Inferring Ocean Heat Uptake from Satellite Gravimetry and Altimetry

Andrew Delman[1], Maria Hakuba[2], Ian Fenty[2]

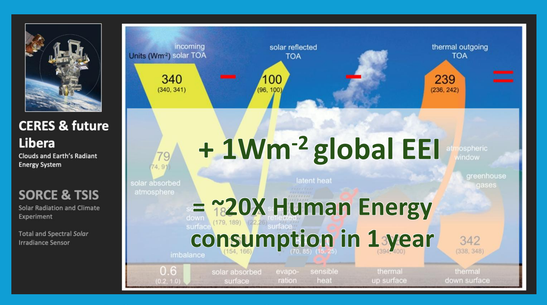
[1]University of California Los Angeles, Los Angeles, CA, USA

[2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

Questions? Feel free to contact me at andrewdelman@ucla.edu.

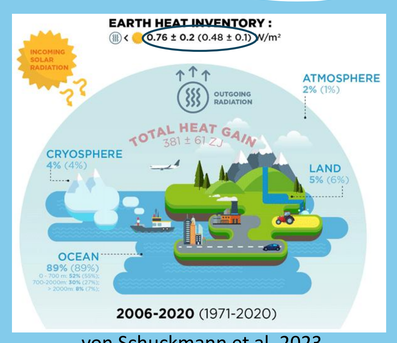
Motivation: The story of Earth's Energy Imbalance (EEI)

1



Earth's energy imbalance (EEI), observed at the top-of-the atmosphere, is highly uncertain due to radiometric inaccuracy.

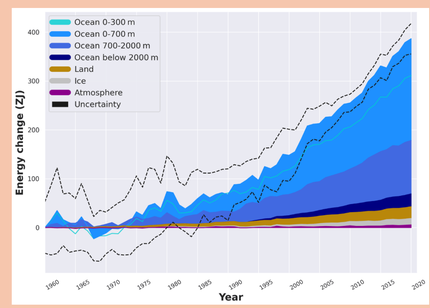
2



von Schuckmann et al. 2023

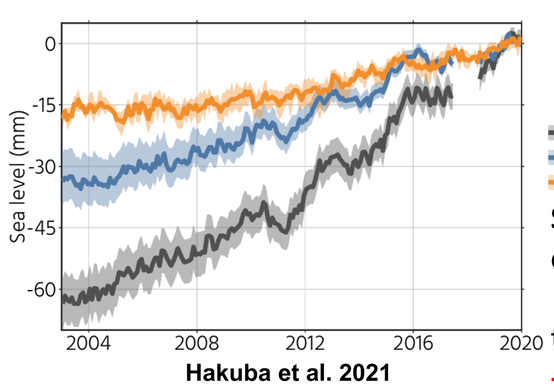
EEI can be constrained by **heat inventory analysis** (of ocean, land, cryosphere, atmosphere).

3



~90% of the energy imbalance is absorbed by the ocean, so EEI estimates largely hinge on **ocean heat uptake**.

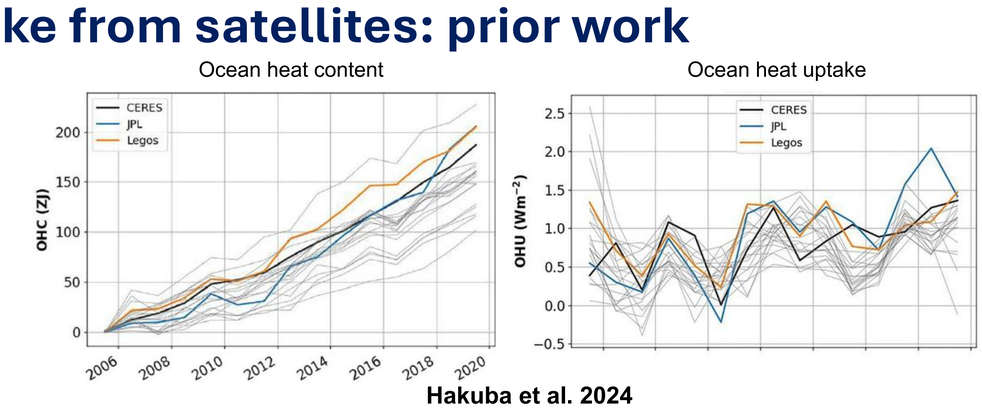
Ocean heat content/uptake from satellites: prior work



Hakuba et al. 2021

Sea water's expansion efficiency of heat:

+1 mm yr^{-1} change in thermosteric sea level equals **+0.5 Wm^{-2}** in ocean heat uptake.



Hakuba et al. 2024

Black: top of atmosphere (CERES)

Gray: Hydrography obs, ocean reanalysis, model

Blue/**Orange**: From satellite altimetry - GRACE

Ocean's "effective" thermal expansion efficiency

$$\Delta h_{\text{steric}} \approx \int \alpha \Delta T \, dz \approx \alpha_{\text{eff}} \int \Delta T \, dz$$

Satellites provide this — α depends on T,S,p and varies with depth — What we need — End goal

Estimates of α_{eff} can differ by >40% across different hydrographic products and models!

"Effective" expansion efficiency is NOT just vertical mean α – it depends on where the heat goes

Compute α_{eff} by linear regression

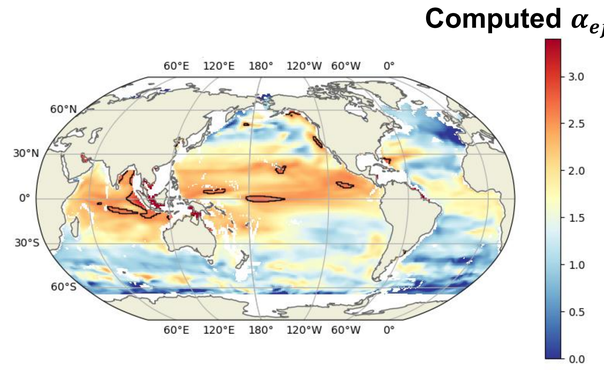
dT is T anom relative to reference mean (2006-2017)

$$\alpha_{\text{eff}} = \frac{\overline{(\Delta h_{\text{steric}}/H)\,dT}}{\overline{dT^2}}$$

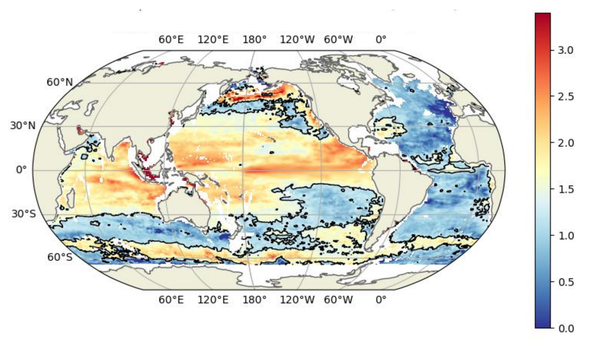
(Time mean (2006-2017))

Computed α_{eff} [10^{-4} °C^{-1}]

NASA ECCO v4r4 state estimate



ECMWF ORAS5 ocean reanalysis



By combining equations above and decomposing α and dT into vertical mean and deviation:

$$\alpha = [\alpha] + \alpha'$$

$$dT = [dT] + dT'$$

Can express α_{eff} as:

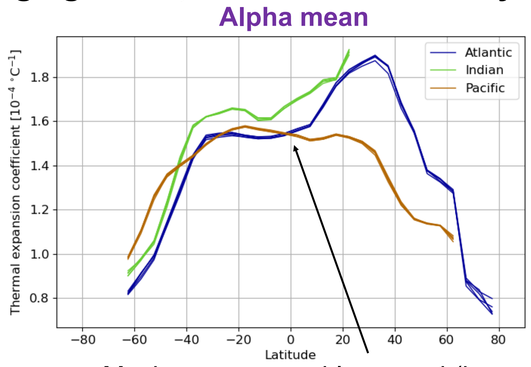
$$\alpha_{\text{eff}} = \overline{[\alpha]} + \frac{\overline{[\alpha' dT'][dT]}}{\overline{[dT]^2}}$$

Alpha mean — Alpha-dT vertical covariance trend …from differential heat uptake in shallow vs. deep ocean

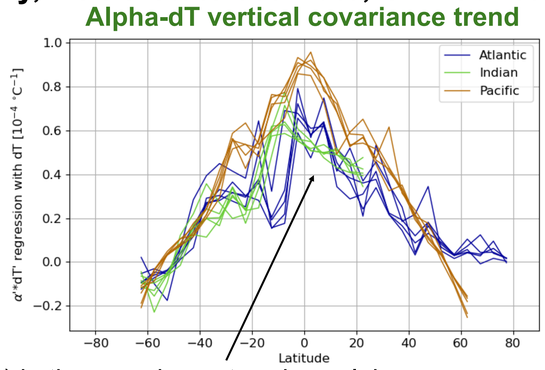
Contributions to α_{eff}, as computed from various products ("ensemble members")

(SIO Argo gridded, EN.4.2.2 and NCEI hydrography, ECCO state estimate, ORAS5 reanalysis)

Alpha mean



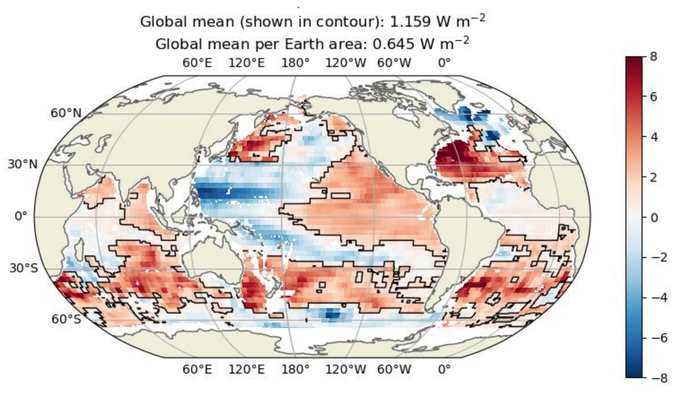
Alpha-dT vertical covariance trend



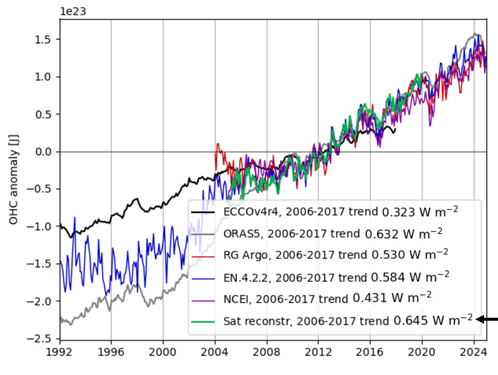
Much more ensemble spread (i.e., uncertainty) in the covariance trend vs. alpha mean

Preliminary satellite-based OHC reconstruction – based on "ensemble"-mean α_{eff}

2006-2017 0-2000 m OHC trend (OHU), based on reconstruction from satellite steric height (altimetry – gravimetry)



Global 0-2000 m OHC time series comparison, satellite reconstruction vs. other products



~89% of total EEI is due to ocean (OHC)

↓

~90% of ocean OHC change is in top 2000 m

↓

Compare with ~80% of von Schuckmann et al. (2023) total EEI estimate:

0.8*(0.76 ± 0.2 W m^{-2})

= 0.61 ± 0.16 W m^{-2}

Note: 2nd GEWEX Earth's Energy Imbalance Assessment Workshop June 1-5, 2026 in Pasadena:

https://climatesciences.jpl.nasa.gov/events/20260601-workshop/index.html

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