

Ocean Heat uptake and its relationship to rising SST in the NCEI and SODA3/4 products

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Outline

1. Global heat flux estimates
2. Geographic distribution of uptake
3. Term decomposition

NCEI MONTHLY GLOBAL OCEAN TEMPERATURE ANOMALY 66°S-66°N

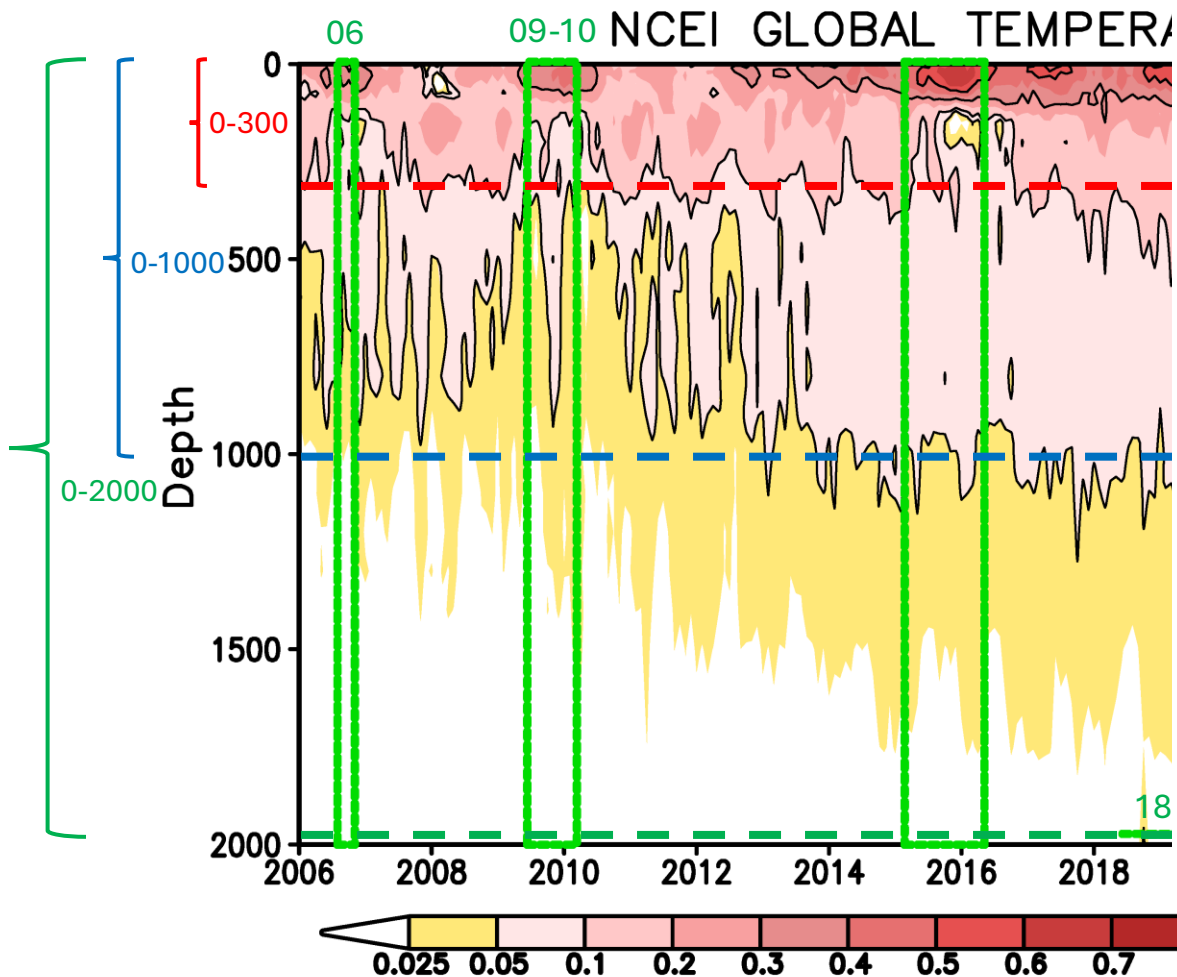
{relative to 1955-2006}

Considered by Hakuba et al 2024

recent data

Three layers

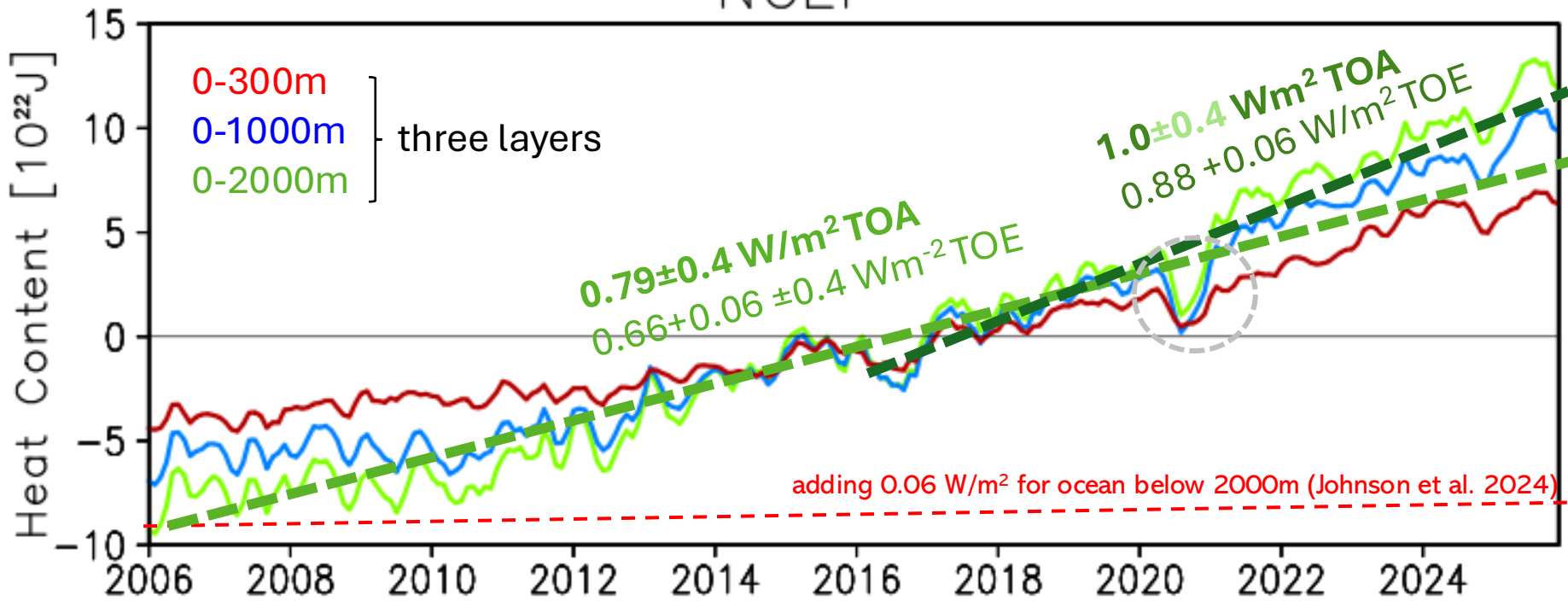
El Ninos
15-16



Data



NCEI



SODA3/4

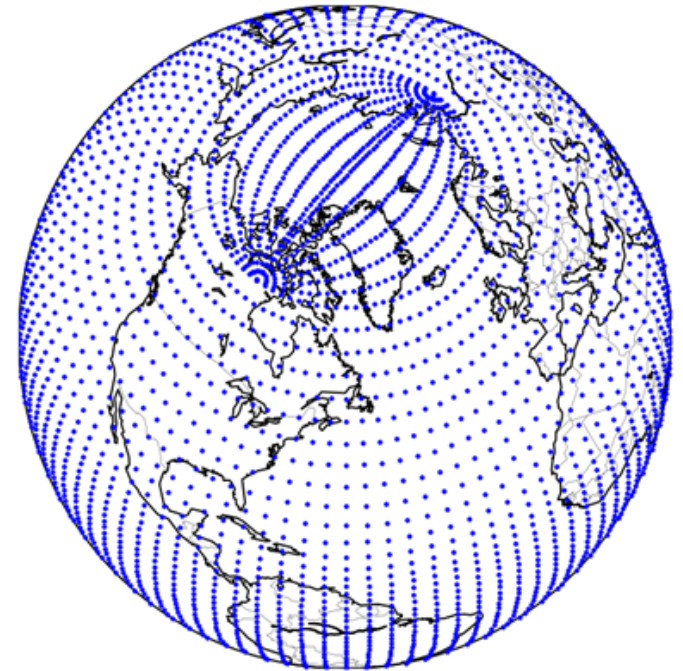
Ocean/Ice Model

- SODA4: 0.1°x0.1° horizontal resolution
- SODA4: 75 z*-coordinate vertical levels
- GFDL MOM5 numerics
- 5 category SIS1 sea ice
- New monthly discharge data set
- ERA5 forcing

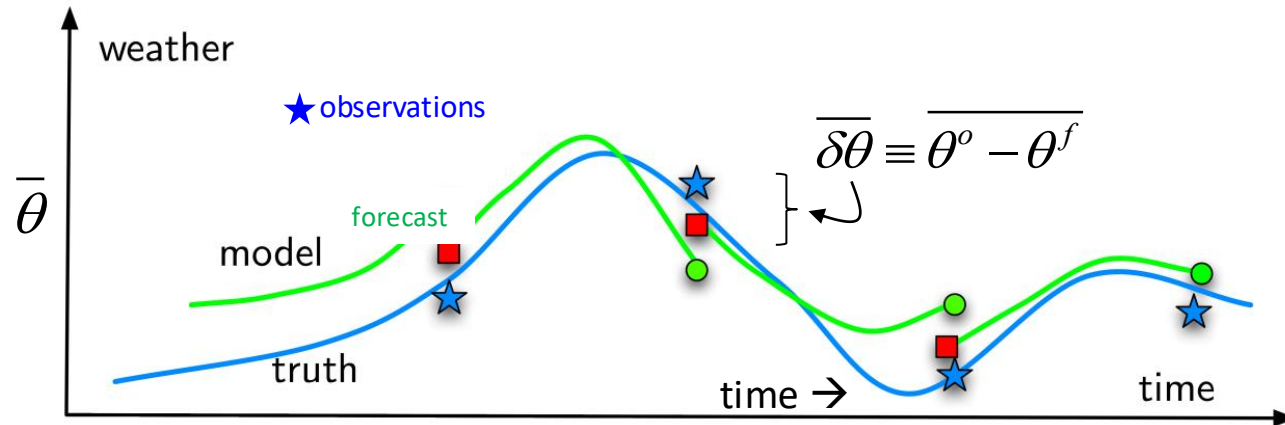
Data Assimilation

- WOD Temp/Salt obs
- satellite SST
- PIOMAS sea ice (*flux-based assimilation*)
- Bias Correction
 - Surface flux bias correction based on examination of **analysis increments**:

$$\overline{\mathbf{K}[\omega^o - \mathbf{H}(\omega^f)]}$$



Correcting for biased surface fluxes

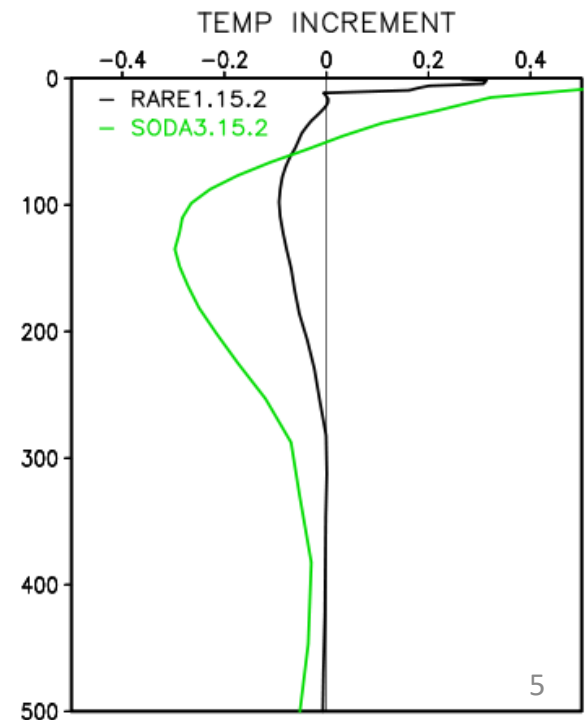


Increment equations

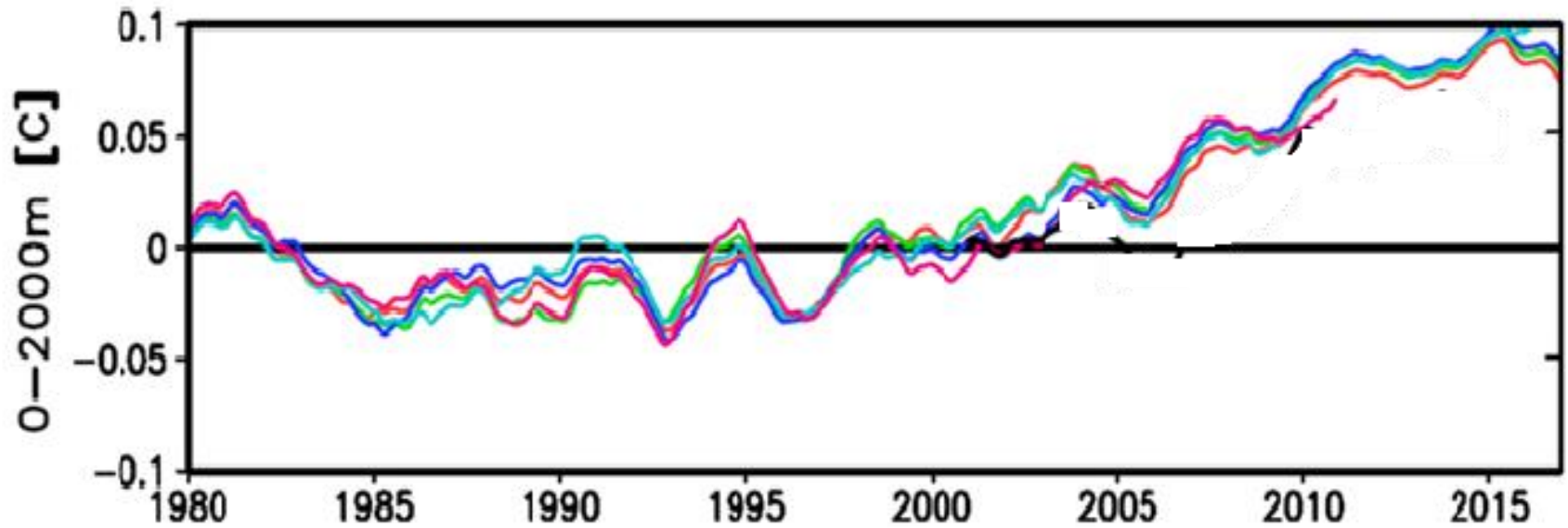
$$\int \left(\frac{\delta\theta}{\Delta t} + \mathbf{u} \cdot \nabla \delta\theta + \delta\mathbf{u} \cdot \nabla \theta \right) dz \cong \frac{\delta Q}{\rho C_p}$$

$$\int \left(\frac{\delta S}{\Delta t} + \mathbf{u} \cdot \nabla \delta S + \delta\mathbf{u} \cdot \nabla S \right) dz \cong \delta(P - E + R)S_o$$

$$m \left(C + \frac{L\mu S}{T_{ice}^2} \right) \frac{dT_{ice}}{dt} \cong \delta F$$



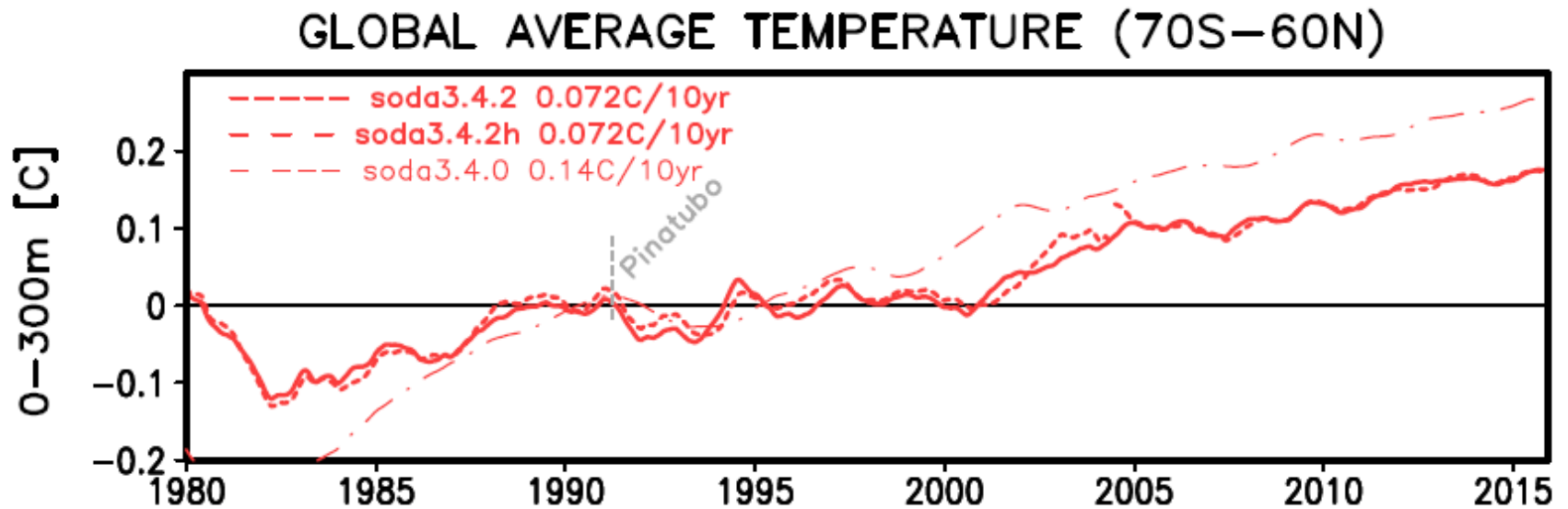
Error from surface forcing



Forcings

- ERA-I
- MERRA-2
- JRA55-DO
- ...

Impact of observation coverage

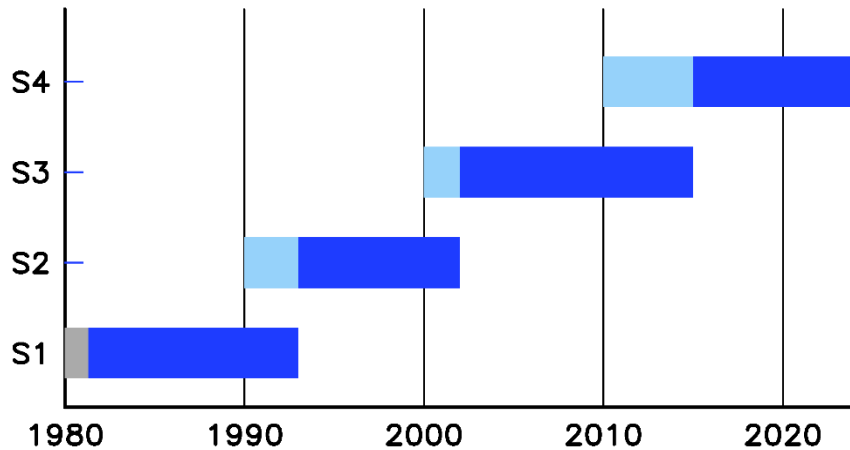


SODA4 in 4 streams

(due to expedience)

File Structure

SODA4 STREAMS



https://dsrs.atmos.umd.edu/DATA/soda4.15.2_s1
https://dsrs.atmos.umd.edu/DATA/soda4.15.2_s2
https://dsrs.atmos.umd.edu/DATA/soda4.15.2_s3
https://dsrs.atmos.umd.edu/DATA/soda4.15.2_s4

Chepurin et al 2026



soda4.15.2_s1:

- ORIGINAL

ocean (5dy, mn)

`soda4.15.2_5dy_ocean_or_1987_11_12.nc`

`soda4.15.2_5dy_ocean_or_1987_11_17.nc`

...

ice (5dy, mn)

transport (10dy)

- REGRIDED

ocean (5dy, mn)

ice (5dy, mn)

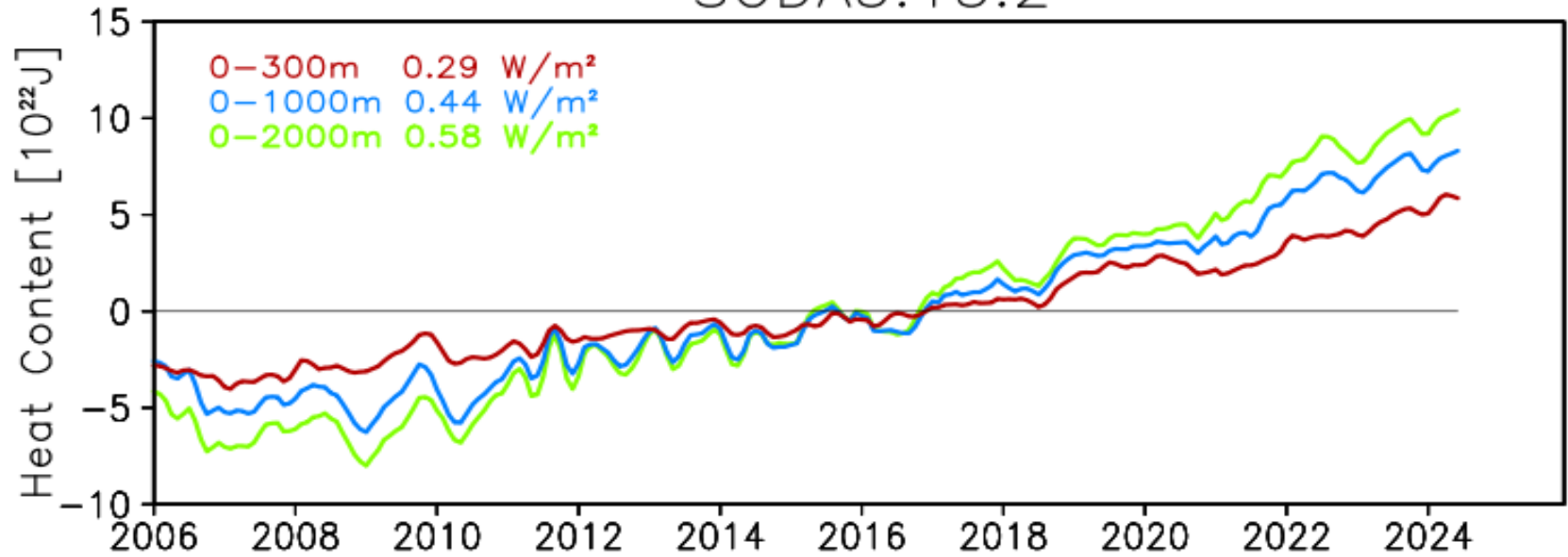
- SODA (10dy)

soda4.15.2.0 simulation

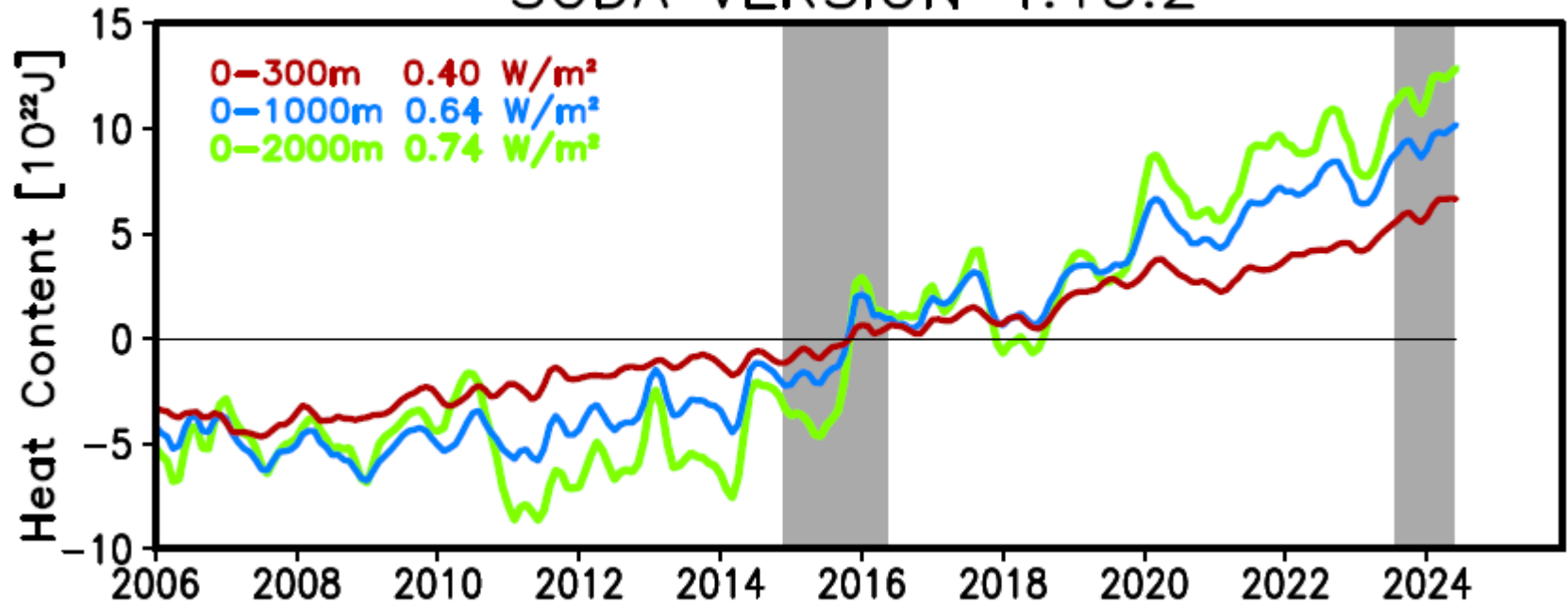
Chepurin, Carton, Sun, and Penny (2026)

<https://arxiv.org/pdf/2508.17462>

SODA3.15.2



SODA VERSION 4.15.2



Global Storage

0-1000m trend 2006-2024

Atlantic

- North subpolar gyre is cooling
- Both subtropical gyres are warming rapidly

Pacific

- Warming
- Western north tropics is cooling (ENSO & PDO?)

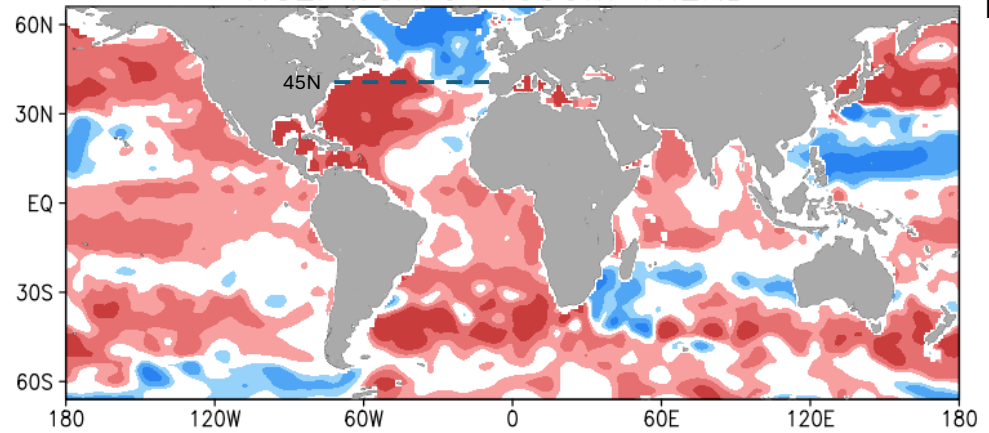
Indian

- Arabian Sea warming

Southern Ocean

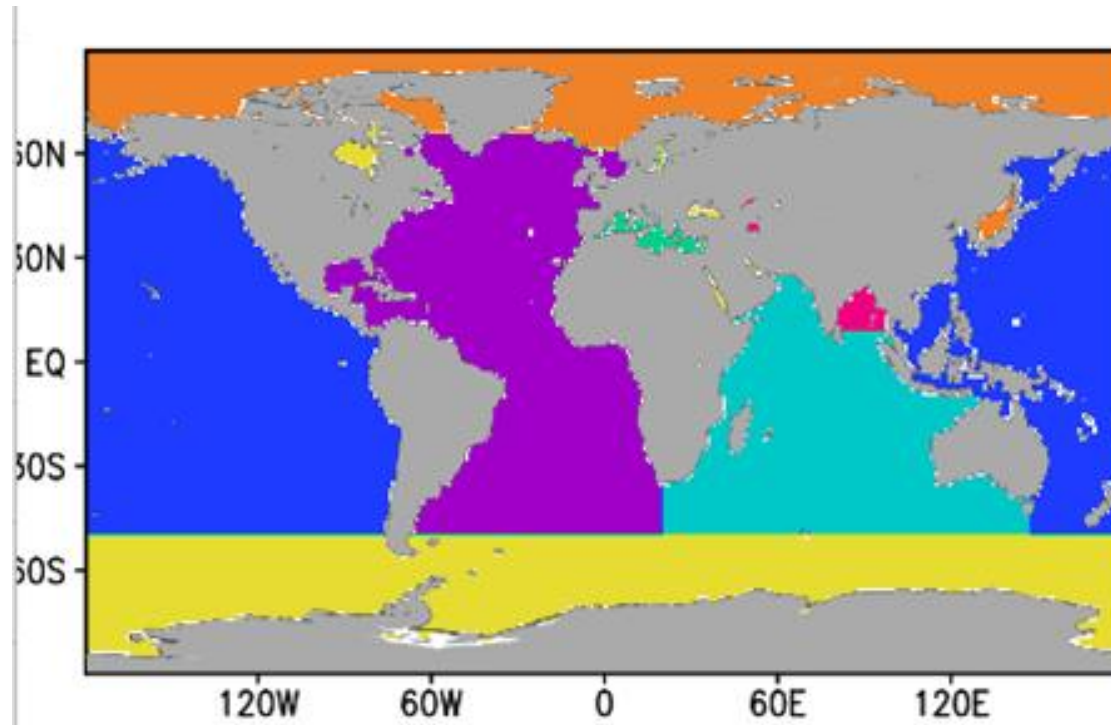
- Generally warming

reanalyses



NCEI, SODA3 and SODA4
are qualitatively
consistent

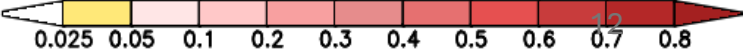
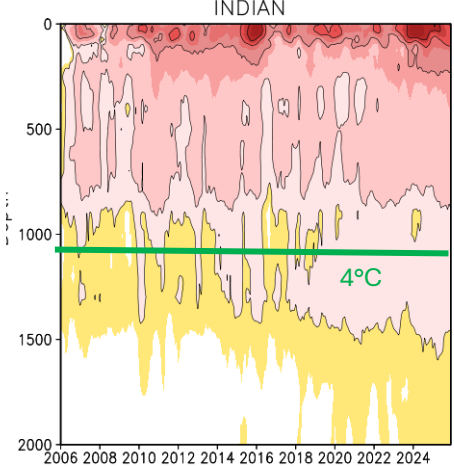
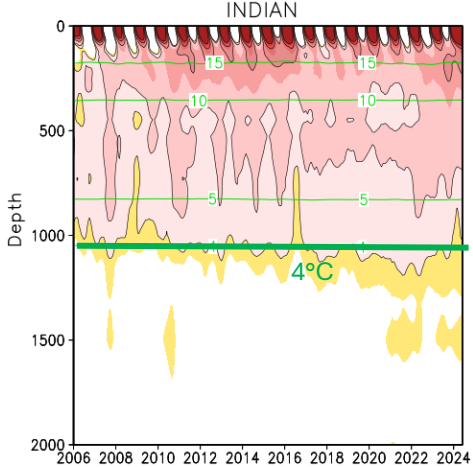
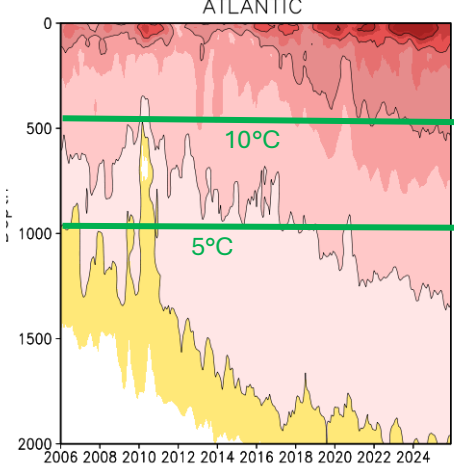
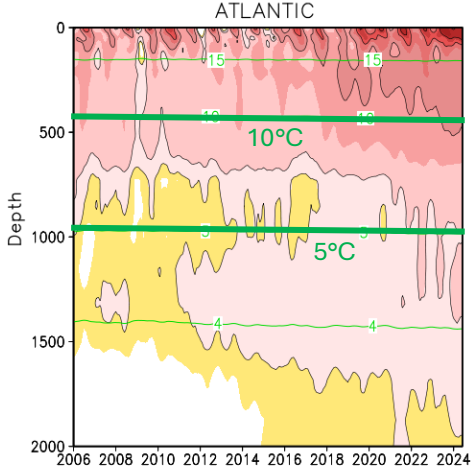
Storage in individual basins



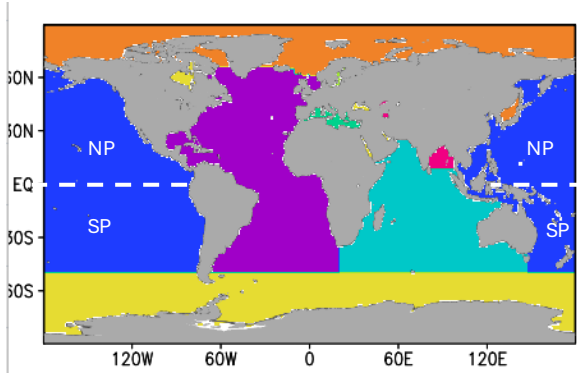
different reference periods

SODA3.15.2
{REL TO 1985-1994}

NCEI
{REL TO 1955-2006}

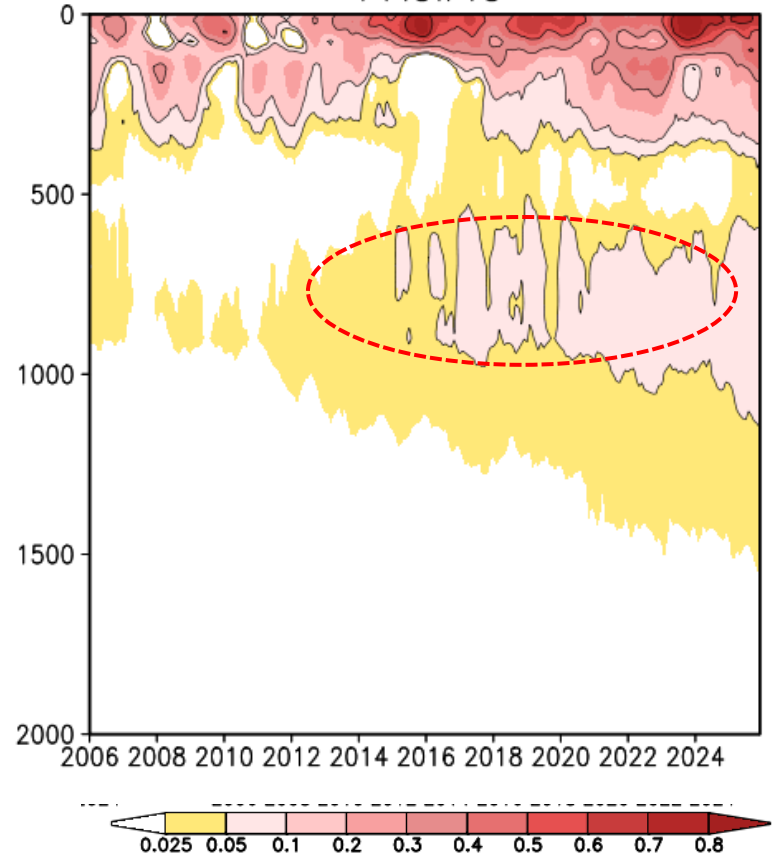


NCEI
{REL TO 1955-2006}

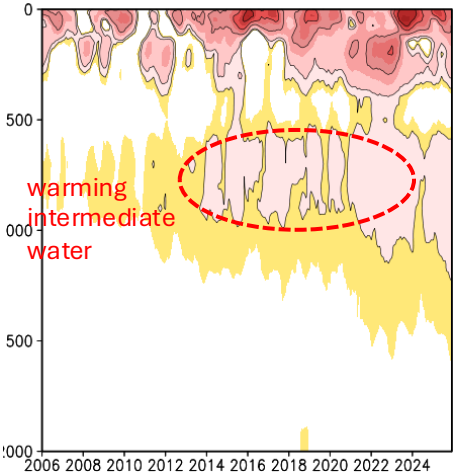


NCEI

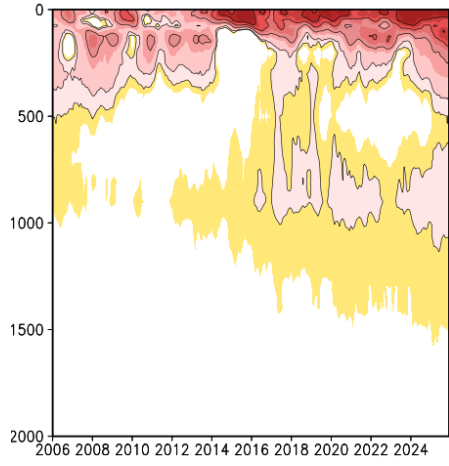
PACIFIC



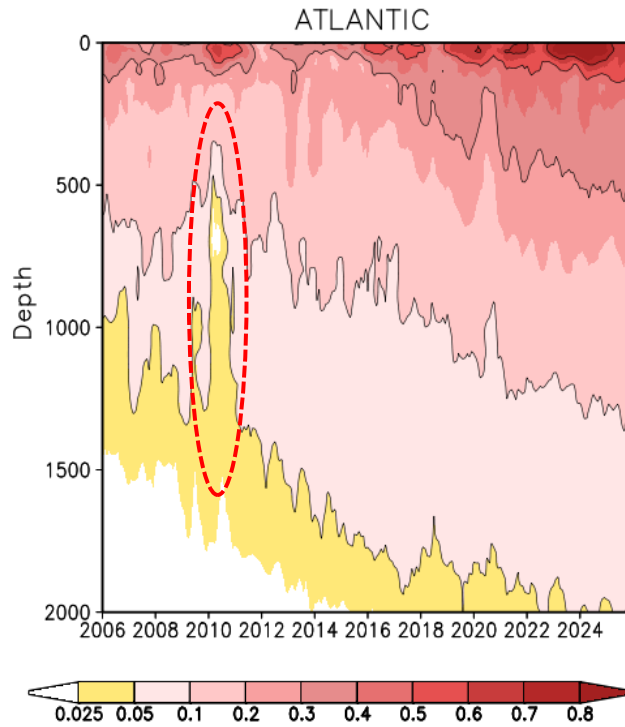
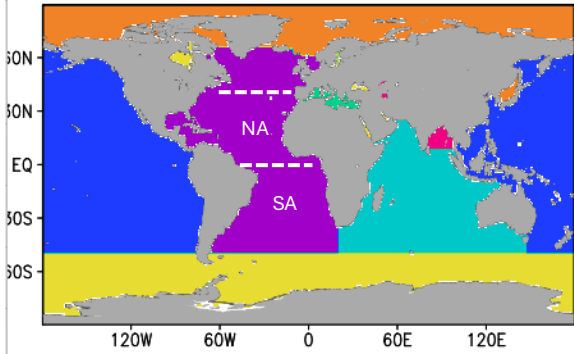
South Pacific



North Pacific



NCEI
{REL TO 1955-2006}



Washington DC winter '09/'10



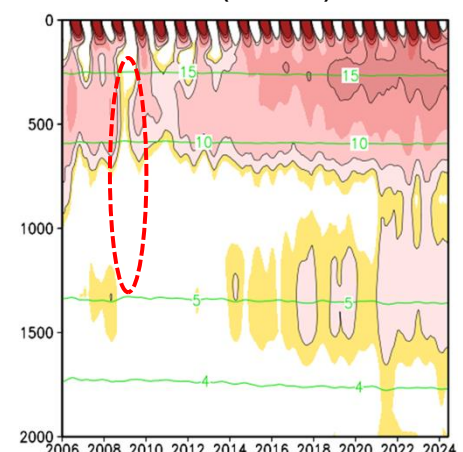
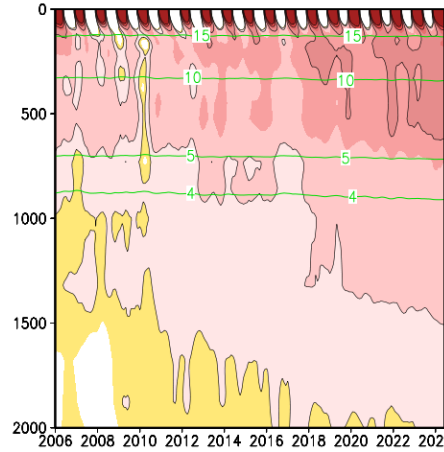
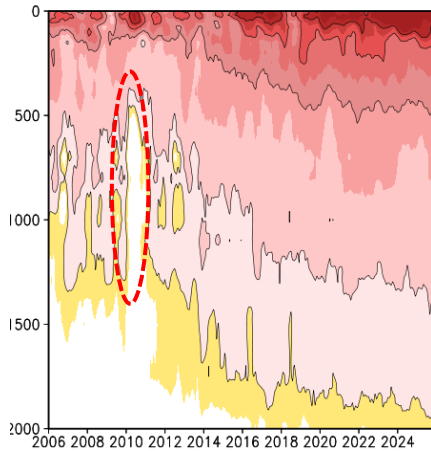
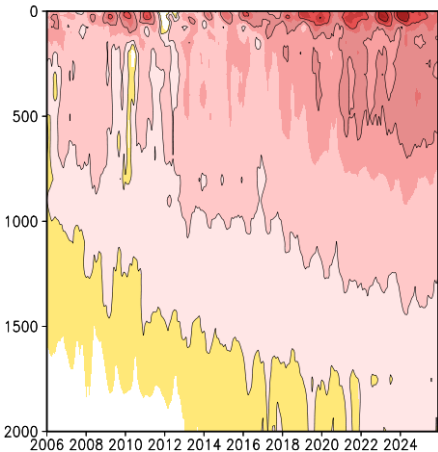
← SODA3 →
(1985-1994)

South Atlantic

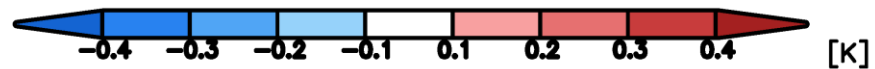
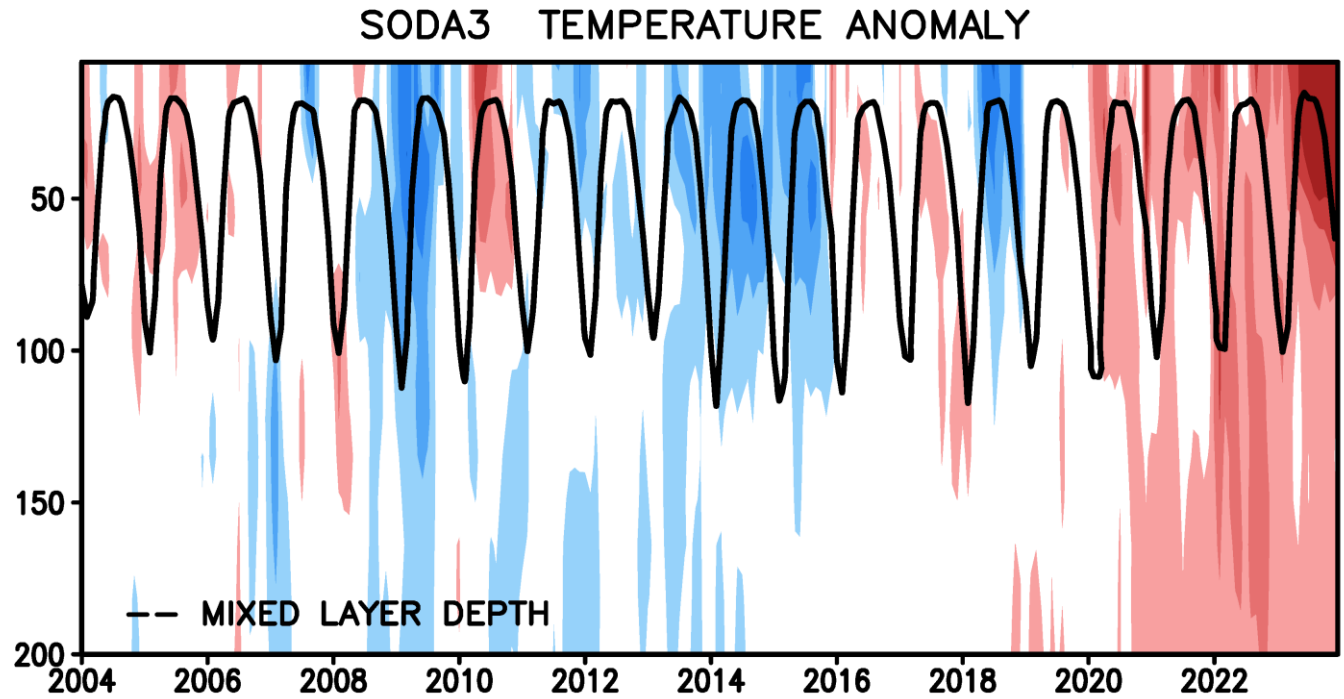
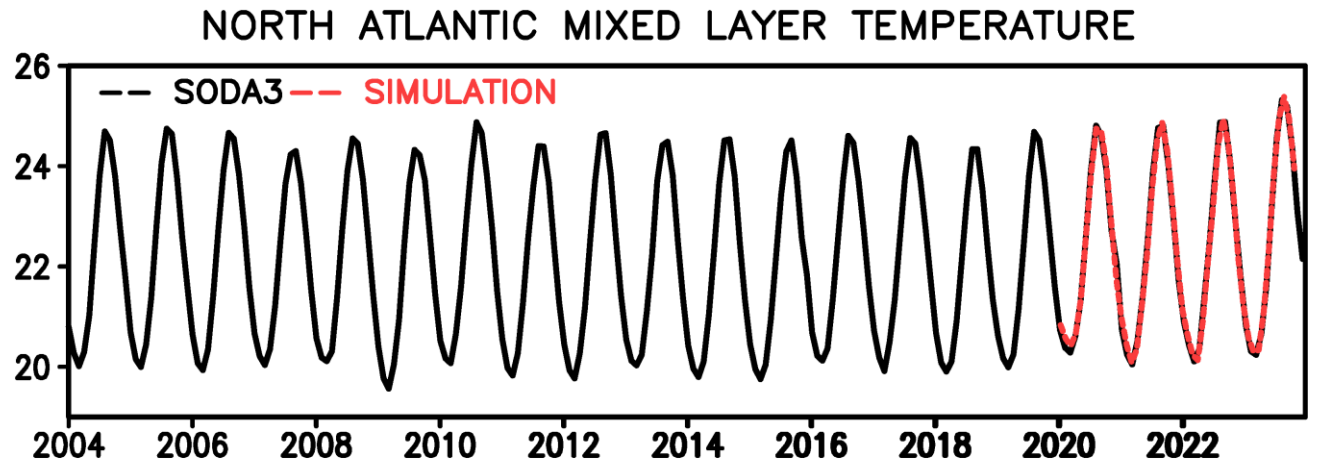
North Atlantic
(0°-45°N)

South Atlantic

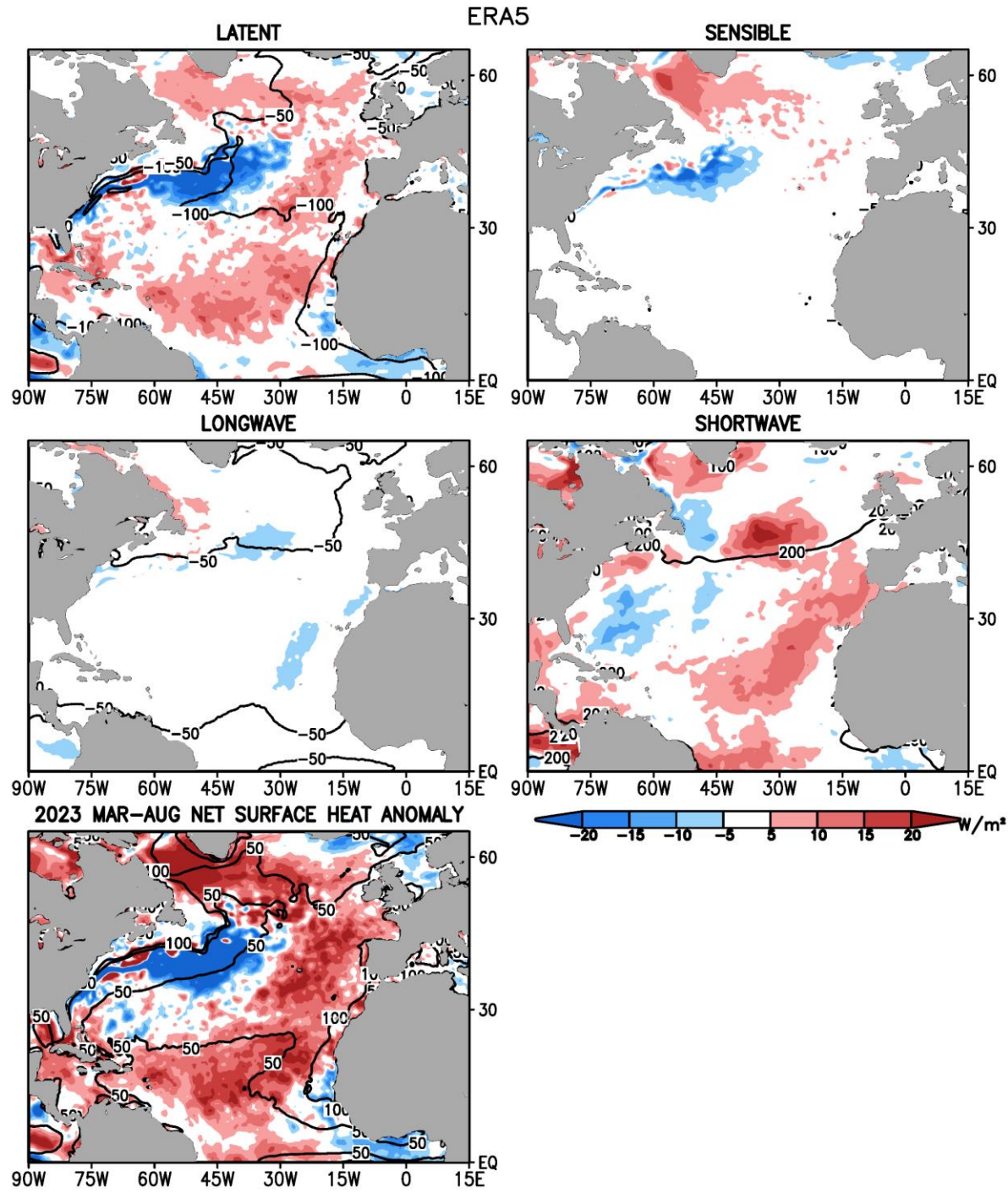
North Atlantic
(0°-45°N)



Simulation:
closed ocean
heat budget

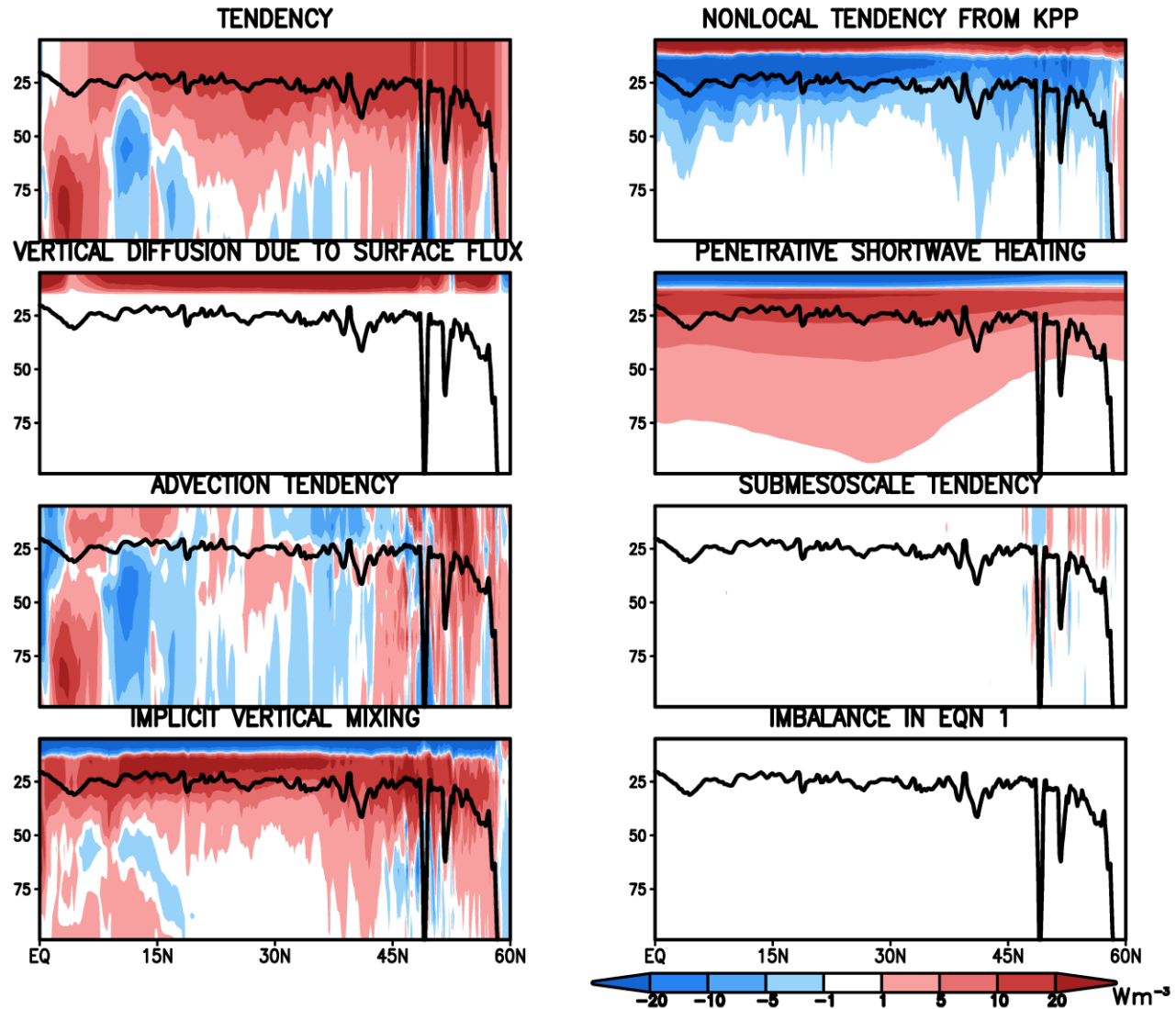


Decomposition of the ERA5 net surface flux during the summer of 2023



$$\rho_o C_p \int_{-D}^{\eta} \frac{\partial \theta}{\partial t} dz = -\rho_o C_p \int_{-D}^{\eta} [\nabla \cdot (\mathbf{u}\theta) + \text{submesoscale} + \text{other}] dz + (Q_{z=0} - Q_{z=-D})$$

Term
decomposition
along 30°W
spring/summer, 2023



Conclusions

1. Global heat uptake

1. NCEI vs SODA – pretty similar
2. NCEI TOA EEI:
 1. $0.64 \pm 0.4 \text{ W/m}^2$ (2006-2019)
 2. $0.79 \pm 0.4 \text{ W/m}^2$ (2006-2025)
 3. $1.0 \pm 0.4 \text{ W/m}^2$ (2016-2025)
3. SODA3/4 TOA EEI:
 1. SODA3: 0.64 W/m^2 (2006-2024)
 2. SODA4: 0.8 W/m^2 (2006-2024) } *more uptake with better resolution*
4. Experiments suggest surface forcing errors are manageable

2. Basin-by-basin heat uptake

1. Atlantic: subpolar gyre is cooling, subtropical gyres warming rapidly (e.g. 2023!)
2. Pacific: western north tropics is cooling, North Pacific and eastern tropics warming
3. Indian: Arabian Sea is warming
4. Southern Ocean: warming of the upper 500m but less evident in SST

3. Heat budget decomposition depends on timescale