

EVIDENCE OF ACCELERATION IN ASPECTS OF THE GLOBAL ENERGY AND WATER CYCLES



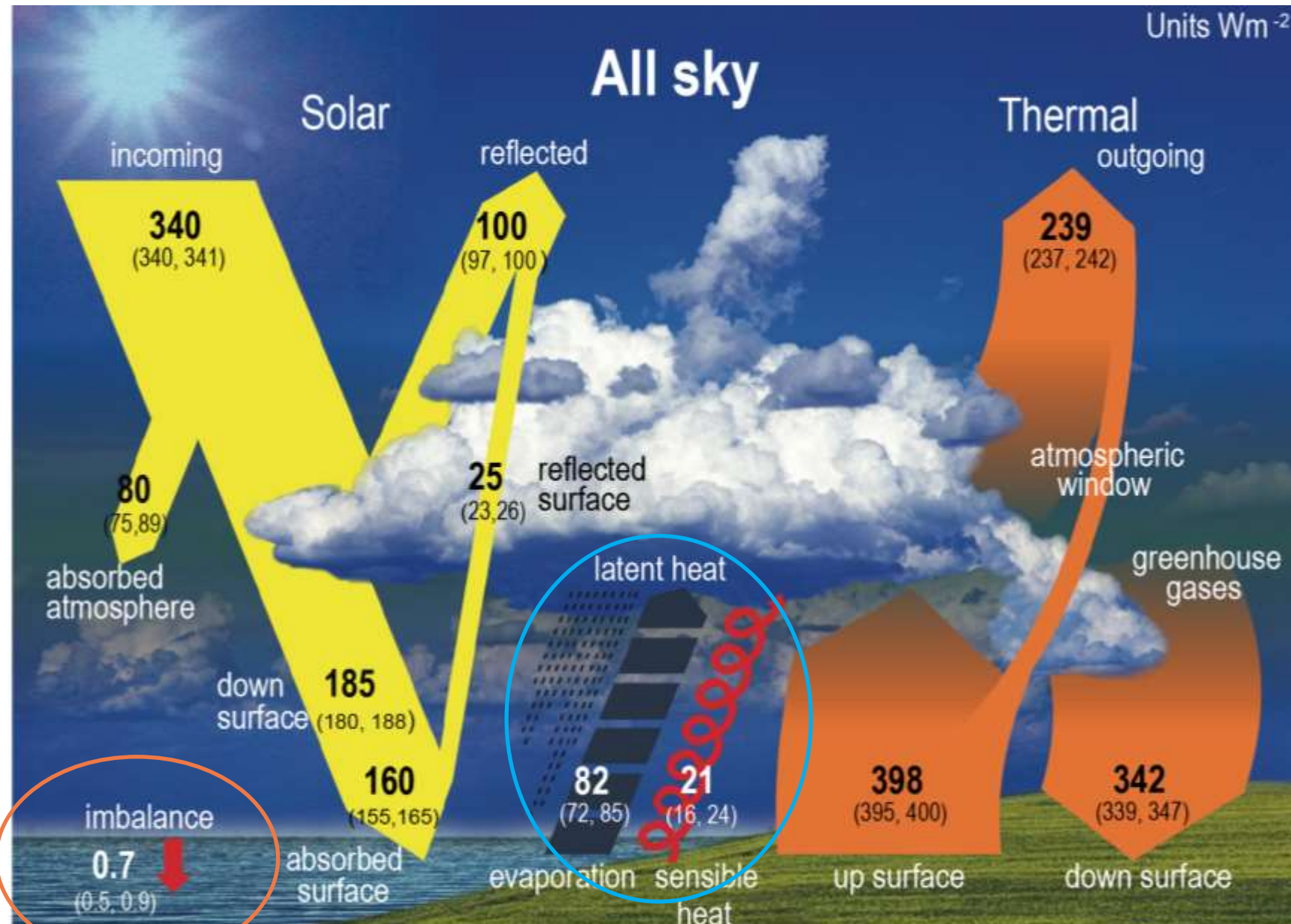
Richard P. Allan

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[@rpallanuk](https://twitter.com/rpallanuk)

National Earth Observation Conference 9-12 September 2024





EARTH'S ENERGY BALANCE

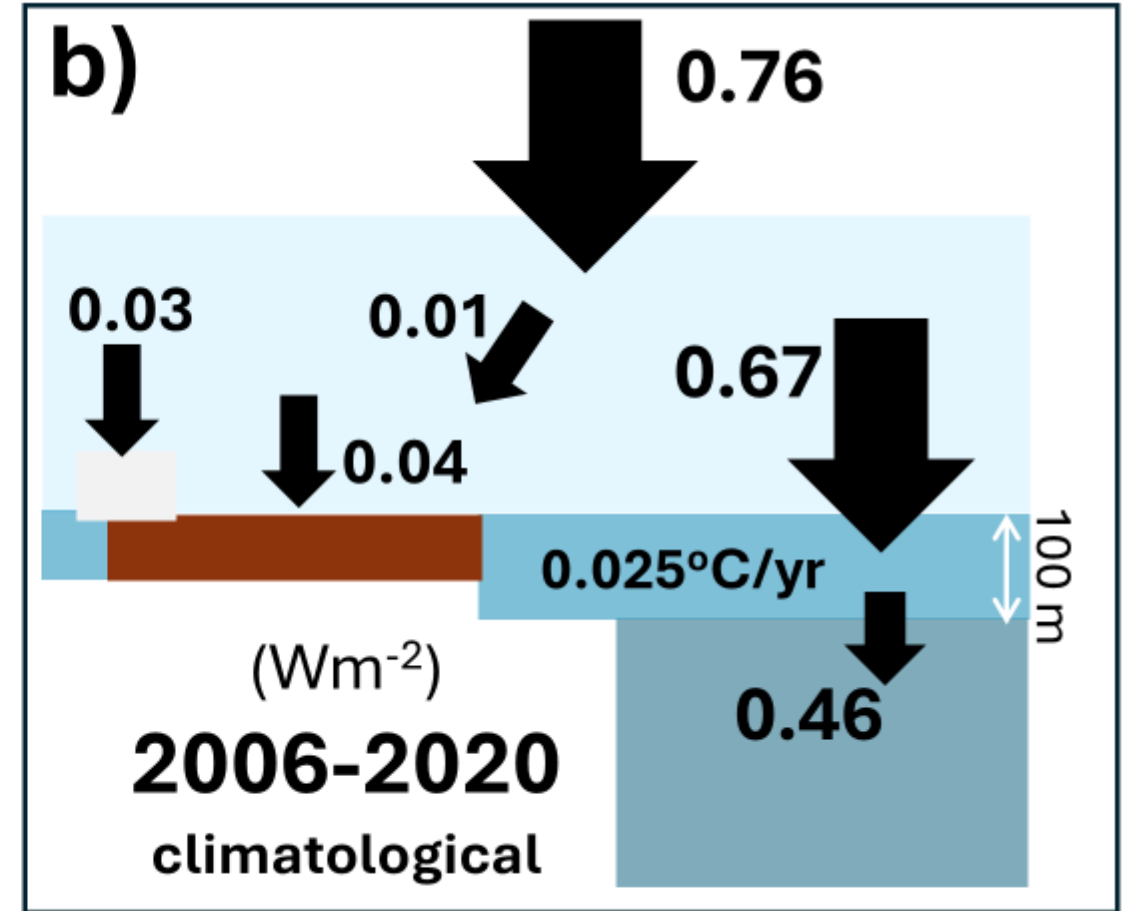
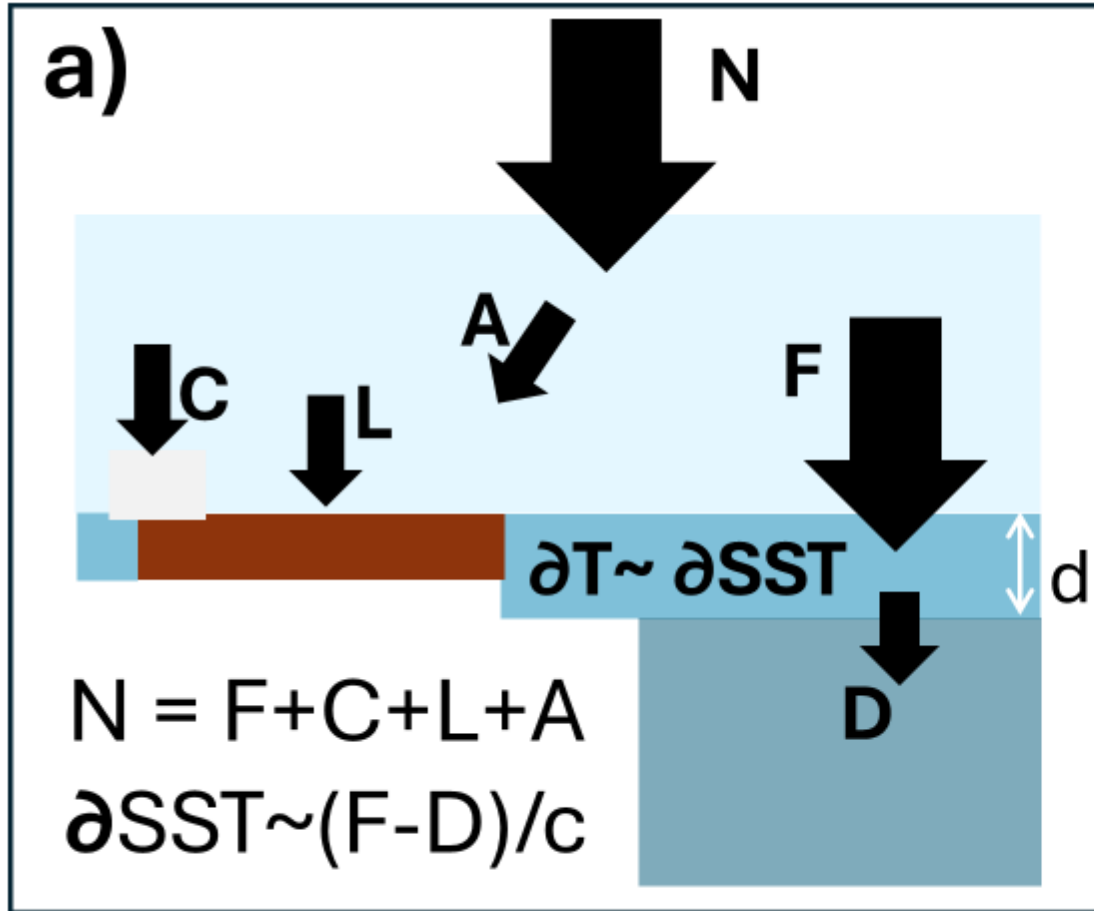
← Forster et al. (2021) IPCC WG1, [Fig. 7.2](#)

see also: [Stephens et al. \(2012\) Nature Geosci.](#)

Spot the imbalance...

Latest bottom up estimate 0.76 Wm^{-2} 2006-2020: [von Shuckmann et al. \(2023\) ESSD](#)

CLIMATOLOGICAL HEAT INVENTORY



[von Shuckmann et al. \(2023\) ESSD](#)

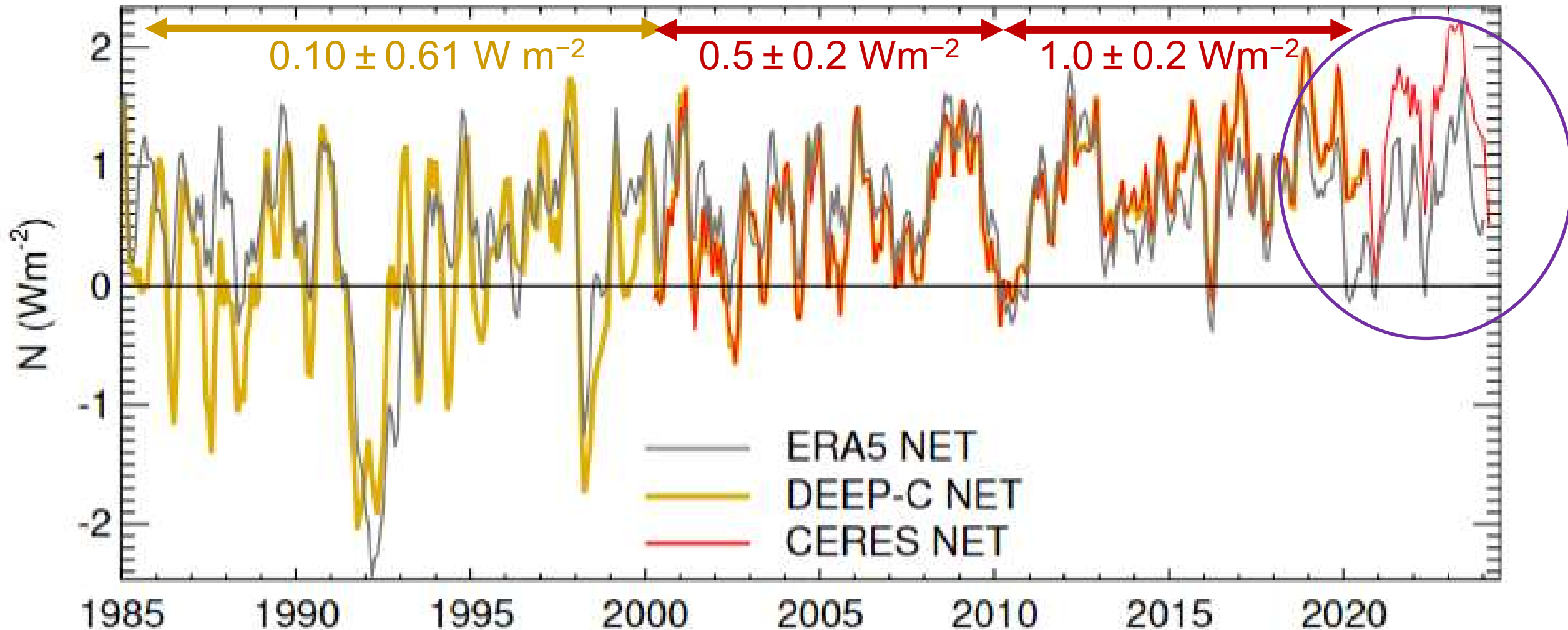
INCREASING NET HEATING OF PLANET



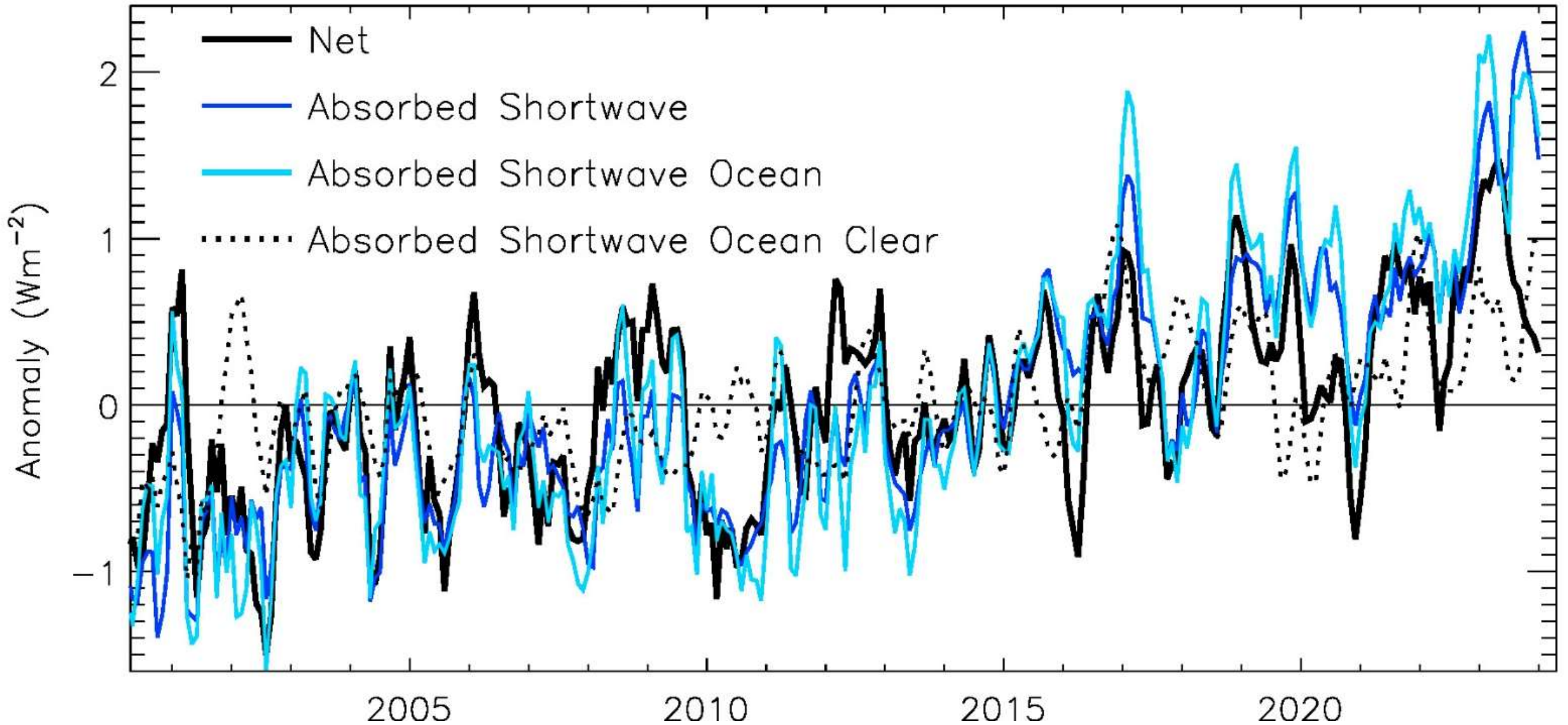
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(c) CERES Anomalies



PATTERN OF GROWING IMBALANCE

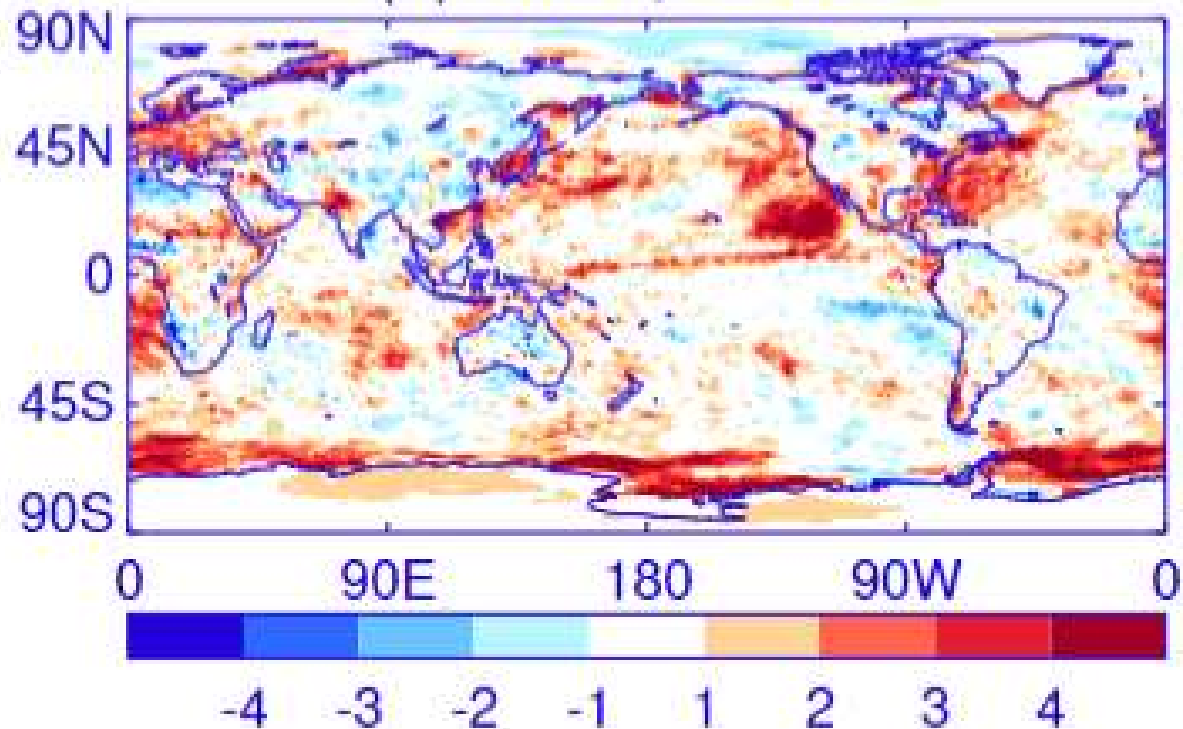


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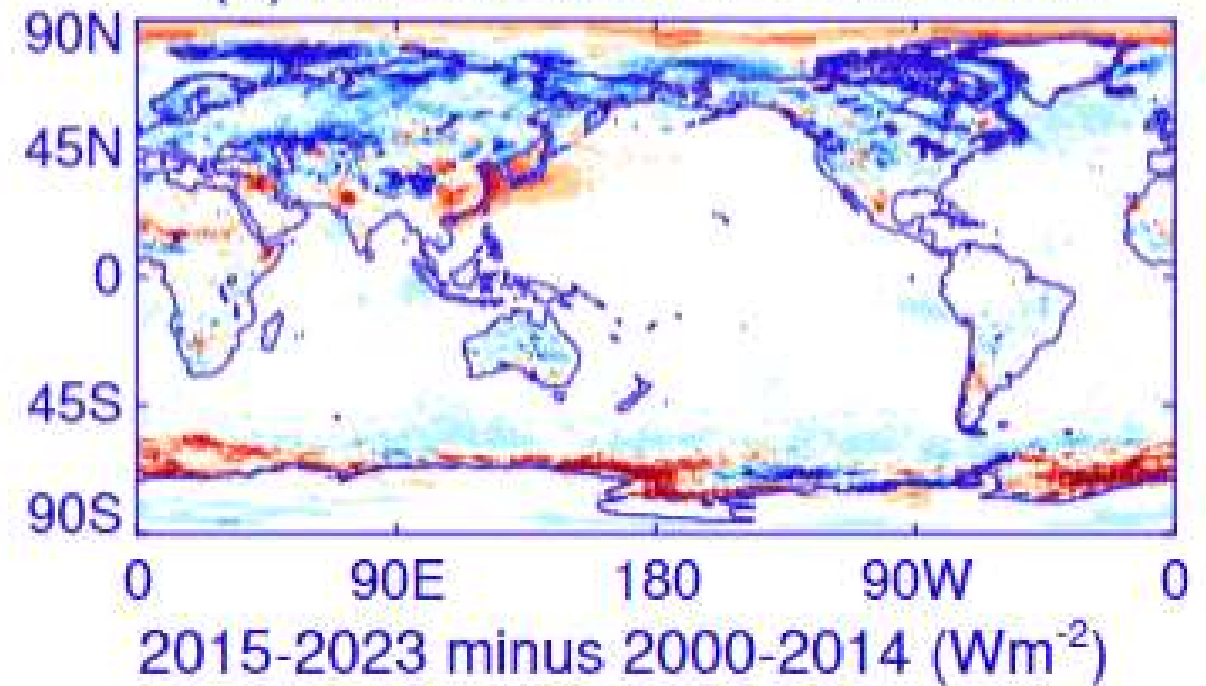


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(a) dNET, CERES

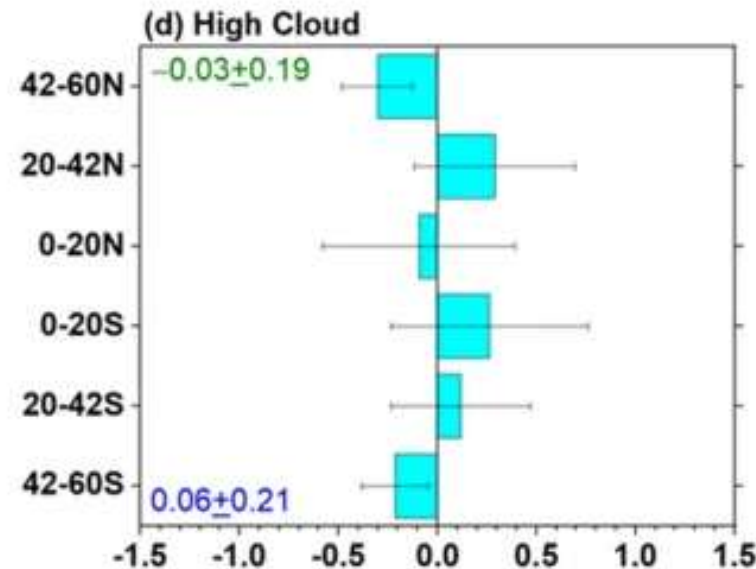
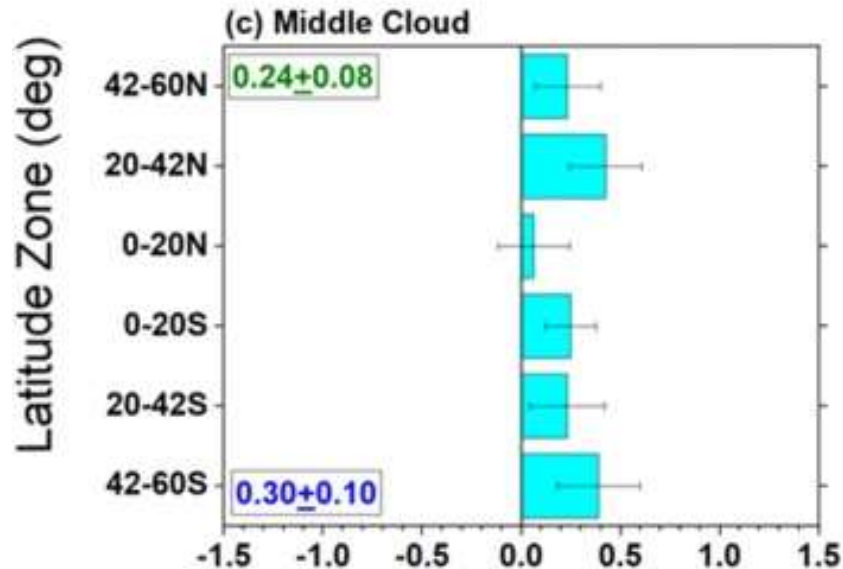
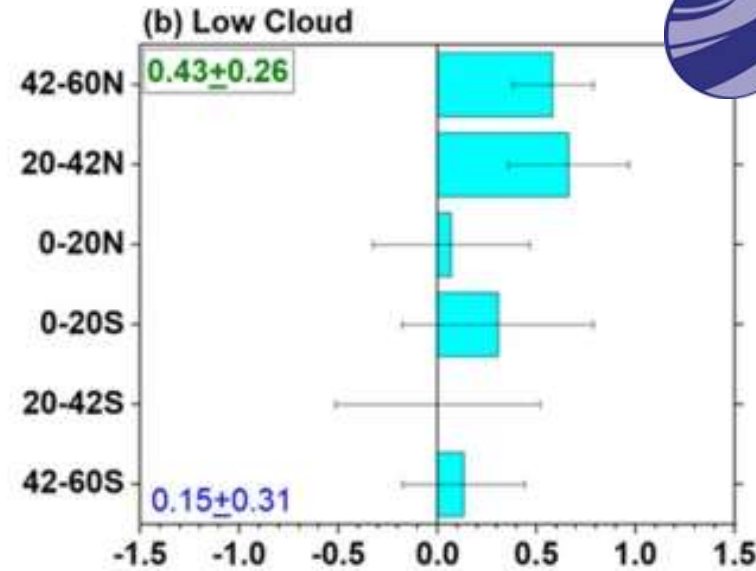
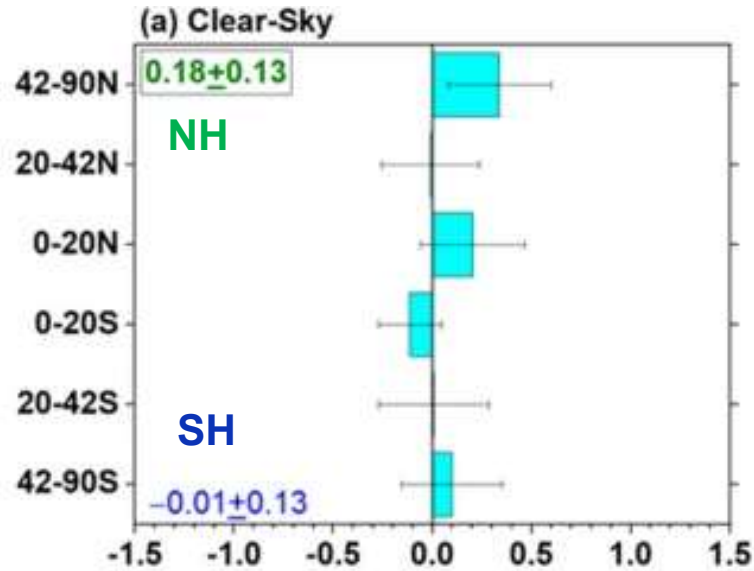


(d) dASR clear CERES-ERA5



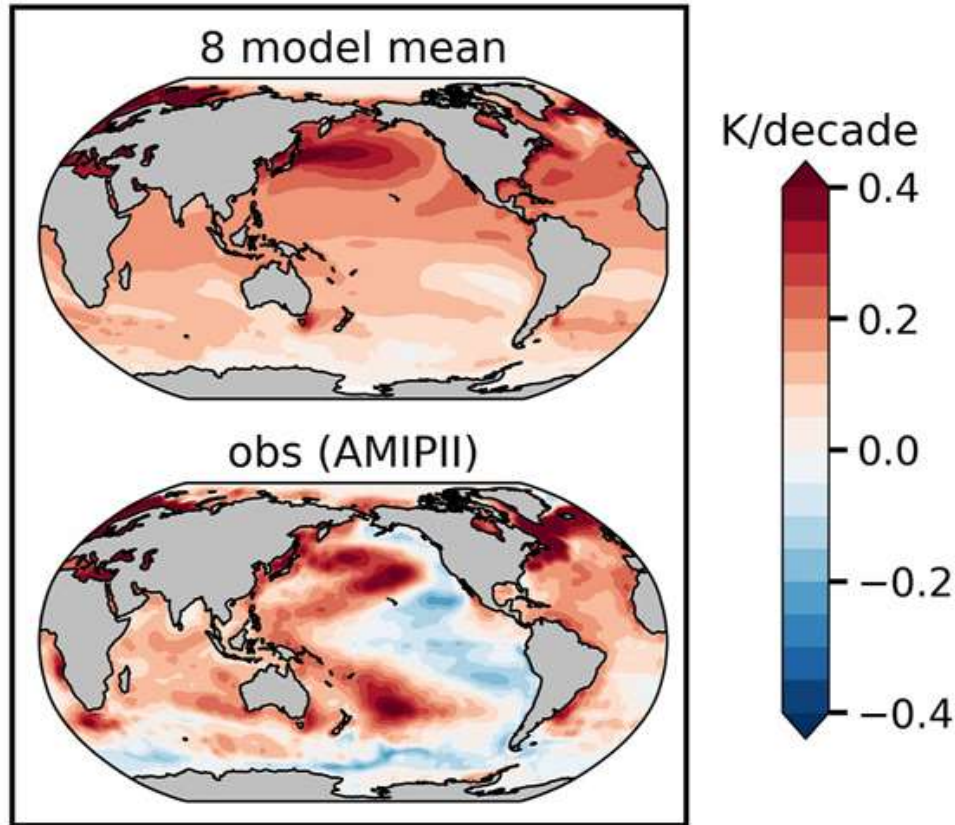


CONTRIBUTION OF CLOUD TO IMBALANCE TREND



Loeb et al. (2024)
Surv. Geophys

UNEXPECTED PATTERN OF GLOBAL WARMING

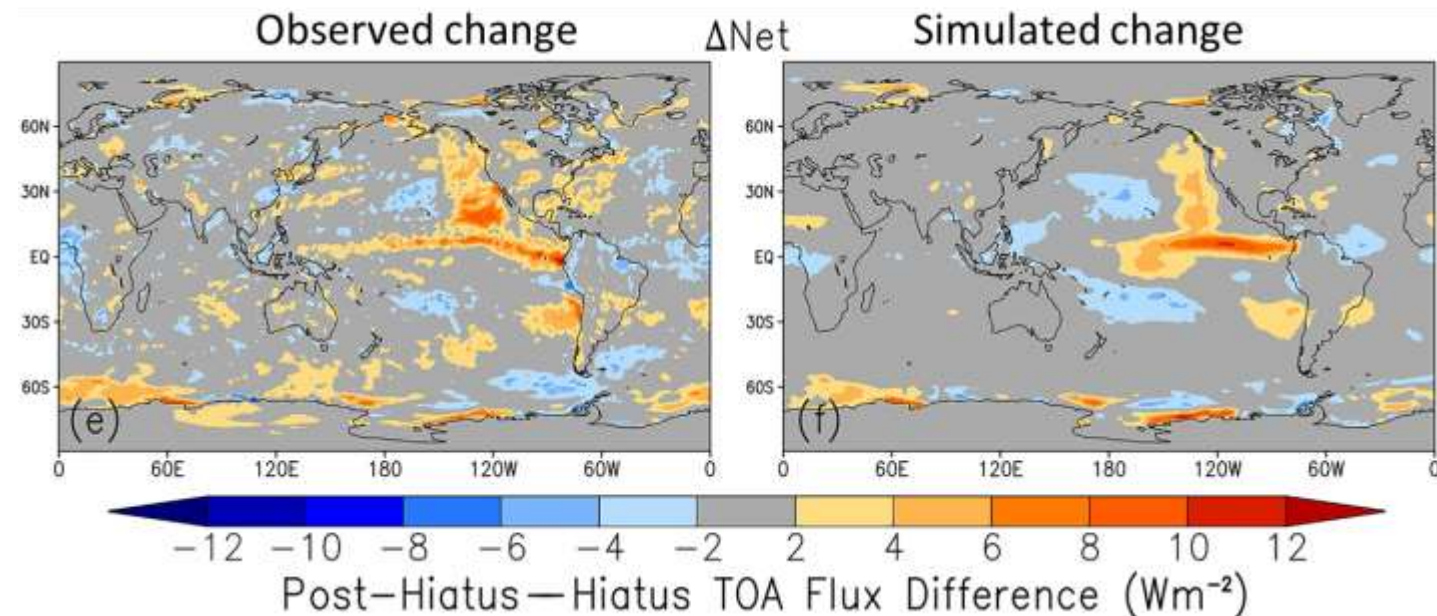


This has weakened amplifying climate feedbacks relative to coupled models ([Andrews et al. 2022 JGR](#))

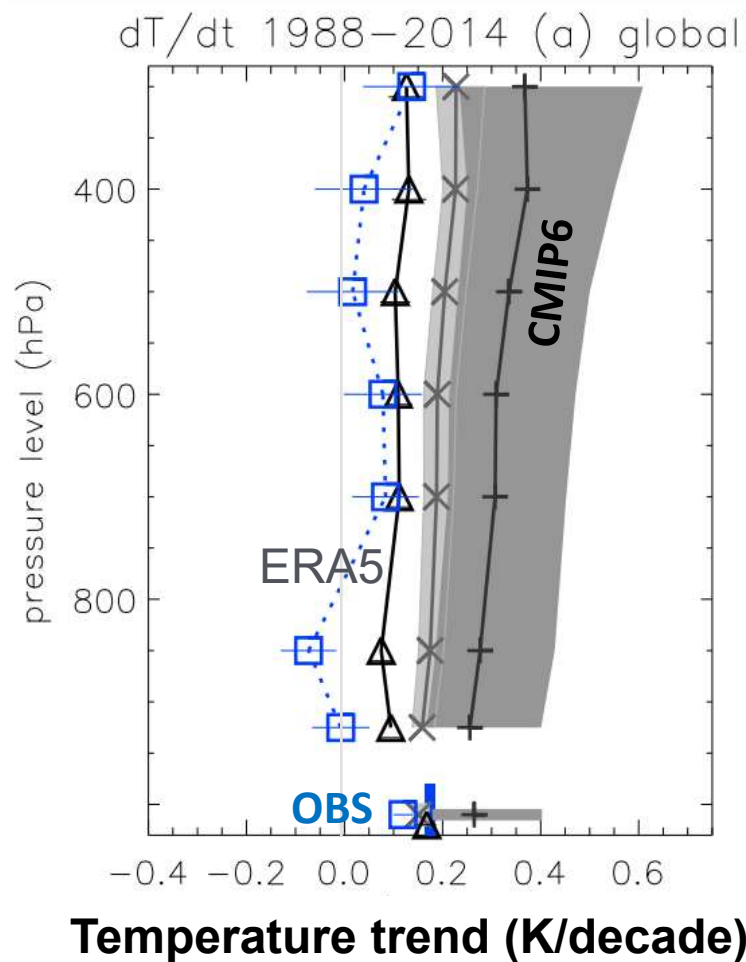
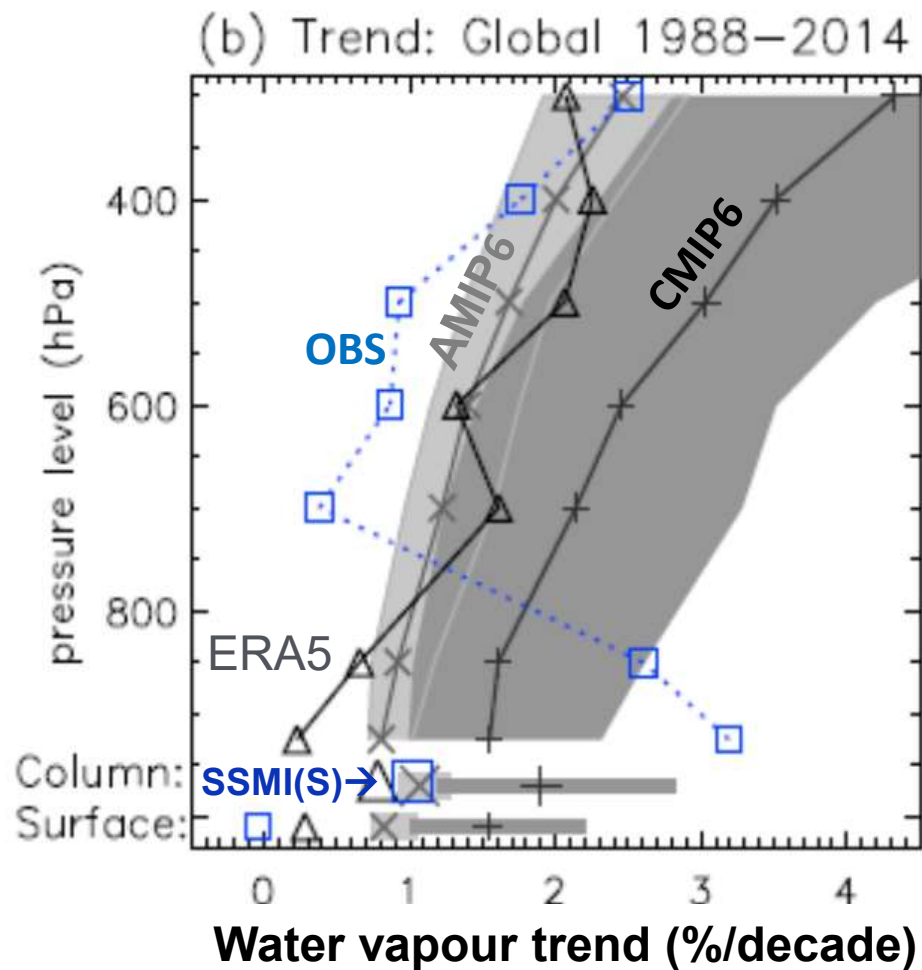
Temporary (?) reversal 2015/16? ([Loeb et al. 2020 GRL](#))

Pattern of observed warming (1979-2014) is unexpected!

[Dong et al. \(2021\) GRL](#)



STRONGER WARMING & MOISTENING IN MODELS

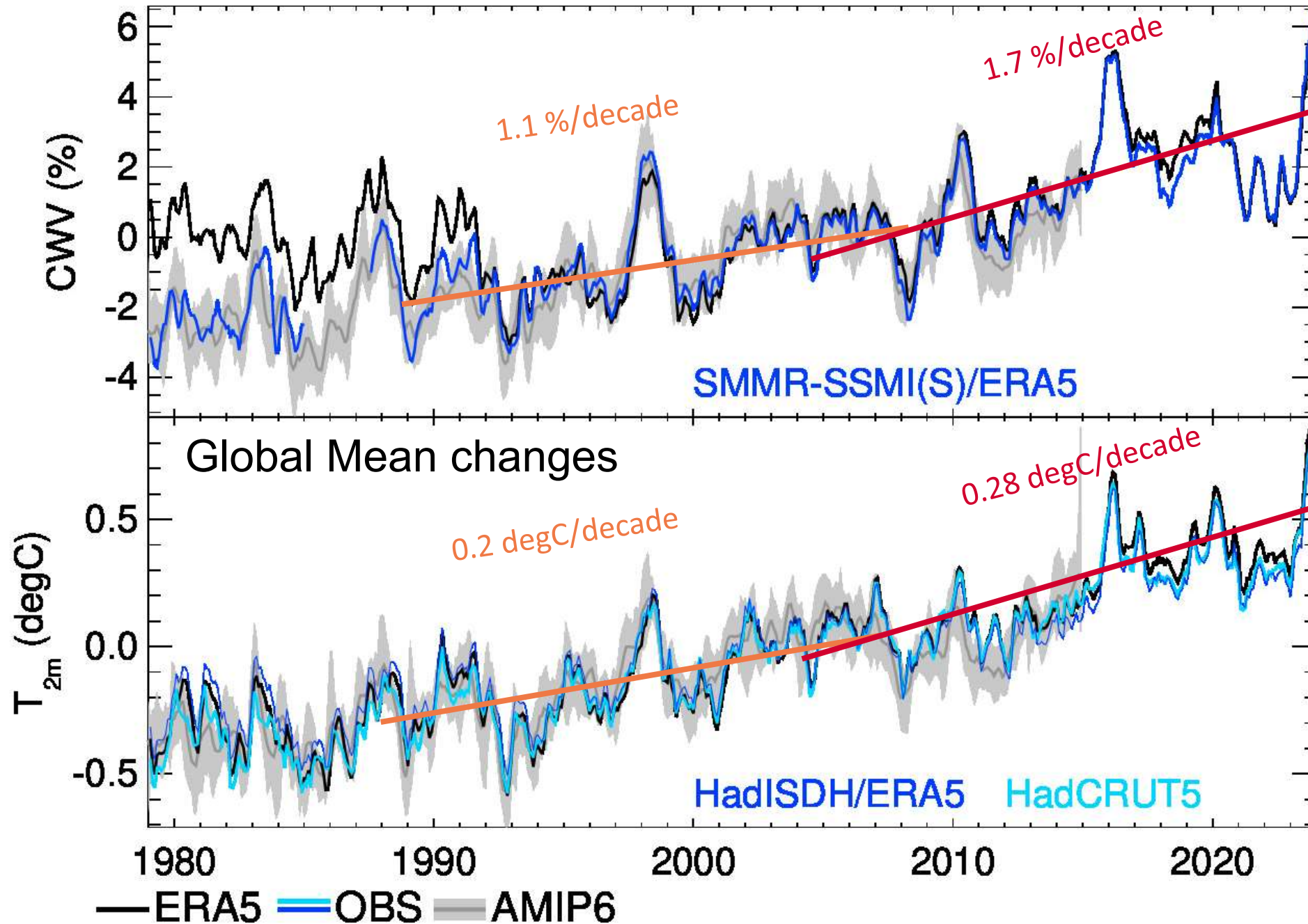


CMIP6 overdo
warming/moistening
due to warming
pattern (internal
variability?)

[Allan et al. 2022 JGR](#)

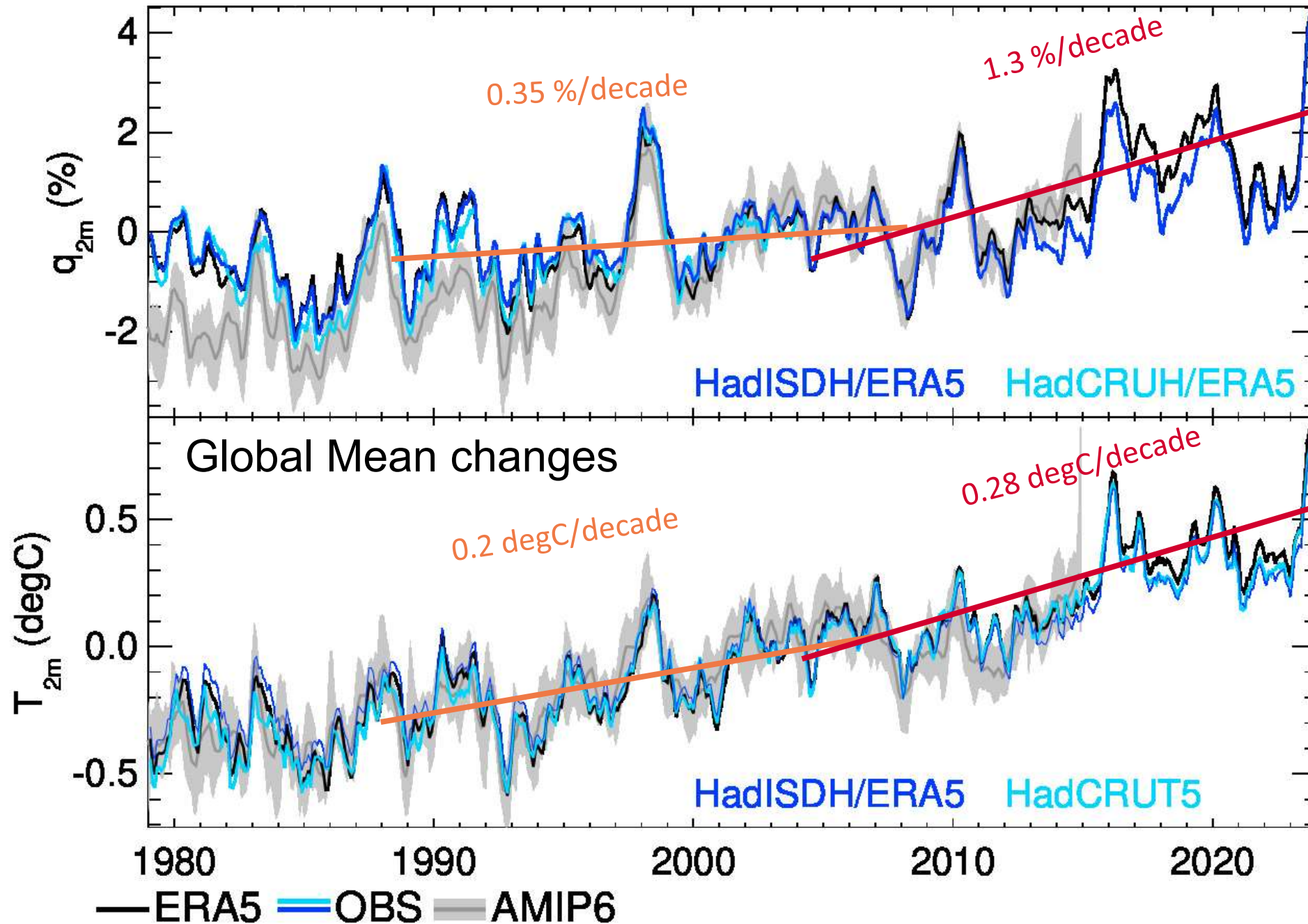


COLUMN WATER VAPOUR

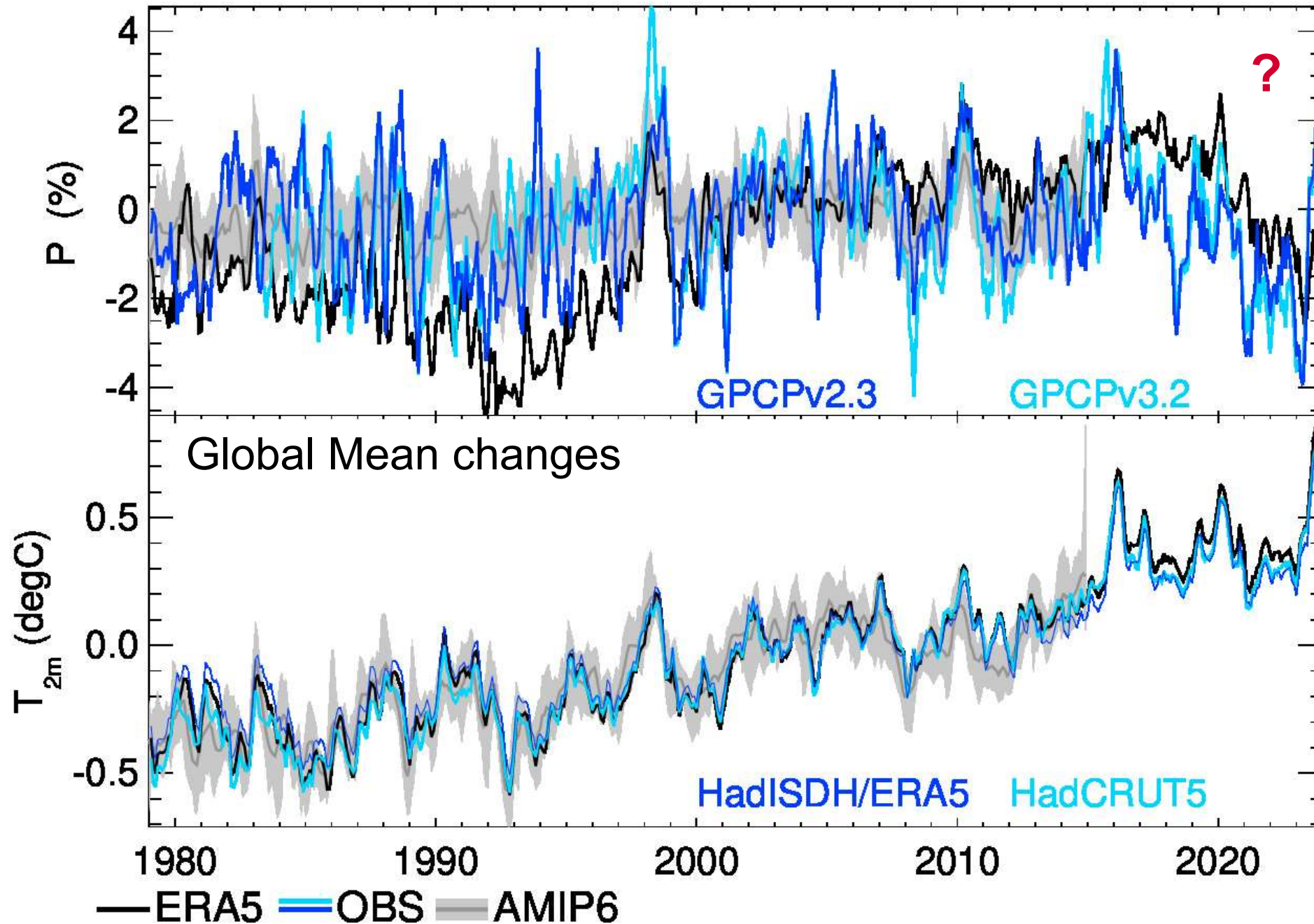


Allan et al. (2022)
JGR updated to
2023

SURFACE WATER VAPOUR



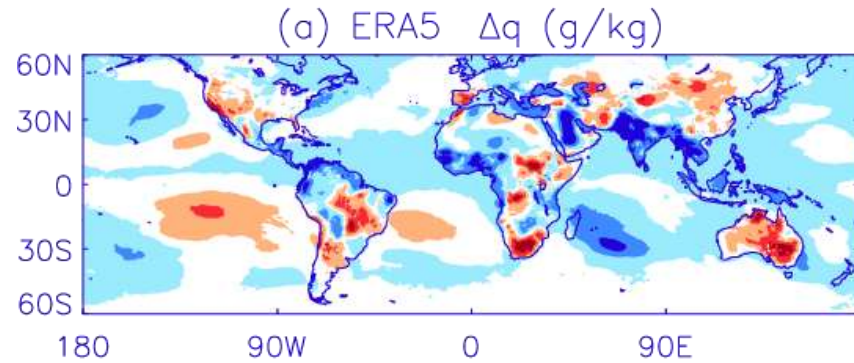
Allan et al. (2022)
JGR updated to
2023



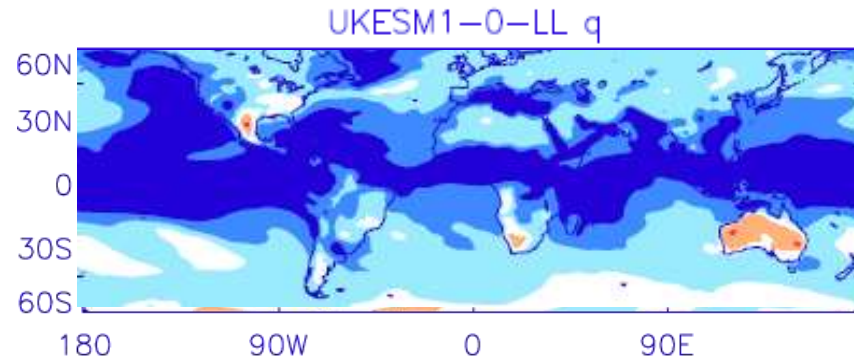
PRECIPITATION

see [Allan et al. \(2020\) NYAS](#);
[Allan \(2023\) ERL](#)

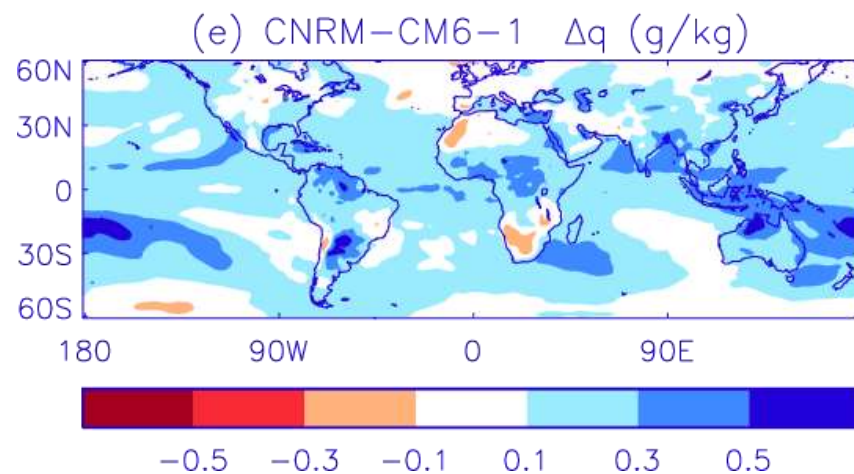
UNDERESTIMATION OF CONTINENTAL DRYING?



ERA5



Climate models

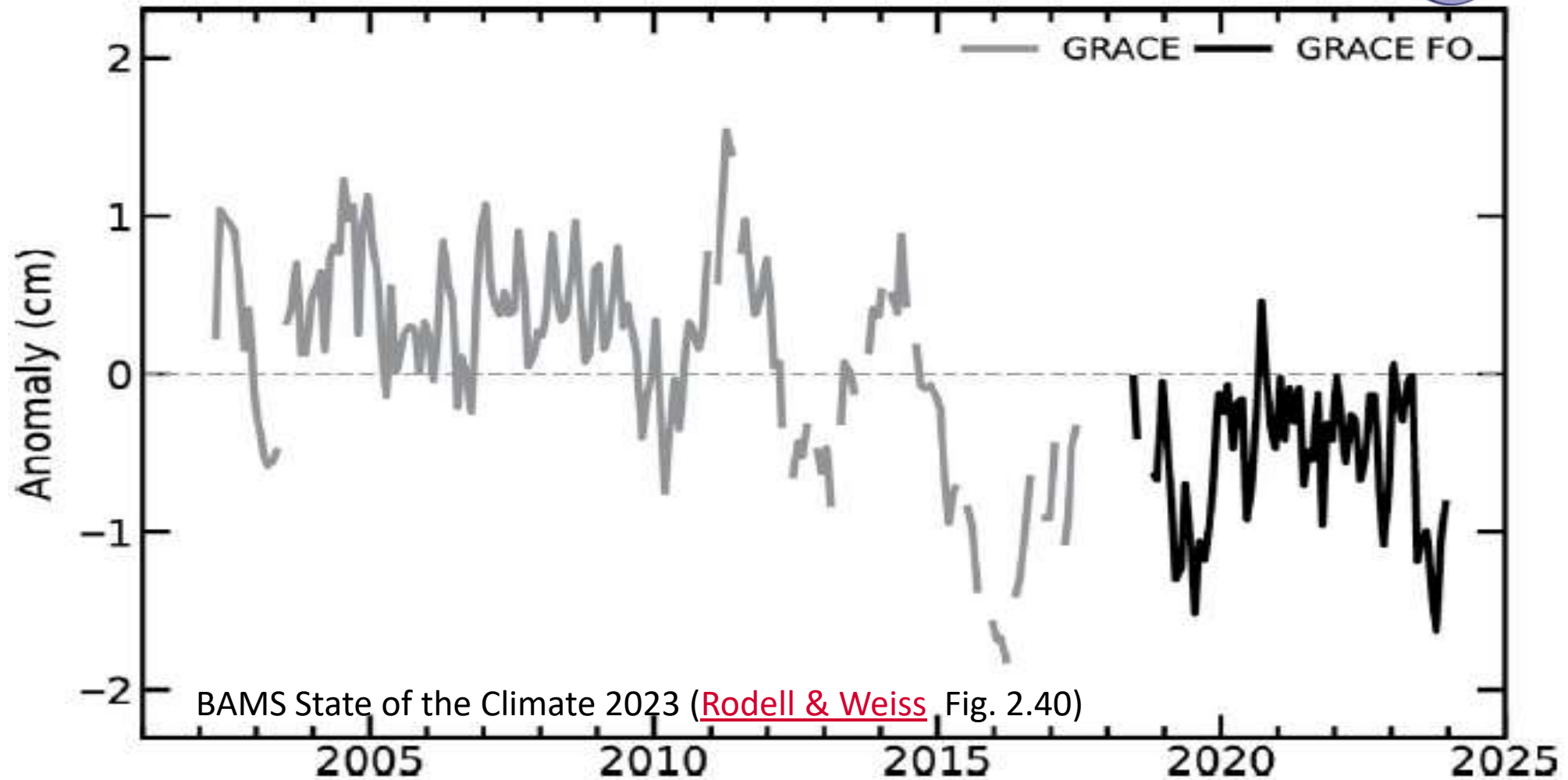


Declining Relative Humidity over land consistent with larger warming over land than sea e.g. [O’Gorman & Byrne \(2018\) PNAS](#)

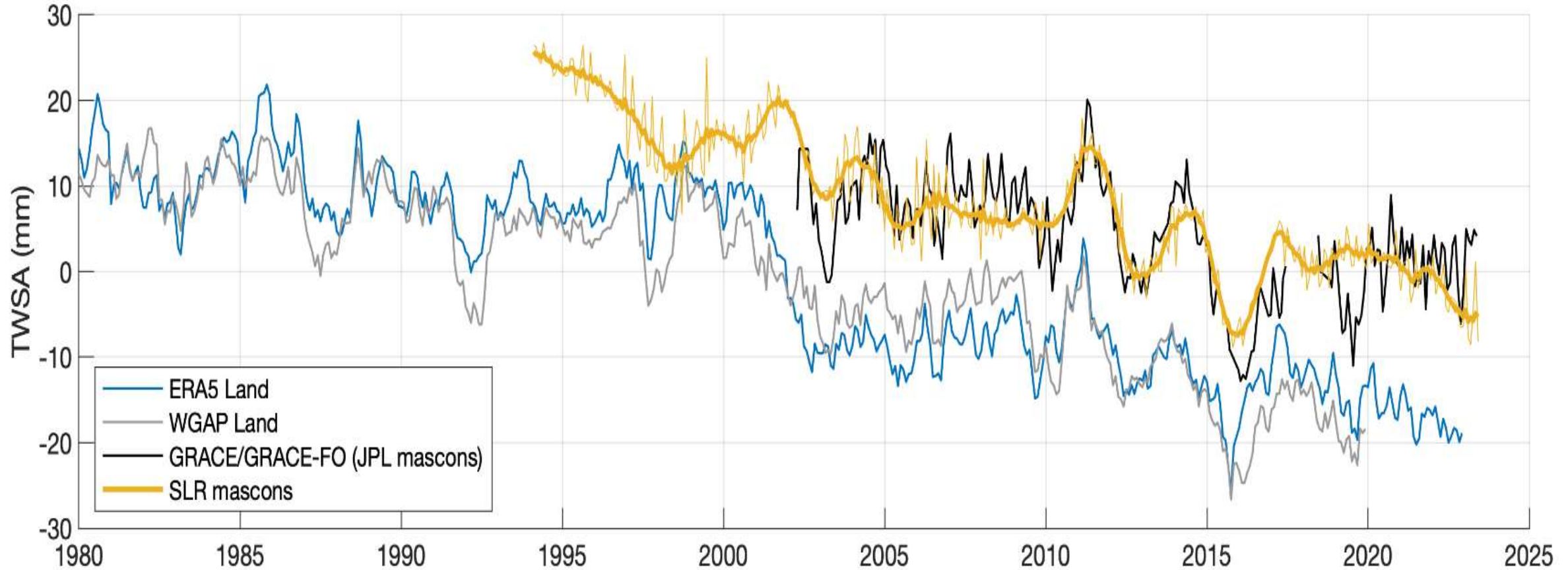
Climate models overestimate water vapour increases since 1988, particularly over arid & semi-arid land regions

← 2004-2019 minus 1988-2003 water vapour changes [\(Allan & Douville 2024 PNAS\)](#); see [Simpson et al. \(2024\) PNAS](#); [Dunn et al. 2017 ESD](#)

DECLINING TERRESTRIAL WATER STORAGE



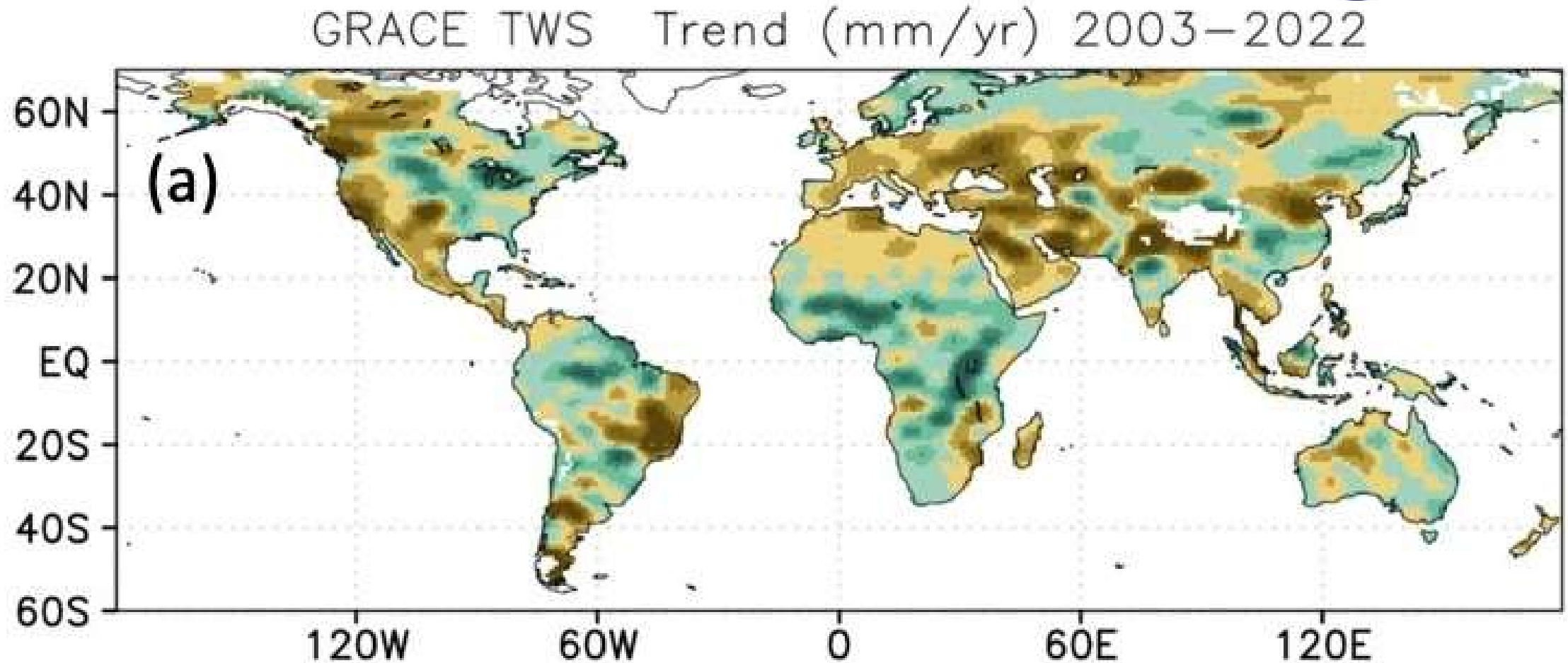
DECLINING TERRESTRIAL WATER STORAGE (GRACE/GRACE-FO & COMBINED MODEL/OBS DATA)



Rodell et al. 2024 Surv. Geophys. Also Sammy Petch's talk

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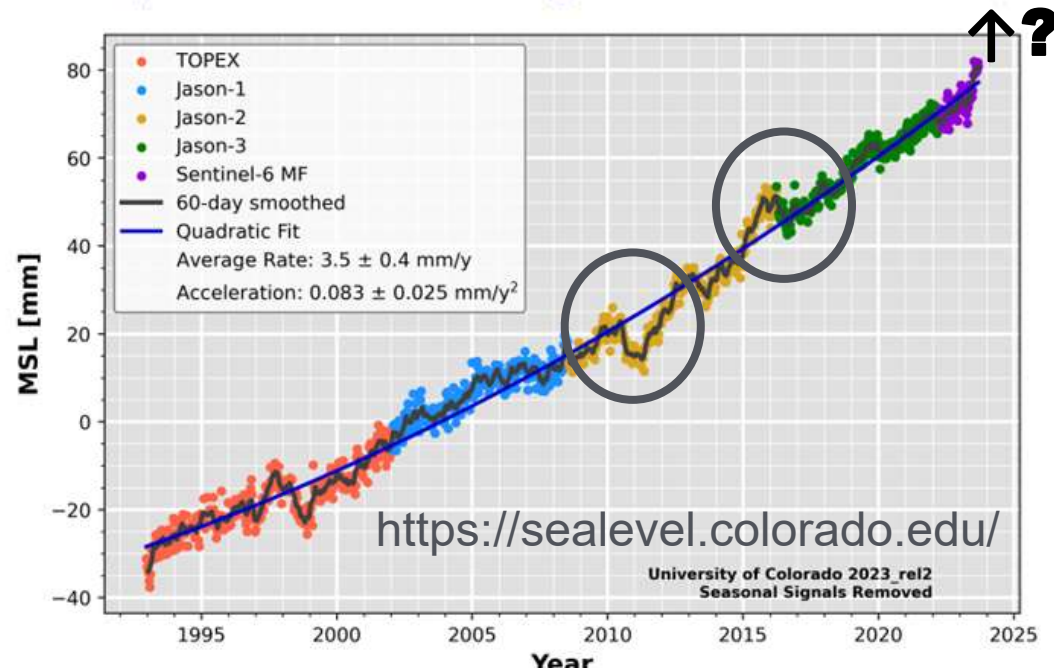
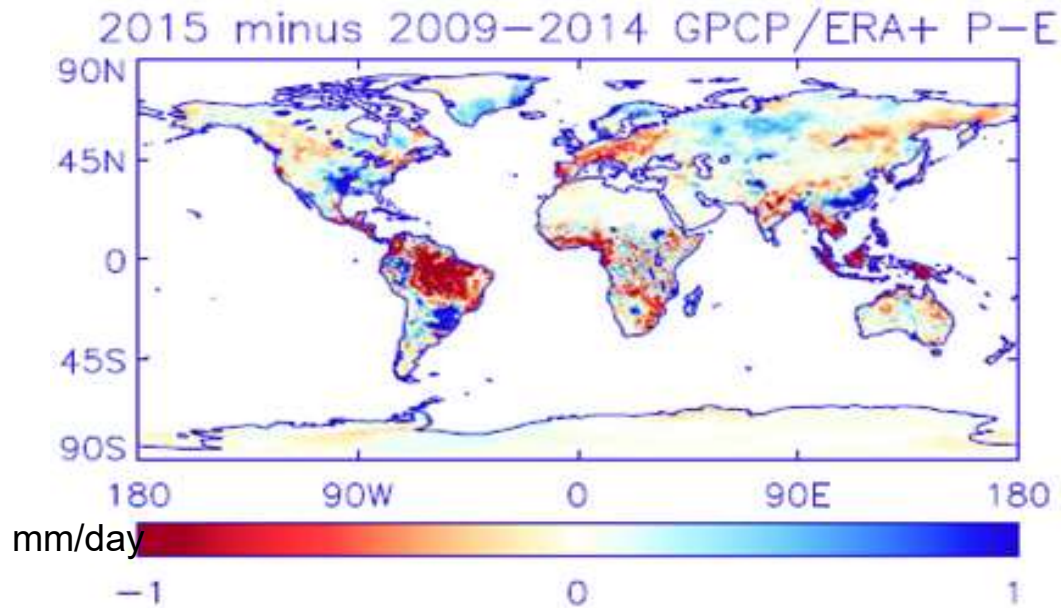
DECLINING TERRESTRIAL WATER STORAGE (GRACE, GRACE-FO)



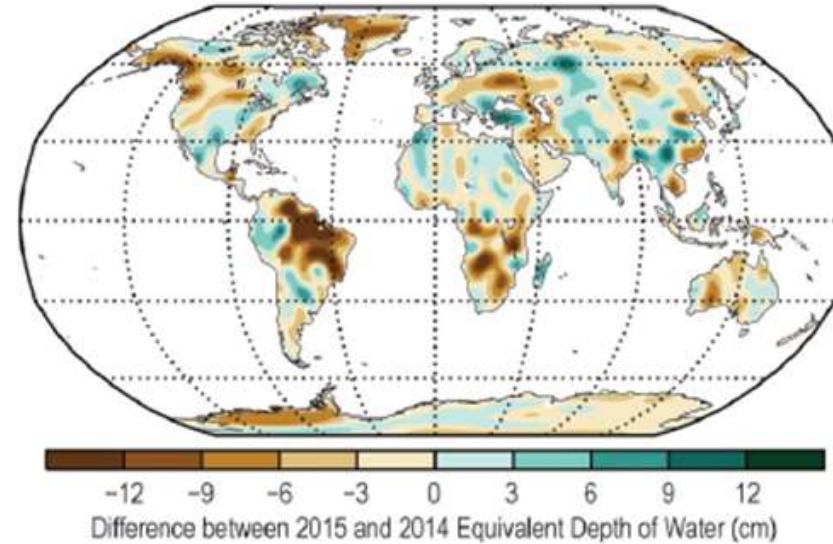
Rodell et al. 2024 Surv. Geophys.

Chasing water through 2015/16 El Niño

2023/24?

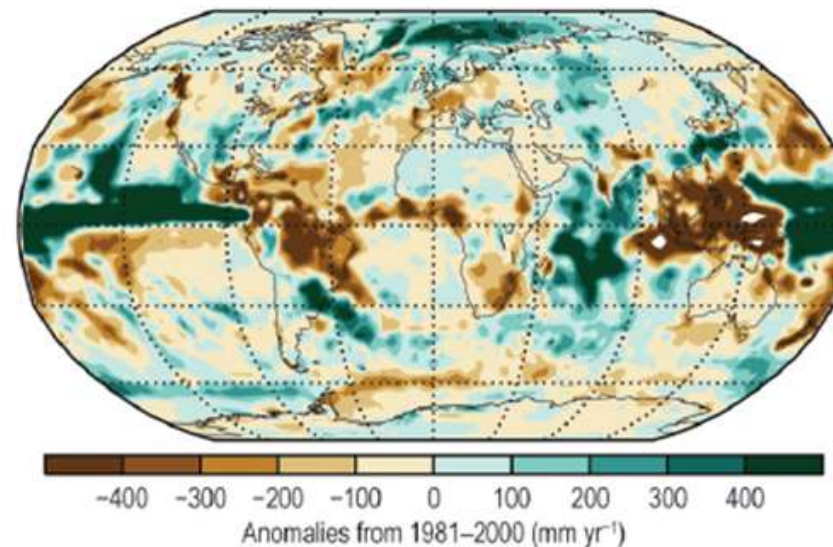


(g) Terrestrial Water Storage

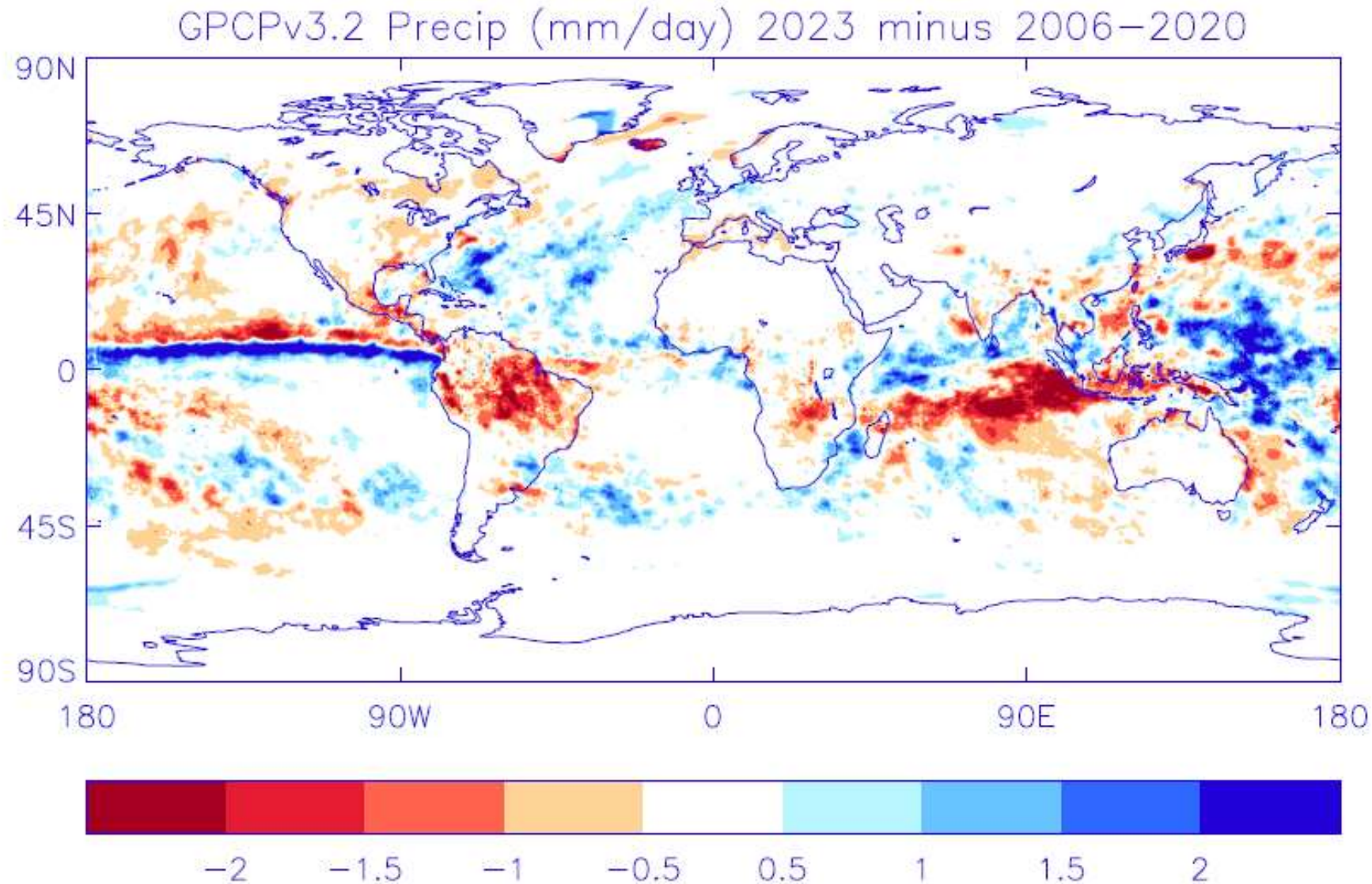


(h) Precipitation

state of the climate 2015



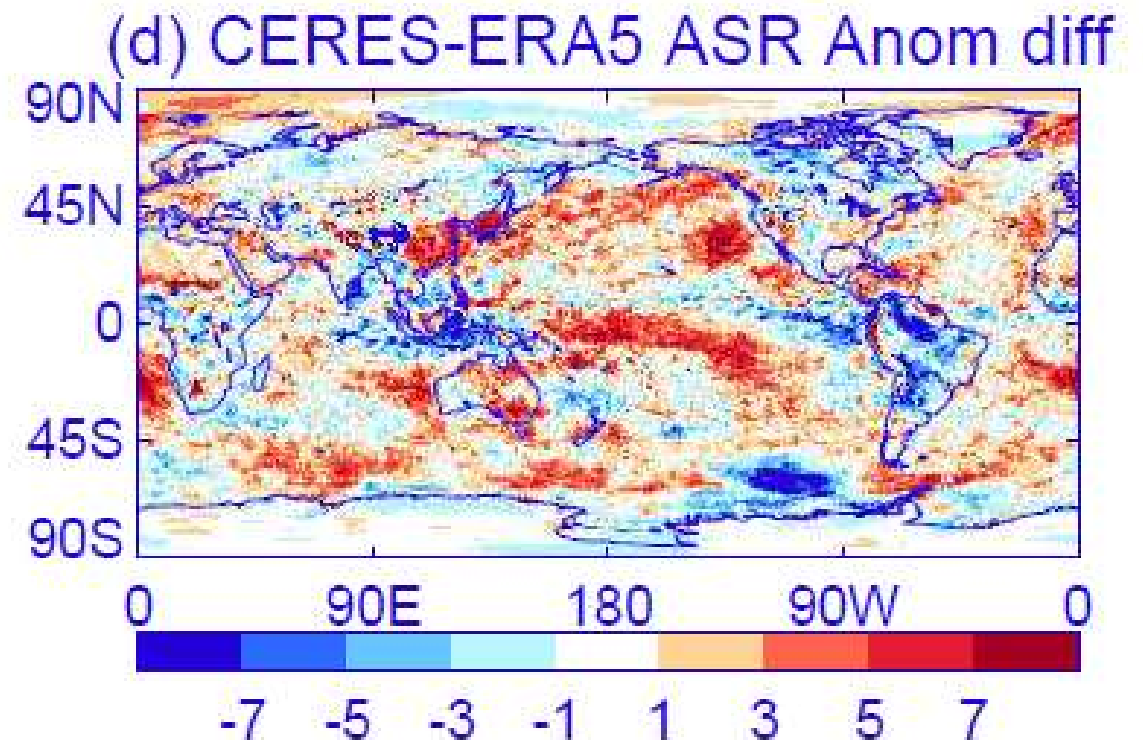
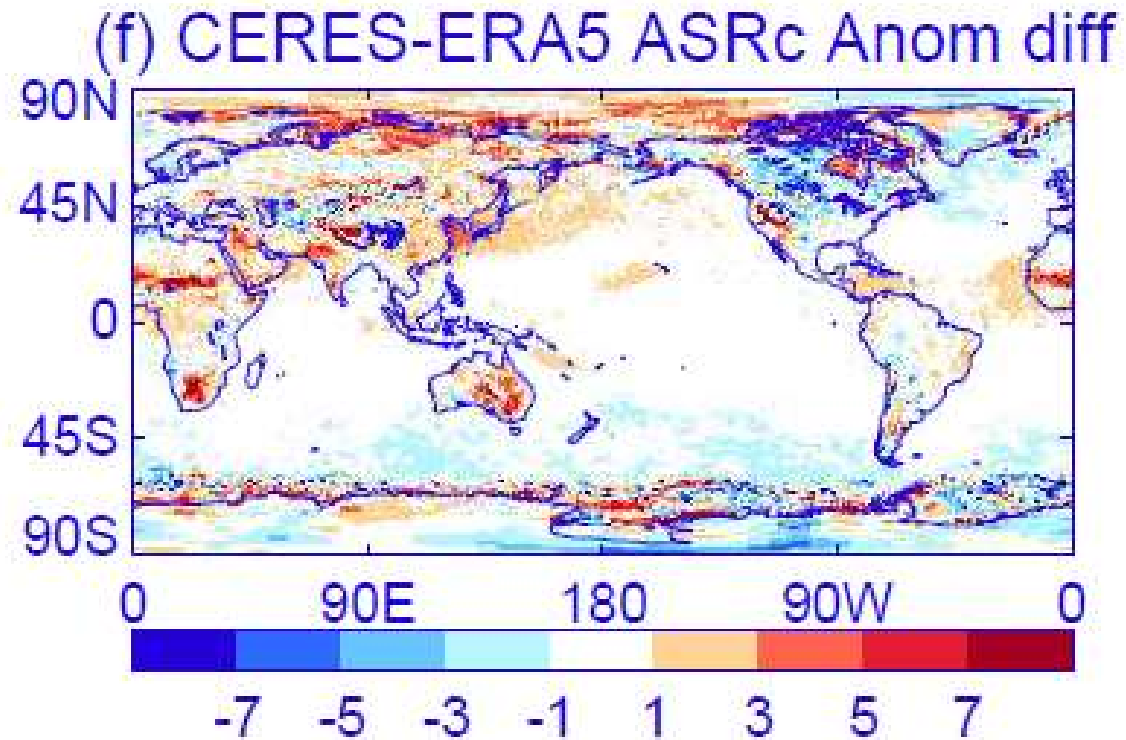
Boening et al. (2012) GRL: The 2011 La Niña so strong, the oceans fell



PRECIPITATION ANOMALY 2023

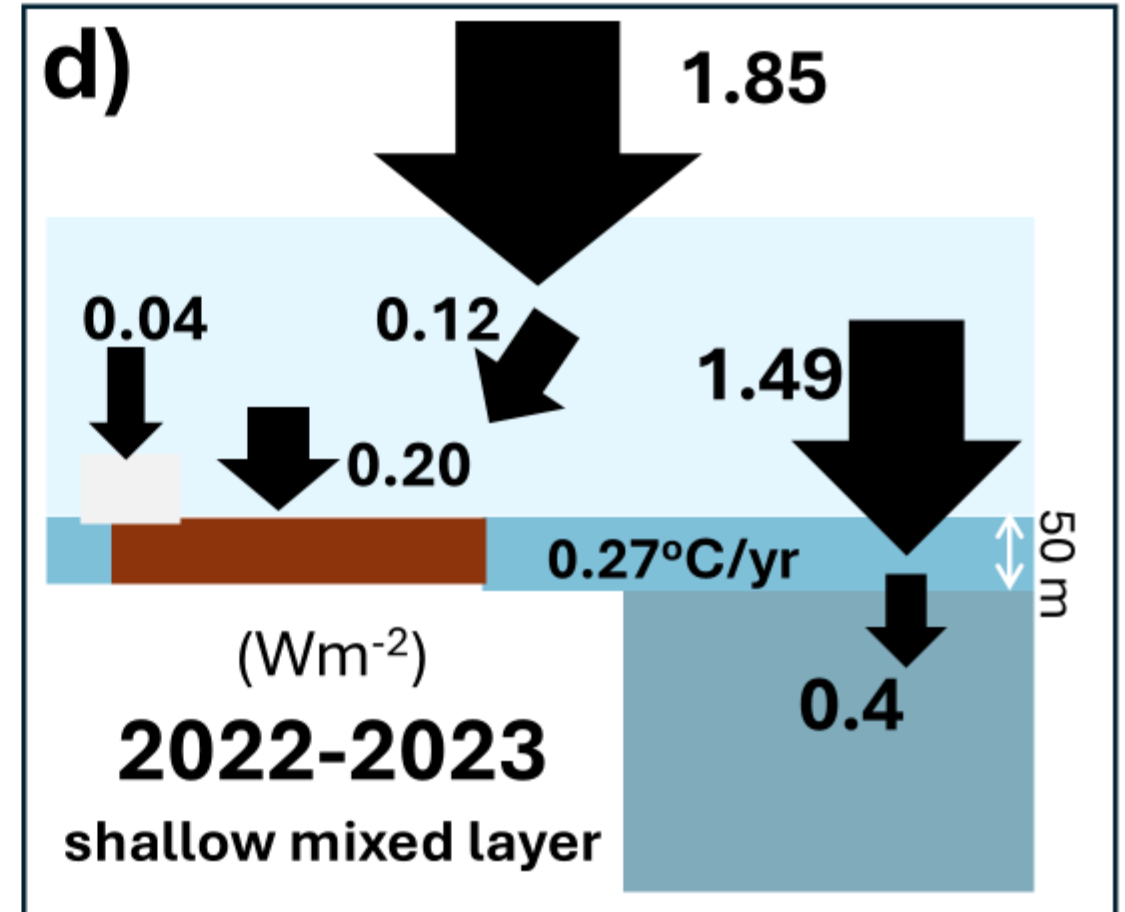
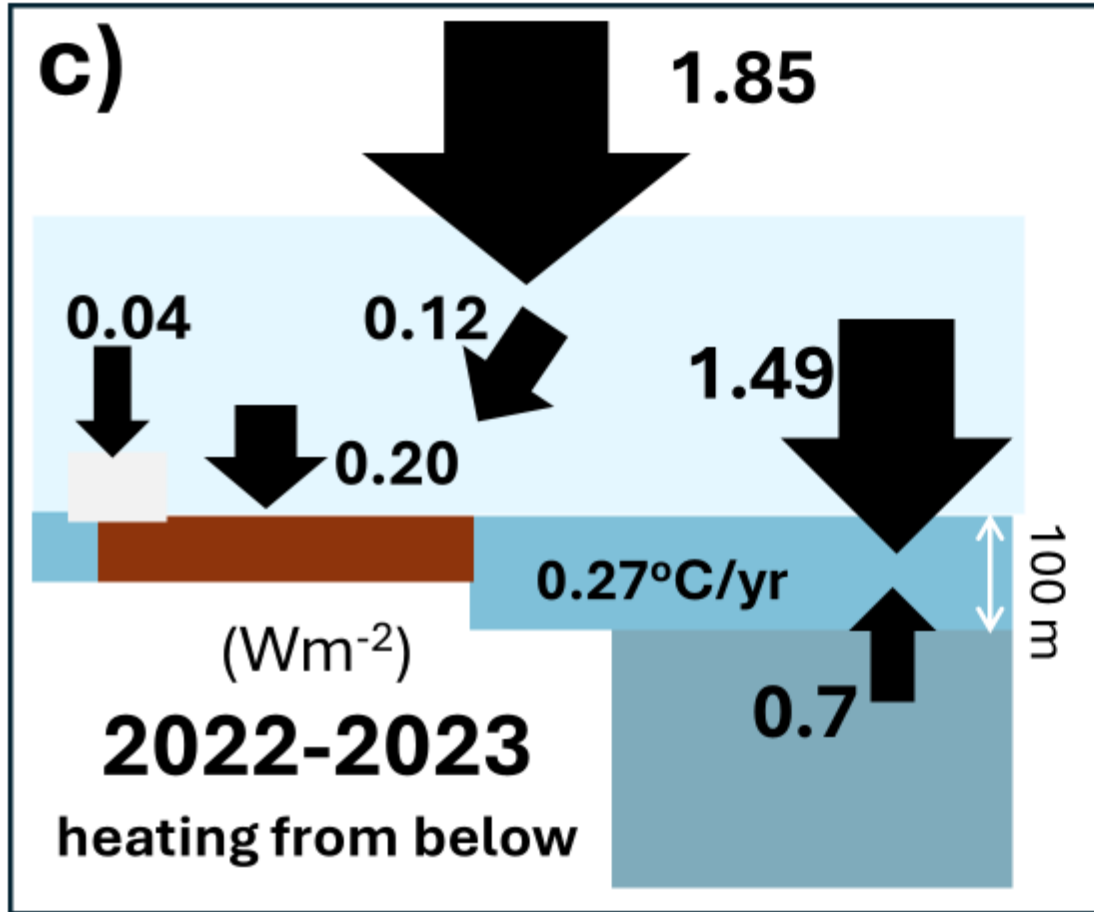
ENERGY IMBALANCE CHANGES 2022-23

CERES Net Imbalance Aug 2022-Jul 2023: **1.92 Wm⁻²** (+1.09 Wm⁻² larger than 2006-2020)



see e.g. [Hodnebrog et al. \(2024\) Comm. Earth Env.](#); [Kuhlbrodt et al. \(2024\) BAMS](#)

CAN ENERGY BALANCE EXPLAIN SURGE IN OCEAN WARMING 2022-23?



(more in Chris Merchant talk, 9:15am Wednesday, Session 4C)

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CONCLUSIONS



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- Global **warming** rate increasing: 0.2 °C/decade 1988-2007 to 0.28 °C/decade 2004-2023
 - See also [Samset et al. \(2023\) Comm. Earth Env.](#)
- Global **moistening** rate increase: 1.1 %/decade 1988-2007 to 1.7 %/decade 2004-2023
 - Update of [Allan et al. \(2022\) JGR](#)
- No long-term change in global precipitation
 - atmospheric stabilising effect of greenhouse gas increases offset increases due to warming
 - Rapid increases in extreme precipitation with moistening, decreases in precipitation elsewhere to balance books (e.g. [Allan et al. 2020 NYAS](#))
- Declining terrestrial water storage, acute in some regions (e.g. eastern South America, Mediterranean, parts of Asia) (Rodell et al. 2024 Surv. Geophys)
- Earth's energy imbalance is increasing (0.5 Wm⁻² 2000-2010, 1.0 Wm⁻² 2011-2020)
 - Mostly from reduced sunlight reflection over cloudy ocean (e.g. [Loeb et al. 2024 Surv Geophys](#))
 - Symptomatic of accelerating climate change
 - accelerating sea level rise (but also contribution from ice melt, water storage changes)

QUESTIONS



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- Is terrestrial water storage declining (Rodell et al. 2024 Surv. Geophys)?
- Why is drying of arid and semi-arid land regions more than in models ([Simpson et al. 2024](#); [Allan & Douville 2024](#) PNAS)
- Are there missing feedbacks/physics? Is pattern of warming involved (e.g. [Andrews et al. 2022 JGR](#); [Armour et al. \(2024\) PNAS](#))?
- Why is planet becoming dimmer? ([Loeb et al. 2024 Surv Geophys](#))
- Is global dimming response to aerosol decreases or warming patterns? Forcing, feedback or internal variability? [Hodnebrog et al. \(2024\) Comm. Earth Env.](#); [Meyssignac et al. \(2023\) Nature Comm. Earth Env.](#):
- Can mixed layer energy balance explain surge in warming?
 - Can only explain 2022/23 SST rise if all heat absorbed by upper 70m ocean
 - During 2006-2020, the 'effective' layer of ocean heated was ~300m
 - How are energy & water cycle involved in 2022-2023 surface warming surge?(more in Chris Merchant talk, 9:15am Wednesday, Session 4C)