All-Atlantic Ocean Research and Innovation Alliance

2024 Intergenerational Dialogue

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Estimating Atlantic meridional heat transport through Bayesian modelling of altimetry, Argo and GRACE data

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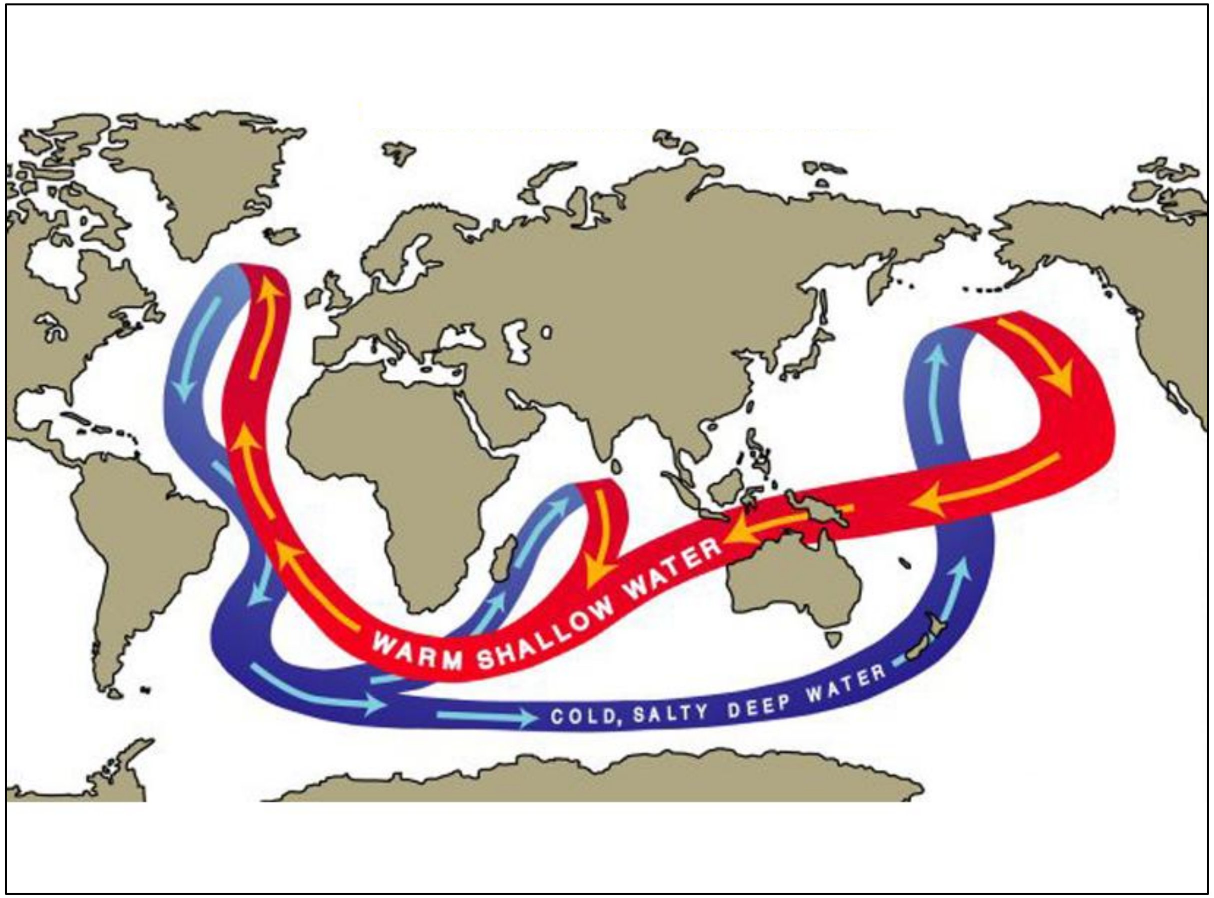
epoc explaining and predicting the ocean conveyor

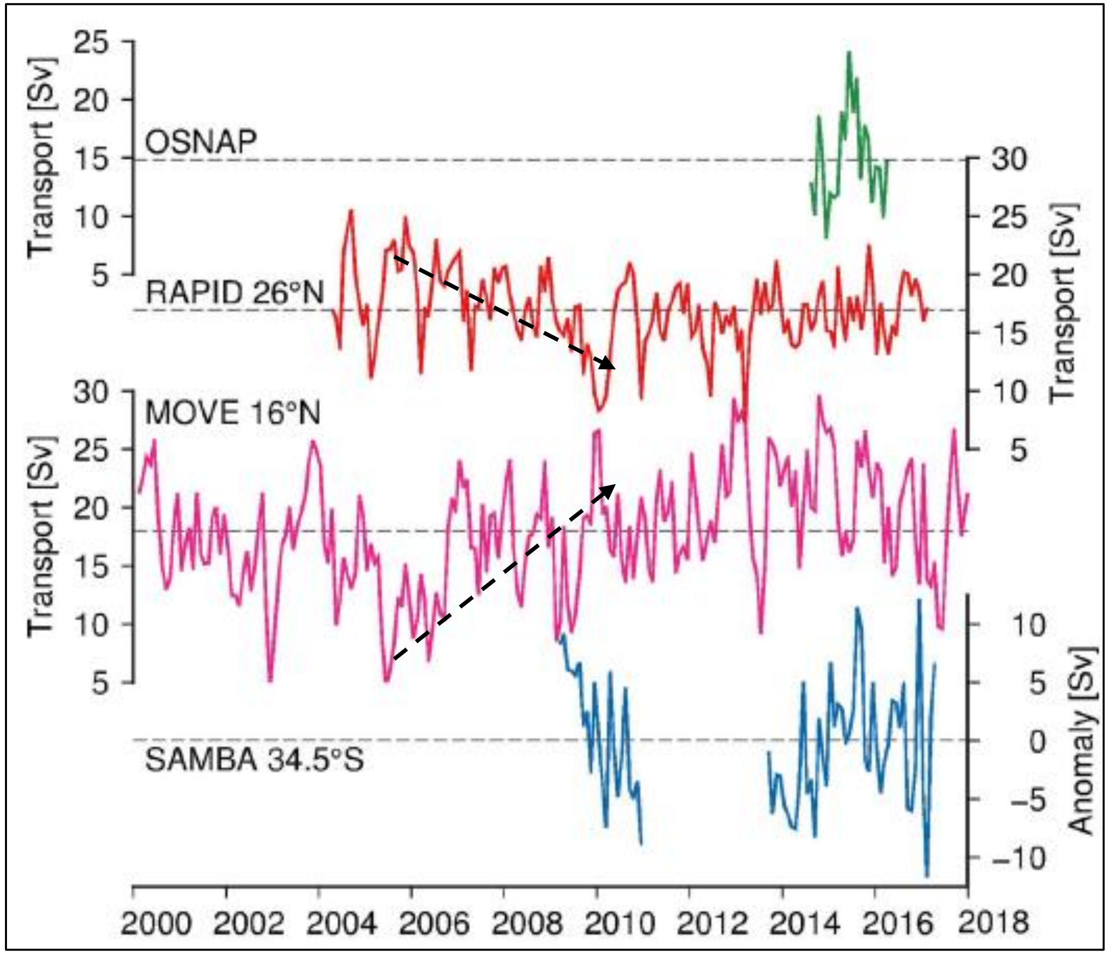
National Oceanography Centre

- A large system of ocean currents that carry warm shallow water from the tropics to the northern latitudes and cold deep water southward across the equator
- Plays crucial role in redistributing heat, freshwater and dissolved gases
- Has pivotal role in regulating the earth's climate system and the biosphere



Largely viewed as a "Global conveyor belt"

Motivation: To what extent does the AMOC function like a conveyor belt?



- Observations across various latitudes reveal a lack of meridional coherence, challenging the theoretical framework of the conveyor belt model (Eleanor et al., 2019)
- For instance, the conflicting long-term trends observed at 16°N and 26°N
- The sparse spatial and temporal coverage of observations hinders a comprehensive understanding of the AMOC
- Alternative methods, including advanced statistical approaches, could provide more detailed insights to enhance our understanding of AMOC and its associated processes

EPOC has five overarching scientific objectives:

- Generate comprehensive records of AMOC transports across the whole Atlantic, to assess the timescales of transport variability and the degree to which the AMOC behaves as a conveyor belt
- Determine key processes that make-or-break meridional connectivity of ocean transports, and assess their representation in models, especially in high resolution coupled simulations
- Identify the processes and drivers of recent change in the AMOC and infer the likely roles of natural and anthropogenic forcings, and internal variability
- Assess the key processes of future AMOC changes and identify indicators of abrupt changes and AMOC related climate impacts with societal relevance
- Design, and deploy elements of, a next generation observing system for the entire system of the AMOC

Possible Approach: Using the budget equation

Following Kelly et al. (2014, 2016), we model non-seasonal **heat and freshwater budgets** in terms of sea-level components:

Heat budget

$$\frac{\partial TSL}{\partial t} = \frac{\alpha Q_{net}}{\rho_0 C_p} + U_T$$

TSL: Thermosteric sea level
U_T: Convergence of TSL

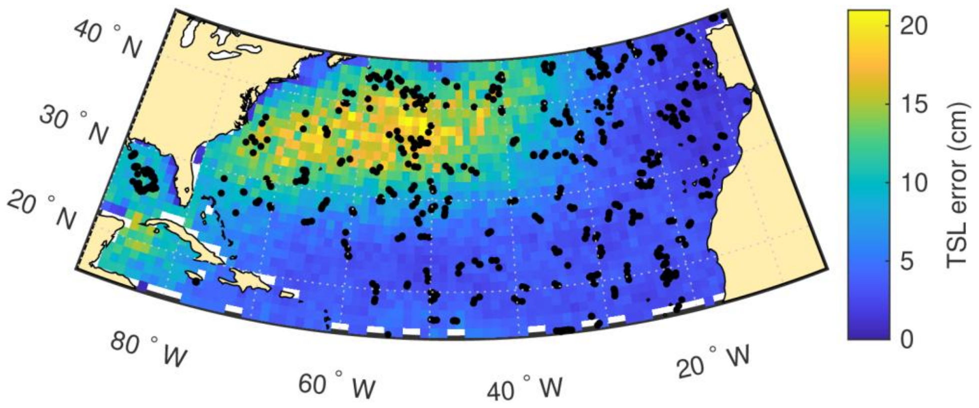
Freshwater budget

$$\frac{\partial HSL}{\partial t} = \beta S_0 (P - E) + U_S$$

HSL: Halosteric sea level
U_S: Convergence of HSL

- The goal is to infer U_T and U_S by evaluating the budgets using observational data

TSL standard errors and Argo profiles in Jan 2010



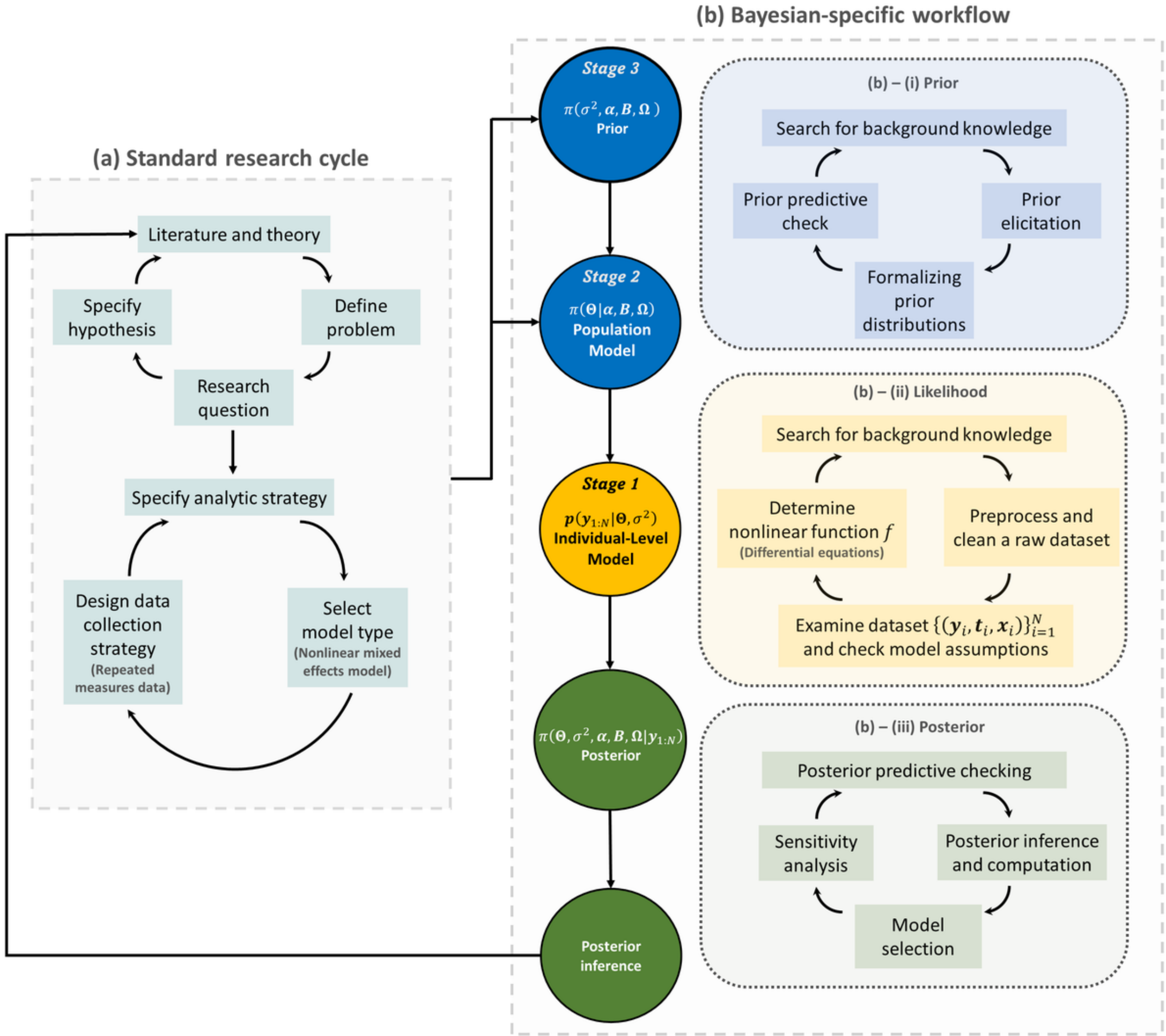
Main Caveats

- The gridded hydrographic data used here are based on Argo data that are sparse in both space and time
- This leads to noisy and biased estimates of TSL and HSL

Prior
↓
Likelihood
↓
Posterior distribution
↓
Posterior Inference

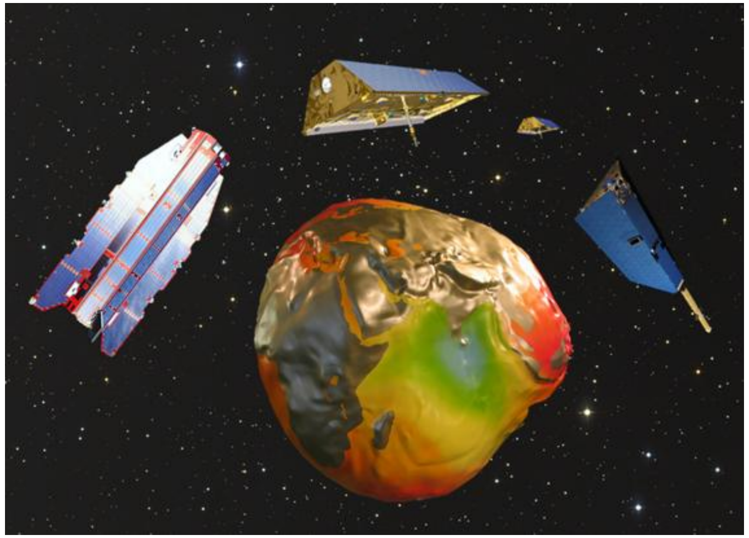
- The Bayesian approach allows to determine the posterior distribution by combining the prior knowledge and the likelihood
- Rigorous error propagation
- Suitable for data poor regions
- Computationally light compared to numerical models

Some basics of Bayesian Hierarchical Modeling

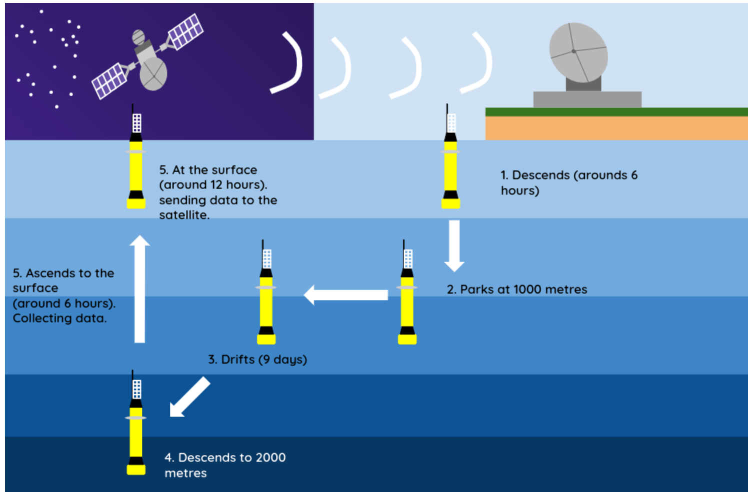


Datasets used

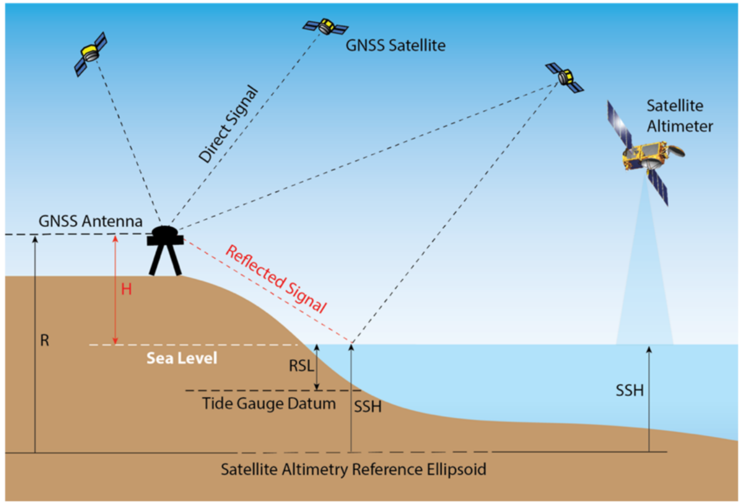
Ocean mass: Gravimetry



Hydrography : Argo



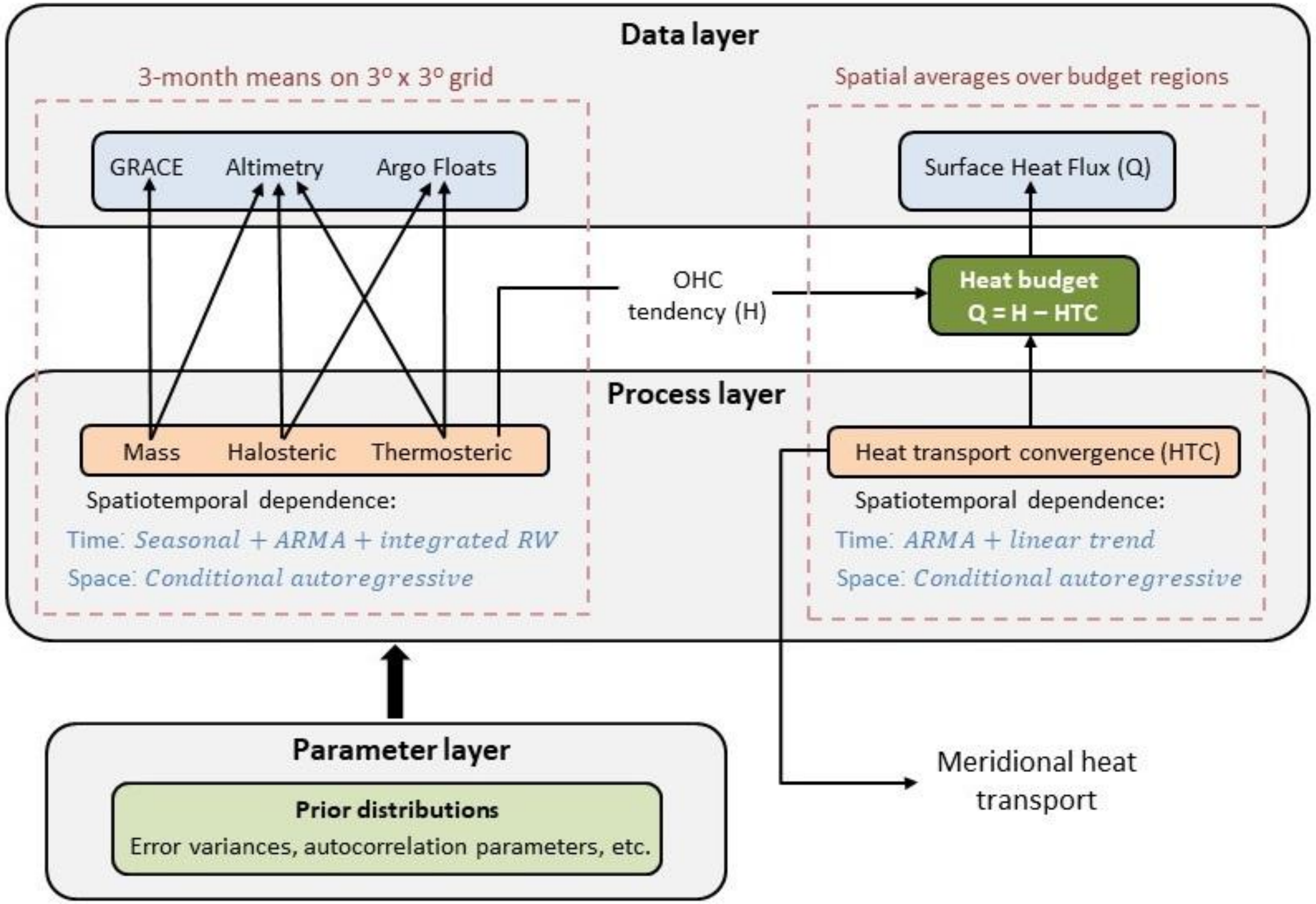
Sea surface height : Satellite altimetry



SSH – OM = TSL+HSL

Our model

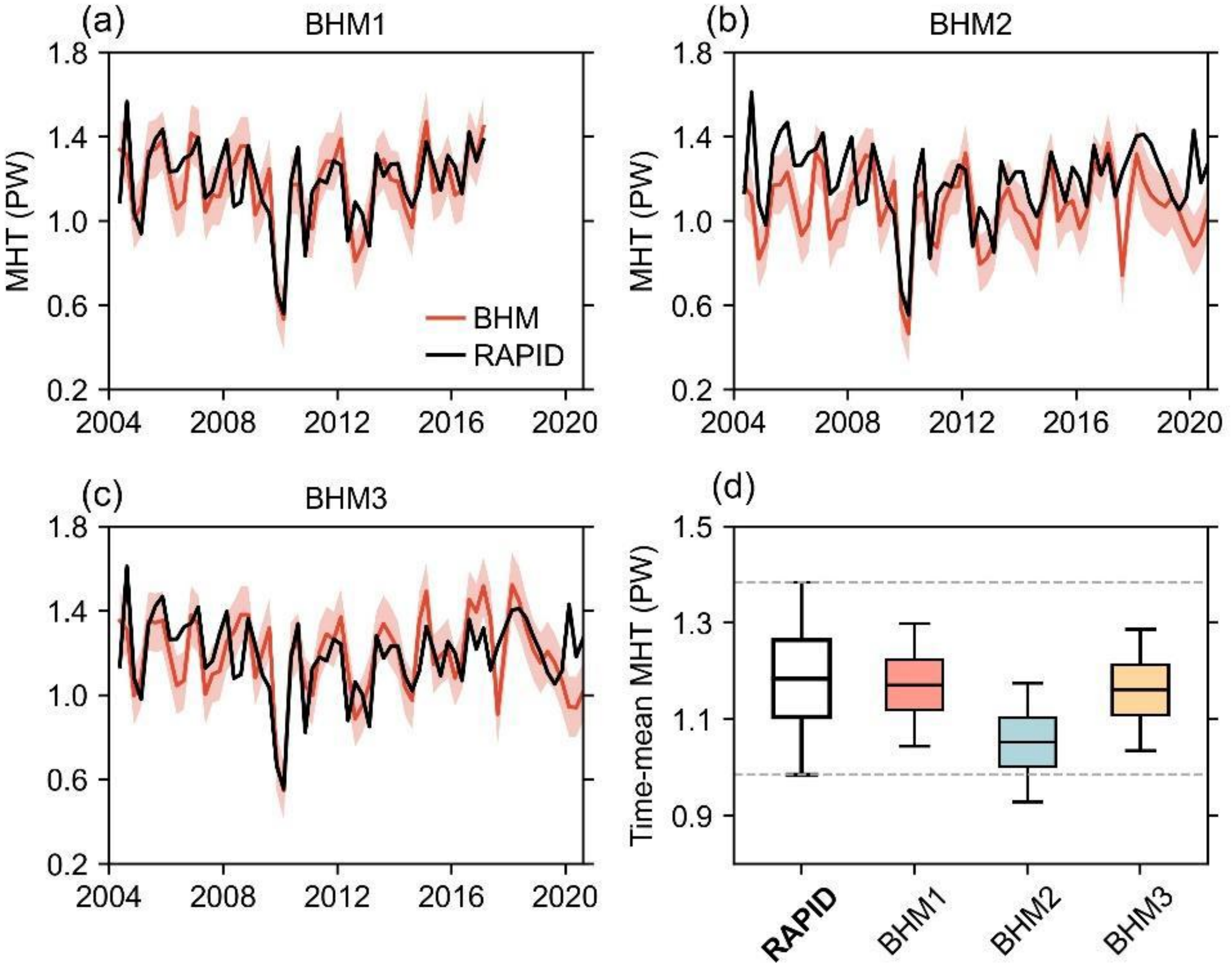
We use a statistical modelling approach to get the heat and fresh-water distribution by combining prior knowledge obtained from observations



Benefits of our approach

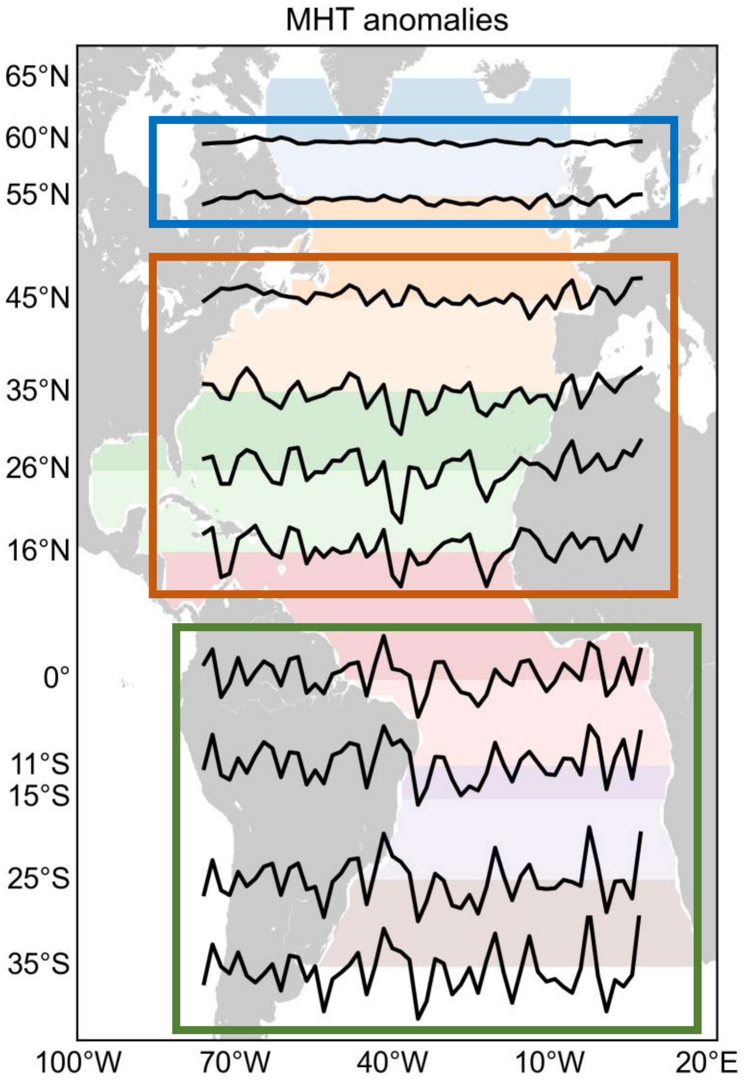
- Estimates of TSL and HSL are constrained by using data from satellite altimetry, GRACE, and ARGO
- Joint spatiotemporal modelling of all observational datasets and their error structures
- Information sharing across both datasets and space
- Missing data are accommodated
- Rigorous error propagation
- Prior information incorporation

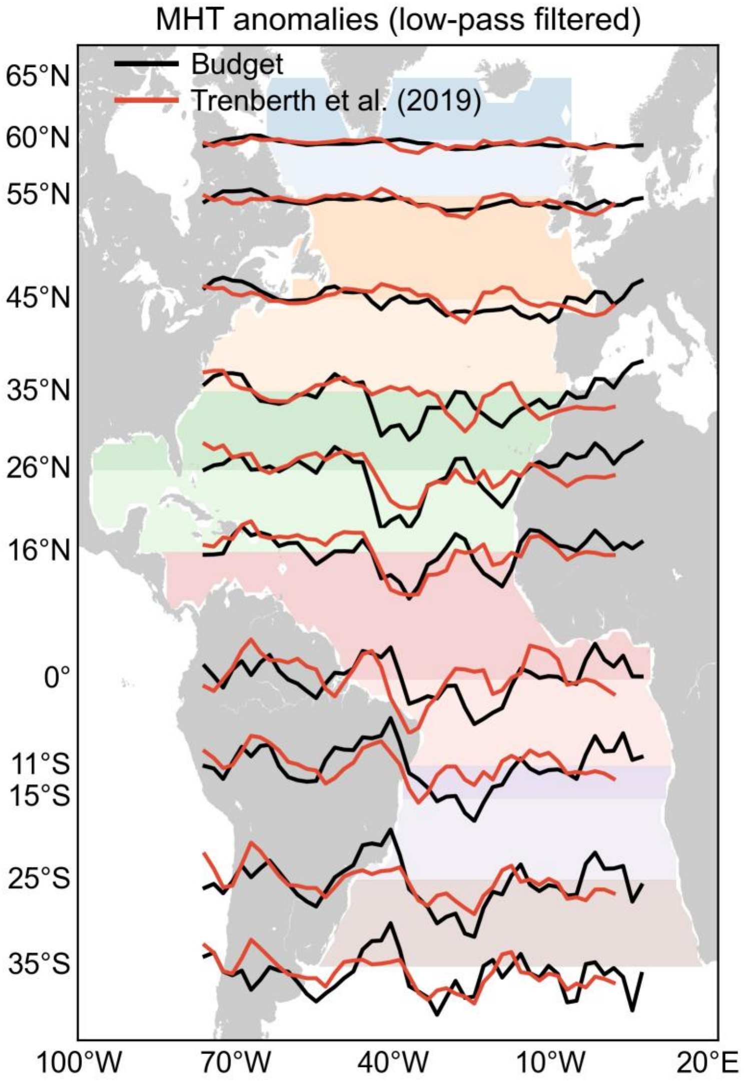
Results: Validation of Bayesian estimates of Meridional Heat Transport (MHT)



- Our estimates compare well with the RAPID estimates of MHT at 26°N (correlation > 0.7)
- Both mean and variability (quarterly values) are captured well with our approach
- The correlation further improves when a linear trend is removed

Results: Meridional coherence of the heat transport





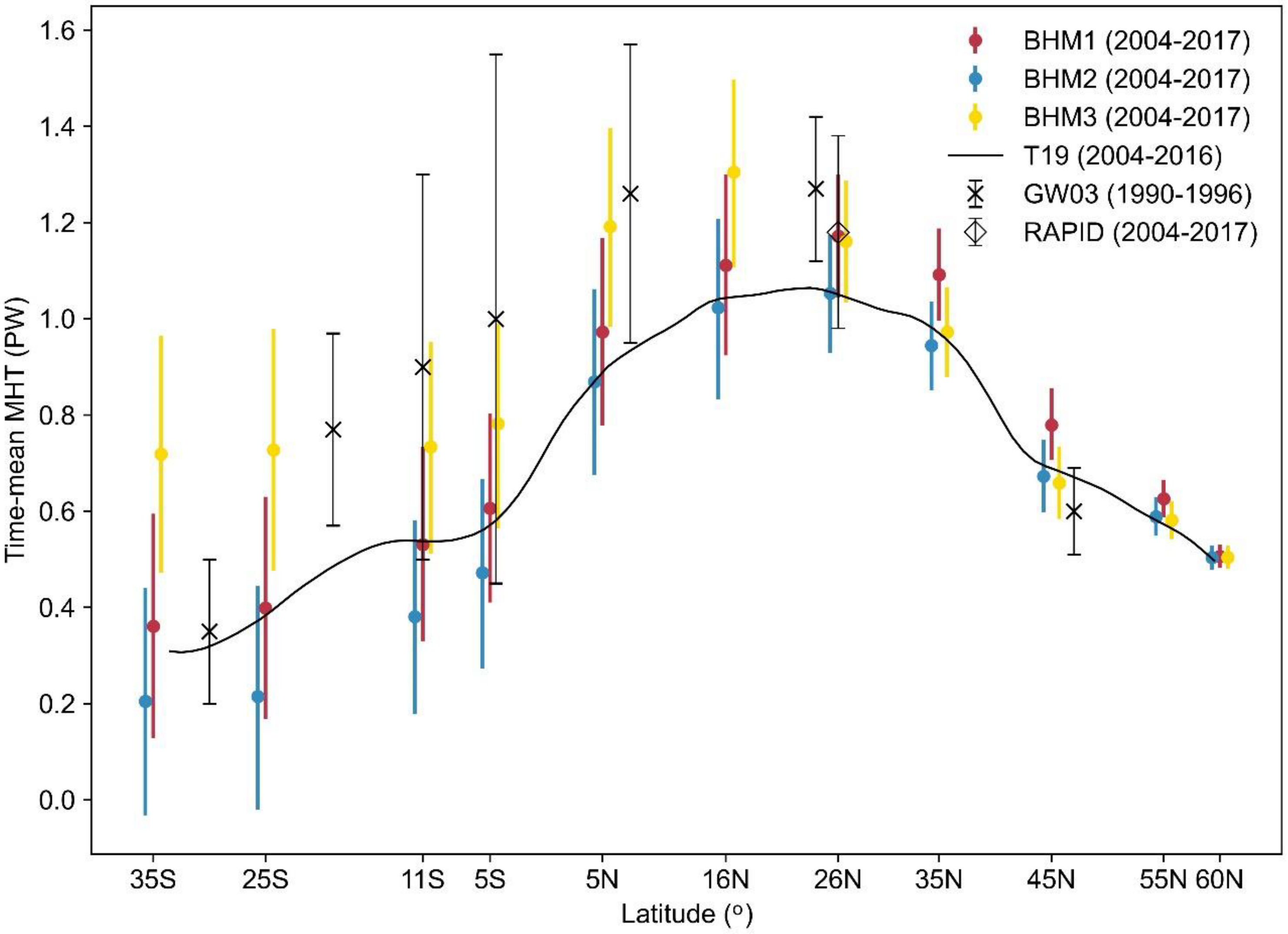
- Our estimates compare well with other estimates of MHT based on ocean heat content and atmospheric heat fluxes (Trenberth et al. 2019)
- Our estimates across the latitude reveal a lack of meridional coherence across the entire basin

Based on our estimates, we identify three regimes of latitudinal coherence:

1. **Southern Atlantic regime**
2. **N-Tropical-subtropical regime**
3. **N Sub-polar to polar regime**

The results from our estimates can be used while designing the next generation observation framework !!

Results: Time-mean MHT across latitudes



Summary & Conclusion

- The non-seasonal components of meridional heat transport is estimated in terms of sea level
- The spatio-temporal fusion of observations through a Bayesian modeling approach allows the estimation of MHT as a probabilistic distribution
- Computationally light and efficient for poorly sampled oceanic regions
- The estimates depend on the constant of integration at a given reference latitude

Ref: Calafat, F. M., Vallivattathillam, P., and Frajka-Williams, E.: Estimates of Atlantic meridional heat transport from spatiotemporal fusion of Argo, altimetry and gravimetry data, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2025-1216, 2025.

Thank You

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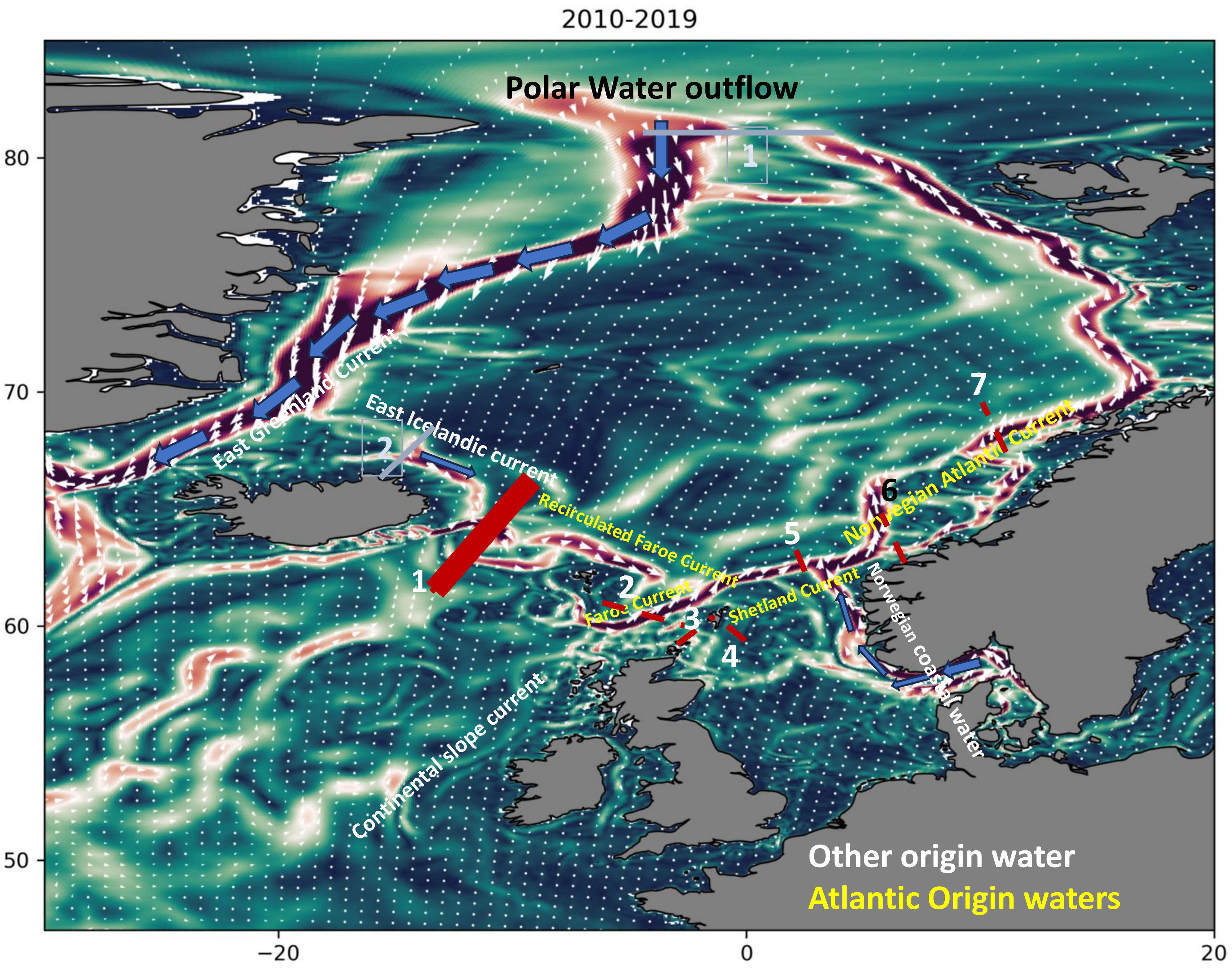


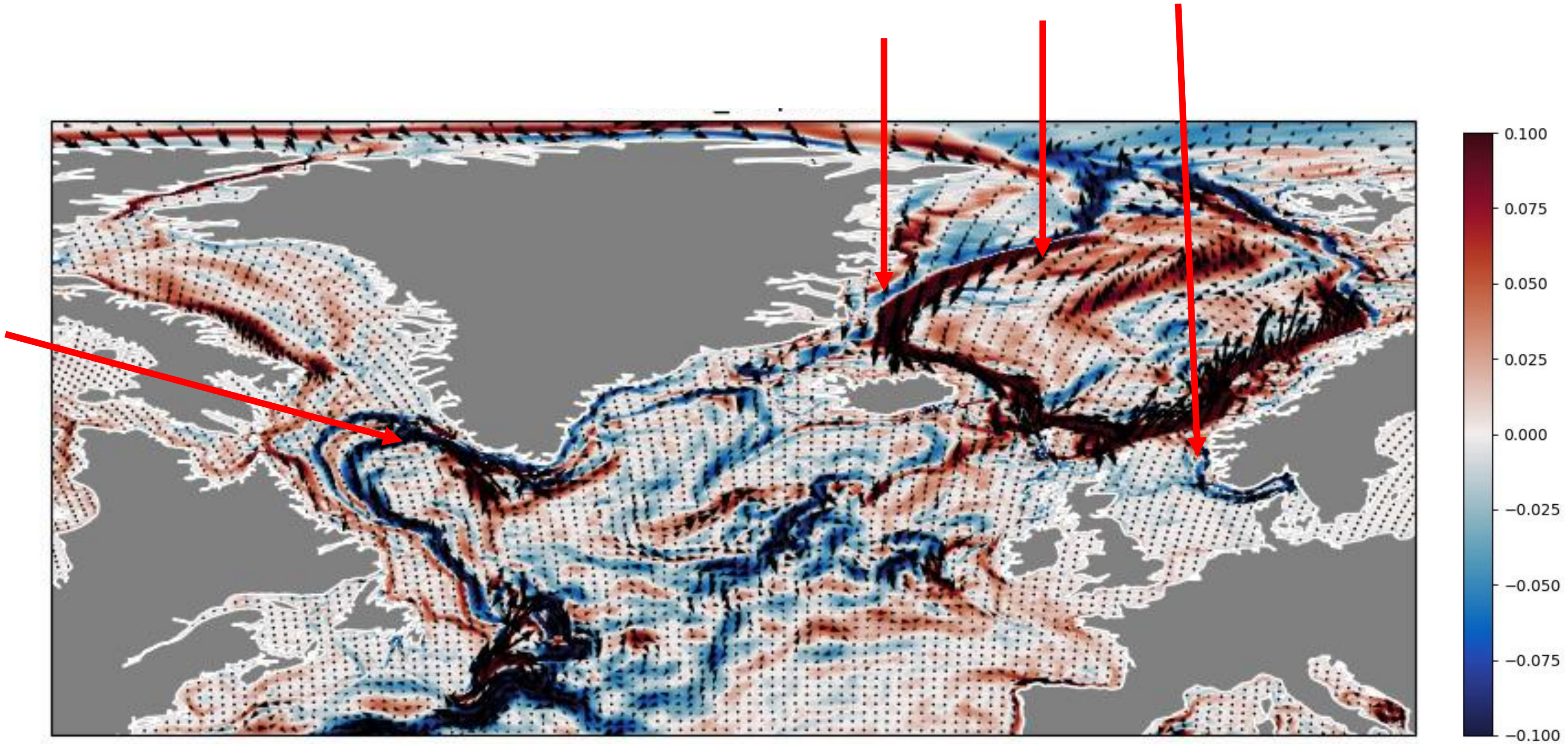
Key gateways for the Atlantic water inflow:

1. Iceland-Faroe ridge
2. FSC-FIM
3. FIC
4. SSC
5. Norwegian entrance
6. Norwegian exit
7. NSC

Key gateways for polar/transformed water outflow:

1. Fram Strait
2. North of Iceland

Future response of the mean circulation in the upper layer (0-200m average)



Interesting transformation of large-scale circulation patterns in response to climate change !