Department of Meteorology

University of Reading

SOME DISCUSSION ON THE INCREASE IN EARTH'S HEATING RATE

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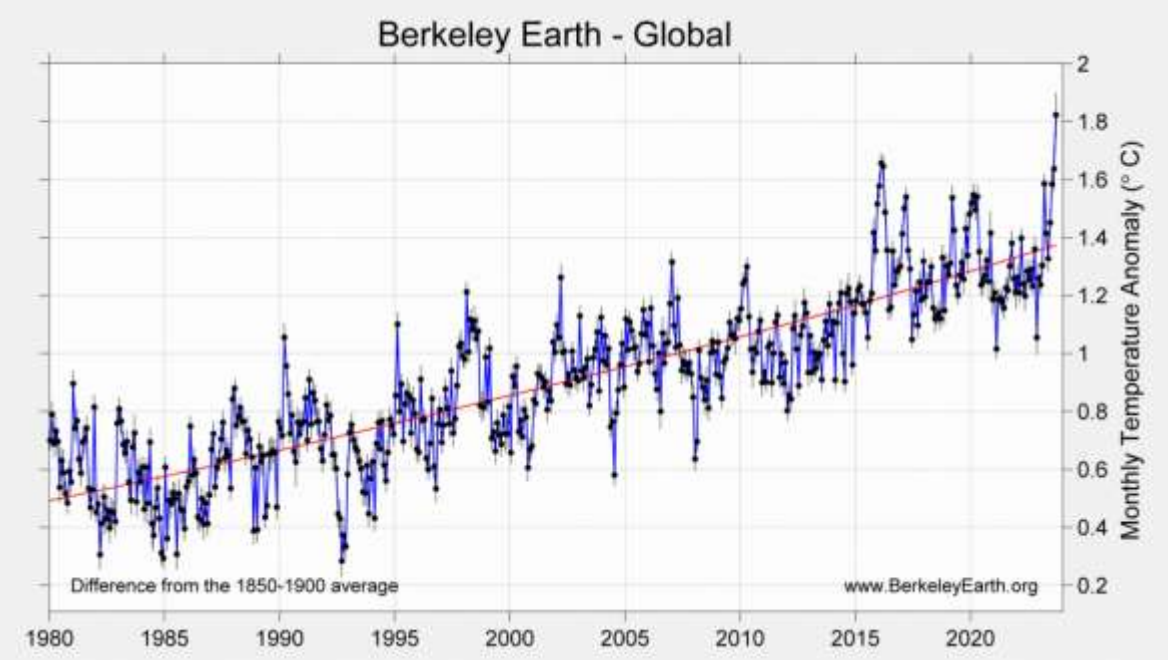
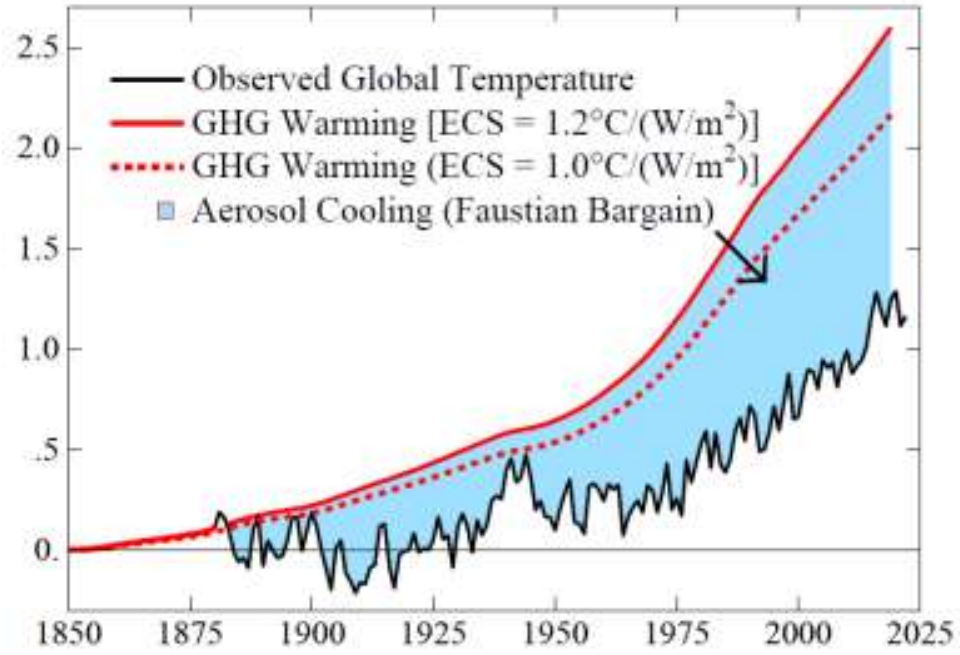
ACRC meeting 30 October 2023

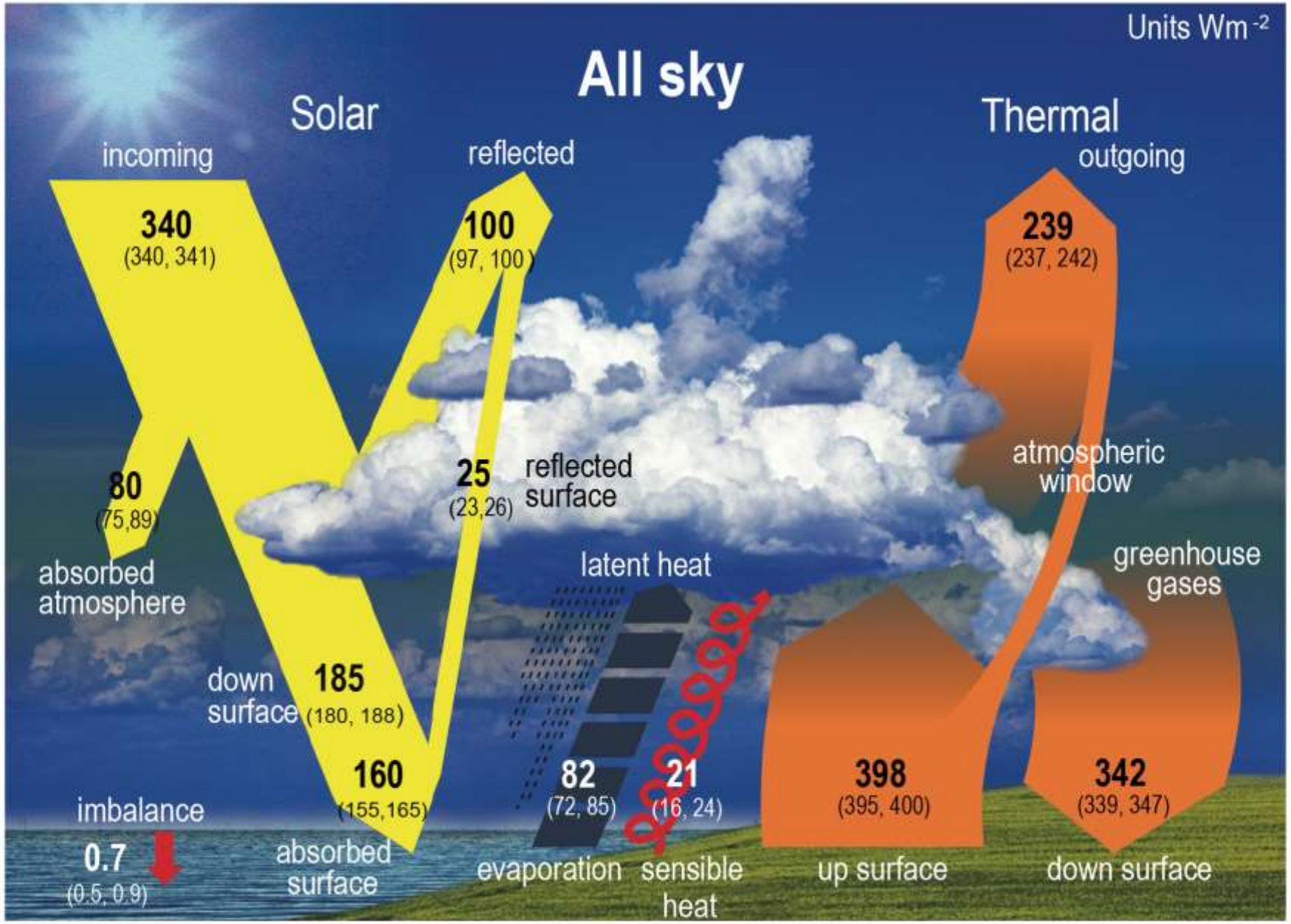
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

INTRODUCTION

- Earth's energy imbalance is driving climate change
- Need to reduce this imbalance to zero to limit climate change
- But the imbalance increasing… what is causing this and is it contributing to the apparent spike in global temperatures?







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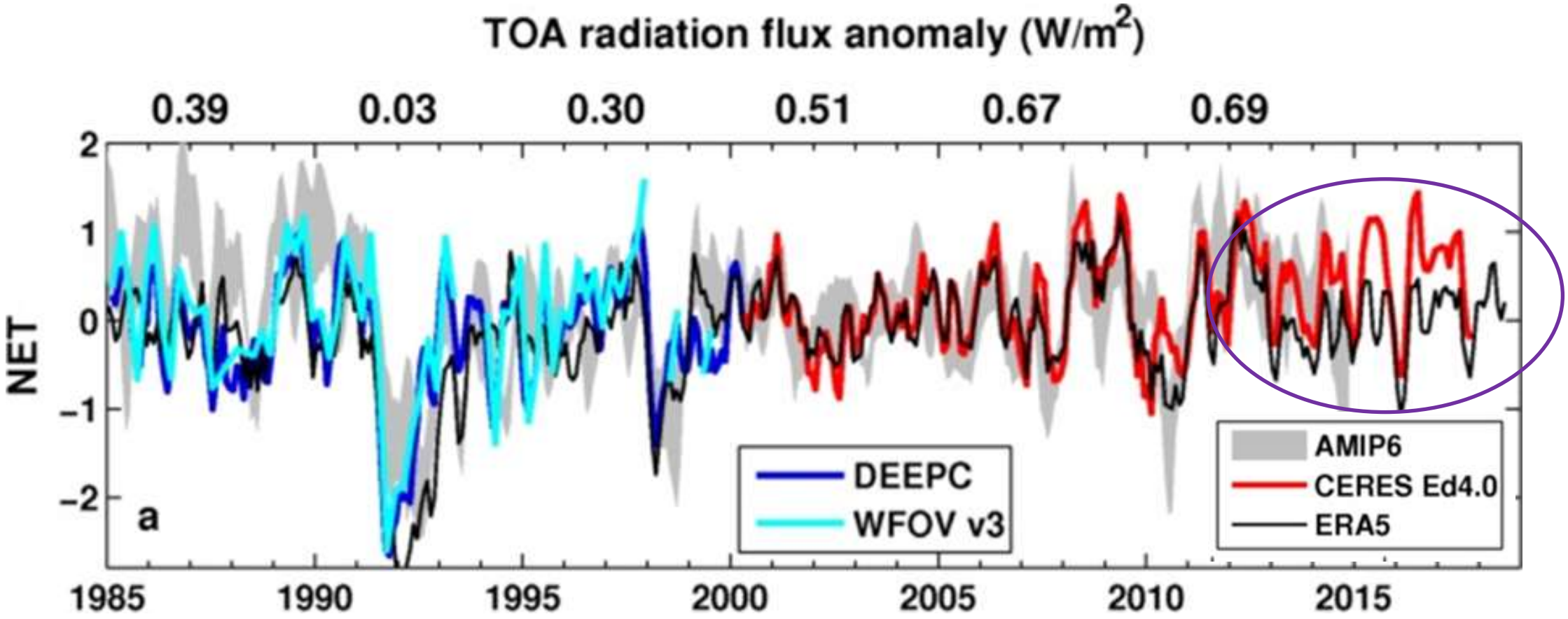
- **SPOT THE IMBALANCE…**

← Earth's present day energy budget

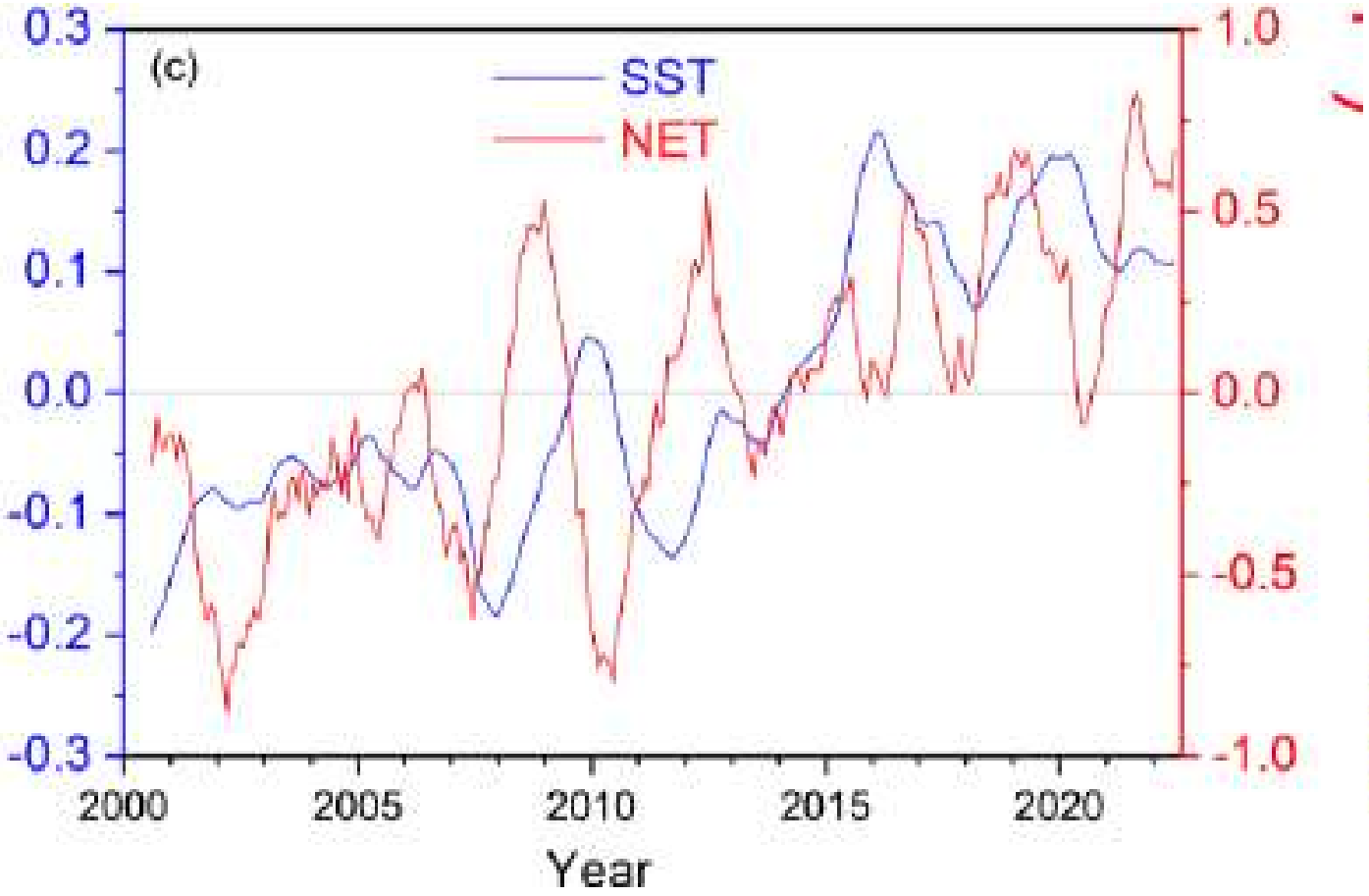
Forster et al. (2021) Chapter 7 of IPCC report, Figure 7.2

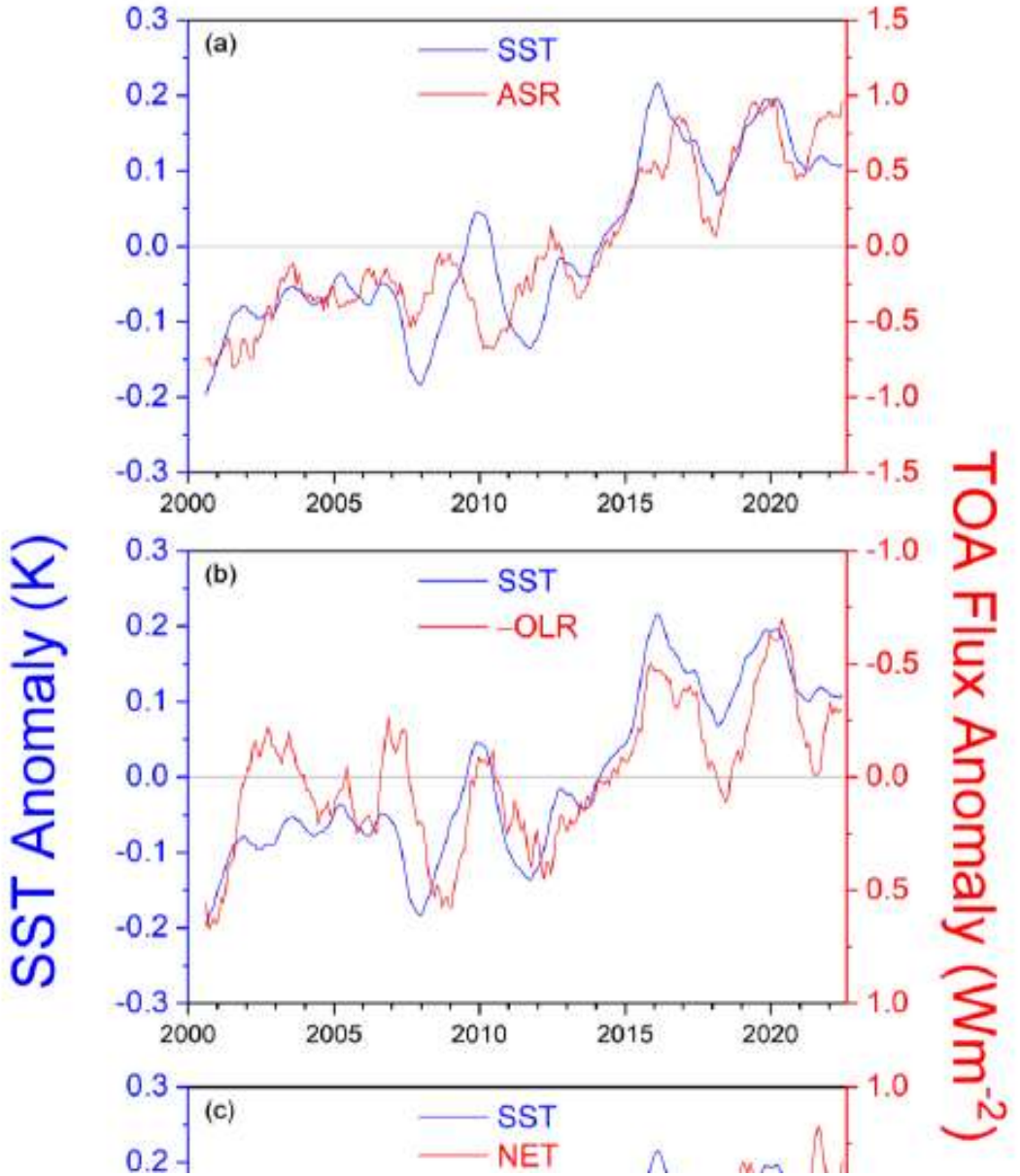
CURRENT ENERGY BUDGET CHANGES

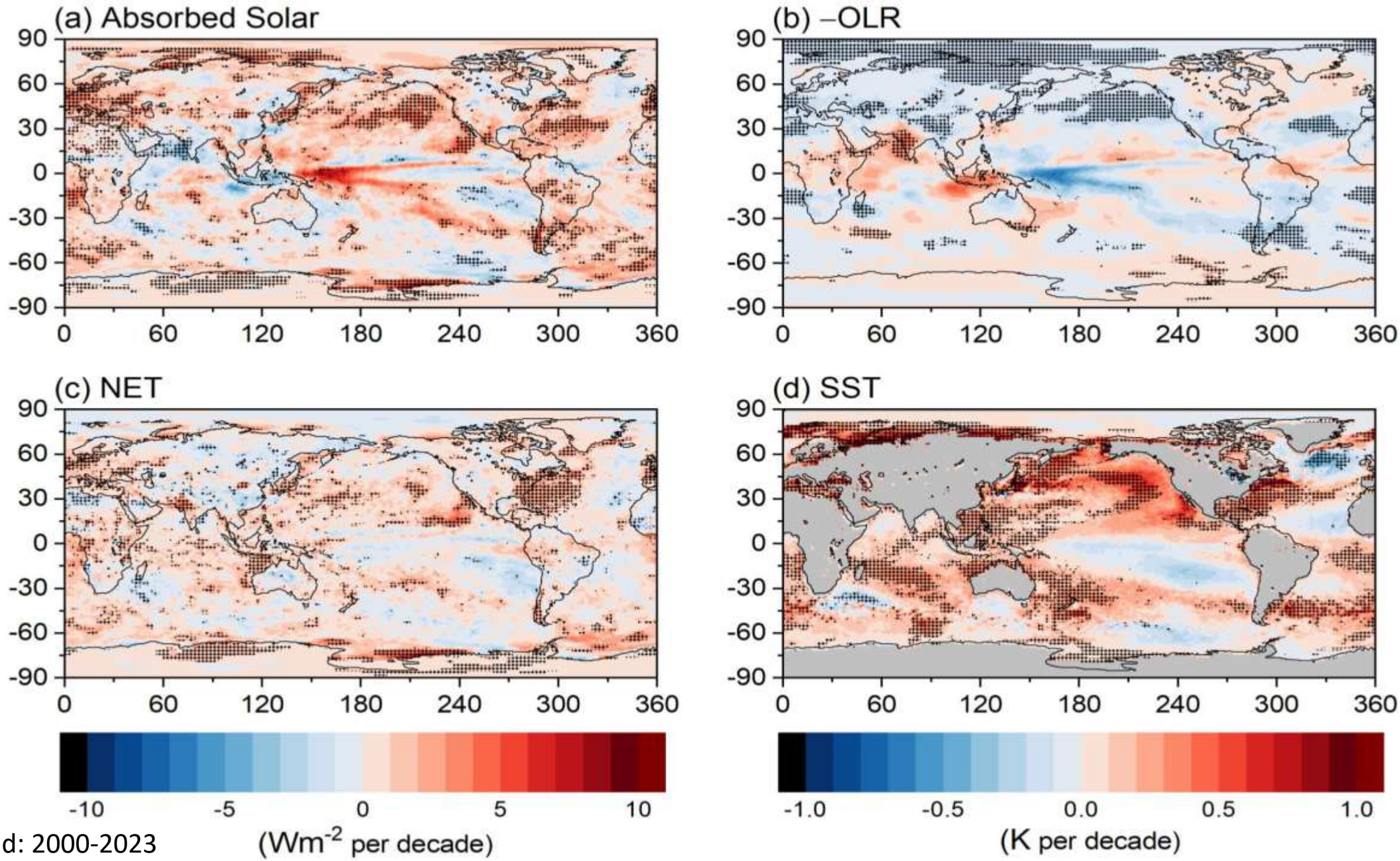


Liu et al. (2020) Clim. Dyn. based on method in Allan et al. (2014) GRL

LATEST CERES EBAF V4.2







Trend: 2000-2023

ROLE OF LOW ALTITUDE CLOUD?

AGU ADVANCING EARTH AND SPACE SCIENCE

Geophysical Research Letters

RESEARCH LETTER
10.1029/2019GL086705

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

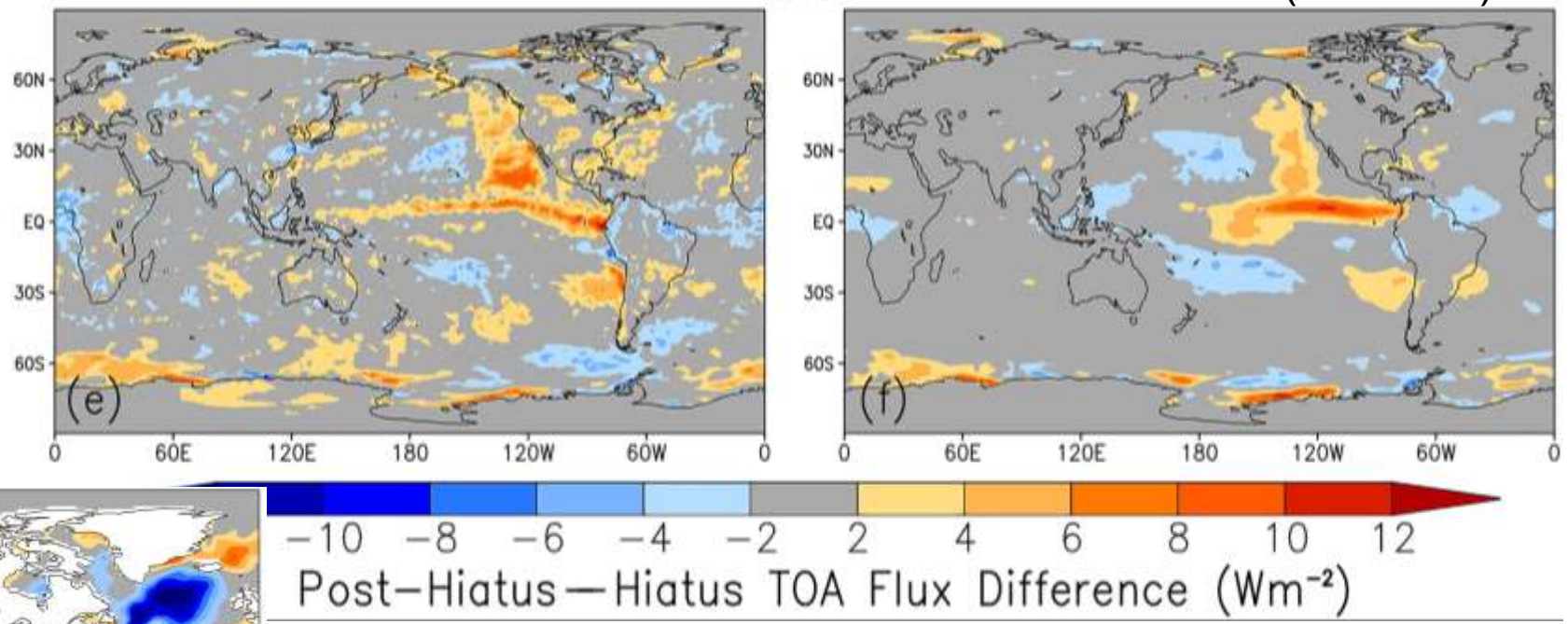
Norman G. Loeb[1], Hailan Wang[2], Richard P. Allan[3], Timothy Andrews[4], Kyle Armour[5], Jason N. S. Cole[6], Jean-Louis Dufresne[7], Piers Forster[8], Andrew Gettelman[9], Huan Guo[10], Thorsten Mauritsen[11], Yi Ming[10], David Paynter[10], Cristian Proistosescu[12,13], Malte F. Stuecker[14], Ulrika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

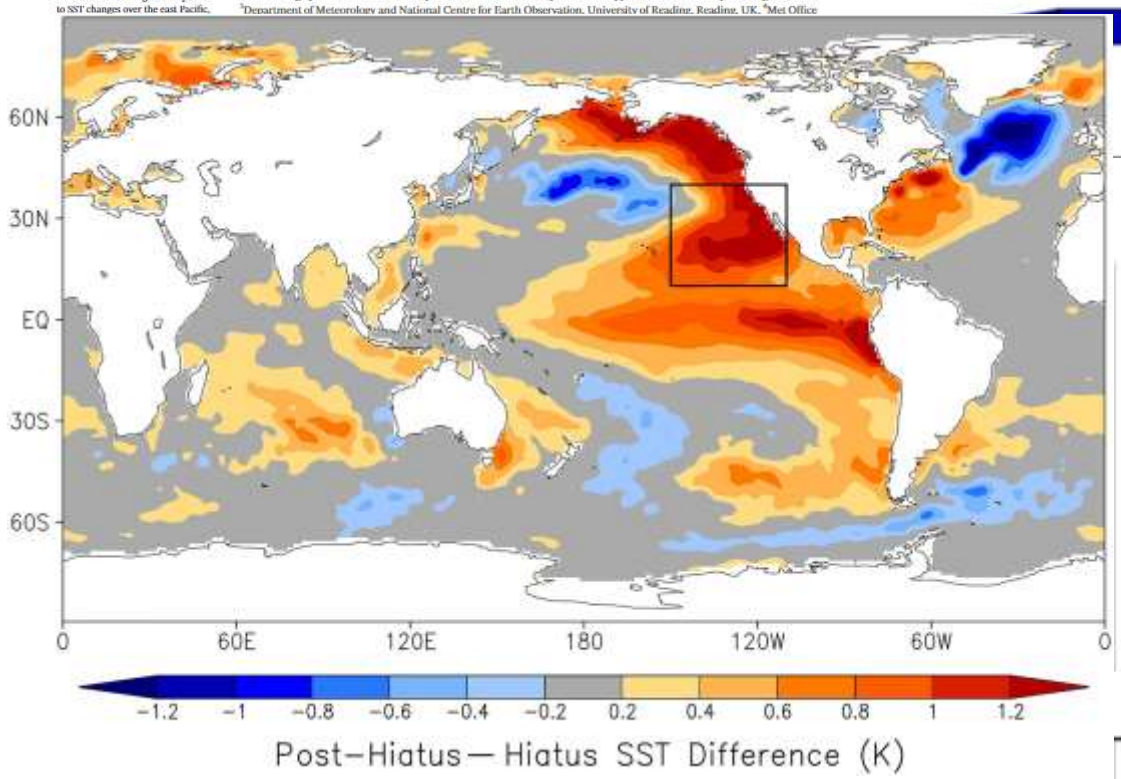
[1]NASA Langley Research Center, Hampton, VA, USA, [2]Science Systems and Applications, Inc., Hampton, Virginia, USA, [3]Department of Meteorology and National Centre for Earth Observation, University of Reading, Reading, UK, [4]Met Office

Key Points:

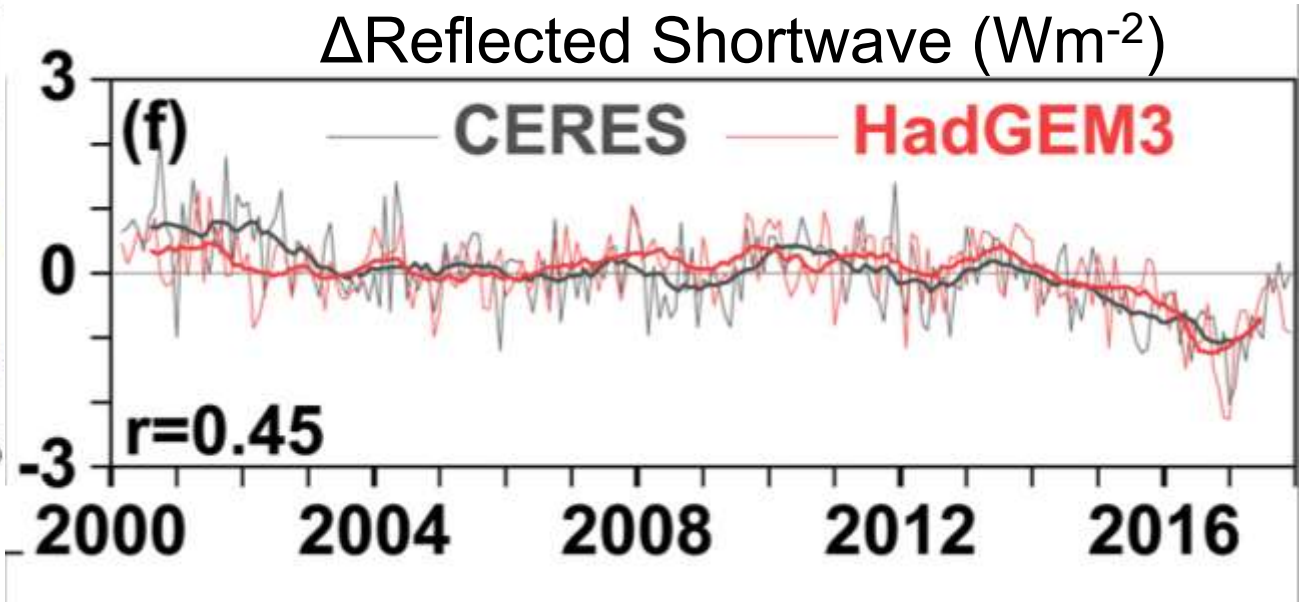
- There is good agreement between radiation budget variations observed by CERES and simulated by seven state-of-the-art climate models
- The relationship between global mean net TOA radiation and surface temperature is sensitive to changes in regions dominated by low clouds
- Most models underestimate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

CERES ΔNet Extended AMIP (7 models)

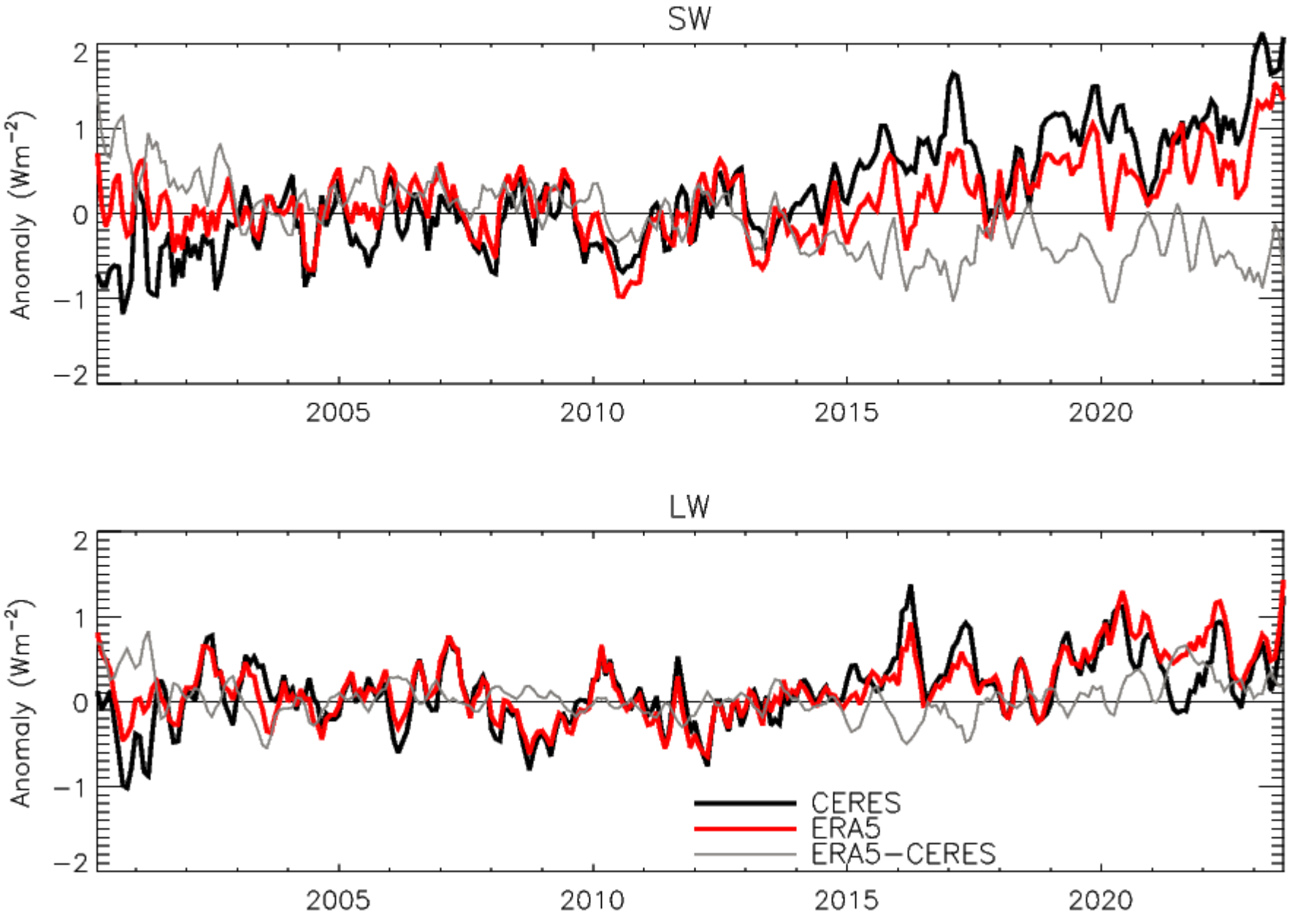




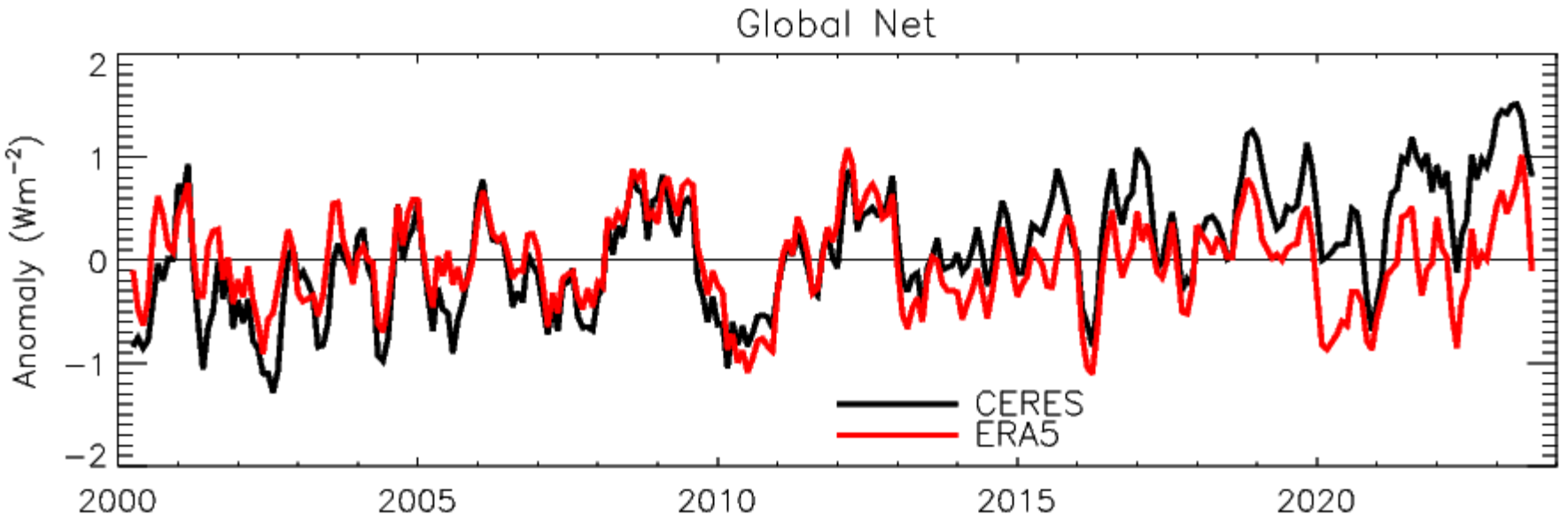
ΔReflected Shortwave (Wm^{-2})

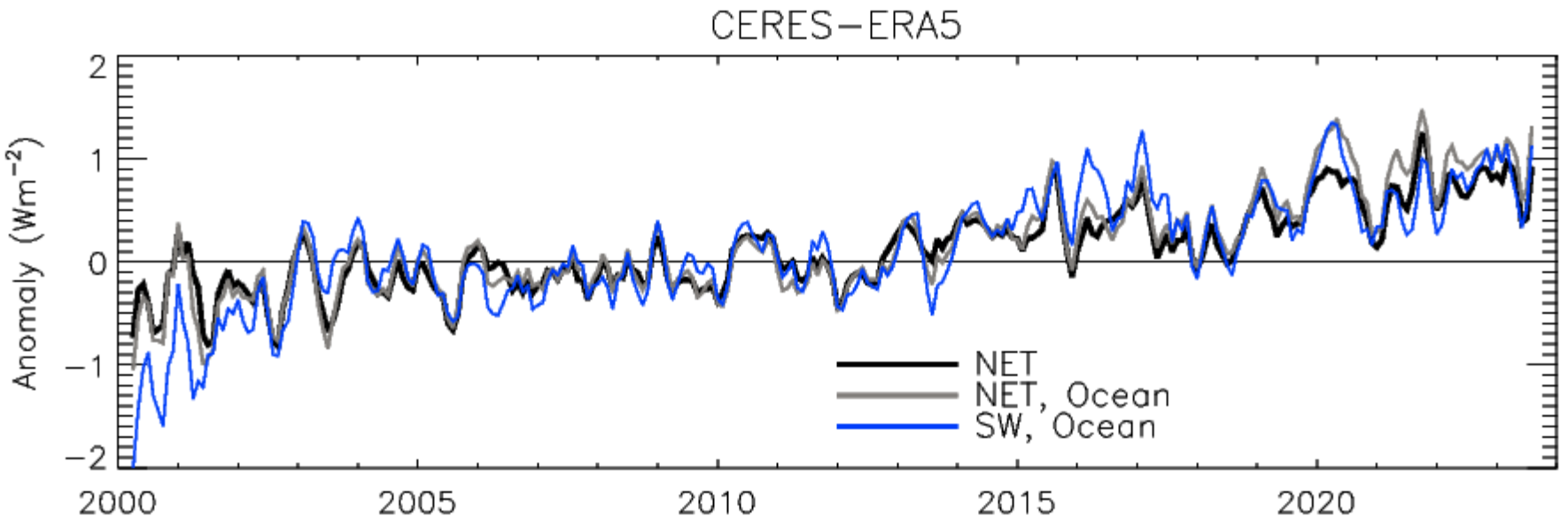


CERES and ERA5 global changes in SW and LW 2000-2023

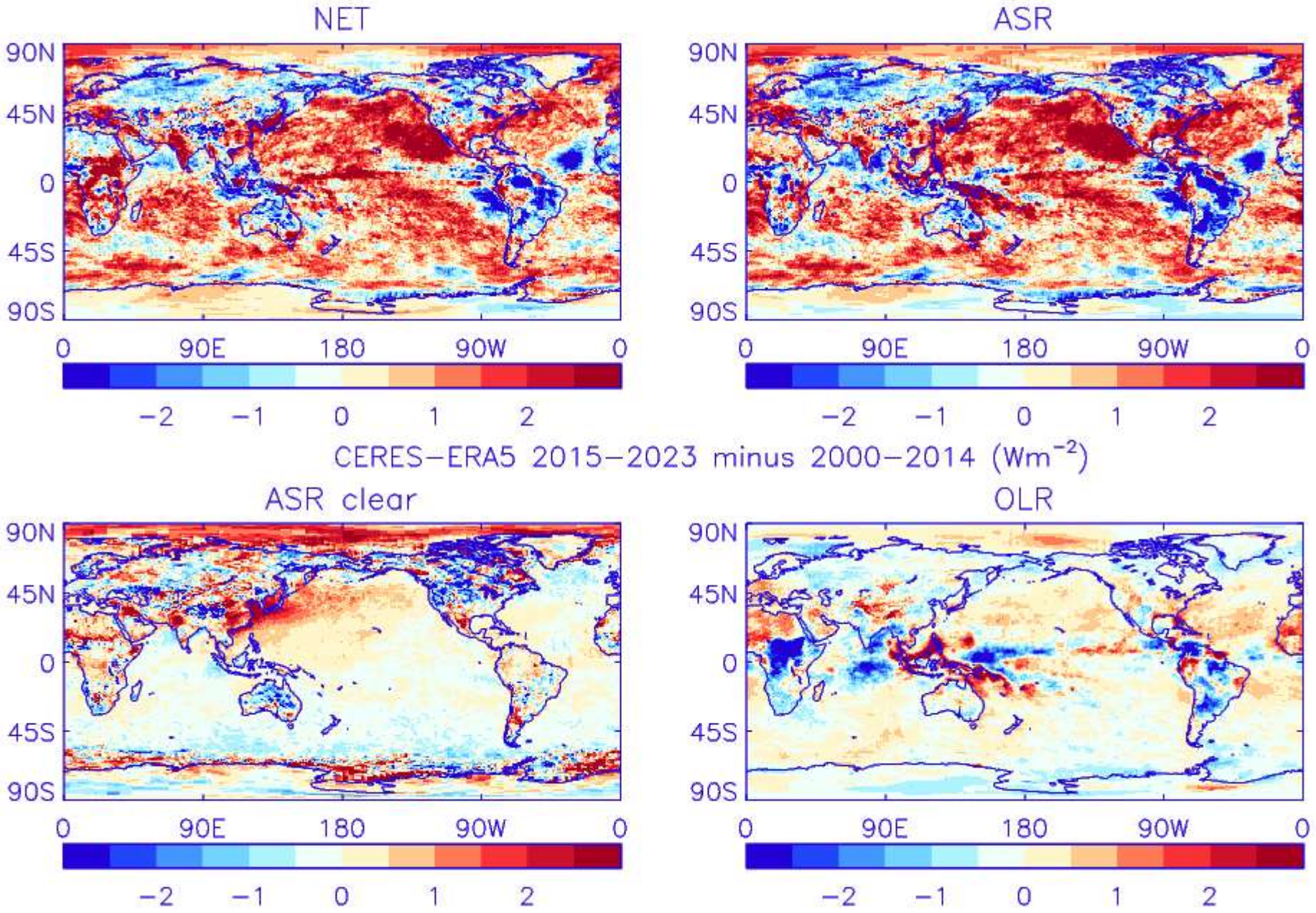


- Globally, increases in absorbed sunlight only partially offset by increased infrared emissions to space
- Observed longwave changes quite well represented by ERA5
- Increase in CERES-ERA5 absorbed SW (early part affected by Terra-only issues?)
- But both ERA5 and CERES show increase in absorbed solar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



- Change in CERES-ERA5 difference
- Large signals over subtropical stratocumulus cloud
- …which ERA5 poorly represents
- East Asia aerosol has reduced more than ERA5 (which uses CMIP historical & projection scenarios)

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

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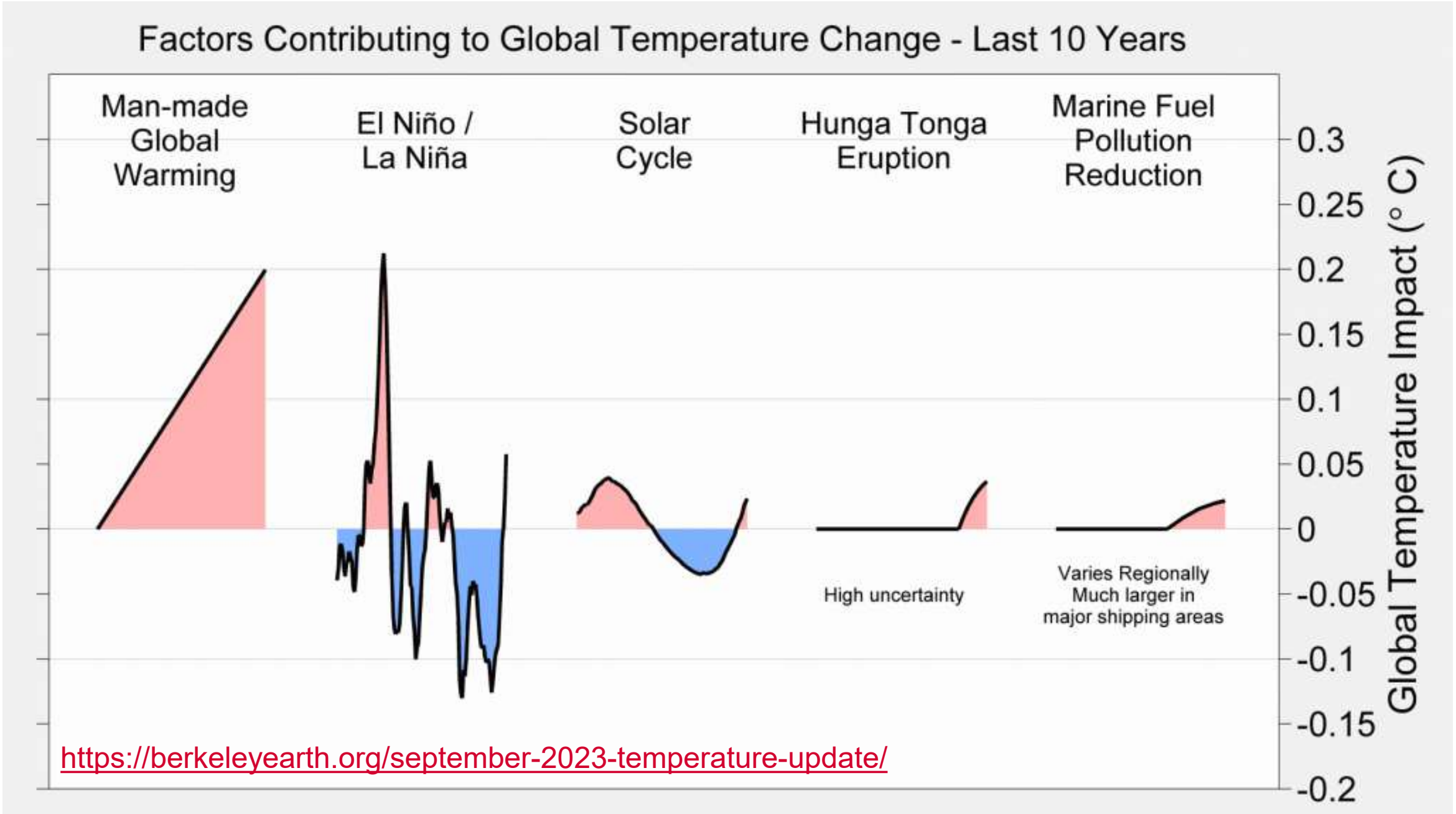
- Loeb et al. (2021) GRL attribute increased absorbed solar radiation to decreased reflection by clouds and sea-ice and decreased outgoing longwave radiation (OLR) due to increases in trace gases and water vapor
- Greenhouse gas forcing e.g. Kramer et al. (2021) GRL: instantaneous radiative forcing has 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


Factors Contributing to Global Temperature Change - Last 10 Years
Man-made Global Warming
El Niño / La Niña
Solar Cycle
Hunga Tonga Eruption
Marine Fuel Pollution Reduction
High uncertainty
Varies Regionally Much larger in major shipping areas
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
Global Temperature Impact (° C)
https://berkeleyearth.org/september-2023-temperature-update/

SUMMARY

- Heating of climate system accelerating

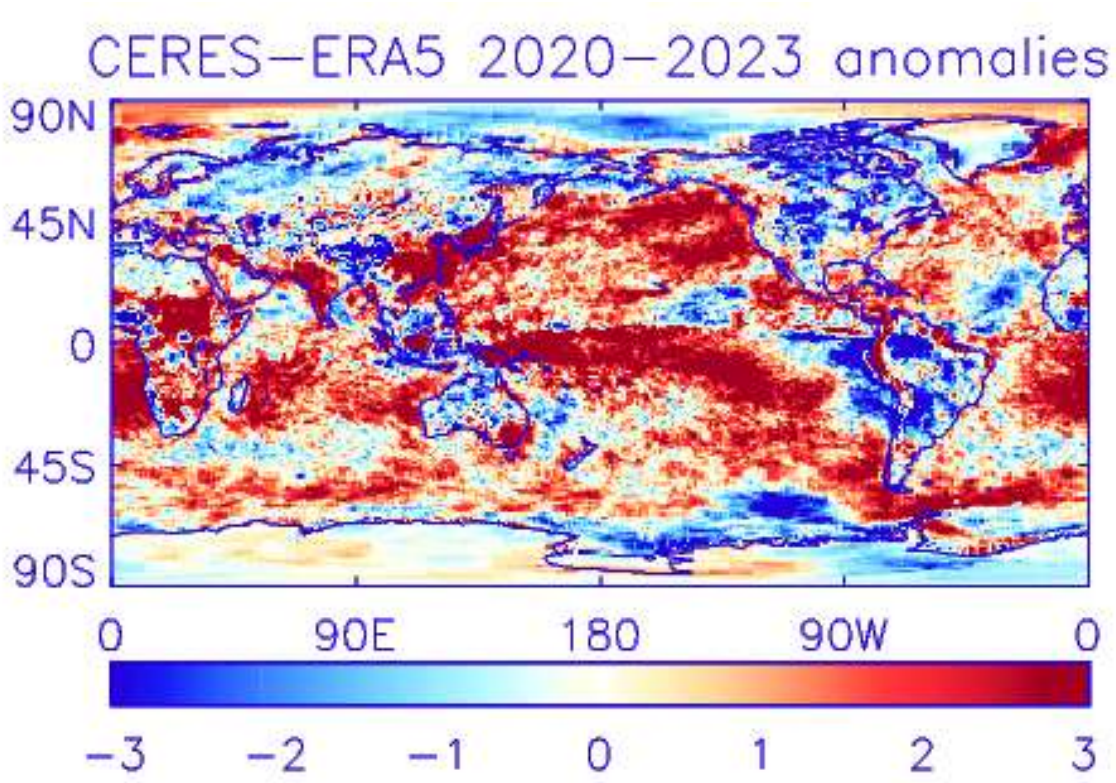
… but needs to reduce to “net zero”)

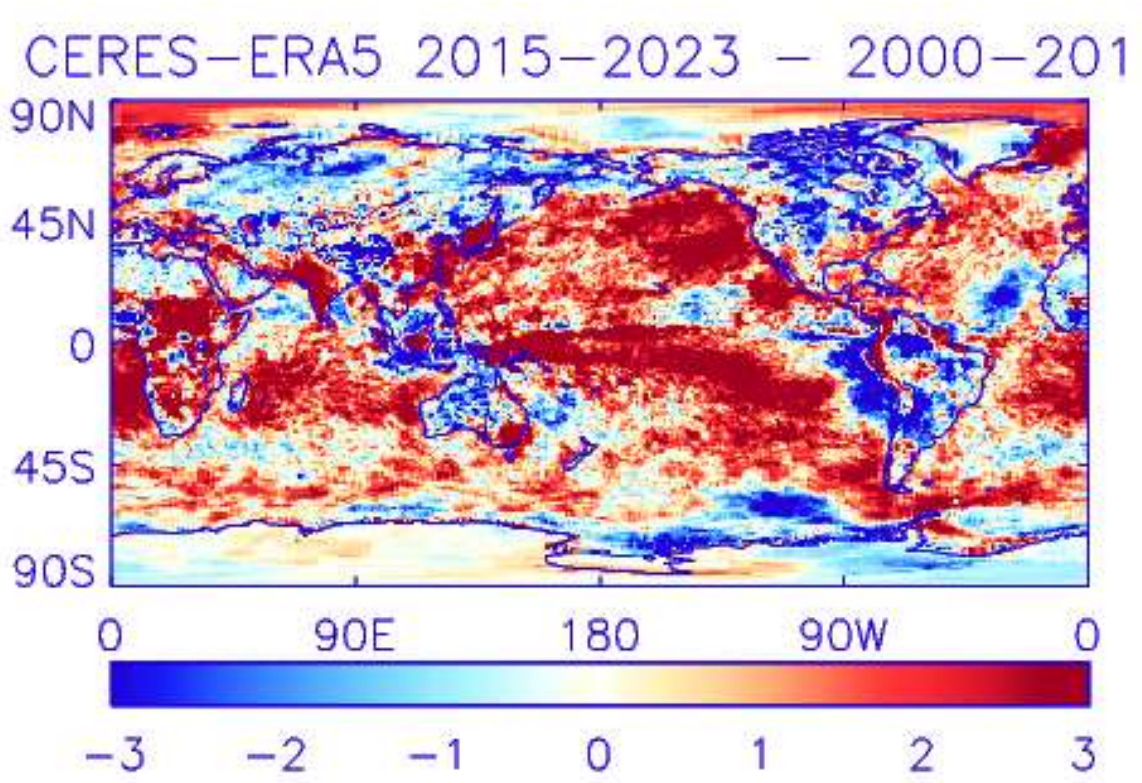
  - 0.48 Wm^{-2} 1971-2020, 0.74 Wm^{-2} 2006-2020 (von Shuckmann et al. (2023) ESSD)
  - 0.5 Wm^{-2} increase 2000-2010 to 2011-2020 (increased absorbed sunlight partly offset by increased outgoing longwave)

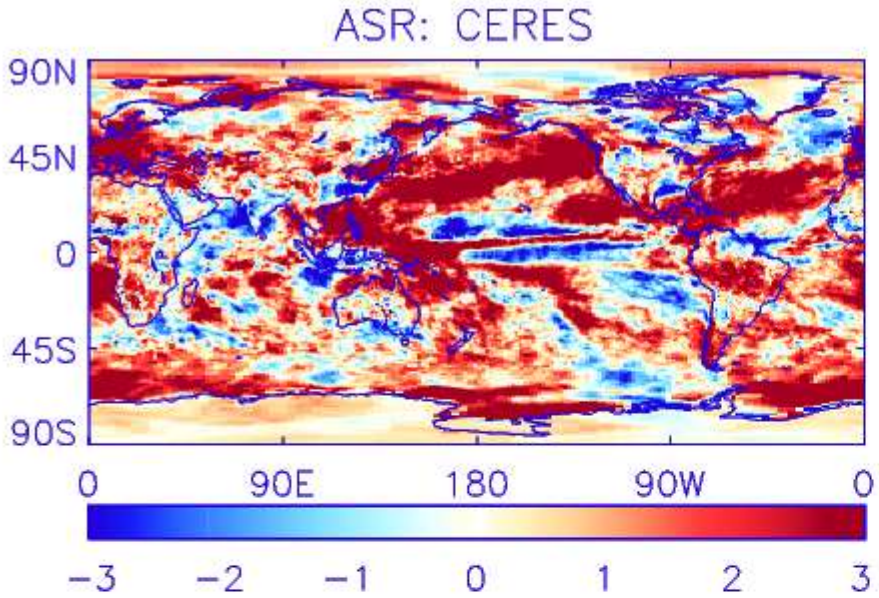
- Radiative forcing is increasing, but decreased low altitude cloud in subtropical Pacific relating to SST pattern may be contributing Loeb et al. 2021 GRL
- Both CERES and ERA5 show increased absorption of sunlight, but this effect is larger in CERES and in ERA5 LW emission compensates for SW absorption
- 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…

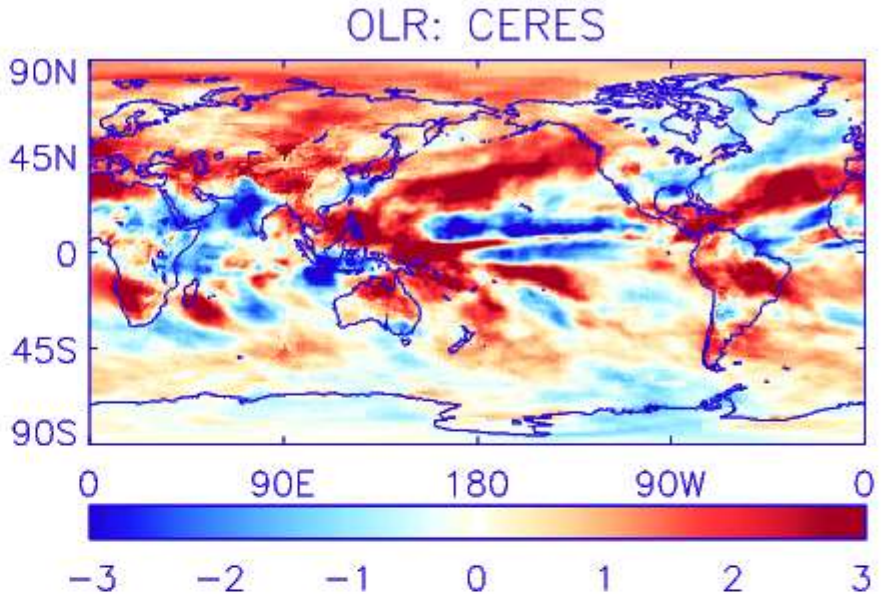
EXTRA SLIDES

MORE RECENT CERES-ERA5 ANOMALIES









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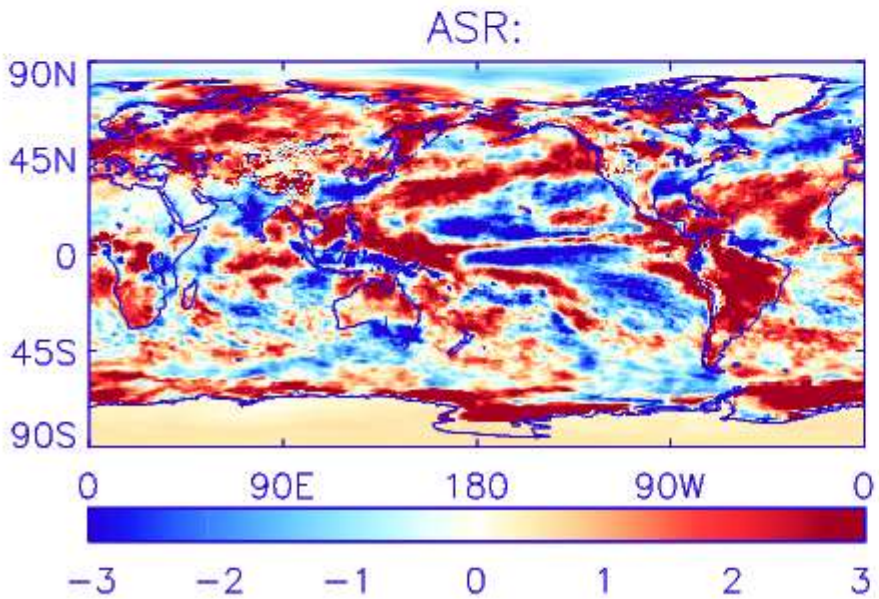
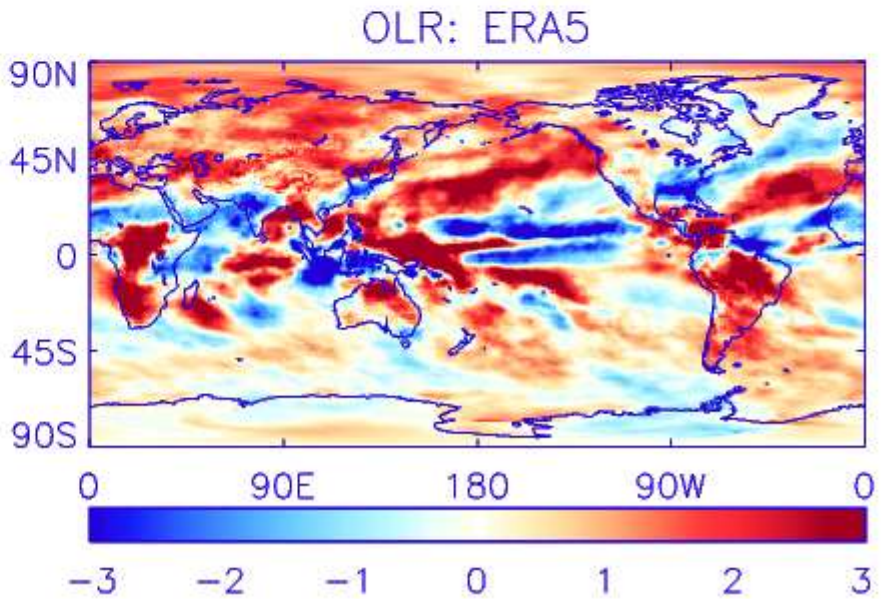
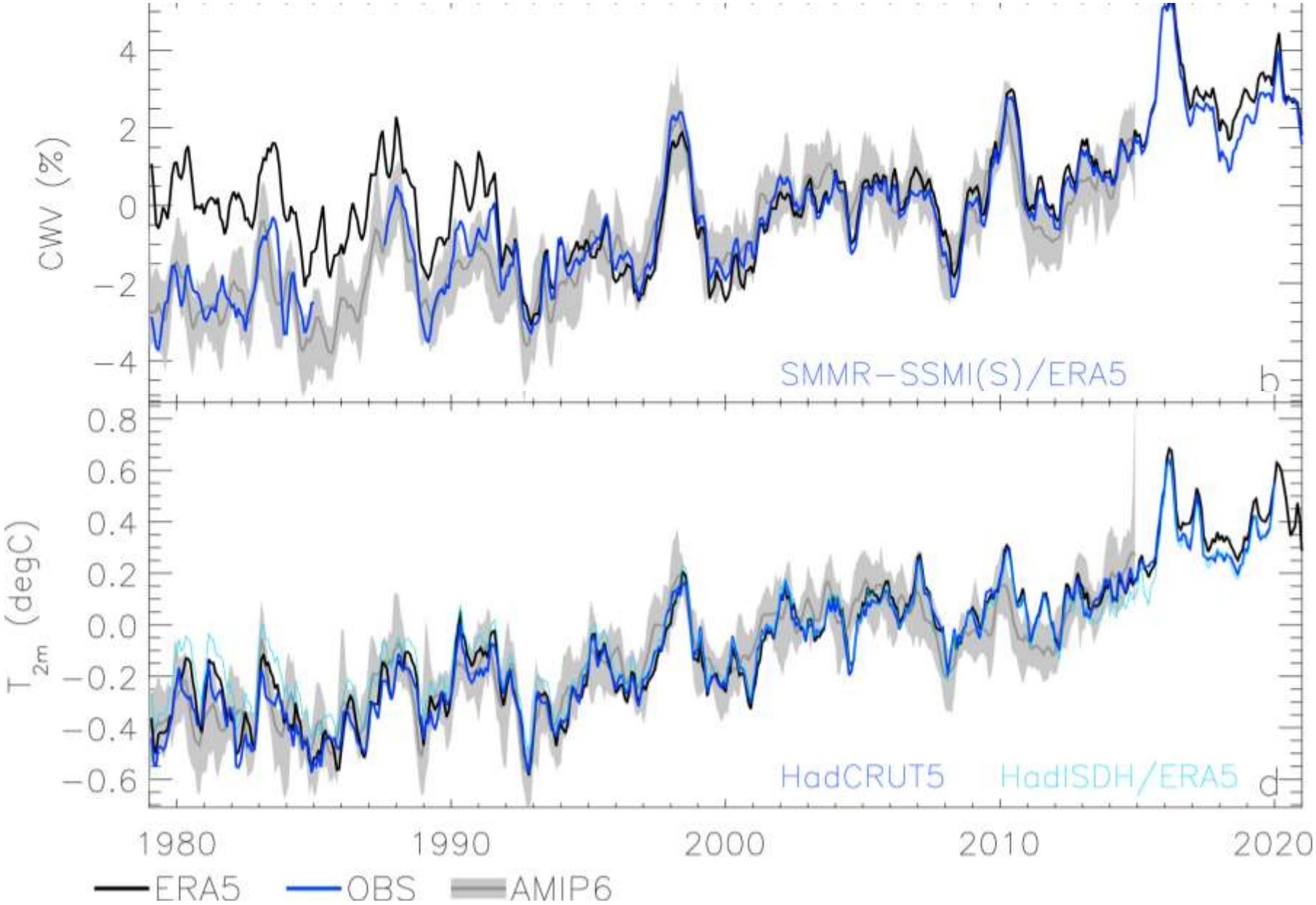
- 2015-2023 minus 2000-2014

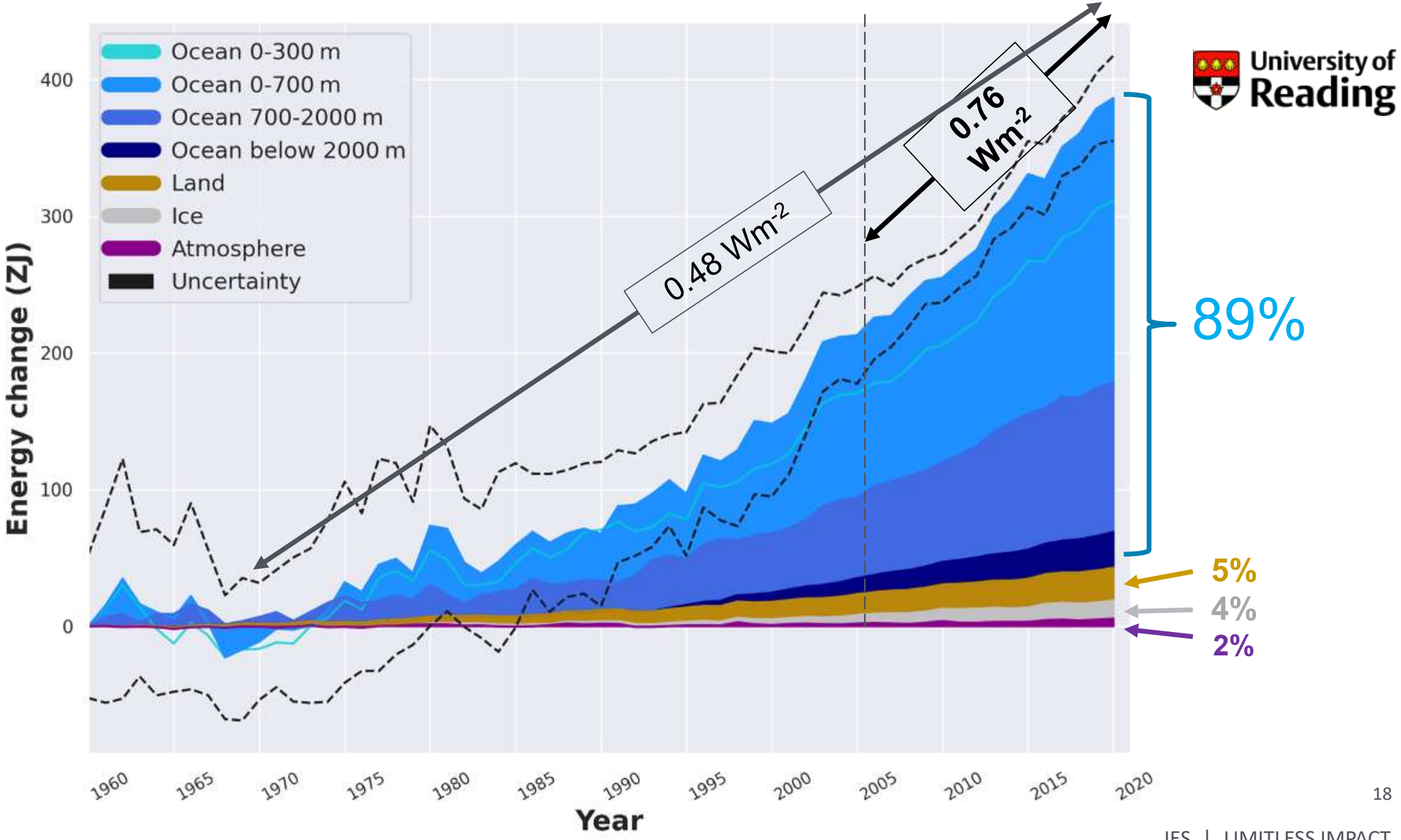






- Increasing water vapour, particularly over the ocean is absorbing more sunlight (as well as increasing the greenhouse effect)
- This is consistent between ERA5 and SSMI(S) observations

Allan et al. (2021) JGR



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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
  - 89% in ocean, 5% in land, 4% melting ice, 2% atmosphere
  - 40% of ocean heating in upper 300m; 91% in upper 2000m

- Comparison to independent ocean heat content & sea level rise records good consistency check
- Decreased low altitude cloud in subtropical Pacific contributed to recent additional heating (also decreases in OLR relating to water vapour & trace gases plus ice melt) Loeb et al. 2021 GRL
- Gaps in record major issue in assessing changes in energy budget crucial in understanding radiative forcing, heating of the system and feedback response