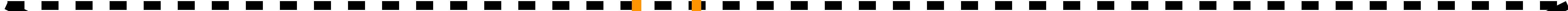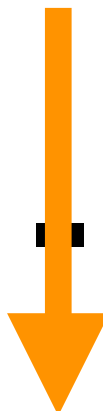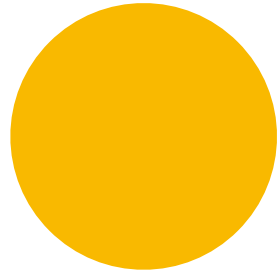# Tracking Earth Energy Imbalance and Marine Heatwaves across the Global Sunlit Ocean
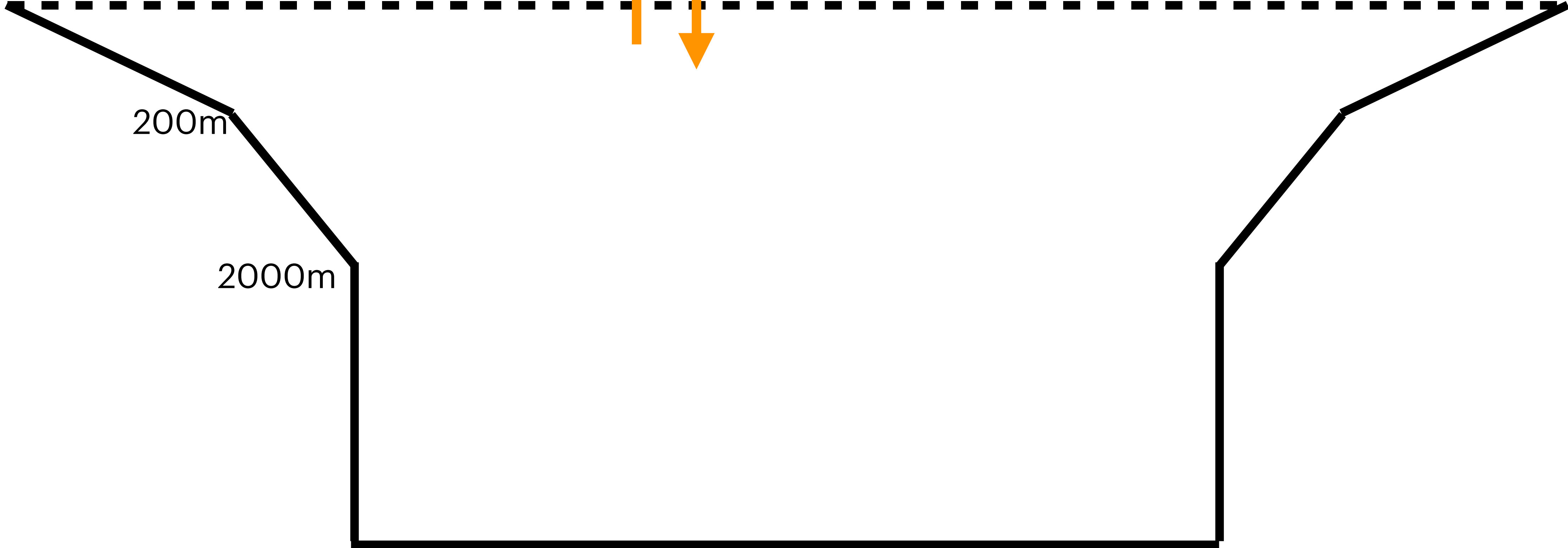
US-CLIVAR Summit 2023

Gaël Forget, Ke Chen   Seattle, USA   2023/08/01
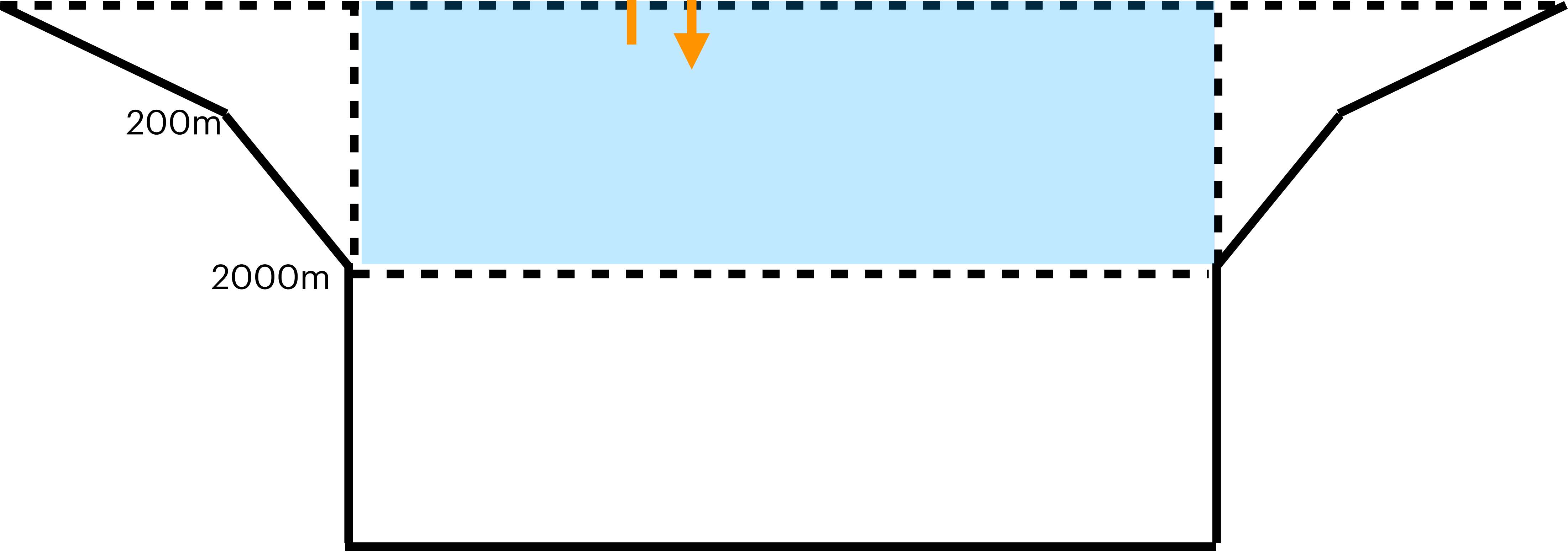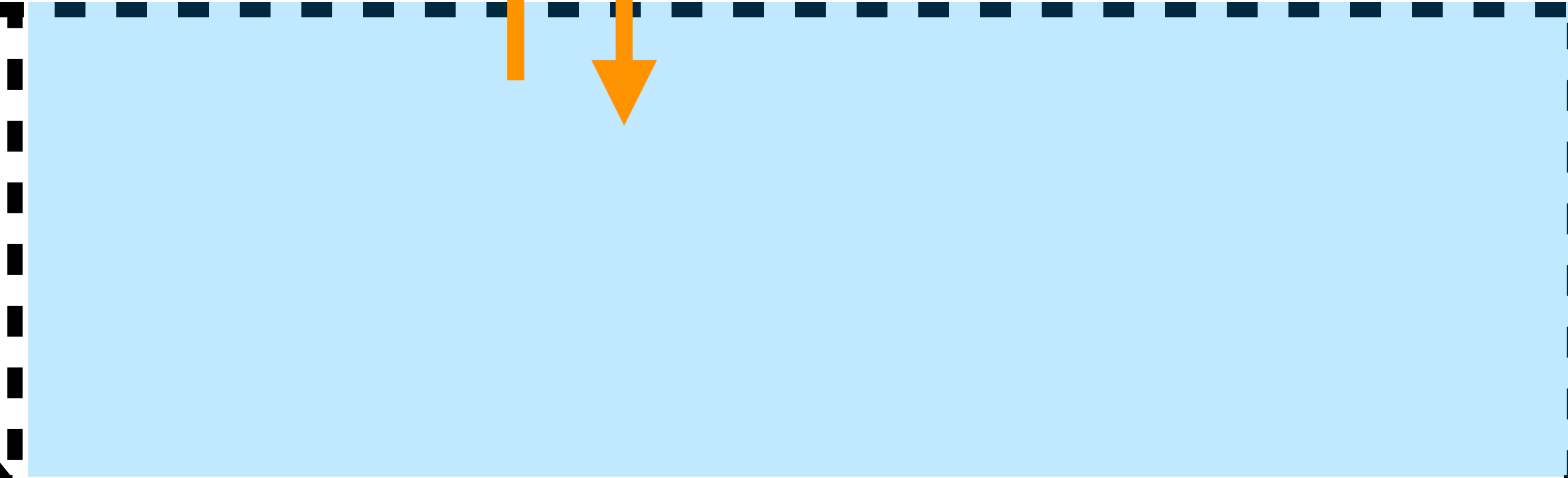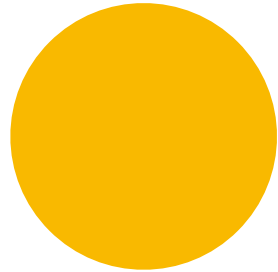
200m

2000m

200m

2000m
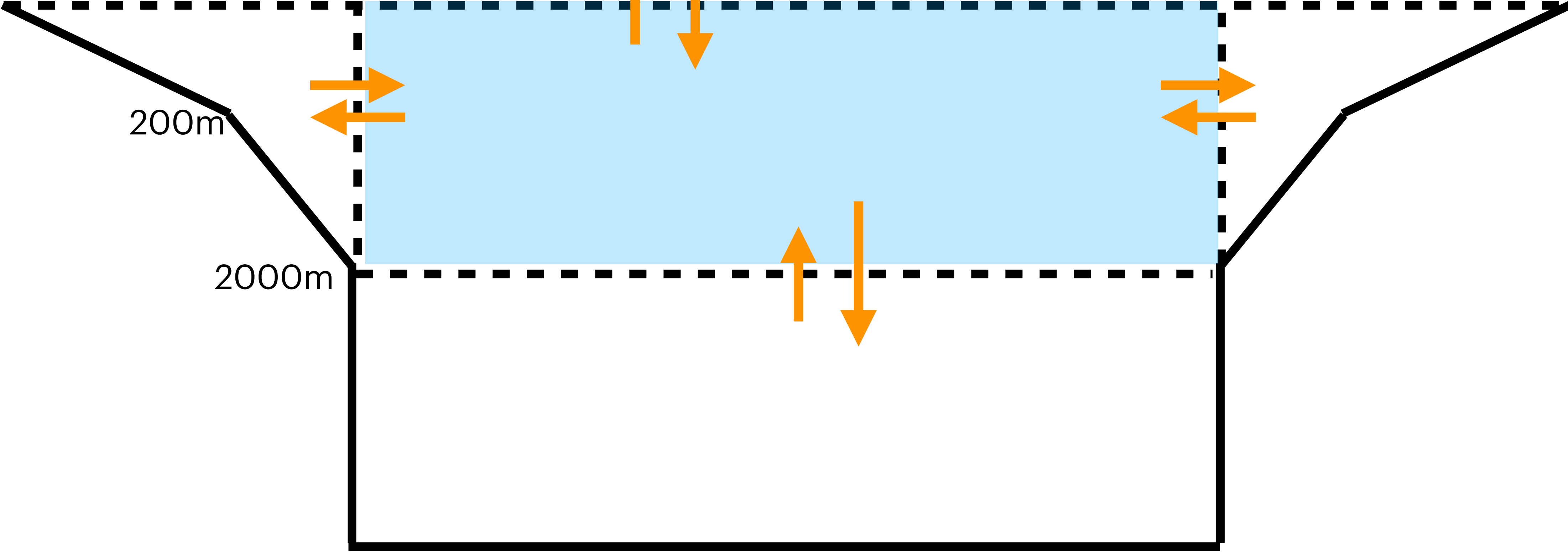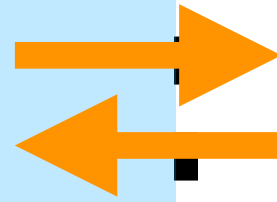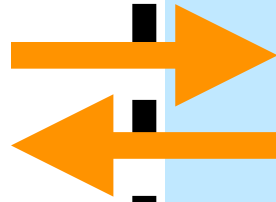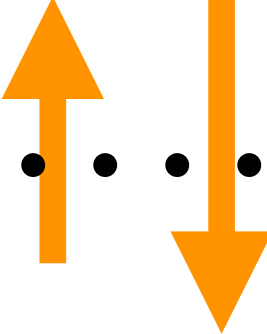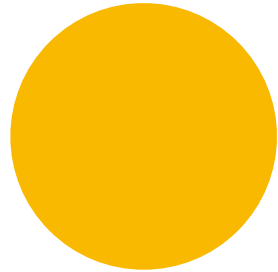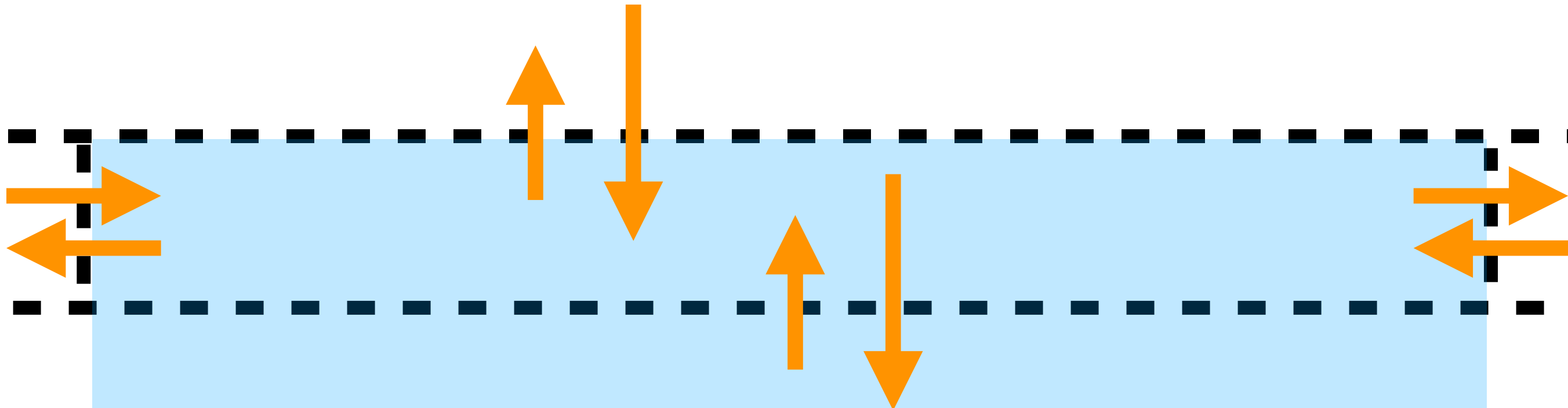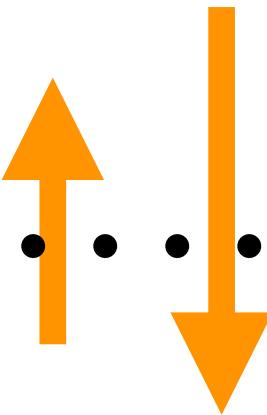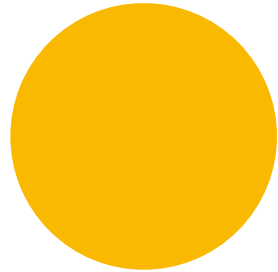
200m

2000m

200m

2000m
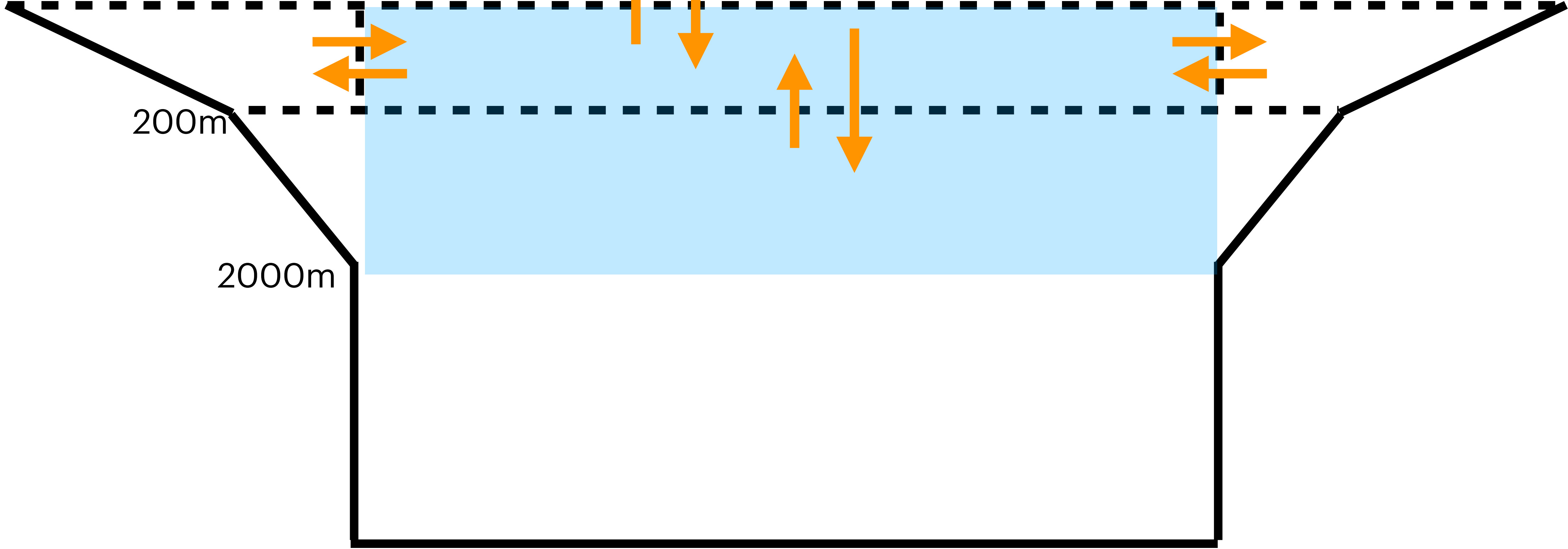
- what are the gaps in observation that prevent us from tracking Earth's energy imbalance throughout the upper 200m of the Global Ocean?
  - Need more sampling over areas that are too shallow for Argo to cover?
  - Need in situ measurements of air-sea fluxes with global coverage?
  - How much vertical resolution do we need in the top few meters?
  - How much could innovative remote sensing techniques help?
- what are the gaps in understanding pathways, recirculations, feedbacks, and impacts of upper ocean warming?
  - Do we understand vertical heat fluxes through the sea surface and below accurately enough?
  - How much vertical resolution do models need in the upper few meters?
  - Do we understand lateral heat fluxes across e.g. the 200m depth isobath accurately enough?
 - What are the leading sources of uncertainty in open-ocean and coastal heat budgets?
- how can we make progress towards a more synthetic and quantitive view of the heat budget across the global sunlit ocean layer?
  - Can global ocean state estimates constrained by Argo, SST, etc provide a comprehensive answer?
  - How should we nest regional models that can better resolve e.g. coastal heat budgets?
  - How can we best isolate trends from climate variability?
  - How can we rationalize marine heatwaves in terms of heat budget?

Energy Imbalance in the Sunlit Ocean Layer (SOL-EI)

US-CLIVAR Summit 2023

Gaël Forget   Seattle, USA   2023/08/01

Sea Surface Temperature

Global (90°S-90°N) monthly sea surface temperature anomaly
NOAA OISST V2.1
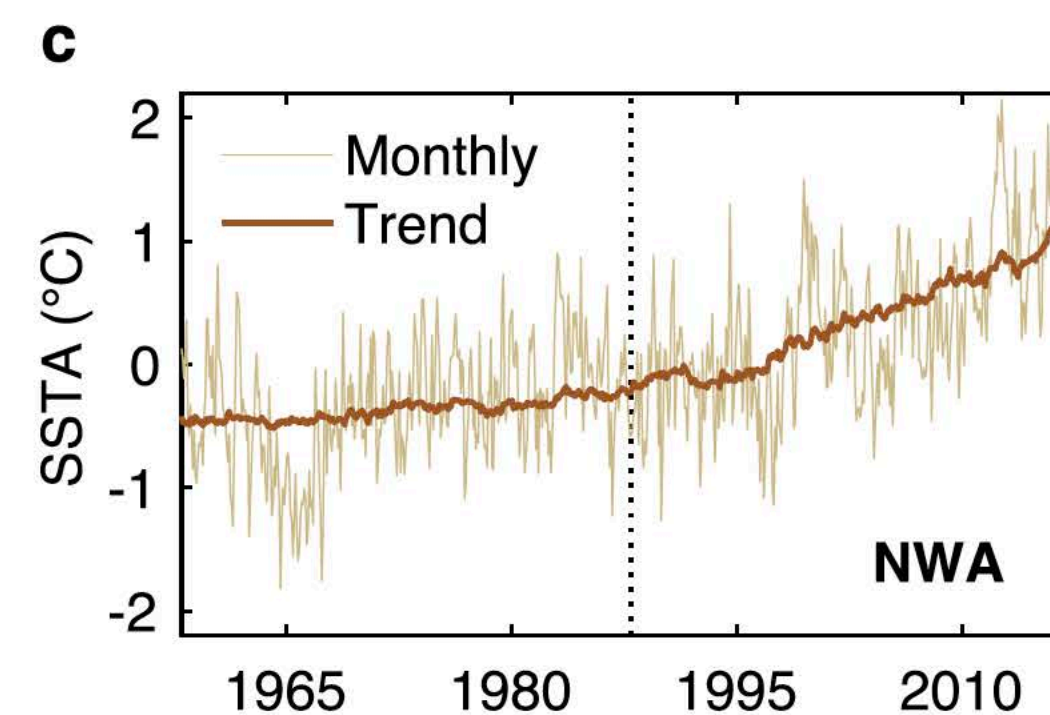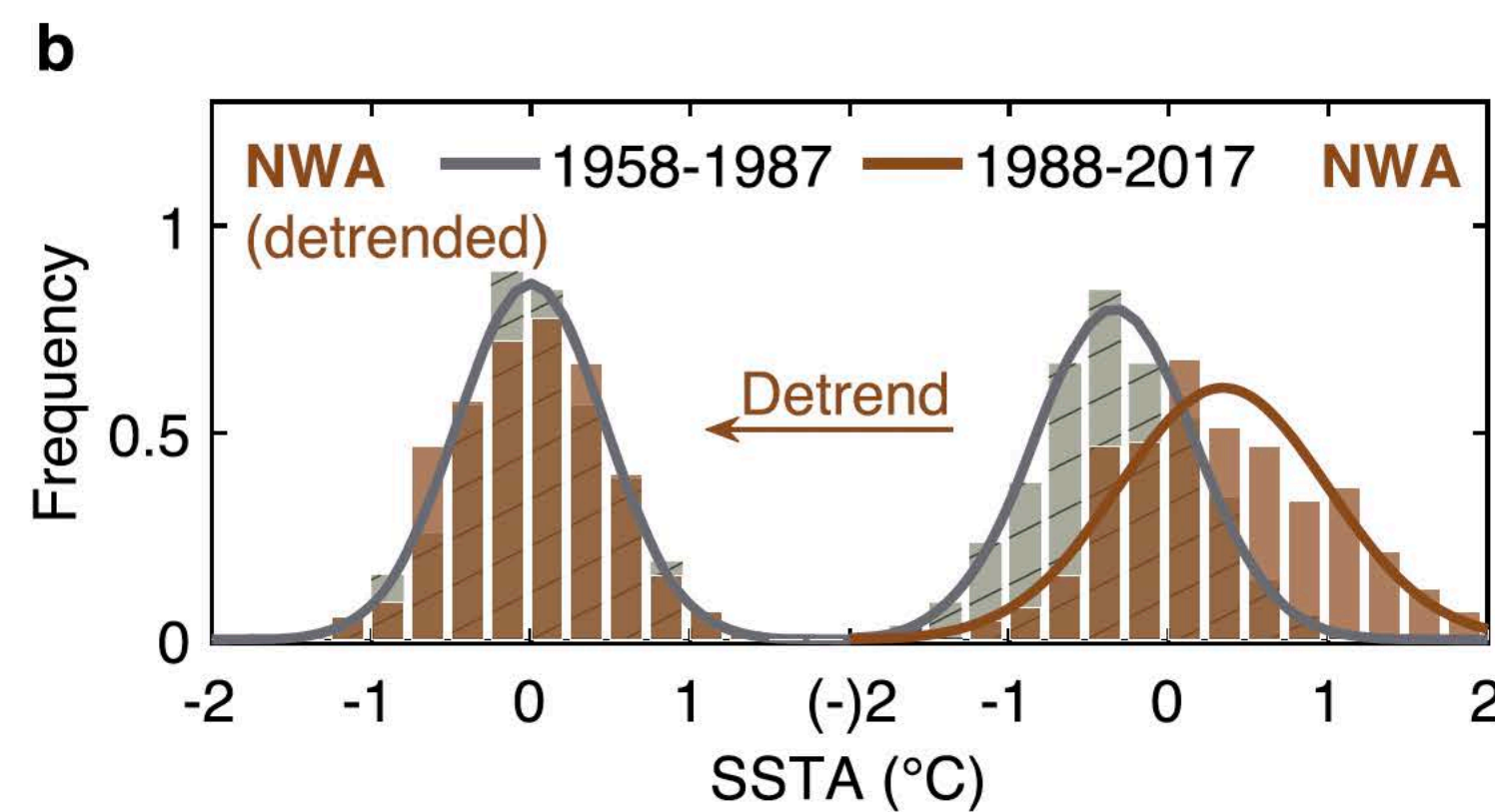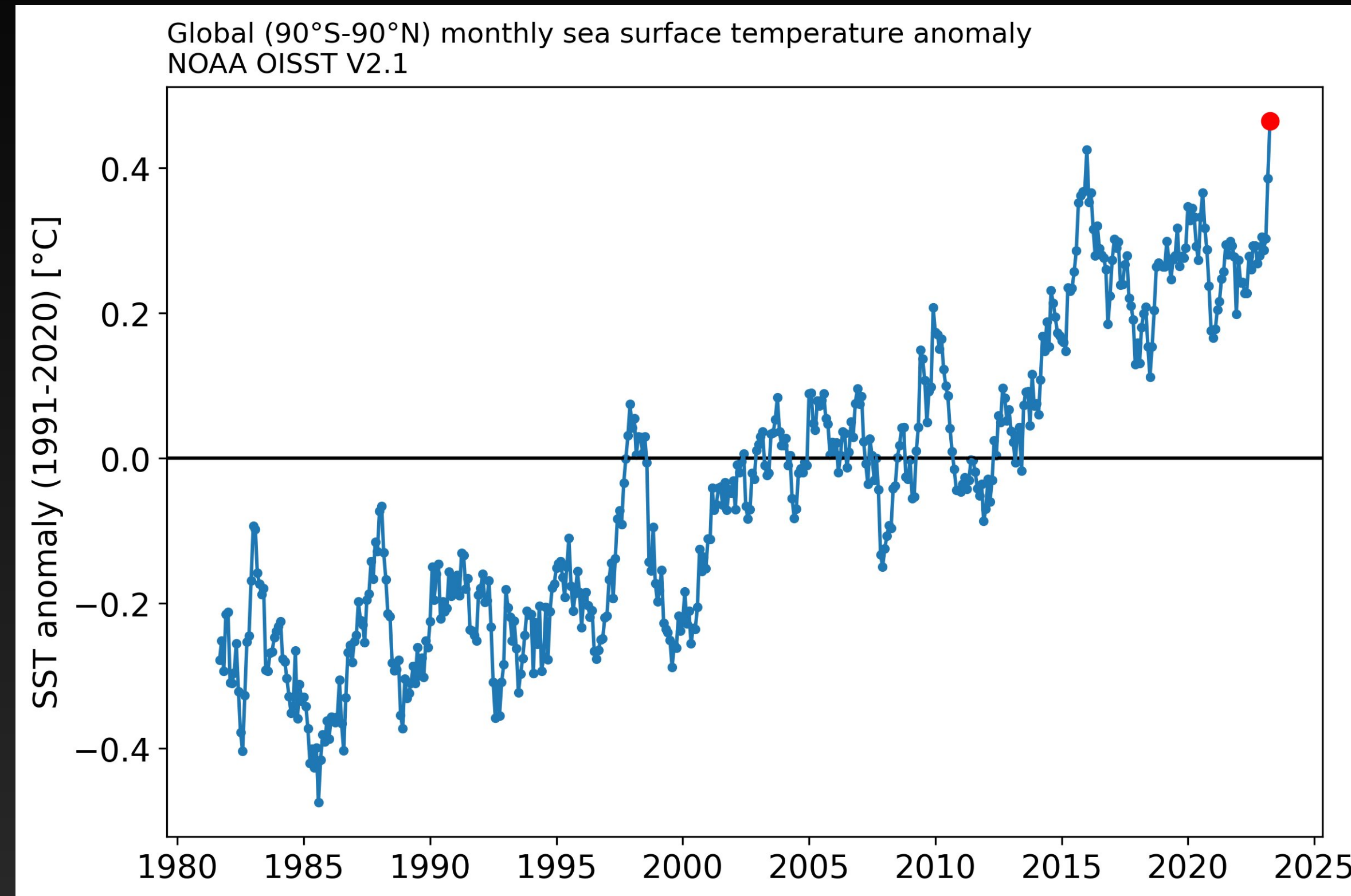
Xu et al 2022

Earth Energy Imbalance
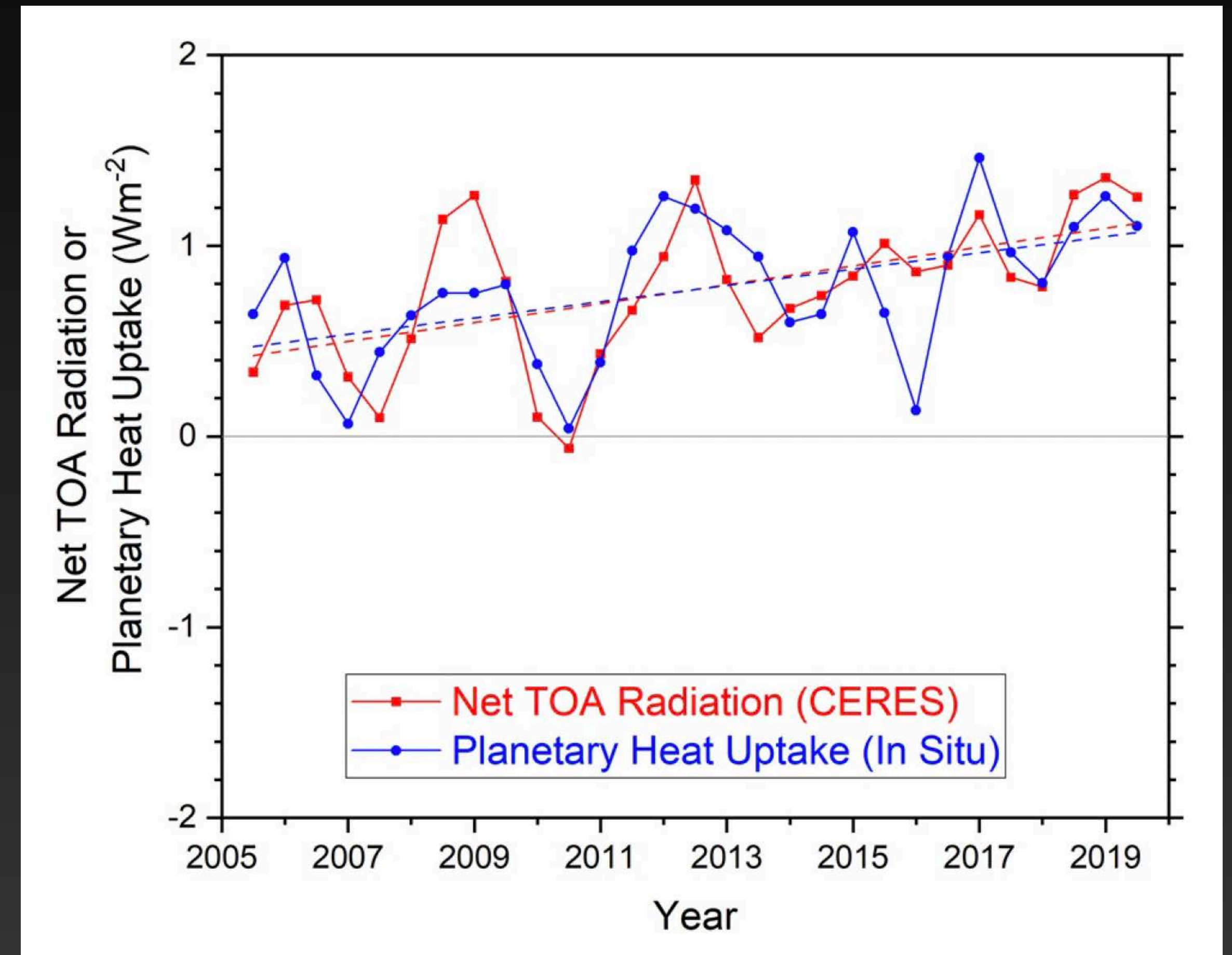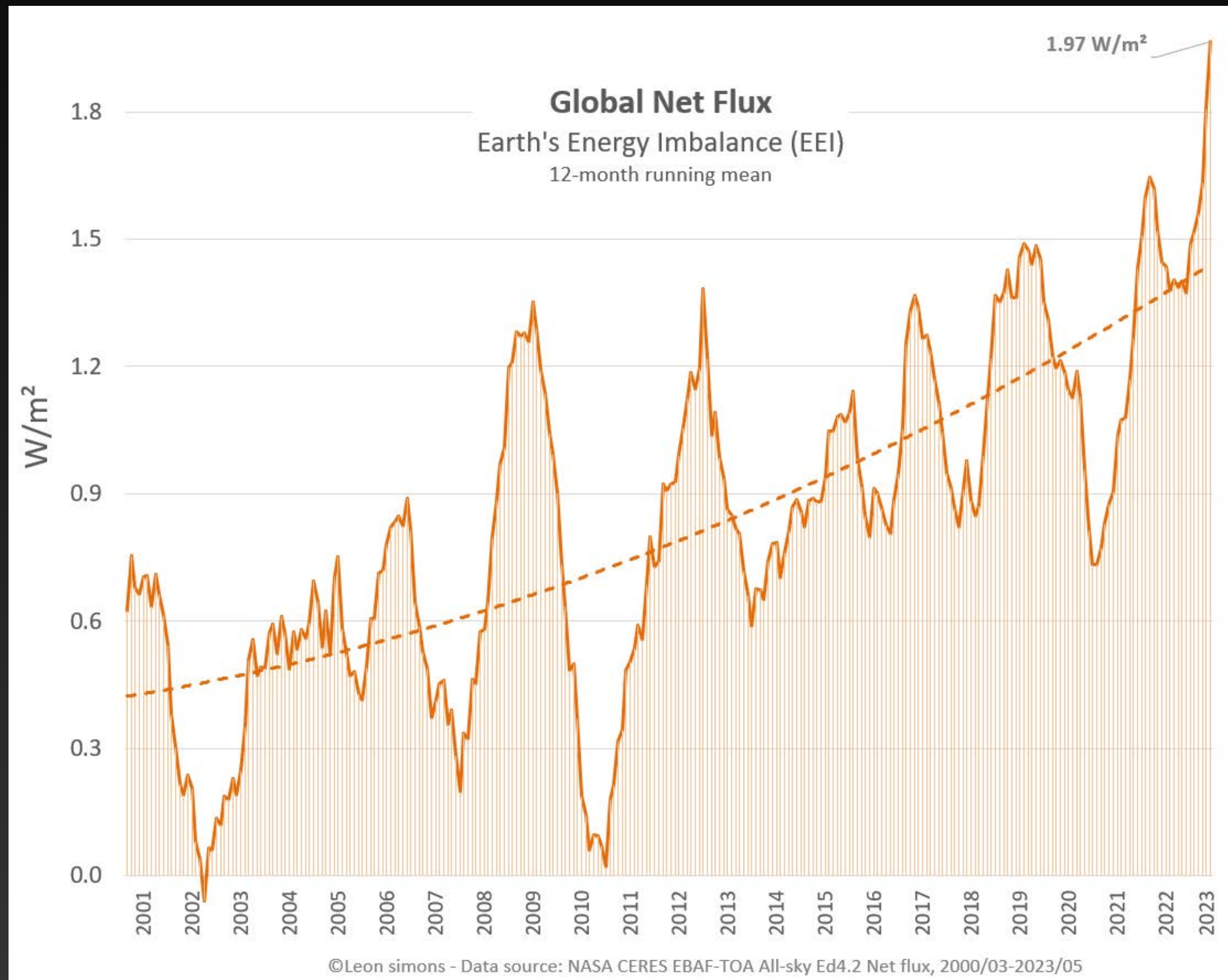
Loeb et al 2021

Outline

- Global mean trends in EEI and SST

- Ocean heat transports and time scales

- Global mean trends in the Sunlit Ocean Layer (0-200m)

- Spatiotemporal variability in SOL temperature

- Take home message & questions

Lateral Ocean Heat Transport

Meridional Ocean Heat Transport (top to bottom)
from an ensemble of air-sea flux / EEI estimates

Forget & Ferreira 2019

Three-Dimensional Ocean Transport

Three-Dimensional Ocean Transport

Rousselet, Cessi, Forget 2021
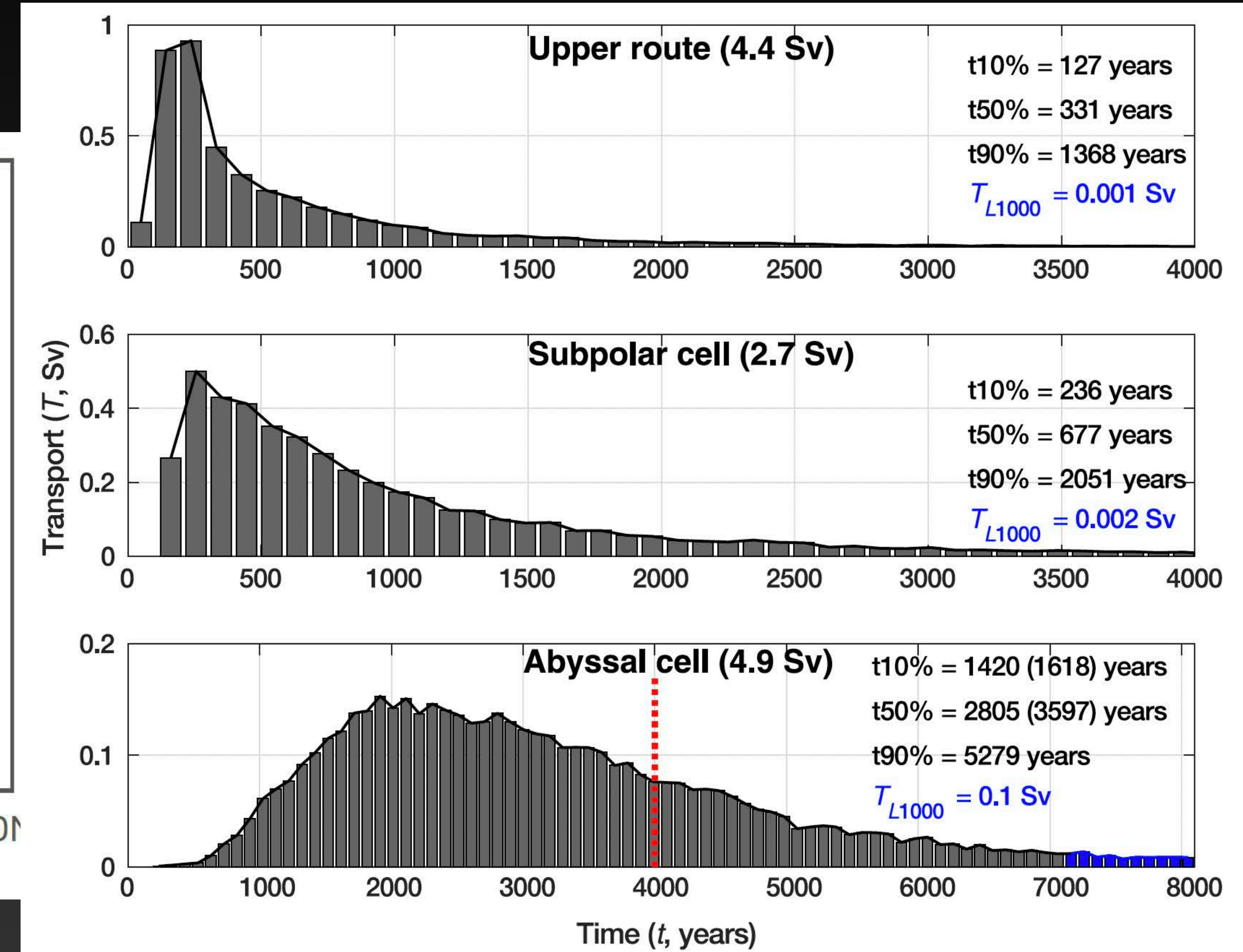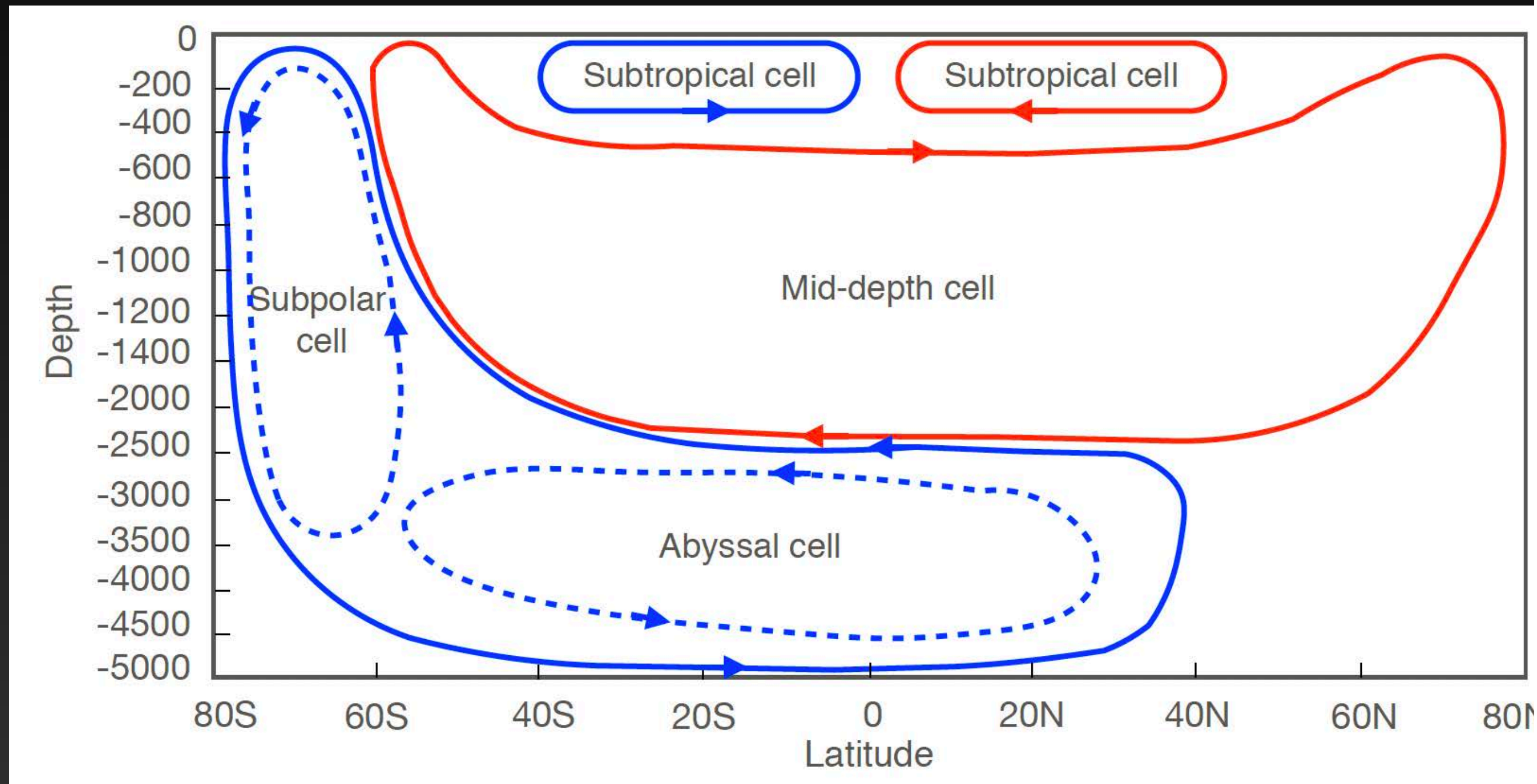
Using ECCO time mean circulation, we tracking particle trajectories backward in time from an "exit" section in the South Atlantic (6S above a target density surface) to specific "entry" sections

Mixed Layer in ECCOv4

ECCO stratification at 300m
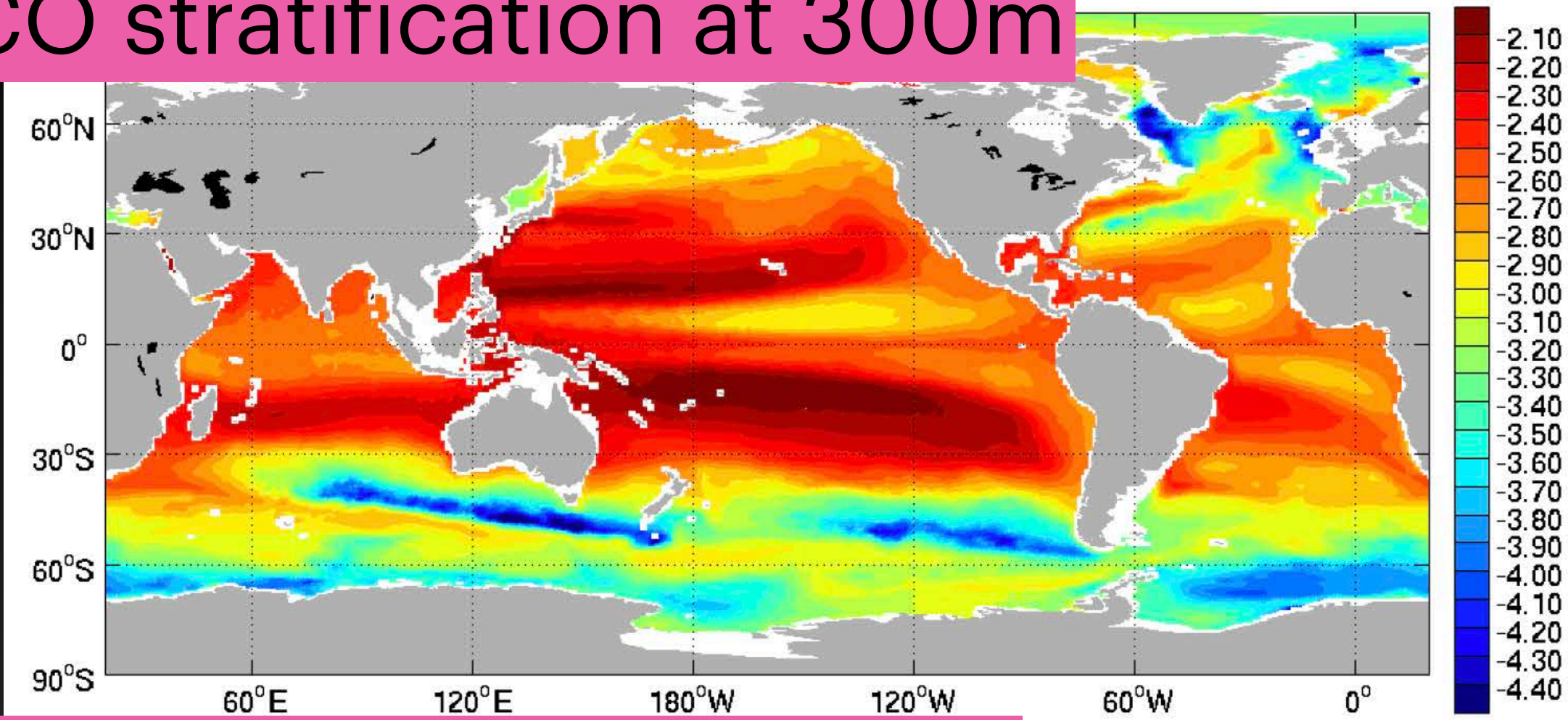
ECCO MLD
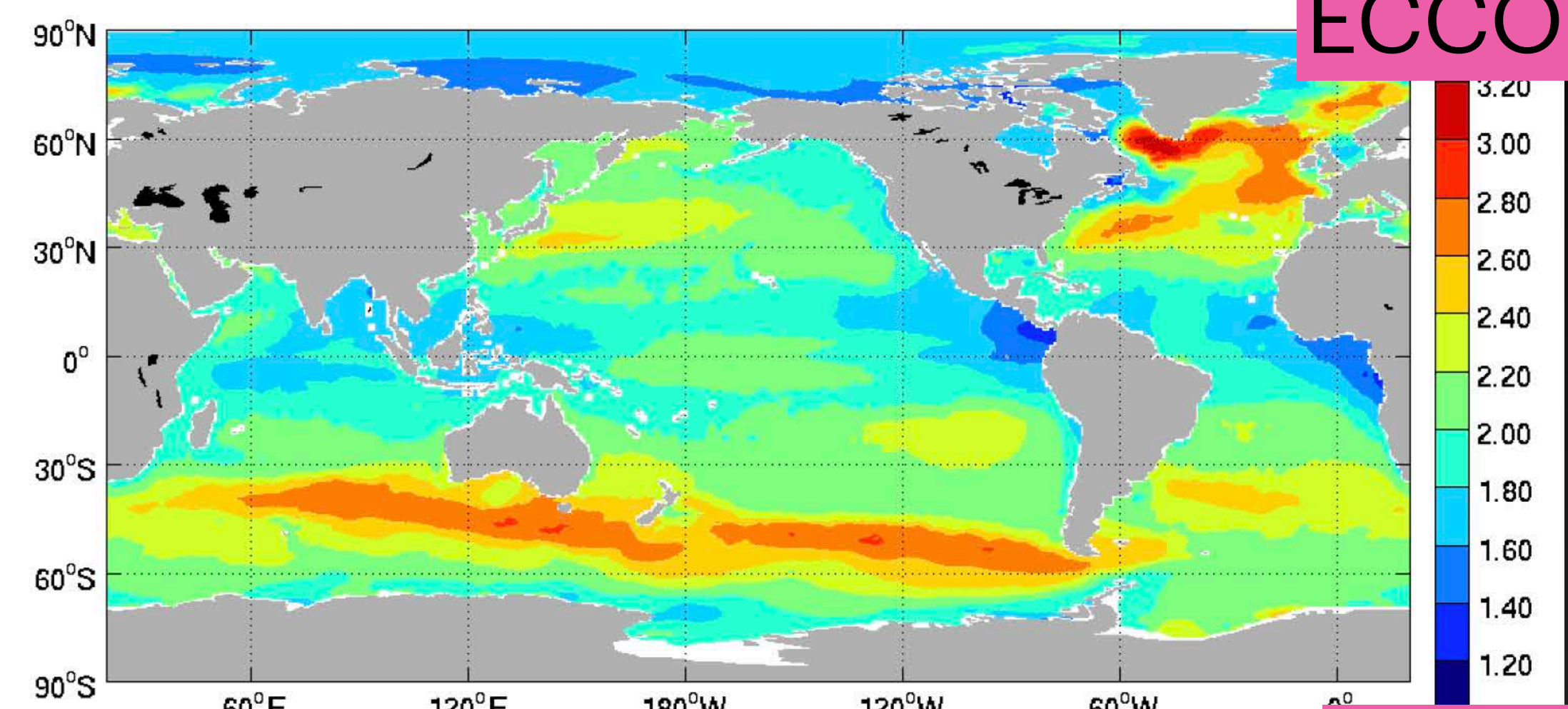
Argo stratification at 300m
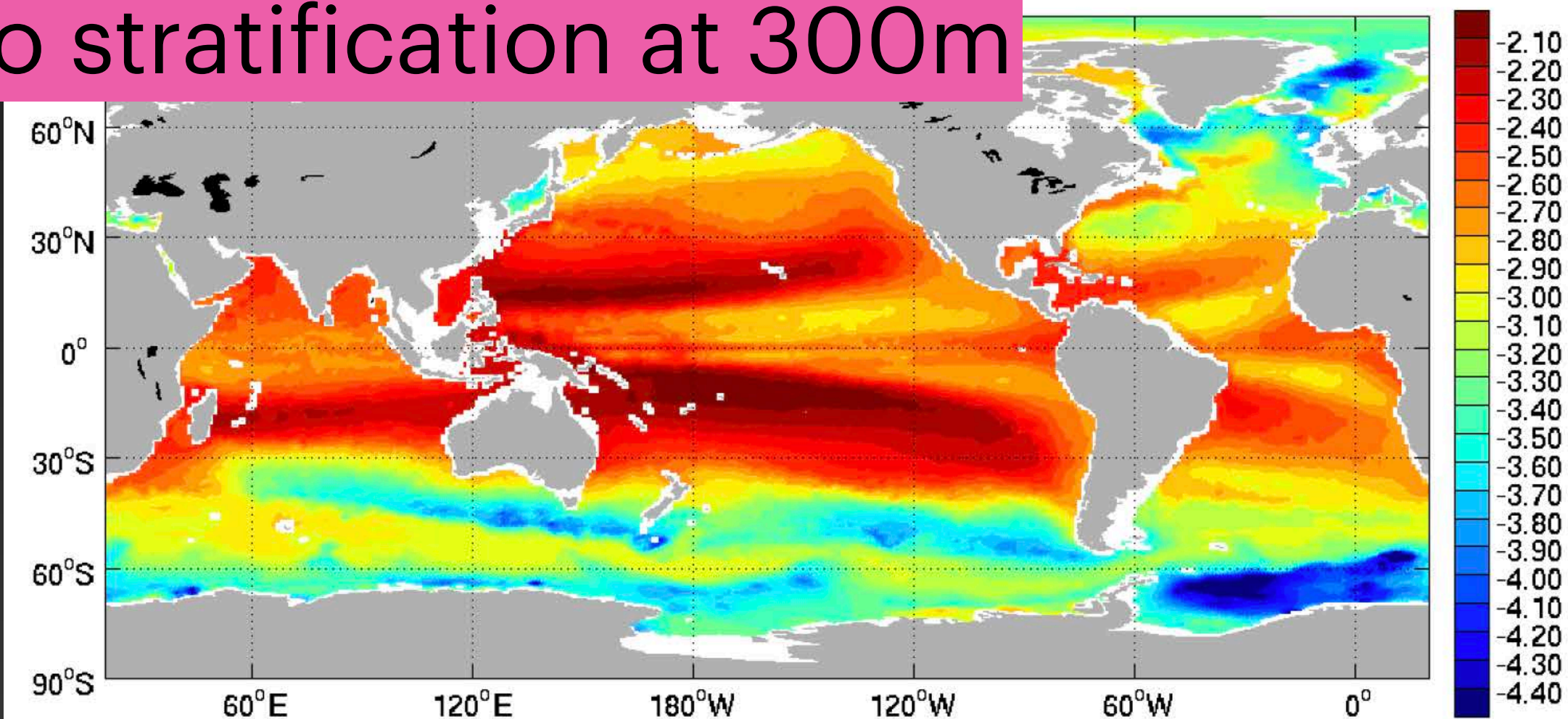
Argo MLD
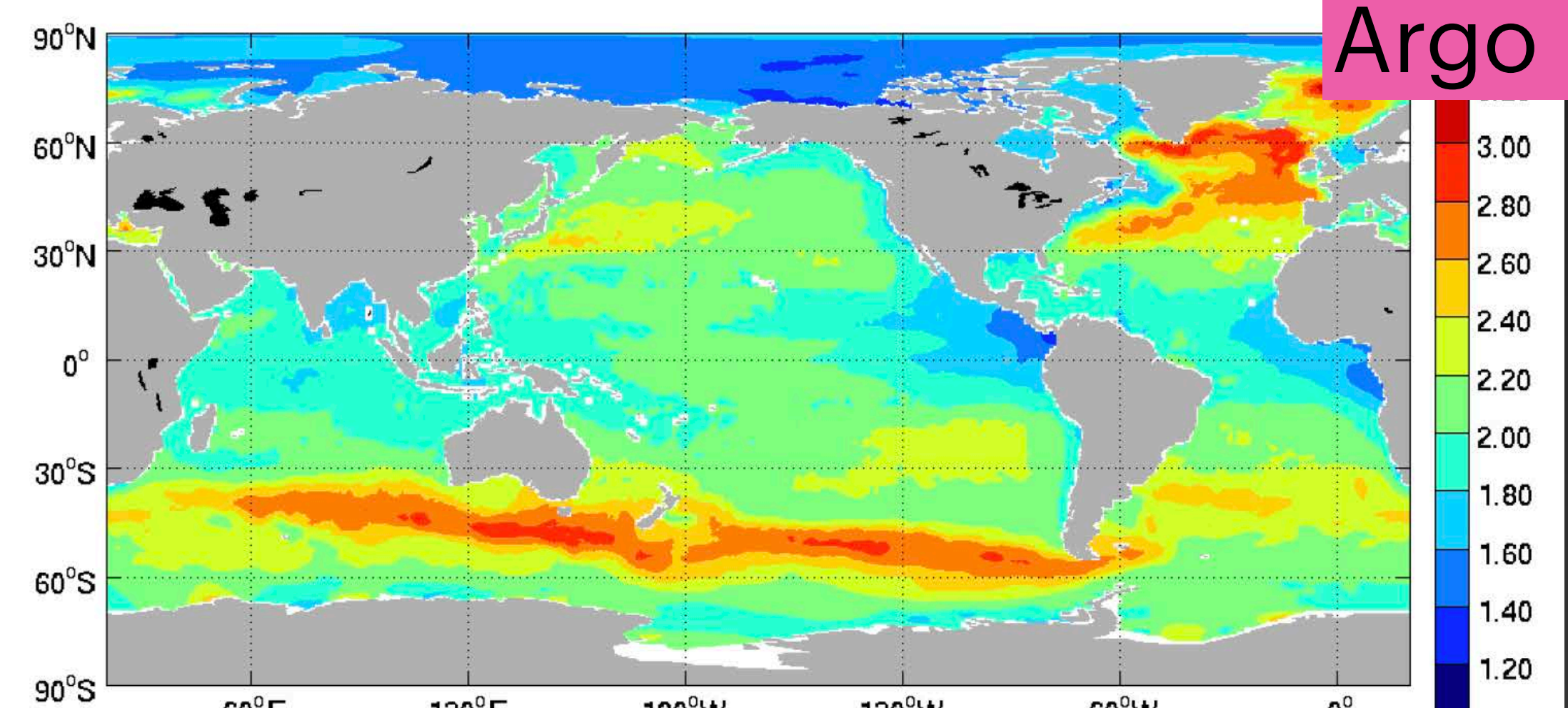
Forget et al 2015   Forget et al 2011   Forget & Wunsch 2008

... for 200m depth and other relevant variables
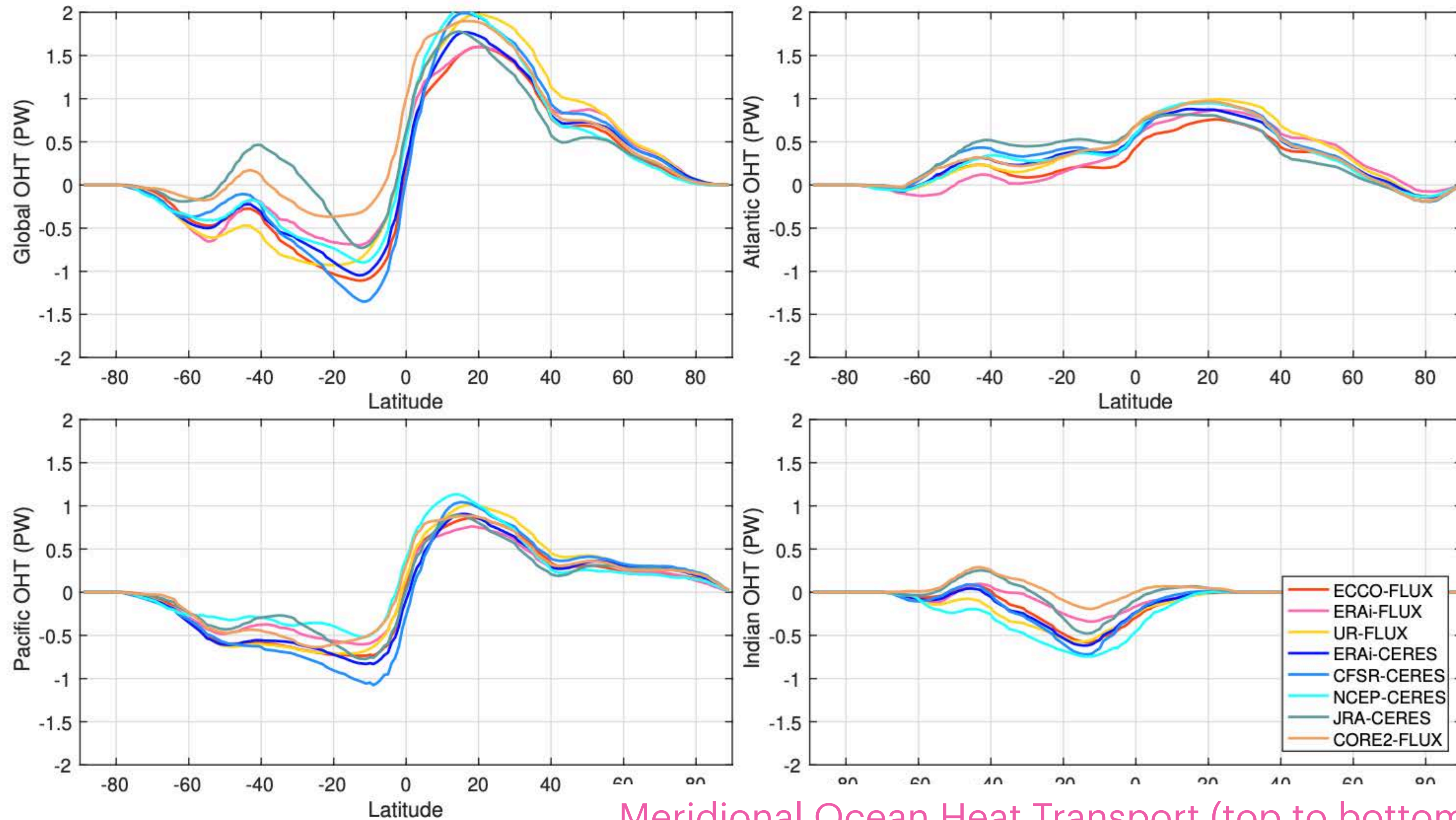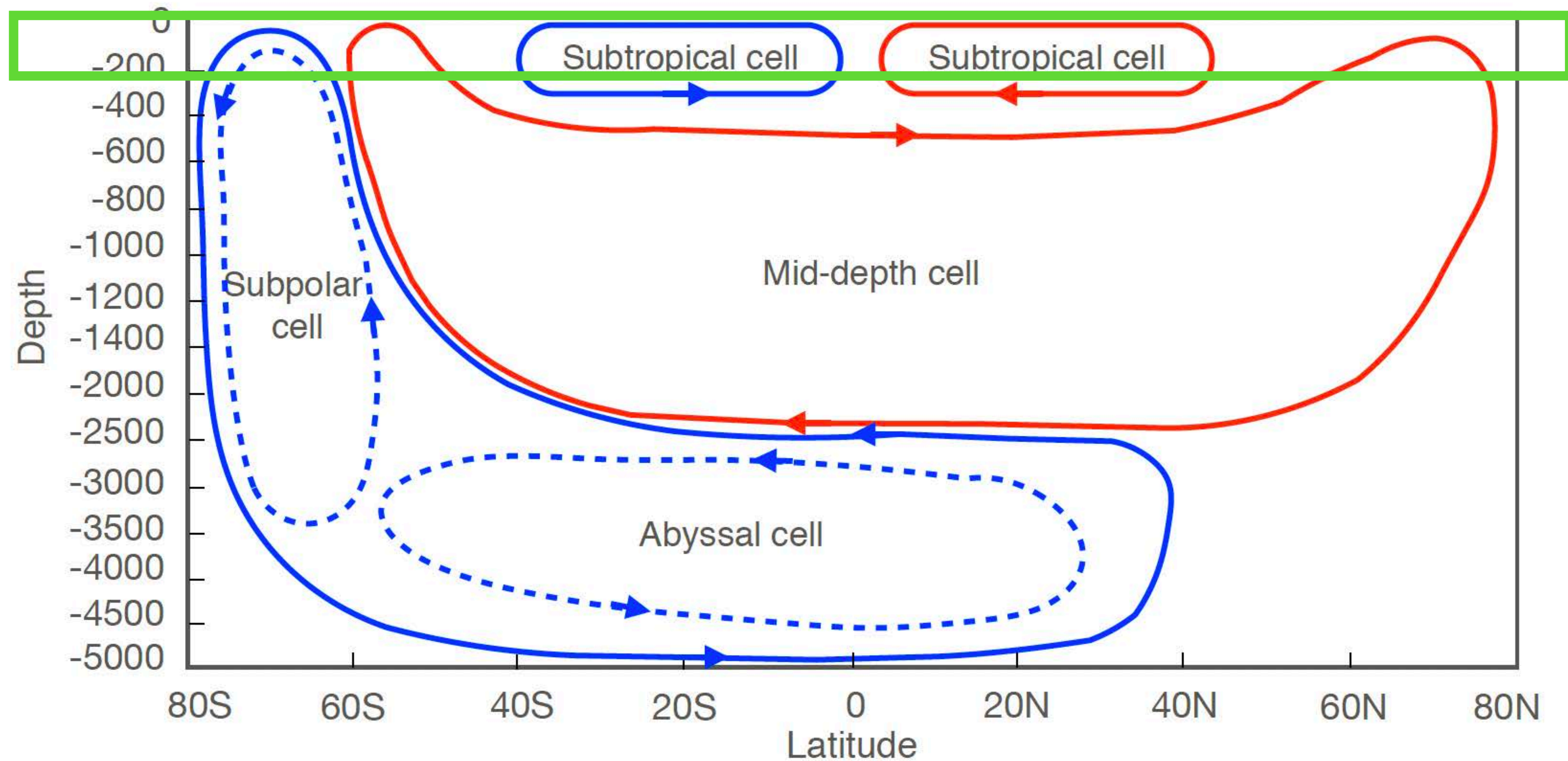
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Reanalyses Intercomparison

+0.5

-0.5

degree

0.0

2000

2010

1993-2019

EN4　　GFDL_ECDA　　GONDOLA100A　　UR025　　ECCOv4r2　　ECCOv4r4
GECCO2　　GLORYS2V4　　ORAS5　　cglorsv7　　ECCOv4r3　　ECCOv4r5_rc2

Forget (in prep)　　*Jackson et al 2019*　　Surface Layer

Reanalyses Intercomparison

+0.2

-0.2

1993-2019

200m depth

Forget (in prep)   Jackson et al 2019

Reanalyses Intercomparison

+0.05

-0.05

degree

0.00

-0.10

2000

2010

1993-2019

EN4   GFDL_ECDA   GONDOLA100A   UR025   ECCOv4r2   ECCOv4r4
GECCO2   GLORYS2V4   ORAS5   cglorsv7   ECCOv4r3   ECCOv4r5_rc2

1000m depth

Forget (in prep)   *Jackson et al 2019*
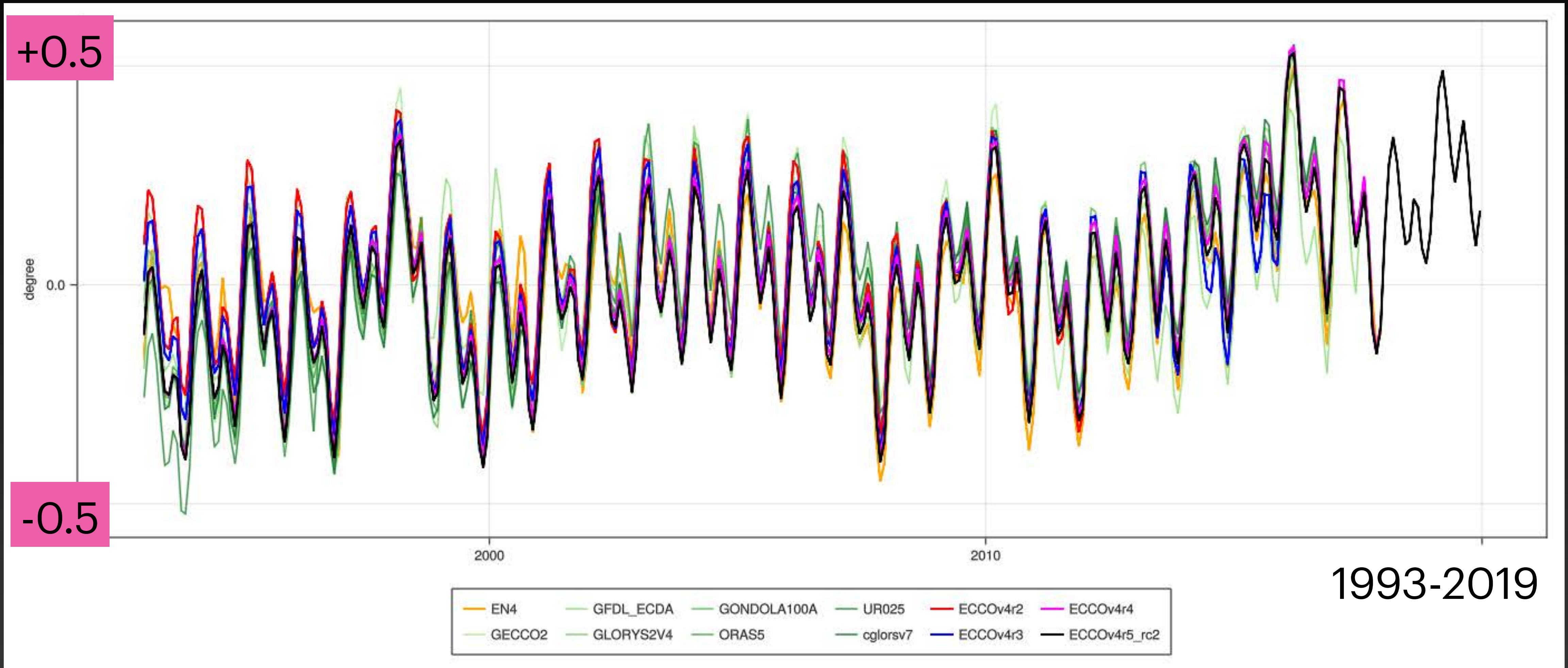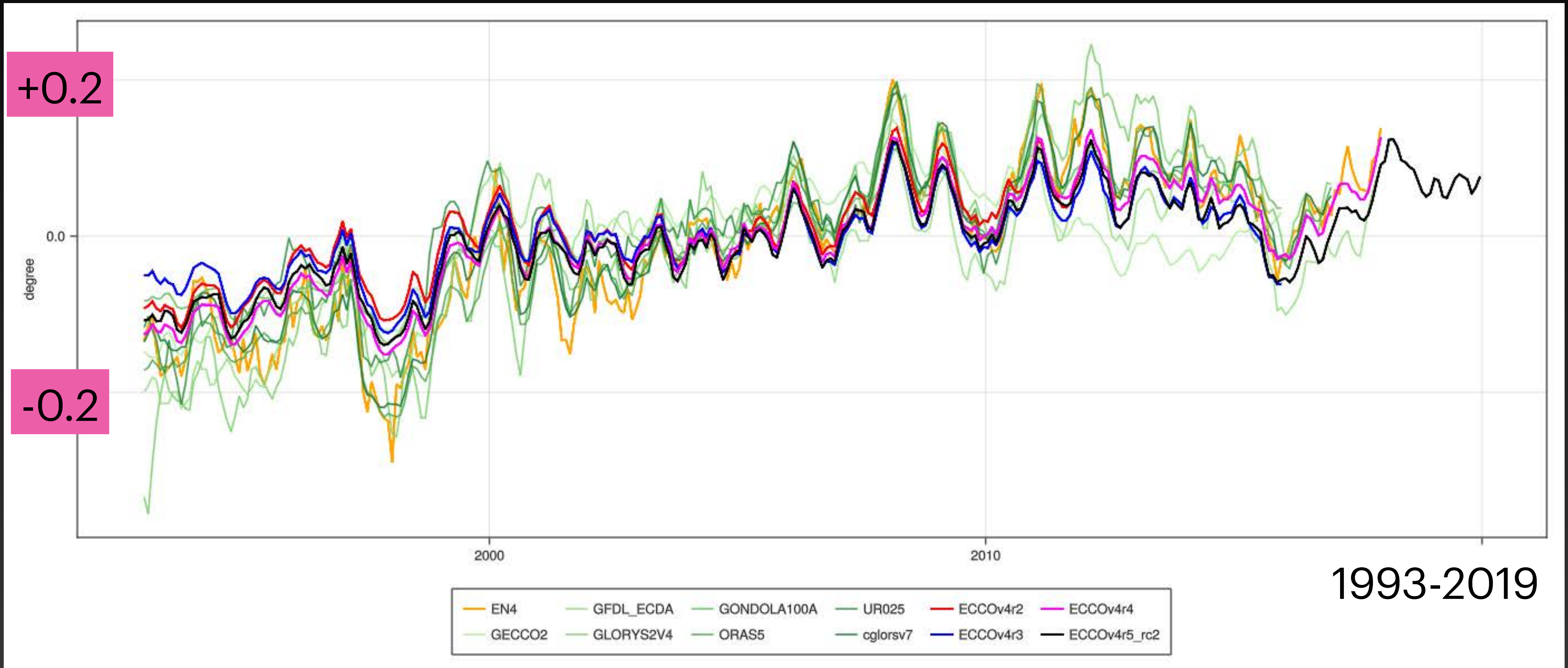
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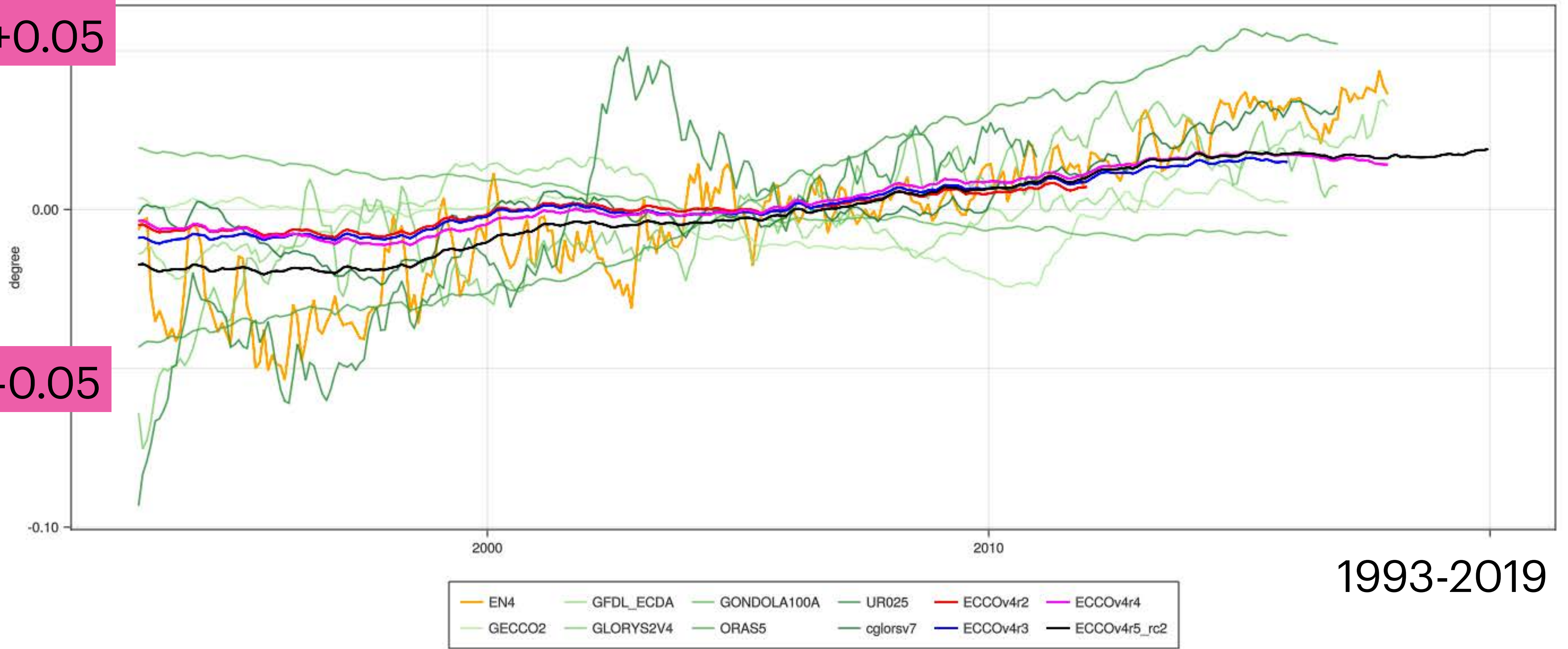
- Take home message & questions

4O-Year Record of SST from NCEI

OISST anomaly

Forget (in prep)

28-Year Record of SST & T$_{200}$ from ECCO

Forget (in prep)

Stratification vs Heat Content

SST

Potential Temperature (degree C) -- minus 1992-2011 monthy mean -- at -5m

T$_{200}$

Potential Temperature (degree C) -- minus 1992-2011 monthy mean -- at -195m

surface layer - 200m depth
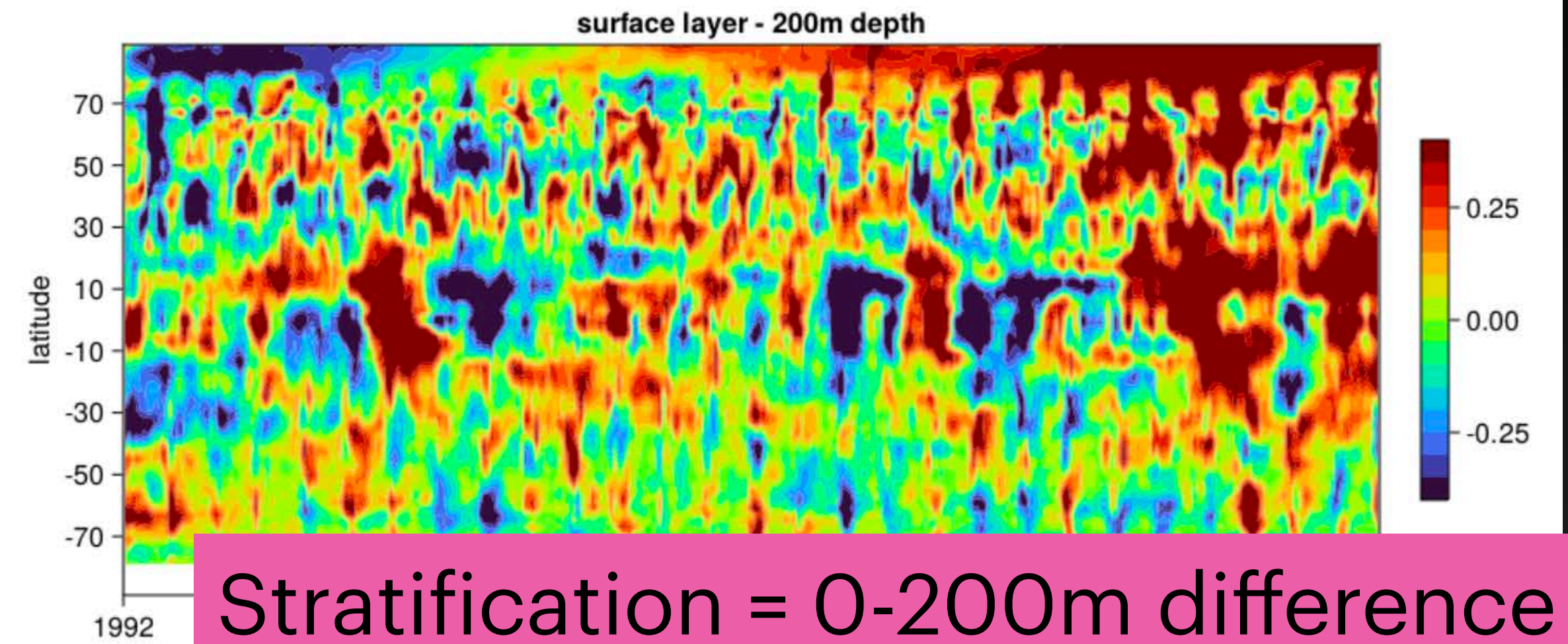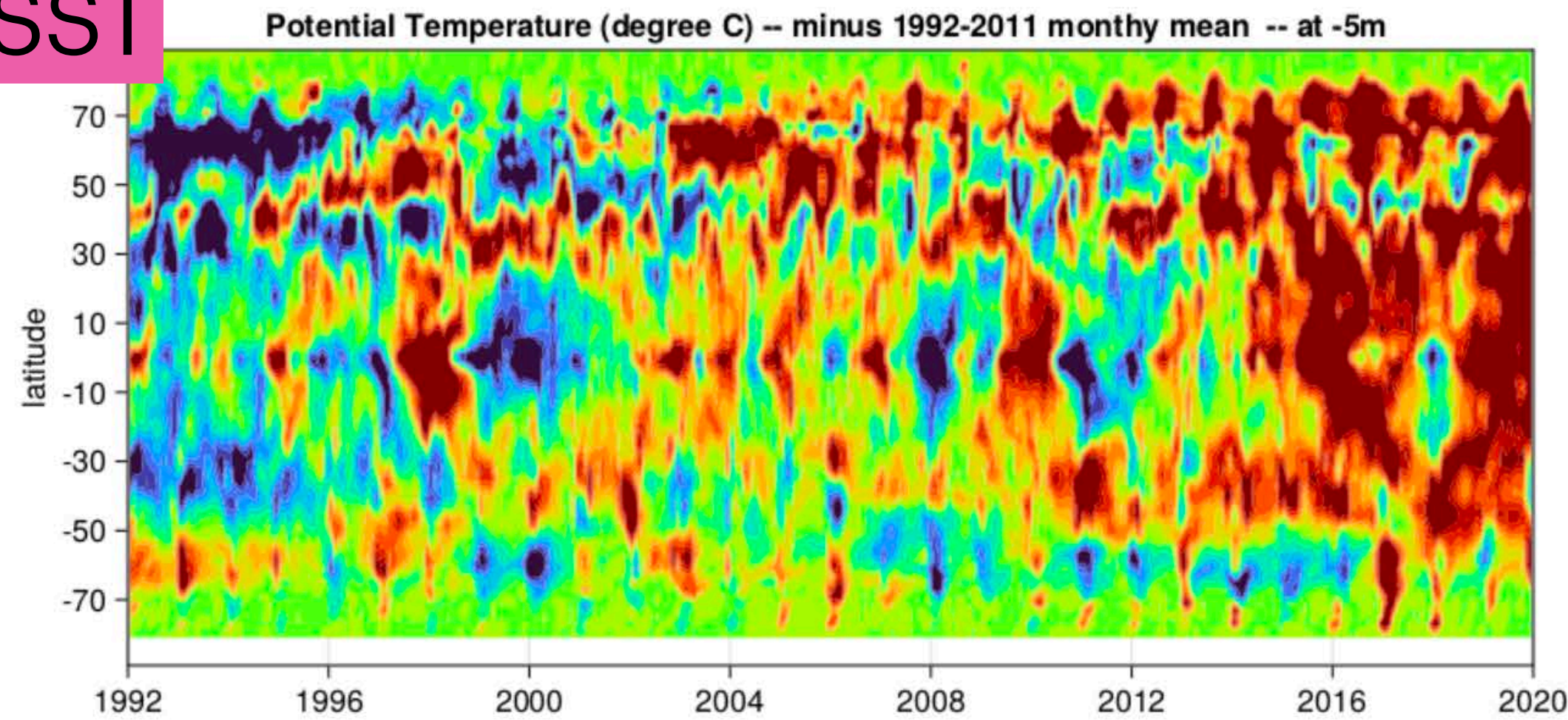
Stratification = 0-200m difference

surface to 200m depth average
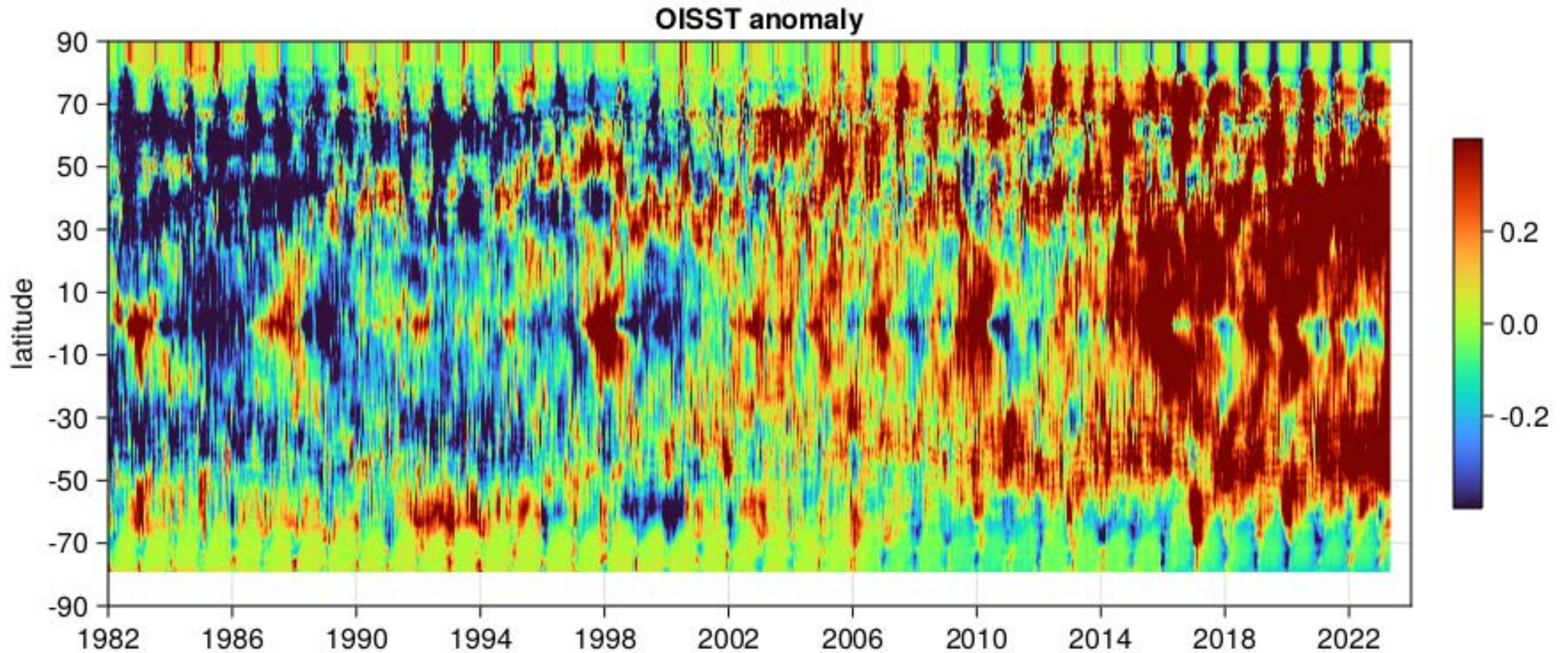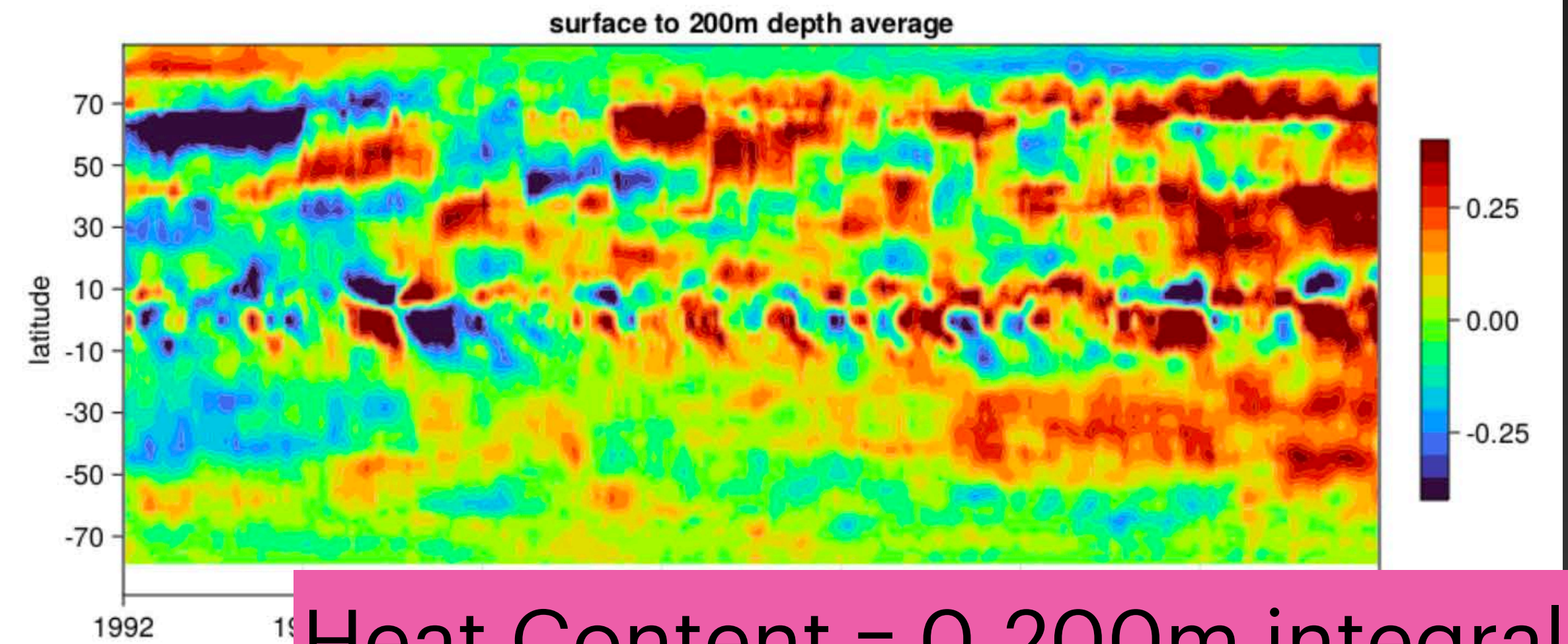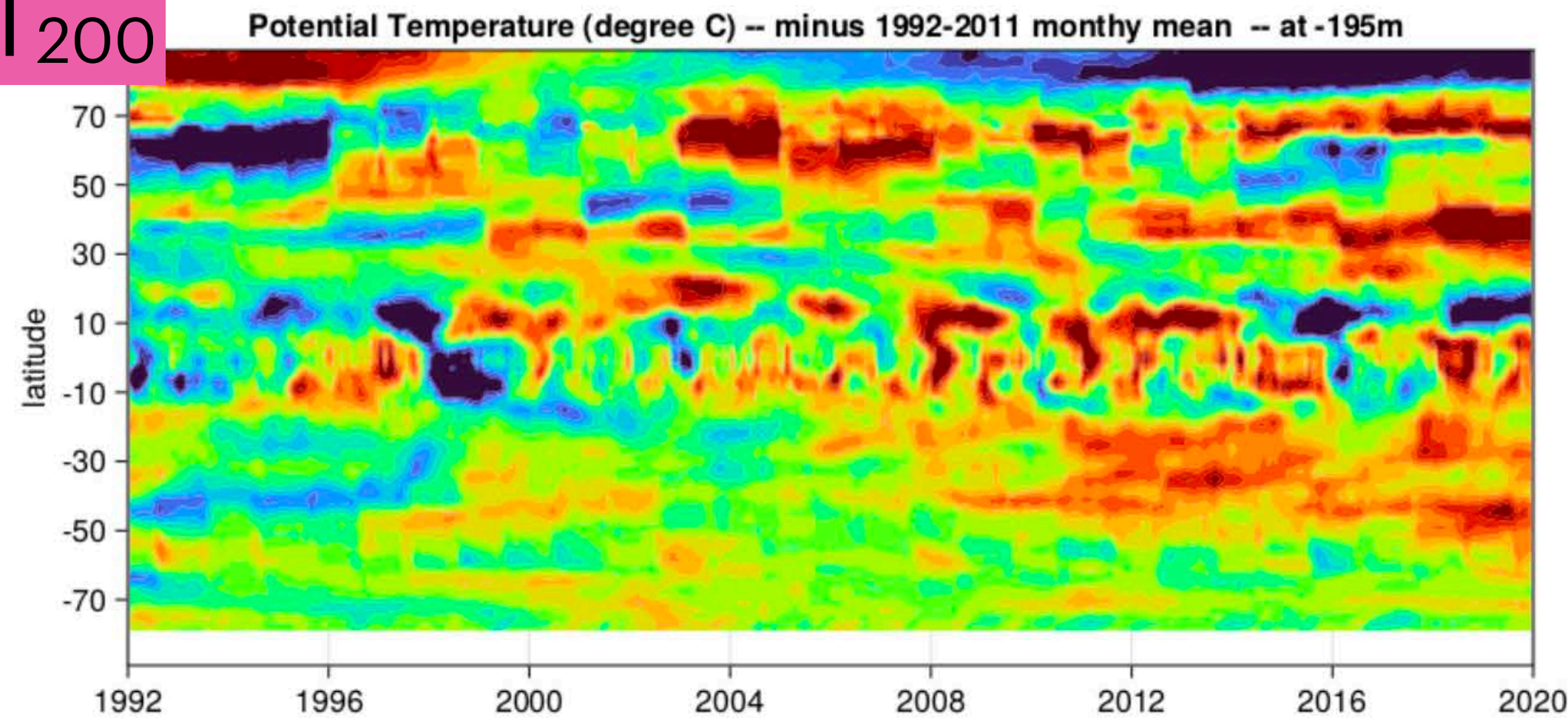
Heat Content = 0-200m integral
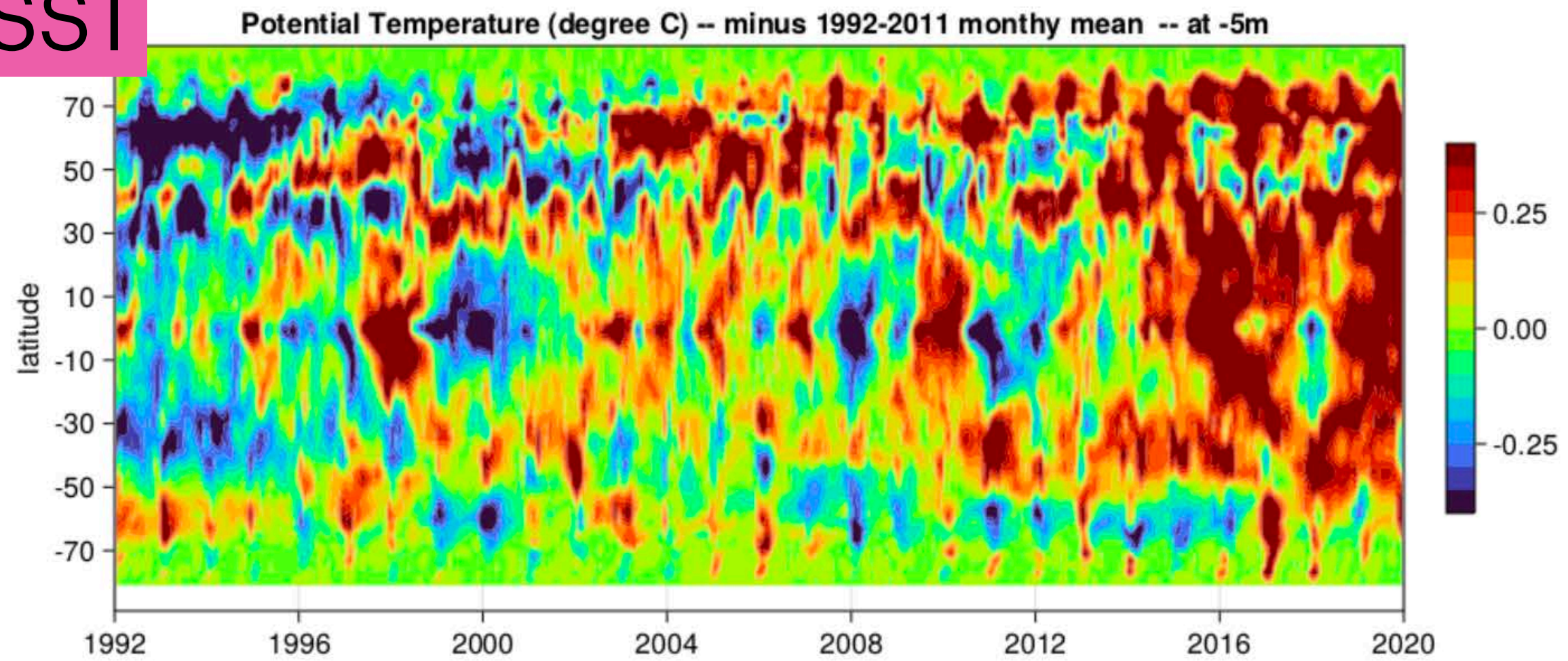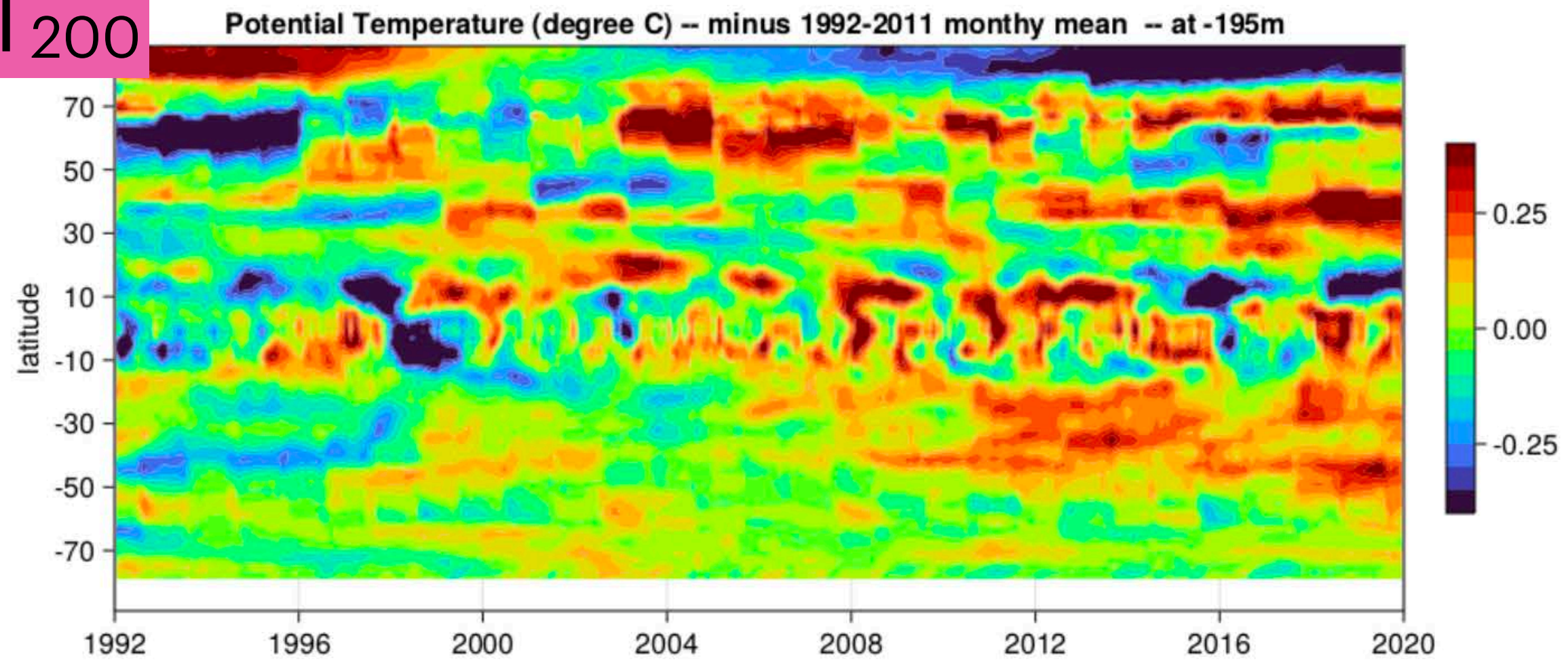
Forget (in prep)

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Take Away Messages

- Global mean SST(t) and T_{200}(t) seem robust across reanalyses — ranging from EN4, to sequential data assimilation, and to ECCO.

- SOL-EI : heat convergence between 0 and 200m depth in ECCO is proposed as initial estimate of Energy Imbalance in the Sunlit Ocean Layer.

- Important impacts of EEI are likely playing out right now in the SOL (incl. on marine ecosystems, marine heat waves, and major climate feedbacks).

- SST(t) reflects stratification changes while T_{200}(t) may be a better proxy for heat storage change in the SOL.

- ECCO provides lateral transports & pathway estimates to help decipher SOL-EI as well as the sequestration of EEI in the deep ocean.

Postdoc position available