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AN UPDATE ON EARTH'S HEAT INVENTORY

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Lead by Karina von Shuckmann and a cast of thousands, thanks also to Chunlei Liu

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INTRODUCTION

- Energy budget fundamental diagnostic of climate change
- Earth's Heat Inventory can be part of Global Stocktake of Paris agreement
- Latest Heat Inventory 1971-2020: von Schuckmann et al. (2023) ESSD
  - Heating of oceans,
  - Heating of land,
  - Melting/heating of ice
  - Warming/moistening of atmosphere
- Is heating increasing? Changes in Earth's Energy Imbalance from satellite

MULTI-DECADAL EARTH RADIATION BUDGET RECORD

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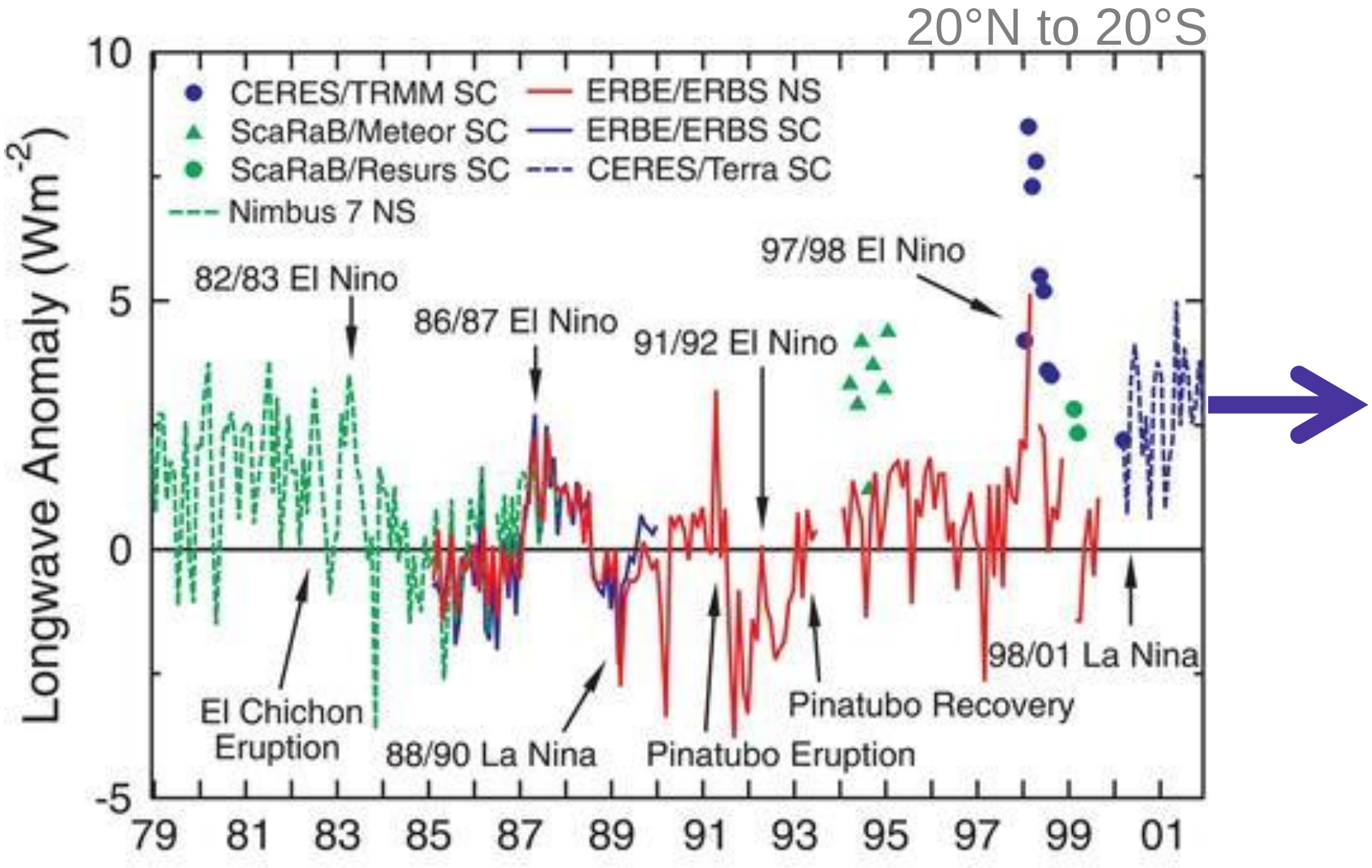
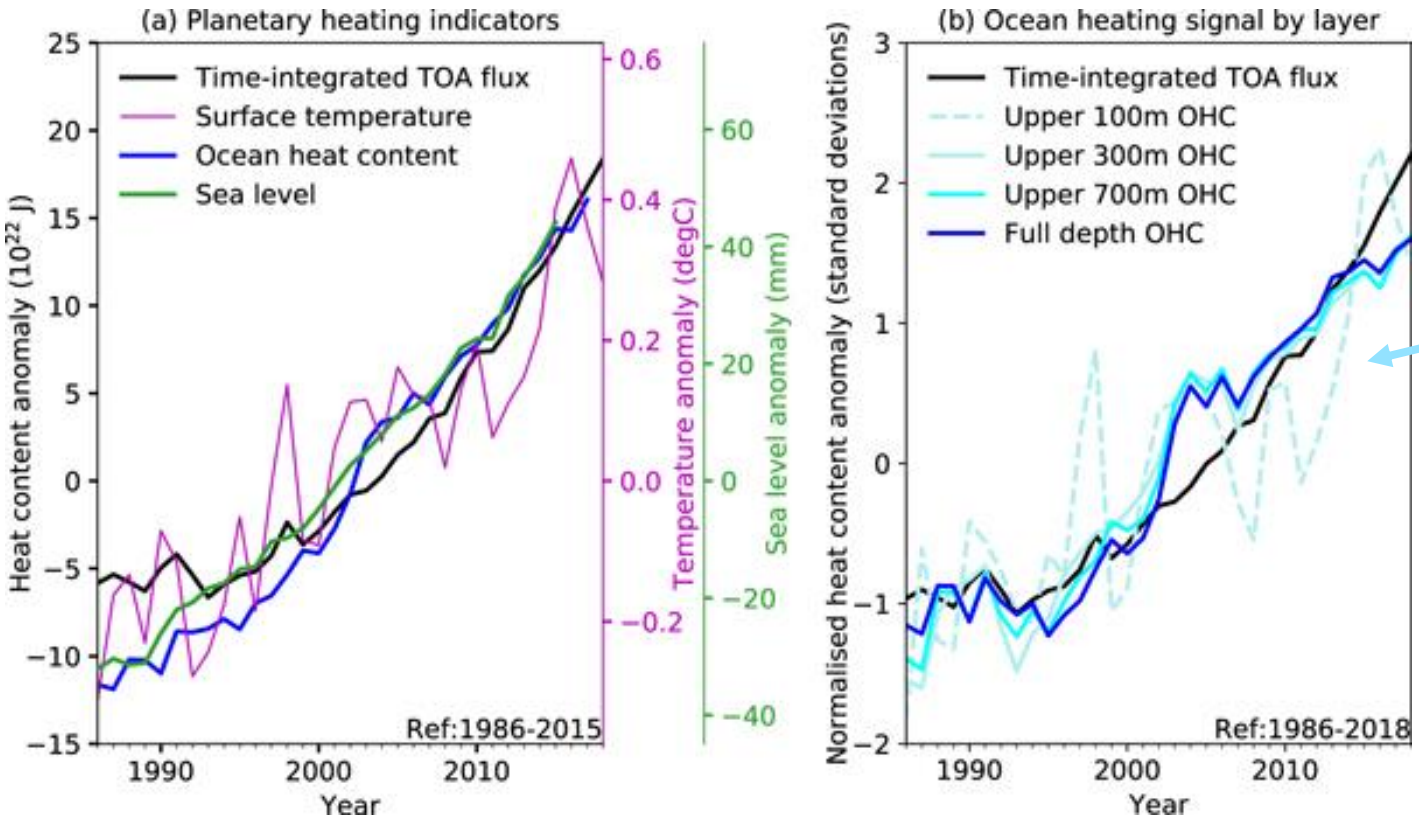
- Diagnose global climate forcing and feedback response
- Evaluate regional radiative processes related to climate
- Understand drivers of variability and trends
- Homogeneity, sampling & calibration issues
- Consistency with heat content/sea level e.g. Loeb et al. (2012) Nat. Geosci; Allison et al. (2020) ERC; Cheng et al. 2017 Sci. Adv.



Wong et al. (2006) J Clim; Wielicki et al. (2002) Science

PLANETARY HEATING SINCE THE 1980S FROM MULTIPLE INDEPENDENT DATASETS



Heating:

- 1985-1999: **0.10 ± 0.61 W m^{-2}**
- 2000–2016 **0.62 ± 0.1 W m^{-2}**

Liu et al. 2020 Clim. Dyn

- Surface temperature determined by upper mixed layer ocean heat e.g. Allan (2018) Nature Clim.

Allison et al. (2020) ERC doi:10.1088/2515-7620/abbb39

See also Cheng et al. 2017 Sci. Adv.

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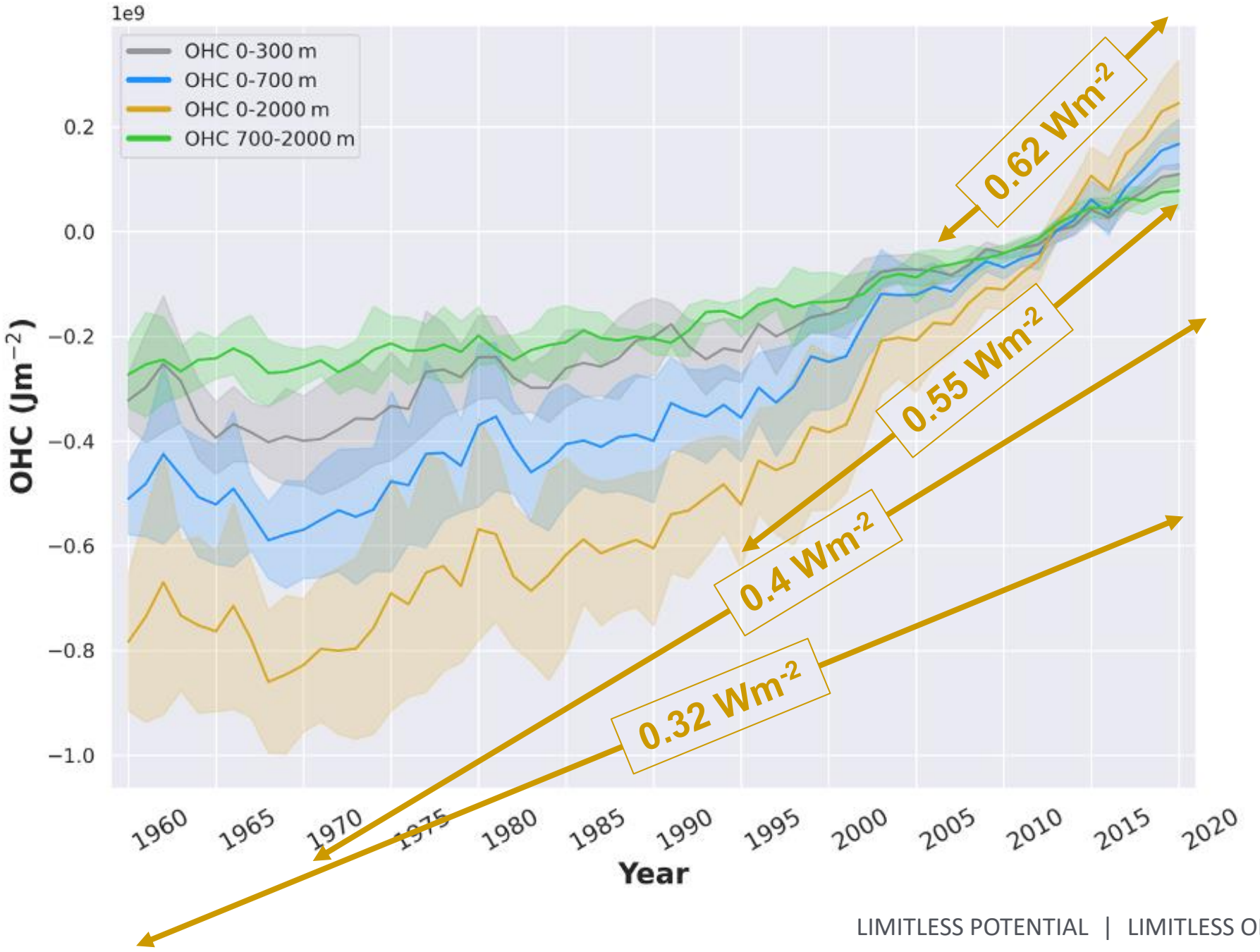
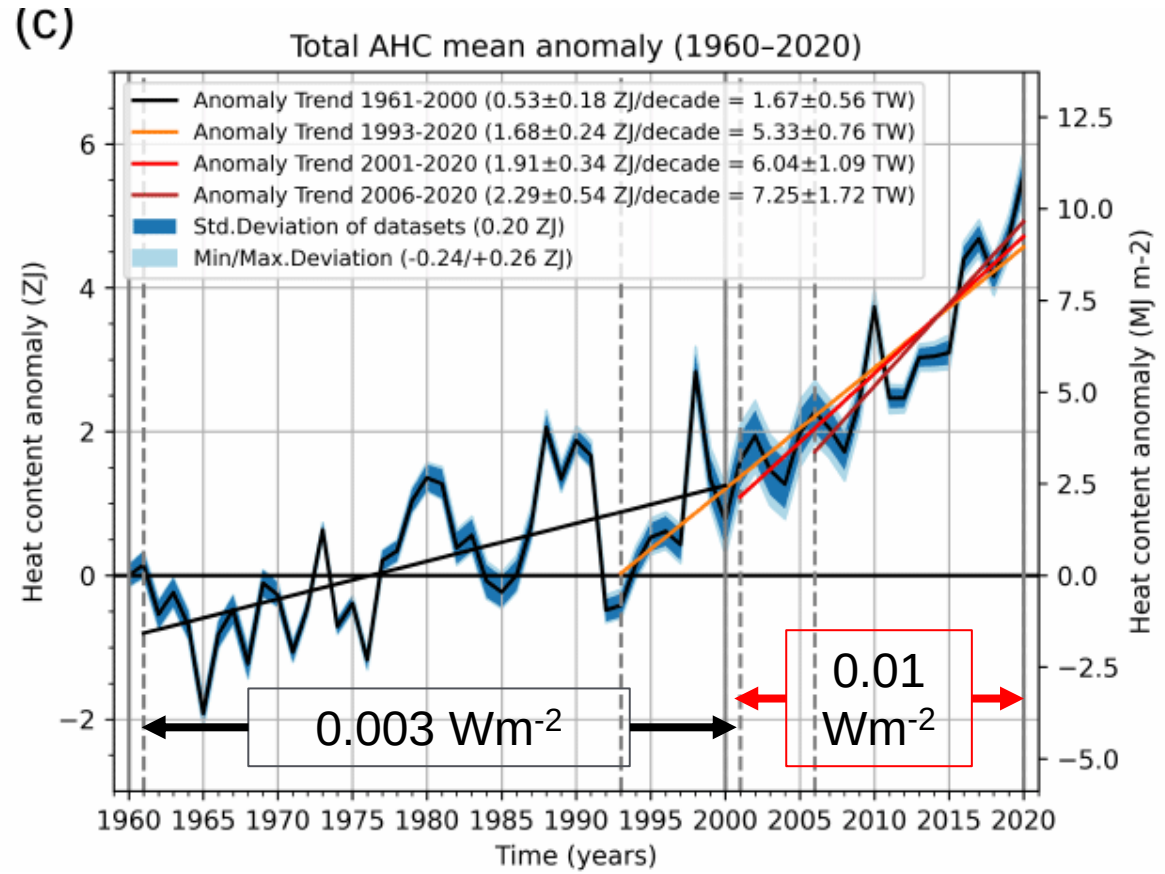
OCEAN HEAT CONTENT

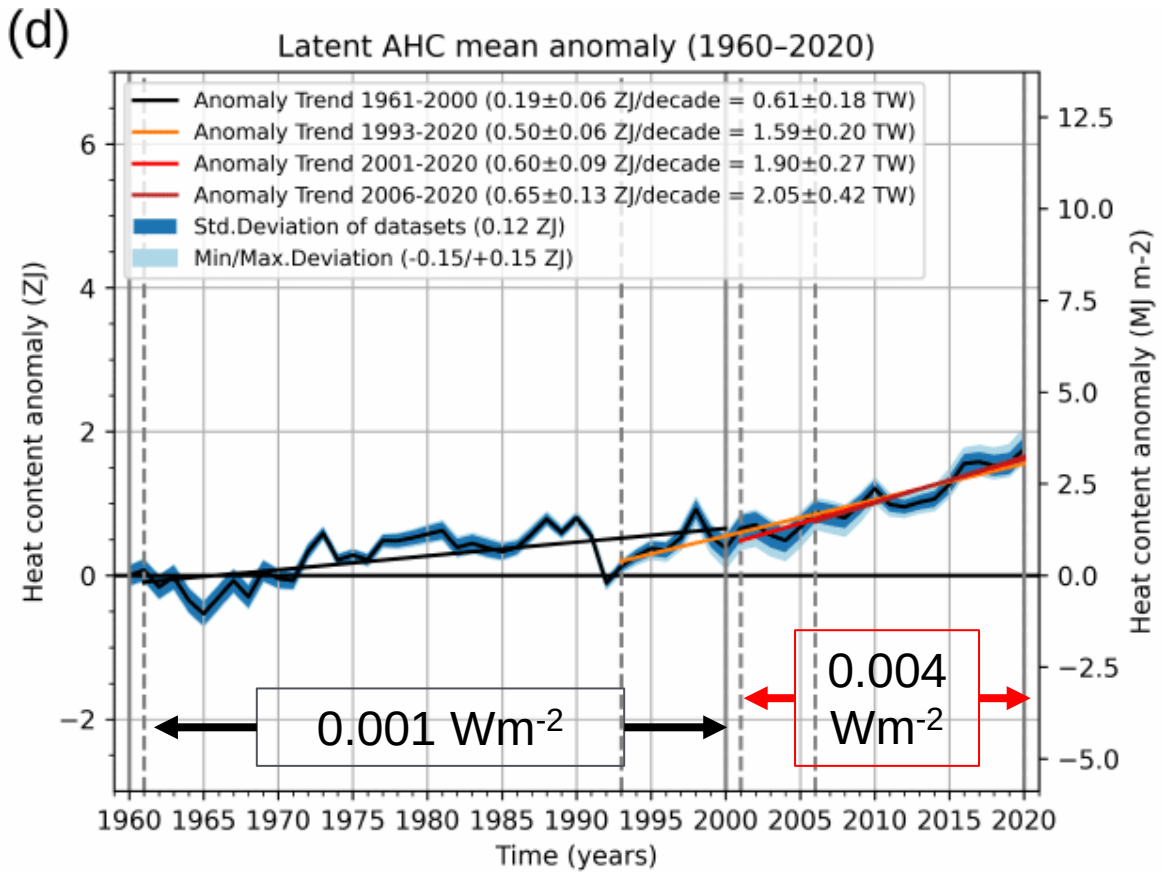


GJ per m^2 of 60^{o}S-60^{o}N ocean area

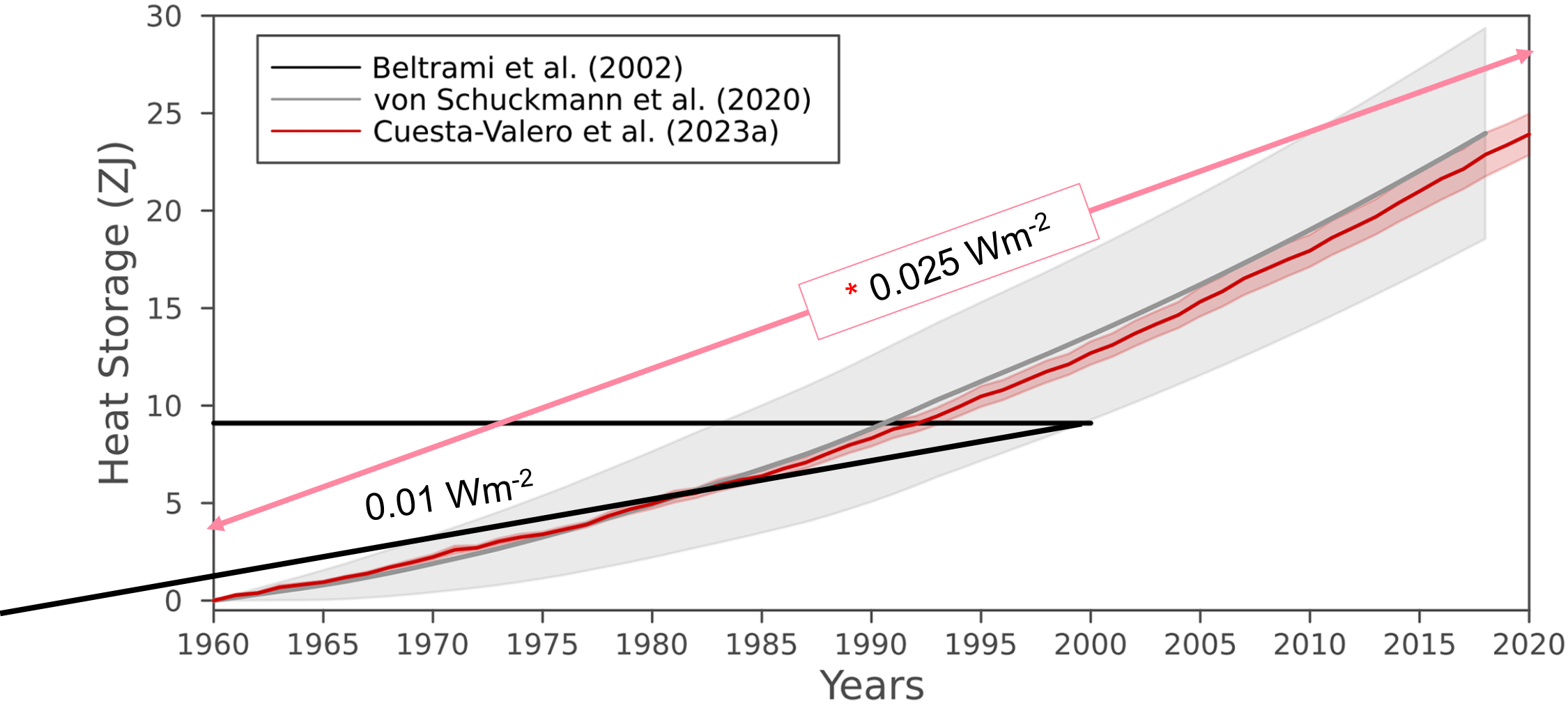
Also shown, equivalent Wm^{-2} for global surface area

ATMOSPHERIC HEAT CONTENT



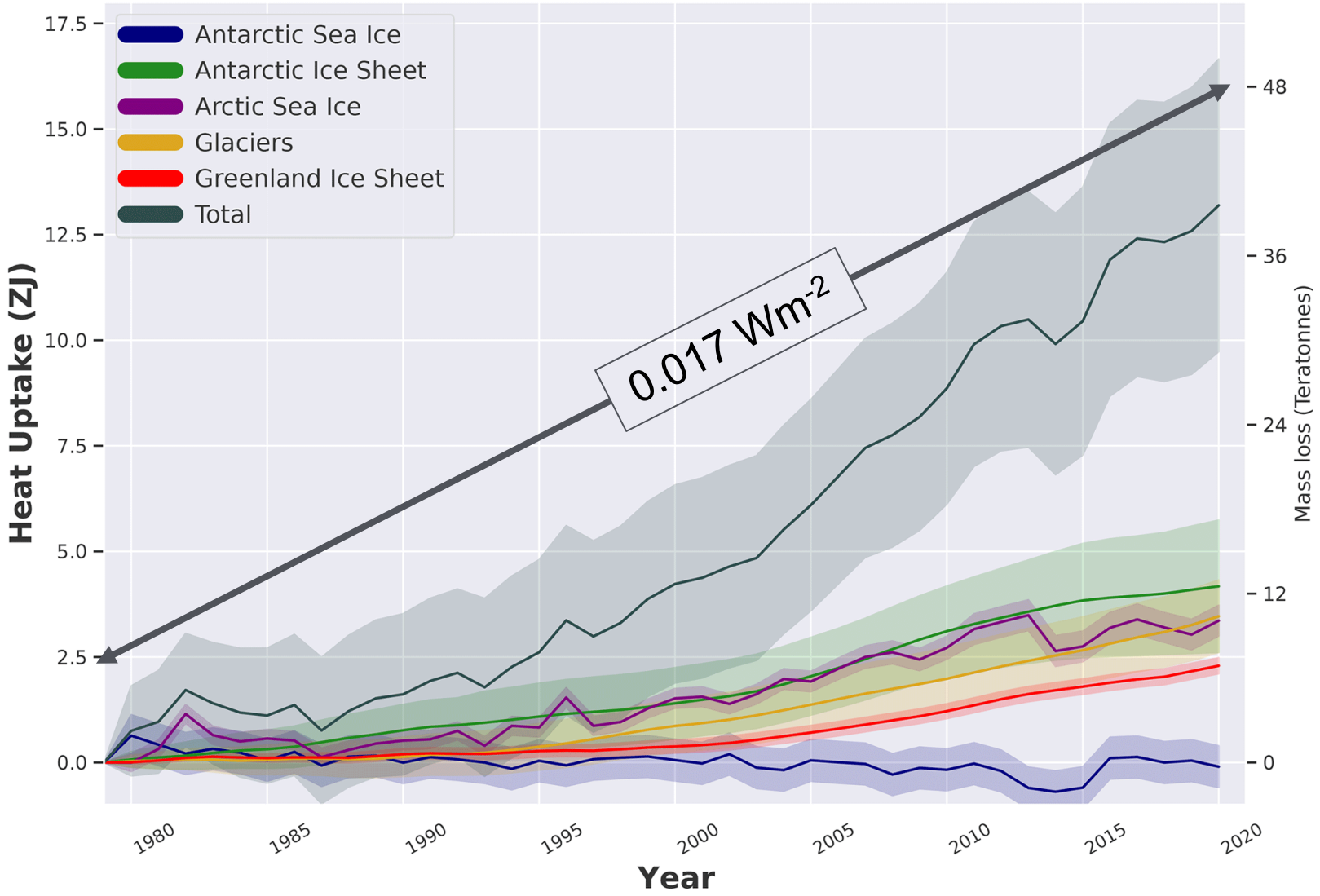


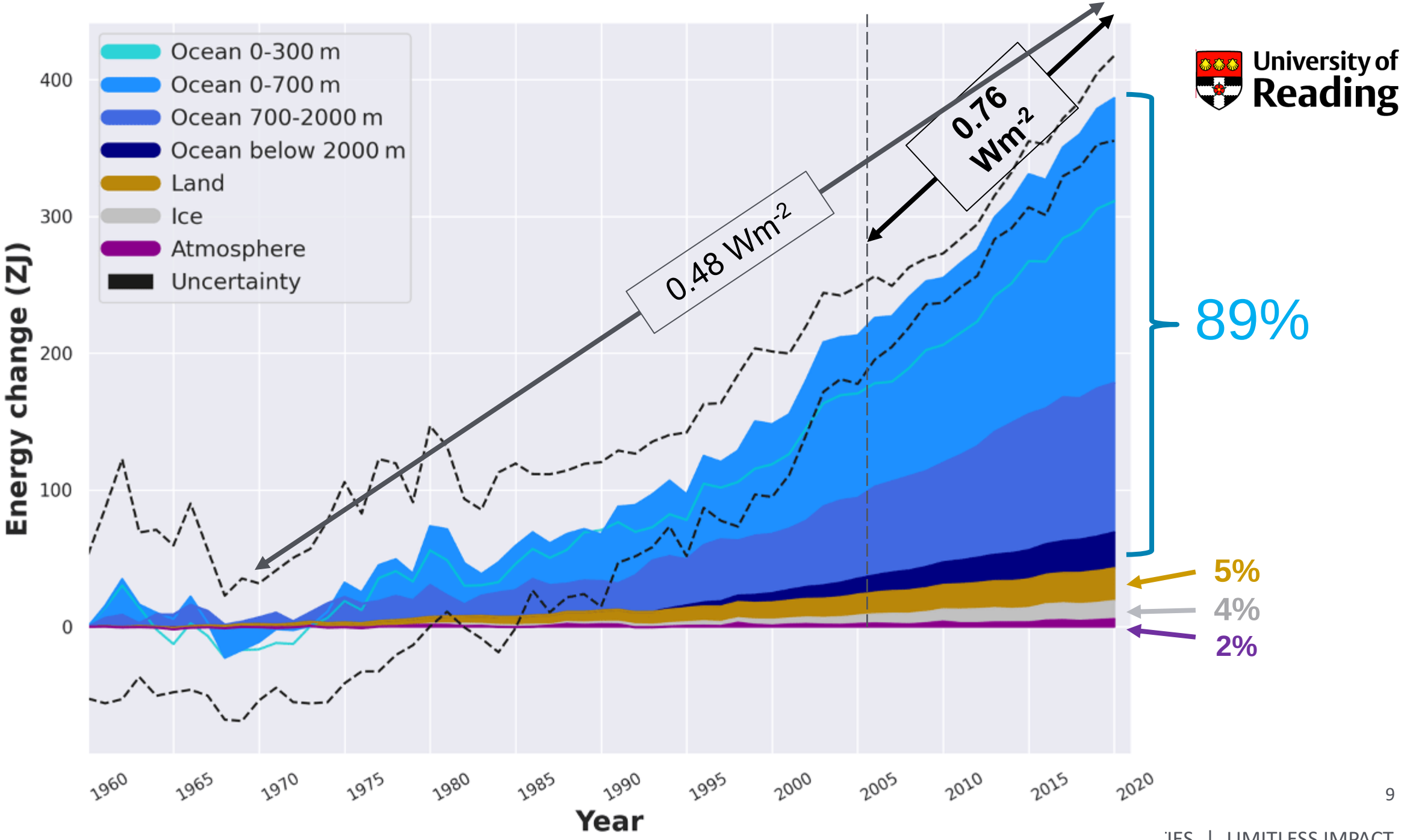
HEATING OF THE LAND



*including heat storage within inland water bodies 0.0002 Wm^{-2} since 1960, with permafrost thawing accounting for 0.002 Wm^{-2}

HEAT USED MELTING ICE





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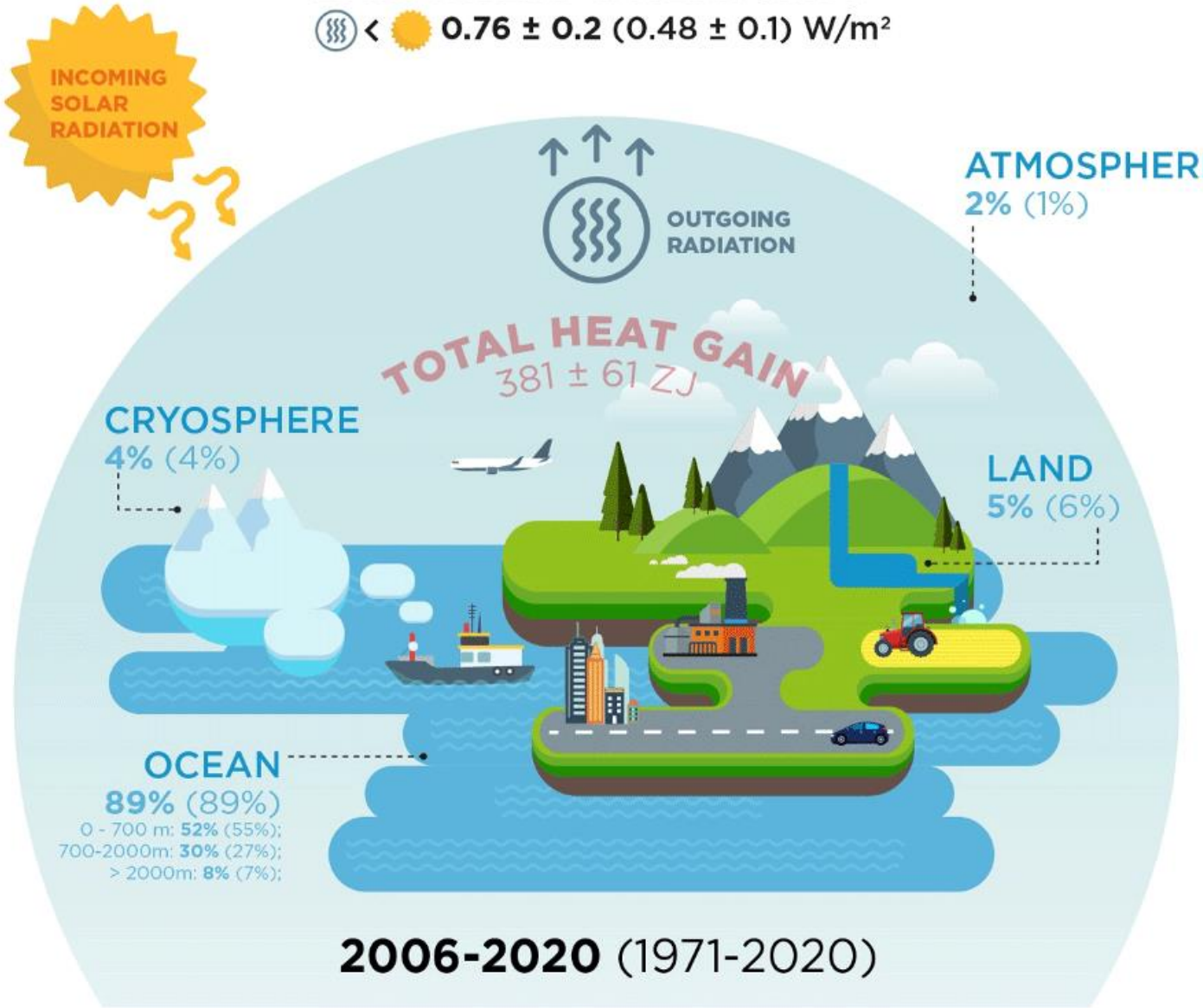
EARTH HEAT INVENTORY :

0.76 ± 0.2 (0.48 ± 0.1) W/m²



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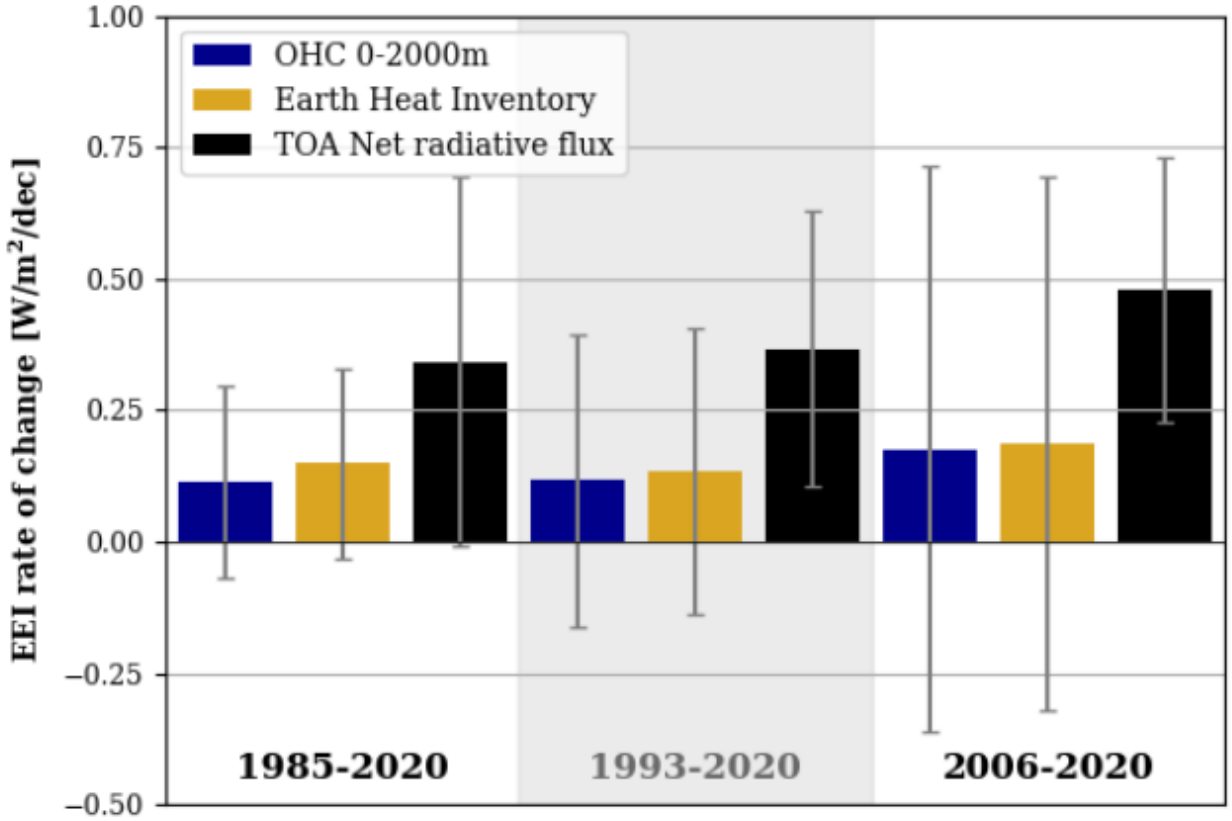
https://doi.org/10.5194/essd-15-1675-2023

Open Access Earth System Science Data

Heat stored in the Earth system 1960–2020: where does the energy go?

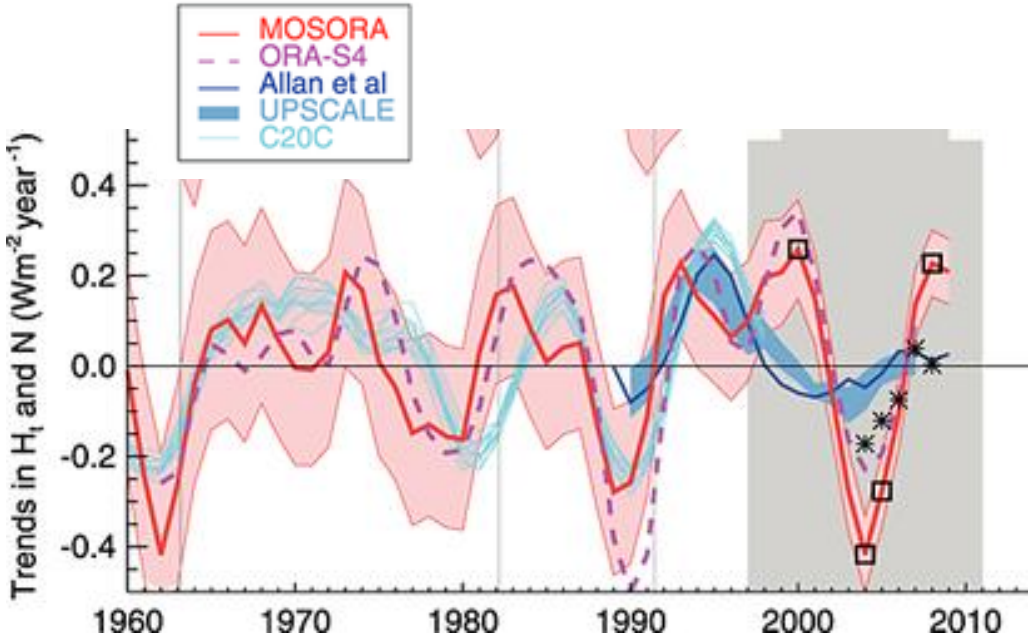
Karina von Schuckmann[1], Audrey Minière[1], Flora Gues[2,1], Francisco José Cuesta-Valero[3,4], Gottfried Kirchengast[5,6], Susheel Adusumilli[7], Fiammetta Straneo[7], Michaël Ablain[8], Richard P. Allan[9], Paul M. Barker[10], Hugo Beltrami[11], Alejandro Blazquez[12], Tim Boyer[13], Lijing Cheng[14,15], John Church[17], Damien Desbruyeres[16], Han Dolman[18], Catia M. Domingues[19], Almudena García-García[3,4], Donata Giglio[20], John E. Gilson[7], Maximilian Gorfer[5], Leopold Haimberger[21], Maria Z. Hakuba[22], Stefan Hendricks[23], Shigeki Hosoda[24], Gregory C. Johnson[25], Rachel Killick[26], Brian King[27], Nicolas Kolodziejczyk[16], Anton Korosov[28], Gerhard Krinner[29], Mikael Kuusela[30], Felix W. Landerer[22], Moritz Langer[31,32], Thomas Lavergne[33], Isobel Lawrence[34], Yuehua Li[35], John Lyman[25], Florence Marti[8], Ben Marzeion[36], Michael Mayer[21,37], Andrew H. MacDougall[38], Trevor McDougall[10], Didier Paolo Monselesan[39], Jan Nitzbon[40,41], Inès Otosaka[42], Jian Peng[3,4], Sarah Purkey[7,43], Dean Roemmich[7,43], Kanako Sato[24], Katsunari Sato[44], Abhishek Savita[45], Axel Schweiger[46], Andrew Shepherd[47], Sonia I. Seneviratne[48], Leon Simons[49], Donald A. Slater[50], Thomas Slater[51], Andrea K. Steiner[5], Toshio Suga[52,24], Tanguy Szekely[53], Wim Thiery[54], Mary-Louise Timmermans[58], Inne Vanderkelen[54,55,56,57], Susan E. Wjiffels[39,59], Tonghua Wu[60], and Michael Zemp[61]

ACCELERATING CLIMATE CHANGE?

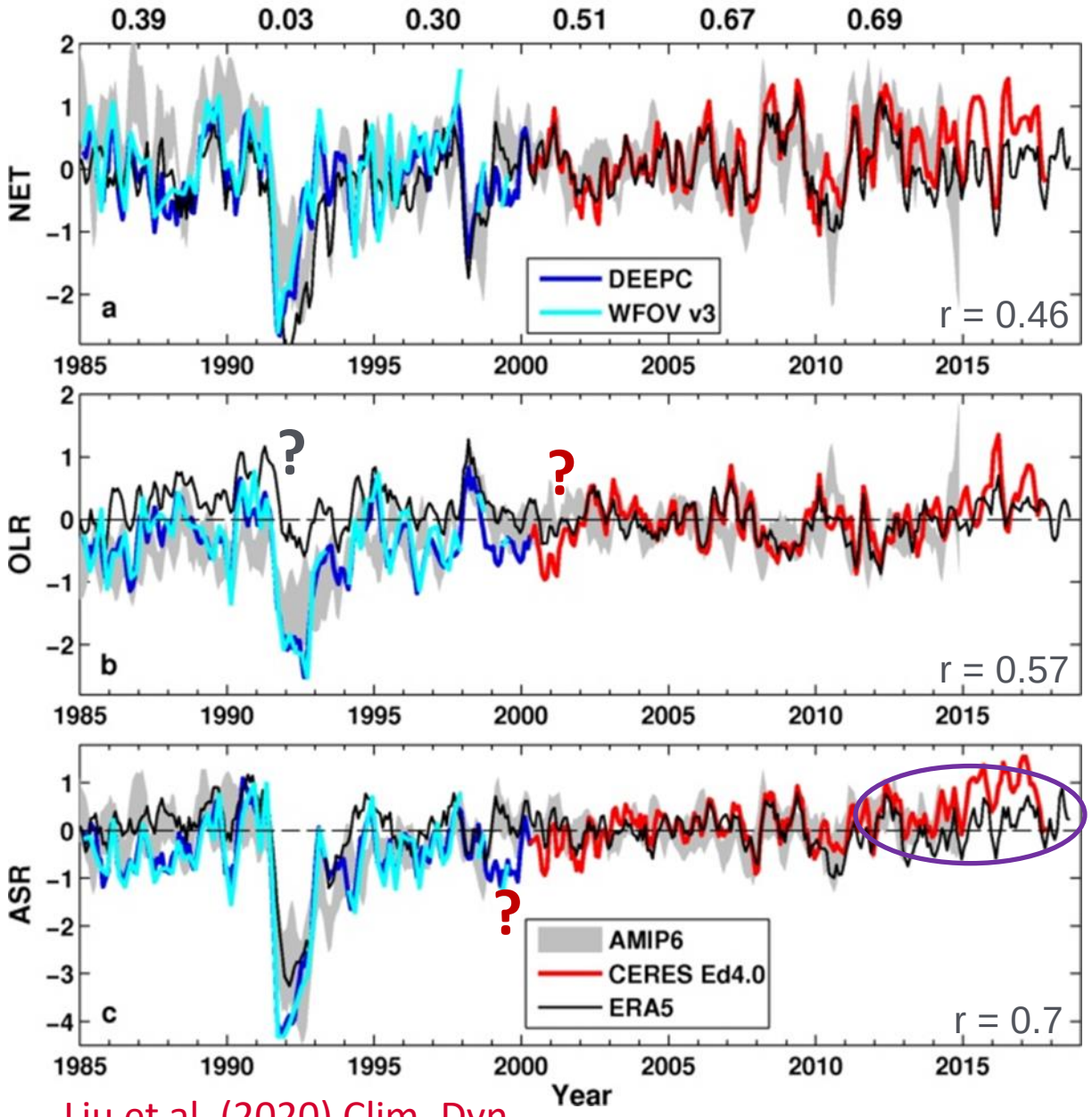


Can we monitor rate of change of heating??
von Shuckmann et al. (2023) ESSD

e.g. Smith et al. (2015) GRL found inconsistencies in trends of heating & related this to ocean observing system



CURRENT ENERGY BUDGET CHANGES



Liu et al. (2020) Clim. Dyn.

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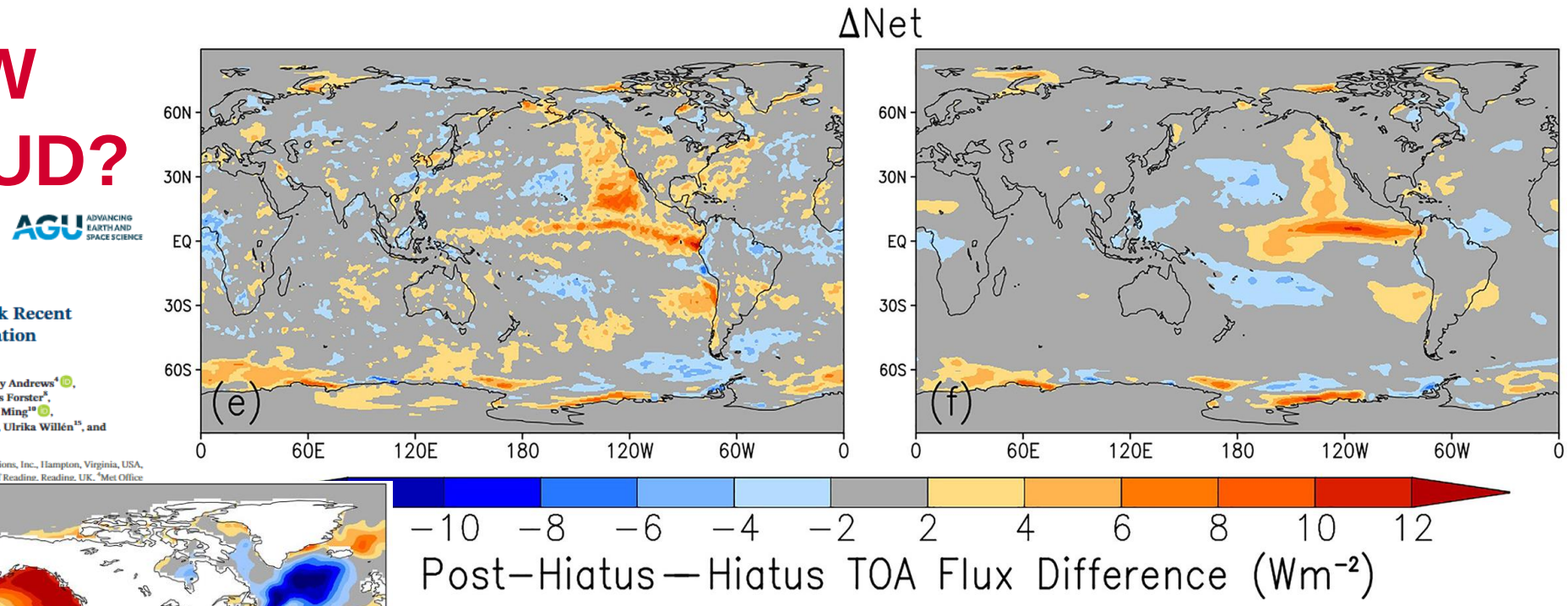
- Large uncertainty in pre-CERES EEI remains
  - Update to using AMIP6 adjustments increases change from ~0.3 Wm^{-2} (Liu et al. 2017) to ~0.5 Wm^{-2} (Liu et al. 2020) & uncertainty range
- Consistent with ocean heat content changes (Cheng et al. 2017 Sci. Adv.), lower than Resplandy et al. (2019) Sci. Rep. Who have larger range following correction (0.3-1.3 Wm^{-2})
- ERA5 does not capture observed ASR increase after warming slowdown (e.g. Loeb et al. 2018)
  - ↑Heating 2015/16
  - Cloud plus aerosol? Calibration drift?

ROLE OF LOW ALTITUDE CLOUD?



AGU ADVANCING EARTH AND SPACE SCIENCE

Geophysical Research Letters

RESEARCH LETTER
10.1029/2019GL086705

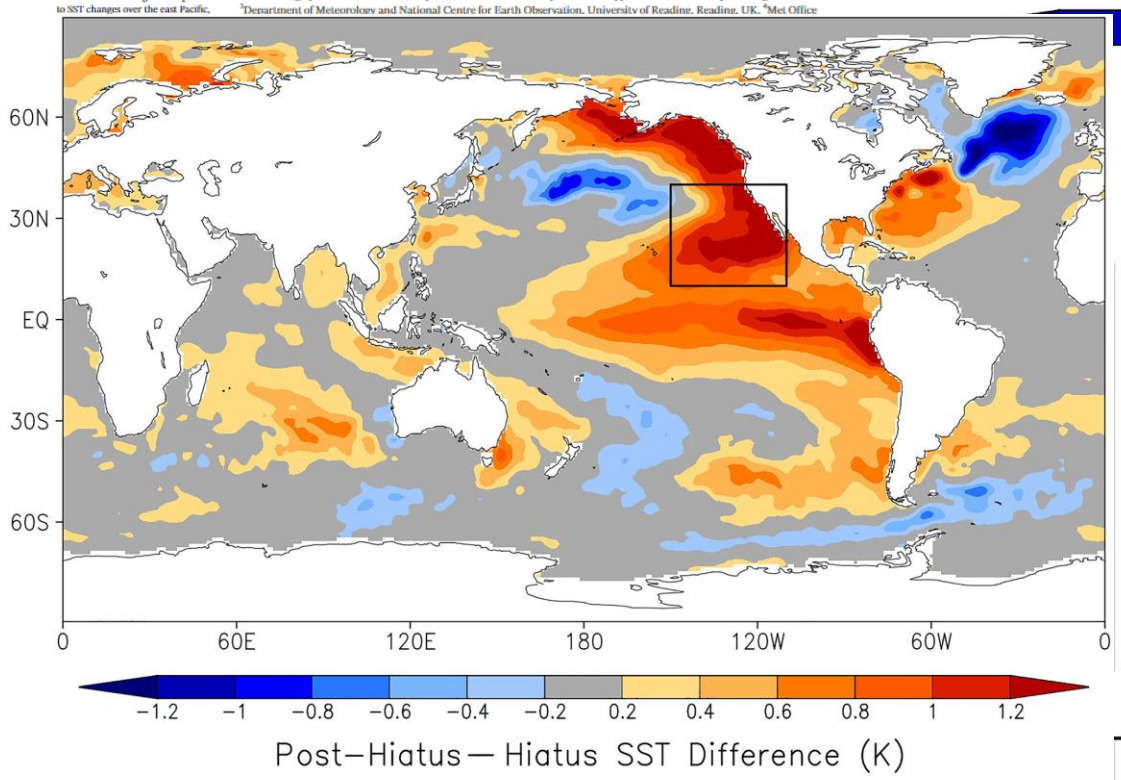
Key Points:

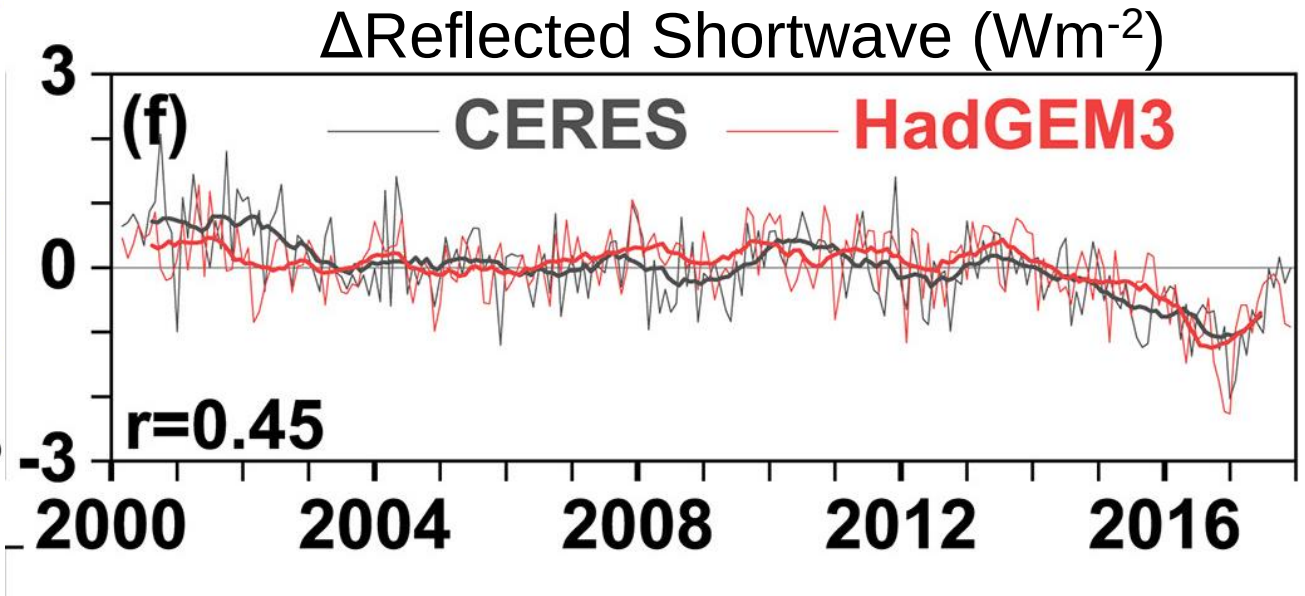
- There is good agreement between radiation budget variations observed by CERES and simulated by seven state-of-the-art climate models
- The relationship between global mean net TOA radiation and surface temperature is sensitive to changes in regions dominated by low clouds
- Most models underestimate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

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

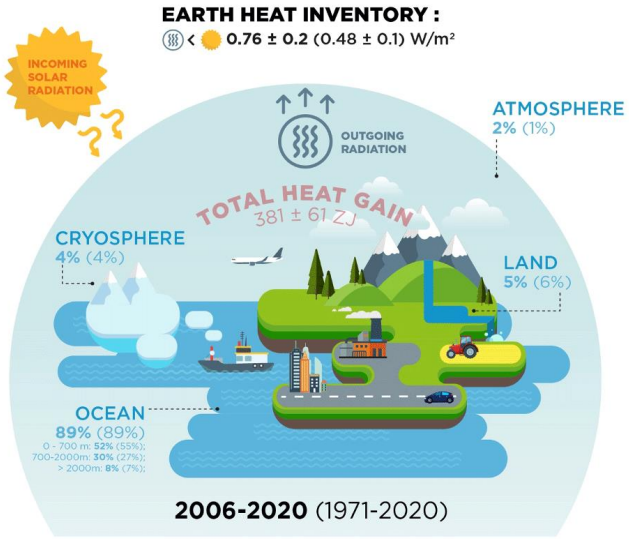
Norman G. Loeb[1], Hailan Wang[2], Richard P. Allan[3], Timothy Andrews[4], Kyle Armour[5], Jason N. S. Cole[6], Jean-Louis Dufresne[7], Piers Forster[8], Andrew Gettelman[9], Huan Guo[10], Thorsten Mauritsen[11], Yi Ming[10], David Paynter[10], Cristian Proistosescu[12,13], Malte F. Stuecker[14], Ulrika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





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