Department of Meteorology

University of Reading

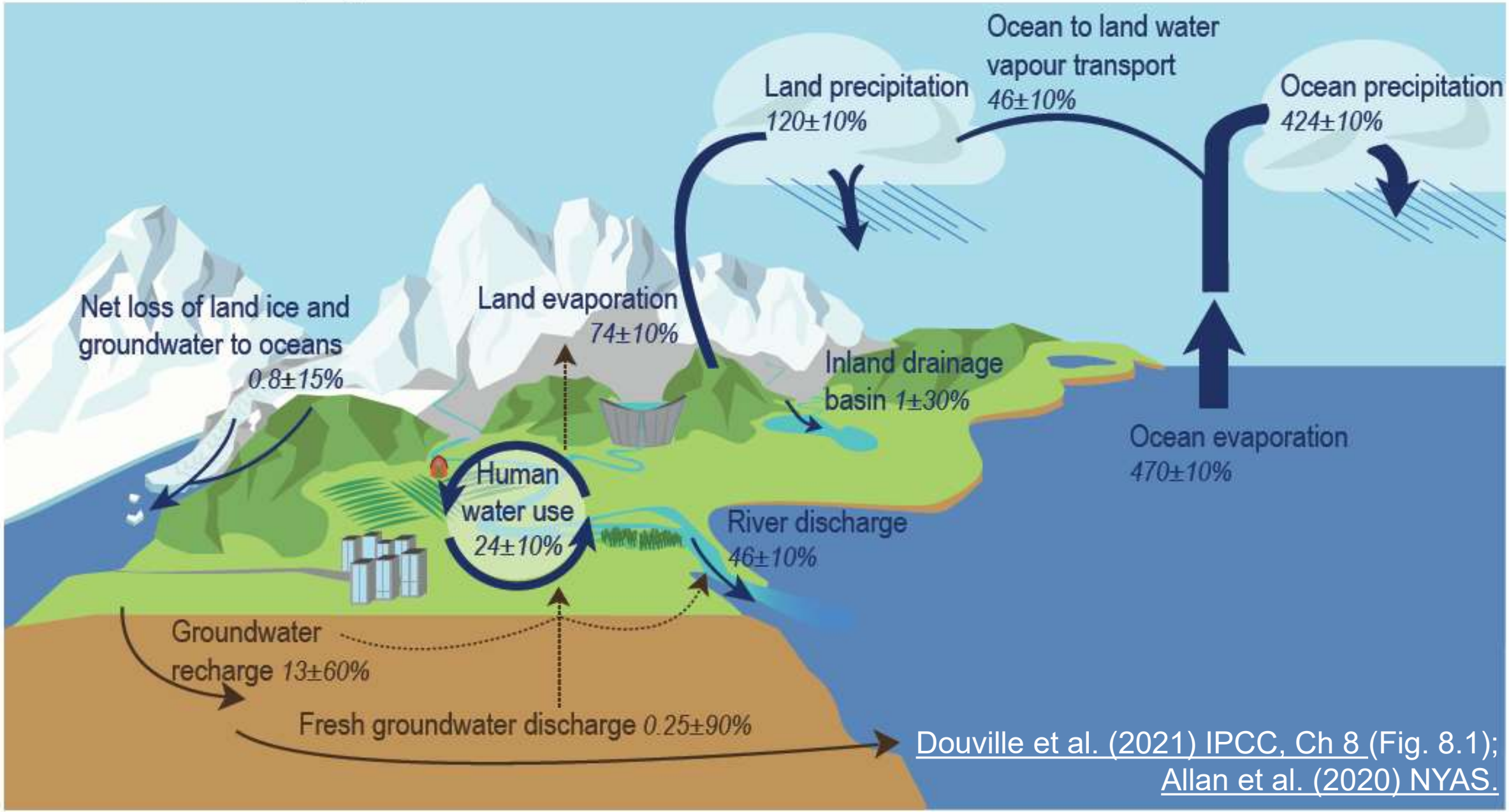
AMPLIFIED SEASONAL RANGE IN PRECIPITATION MINUS EVAPORATION

Richard Allan @rpallanuk r.p.allan@reading.ac.uk

NCEO National Meeting, Leeds, 12th September 2023

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

The Global Water Cycle

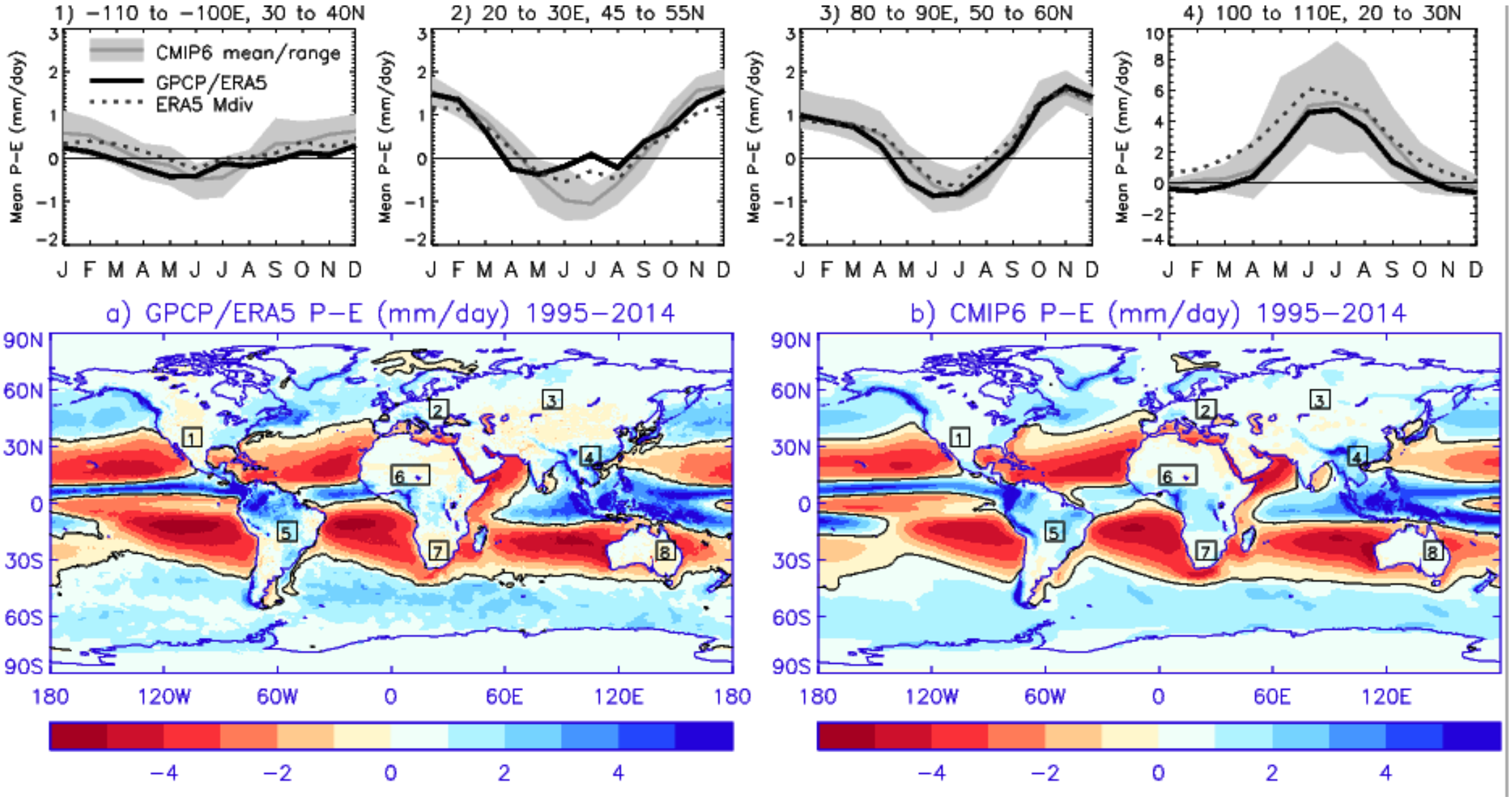


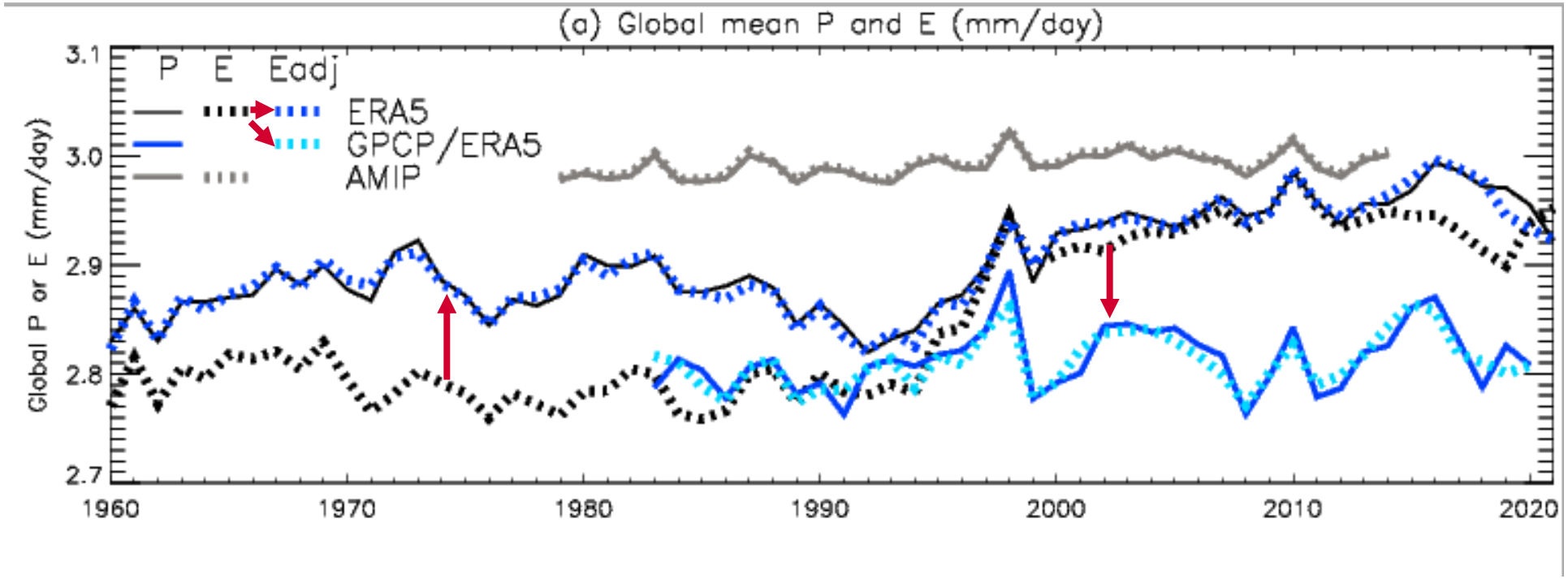
Douville et al. (2021) IPCC, Ch 8 (Fig. 8.1);
Allan et al. (2020) NYAS.

Climatological P minus E

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

University of Reading





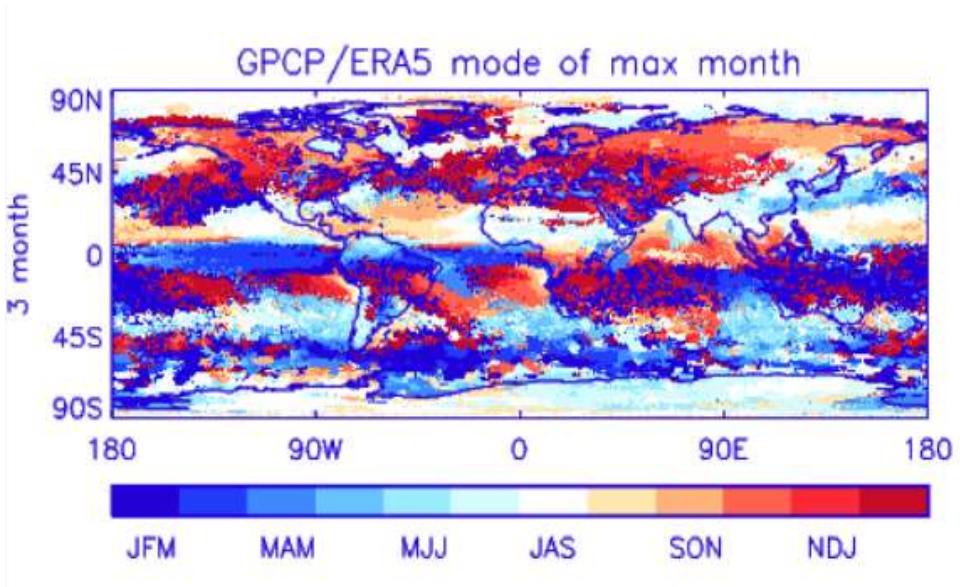
University of Reading

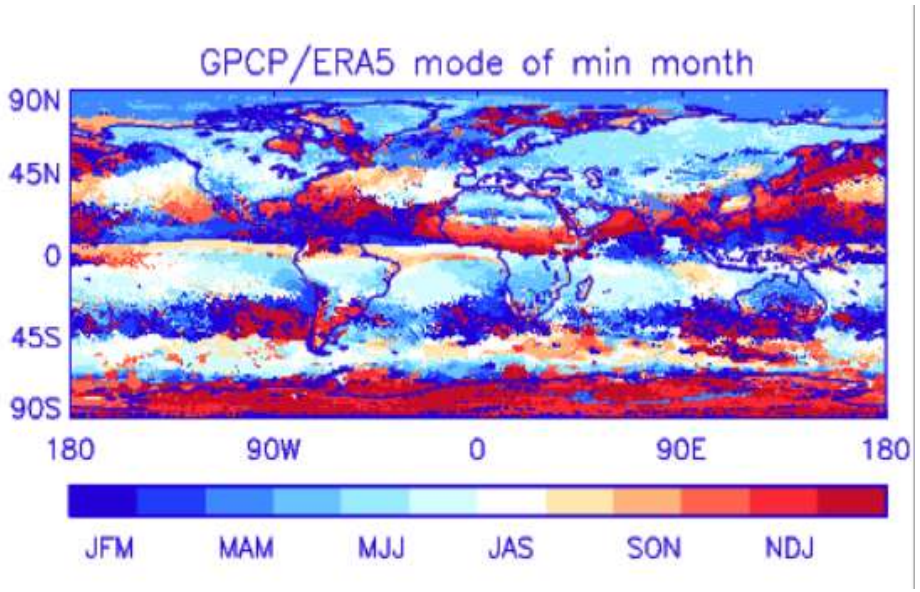
Method

Constrain to Global mean $\int(P - E) = 0$

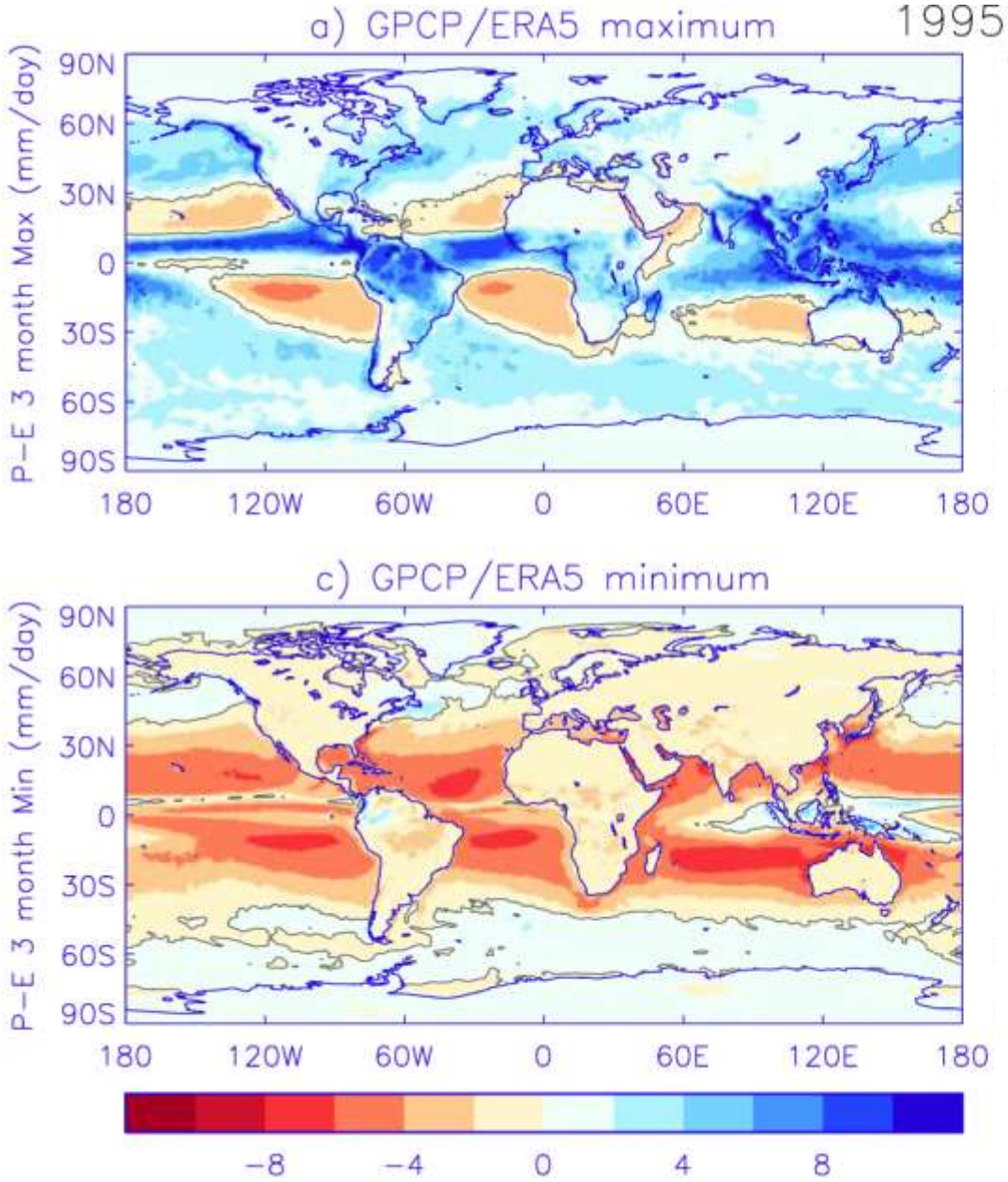
Calc annual max & min P-E

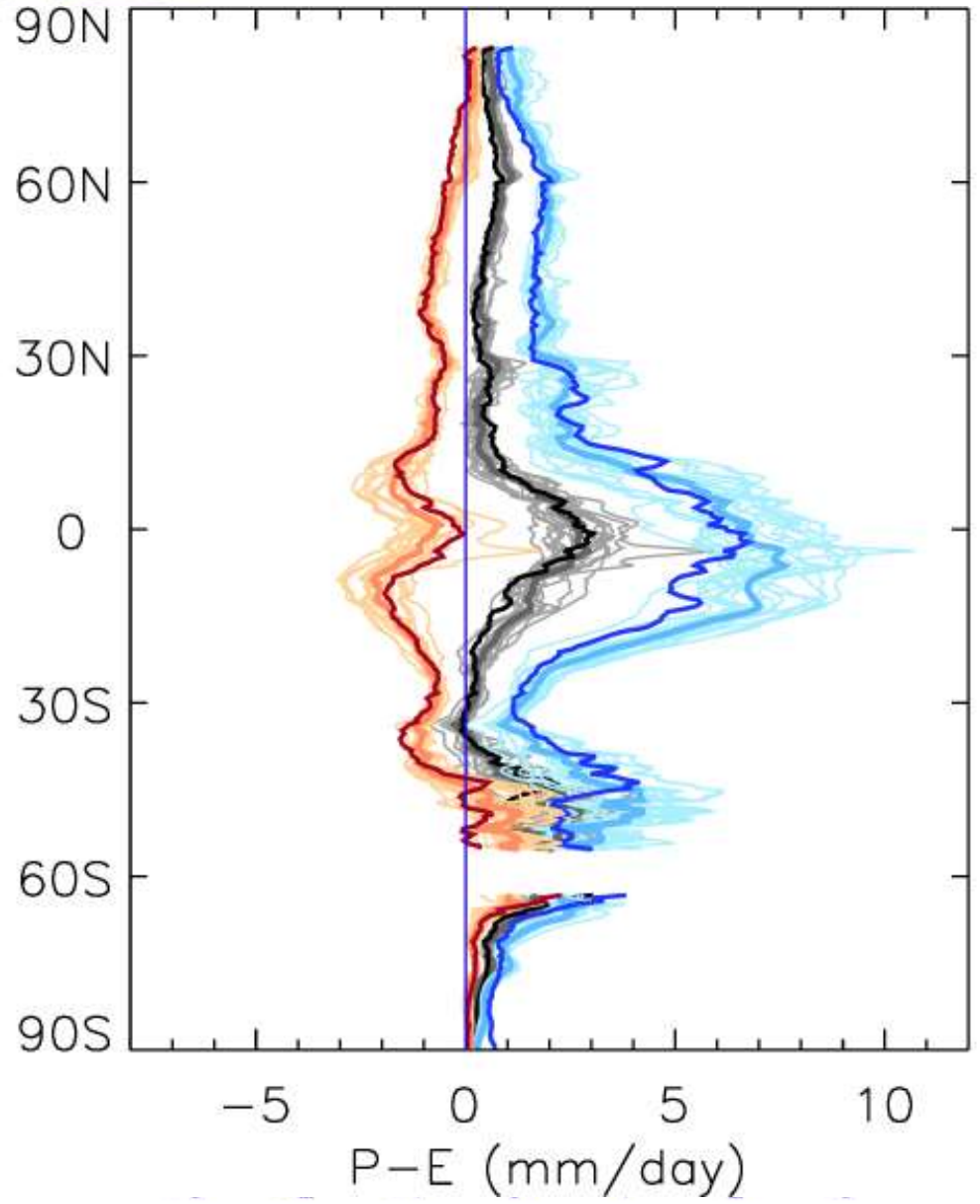
GPCP/GPCC/ ERA5/ERA5 MDiv amip, historical, ssp2-4.5 17 models





Land zonal mean





University of Reading

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

GPCP /ERA5 CMIP6

MAX

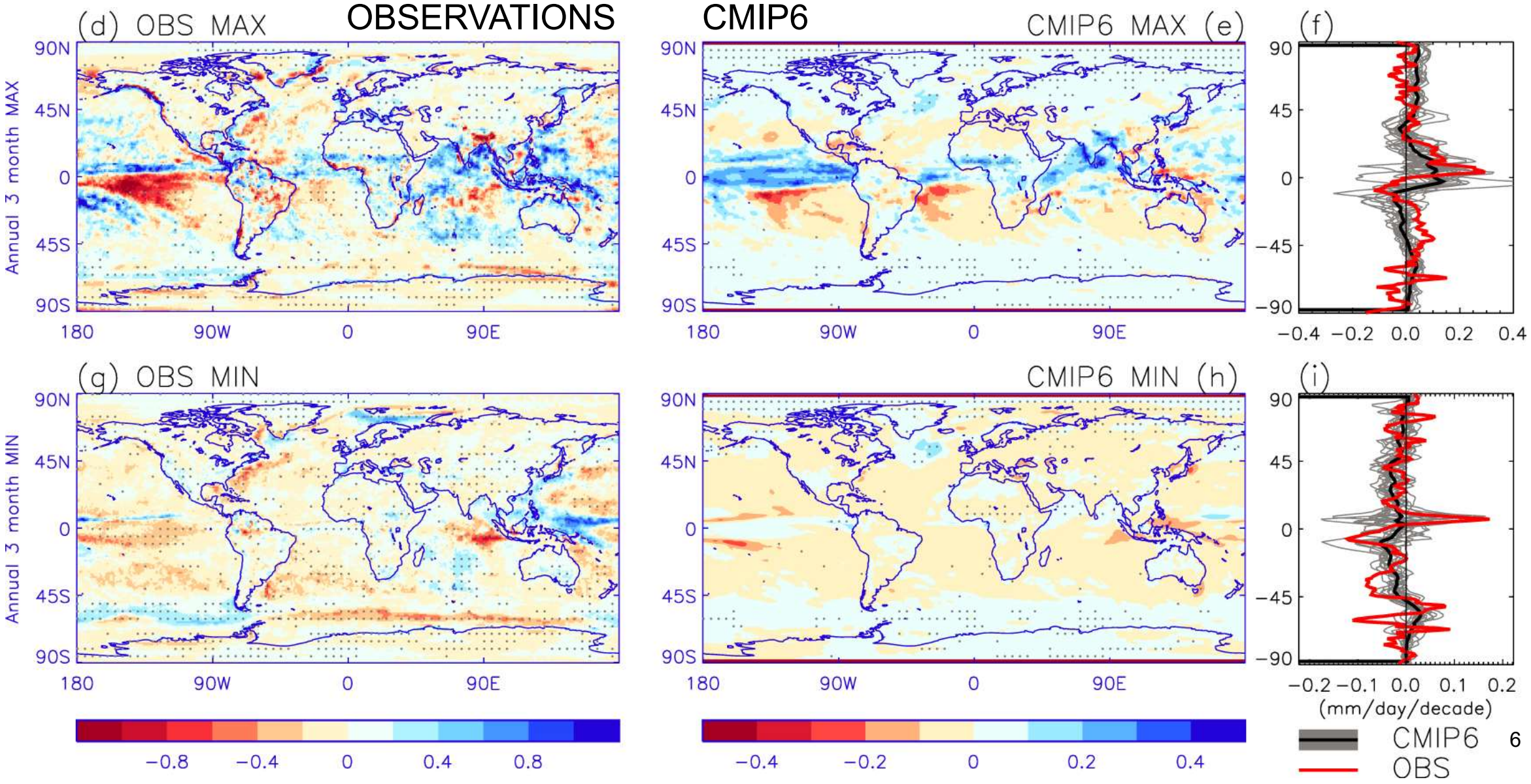
MEAN

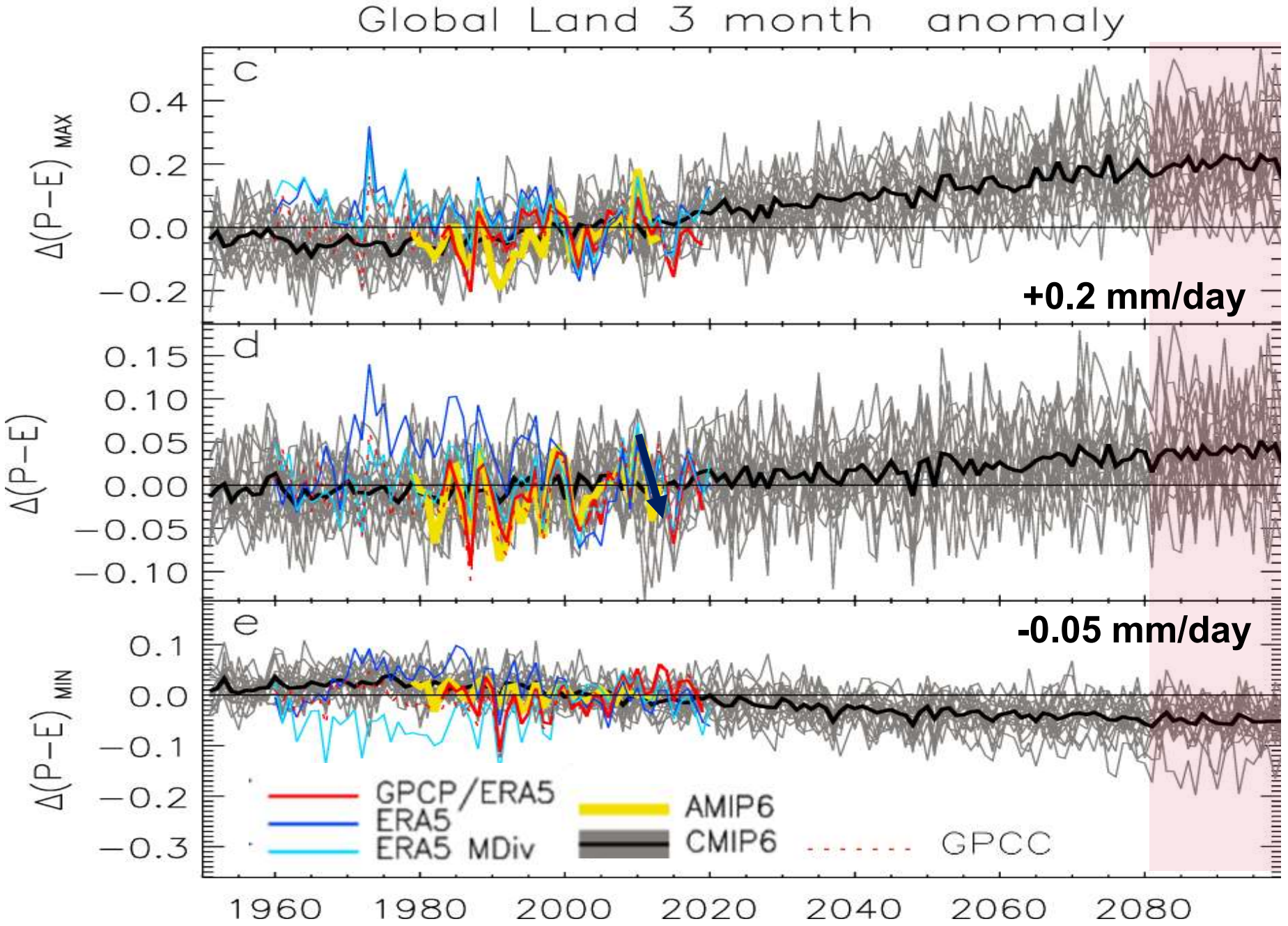
MIN

Allan (2023) ERL

P-E Trends: 1983-2019

University of Reading

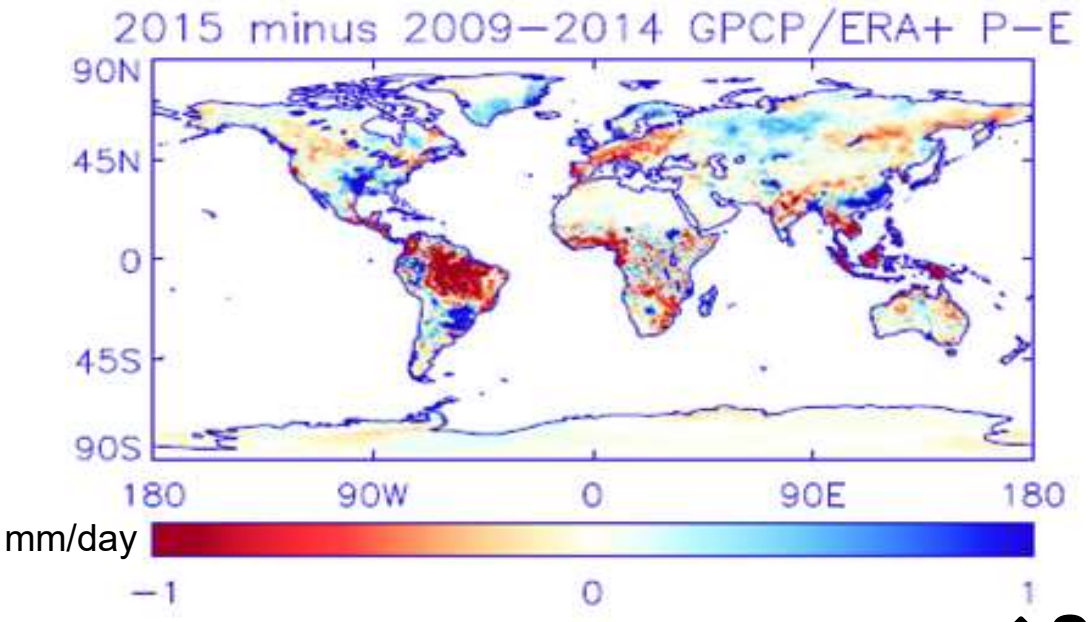


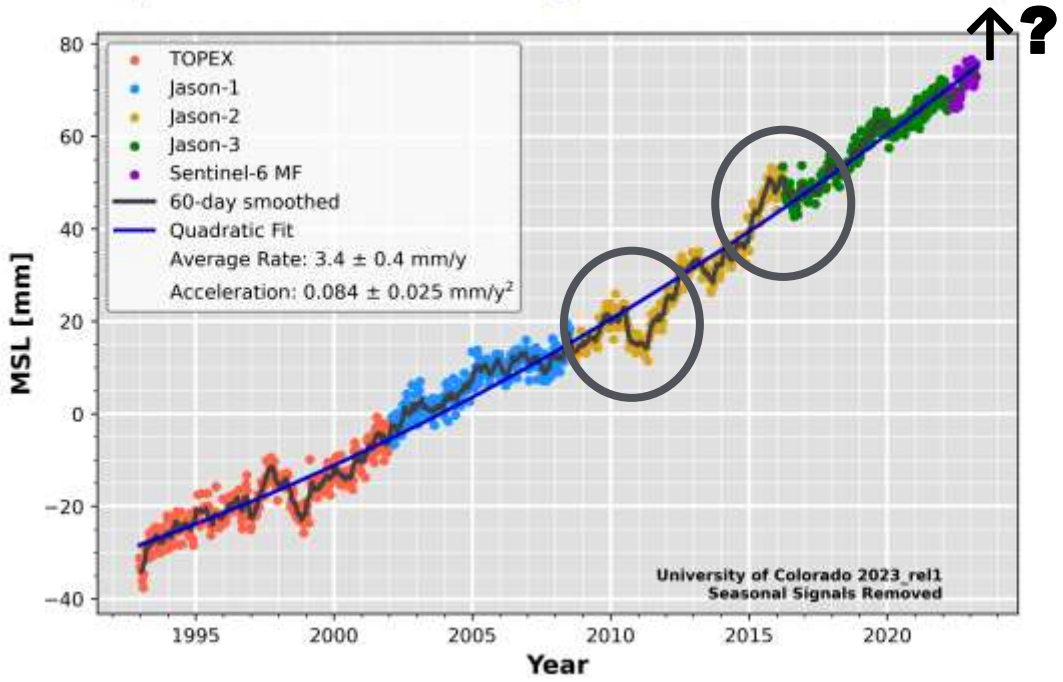


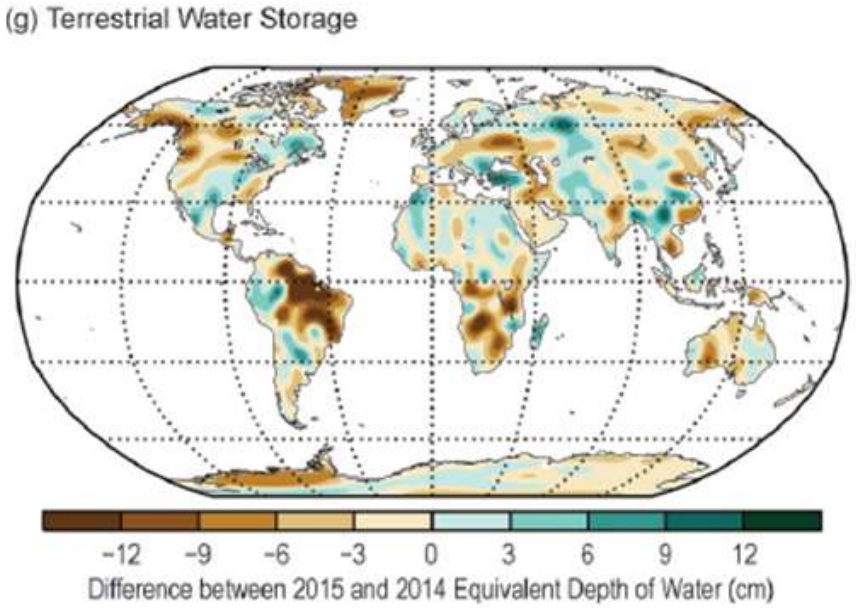
University of Reading

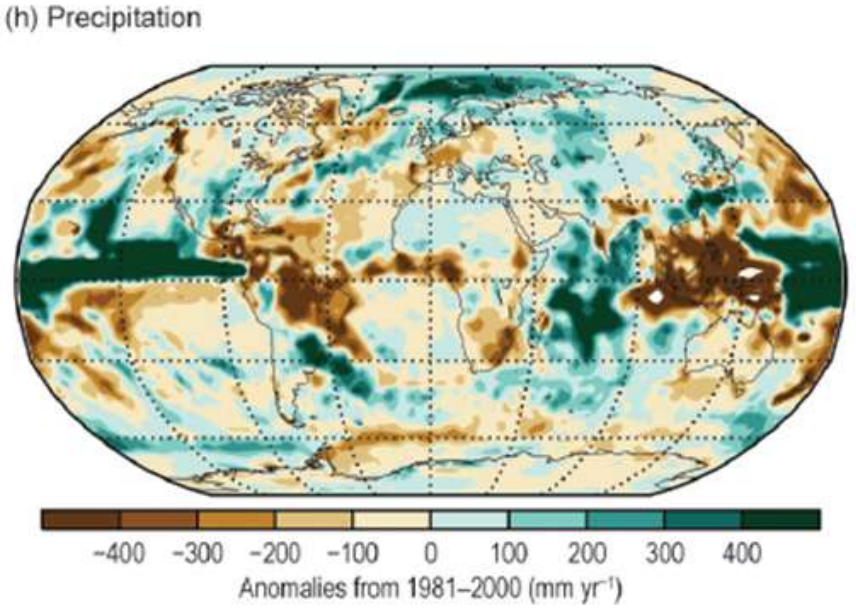
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Allan (2023) ERL









University of Reading

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Chasing water through 2015/16 El Niño

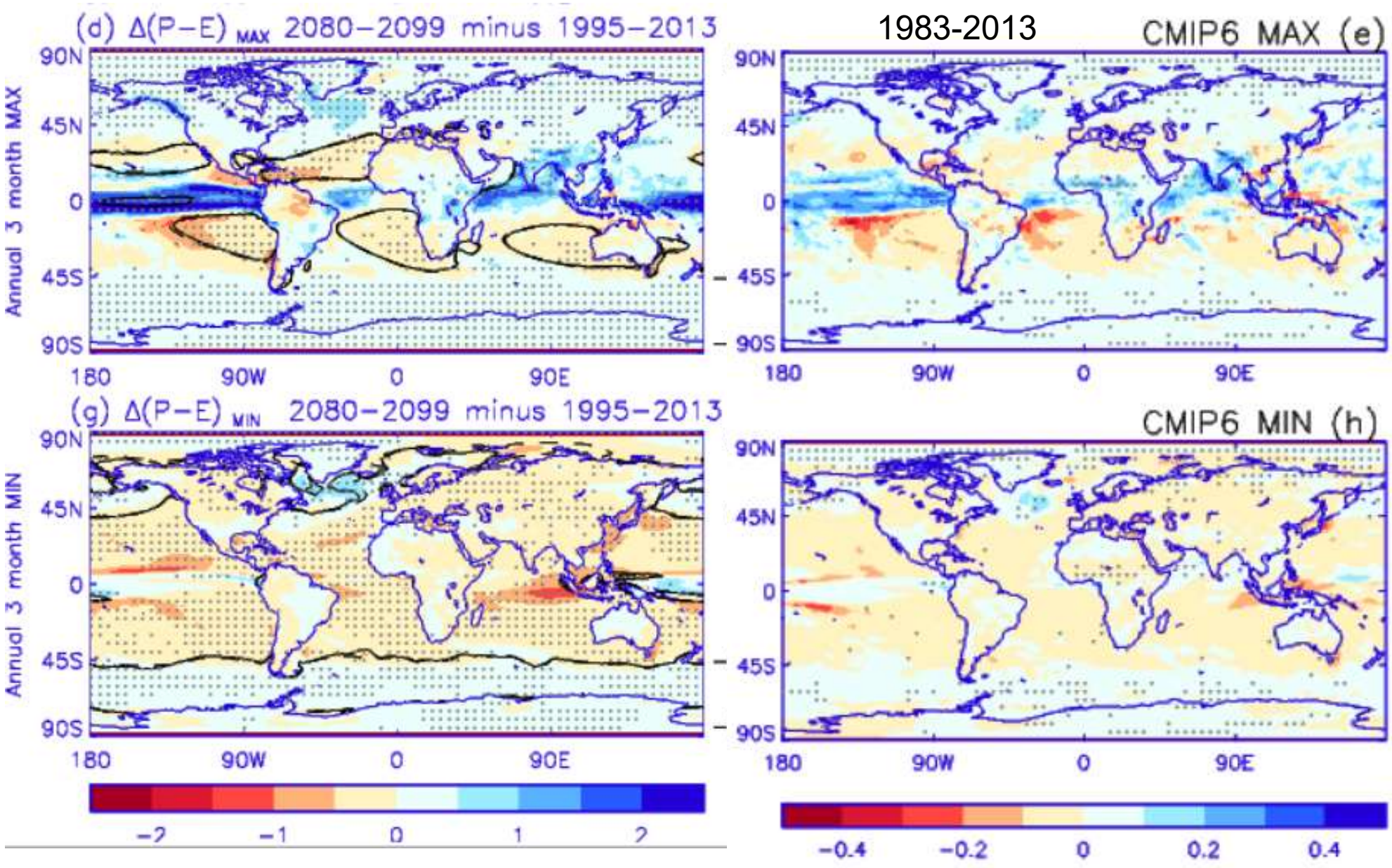
← BAMS state of the climate 2015

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

FUTURE CHANGE

CURRENT TRENDS

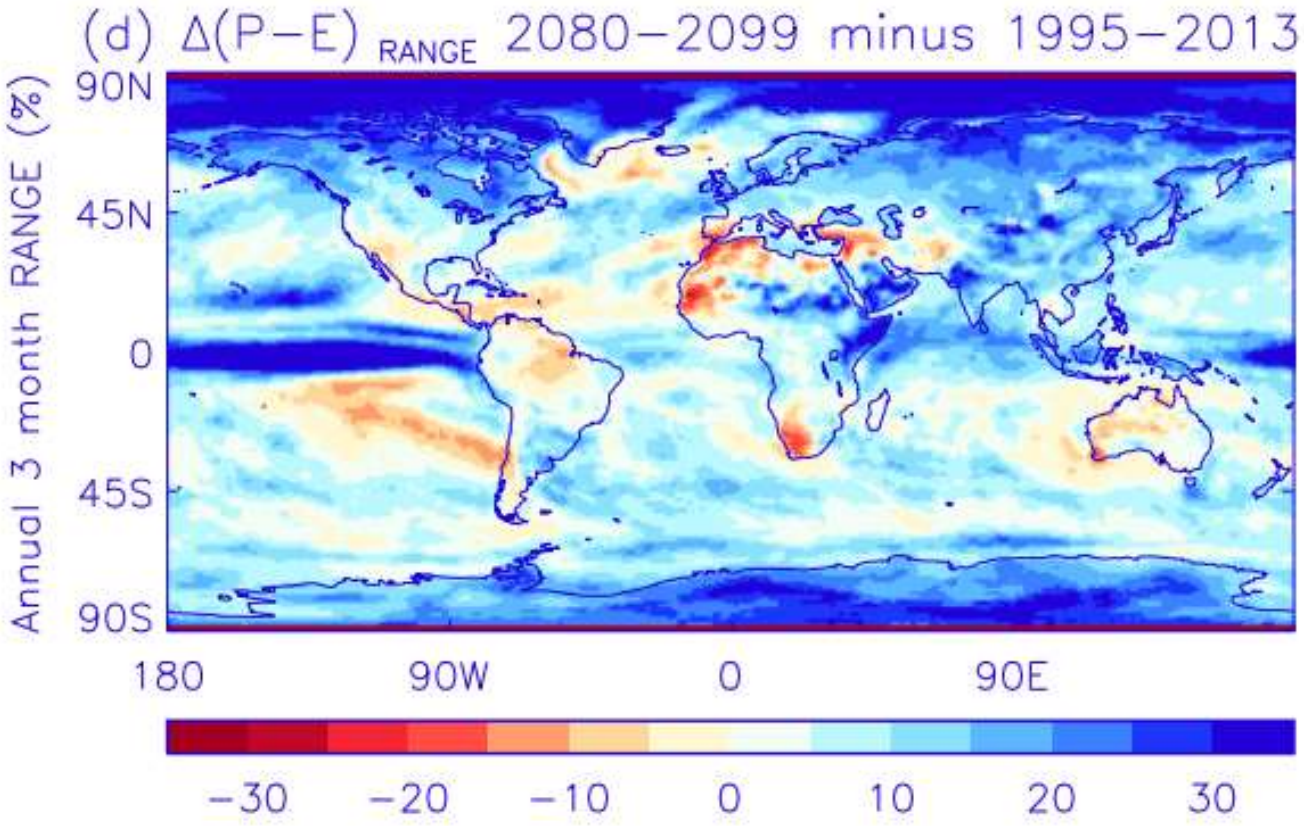
1983-2013

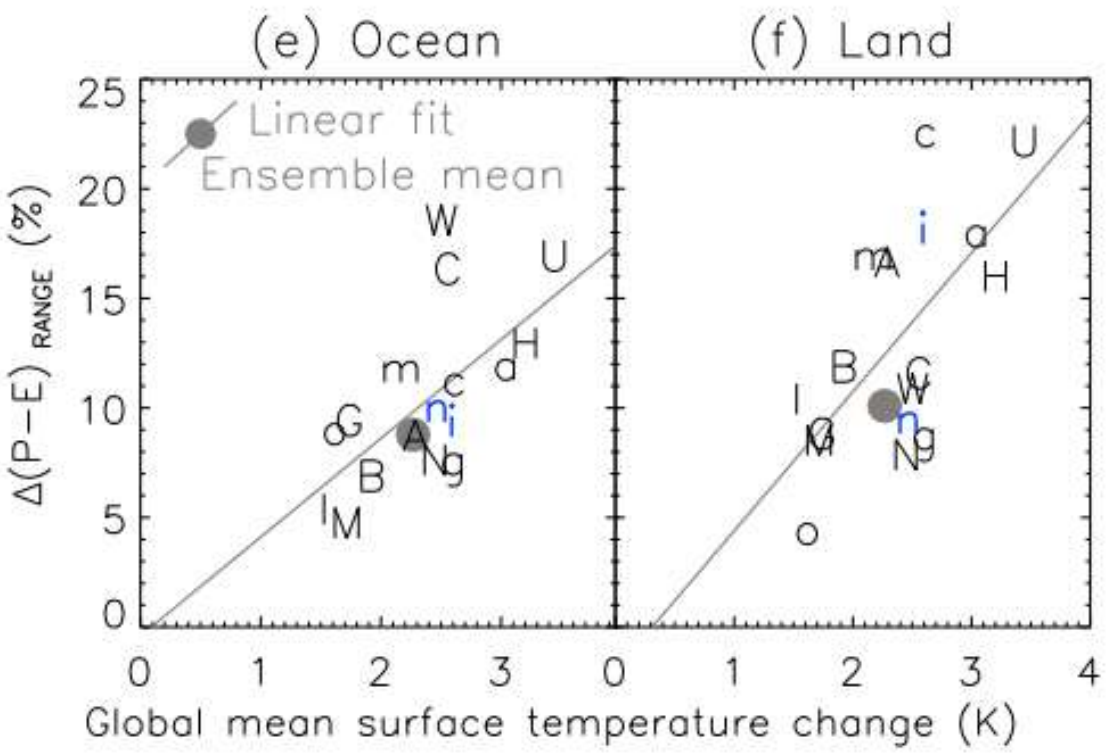


MAX

MIN

Thermodynamic amplification of P-E





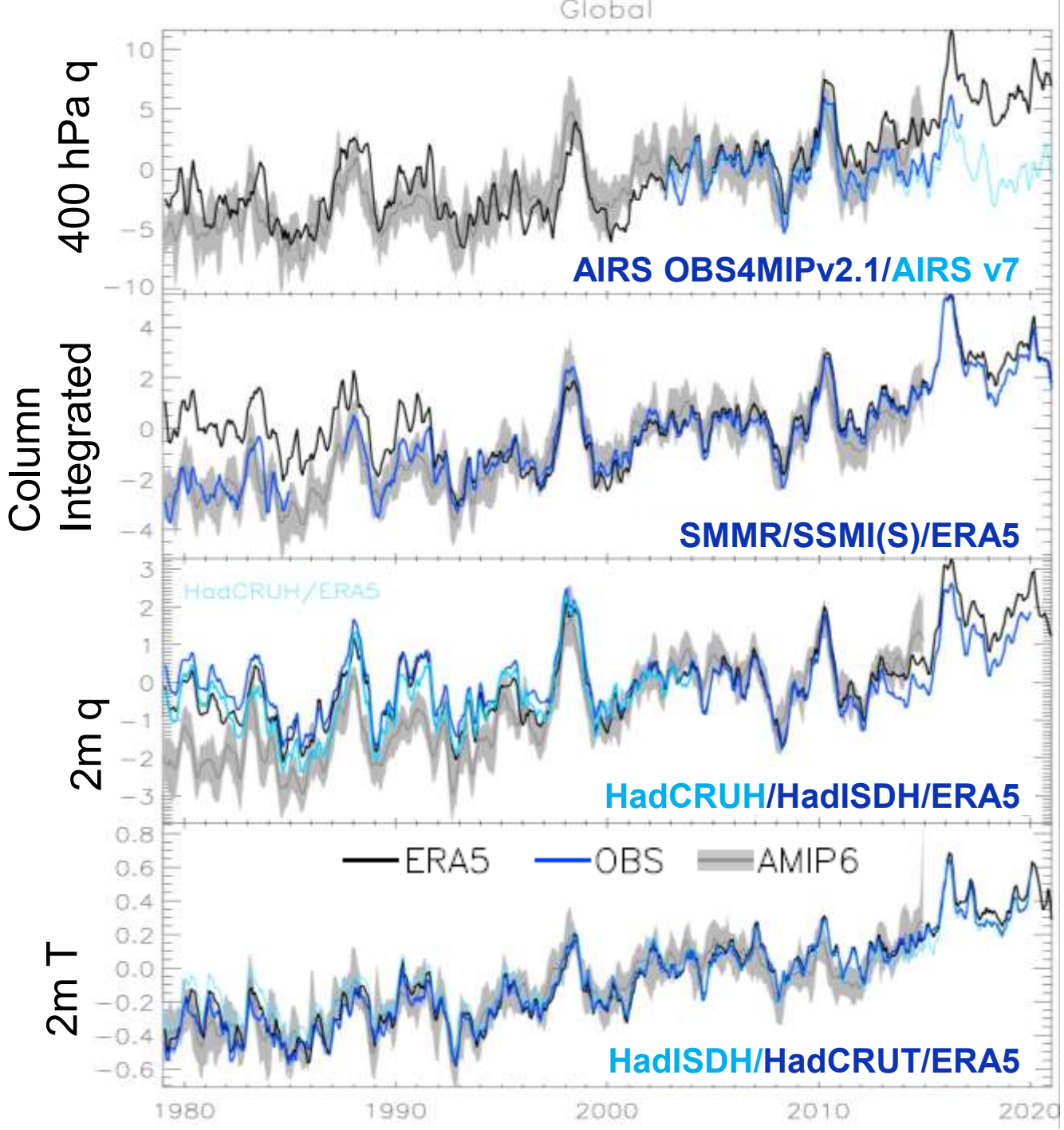
Allan (2023) ERL Supplementary Fig. S17

Conclusions

- More intense water cycle increases transport of water to land
- But moisture export also enhanced in season of strongest drying
- Wet season wetter by ~4%/^{o}C, drying season ~3%/^{o}C more intense
- Amplified seasonal range in P-E (>20% by 2100 over northern land)
- Similar patterns of present trends/future projection (e.g. Wainwright et al. 2022 GRL)?
- …but models fail to capture pattern of warming effects (e.g. Andrews et al. 2022 JGR)?
- Uncertain response over land (e.g. Allan et al. (2020) NYAS)
  - Do models underestimate continental drying? Allan et al. 2022 JGR, Dunn et al. 2017 ESD
  - Is terrestrial water storage declining? Will 2016 deficit be repeated in 2024?
- Can observations provide emergent constraint on P-E amplification?

University of Reading

EXTRA SLIDES…



Water vapour increasing

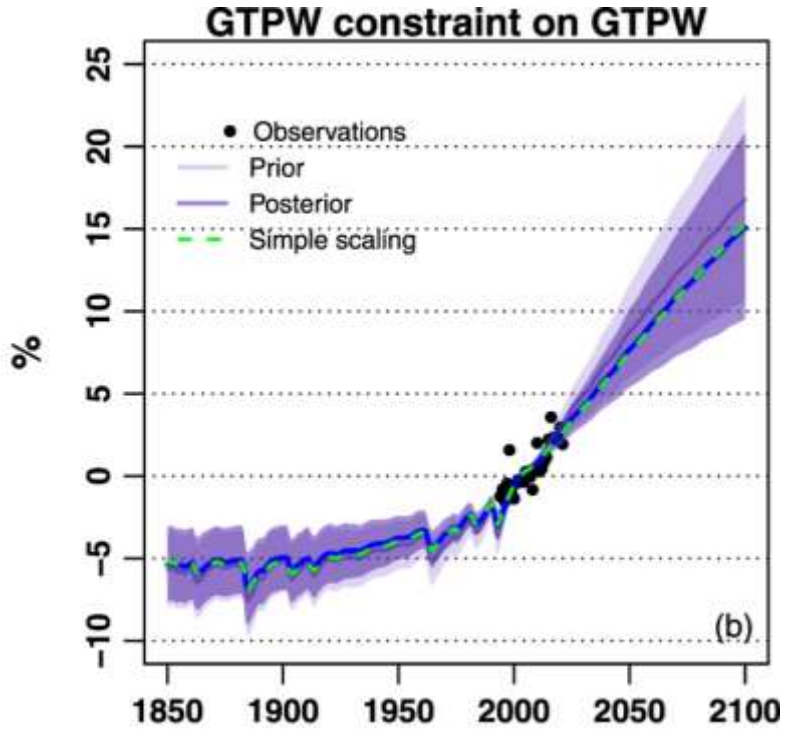
University of Reading

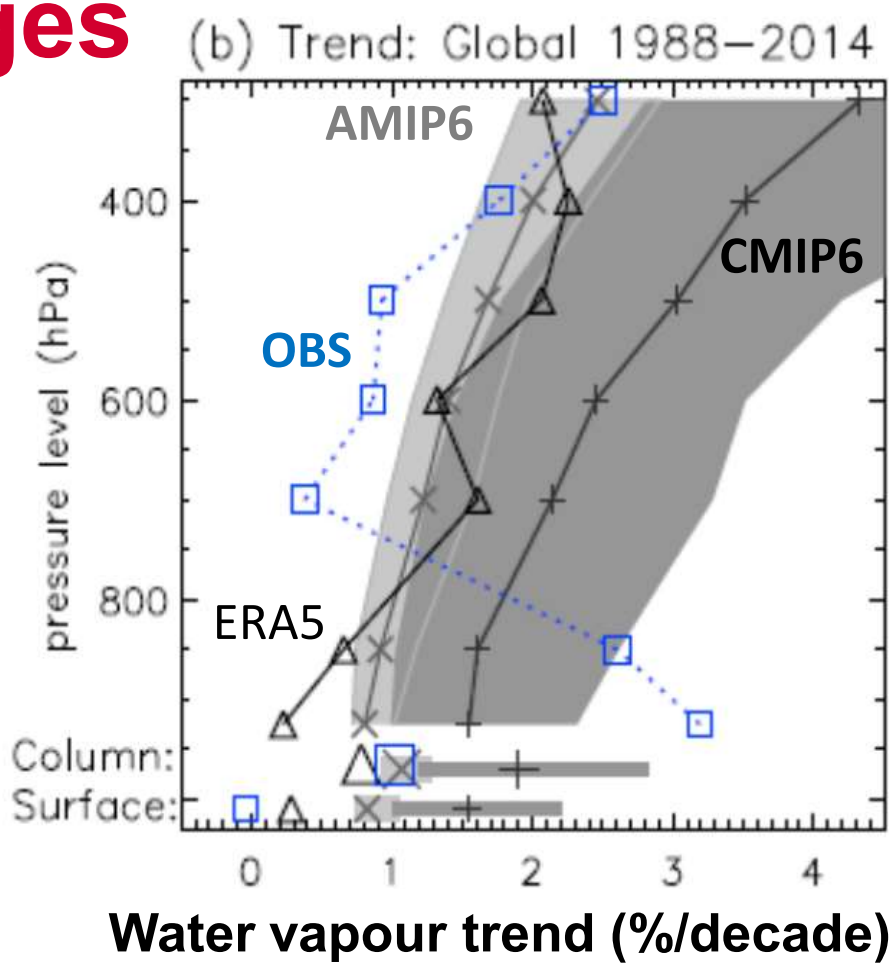
- ENSO variability captured
- Discrepancy in simulated changes in 1980s (ERA5/HadISDH and AMIP6)
  - e.g. Dunn et al. 2017 ESD; Byrne & O'Gorman (2018) PNAS
  - Unrealistic drop in ERA5 column water vapour early 1990s (tropical ocean):
  - e.g. Allan et al. 2020 NYAS
- Divergence between AIRS/ERA5 upper troposphere trends in 2000s (esp. 400-700 hPa tropical oceans)

Allan et al. 2022 JGR

Can current water cycle changes constrain future projections?

- Douville et al. (2022) Comm. Earth & Env. water vapour observations constrain future projections ~ 7% per °C increase in column moisture





- But observed warming/moistening smaller than CMIP6 (e.g. Allan et al. 2022 JGR) due to warming pattern (internal variability?)

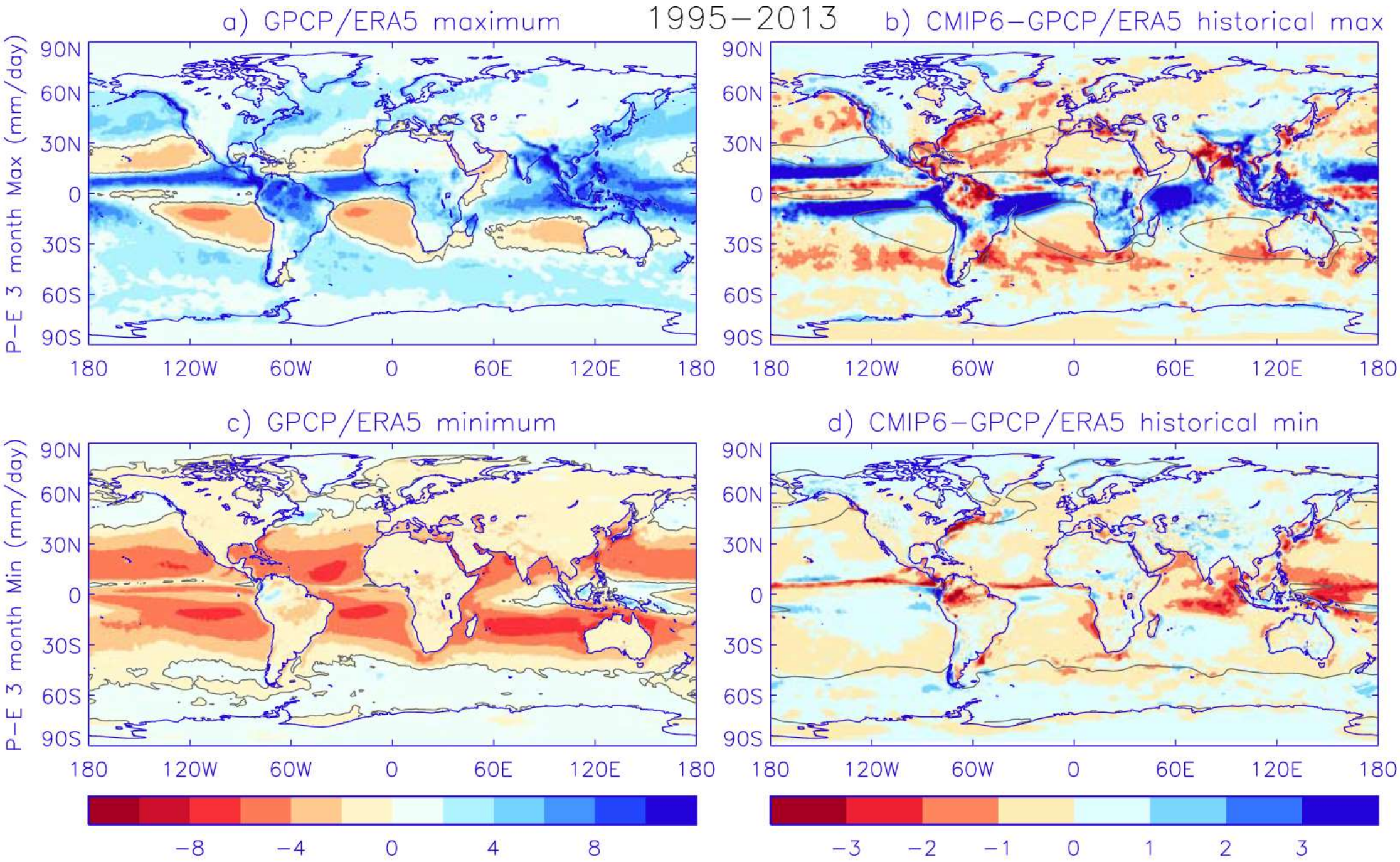
Precipitation minus Evaporation (P-E)

- Net supply of Freshwater (land)
- Surface salinity and circulation (ocean)

- Balanced by moisture transport (atmosphere) & runoff (surface)
- P-E maximum: wet season/months, precipitation driven
- P-E minimum: lack of precip, high evaporation, drying ground
  - diagnostic of dry period onset intensity
  - relevance to flash droughts e.g. Black (2023) Adv. Atmos. Sci.

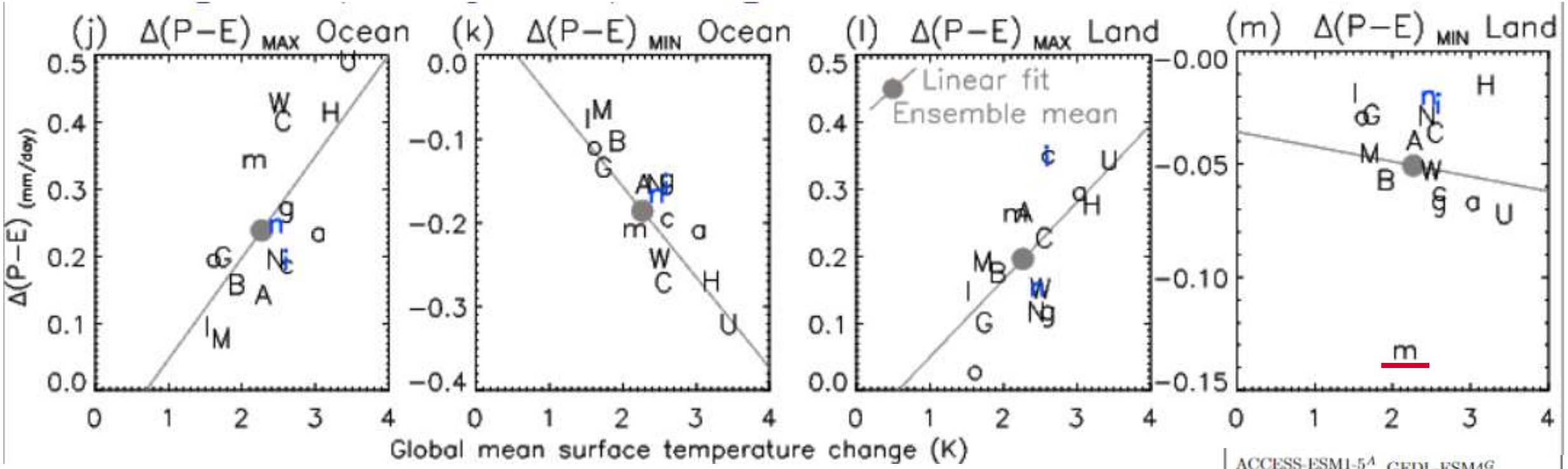
METHOD:

- annual grid-point mean P-E and 3-month or 1-month annual max & min
- GPCP/ERA5 (1983-2019); ERA5, ERA5 moisture divergence (1960-2020)
- 17 CMIP6 models historical/ssp2-4.5 (1950-2014-2100); amip (1979-2014)


1995–2013
a) GPCP/ERA5 maximum
b) CMIP6–GPCP/ERA5 historical max
c) GPCP/ERA5 minimum
d) CMIP6–GPCP/ERA5 historical min
P–E 3 month Max (mm/day)
P–E 3 month Min (mm/day)
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180
−8
−4
0
4
8
−3
−2
−1
0
1
2
3

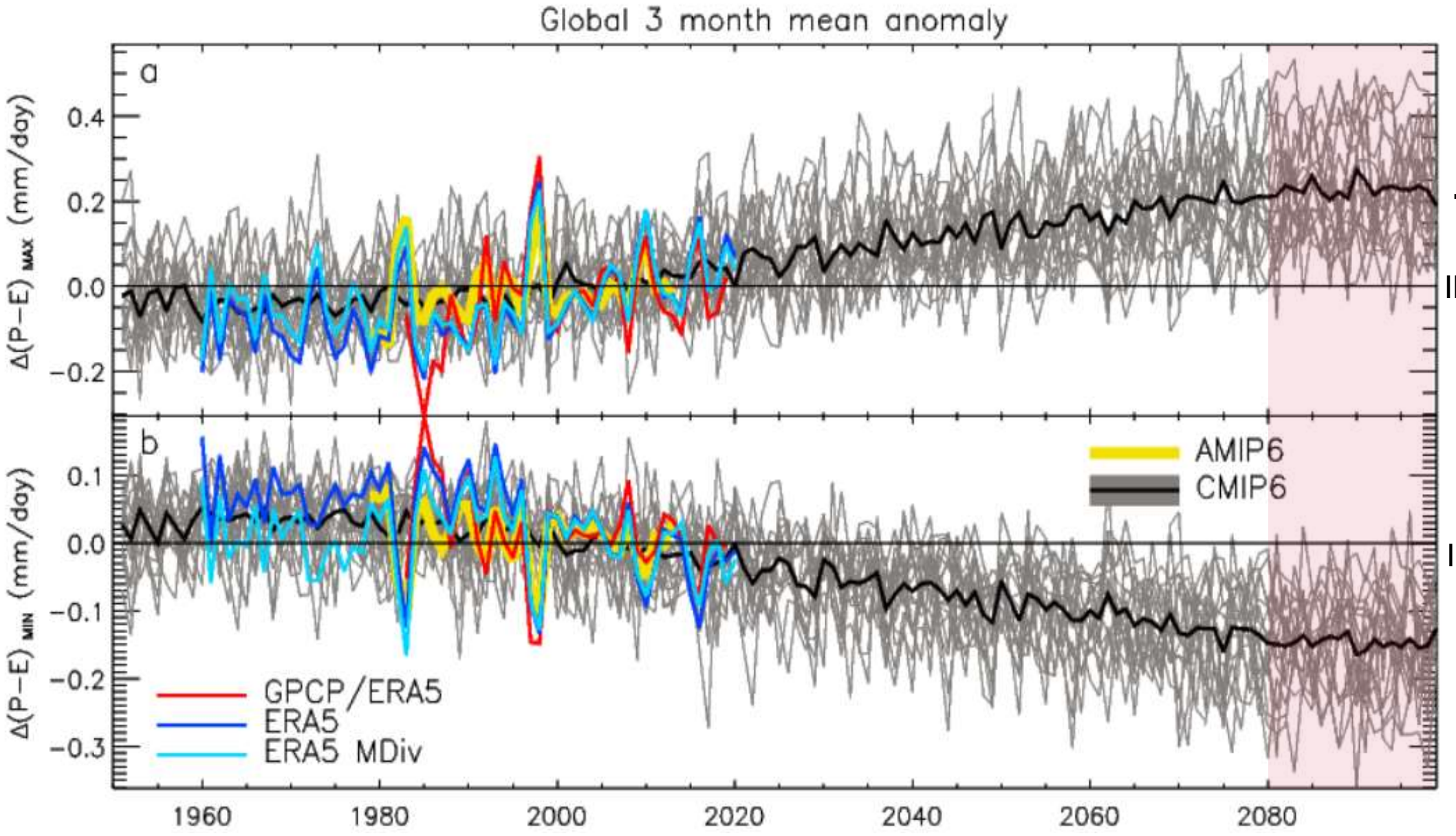
Thermodynamic amplification of P-E

University of Reading



- Thermodynamic amplification of seasonal P-E with warming
- Changes over land across models less coherent (right)

ACCESS-ESM1-5[A]	GFDL-ESM4[G]
BCC-CSM2-MR[B]	GISS-E2-1-G[g]
BCC-ESM1[b]	HadGEM3-GC31-LL[H]
CanESM5[a]	INM-CM5-0[I]
CESM2[C]	IPSL-CM6A-LR[i]
CESM2-WACCM[W]	MIROC6[M]
CMCC-CM2-SR5[C]	MRI-ESM2-0[m]
CNRM-CM6-1[N]	NorESM2-LM[n]
CNRM-ESM2-1[n]	UKESM1-0-LL[U]



UKESM1-0-LL

+0.23 mm/day

INMCM; MICROC6

INMCM; MICROC6

-0.15 mm/day

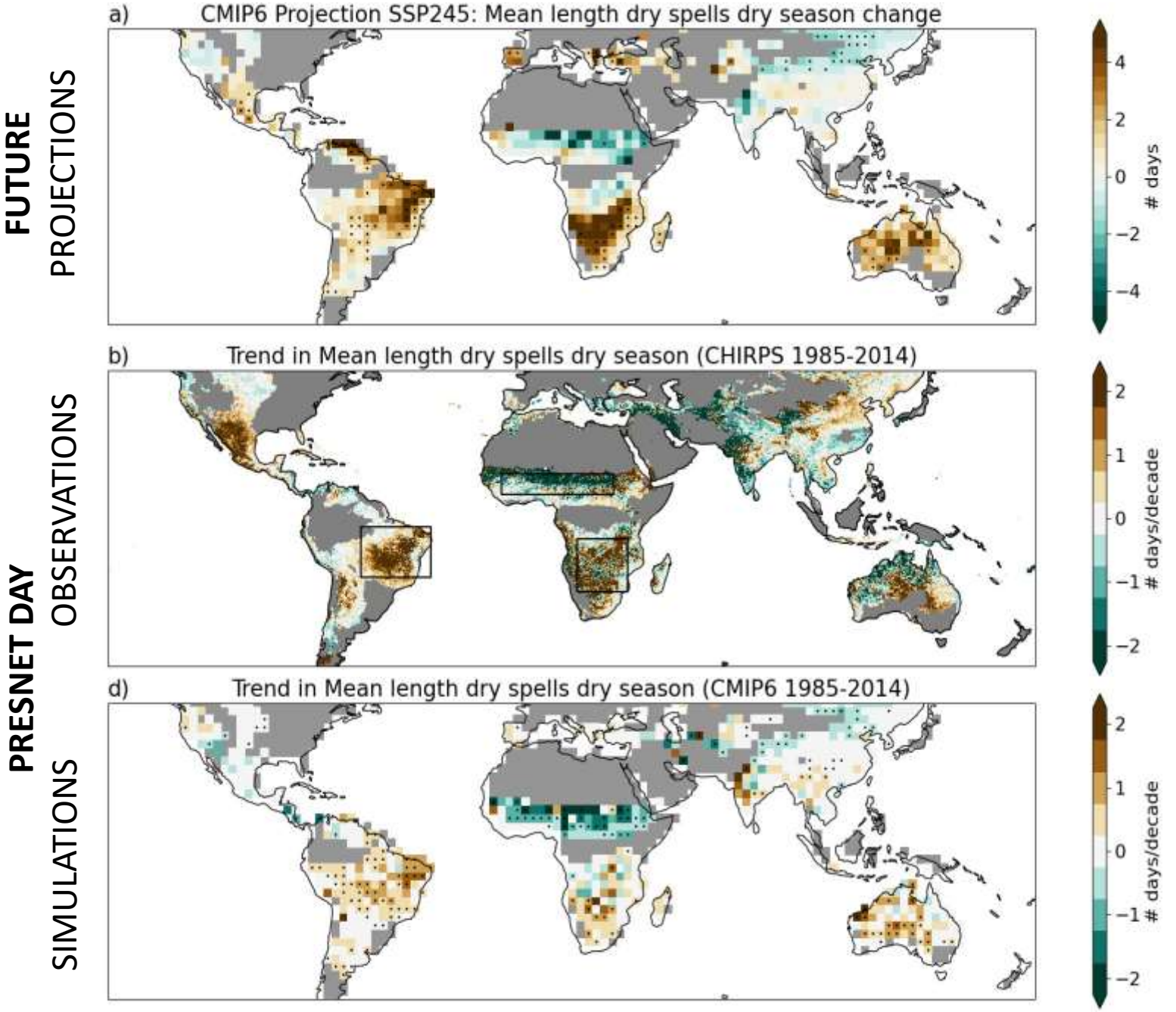
UKESM1-0-LL

Similar to changes in wettest vs driest regions precip Liu & Allan (2013) ERL

Emerging signals

- Emerging signals of more intense dry seasons over eastern Brazil, southern Africa and Australia (opposite in Sahel)

Wainwright et al. (2022) GRL →



Conclusions

- Amplification of P-E signal over ocean well understood
- P-E changes over land not well understood
- Seasonal amplification of P-E patterns?
  - Wet season P > E; Dry season (onset) E > P
  - Intensification of wet season (+4.2 → +4.4 mm/day global land)
  - More intense dry season onset over northern continents but not apparent over tropics? (-1.15 → -1.2 mm/day global land)
  - See also IPCC (2021) TS Box 8.2; Chapter 8, Section 8.2
- Emerging regional signals of hydrological change?
  e.g. Wainwright et al. (2022) GRL
- Changing atmospheric circulation crucial but low confidence
  e.g. IPCC (2021) Fig. 8.21