Ocean Energy Imbalance in ECCO Estimates and its relation to CERES

CERES science team meeting,
NASA Langley, Hampton, VA

Gaël FORGET, 2026/10/28

Part 1 : ECCO, Argo, and CERES

- Trends and Interannual Variability since 2004

Slides provided by Ian Fenty, Andrew Delman, Ou Wang, Ichiro Fukumori

from Jet Propulsion Laboratory / CalTech

Estimating the Circulation and Climate of the Ocean (ECCO)

Main Activities

1. **Global ocean state estimates**

   complete, physically-consistent observation-constrained reconstructions of the full-depth, time-evolving global ocean & sea-ice physics and thermodynamics + ocean biogeochemistry

   - horizontal scales: ~10 km … 100 km
   - temporal scales: years … decades

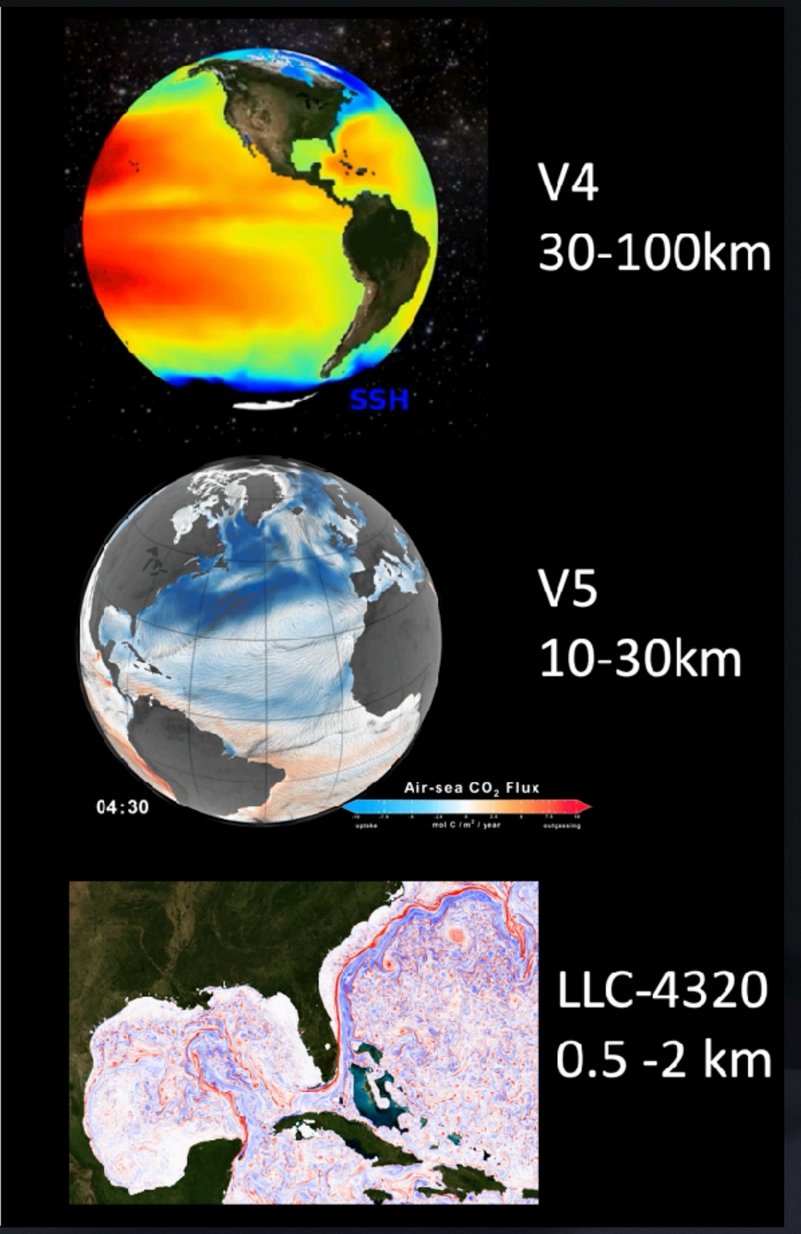
2. **High-resolution simulations:**

   global and regional ocean-only and coupled ocean/sea-ice/atmosphere/biogeochemistry models

   - model horizontal scales: 0.5 km … 10 km
   - temporal scales: hours … years

Climate variability

Process studies



Forget et al 2015: ECCO version 4: an integrated framework for non-linear inverse modeling and global ocean state estimation, Geosci. Model Dev., https://doi.org/10.5194/gmd-8-3071-2015

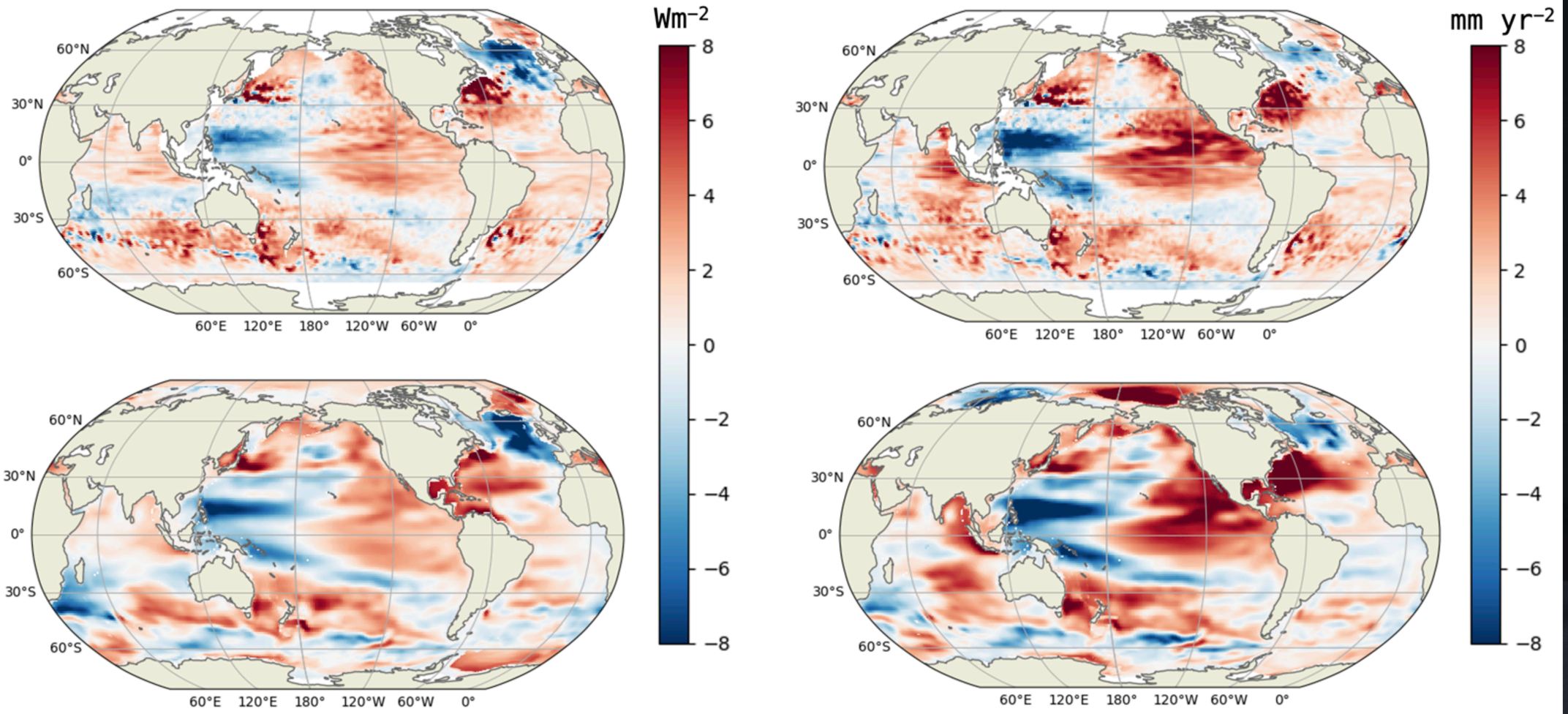
ECCO heat and steric height trends are consistent with Argo [0-2000 m]

Ocean Heat Trend (Wm^{-2})

Steric height trend ($mm\ yr^{-2}$)

Argo

ECCO

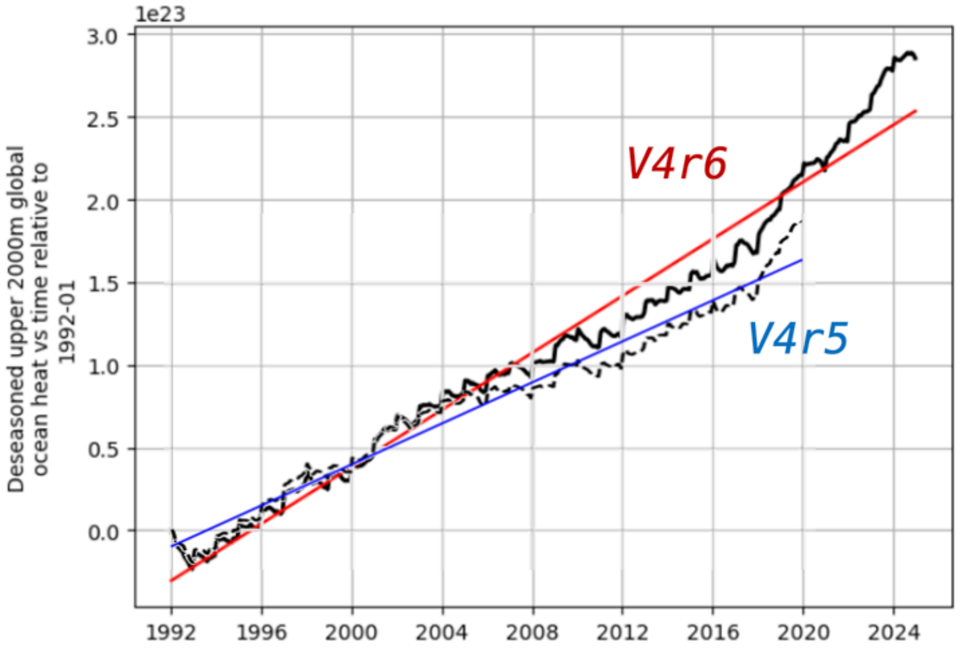


Courtesy Andrew Delman

https://ecco-group.org/

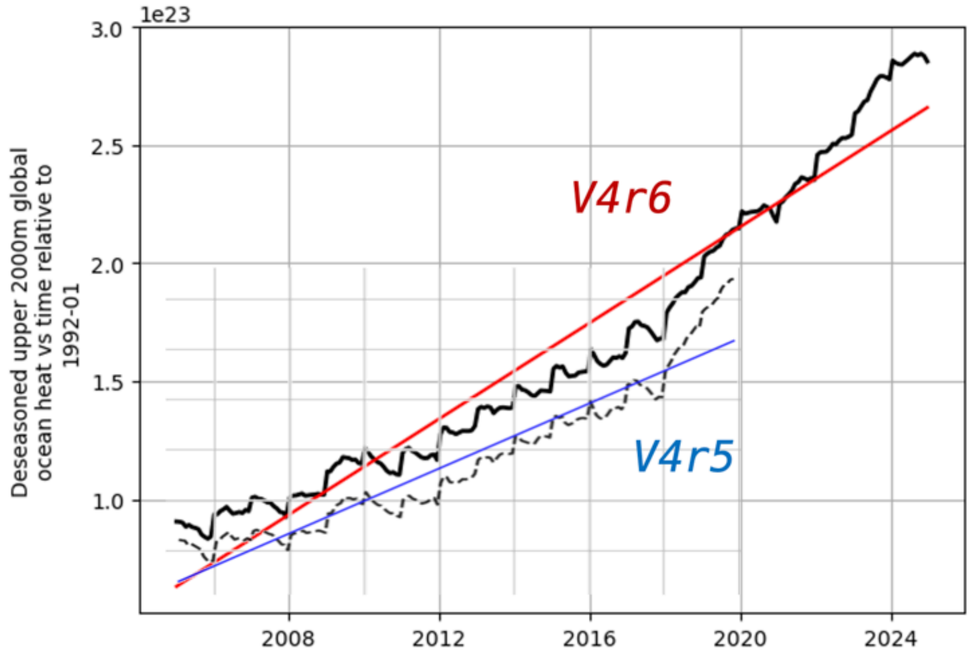
ECCO V4r6 vs V4r5 Global Ocean Heat Content (Joules) [0-2000m]

Full period (1992–2026)



– V4r6 0.78 Wm^{-2}
-- V4r5 0.55 Wm^{-2}

Argo period (2005–2026)

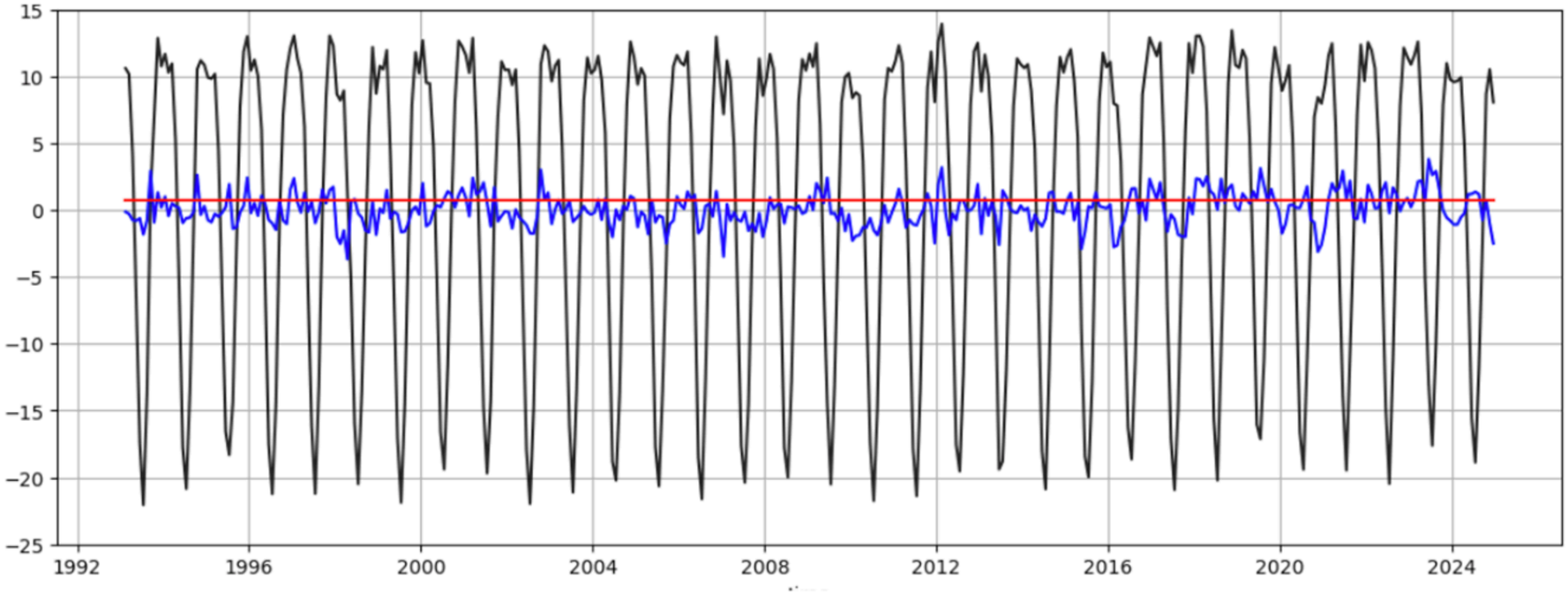


– V4r6 0.94 Wm^{-2}
-- V4r5 0.57 Wm^{-2}

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V4r6 & V4r5

ECCO Monthly-Mean Global Net Ocean Heat Flux 1992-2026



Amplitude of global mean heat flux seasonal cycle: ~ 30 Wm^{-2}

Amplitude of global mean heat flux anomaly w.r.t. seasonal cycle: *~ 2 Wm^{-2}*

Time and global mean net heat flux: *~0.80 Wm^{-2}*

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V4r6

ECCO V4r6 vs EBAF TOA 4.2.1 Net Heat Flux Anomalies (Wm^{-2})

Detrended anomalies w.r.t. seasonal cycle

Monthly-mean, correlation=0.50, explained variance=0.07

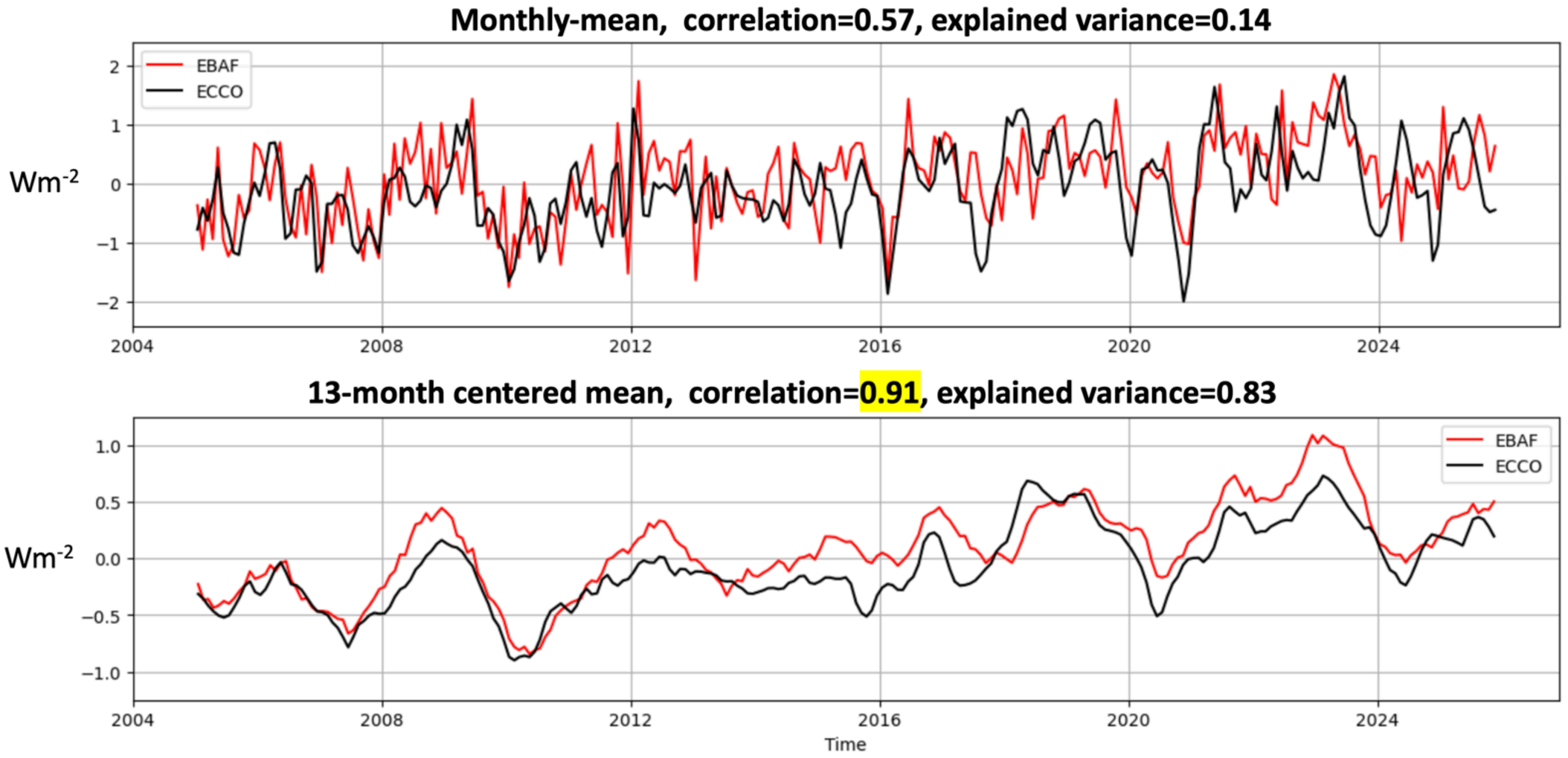


13-month centered mean, correlation=0.78, explained variance=0.61



ECCO V4r6 vs EBAF TOA 4.2.1 Net Heat Flux Anomalies (Wm^{-2})

Argo Period: Not Detrended anomalies w.r.t. seasonal cycle



Part 2 : Ocean Energy Imbalance

- Trends and Interdecadal Variability since 1980
- Sunlit Ocean Layer (0-200) heat budget

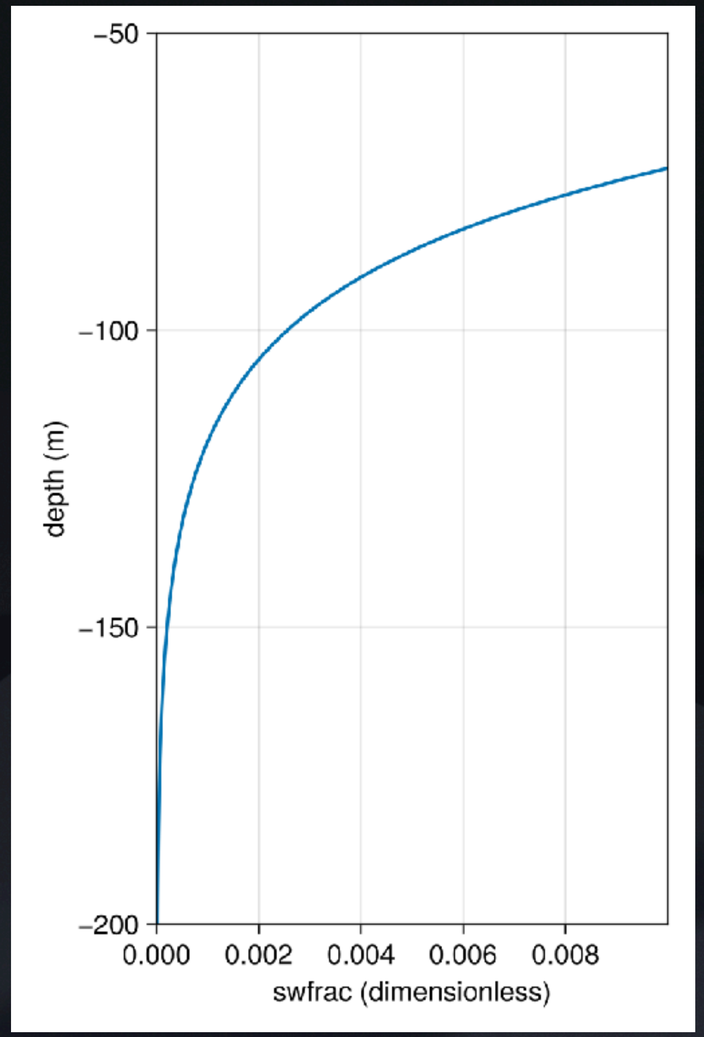
Forget (revised) : Ocean heat transport convergence shapes regional energy imbalance in the sunlit ocean layer

The Sunlit Ocean Layer (SOL) = 0-200m

Exponential decay of downward short wave radiation with depth:

- As parameterized in ECCO4 (MIT general circulation model)
- Below 200m → zero DSW radiation

in the sunlit ocean layer



OCCA2 : an extension of ECCO4

- OCCA2.2a (1980-present) :
    - Reuse ECCO4 model & optimized mixing parameters from 1992-2011
    - Switch to ERA5 forcing fields (1940-present)
    - Add climatological mean adjustment (to match ECCO4 forcing over 1992-2011)
    - Set up 1980 initial conditions, obtained during spin up phase (1960-1980)
- OCCA2.2b (1980-present) : OCCA2.2a + time mean difference to ECCO4 (over 1992-2011)
- OCCA2.2c (1980-present) : OCCA2.2b + time mean difference to Argo (over 2004-2022)
- OCCA2.2d (2004-2022) : OCCA2.2c + time variable difference to Argo (over 2004-2022)

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Global Ocean Warming

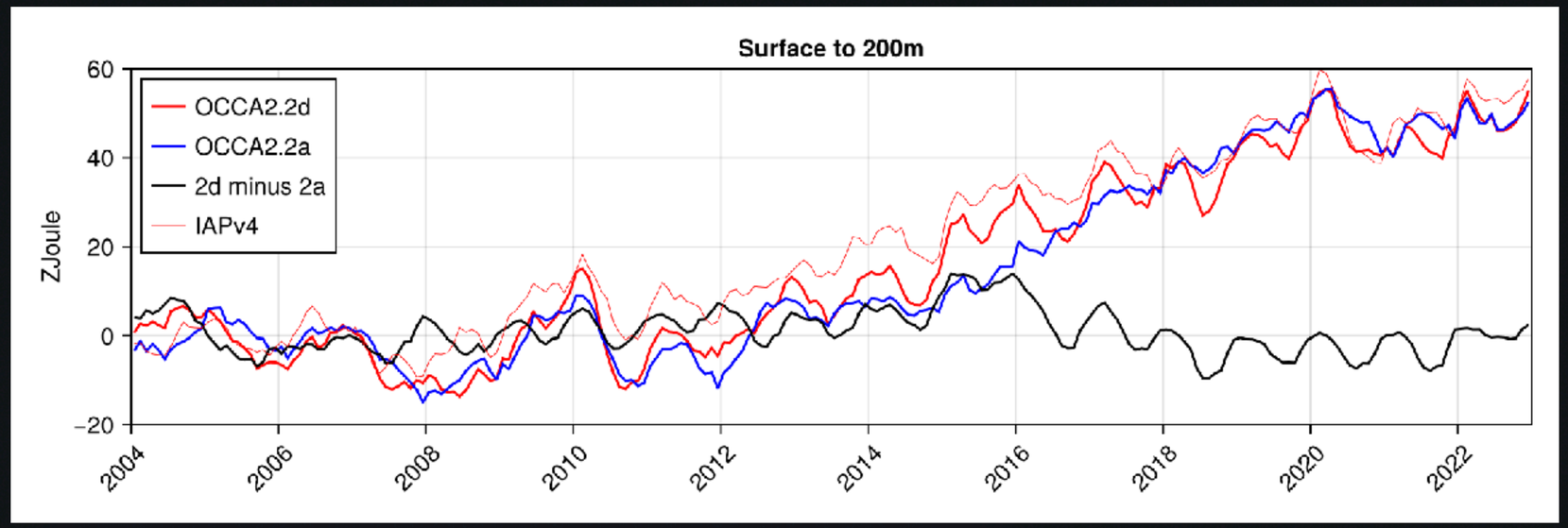
Forget (revised)

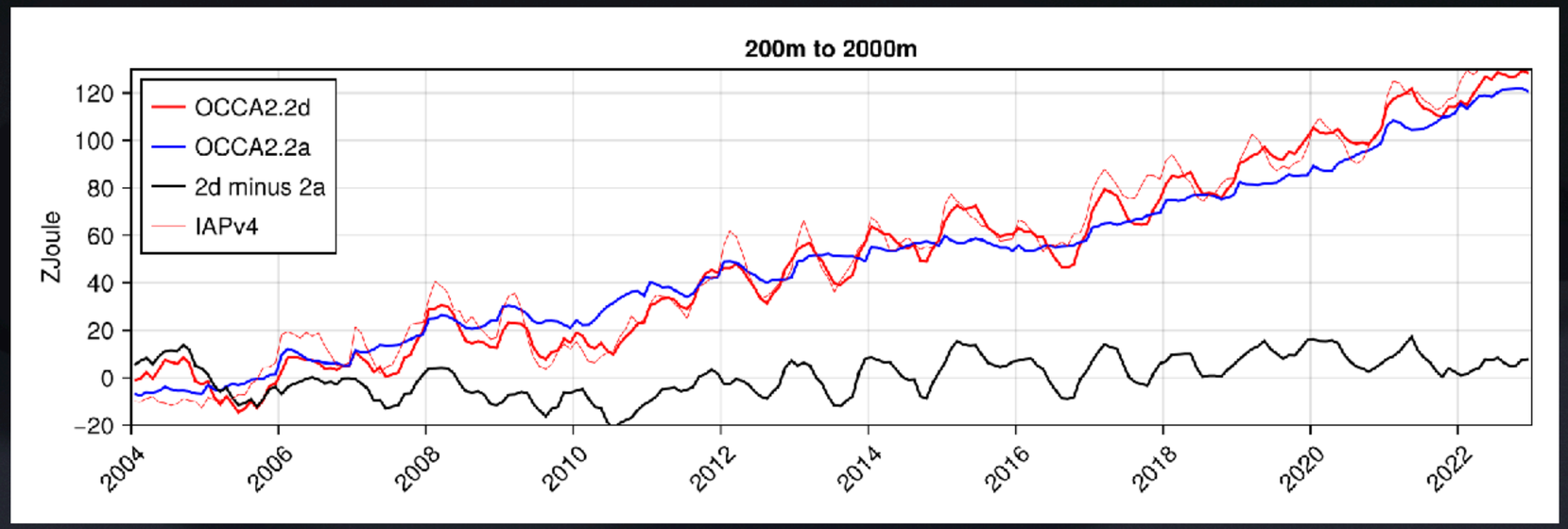
Above 200m depth

(=Sunlit Ocean Layer=SOL)

Below 200m depth

(down to 2000m)





Defining Ocean Energy Imbalance

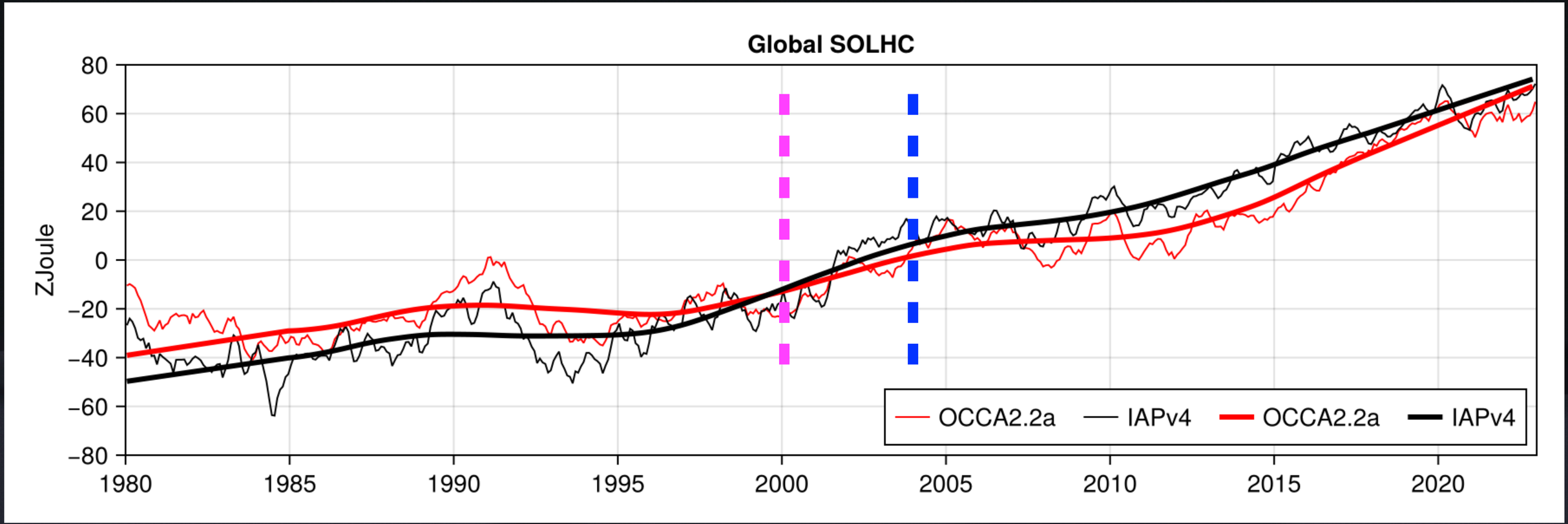
- **Monthly heat budget**
  - Left-Hand-Side : ocean heat content change rate
  - Right-Hand-Side : forcing and transport convergence
  - Integrate over time & then apply 12-month running mean
- **Ocean Energy Imbalance (as an equation)**
  - Start from monthly heat budget as before
  - Apply a ten-year running mean to each term consistently
  - Integrate over time

Forget (revised)

SOL Heat Content

Filtered and unfiltered

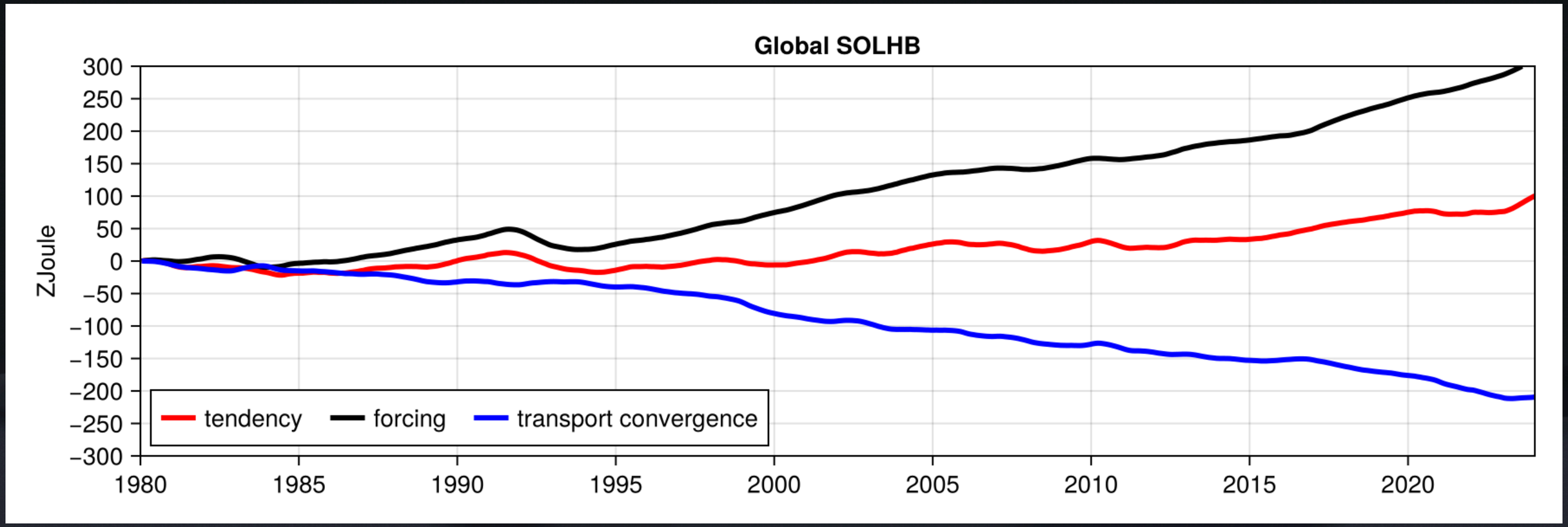
Forget (revised)



SOL Heat Budget

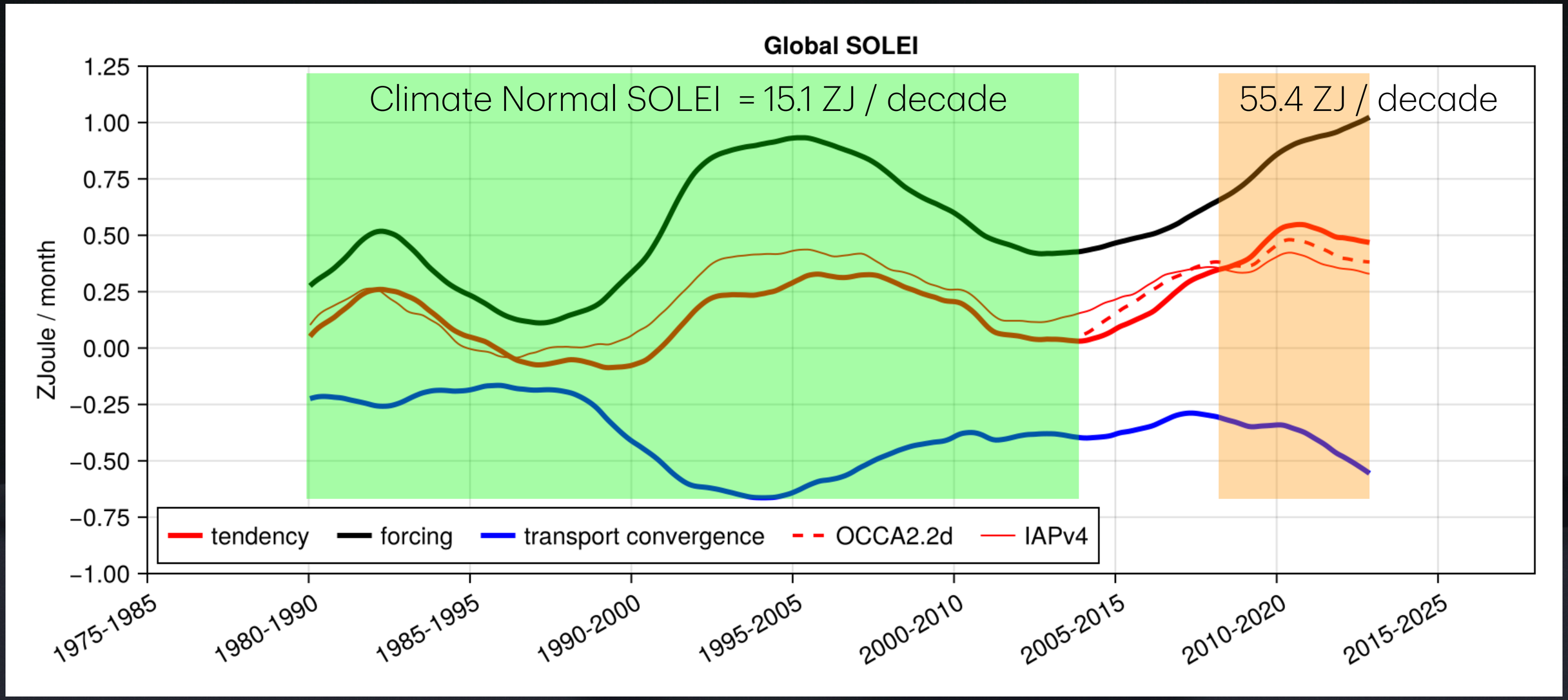
Time-integrated from 1980

Forget (revised)



SOL Energy Imbalance

Forget (revised)



Part 3: Regional SOLEI

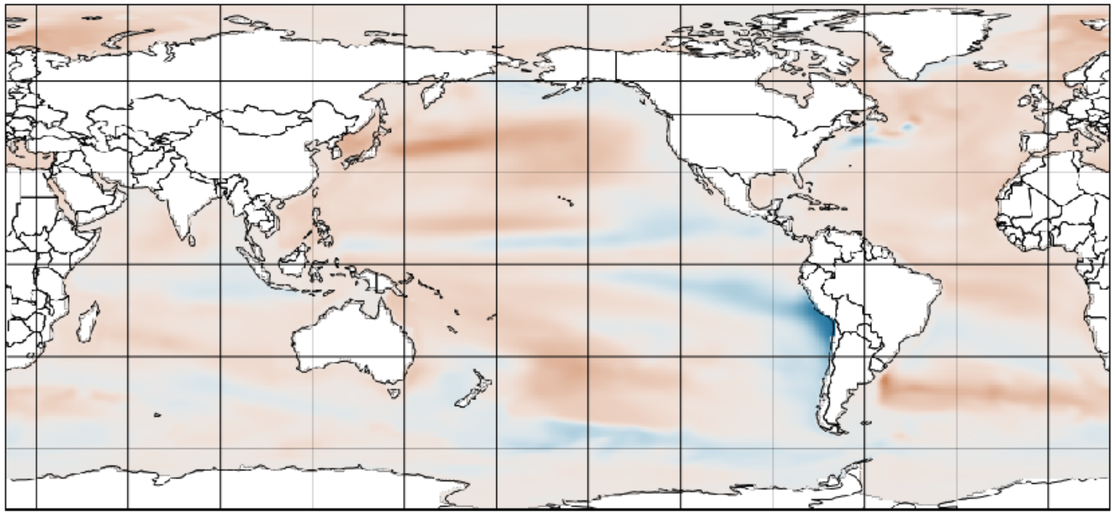
- Why is regional analysis harder?
  - Ocean heat uptake from the Atmosphere is very heterogeneous
  - Ocean heat transport term is now 3D convergence (not just vertical)
  - The climatological-mean balance is between those two large terms

➡ Need to focus on SOLEI anomaly (or relative SOLEI)

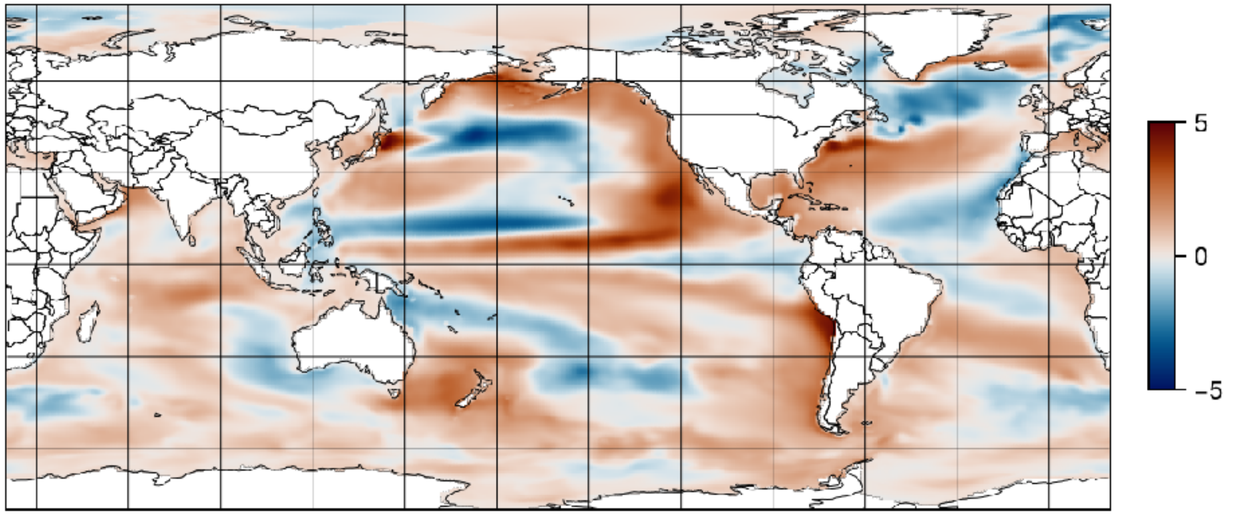
➡ Need to define a climate normal SOLEI

Relative SOLEI (storage term)

Climate Normal SOLEI (1985-2009)



Relative SOLEI (2013-2017)

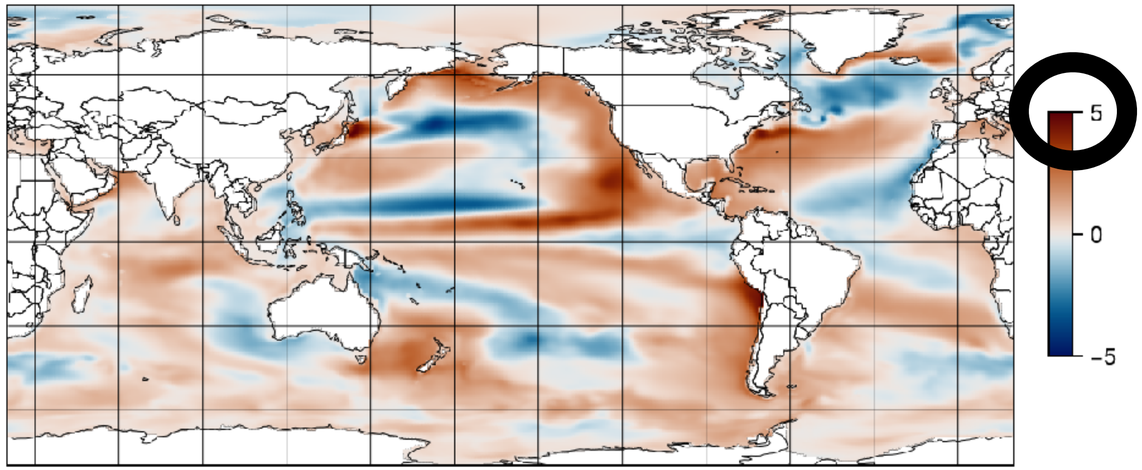


Units : W/m²

Forget (revised)

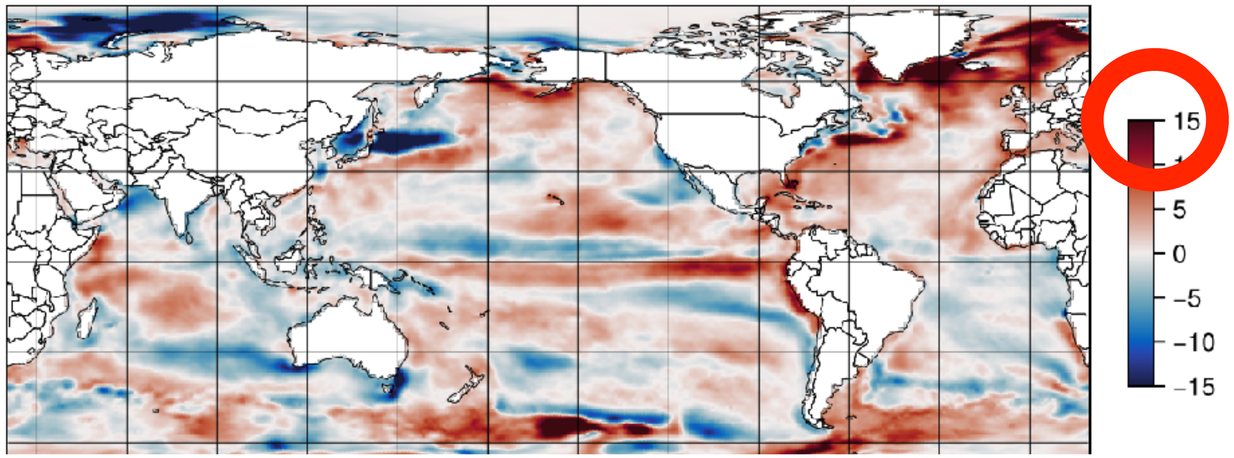
Relative SOLEI (as an equation)

Relative SOLEI (2013-2017)



+/- 5 W/m²

Surface Forcing

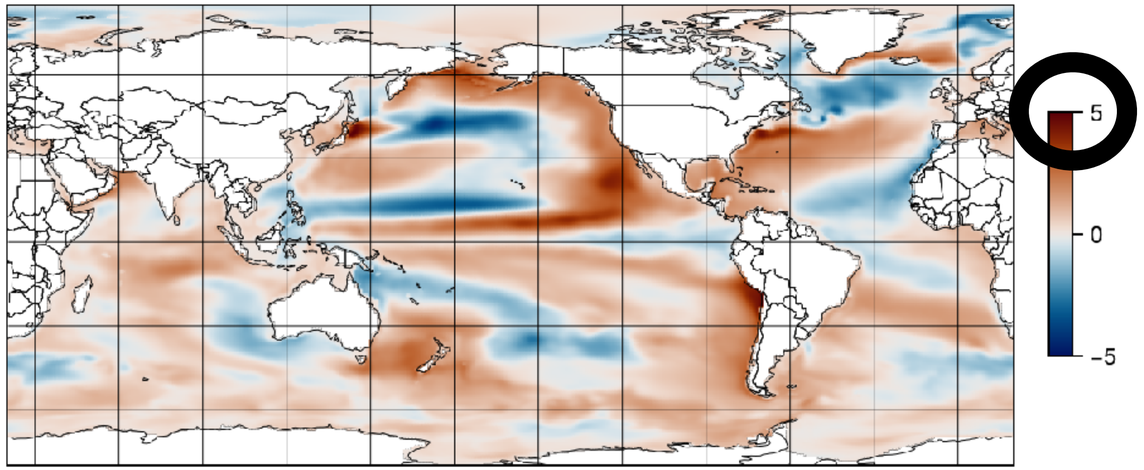


+/- 15 W/m²

Forget (revised)

Relative SOLEI (as an equation)

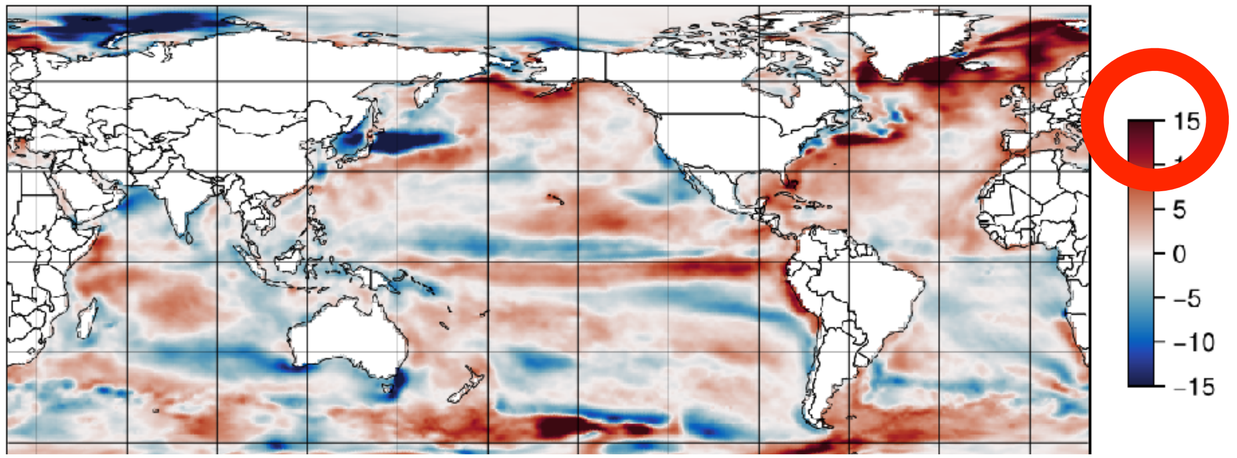
Relative SOLEI (2013-2017)



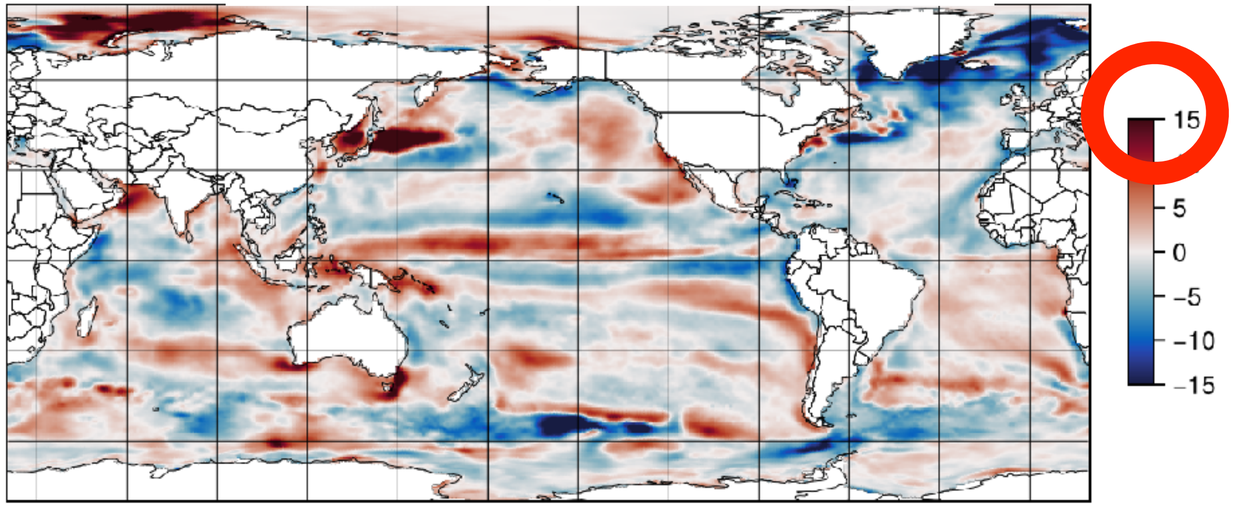
+/- 5 W/m²

Forget (revised)

Surface Forcing



Ocean Transport Convergence



+/- 15 W/m²

Summary

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  - ✓*Closed heat budget provided by ECCO estimates*

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- Global OEI and SOLEI show large interdecadal variations
- The geography of SOLEI is highly heretogenous
  - ✓*Can only be elucidated by subtracting a climate normal heat budget*
  - ✓*Regional SOL warming is NOT simply predicted by regional heat uptake*