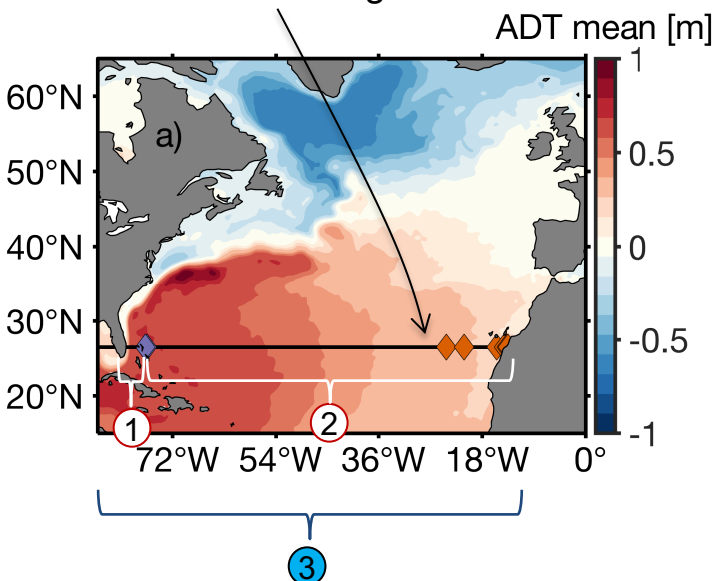


A dynamically based method for estimating the Atlantic overturning circulation at 26°N from satellite altimetry

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read more here: doi.org/10.5194/os-2021-10 Ocean Sci. Discuss. [preprint], in review, 2021

RAPID line/moorings

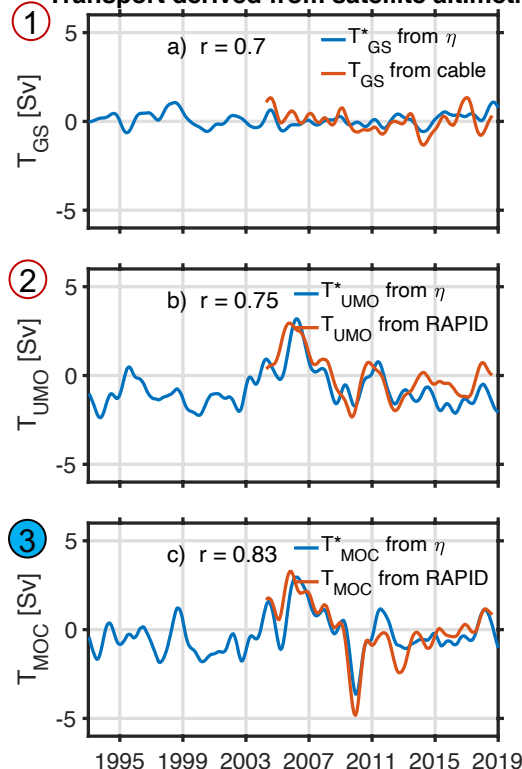


a) Satellite altimetry can be used to calculate the AMOC directly (right, blue lines), compared to RAPID (red lines), where the MOC is defined as:

$$T_{MOC} = T_{\text{Gulf Stream}} + T_{\text{Ekman}} + T_{\text{upper mid-ocean}}$$

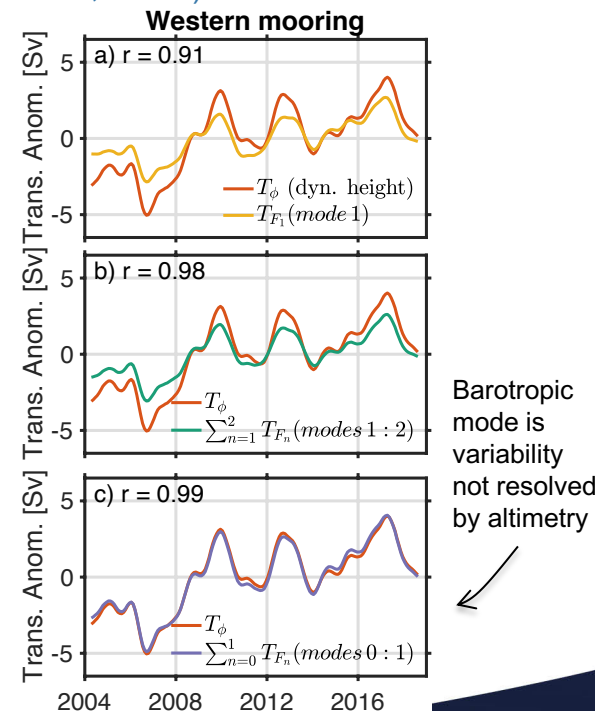
(3) Satellite Altimetry (1) ERA5 Wind stress (2) Satellite Altimetry

Transport derived from satellite altimetry



b) The methods can be extended to produce a historical reconstruction of the MOC.

c) How much does the vertical structure of the flow, which cannot be inferred from altimetry, matter? Using RAPID moorings, we find that the majority of variability explained by 1st baroclinic mode (83%) and the remainder by the barotropic mode (mode 0; below).



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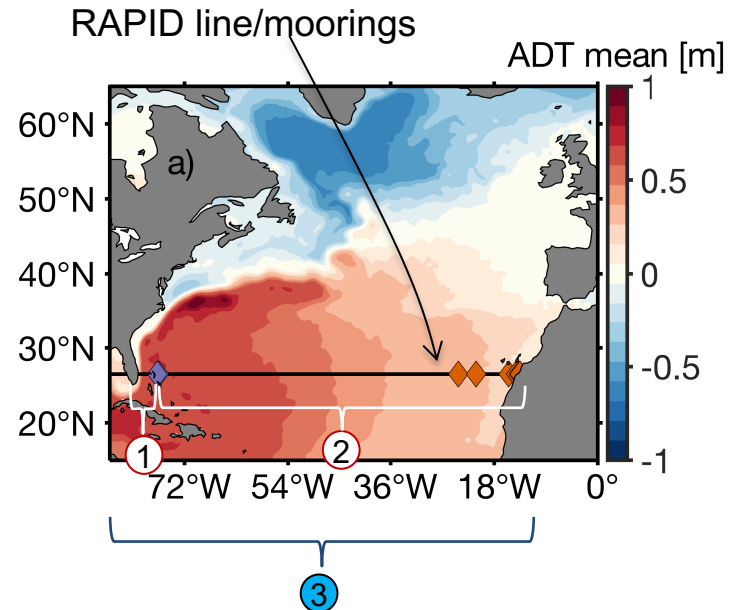
More information...

1. Motivation
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3. Evaluation of satellite and mooring data
4. Modal decomposition
5. Vertical structure of the flow
6. Reconstructing AMOC transport from satellite altimetry
7. Historical reconstruction of the AMOC (1993-2018)



1. Motivation

- Mooring arrays such as RAPID have made a step change in our understanding of large-scale circulation, but are limited to measurements at a single latitude
- Satellite altimetry has been shown to provide reliable estimates of surface ocean transports
- Using geostrophy, satellite altimetry can be used to calculate the AMOC directly, where the MOC is defined as



$$T_{MOC} = T_{\text{Gulf Stream}} + T_{\text{Ekman}} + T_{\text{upper mid-ocean}}$$

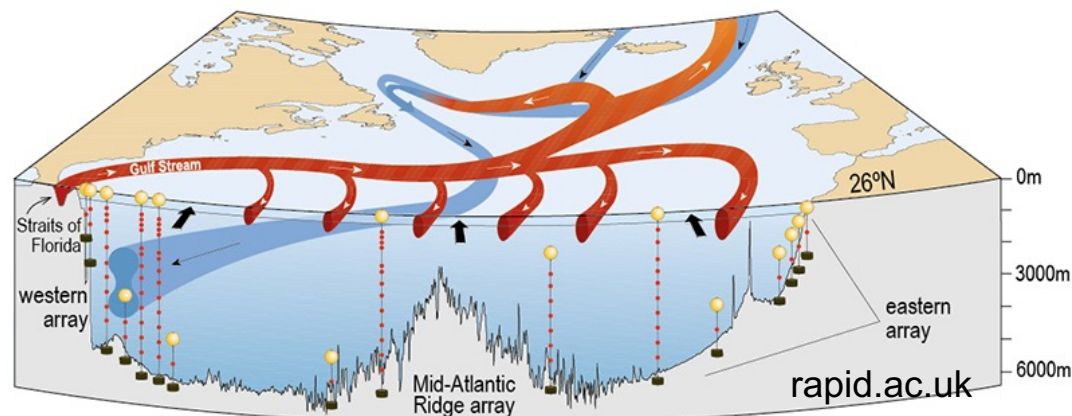
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Satellite Altimetry ERA5 Wind stress Satellite Altimetry

2. Data and methods

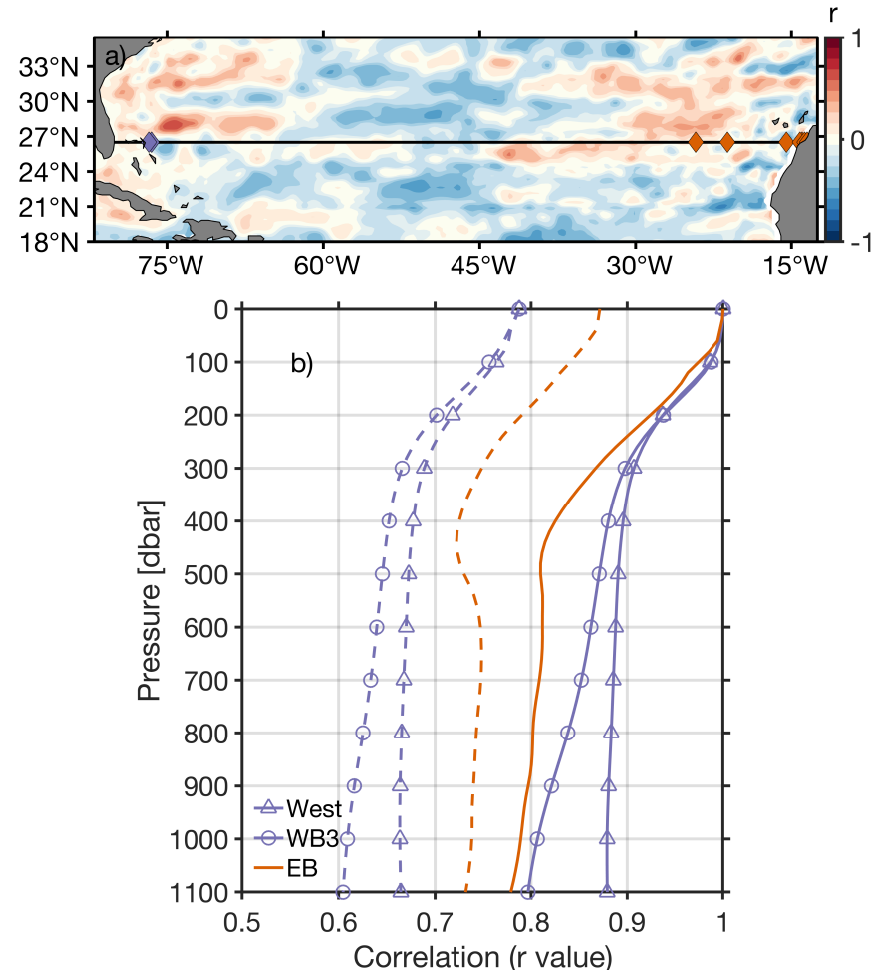
- Satellite data: CMEMS gridded multi-mission altimetry product, with 1/4 deg. resolution in space and monthly in time.
- RAPID data: MicroCATs record hourly. Tidal fluctuations removed with 2-day low pass filter. Transport estimates are gridded at 12-hour resolution. Final 10 day pass filter applied.
- All data is monthly averaged, annual seasonal climatology removed, and smoothed with an 18-month Gaussian filter.

Location of RAPID moorings



3. Evaluation of satellite and mooring data

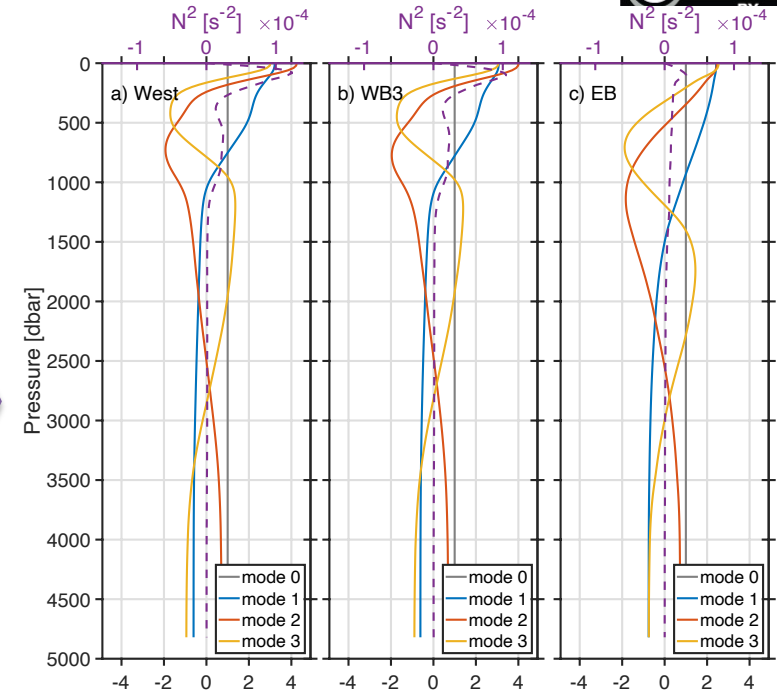
1. Top panel: correlation map between RAPID upper-mid ocean transport and sea level anomaly (SLA) at each grid point.
2. Bottom panel: correlation map between SLA at the location of the western (purple diamonds) and eastern (orange diamonds) moorings and dynamic height from the respective moorings, indicating variability observed at sea surface is a good measure and coherent with variability observed from moorings to at least 1,000 dbar.



4. Modal decomposition

1. Satellite altimetry can measure surface geostrophic velocities but cannot be used to infer the vertical structure of the flow.
2. Thus, to understand the contribution of the flow's vertical structure to meridional mass transport, we use normal mode decomposition, where the vertical structure of vertical and horizontal velocity, G_n and F_n respectively are determined from:

$$\frac{d^2 G_n(z)}{dz^2} + \frac{N^2(z)}{c_e^2} G_n(z) = 0, \quad F_n(z) = \frac{dG_n(z)}{dz},$$



3. Contribution of each mode to total variability observed by dynamic height anomaly (ϕ , from RAPID moorings) is further analysed from modal amplitude, c_n , from:

$$c_n(t) = \frac{1}{H} \int_{-H}^0 F_n(z) \phi(z, t) dz$$

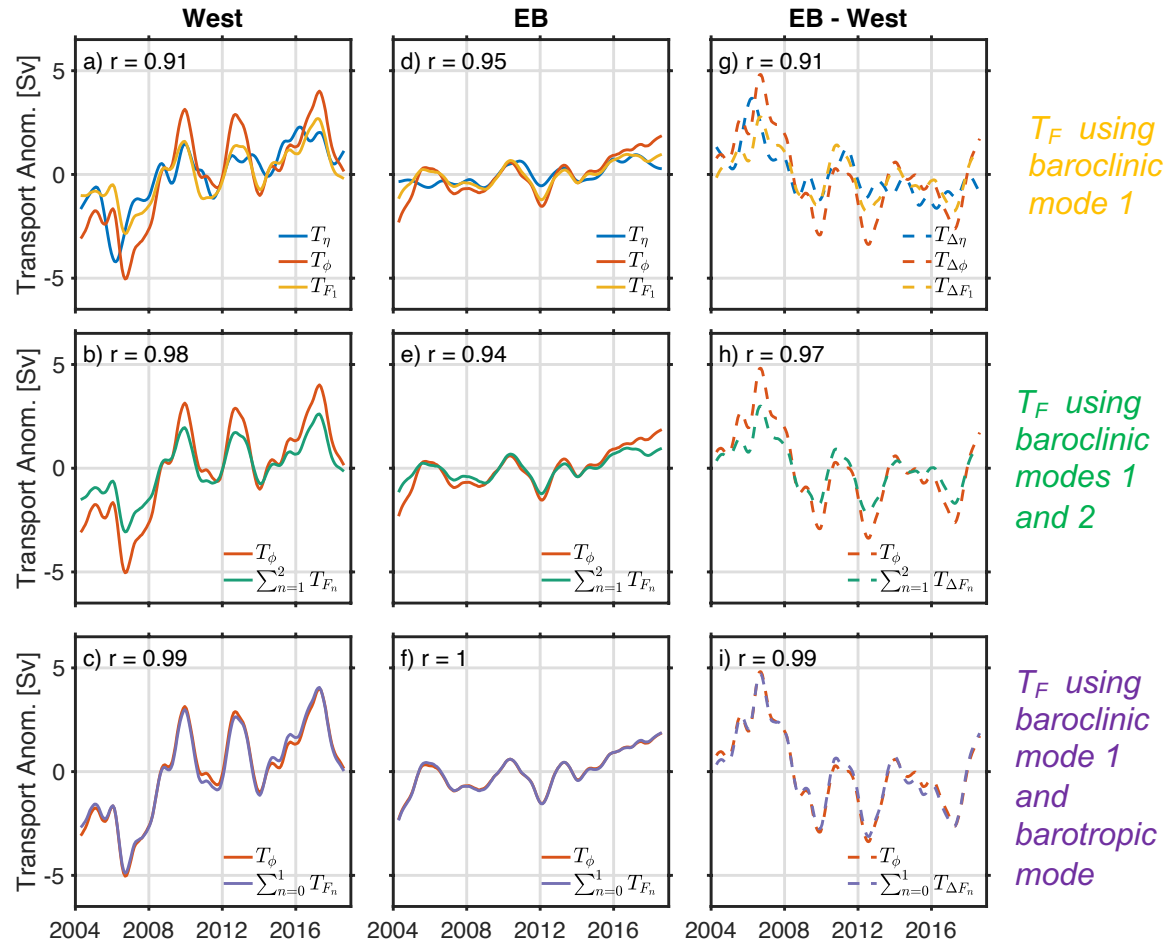
4. Assuming satellite altimetry usually reflects fluctuations associated with amplitude of the 1st baroclinic mode, the satellite-based modal amplitude can be written in terms of SLA, η , such that:

$$\hat{c}(t) = s \frac{g}{[F_1(z=0)]} \eta(t)$$

5. Transport anomalies from RAPID moorings

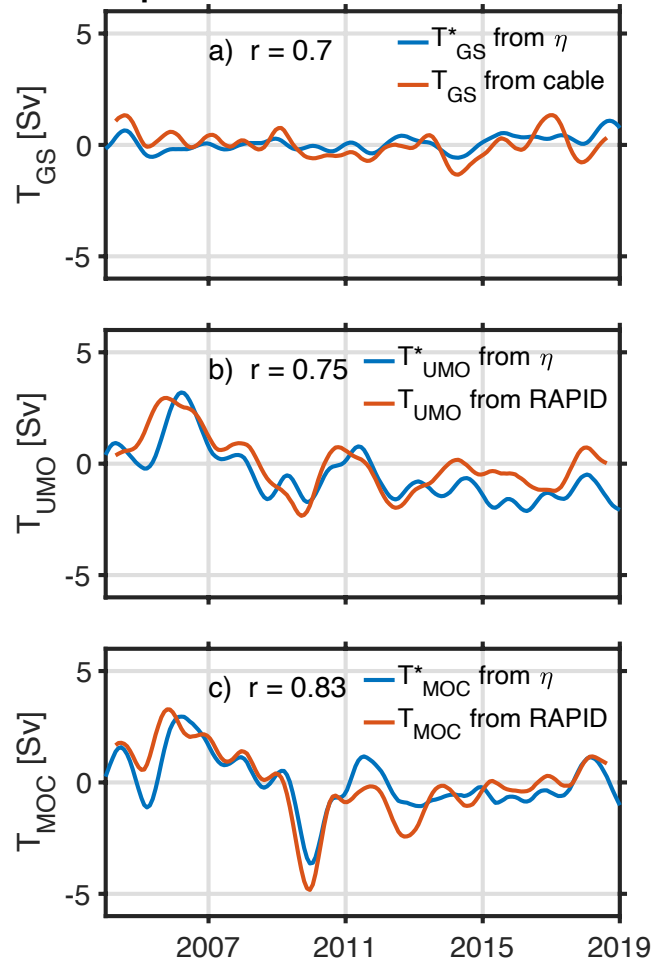
What/how many modes are needed to reconstruct transport observed by RAPID moorings?

- Transport anomalies from satellite (blue line, T_η), dynamic height from the moorings (red line, T_ϕ), and dynamic height reconstruction from individual modes (T_F) at the western and eastern RAPID mooring locations.
- Majority of variability explained by 1st baroclinic mode (83%) and the remainder by the barotropic mode.



6. Reconstructing AMOC transport from satellite altimetry

Transport derived from satellite altimetry



1. Gulf Stream transport from altimetry is computed from the east-west difference in sea level anomaly in the region of the Florida Straits (blue line) and compared with transport from submarine cable data ([Baringer and Larsen, 2001](#)).
2. The satellite-based upper mid-ocean transport is computed combining satellite-based mode amplitude ($\hat{c}$) with the 1st baroclinic mode, F (see slide 6), from the mooring such that:

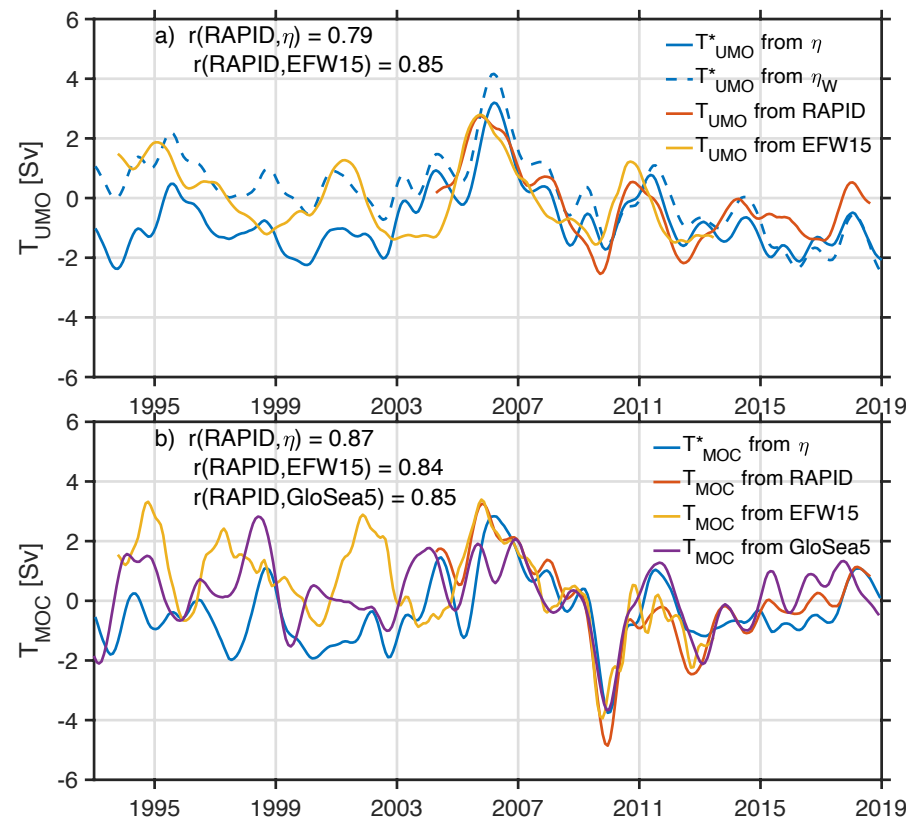
$$T_{UMO}(t) = \frac{1}{f} \left[\hat{c}_E(t) \int_{-1500}^0 F_E(z) dz - \hat{c}_W(t) \int_{-1100}^0 F_W(z) dz \right]$$

3. AMOC transport is the sum of the Gulf Stream, upper mid-ocean transport, and the Ekman transport, where the Ekman transport is derived from ERA5 zonal wind stress.

$$T_{MOC}(t) = T_{GS}(t) + T_{EK}(t) + T_{UMO}(t)$$

7. Historical reconstruction of the AMOC (1993-2018)

1. Upper mid-ocean transport (top panel) and the AMOC (bottom panel) are reconstructed for 1993-2003 period, pre-dating RAPID.
2. The satellite-based estimates (blue lines) are compared with other satellite-based (yellow line) and reanalysis (purple line) proxies. Poor agreement is found between upper mid-ocean and AMOC transport proxies in the 1993-2003 time period.



Further investigation needed to confidently reconstruct the MOC from 1993-2003!

Even more information/how to cite:

Sanchez-Franks, A., Frajka-Williams, E., Moat, B. I., and Smeed, D. A.: A dynamically based method for estimating the Atlantic overturning circulation at 26° N from satellite altimetry, Ocean Sci. Discuss. [preprint], doi.org/10.5194/os-2021-10, in review, 2021.

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