observed by CERES

Norman G. Loeb[1], Hailan Wang[2], Richard P. Allan[3], Timothy Andrews[4], Kyle Armour[5], Jason N. S. Cole[6], Jean-Louis Dufresne[7], Piers Forster[8], Andrew Gettelman[9], Huan Guo[10], Thorsten Mauritsen[11], Yi Ming[10], David Paynter[10], Cristian Proistosescu[12,13], Malte F. Stuecker[14], Ulrika Willén[15], and Klaus Wyser[15]

[1]NASA Langley Research Center, Hampton, VA, USA, [2]Science Systems and Applications, Inc., Hampton, Virginia, USA, [3]Department of Meteorology and National Centre for Earth Observation, University of Reading, Reading, UK, [4]Met Office Hadley Centre, Exeter, UK, [5]Department of Atmospheric Sciences, University of Washington, Seattle, WA, USA, [6]Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada, Victoria, British

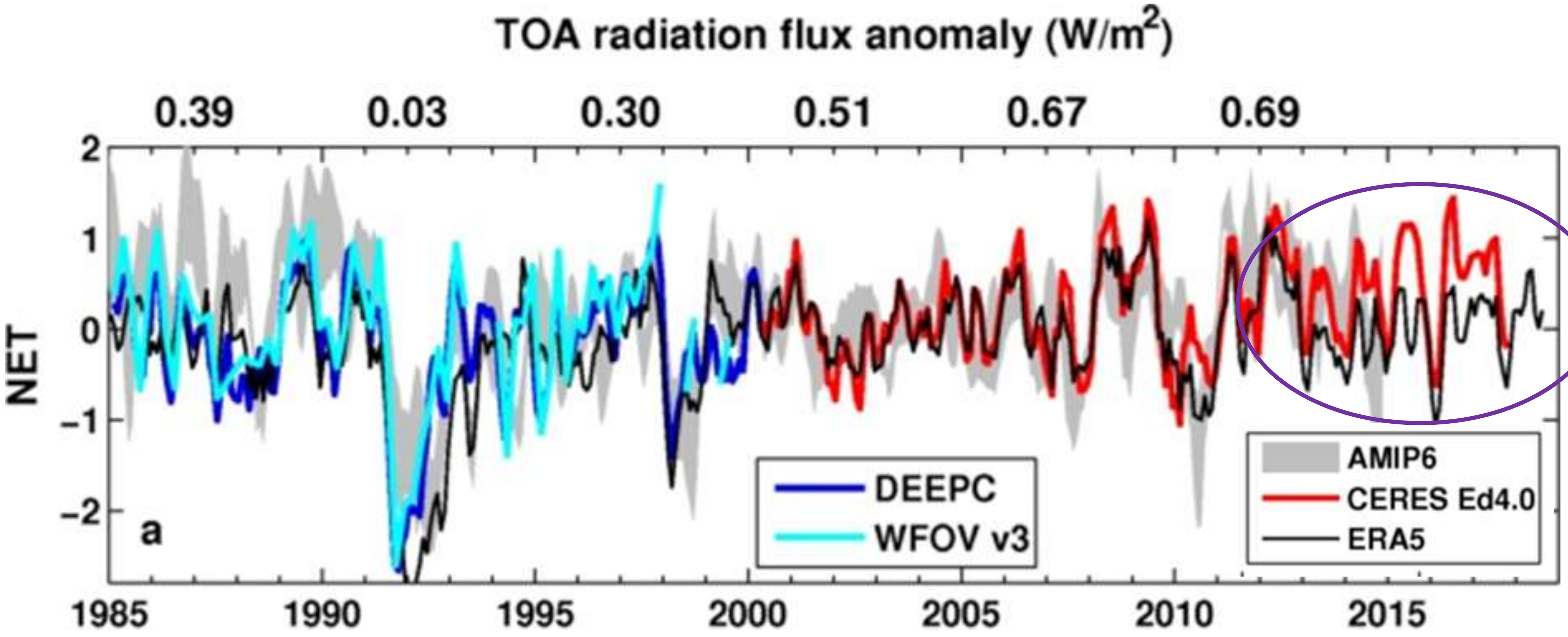






Loeb et al. (2020) GRL

INCREASING NET HEATING OF PLANET



Liu et al. (2020) Clim. Dyn. based on method in Allan et al. (2014) GRL

IS THE PLANET IS SOAKING UP MORE SUNSHINE?

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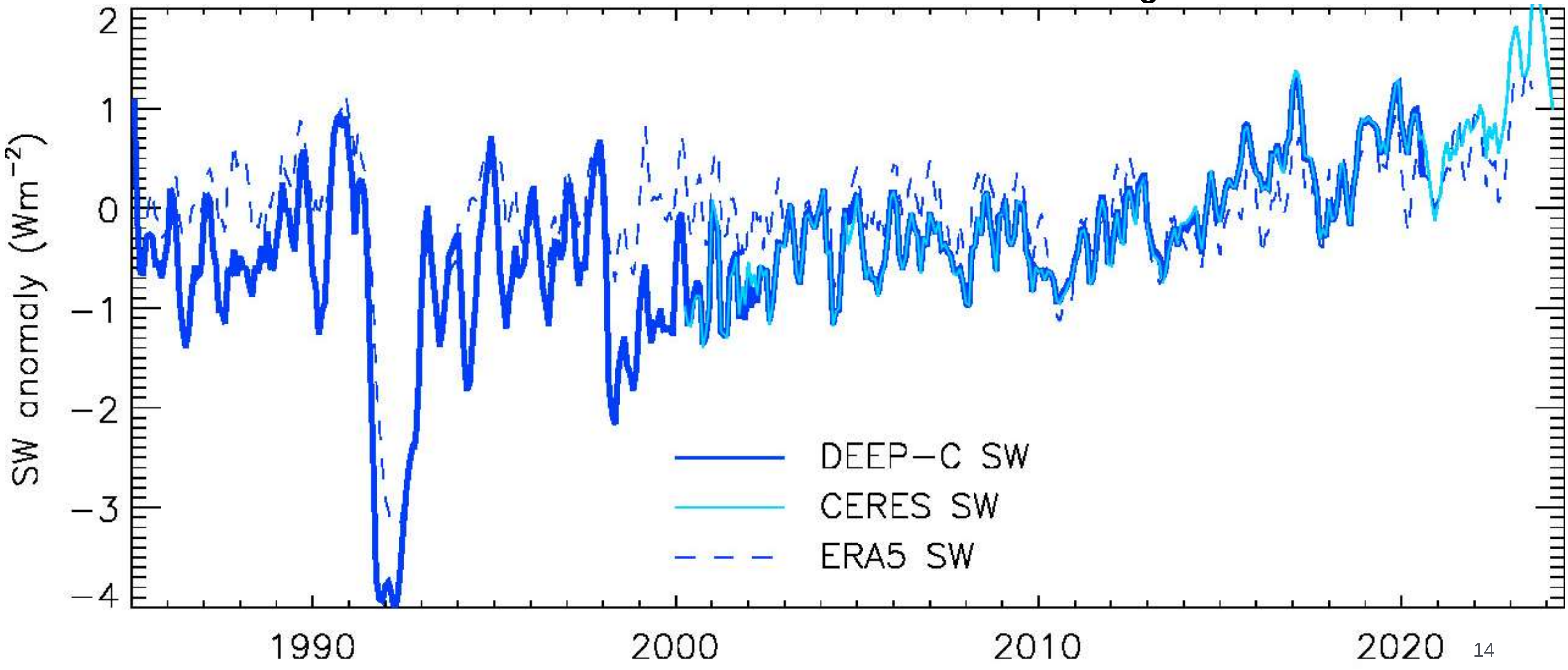
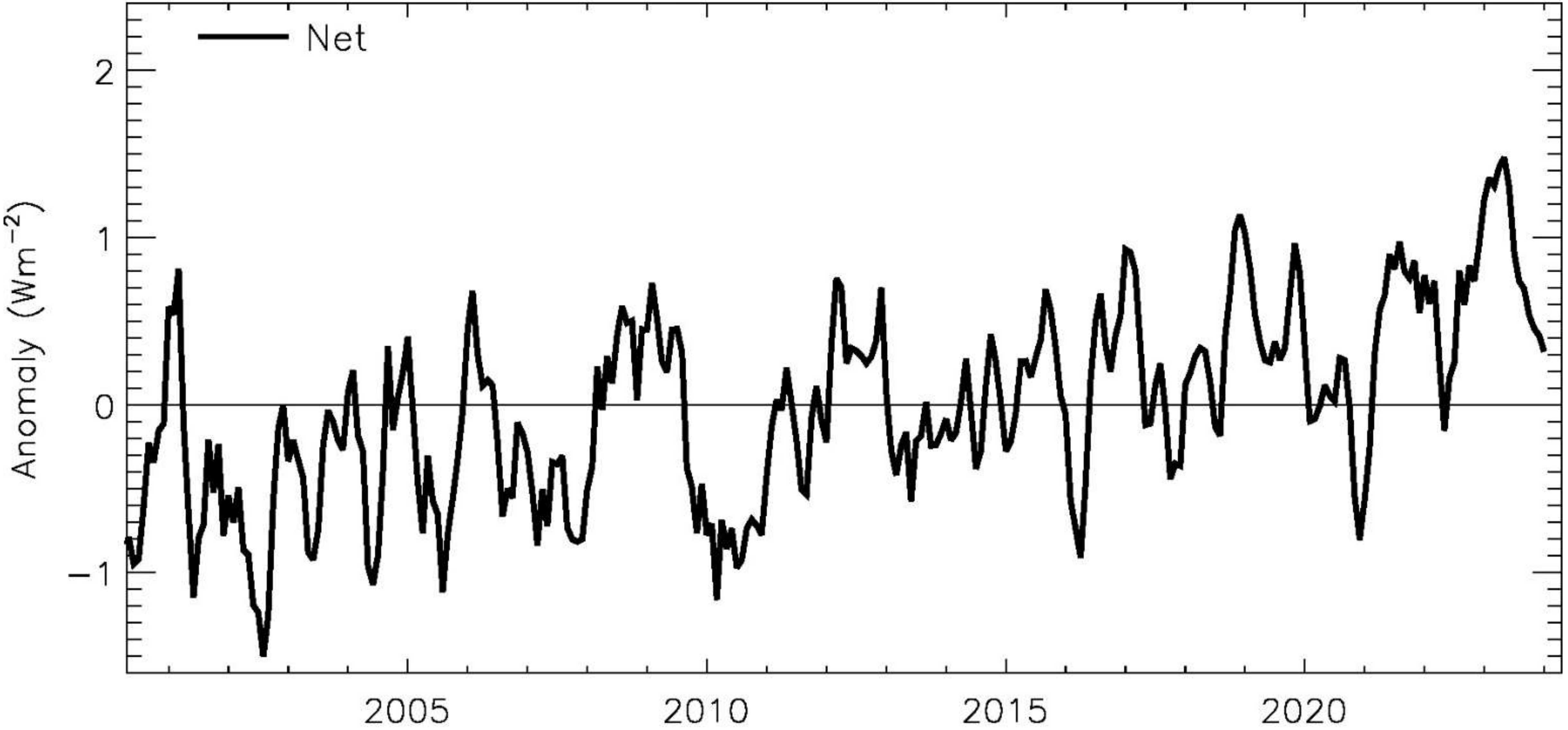
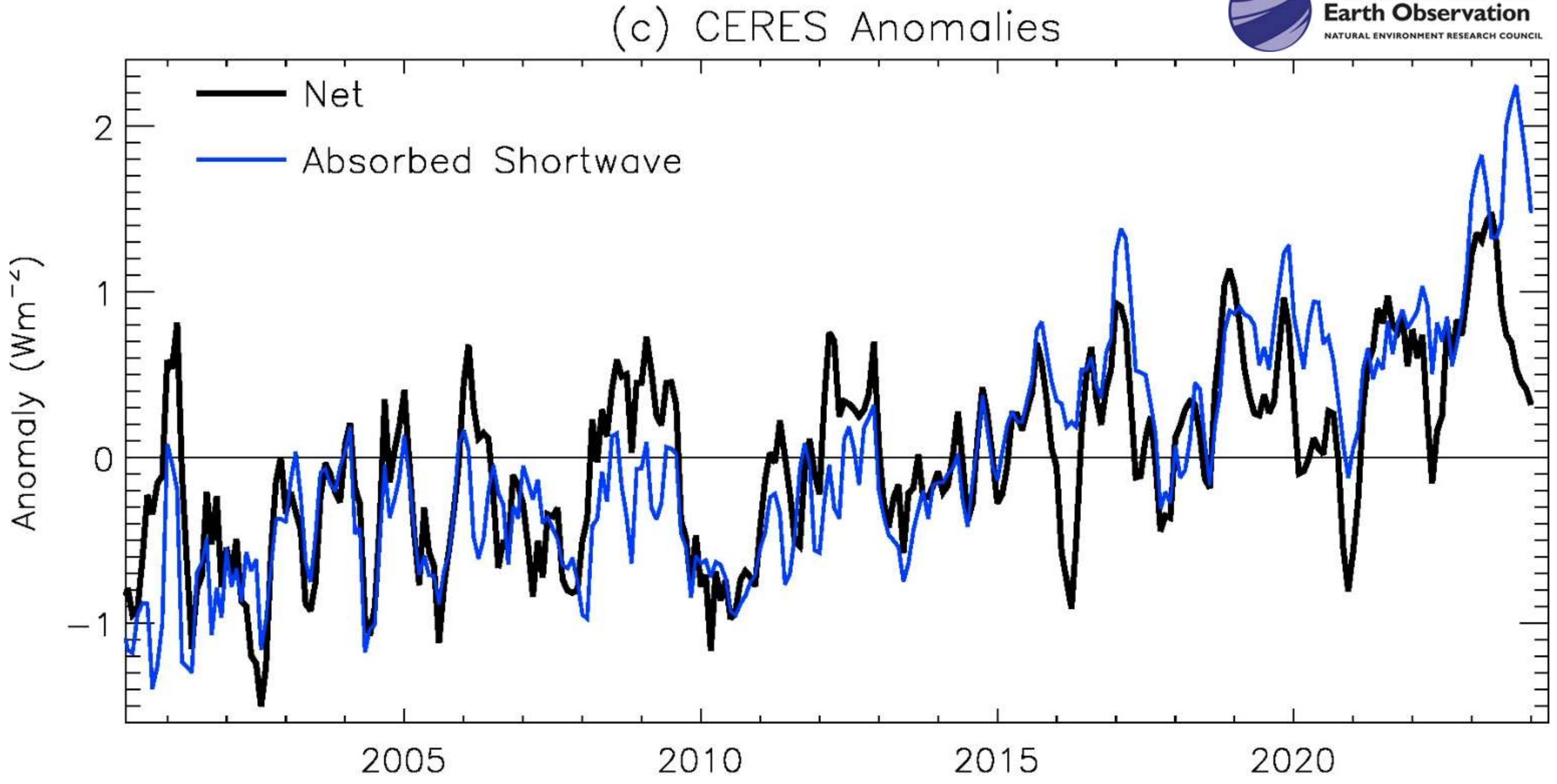
Global mean anomalies in absorbed sunlight



(c) CERES Anomalies




(c) CERES Anomalies
Net
Absorbed Shortwave
Anomaly (Wm^{-2})
2
1
0
−1
2005
2010
2015
2020

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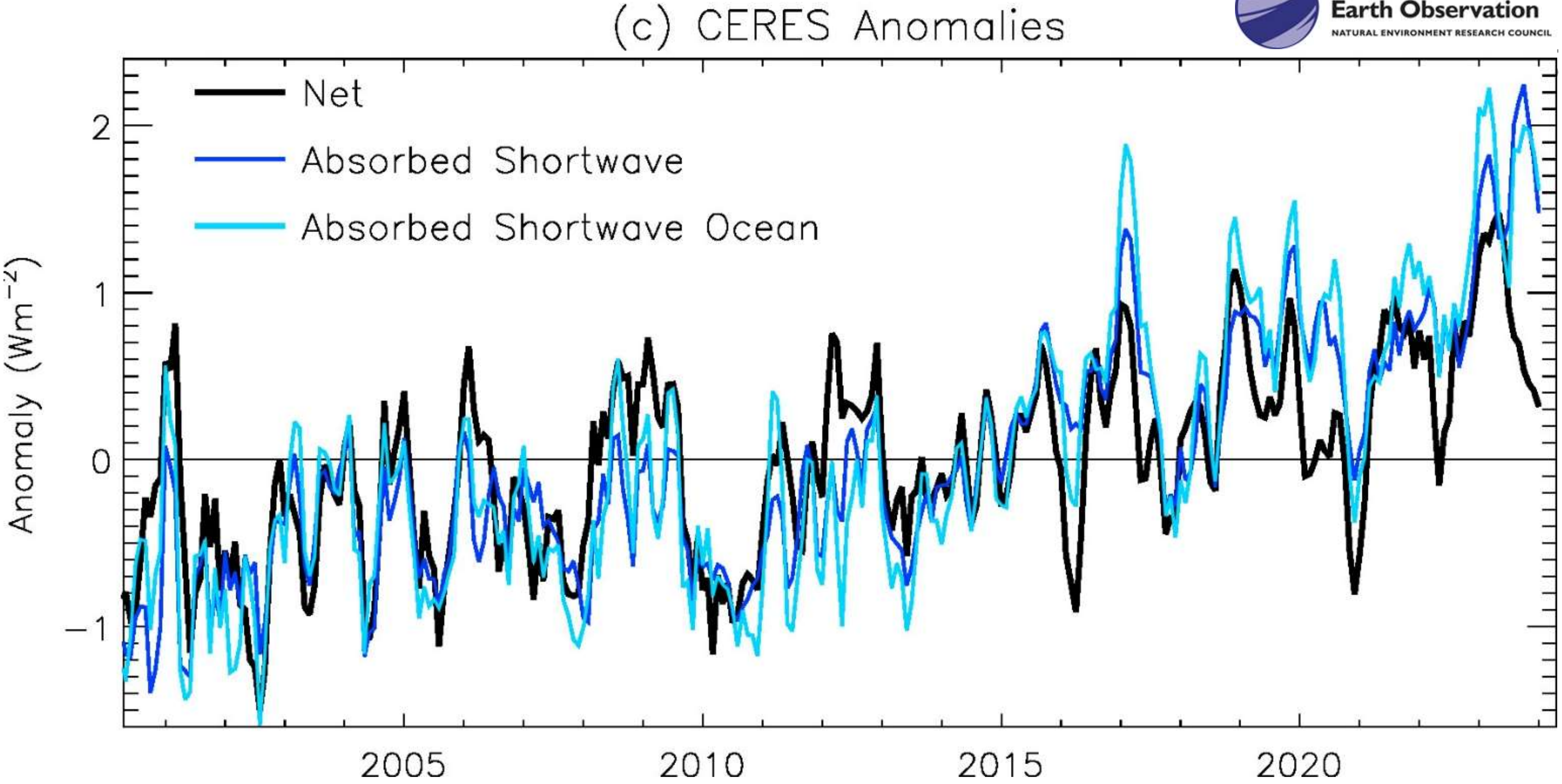

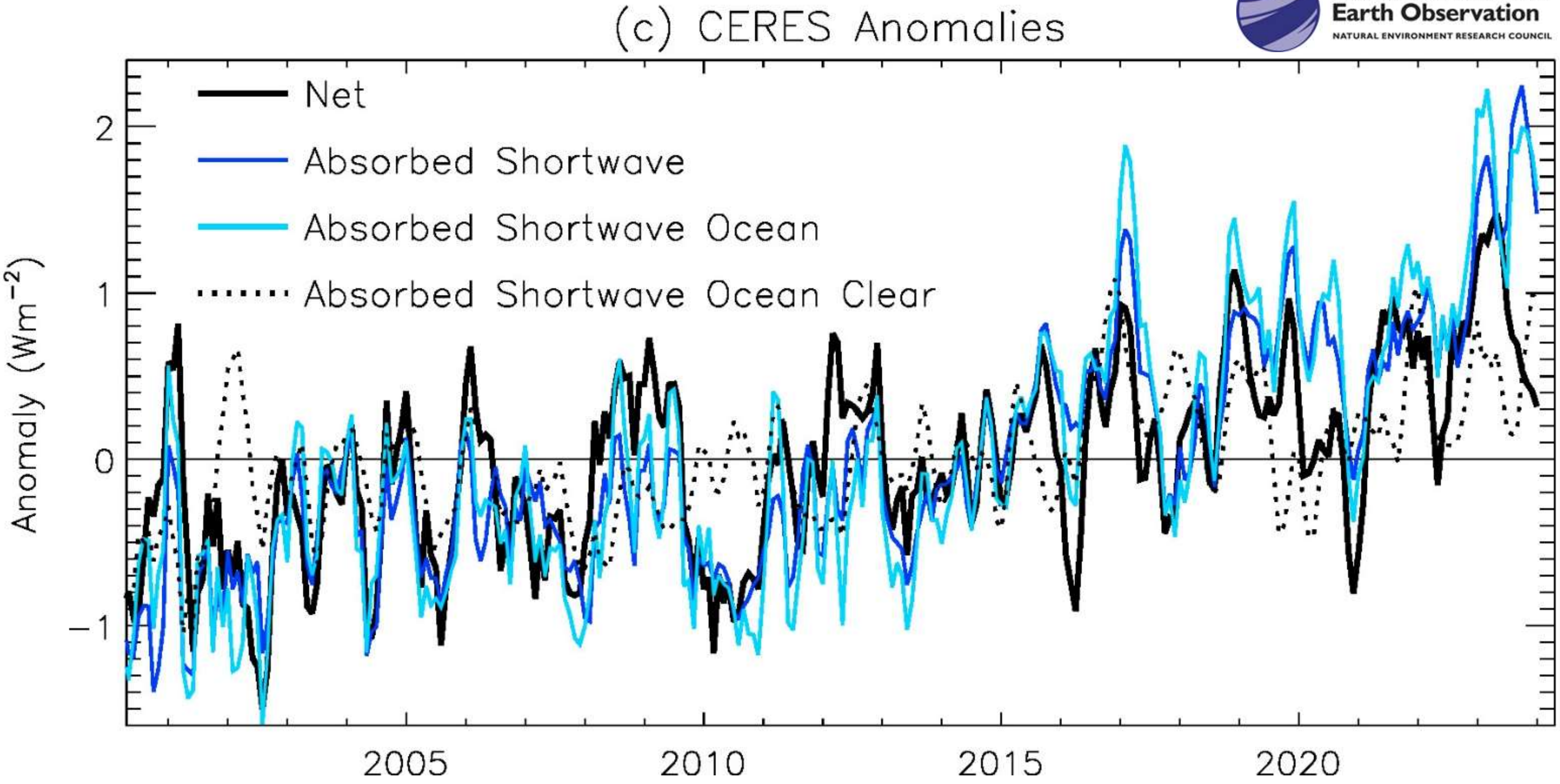

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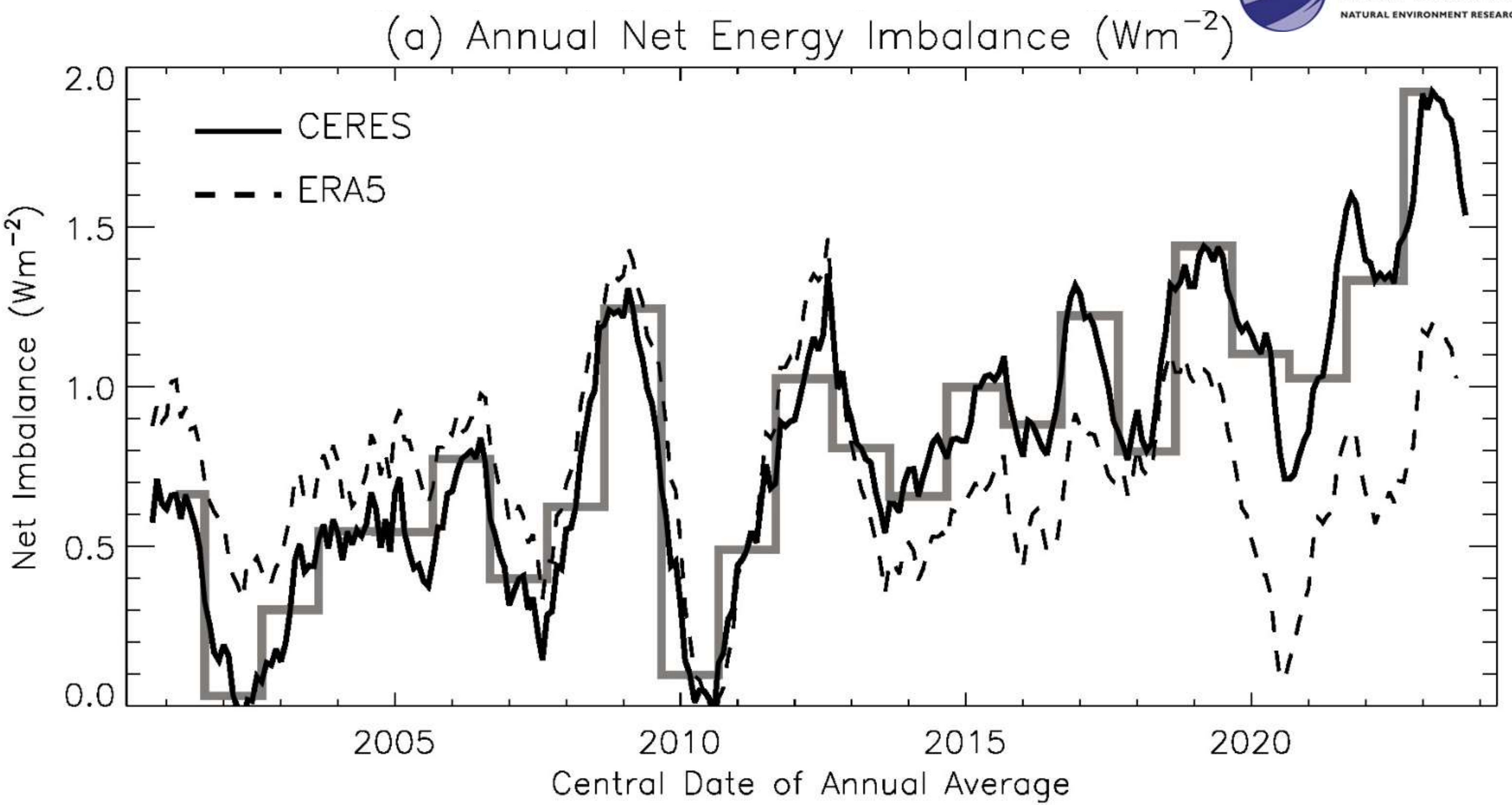
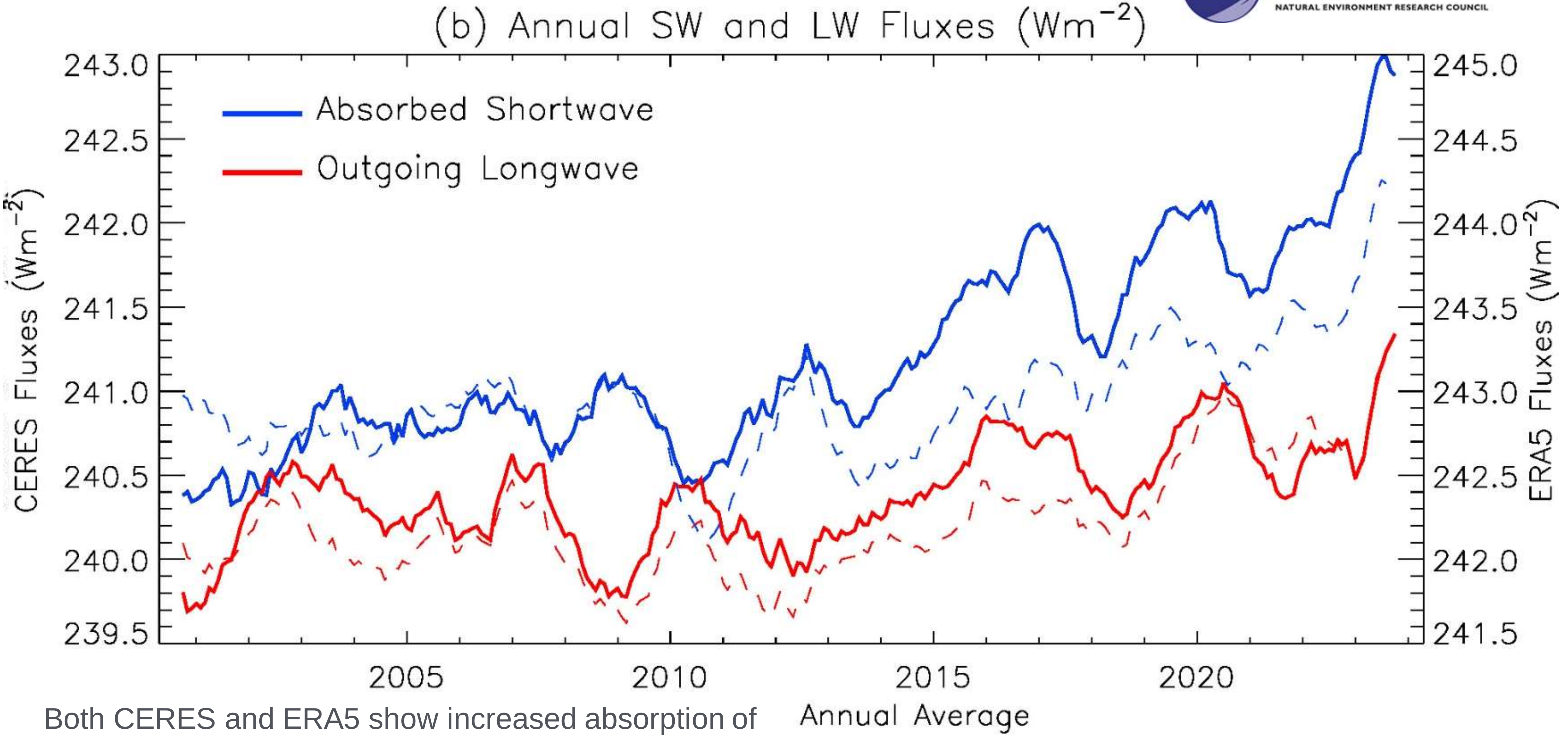
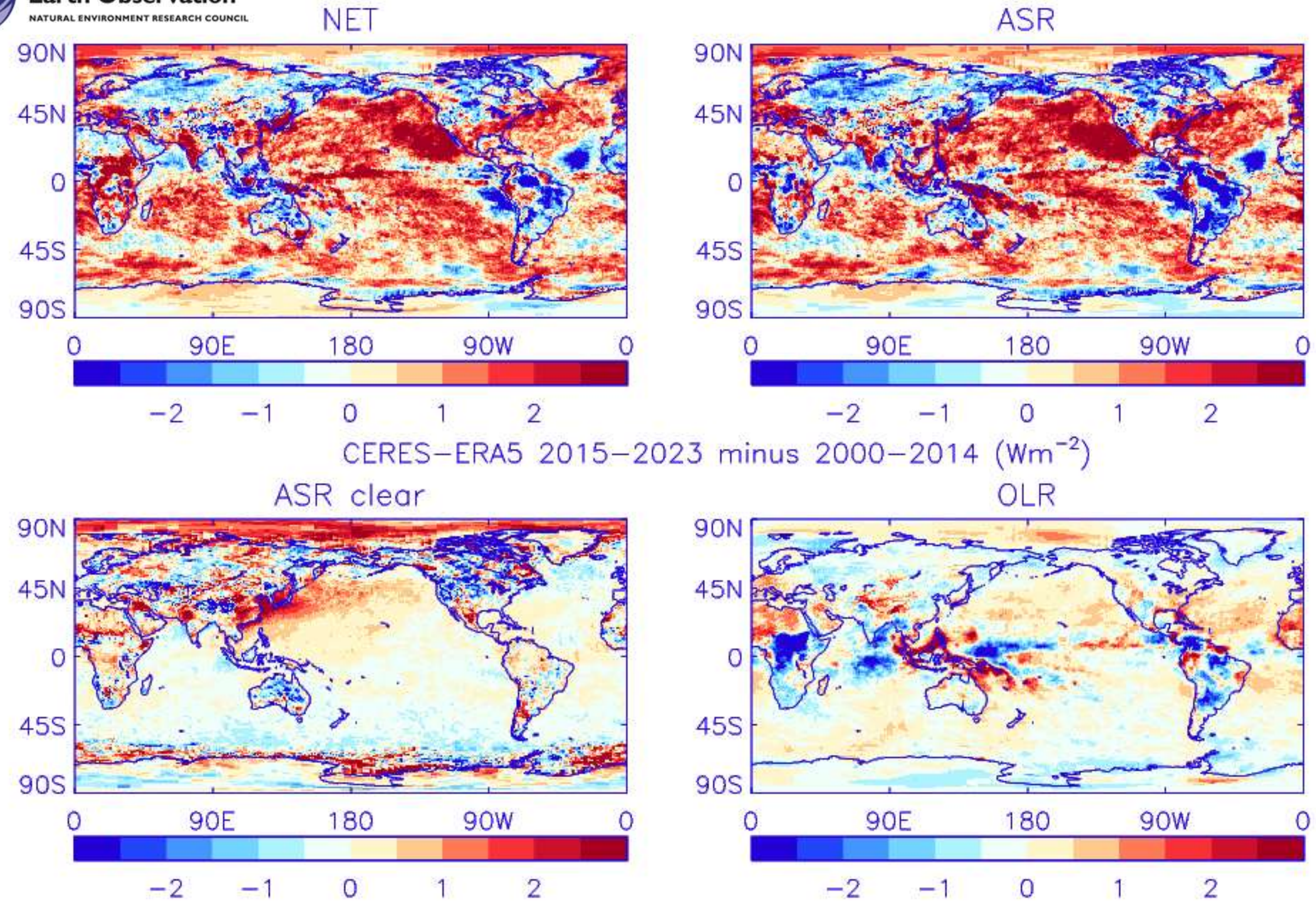


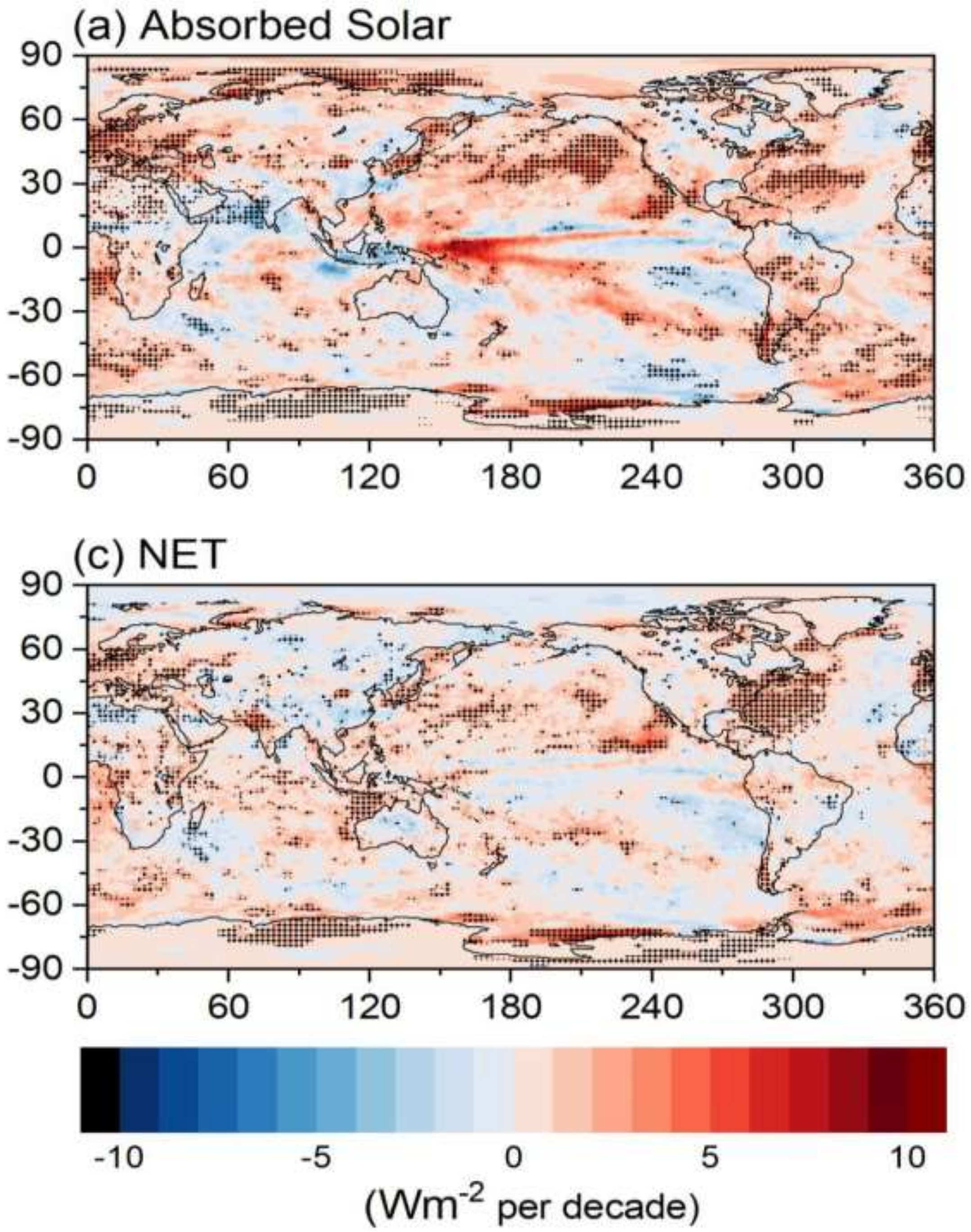
LIMITLESS POTENTIAL | LIMITLESS OPPORTUNITIES | LIMITLESS IMPACT

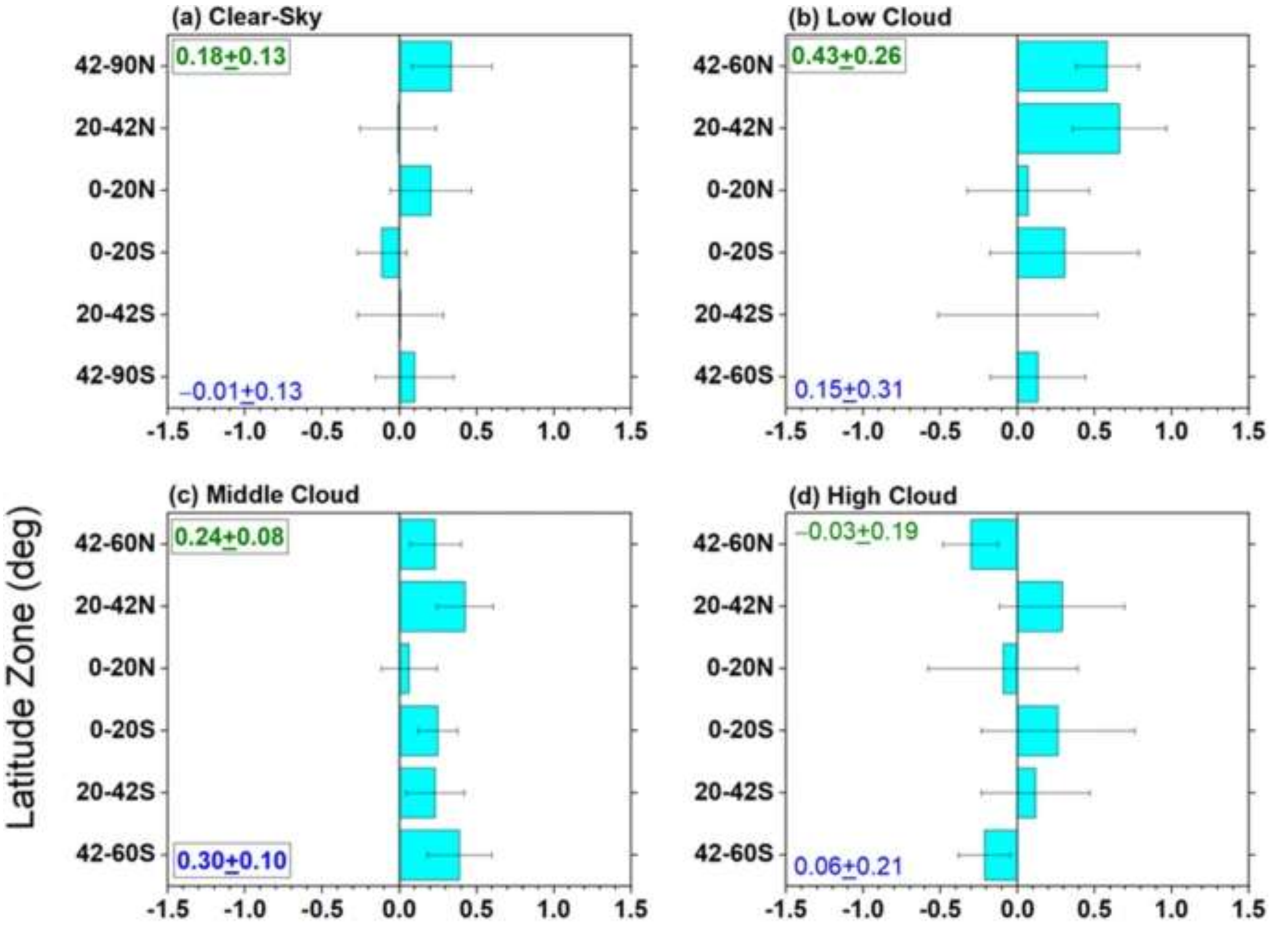


Both CERES and ERA5 show increased absorption of sunlight, but this effect is larger in CERES and in ERA5 LW emission compensates for SW absorption



- Change in CERES-ERA5 <u>differences</u>
- Large signals over subtropical stratocumulus cloud
- …which ERA5 poorly represents
- East Asia aerosol has reduced more than ERA5 (which uses CMIP historical & projection scenarios)
- Arctic ice melted more than in ERA5





[Loeb et al. (2024) Surv. Geophys]

OPEN QUESTIONS

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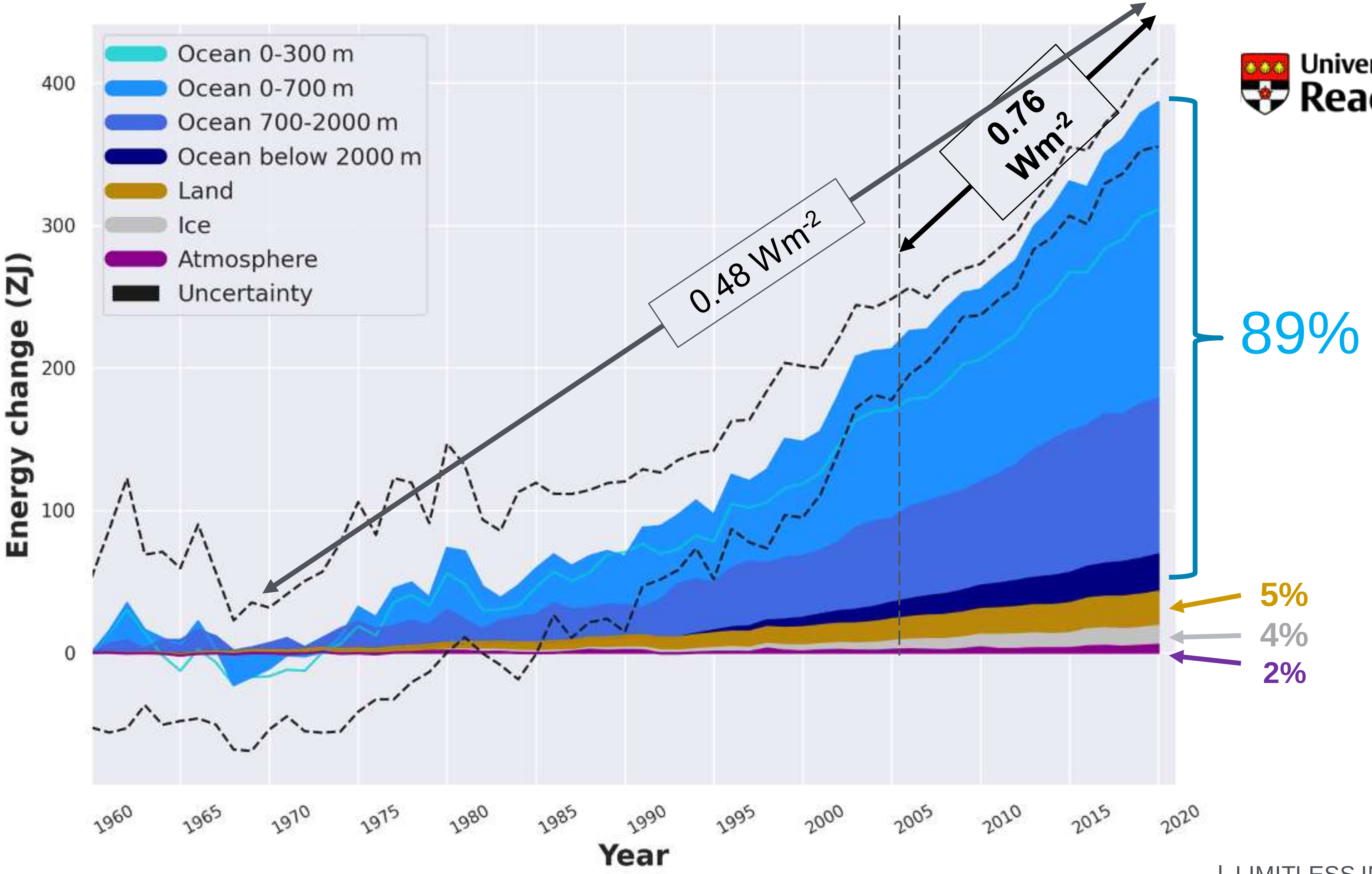
- TRUTHS + Argo = SW + LW? Constraint on global energy & water cycles.
- How bright are clouds? Where do clouds end?
- How are aerosols affecting clouds and Earth's albedo?
- How does hemispheric asymmetry control climate?
- Is systematic bias in absorbed sunlight affecting simulated warming patterns?
- Why is the Earth becoming dimmer?
  - Earth's energy imbalance has increased rapidly over past 10 years

  … from 0.67 Wm^{-2} in 2006-2020 to 1.85 Wm^{-2} in 2022/23
  - due to more absorbed sunlight over the ocean
  - Dominated by cloud effects
  - Not captured by ERA5
- Are current changes subject to sensor degradation?
- Space and time sampling can dominate estimation of biases…

EXTRA SLIDES



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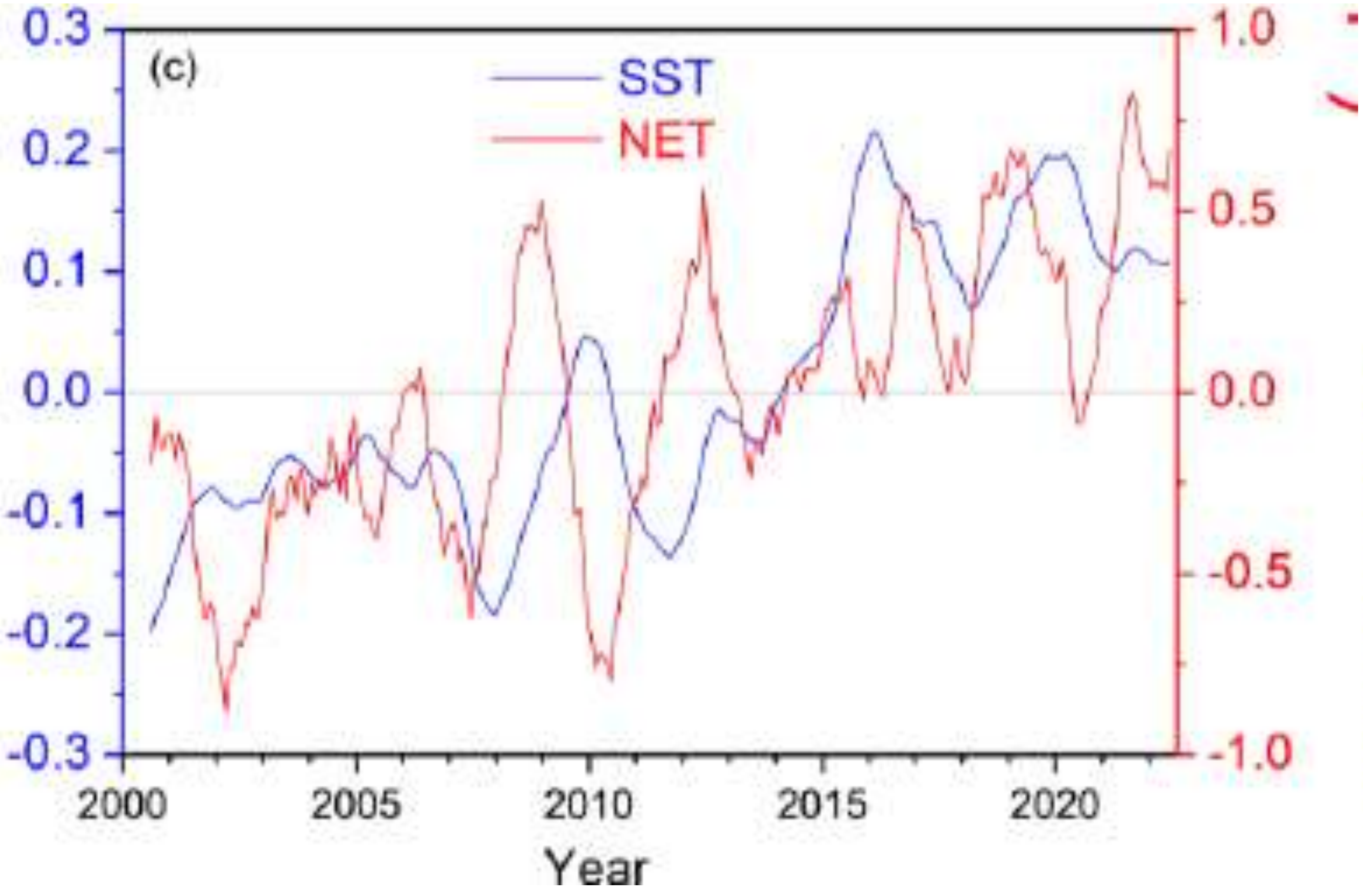
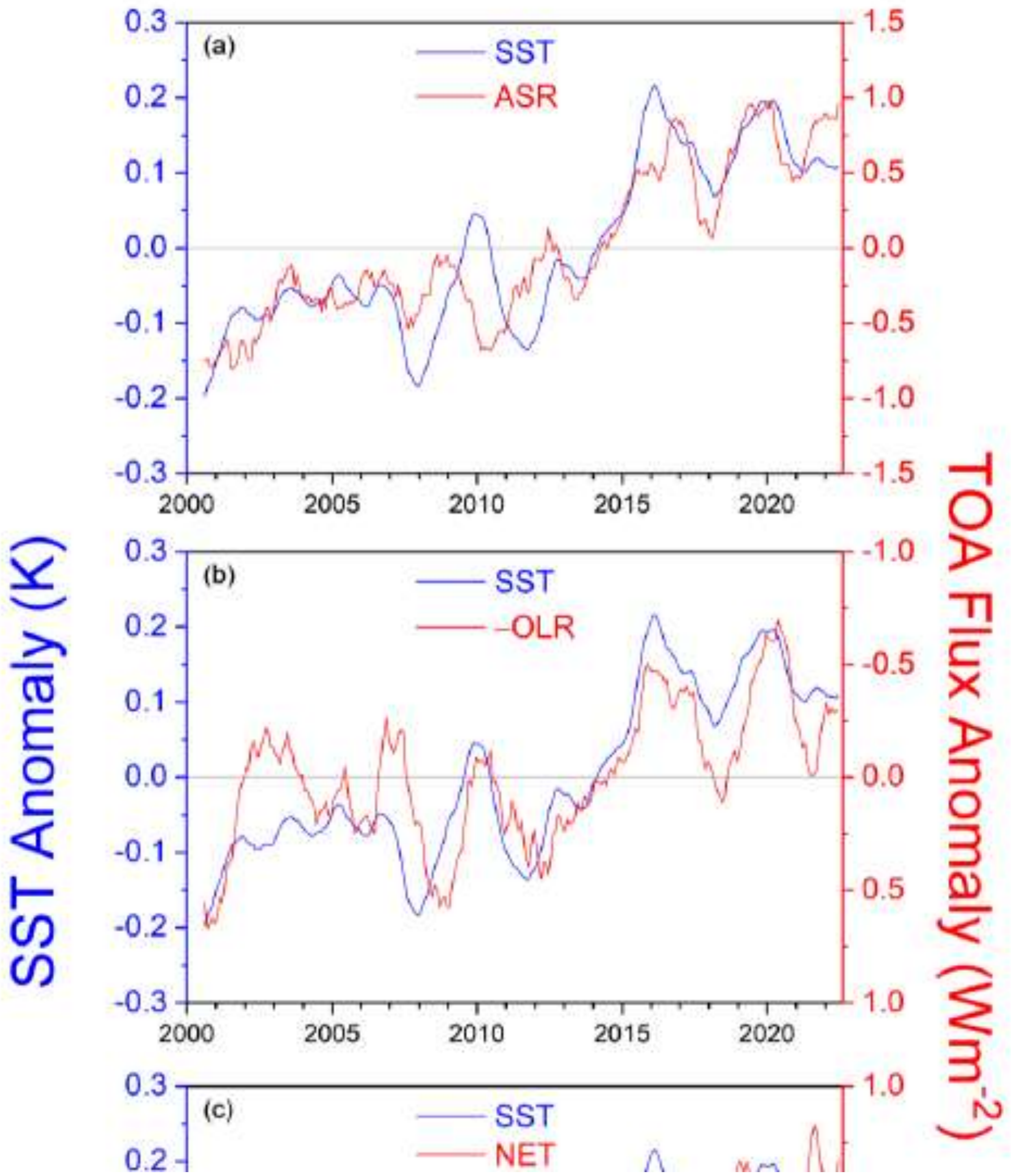
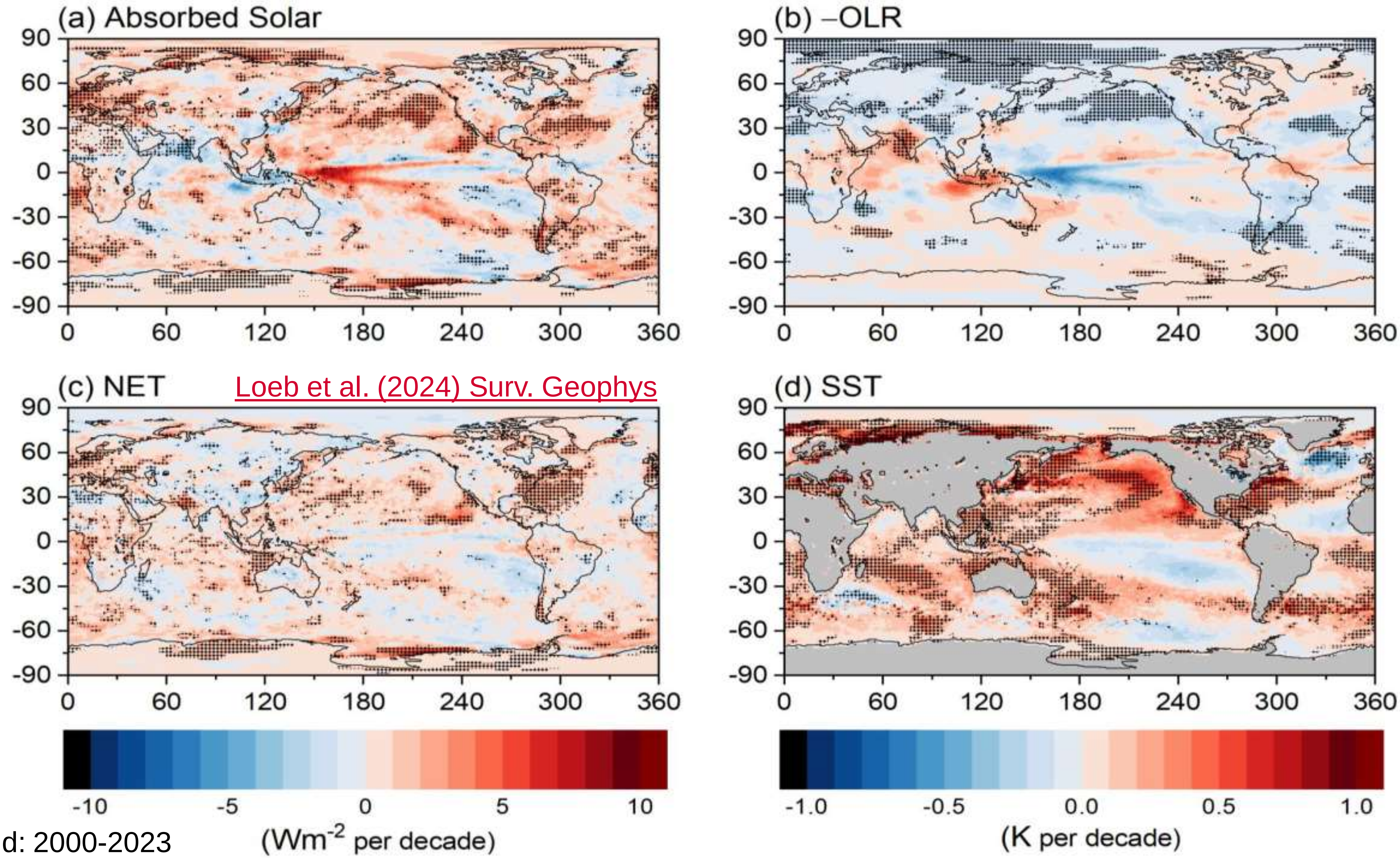
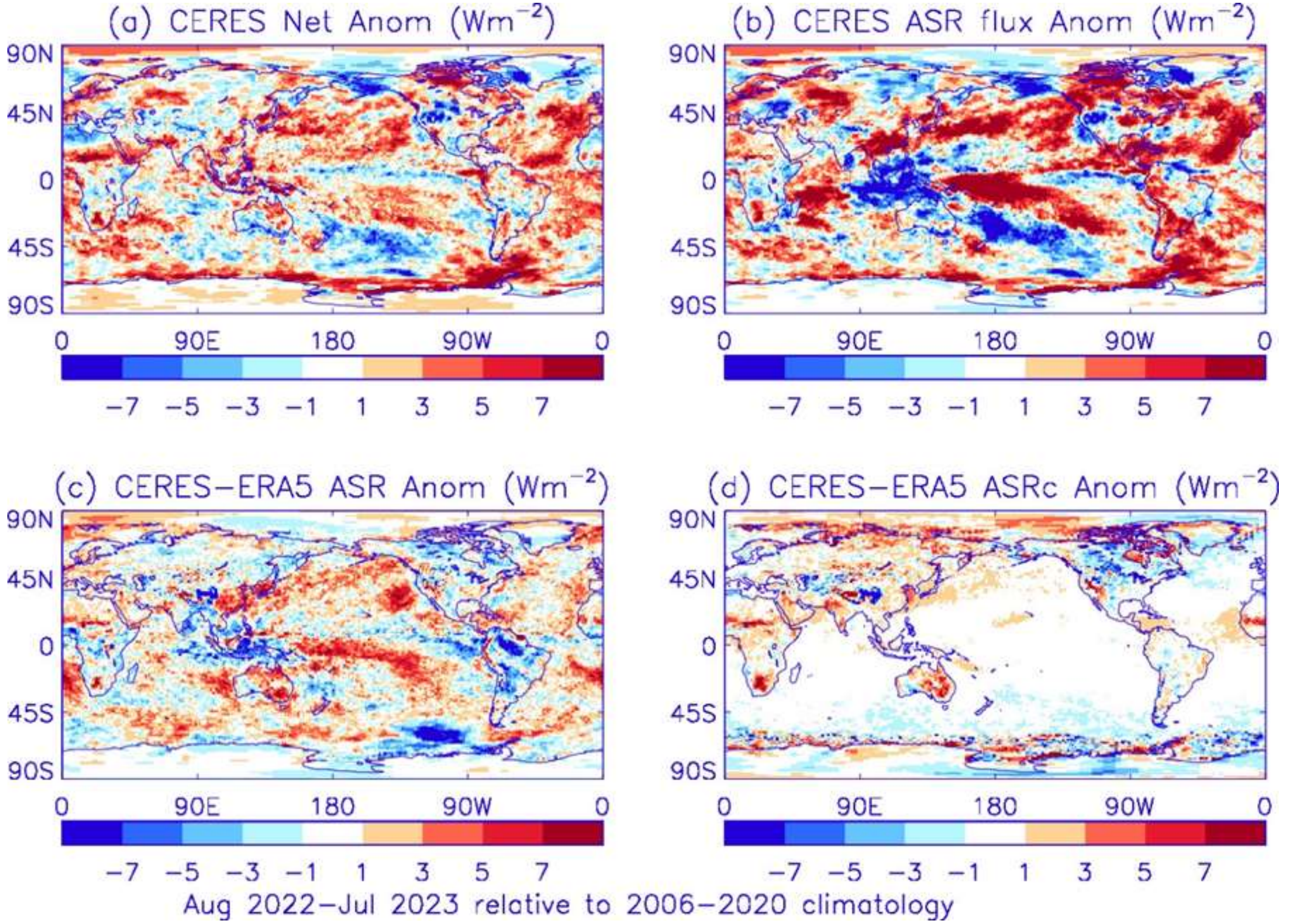
LATEST CERES EBAF



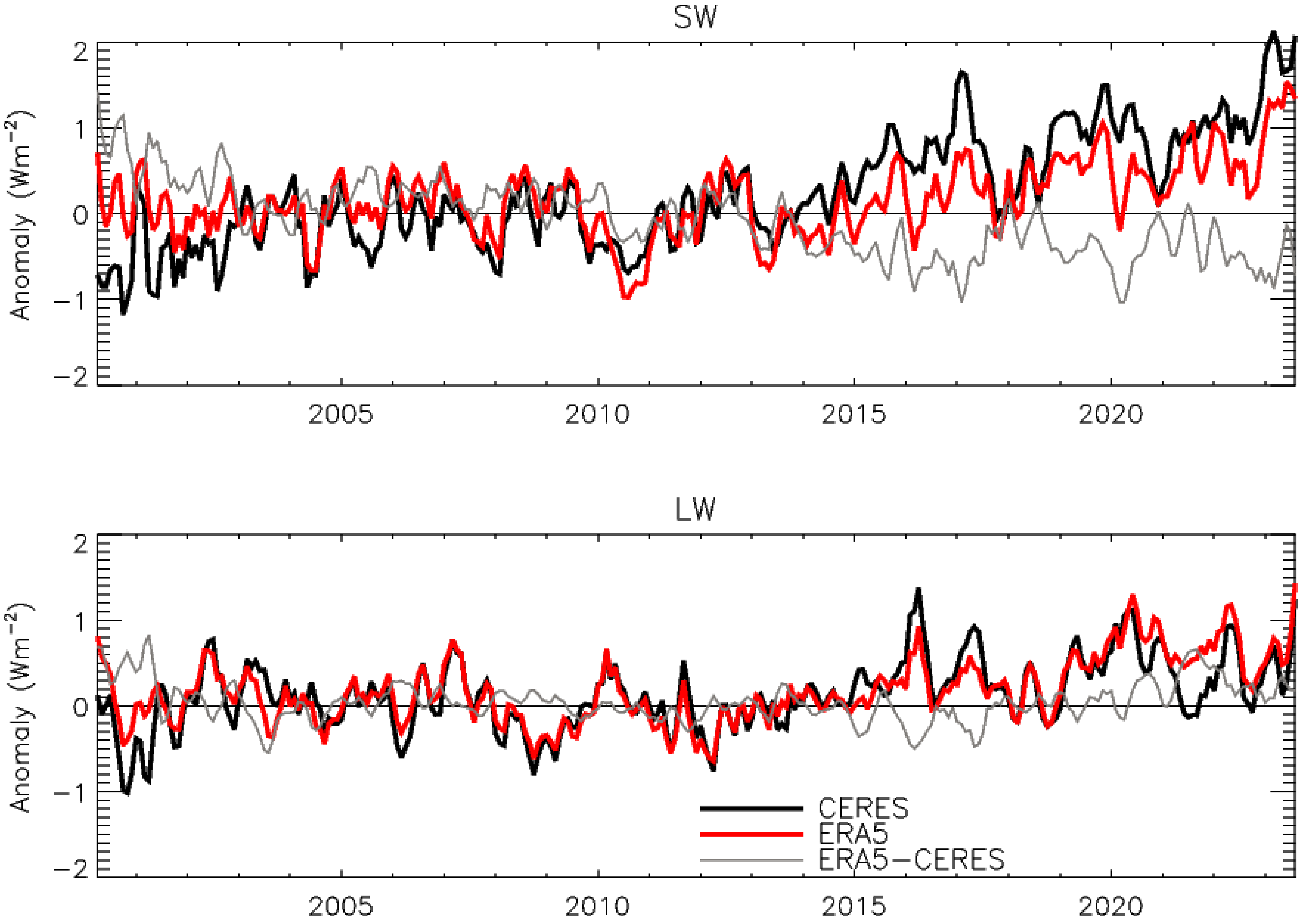




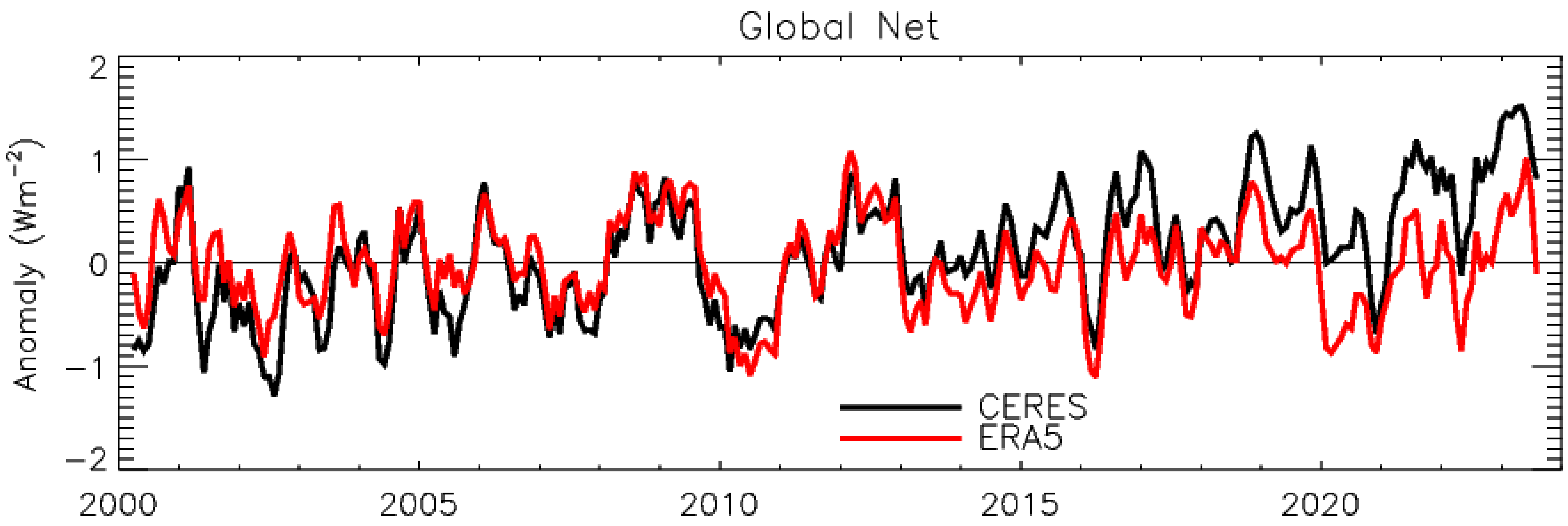
Trend: 2000-2023

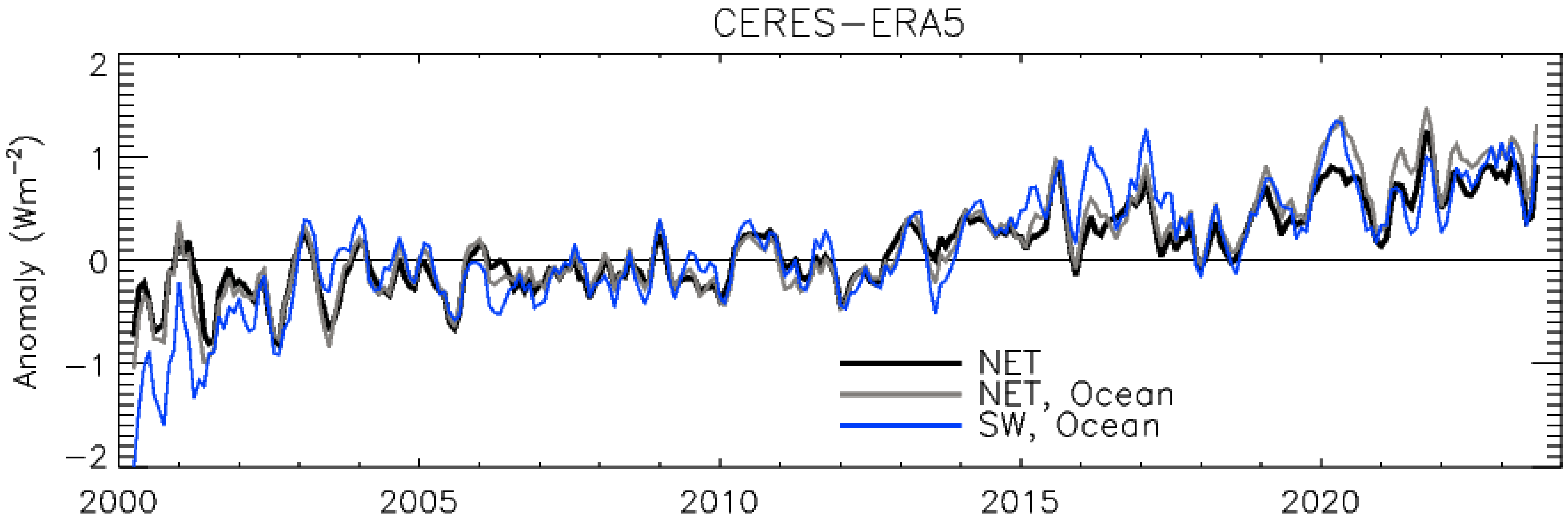

(a) CERES Net Anom (Wm^{-2})
(b) CERES ASR flux Anom (Wm^{-2})
(c) CERES−ERA5 ASR Anom (Wm^{-2})
(d) CERES−ERA5 ASRc Anom (Wm^{-2})
90N 45N 0 45S 90S
0 90E 180 90W 0
−7 −5 −3 −1 1 3 5 7
Aug 2022−Jul 2023 relative to 2006−2020 climatology

CERES and ERA5 global changes in SW and LW 2000-2023



- Globally, increases in absorbed sunlight only partially offset by increased infrared emissions to space
- Observed longwave changes quite well represented by ERA5
- Increase in CERES-ERA5 absorbed SW (early part affected by Terra-only issues?)
- But both ERA5 and CERES show increase in absorbed solar (but ERA5 SW increase is compensated by LW)





- Use CERES minus ERA5 to “remove” the meteorology
- Differences relate to ERA5 forcing, spurious changes relating to observing system, drift in satellite sensor (e.g. Matthews 2018 J. Appl. Meteor.Climatol.)?
- CERES-ERA5 divergence → ocean SW

TBD: WHAT IS CAUSING INCREASE IN ENERGY IMBALANCE AND IS IT LINKED TO 2023 TEMPERATURE SPIKE?

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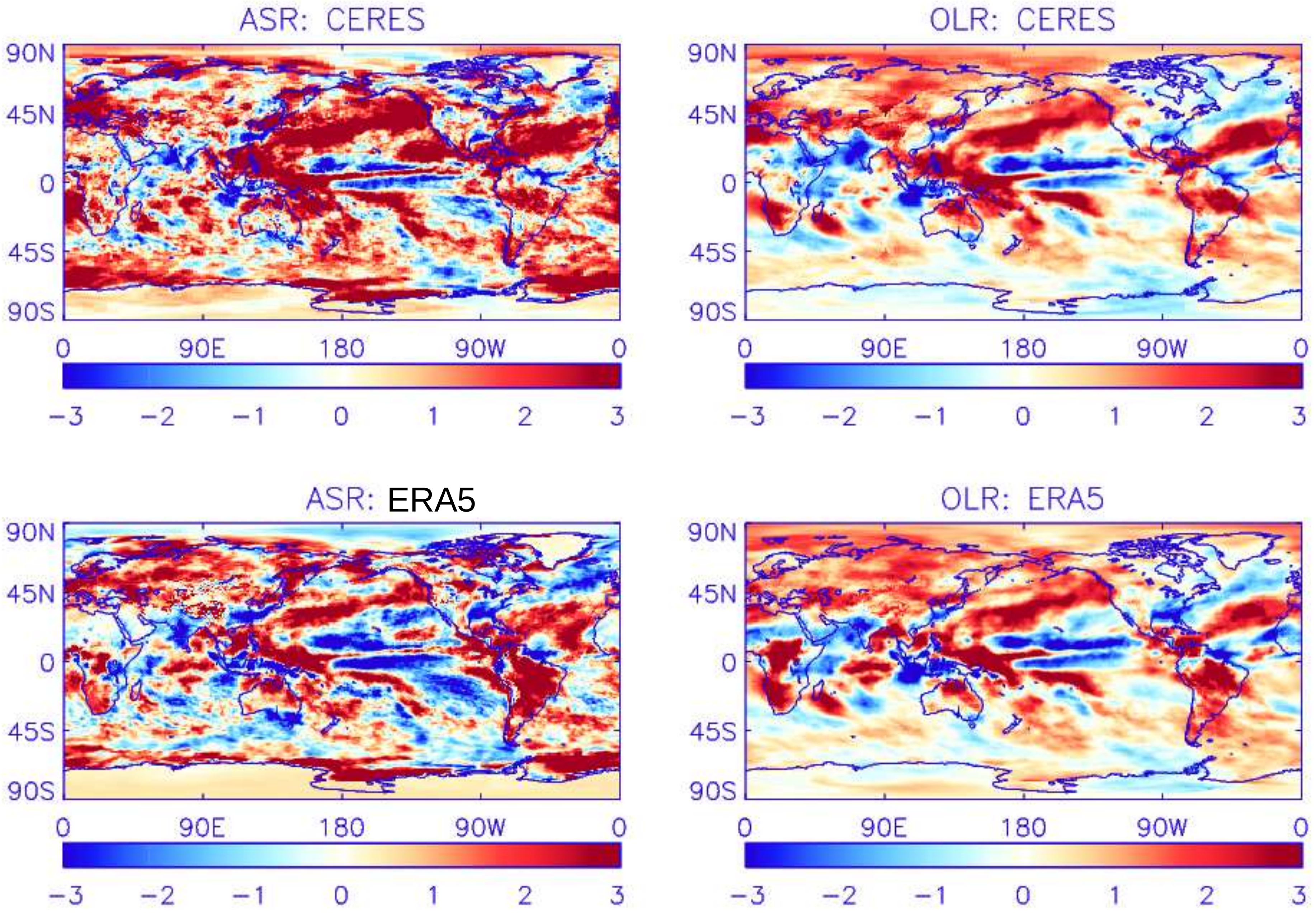
- Loeb et al. (2021) GRL attribute increased absorbed solar radiation to decreased reflection by clouds and sea-ice and decreased outgoing longwave radiation (OLR) due to increases in trace gases and water vapor
- Greenhouse gas forcing e.g. Kramer et al. (2021) GRL: instantaneous radiative forcing has increased 0.42-0.64 Wm^{-2} from 2003 to 2018.
- Declining aerosol forcing: Subba et al. (2020) ASL: increasing forcing 2000-2017 (+0.17 Wm^{-2}/decade TOA), see also Quaas et al. (2022) ACP; additional shipping fuel regulations maybe +0.1 Wm^{-2} e.g. Diamond et al. (2023) ACP: Hansen: arxiv.org/abs/2212.04474 ; indirect cloud effect?
- Temporary (?) shift in SST patterns, unlike model simulations (e.g. Andrews et al. 2022 JGR) that have decreased low-altitude cloud cover/reflection (e.g. Loeb et al. 2020 GRL)
- More recent changes & temperature spike: flip from La Niña to El Niño (increasing global temperature but would tend to reduce net energy imbalance)
- Hunga Tonga stratospheric water vapour injection Millan et al. (2022) GRL ; Jenkins et al. (2023) Nature Clim.:+0.16 Wm-2 ? (Schoeberl et al. (2023) GRL: suggest cooling effect but seem to suggest infrared heating of upper troposphere does not affect surface?)
- Other things: Less Sahara Dust warmed NE Atlantic? (Claire?) Approaching peak in 11-year sunspot cycle; Wildfire effects? Yu et al. (2023) GRL: ERF -0.18 W m^{-2}, dT -0.06 K (cooling) 2014-2022; AMOC effects on North Atlantic SST/S. Ocean, stratification of ocean regions e.g. NE Atlantic? COWL effects (cold ocean, warm land) e.g. Thompson et al. (2008) Nature ; Wallace et al. (1995) Science

SUMMARY

- Heating of climate system accelerating

… but needs to reduce to "net zero")

  - 0.48 Wm^{-2} 1971-2020, 0.74 Wm^{-2} 2006-2020 (von Shuckmann et al. (2023) ESSD)
  - 0.5 Wm^{-2} increase 2000-2010 to 2011-2020 (increased absorbed sunlight partly offset by increased outgoing longwave)
- Radiative forcing is increasing, but decreased low altitude cloud in subtropical Pacific relating to SST pattern may be contributing Loeb et al. 2021 GRL
- Both CERES and ERA5 show increased absorption of sunlight, but this effect is larger in CERES and in ERA5 LW emission compensates for SW absorption
- How are aerosol decreases contributing to heating through cloud effects?
- Multiple components combine to produce 2023 temperature spike (GHGs, aerosol, Hunga Tonga, solar cycle, ENSO, transient ocean/land effects)
- Is net energy imbalance related to temperarature spike? To be discussed…



- 2015-2023 minus 2000-2014