Sampling-Dependent Transition Paths of Iceland–Scotland Overflow Water

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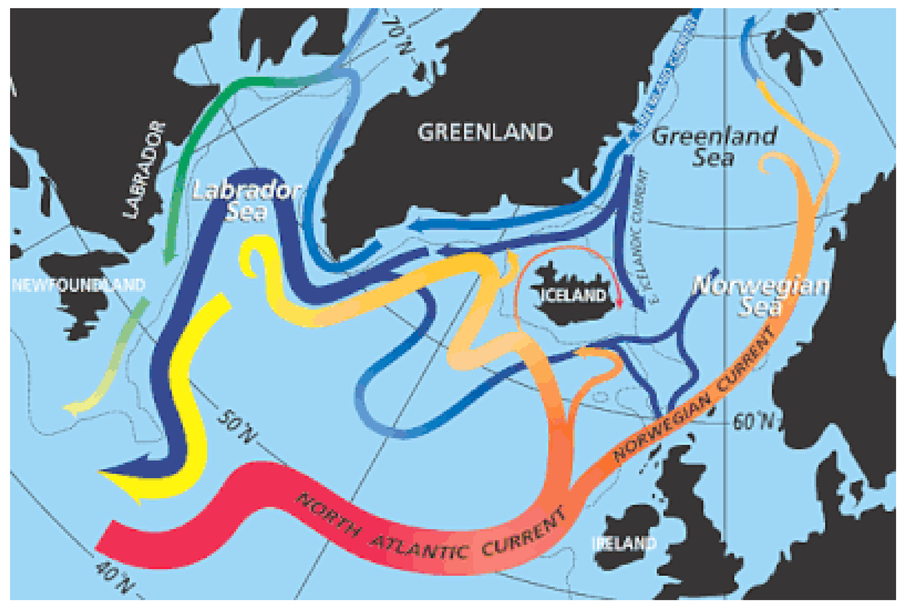
Introduction

The Iceland–Scotland Overflow Water is the lighter of the two overflow components of the North Atlantic Deep Water, the lower limb of the Atlantic Meridional Overturning Circulation. According to Stommel's (1958) abyssal circulation theory, ISOW should flow southward, forming a deep boundary current (DBC).



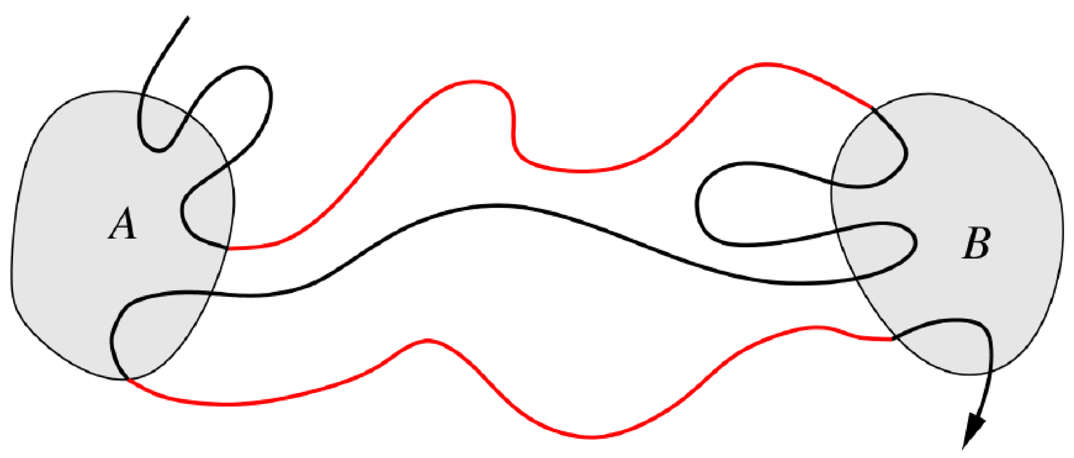
Previous analysis of trajectories of subsurfaces floats challenged the conventional theory of abyssal circulation, which posits that ISOW should flow steadily along a deep boundary current (DBC) around the subpolar North Atlantic before exiting.

Transition path theory (TPT)

In a recent study, TPT is used to characterize the pathways of deep water in the subpolar North Atlantic. Here, the focus is on the effect of the distribution of observations on the identification of those pathways.

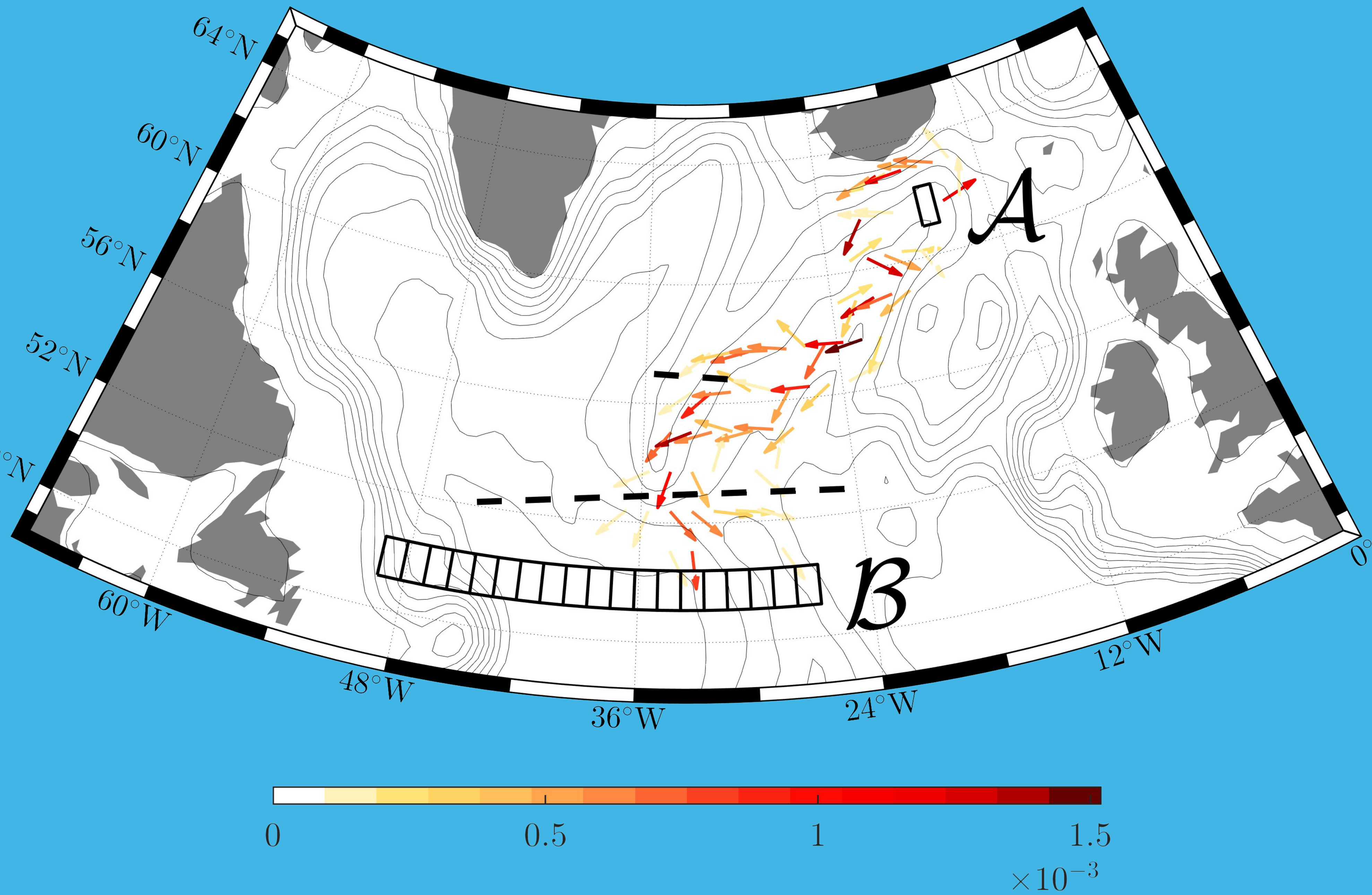
Assuming a stationary advection-diffusion process, a transition matrix is obtained by discretizing the domain $\mathcal{D}$ into N boxes $\{B_1, \ldots, B_N\}$ and evaluating $P_{ij} = \Pr(X_{n+1} \in B_j \mid X_n \in B_i)$. P_{ij} describes the evolution of water parcels.

Based on this chain, we can evaluate the forward and committor probabilities, the main objects of TPT. Defined as $q_i^+ = \Pr(\tau_{\mathcal{B}}^+ < \tau_{\mathcal{A}}^+ \mid X_0 \in B_i)$ and $q_i^- = \Pr(\tau_{\mathcal{A}}^- > \tau_{\mathcal{B}}^- \mid X_0 \in B_i)$, they allow one to express several statistics about the transitions across the domain (distribution, bottlenecks, currents, expected transition time). The transition currents, defined as $f_{ij} := \Pr(X_0 \in B_i, X_1 \in B_j, \tau_A^- > \tau_{\mathcal{B}}^-, \tau_{\mathcal{B}}^+ < \tau_{\mathcal{A}}^+) = q_i^- \pi_i P_{ij} q_j^+$, indicating the most likely transition channels. In other words, TPT allows for statistical characterization of ensembles of trajectory flowing out from a source $\mathcal{A}$ last and into a target $\mathcal{B}$ next, i.e., those that most productively contribute to transport (red segments).

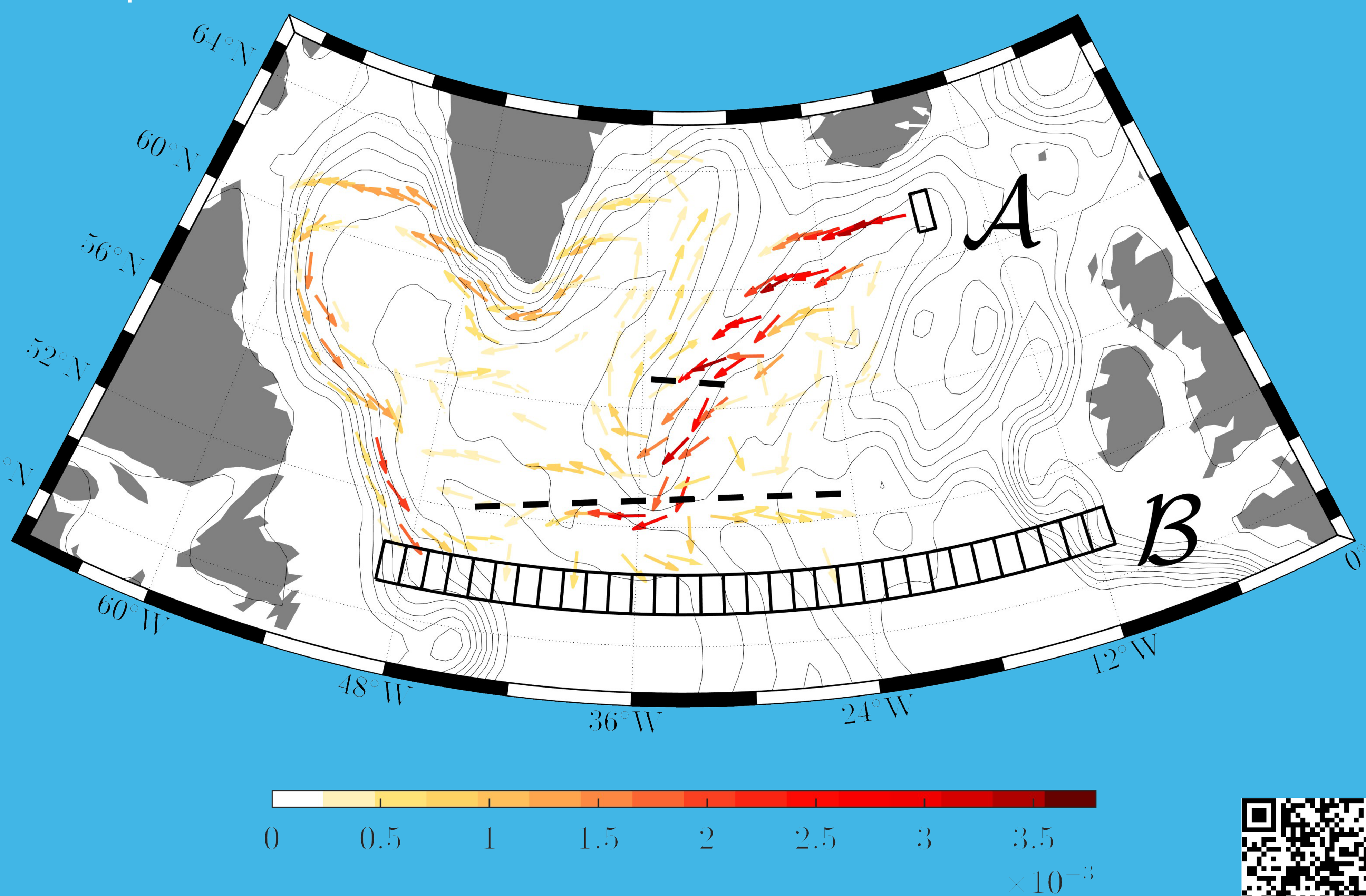


How does the distribution of observations impact North Atlantic deep water pathways identification?

The transition paths of a Markov chain constructed using the historical subsurface floats (RAFOS and Argo) dataset do not support the presence of a DBC. They indicate outflow along the eastern side of the Mid-Atlantic Ridge.



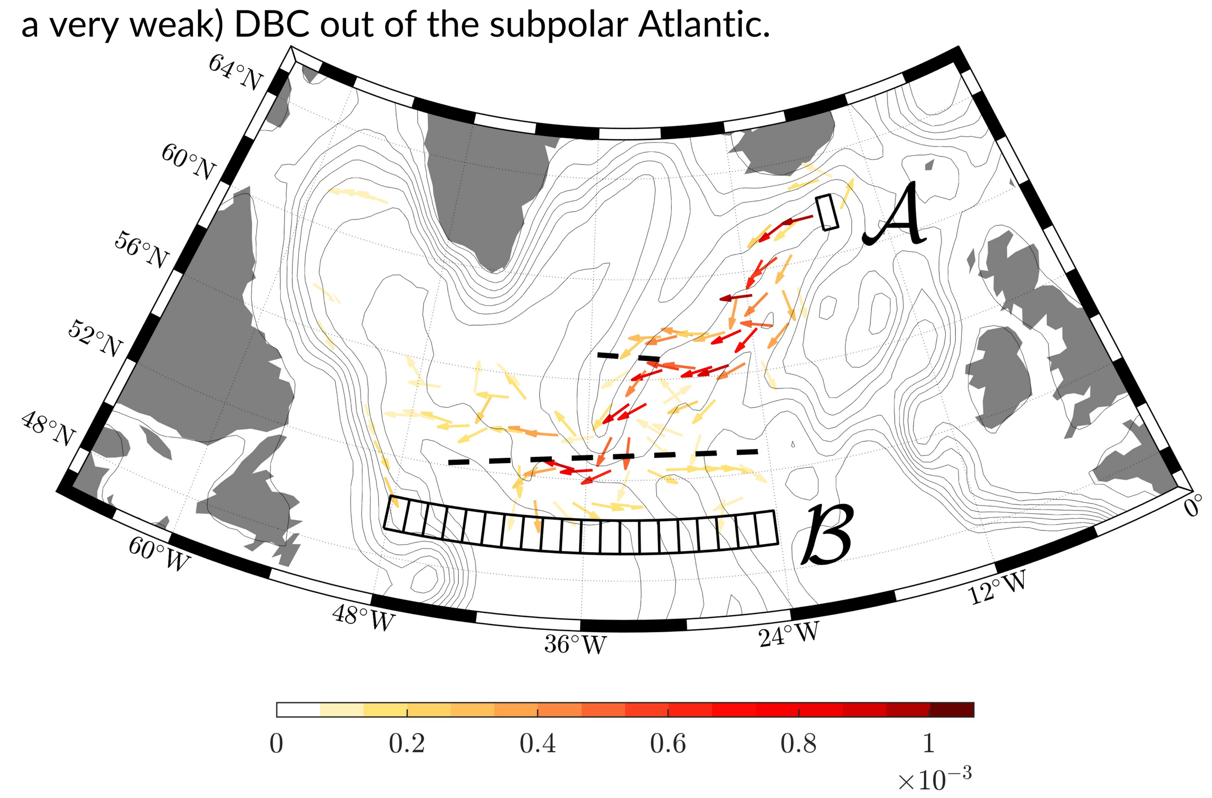
On the contrary, transition paths of a Markov chain constructed using a uniformly and densely distributed set of trajectories, advected by the North Atlantic HYCOM (1/50°) velocity fields, support the presence of a DBC.



Link to the publication

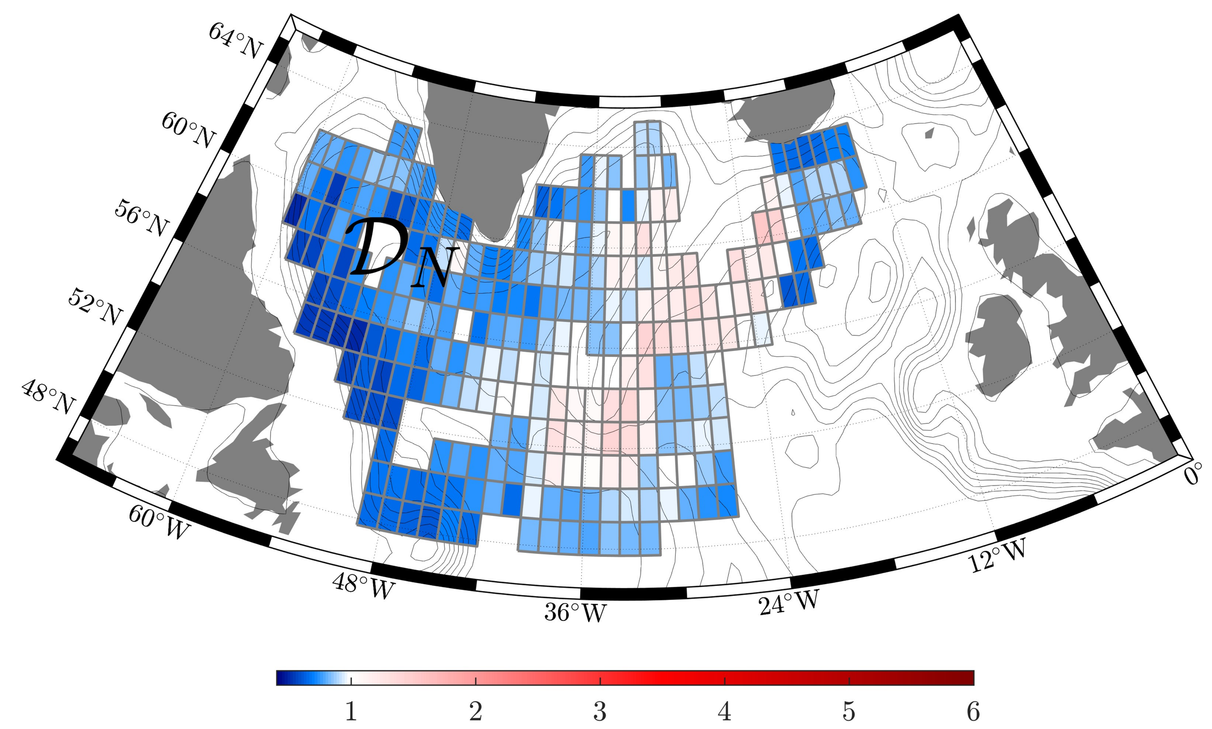
Sampling-dependency

By keeping only a subset of the numerical trajectories—with initial positions close to the available observations—the transitions paths of this *truncated* numerical Markov chain are similar to those of the observed chain. Similarly, the reactive currents show no (or a very weak) DBC out of the subpolar Atlantic.

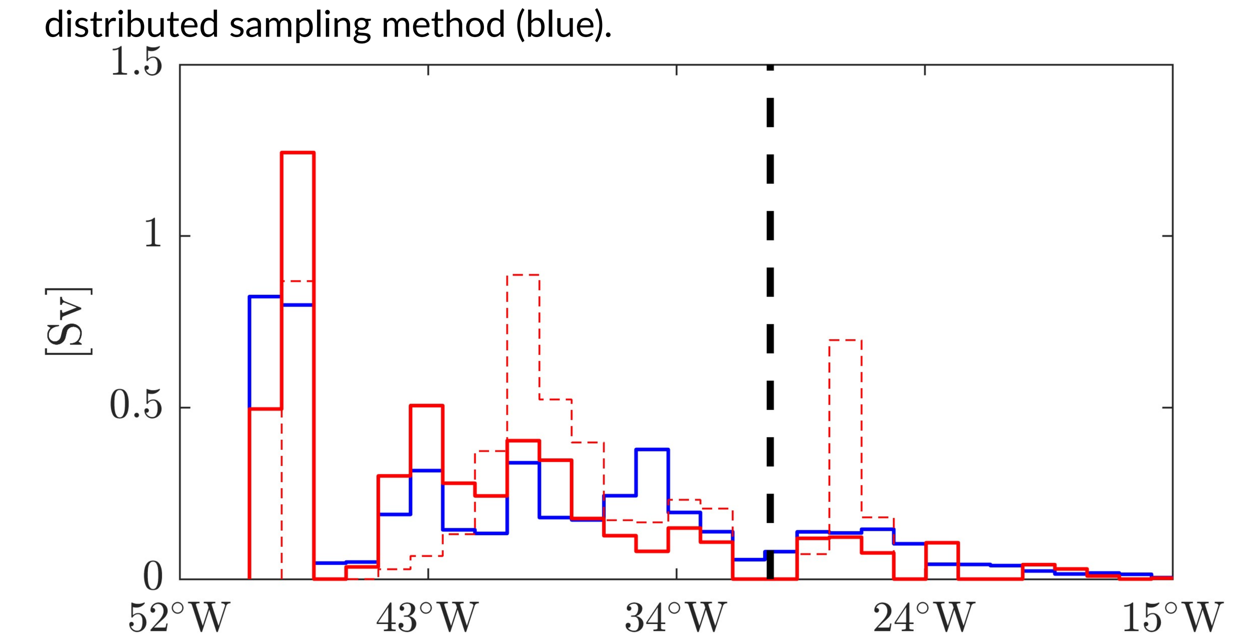


Guiding future deployments

As a measure of uncertainty of the data in the North Atlantic, the averaged signal-to-noise ratio (S/N) of the transition probability of the observed Markov chain is presented below. At each box of the domain, the S/N is obtained from the comparison of the transitional probabilities obtained from 100 realizations using randomly 25% of the available trajectories.



By adding an extra 10% of the available trajectories where $S/N < 3$ to the truncated chain based on the observations (dashed red), the transitions rates into the target B (red) resemble the simulated chain using a uniformly distributed sampling method (blue).



References

F.J. Beron-Vera, M.J. Olascoaga, L. Helfmann and P. Miron, Sampling-Dependent Transition Paths of Iceland–Scotland Overflow Water, JPO, 53, 1151 (2023)

P. Miron, F.J. Beron-Vera and M.J. Olascoaga, Transition paths of North Atlantic Deep Water, JTECH, 39, 959 (2022)