

Reconciling Earth's growing energy imbalance with ocean warming

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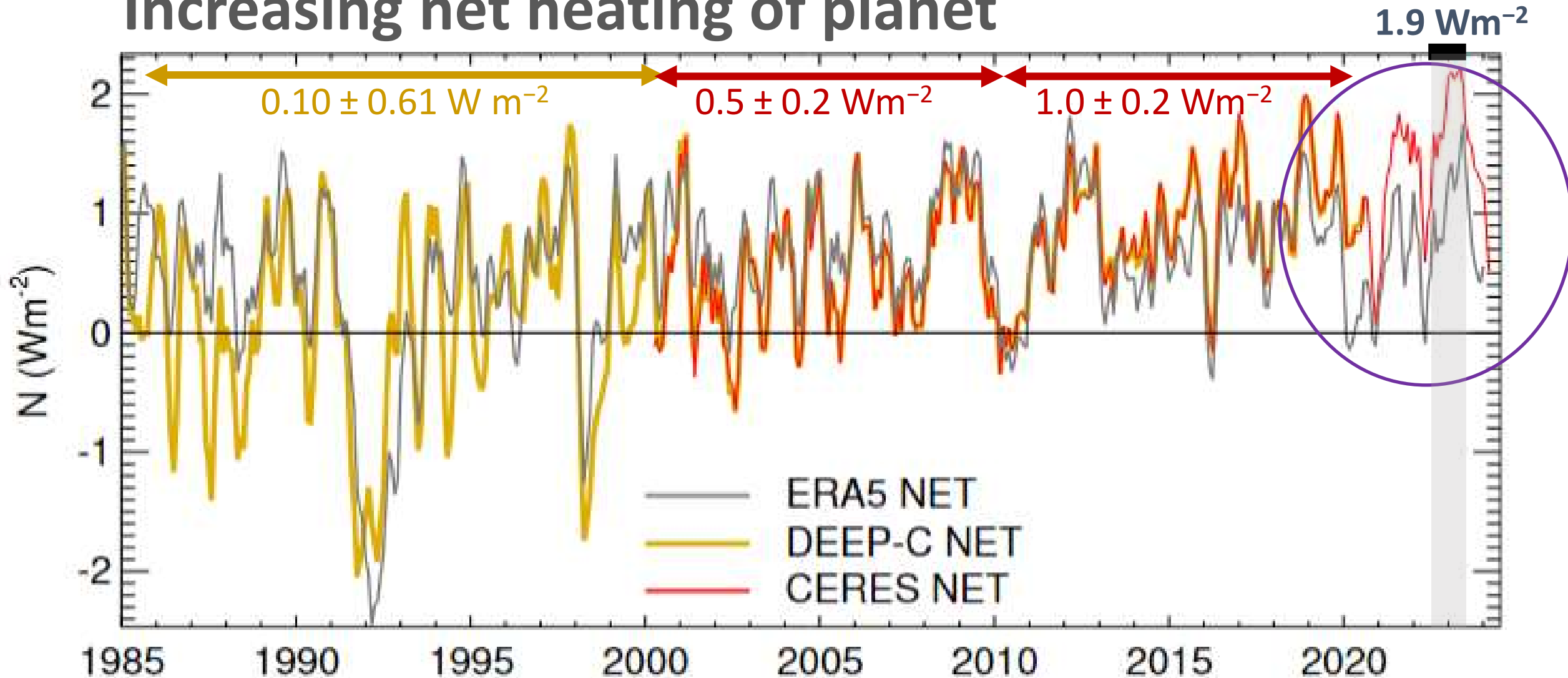


National Centre for
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NATURAL ENVIRONMENT RESEARCH COUNCIL



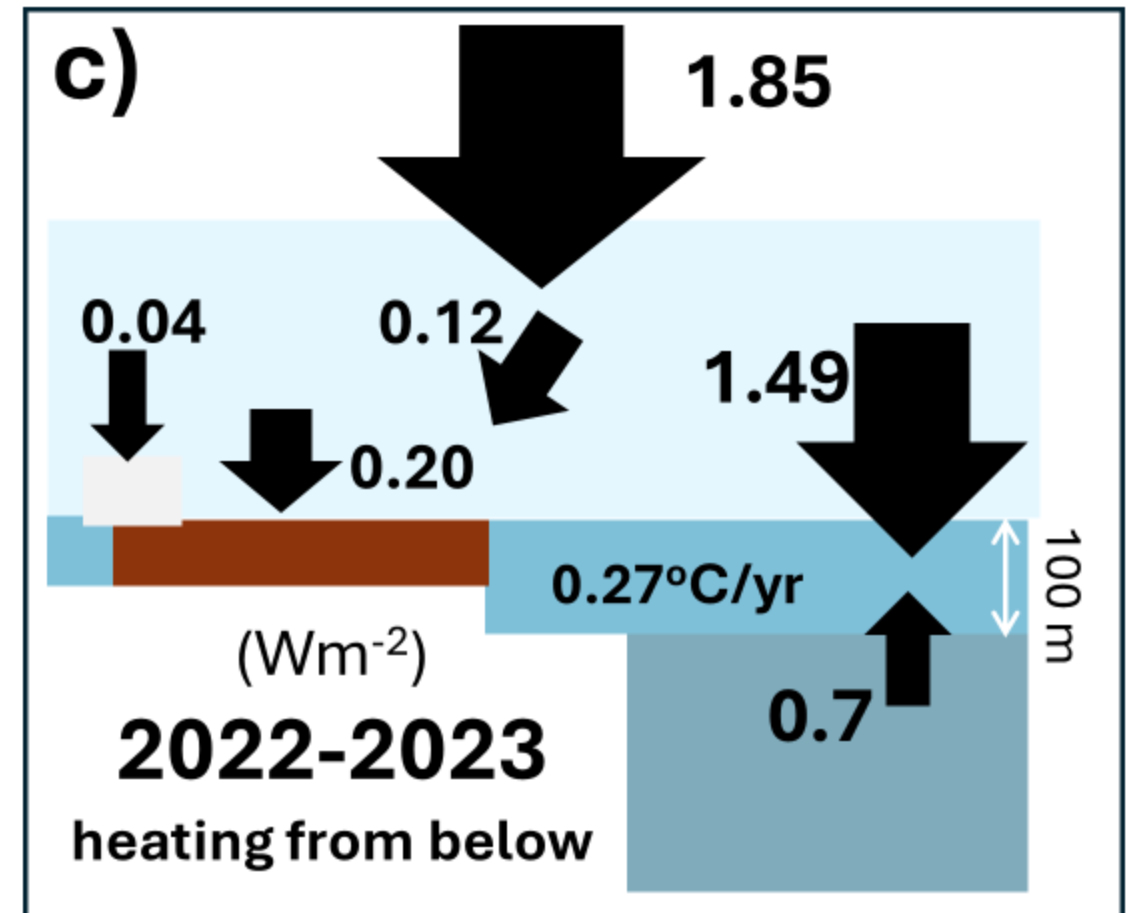
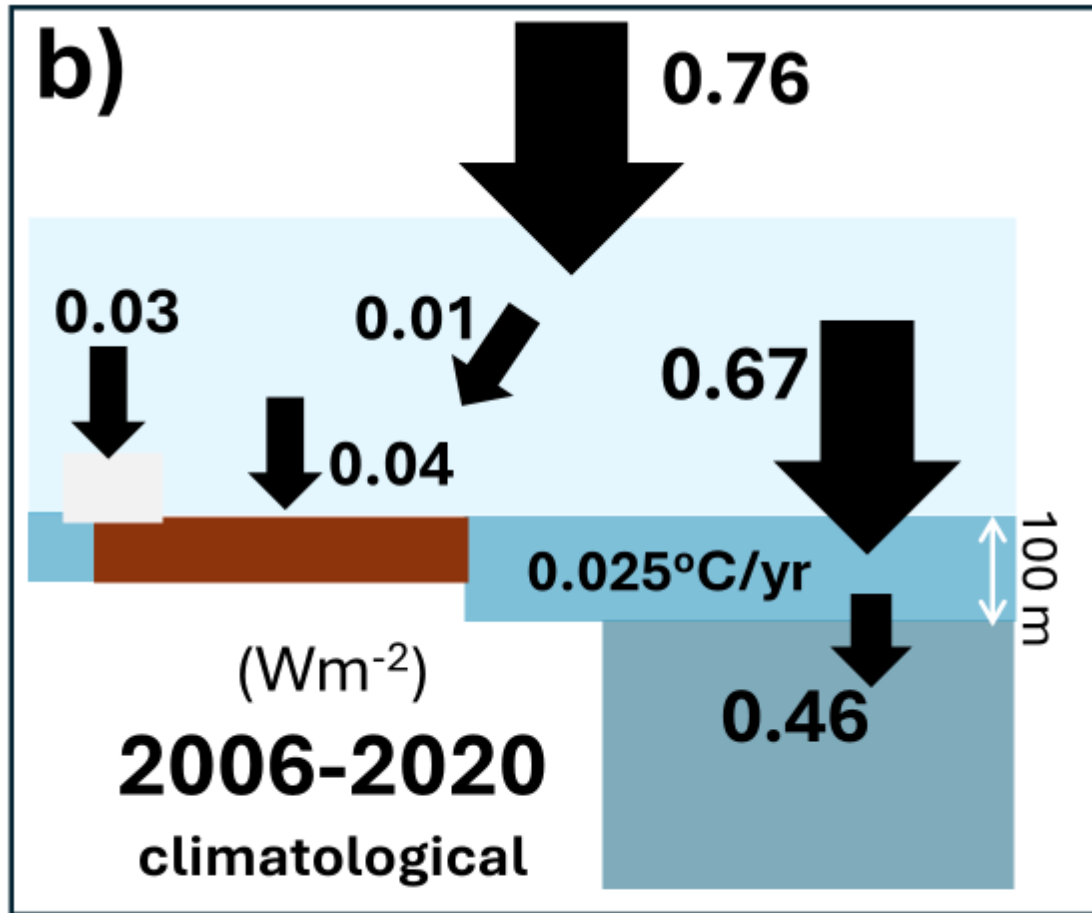
Natural
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Research Council

Increasing net heating of planet



[Liu et al. \(2020\) Clim. Dyn.](#); [Allan & Merchant \(2025\) ERL](#); [Merchant et al. \(2025\) ERL](#)

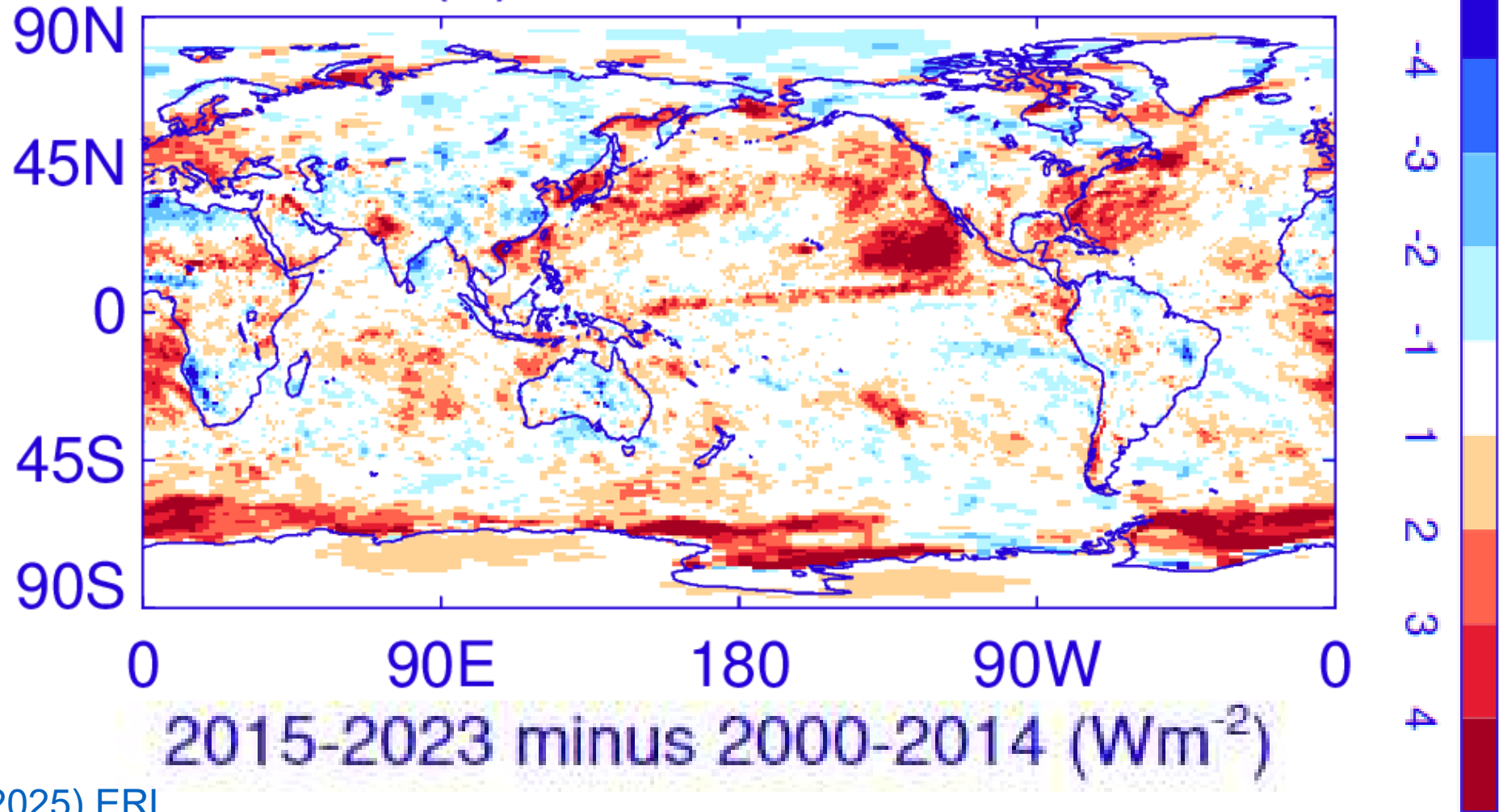
Reconciling energy balance with ocean warming



[von Shuckmann et al. \(2023\) ESSD](#) and estimated for 2022-23 (see [Allan & Merchant \(2025\) ERL](#))

Spatial pattern of imbalance

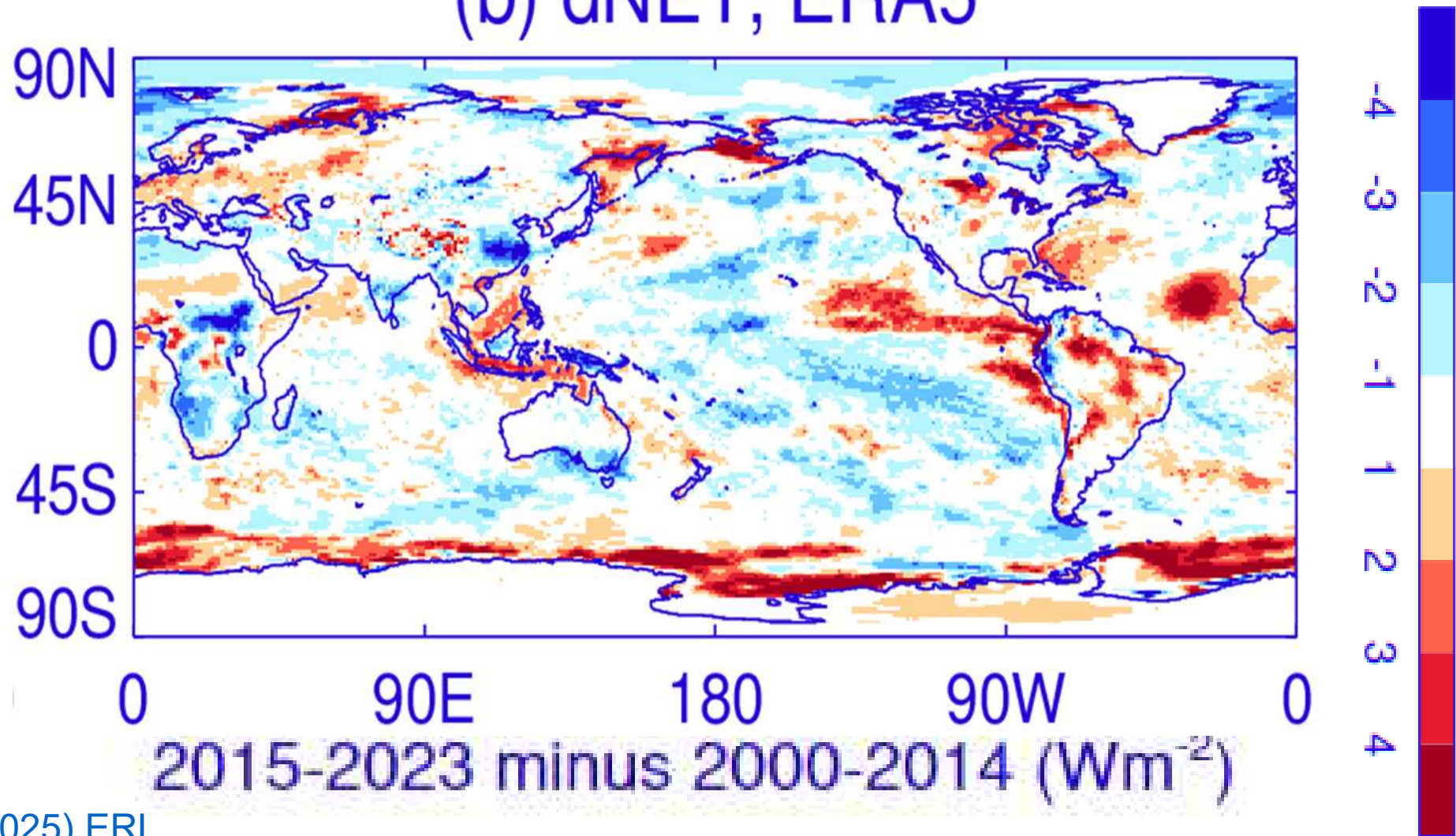
(a) dNET, CERES



[Allan & Merchant \(2025\) ERL](#)

Spatial pattern of imbalance

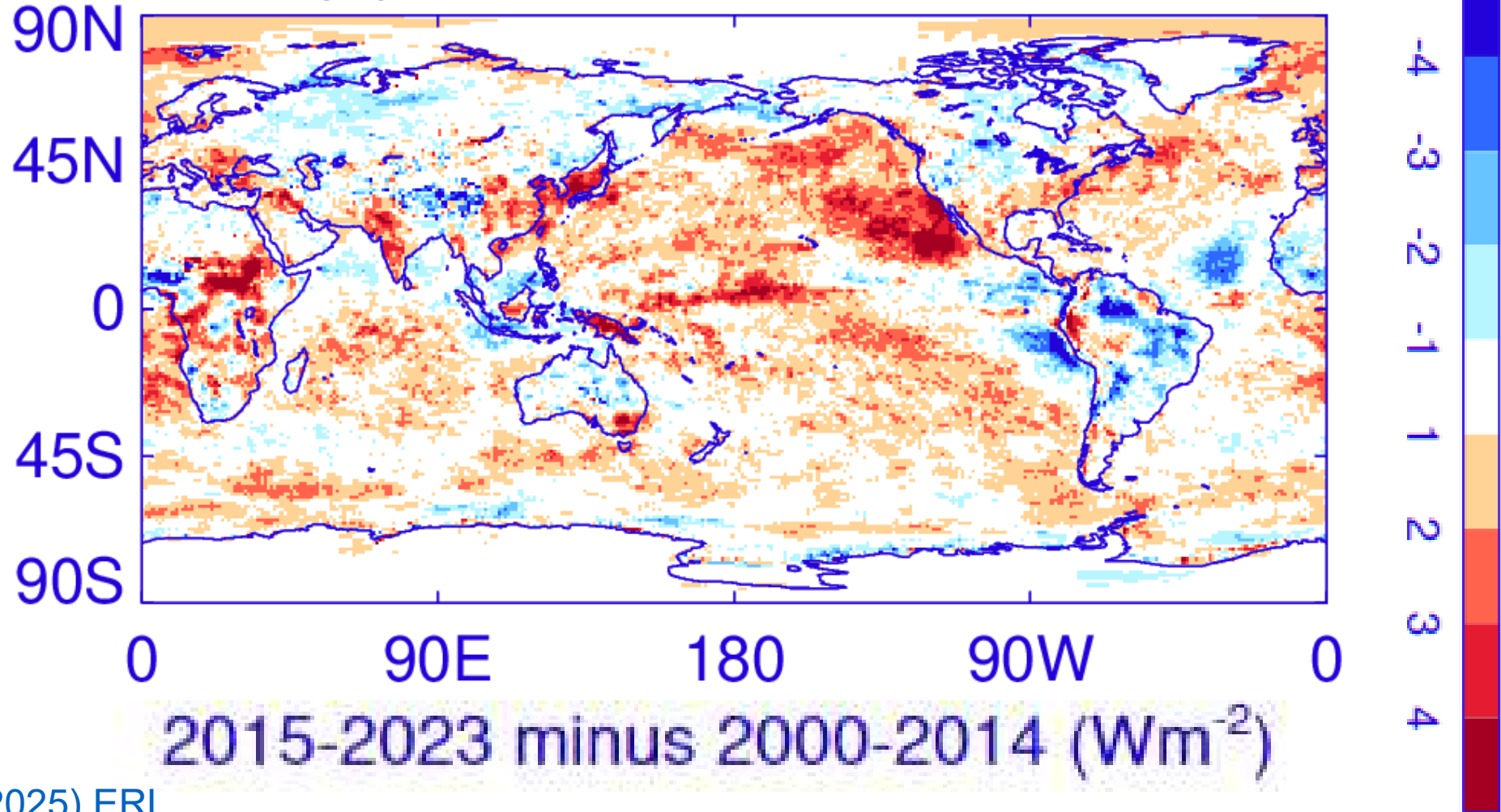
(b) dNET, ERA5



[Allan & Merchant \(2025\) ERL](#)

Spatial pattern of imbalance

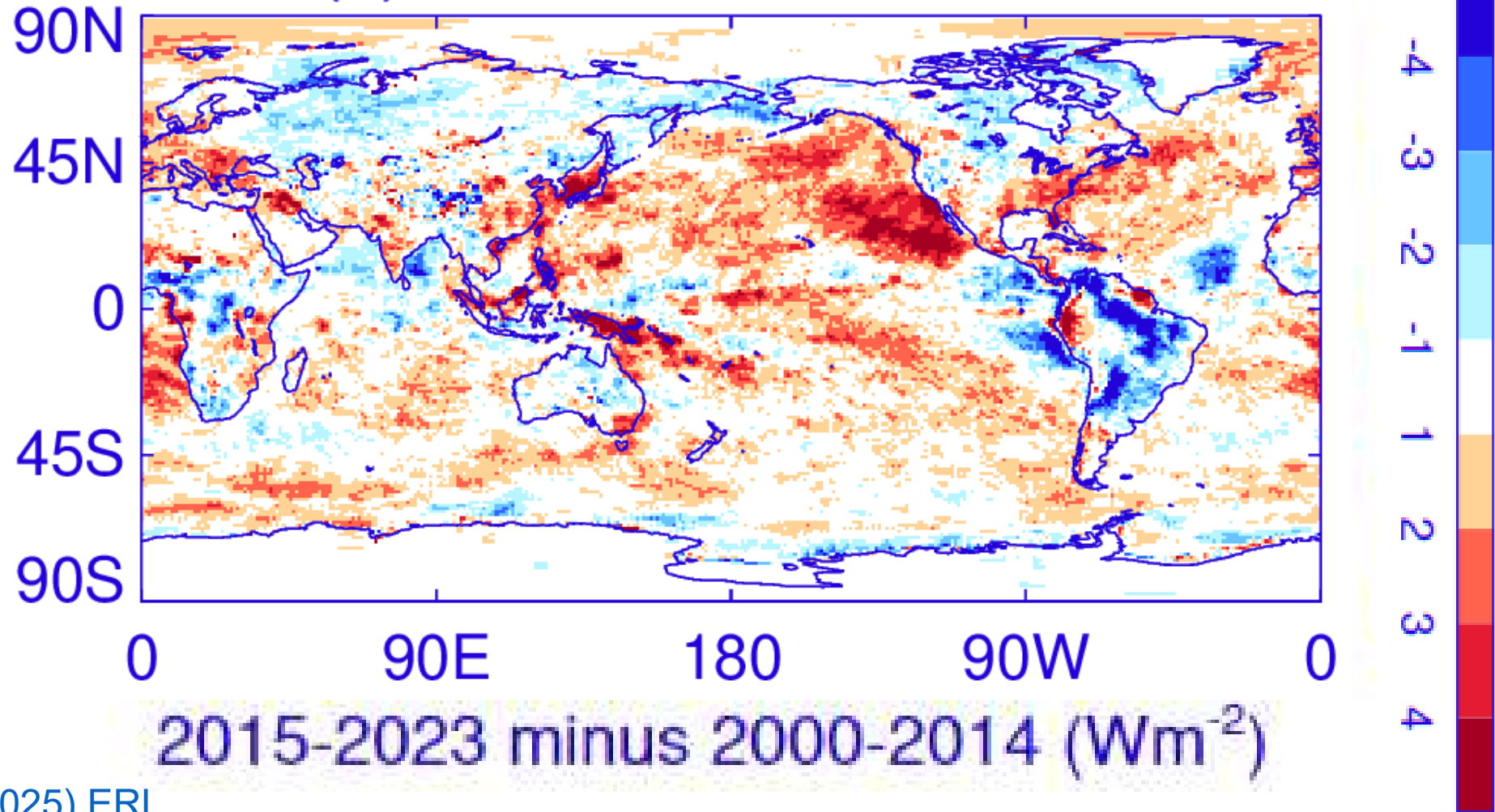
(b) dNET, CERES-ERA5



[Allan & Merchant \(2025\) ERL](#)

Spatial pattern of imbalance

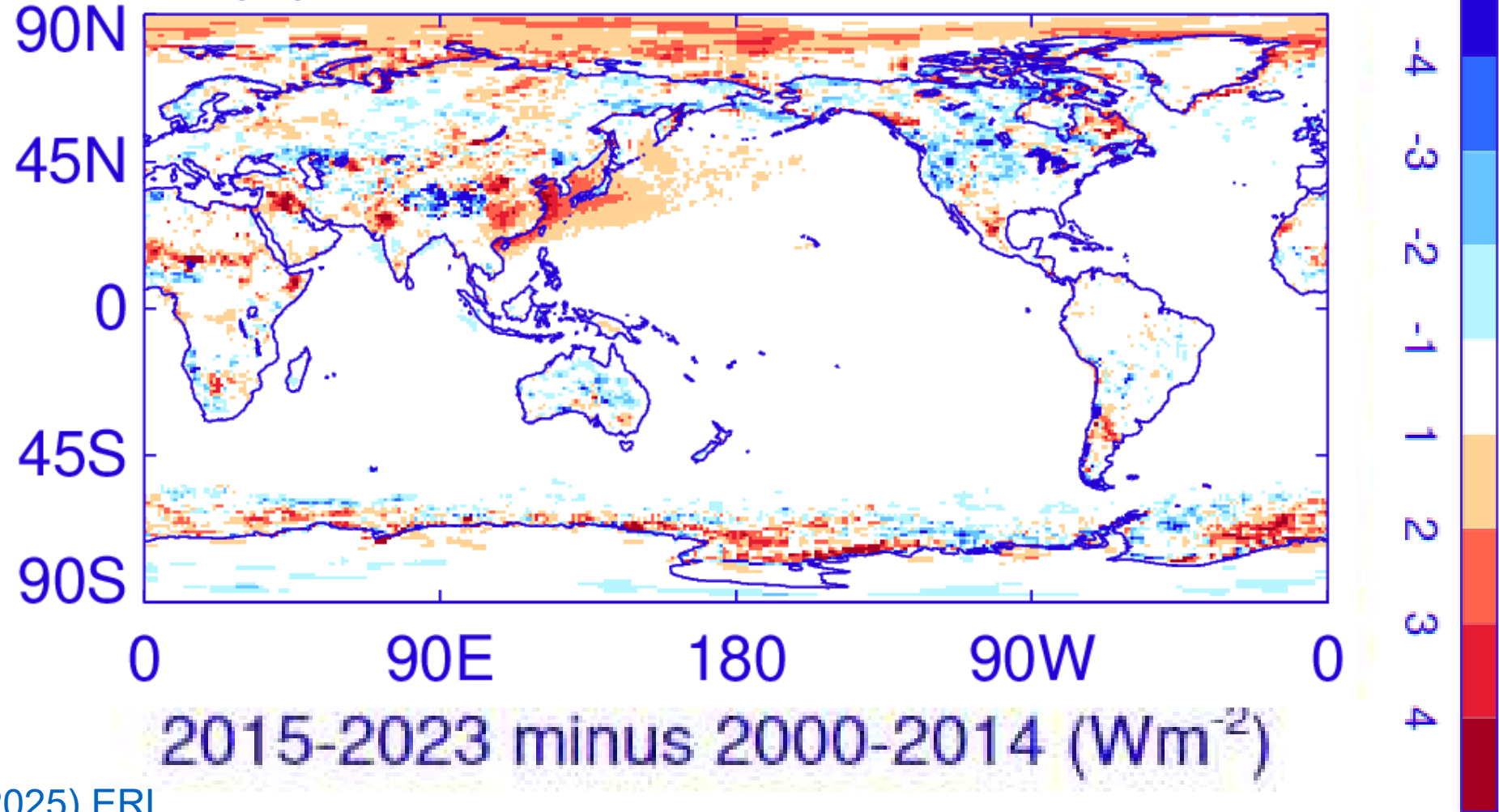
(c) dASR CERES-ERA5



[Allan & Merchant \(2025\) ERL](#)

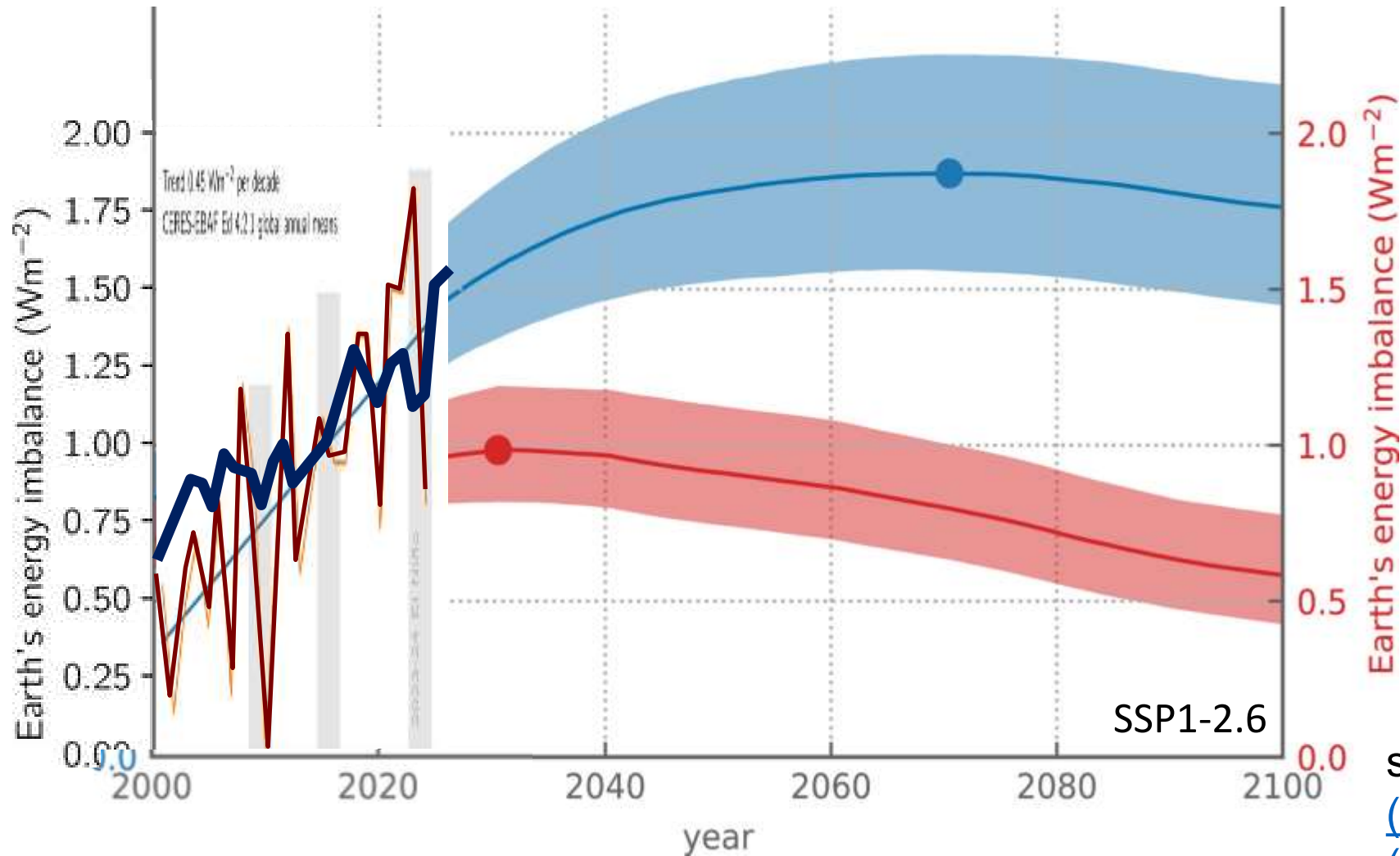
Spatial pattern of imbalance

(d) dASR clear CERES-ERA5



[Allan & Merchant \(2025\) ERL](#)

Looking forward...



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AGU Advances

Commentary Open Access

Earth's Energy Imbalance More Than Doubled in Recent Decades

Thorsten Mauritsen , Yoko Tsushima, Benoît Meysignac, Norman G. Loeb, Maria Hakuba, Peter Pilewski, Jason Cole, Kentaro Suzuki, Thomas P. Ackerman, Richard P. Allan, ... [See all authors](#)

First published: 10 May 2025 | <https://doi.org/10.1029/2024AV001636>

see also: [Allan & Merchant \(2025\) ERL](#); [Merchant et al. \(2025\) ERL](#)

Conclusions



- Earth's energy imbalance is growing $\sim 0.5 \text{ Wm}^{-2}$ per decade = accelerating climate change
- Faster growth than models, must decrease to stabilise climate ([Mauritsen et al. 2025 AGU Adv.](#))
- Surge in warming 2022/23 partly explained by record energy imbalance of 1.9 Wm^{-2} :
 - + deep ocean heat flux reverses ([Allan & Merchant 2025 ERL](#); [Minobe et al. 2025 npj Clim. Atmos. Sci.](#))
 - consistent with triple dip La Nina to El Nino ([Raghuraman et al. \(2024\) ACP Lett.](#))
 - But shallowing of mixed layer may play a role ([England et al. \(2025\) Nature](#))
- What explains growing energy imbalance?
 - More absorbed sunlight over cloudy ocean (& over Antarctic sea-ice) [Loeb et al. \(2024\) Surv. Geophys.](#), [Goessling et al. \(2024\) Science](#), [Allan & Merchant \(2025\) ERL](#), ...
 - Forcing, feedback or internal variability? Mix of cloud feedback/warming pattern effect/reduced aerosol from East Asia & shipping regulations? ([Loeb et al. 2020 GRL](#); [Loeb et al. 2024 Surv. Geophys.](#); [Meyssignac et al. \(2023\) Nature Comm. Earth Env.](#); [Hodnebrog et al. 2024 Comm. Earth Env.](#); [Samset et al. 2025 Comm. Earth Env.](#); [Tselioudis et al. 2025 GRL](#); [Hansen et al. 2025 Environment: SPSPD...](#))
 - Opposite changes over land - could this relate to continental drying? ([Simpson et al. 2023 PNAS](#); [Rodell et al. 2024 Surv. Geophys.](#))

DECLINING TERRESTRIAL WATER STORAGE

(GRACE/GRACE-FO & COMBINED MODEL/OBS DATA)

[Rodell et al. 2024 Surv. Geophys.](#)

