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EARTH'S ENERGY BUDGET CHANGES OVER RECENT DECADES

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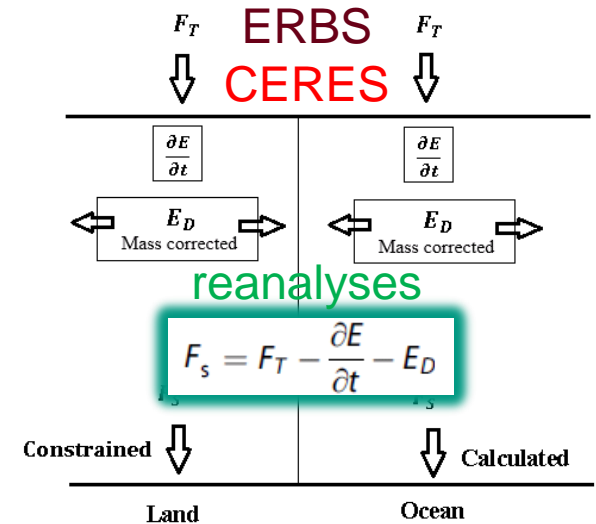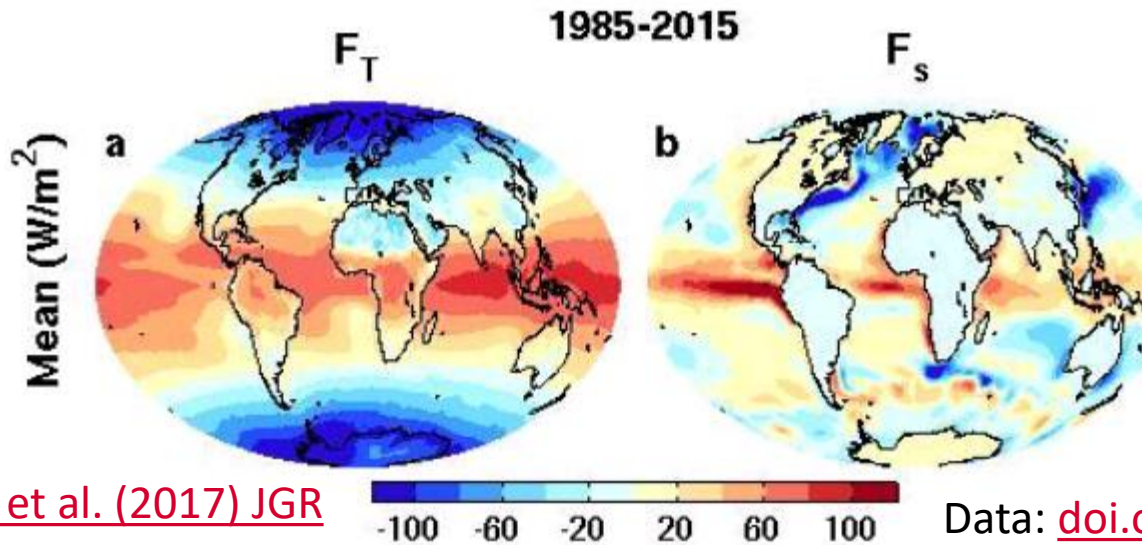LIMITLESS POTENTIAL | LIMITLESS OPPORTUNITIES | LIMITLESS IMPACT

EARTH'S ENERGY BUDGET SINCE 1985

top of atmosphere   surface

$$F_S = F_T - \frac{\partial E}{\partial t} - \nabla \cdot \frac{1}{g} \int_0^{P_s} \left[(1 - q_g) C_a (T - T_o) \right.$$

$$\left. + L_v(T) q_g + \varphi + k \right] v \, dp$$

ERBS

CERES

reanalyses

$$F_s = F_T - \frac{\partial E}{\partial t} - E_D$$

1985-2015

Liu et al. (2017) JGR

Data: doi.org/10.17864/1947.111

- Modelling to combine ERBS/CERES records & estimate uncertainty: Allan et al. (2014) GRL
- Compute surface fluxes using modified energy budget approach: Liu et al. (2020) Clim. Dyn.
- Evaluation of models, reanalyses, satellite products e.g. Williams et al. (2018) *JAMES*; Wittenberg et al. (2018) *JAMES* ; Roberts et al. (2018) *GMD*; Sus et al. (2018) *AMT*, etc
- Southern Ocean cloud biases: Hyder et al. (2018) *Nature Comms*
- Volcanic radiative responses: Schmidt et al. (2018) JGR
- North Atlantic Heat transports: Brydon et al. (2020) J. Clim
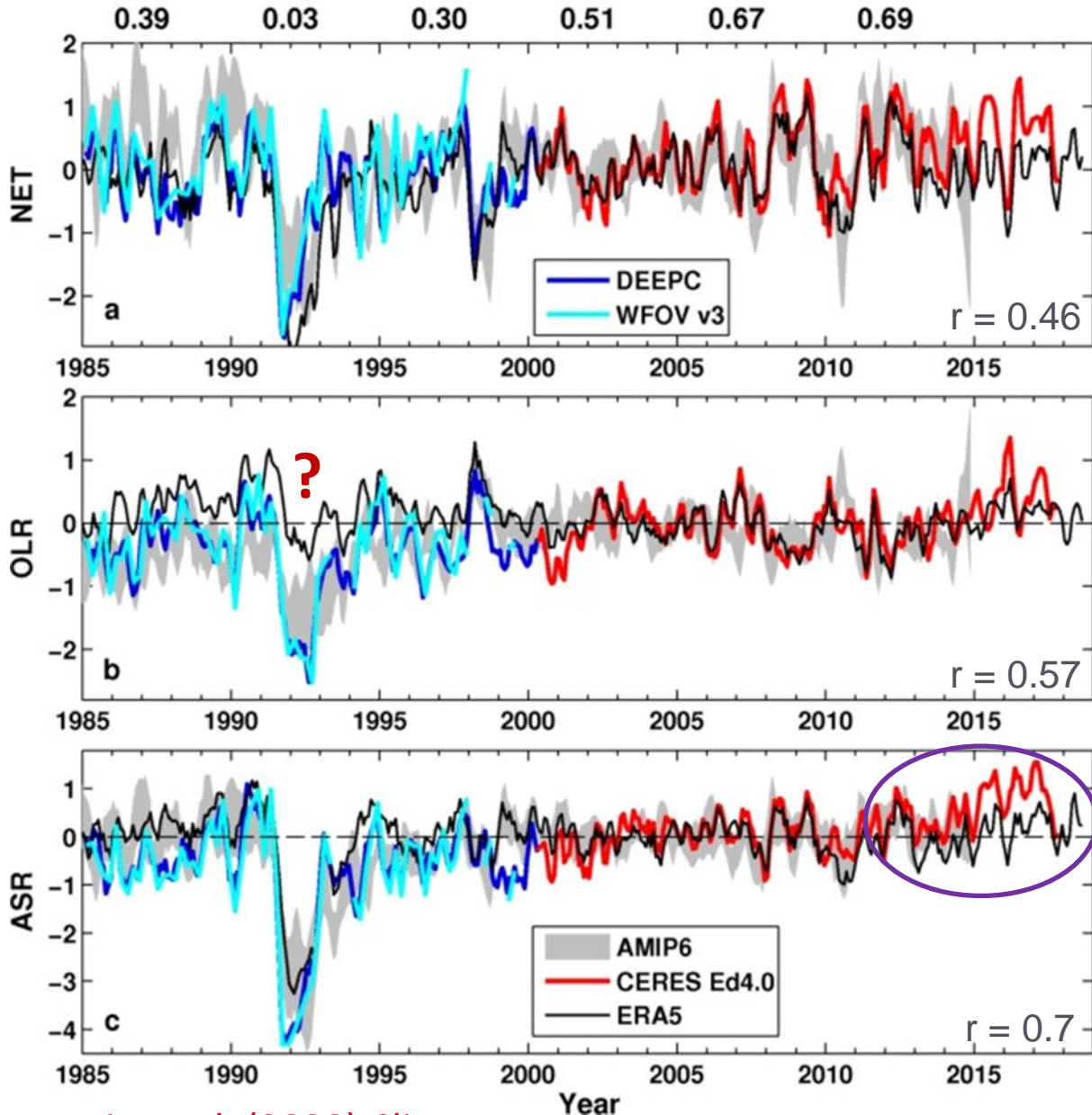- Aerosol effects on energy budget: Schwarz et al. (2020) Nature Geosci.

PLANETARY HEATING SINCE THE 1980S FROM MULTIPLE INDEPENDENT DATASETS
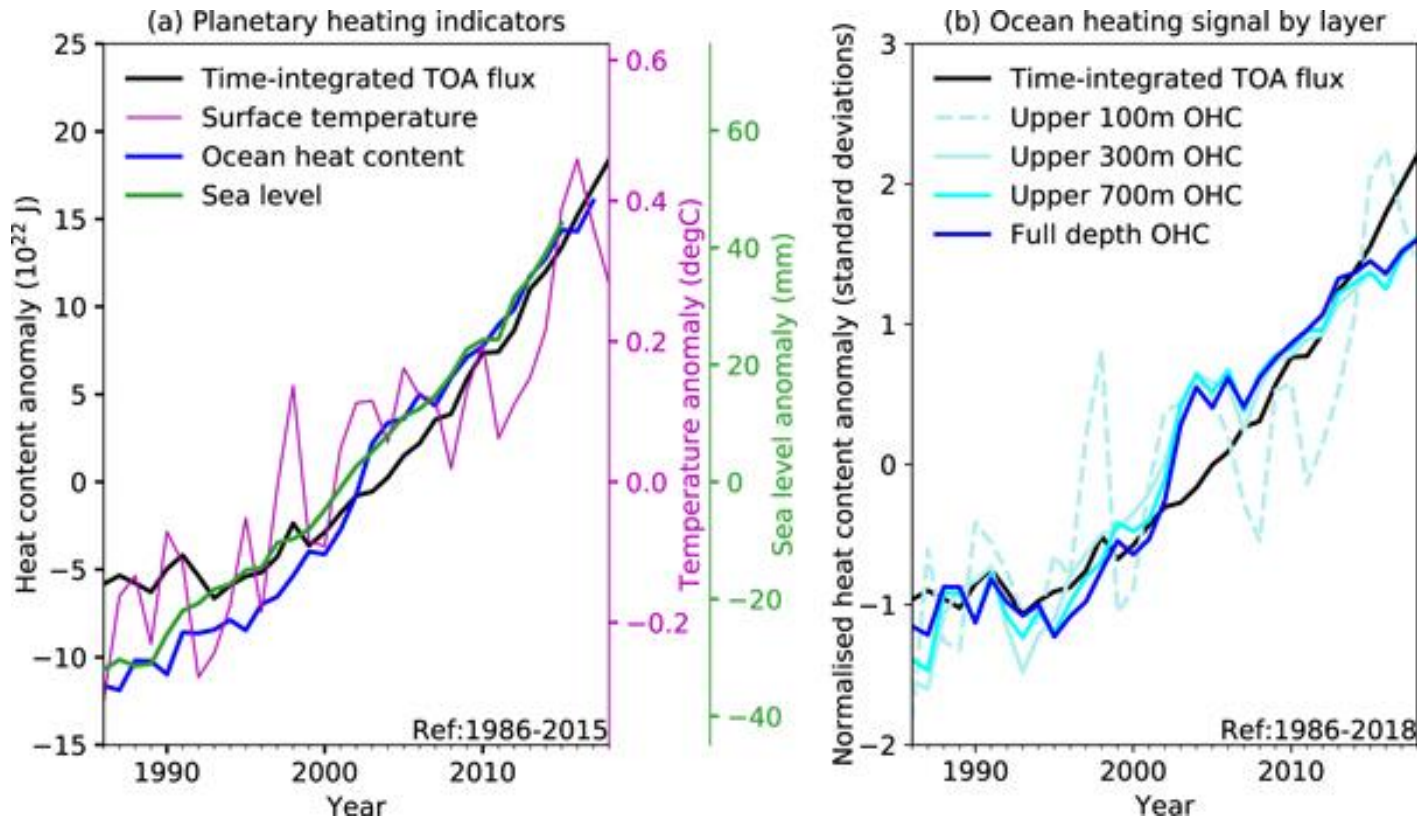
Allison et al. (2020) ERC doi:10.1088/2515-7620/abbb39

See also Cheng et al. 2017 Sci. Adv.

CURRENT ENERGY BUDGET CHANGES

Liu et al. (2020) Clim. Dyn.

- Preliminary comparison with AMIP6 and ERA5

- Large uncertainty in pre-CERES EEI remains

- Pinatubo radiative effect Schmidt et al. (2018) JGR

- Consistent with ocean heat content changes (Cheng et al. 2017 Sci. Adv.), lower than Resplandy et al. (2019) Sci. Rep. which now has 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?

CLOUD FEEDBACKS

CERES EBAF v4.1   ΔNet   CMIP6 model ensemble

Net

SW

r=0.45
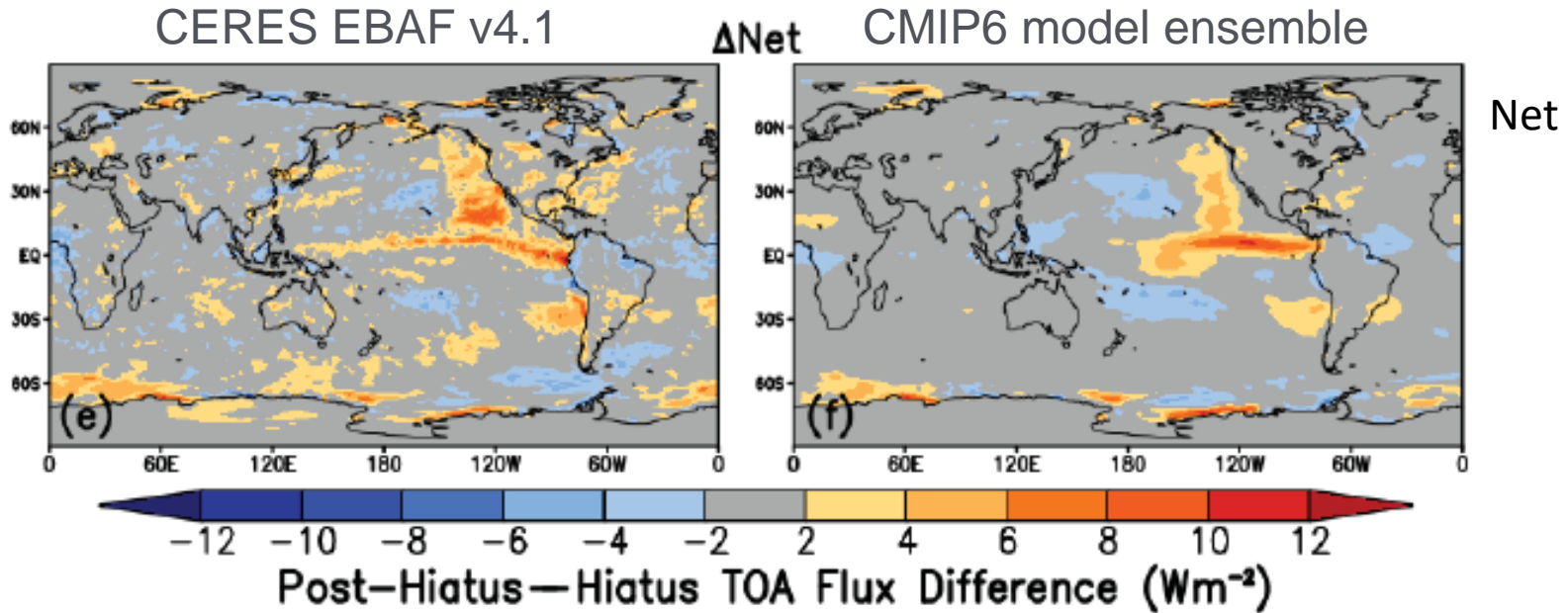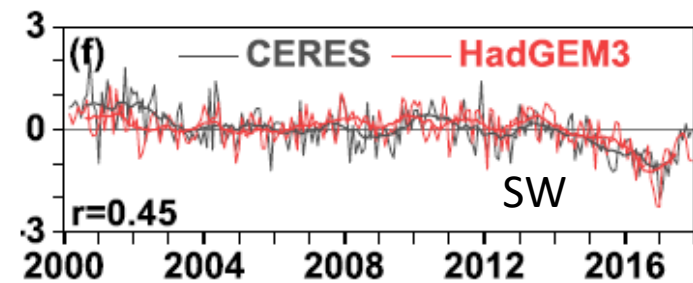
July 2014–June 2017 minus July 2000–June 2014

Post–Hiatus—Hiatus TOA Flux Difference (Wm⁻²)

- Use 2015/16 El Nino as laboratory to test cloud feedbacks (Loeb et al. 2020 GRL)
  - CMIP6 AMIP simulations generally able to capture net flux responses
  - Depends on model ability to represent SW radiation changes in low cloud regions
- Cloud errors and wind-feedbacks also determine systematic model biases in Southern Ocean (Hyder et al. 2018 Nature Comms) and globally (Hyder et al. in prep)

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HEMISPHERIC ASYMMETRY IN EARTH'S ENERGY BUDGET

- Mean position of the tropical rainy belt in northern hemisphere determined by northward energy transport by ocean e.g. Frierson et al. (2013) Nature Geosci
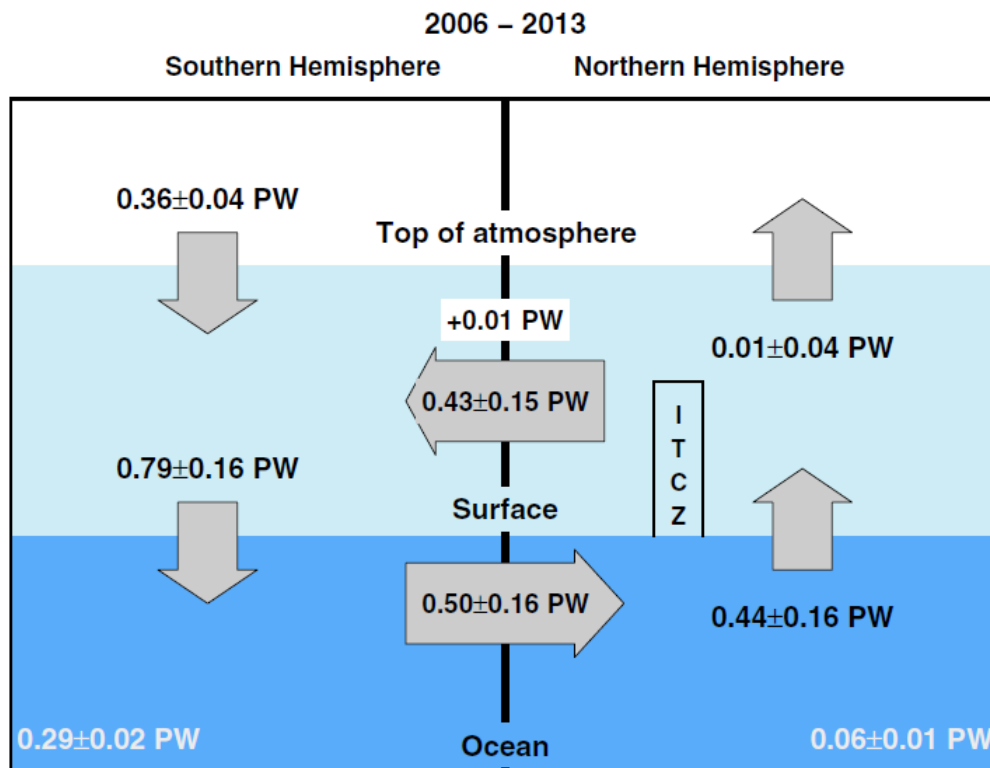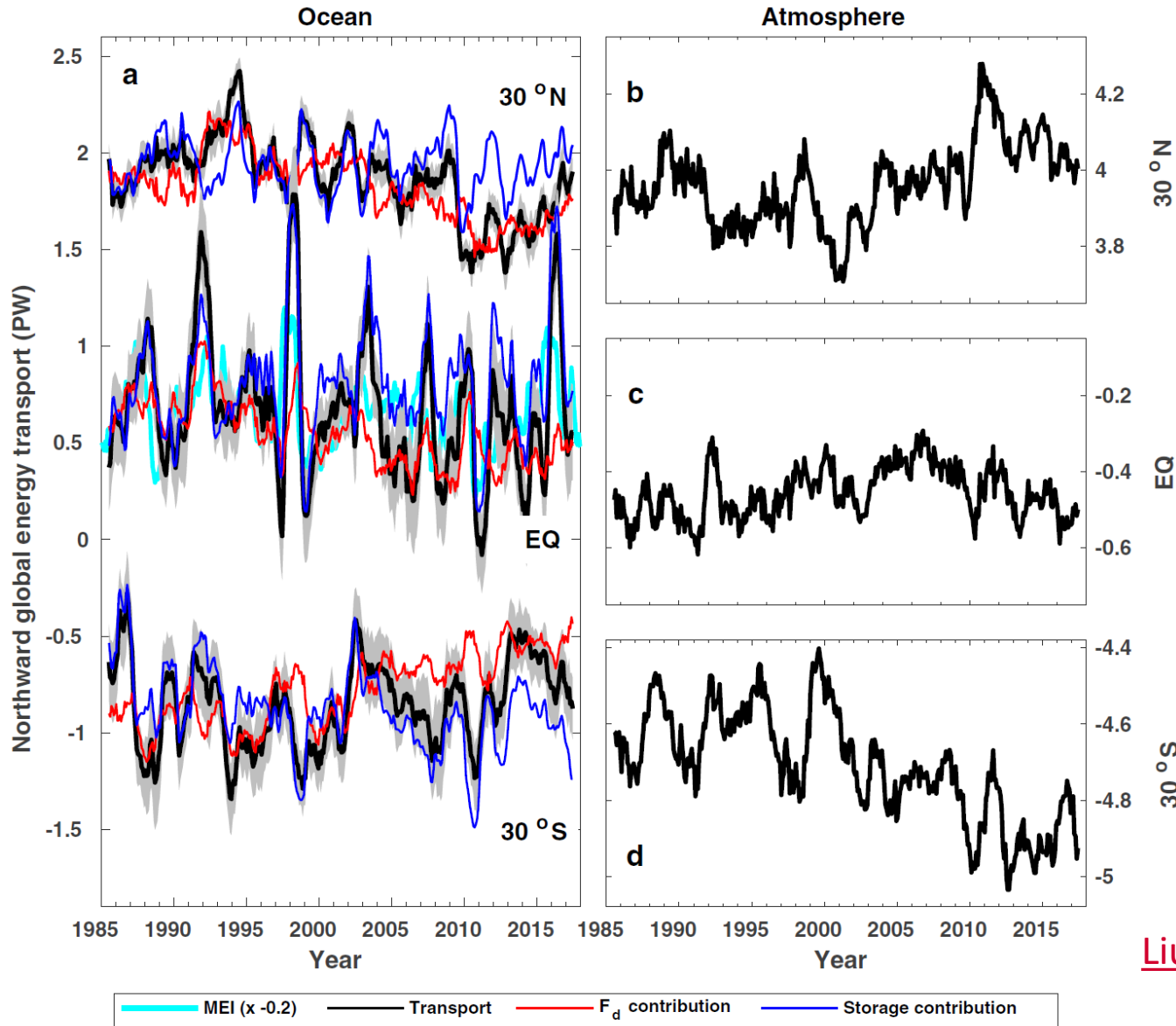

Liu et al. (2020) Clim. Dyn.

Important to quantify hemispheric energy budget:

← Inferred 2006-2013 cross equatorial energy flux (updated from Liu et al. 2017 & Loeb et al. (2015) Clim. Dyn using ocean heating from Roemmich et al. (2015) Nature Clim, Desbruyeres et al. (2016) GRL or ORAS4 reanalysis)

Remember days per month and enthalpy transfers!!
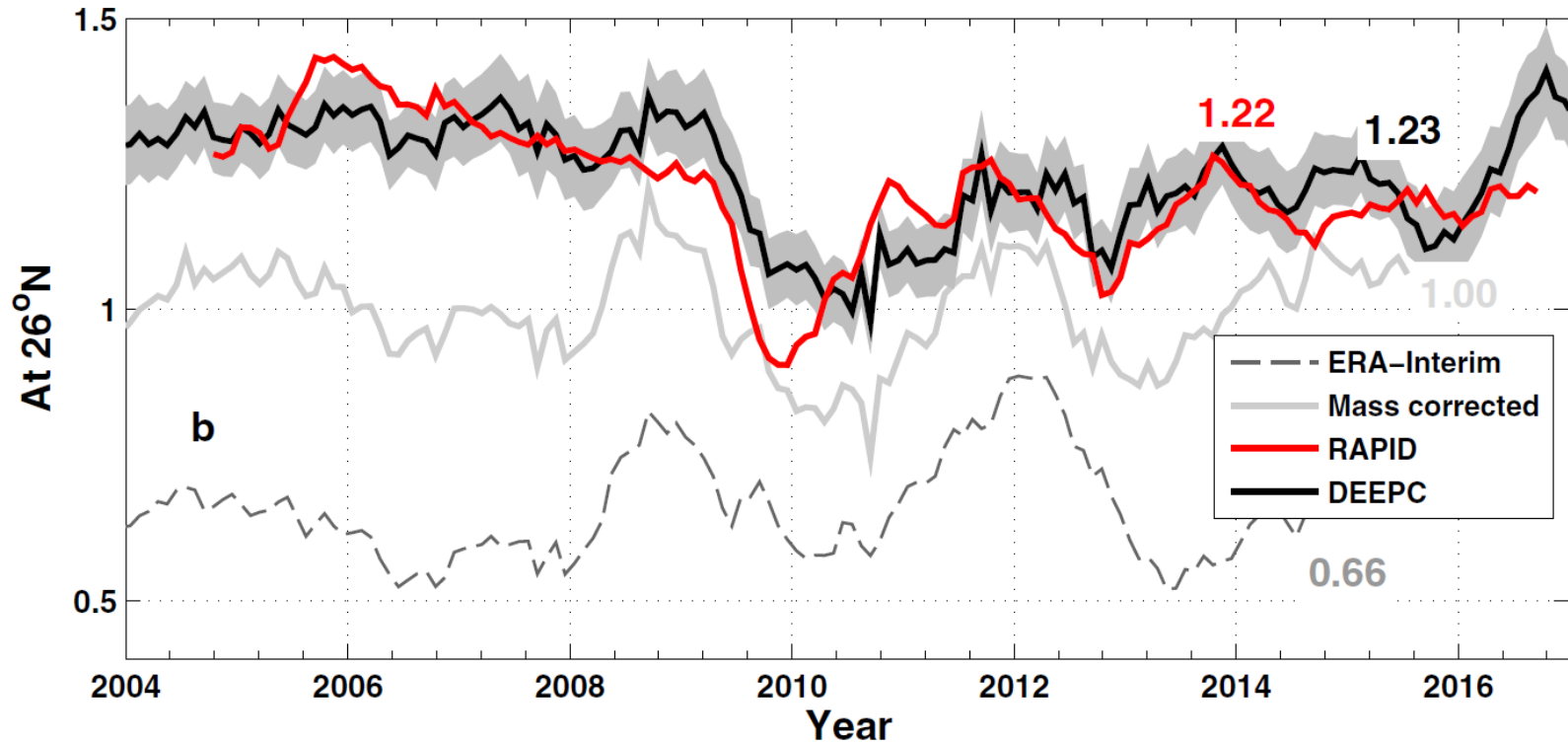
INFERRED MERIDIONAL ENERGY TRANSPORTS

How is atmosphere and ocean circulation responding to energy imbalances?

Increased poleward heat transport by the atmosphere inferred from CERES period?

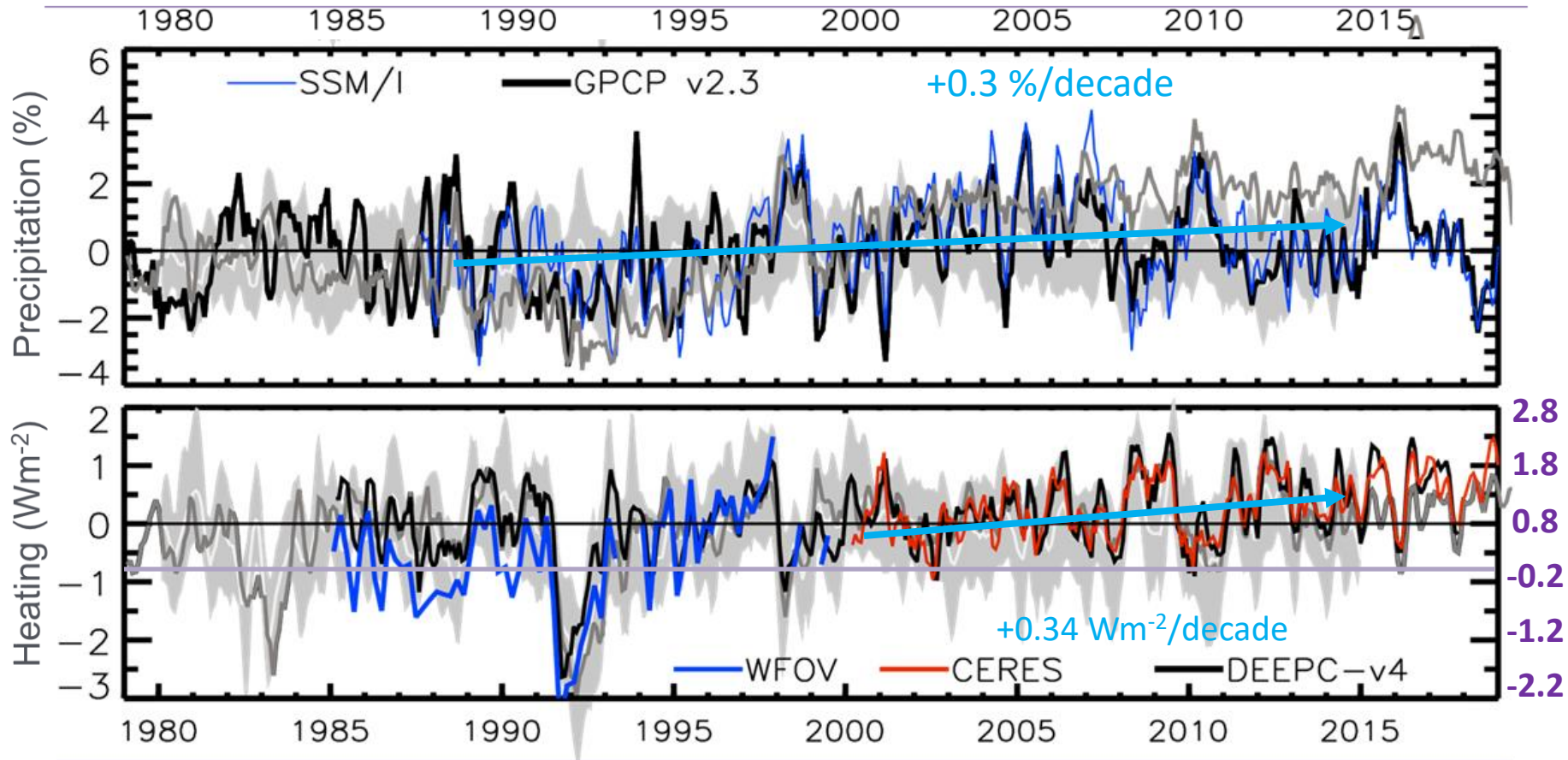Liu et al. (2020) Clim. Dyn.

INFERRED OCEAN ENERGY TRANSPORTS@26N

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Liu et al. (2020) Clim. Dyn.
After Trenberth & Fasullo, 2017 GRL

HOW IS EARTH'S ENERGY BUDGET DRIVING WATER CYCLE CHANGES?

Allan et al. (2014) Surv. Geophys.; Allan et al. (2014) GRL; Allan et al. (2020) NYAS

SUMMARY

- How is Earth's energy budget driving and responding to climate change?

- Multi-decadal estimates of Earth's energy imbalance/sea level *broadly* consistent: Cheng et al. 2017 Sci. Adv.; Nerem et al. 2018 PNAS; Allison et al. 2020 ERL

- What is accuracy of trends in Earth's energy imbalance? *"ensure orbital ERB measurements track true climate, rather than instrument changes"* (e.g. using the moon) Matthews (2018) JAMC

- Where is energy accumulating in the oceans and what are the mechanisms? Are models capturing Earth's energy imbalance and the mechanisms of heat accumulation?

- What are the mechanisms that determine N Atlantic variability and links with Pacific and ocean heat uptake? How are inter-hemispheric, land/ocean and low to high latitude heat transports changing? e. g. Trenberth & Fasullo, 2017 GRL; Liu et al. 2020 Clim. Dyn

- Can models represent water vapour and cloud feedbacks and their change over time? Do climate models underestimate low cloud amplifying feedbacks, internal variability & climate sensitivity? Marvel et al. 2018; Silvers et al. 2017 ; Yuan et al. 2018 ; Loeb et al. 2020 GRL and response to spatial patterns of warming e.g. He & Soden (2016); Richardson et al. (2016); Ceppi & Gregory (2017); Andrews & Webb (2017)

- Observational insight on fast/slow coupling between the energy and water cycles? Joint energy/water cycle approaches e.g. Rodell et al. 2015 J.Clim; Thomas et al. 2019 J. Clim