In-Situ Observations Within The ECCO Reanalysis Framework

2024 IQuOD/GTSPP/SOOP/XBT/IODE meeting

Gaël Forget

Bologna, Italy

2024/11/13

Outline

- What's ECCO?
- In-situ data in ECCO
- The growing ECCO community

ECCO Version 0 : the concept

Carl Wunsch, 1982, Acoustic Tomography and Other Answers

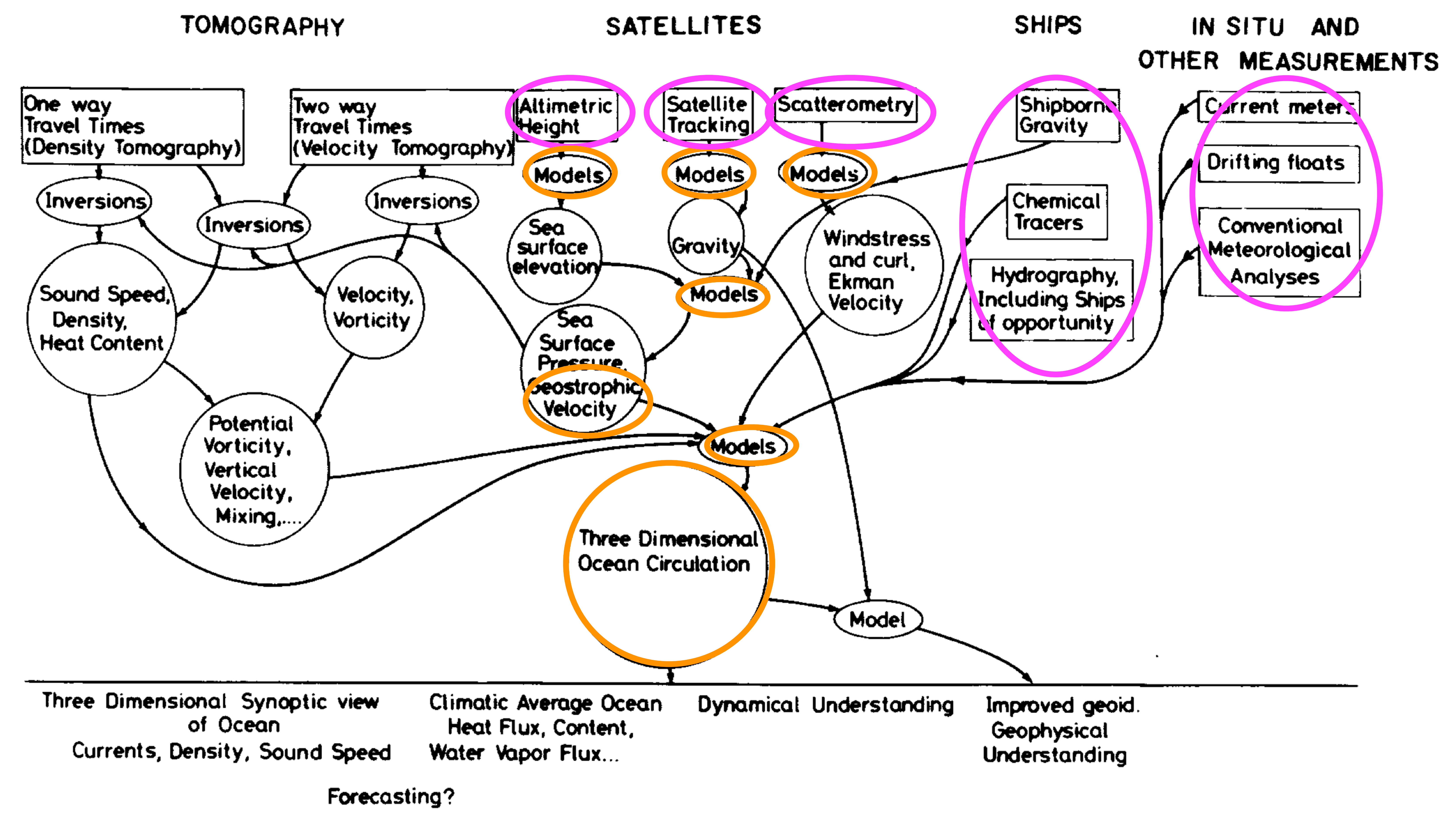

Figure 26. All measurements and models of the ocean can be interconnected to provide global estimates of the state of the three-dimensional ocean. Some side benefits accrue — e.g. improved estimates of the earth's gravity field.

Chapter in *A Celebration in Geophysics and Oceanography; In Honor of Walter Munk on his 65th birthday*

ECCO version 4 : the implementation

An integrated framework for non-linear inverse modeling and global ocean state estimation

Forget, Campin, Heimbach, Hill, Ponte, Wunsch, 2015

Included Observational Data

MDT	DNSC08 mean SSH minus EGM2008 geoid model	1993–2004	6.2×10^4
T, S	Blended monthly climatology		$2 \times 5.7 \times 10^8$
	OCCA	2004–2006	
	WOA 2005	Unclear	
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SLA	Daily bin average of along-track altimetry	1992–2011	7.7×10^7
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Data set	T profiles	S profiles
Argo	833 033	800 269
CTD	379 012	333 266
XBT	597 009	0
ITP	18 033	17 745
SEaOS	103 117	87 806
bobbers	7894	0
CTD	161	161

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$$\frac{\partial \boldsymbol{v}}{\partial t} + (f+\zeta)\hat{\boldsymbol{k}} \times \boldsymbol{v} + \nabla_{z^*}\mathrm{KE} + w\frac{\partial \boldsymbol{v}}{\partial z} + g\nabla_{z^*}\eta + \nabla_h \Phi' = \boldsymbol{D}_{z^*,\boldsymbol{v}} + \boldsymbol{D}_{\perp,\boldsymbol{v}} + \mathcal{F}_{\boldsymbol{v}}, \tag{1}$$

$$\frac{\partial \Phi'}{\partial z} = g\frac{\rho'}{\rho_c}, \tag{2}$$

$$\frac{1}{H}\frac{\partial \eta}{\partial t} + \nabla_{z^*}(s^*\boldsymbol{v}) + \frac{\partial w}{\partial z^*} = s^*\mathcal{F}, \tag{3}$$

$$\frac{\partial(s^*\theta)}{\partial t} + \nabla_{z^*}(s^*\theta\boldsymbol{v}_{\mathrm{res}}) + \frac{\partial(\theta w_{\mathrm{res}})}{\partial z^*} = s^*(\mathcal{F}_\theta + D_{\sigma,\theta} + D_{\perp,\theta}), \tag{4}$$

$$\frac{\partial(s^* S)}{\partial t} + \nabla_{z^*}(s^* S\boldsymbol{v}_{\mathrm{res}}) + \frac{\partial(S w_{\mathrm{res}})}{\partial z^*} = s^*(\mathcal{F}_S + D_{\sigma,S} + D_{\perp,S}),$$

Ocean Model

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Cost Function

$$J(\mathfrak{u}) = \sum_i \alpha_i \times \left(d_i^T \, \mathbf{R}_i^{-1} \, d_i\right) + \sum_j \beta_j \times \left(\mathfrak{u}_j^T \mathfrak{u}_j\right)$$

$$d_i = \mathcal{P}(m_i - o_i),$$
$$m_i = \mathcal{SDM}(\mathfrak{v}),$$
$$\mathfrak{v} = \mathcal{Q}(\mathfrak{u}),$$
$$\mathfrak{u} = \mathcal{R}(\mathfrak{u}'),$$

$$\frac{\partial \boldsymbol{v}}{\partial t} + (f + \zeta)\hat{\boldsymbol{k}} \times \boldsymbol{v} + \nabla_{z^*}\mathrm{KE} + w\frac{\partial \boldsymbol{v}}{\partial z} + g\nabla_{z^*}\eta + \nabla_h \Phi' = \boldsymbol{D}_{z^*,\boldsymbol{v}} + \boldsymbol{D}_{\perp,\boldsymbol{v}} + \mathcal{F}_{\boldsymbol{v}}, \quad (1)$$

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Optimized Parameters

Initial condition for temperature	N/A	2.4×10^6
Initial condition for salinity	N/A	2.4×10^6
Diapycnal diffusivity	Time mean	2.4×10^6
Isopycnal diffusivity	Time mean	2.4×10^6
GM intensity	Time mean	2.4×10^6
Atmospheric temperature at 2 m	Bi-weekly	3.2×10^7
Specific humidity at 2 m	Bi-weekly	3.2×10^7
Precipitation	Bi-weekly	3.2×10^7
Downward longwave radiation	Bi-weekly	3.2×10^7
Downward shortwave radiation	Bi-weekly	3.2×10^7
Zonal wind stress	Bi-weekly	3.1×10^7
Meridional wind stress	Bi-weekly	3.1×10^7

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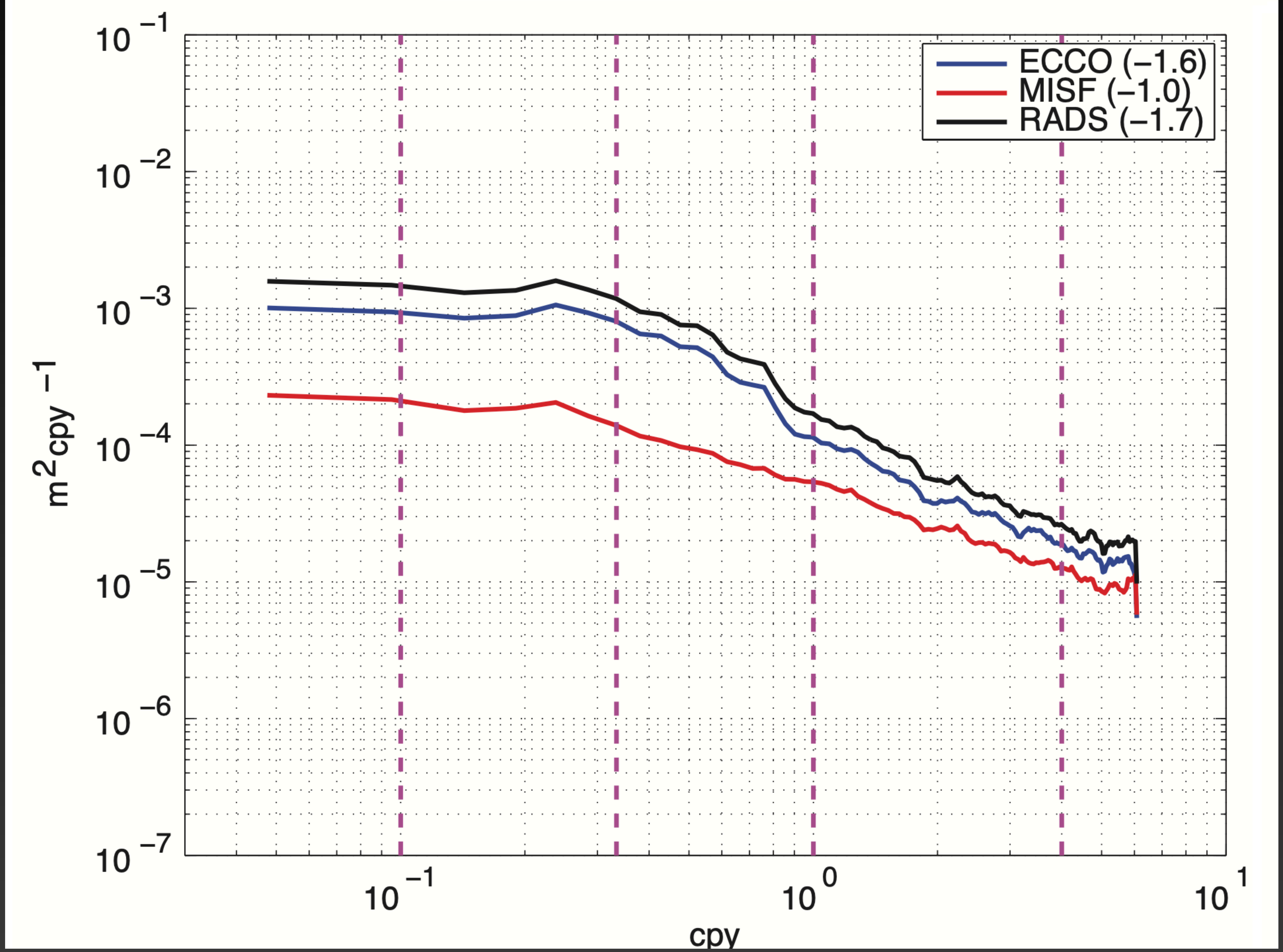
The partition of regional sea level variability

Forget and Ponte, *progress in oceanography*, 2015

Large Scale



1. Compute local frequency spectra; 2. Global average of frequency spectra

The partition of regional sea level variability

Forget and Ponte, *progress in oceanography*, 2015

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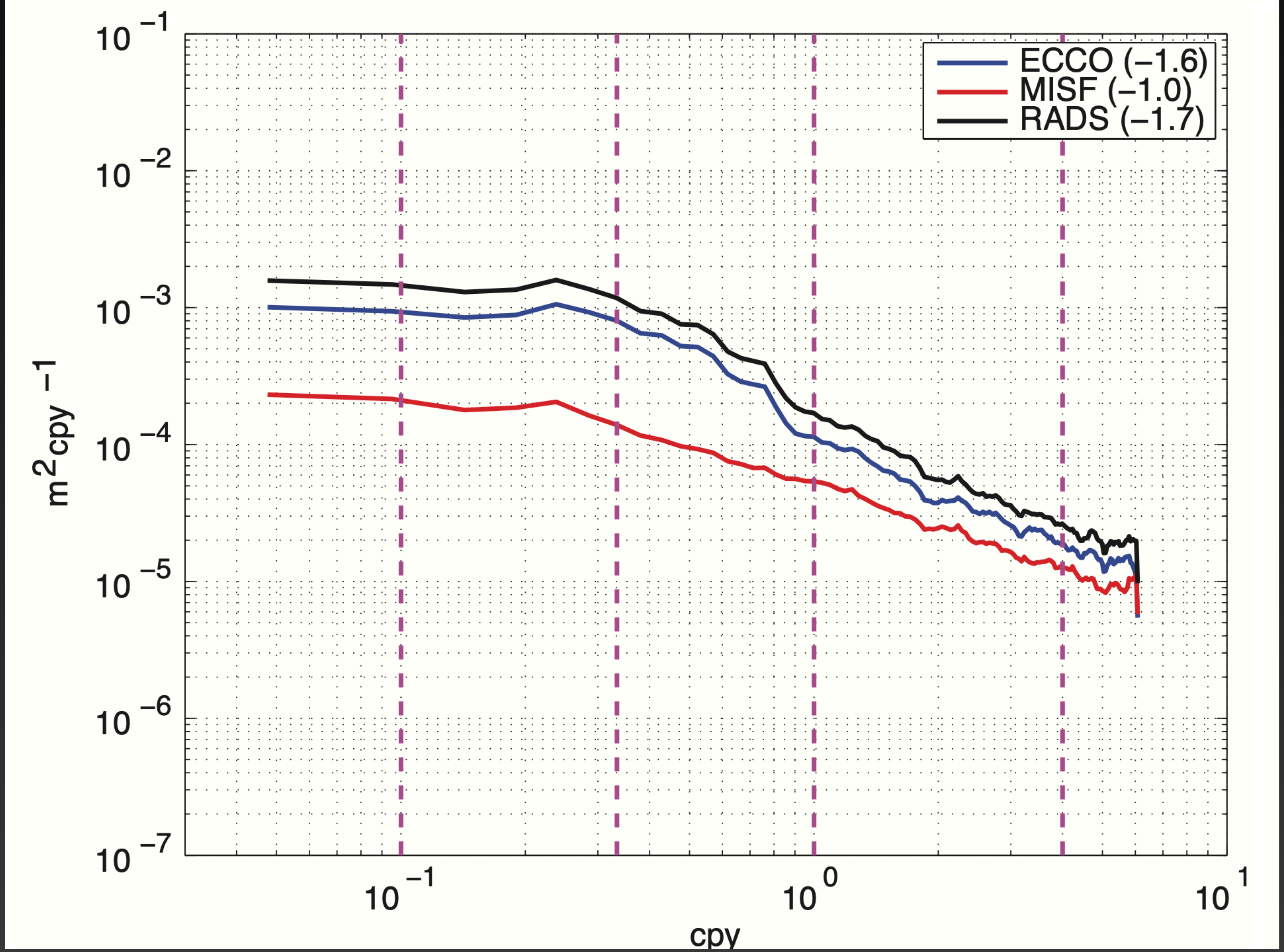
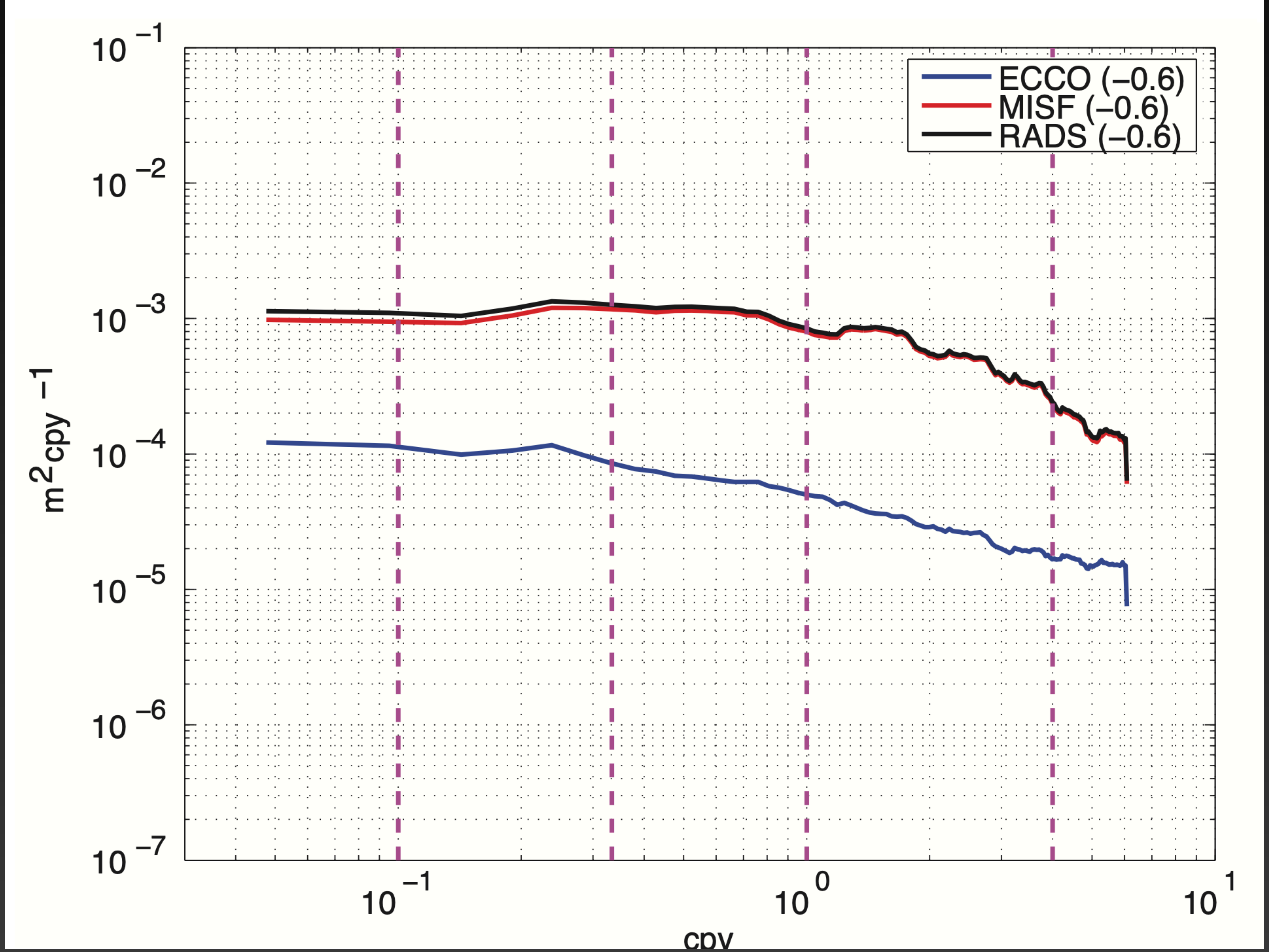


Meso Scale



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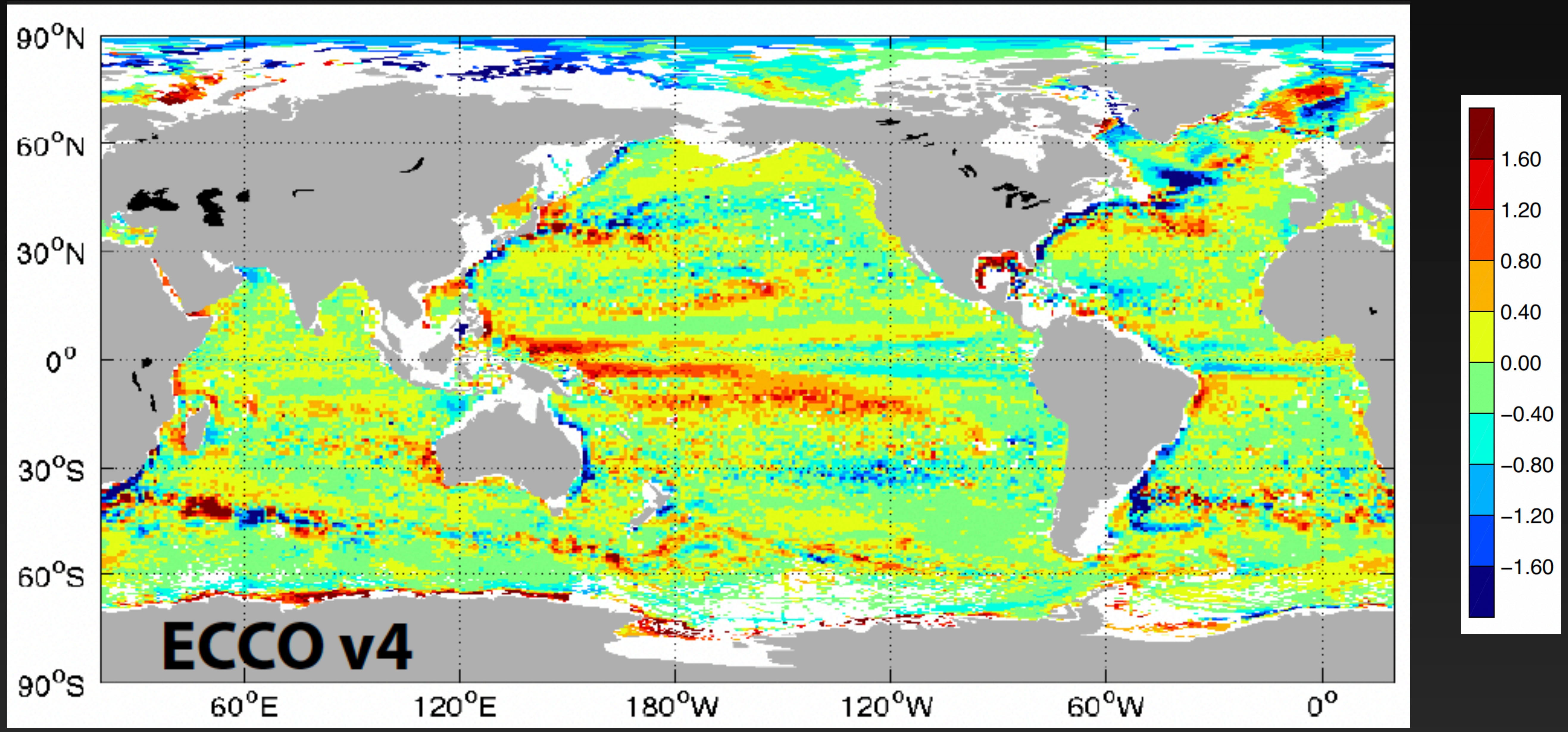
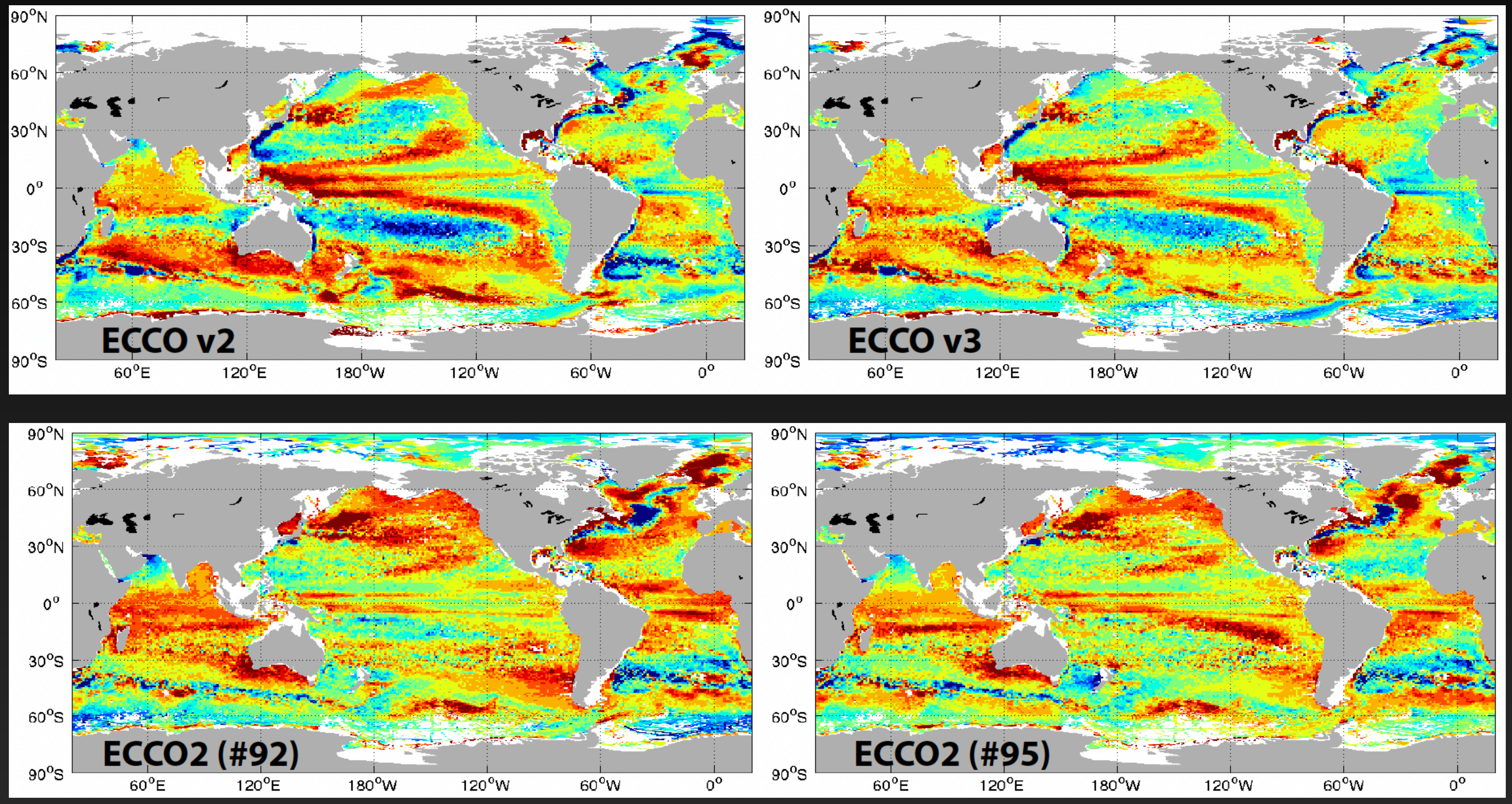
Improved fit to Argo in ECCO4

by optimizing *mixing* parameters



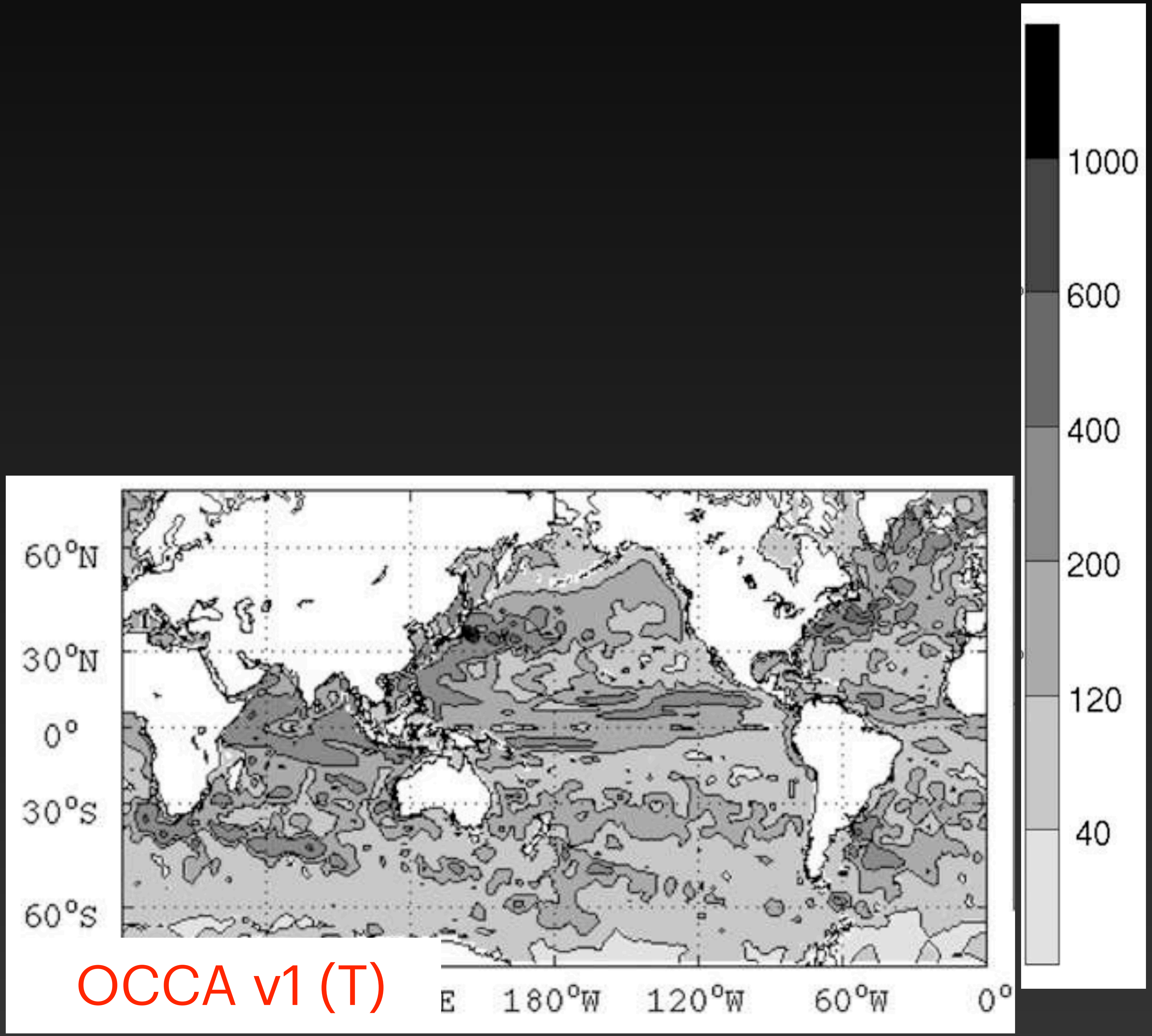


Temperature Misfits (ECCO minus Argo+)

- Forget et al 2015a , https://doi.org/10.5194/gmd-8-3071-2015
- Forget et al 2015b , https://doi.org/10.5194/os-11-839-2015

Mapping Ocean Observations in a Dynamical Framework: A 2004–06 Ocean Atlas

Forget, JPO, 2010



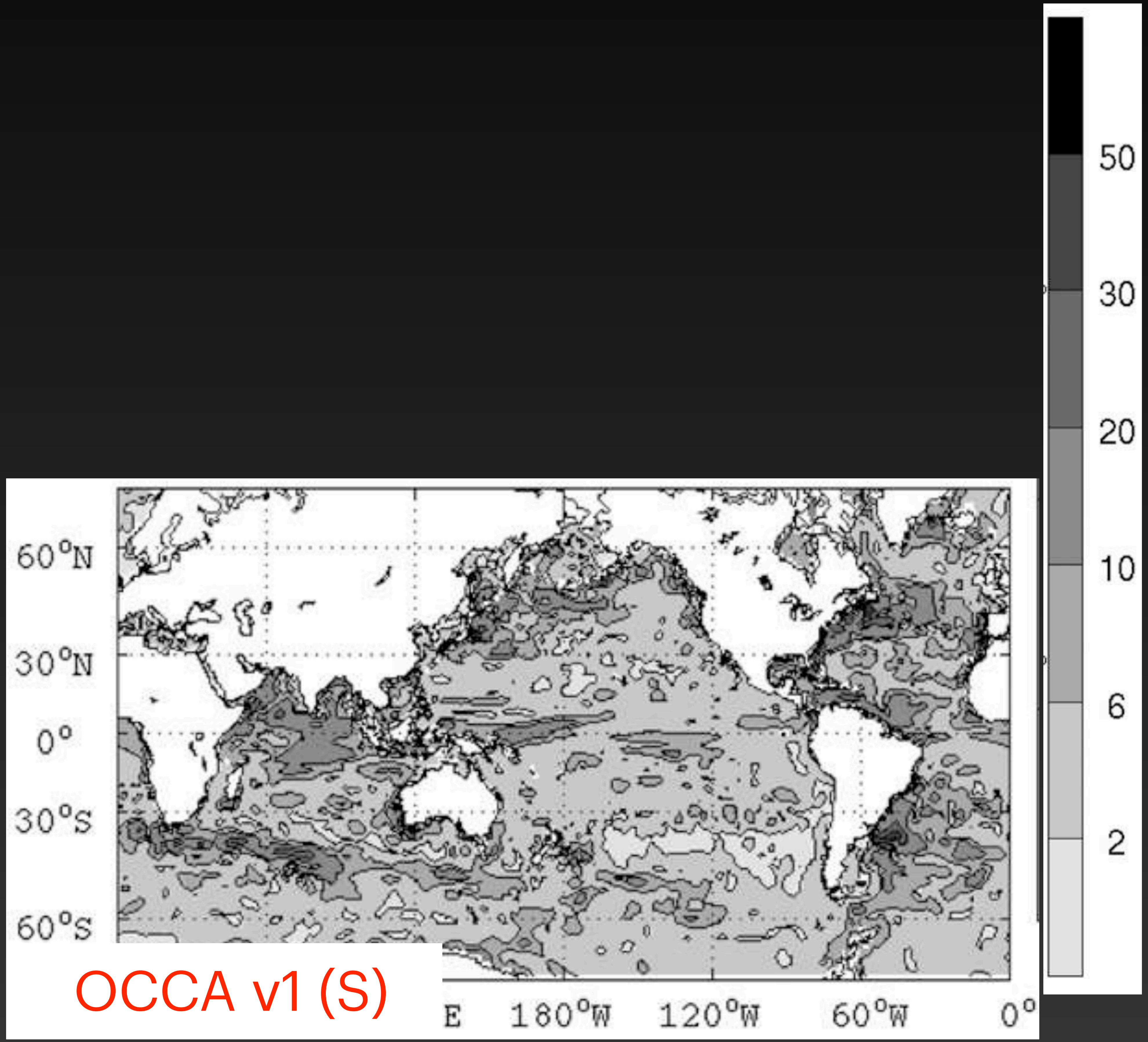


FIG. 14. Magnitude of the flux divergence fluctuation that is implied by the seasonal cycle of the vertically integrated (left) heat (W m^{-2}) and (right) freshwater (mm day^{-1}) content, for (top) *WOA01*, (middle) Fourier truncated *WOA01* (see appendix A), and (bottom) OCCA. The implied fluxes diagnostic computation is $\|\Delta\mathcal{H}/\Delta t\|$, where $\Delta\mathcal{H}$ is the content difference from one month to the next, Δt is

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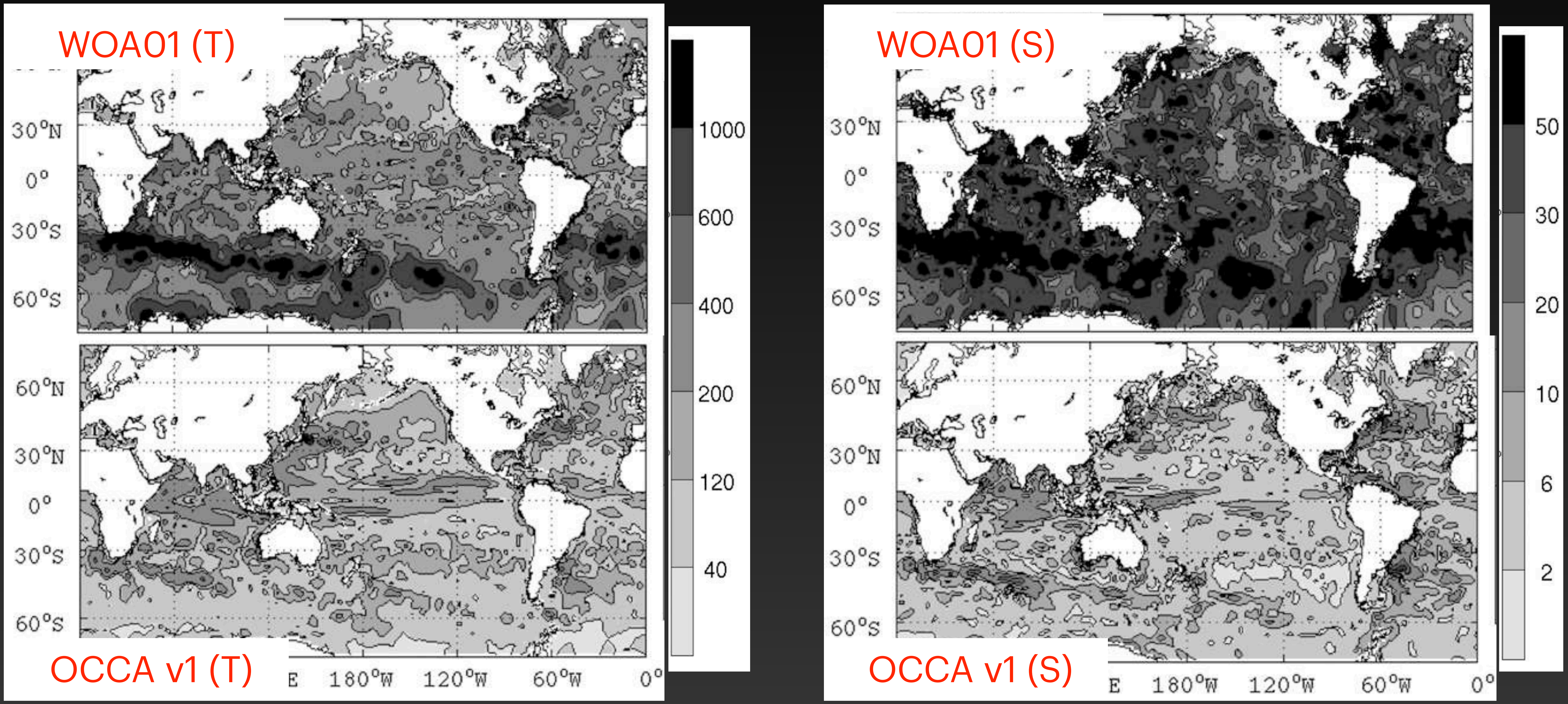

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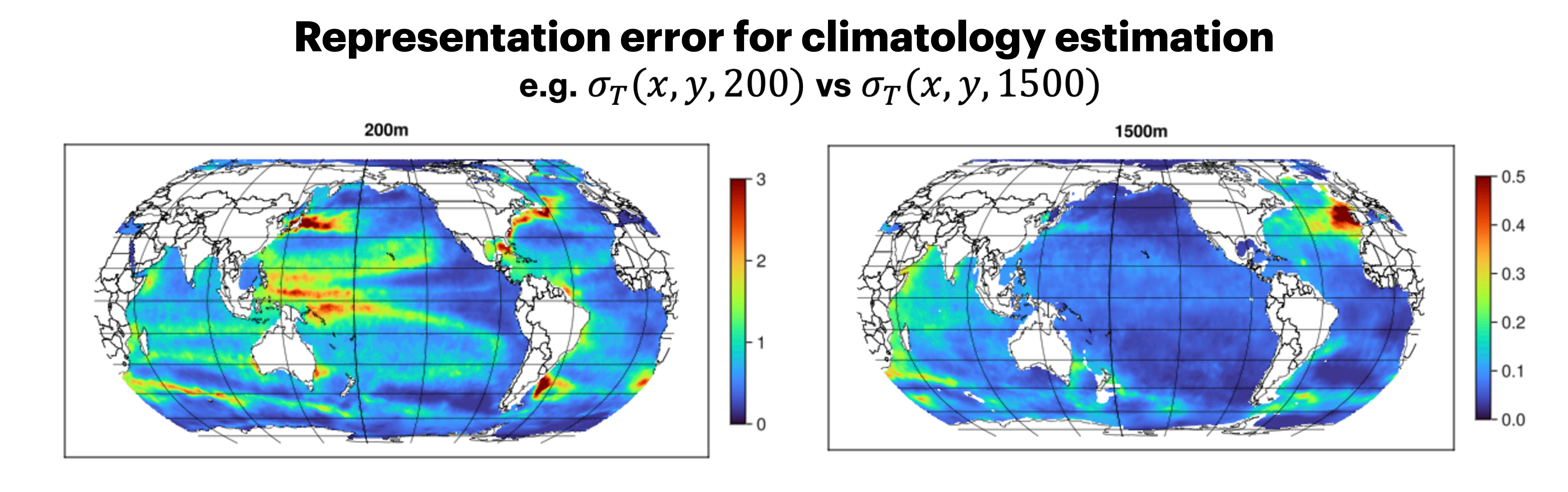
- In-Situ data in ECCO
- The growing ECCO community

In-situ T/S profiles in ECCO

Forget and Wunsch 2007 (updated)



In-situ T/S profiles in ECCO

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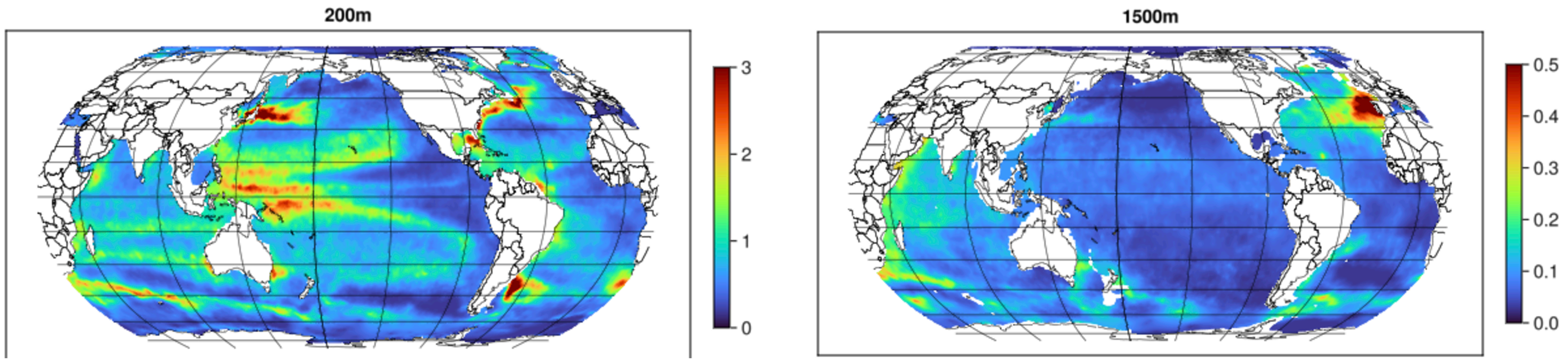
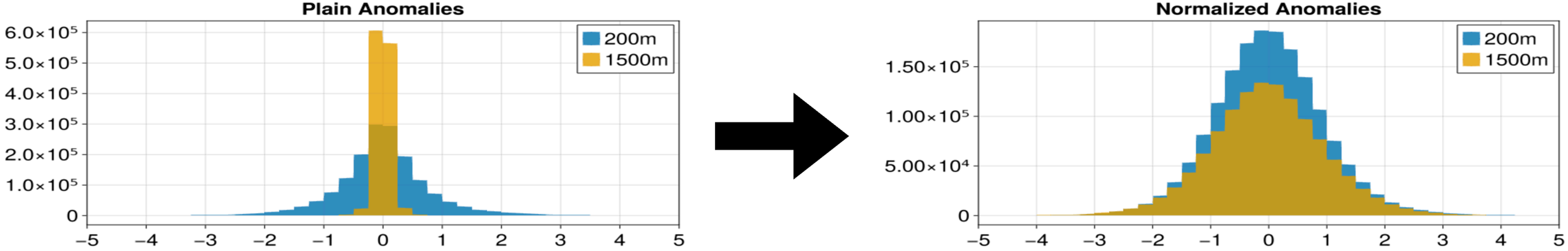
Representation error for climatology estimation

e.g. $\sigma_T(x, y, 200)$ **vs** $\sigma_T(x, y, 1500)$



Normalizing Anomalies

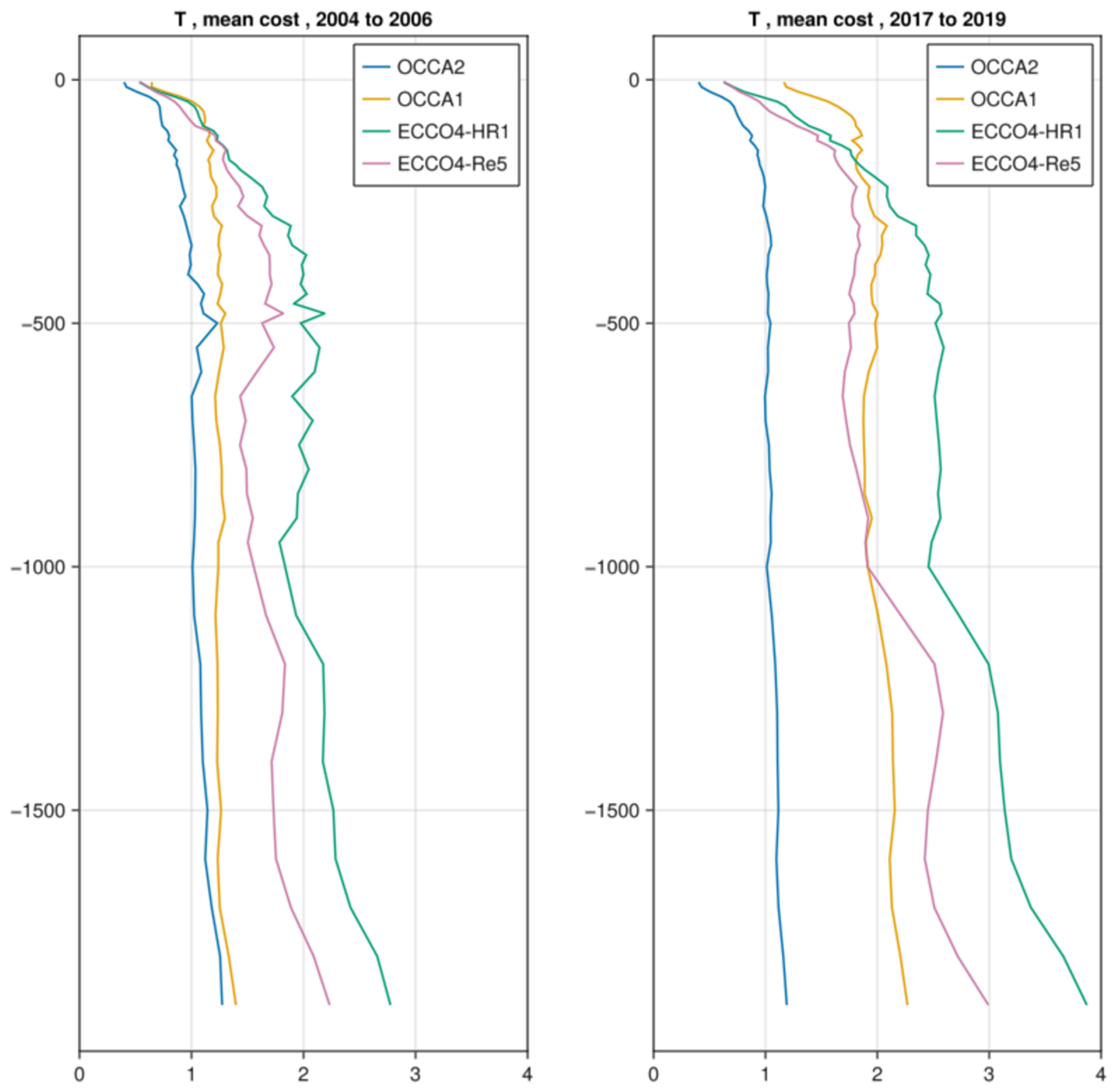
PDF of Climatology minus Argo



In-situ T/S profiles in ECCO

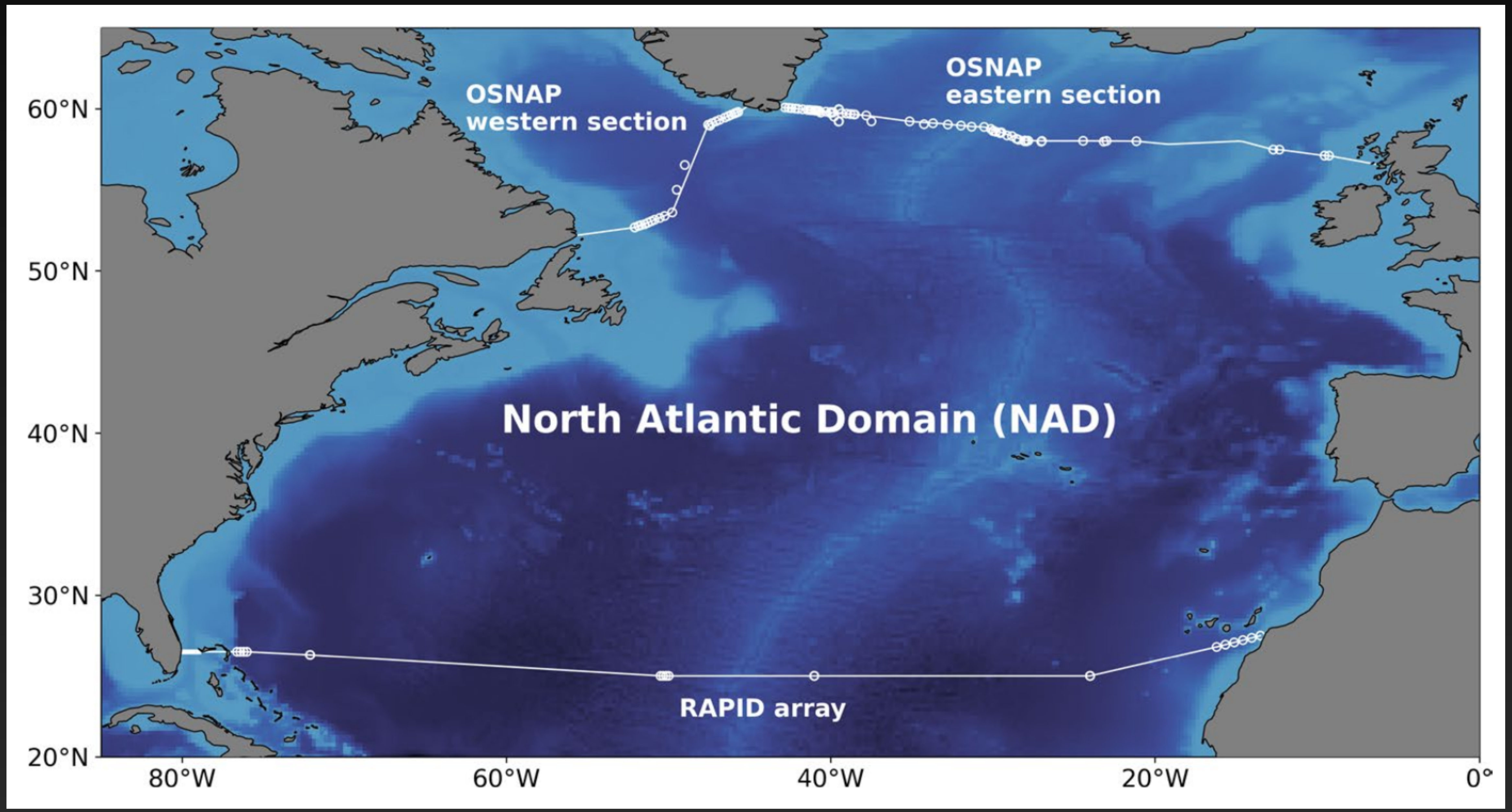
representation error and cost function for climatology estimation

- Goal : define normalized data-to-estimate distance (i.e., cost function)
- Representation Error = signal NOT well resolved by data or estimate
  - e.g., meso- and submeso-scale signals in Argo (3 degree resolution)
  - same signals in Argo objective mapping like IAP, NCEI, or ECCO
- Forget and Wunsch 2007 (Argo, or any T/S profile) :
  - estimate $\sigma_T^2 = \overline{(Tobs - Test)^2}$ via sample variance
  - Map out out $\sigma_T^2(x, y, z)$ via objective mapping
  - Cost function = $\overline{(T - Tobs)^2 / \sigma_T^2}$
- Other example : Forget & Ponte 2015 (altimetry)
- Use Cases : Forget 2011 (OCCA), Forget et al 2015 (ECCO4)
- Work in Progress :
  - Monthly mapping $\sigma_T^2(x, y, z, t)$ for 0-2000m
  - Subtract ECCO, rather than climatology, as $Test$



Uncertainty Quantification via Ensembles

Ocean Heat Transport Estimates



Meyssignac, B., S. Fourest, Michael Mayer, et al.

North Atlantic Heat Transport Convergence Derived from a Regional Energy Budget Using Different Ocean Heat Content Estimates

Surveys in Geophysics, 2024

Uncertainty Quantification via Ensembles

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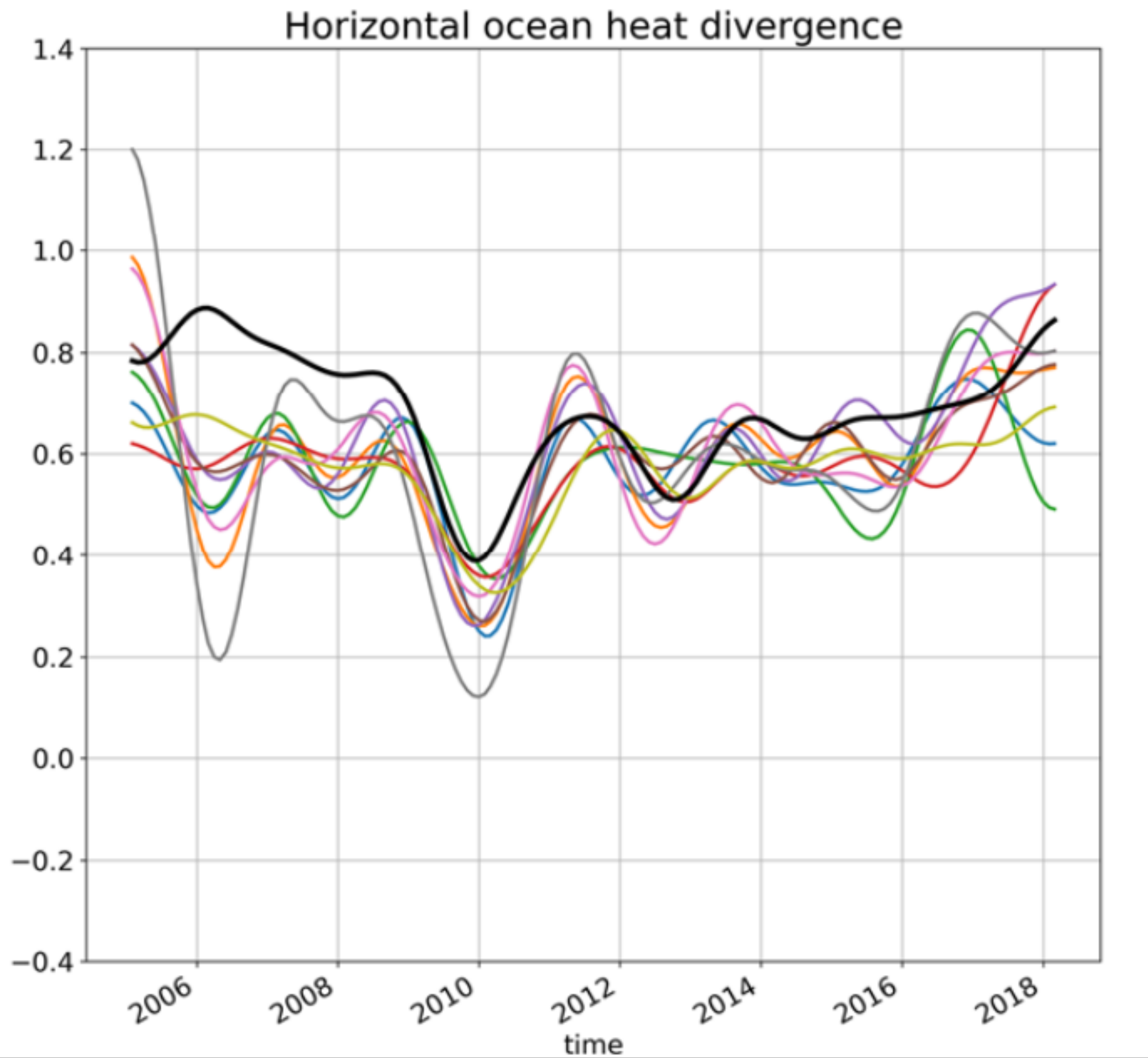

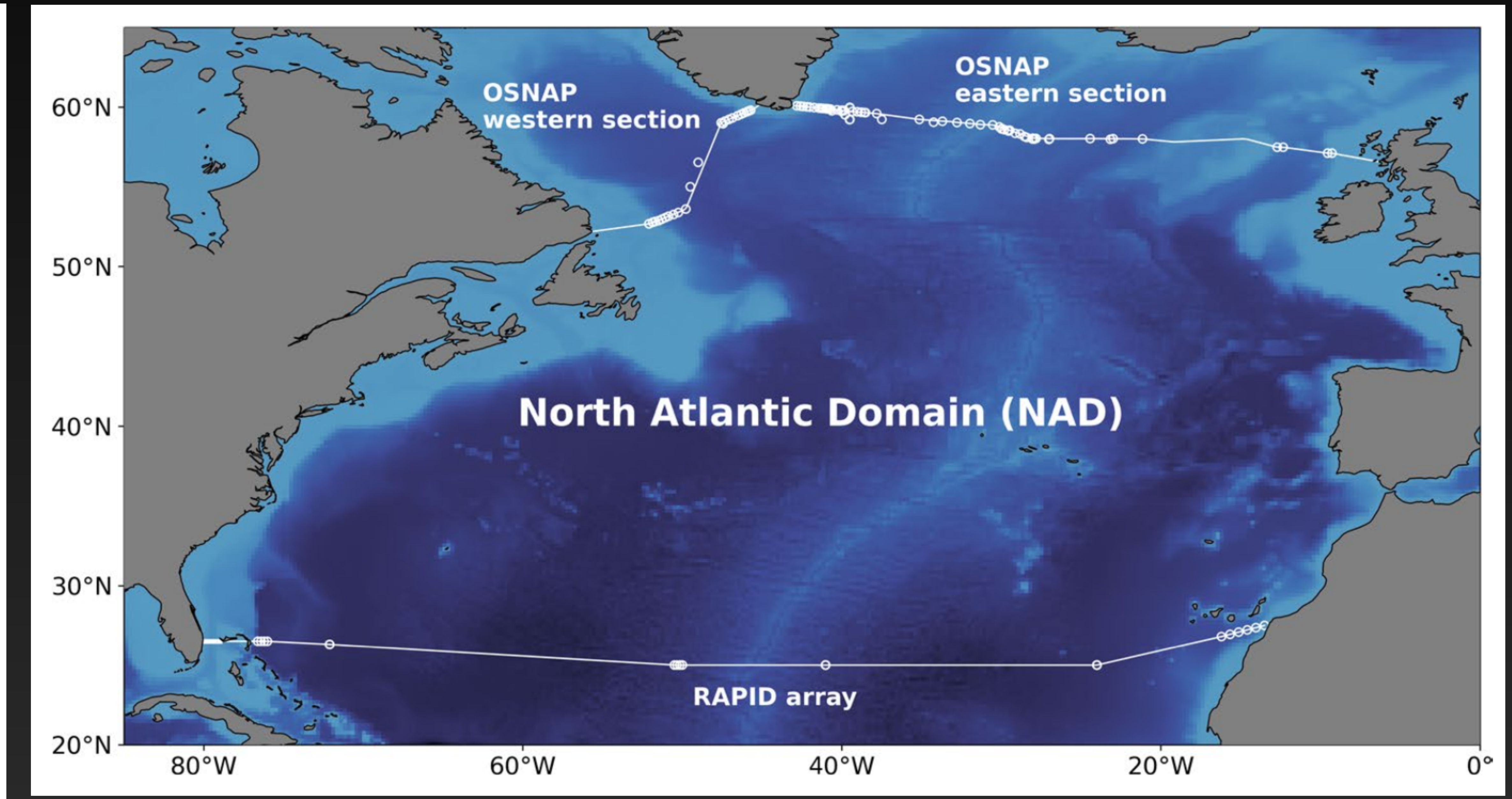

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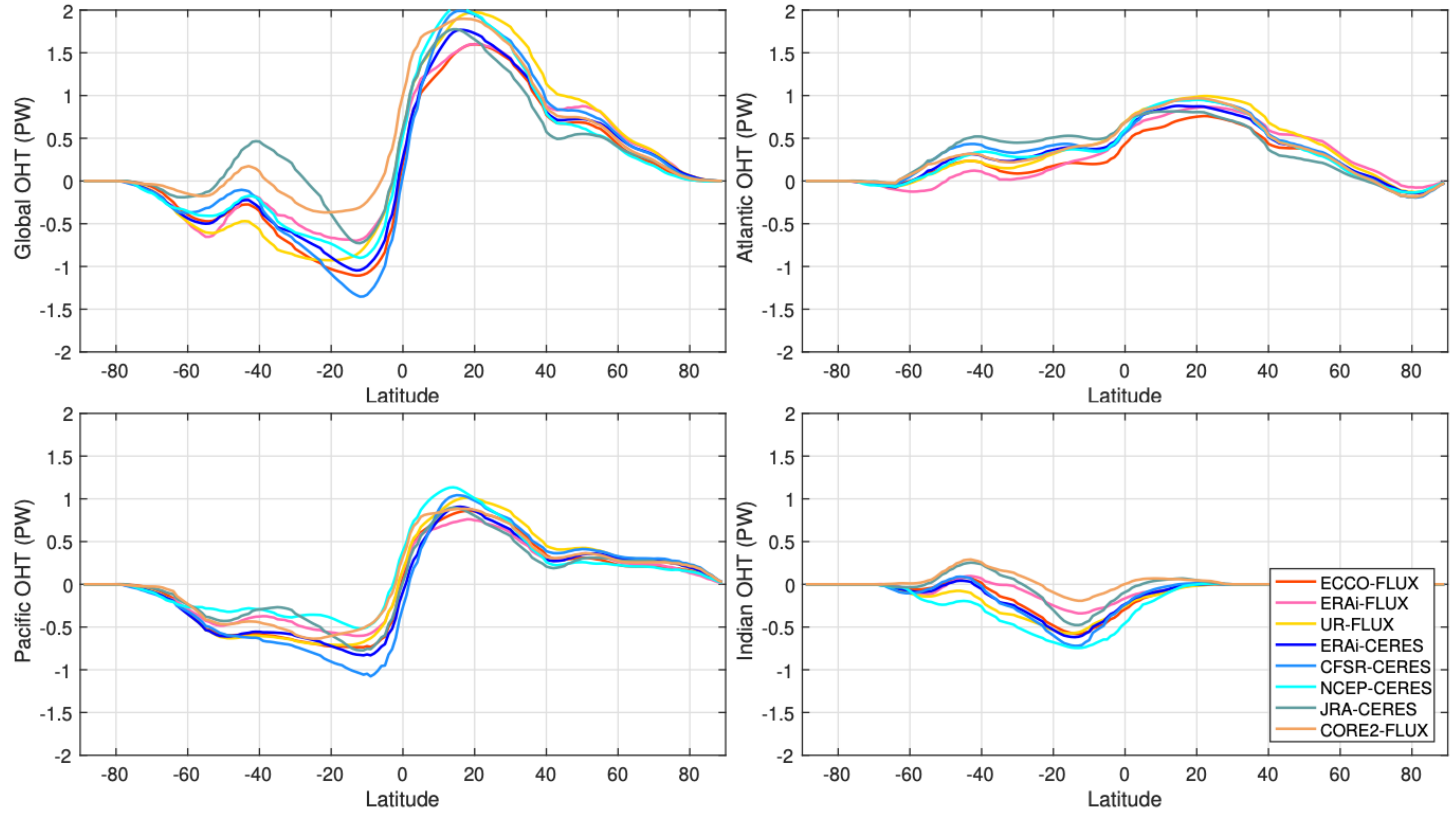


Figure S7: Meridional ocean heat transports (in PW) for the Global Ocean (top left), Atlantic (top right), Pacific (bottom left), and Indian (bottom right) inferred from various air-sea heat flux

See Supplementary of

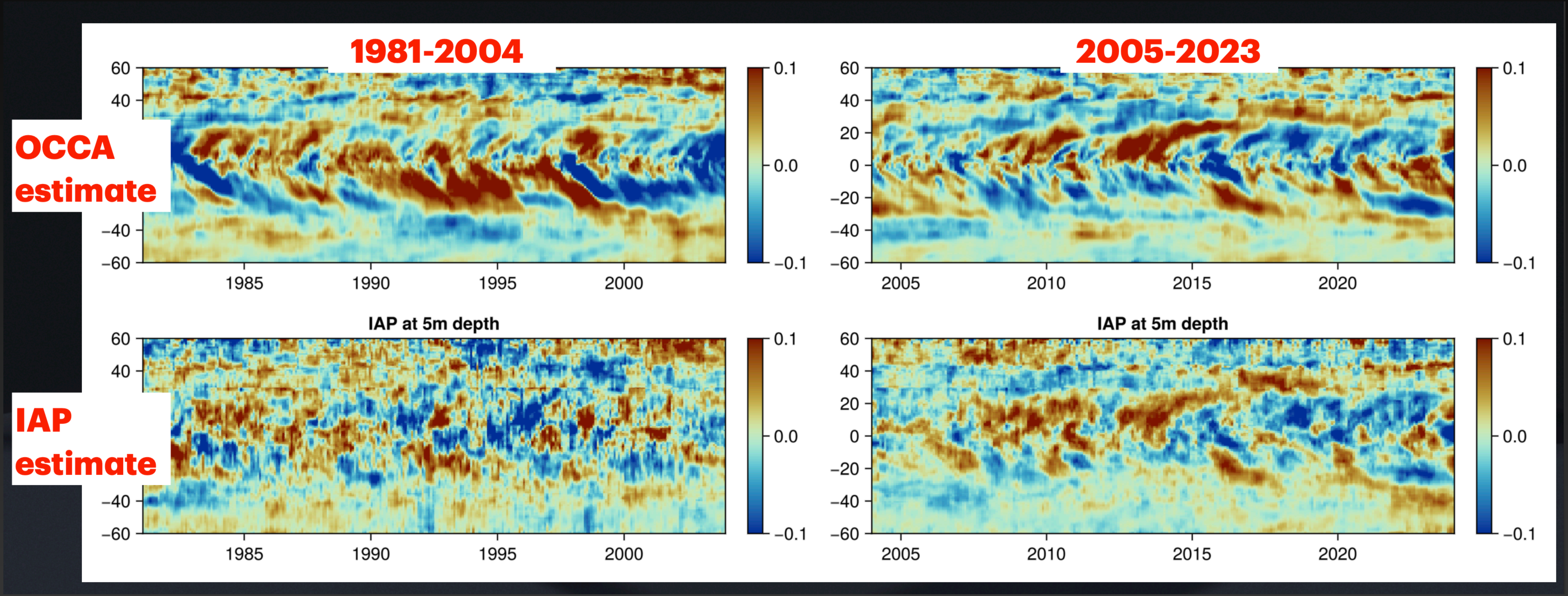
Forget & Ferreira 2019

Global ocean heat transport dominated by heat export from the tropical Pacific.

Nat. Geosci. **12**, 351–354 (2019)

Uncertainty Quantification via Ensembles

Surface Salinity Anomaly Estimates



(from my presentation at GEWEX Meeting, 2024)

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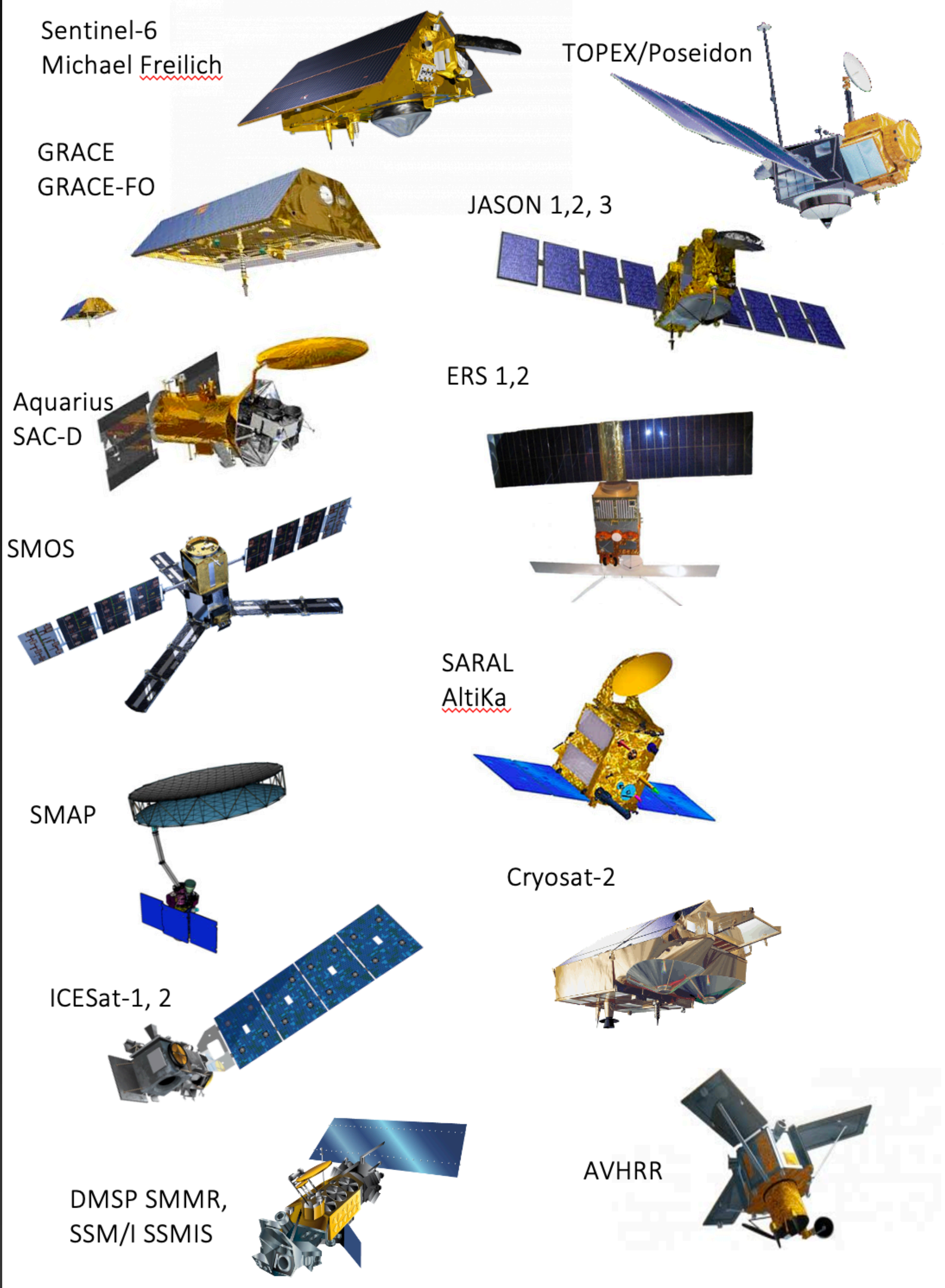
- The growing ECCO community

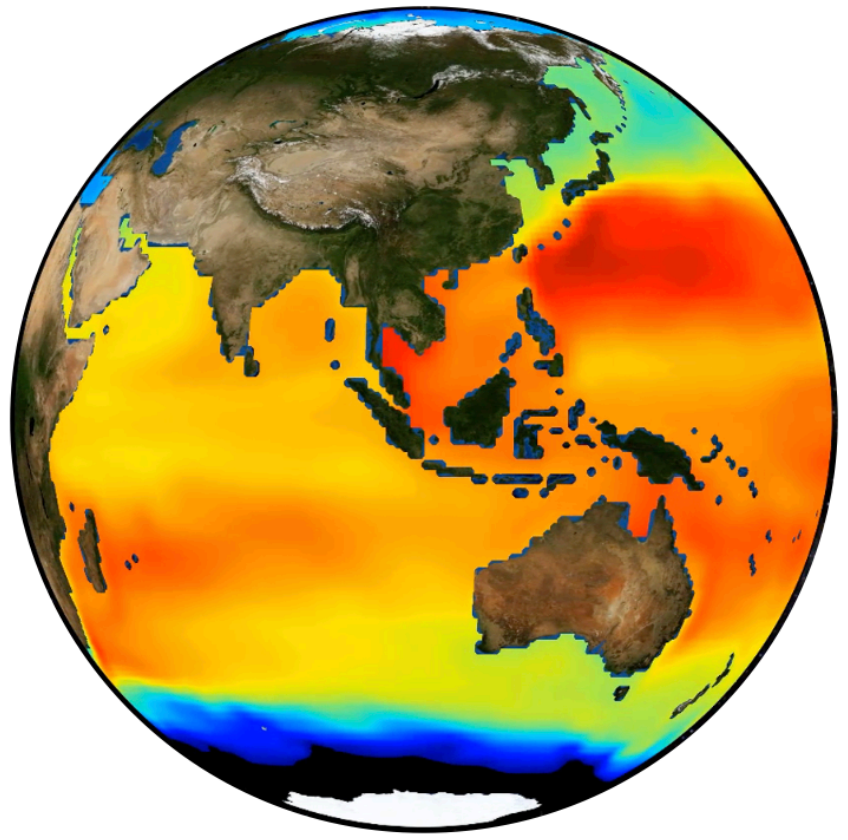
ECCO central production at JPL

Wang, Fenty, Fukumori, Forget, et al

ECCO state estimates are *multi-platform, multi-instrument, multi-variable* synthesis products that integrate ocean and ice observations and models



Coupled Ocean/Sea-ice
General Circulation Model



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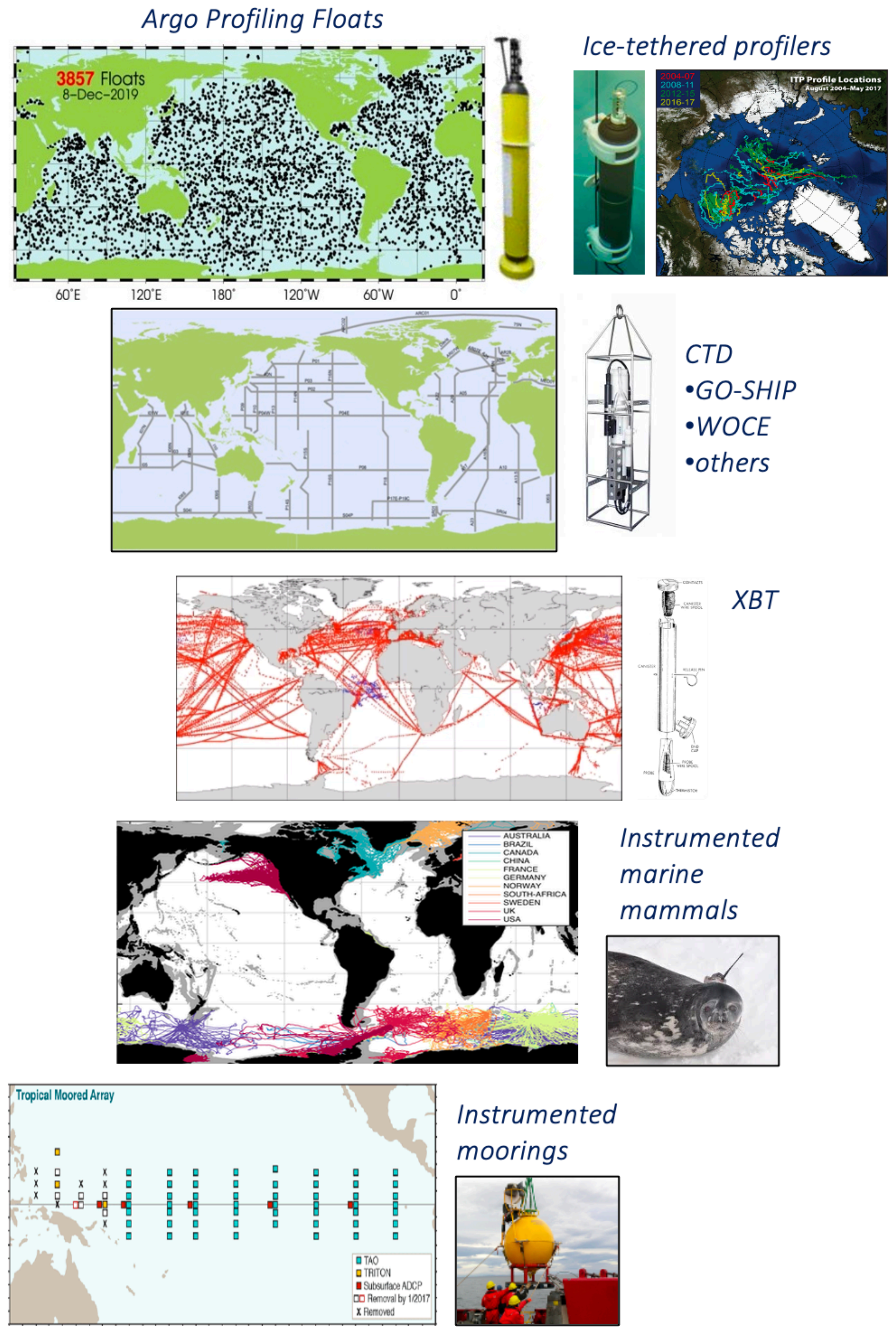


ECCO : community at large

- Use of ECCO state estimates :
  - *~ 2000 papers listed @ ecco-group.org*

- Use of the ECCO estimation framework :
  - *(MIT, JPL,) SIO, UT Austin, WHOI, NCAR, U Washington*
  - *AWI, U Hamburg, BAS, Oxford, …*

ECCO : the next generation

https://ecco-hackweek.github.io/ecco-2024/

Search ⌘ + K

Welcome to ECCO HackWeek!

Details

Event Logistics

Schedule

Team

Participant Conduct

Preparation

What to Expect

Checklist

Intro to Open Science Studio and

Digital Twins for Ocean Robots

▼ Data (Julia)

- Climatology.jl 📖 : accessing, reading, displaying, and analyzing climate data sets stars 15
- OceanRobots.jl 📖 : analysis and simulation of data generated by ocean robots stars 23
- ArgoData.jl 📖 : Argo data processing and analysis stars 18

▼ Data (Julia, 2)

- OceanColorData.jl 📖 : Ocean color data processing and analysis stars 10
- Marine Ecosystems : marine ecosystem observations and models github 403
- Dataverse.jl 📖 : interfaces to Dataverse APIs, collections, datasets, etc stars 7

▼ Models (Julia)

- ClimateModels.jl 📖 : uniform interface to climate models of varying complexity stars 43
- MITgcm.jl 📖 : framework to interact with MITgcm (setup, run, output, plot, ...) stars 31
- MeshArrays.jl 📖 : gridded Earth variables, global domain decomposition, and C-grid support stars 42

▼ Models (Julia, 2)

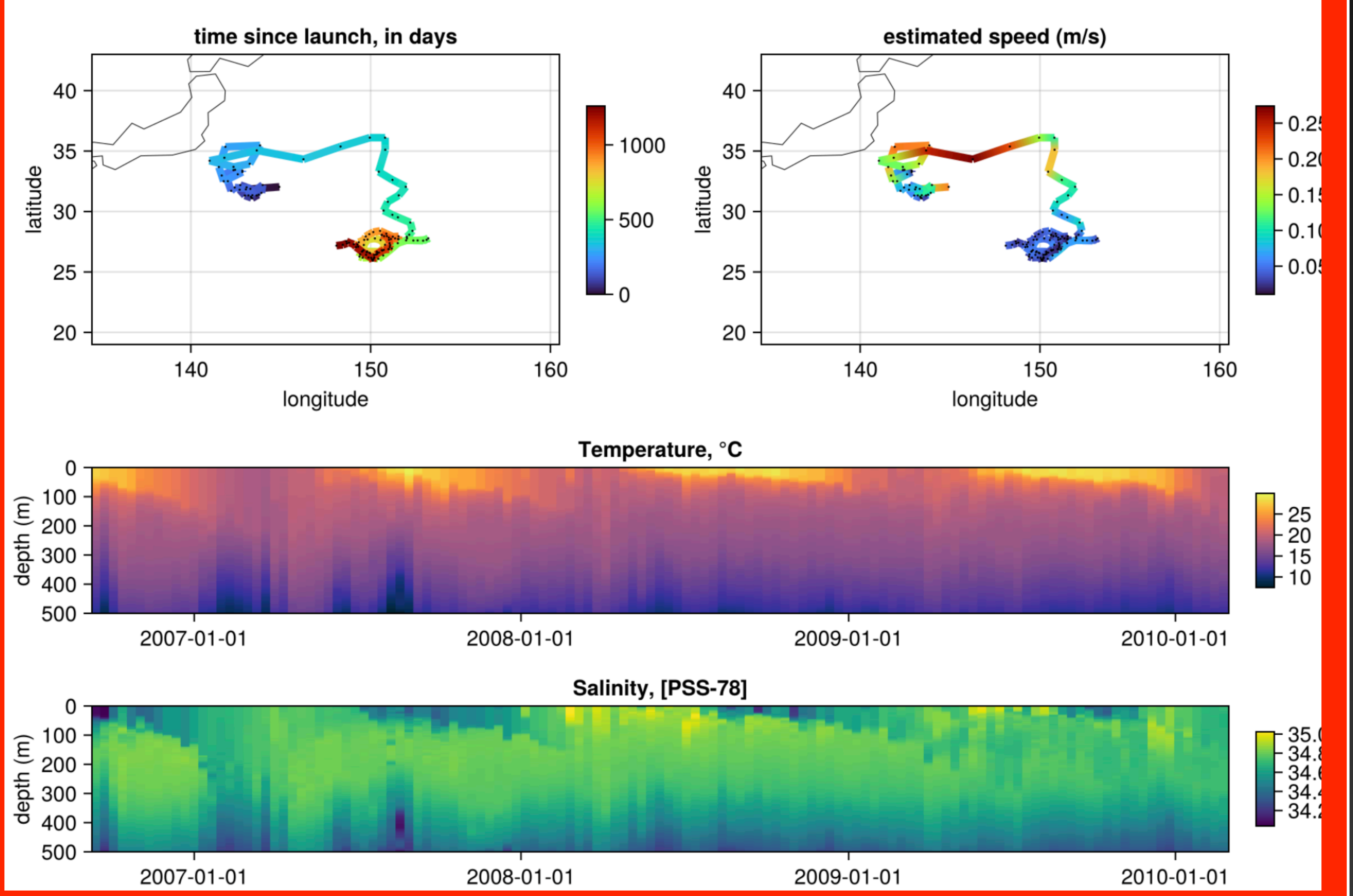
- ECCO.jl 📖 : package enables with automatic differentiation and optimization packages stars 7
- Drifters.jl 📖 : trajectory simulations for point particles in the Ocean and Atmosphere stars 36
- PlanktonIndividuals.jl 📖 : simulation of plankton communities and their interaction with environmental factors stars 30

Code 1: Download and visualize one Argo float data as in Fig. 4.

```
using OceanRobots, ArgoData, CairoMakie

lst=GDAC.files_list(); wmo=6900900
argo=read(ArgoFloat(),wmo=wmo,files_list=lst)

fig=plot(argo,option=:standard)
```



From https://github.com/gaelforget

See my https://www.oceanpredict24.org/ presentation next week ...

Extra Slides

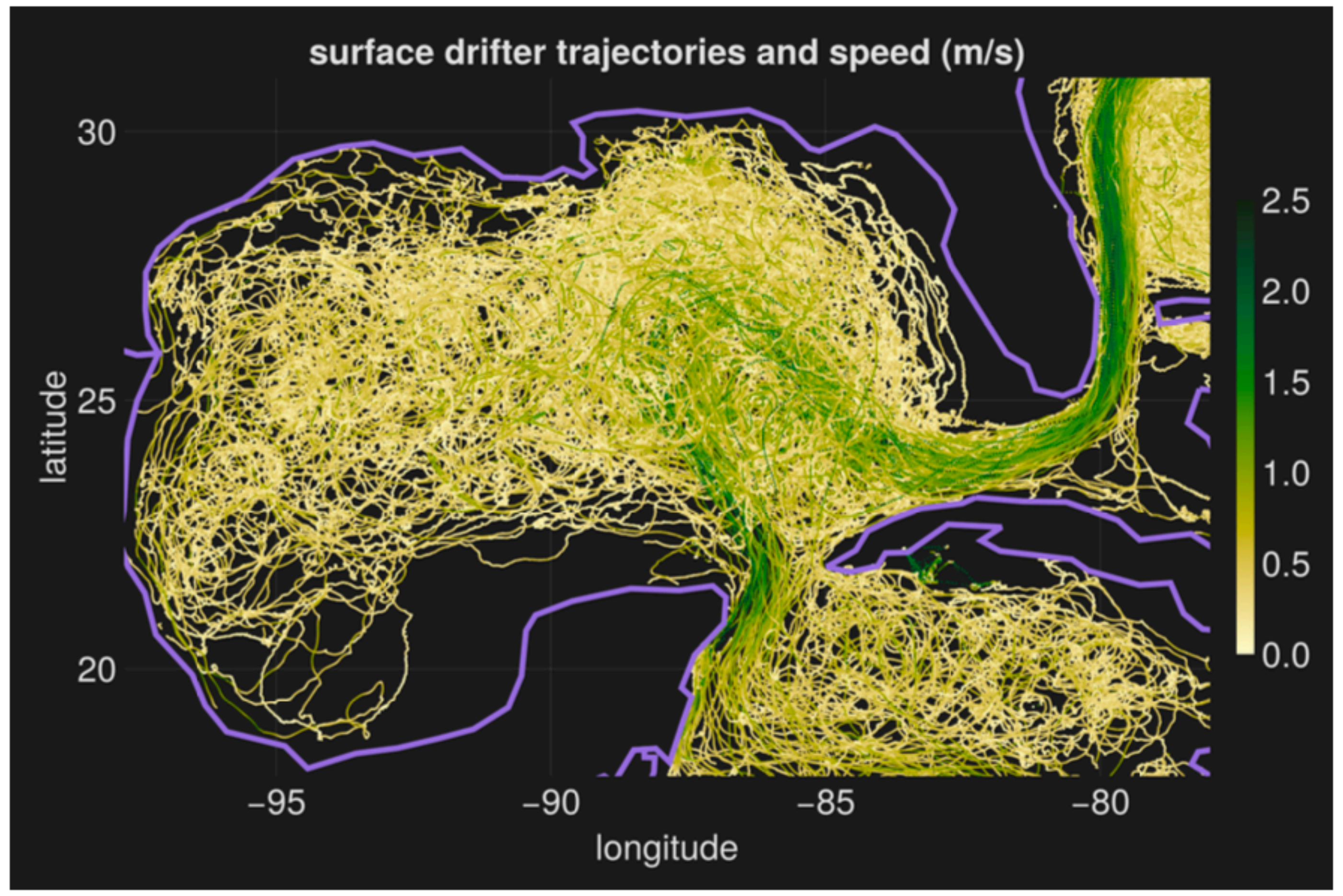


Fig. 6: Drifter trajectories in the Gulf of Mexico region. Large velocities highlight the path of the Gulf Stream, being fed by the loop current.

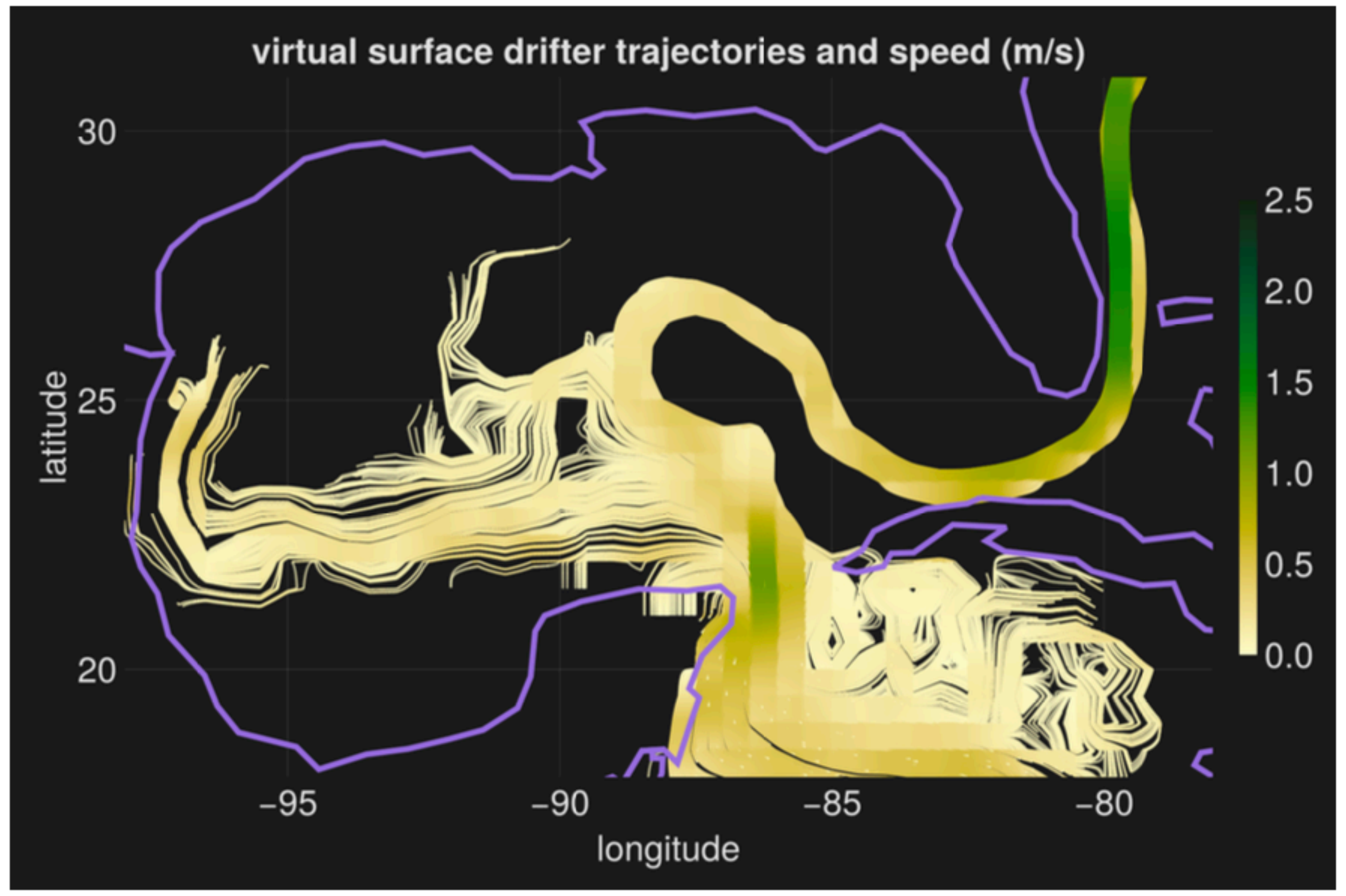


Fig. 7: Virtual drifter trajectories predicted using (1) just the climatological mean flow field estimated from drifters (Fig. 3, and the northward component) and (2) DRIFTERS.JL to calculate trajectories.

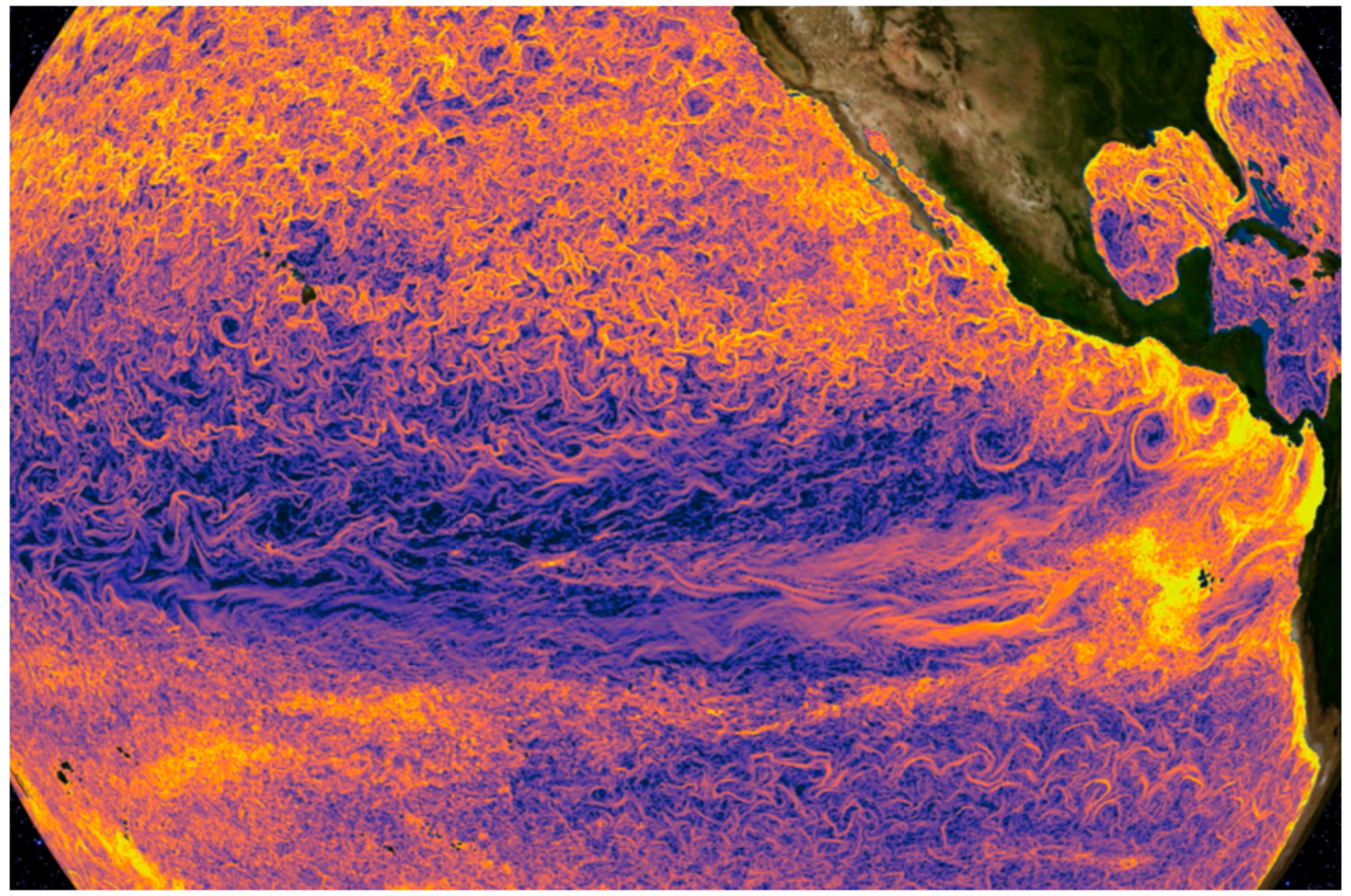


Fig. 8: Temperature fronts in a global km-scale MITgcm simulation. Plotted is the logarithm of the spatial gradient of a temperature snapshot.