

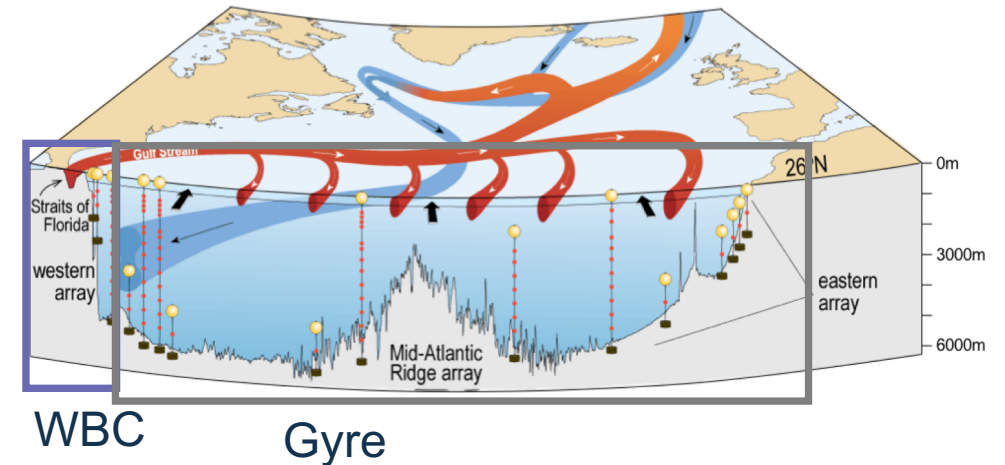
The Antilles and wind-driven gyre circulation at 26°N

MOC = Ekman + Florida Current + Upper mid-ocean

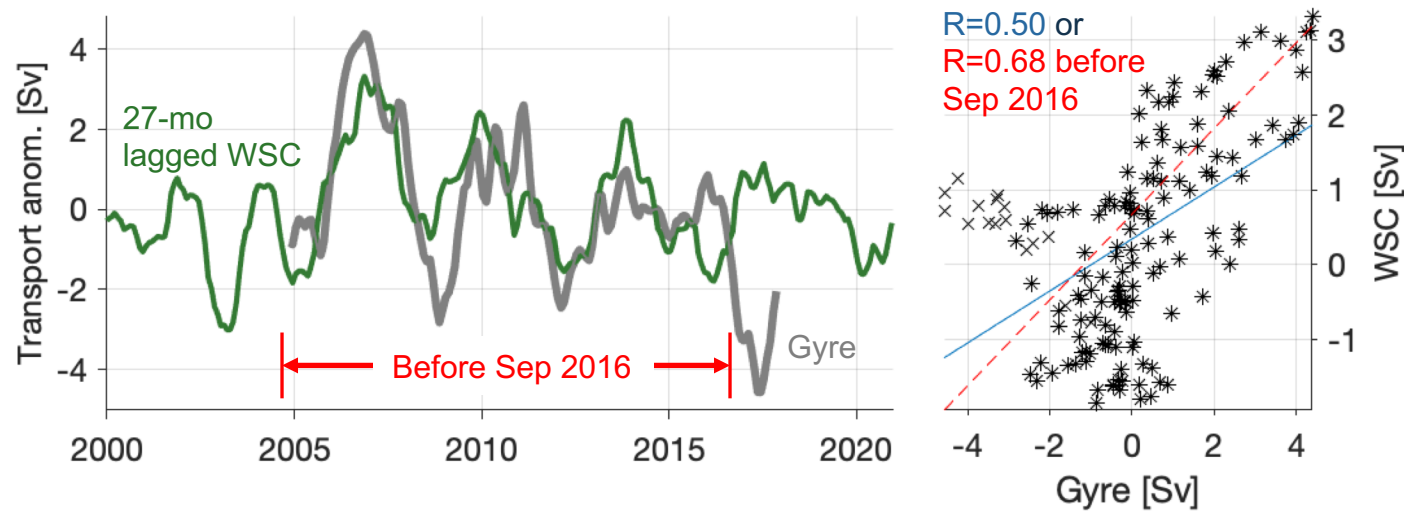
New decomposition for 26°N transports:

MOC = Ekman + **WBC** + **Gyre**

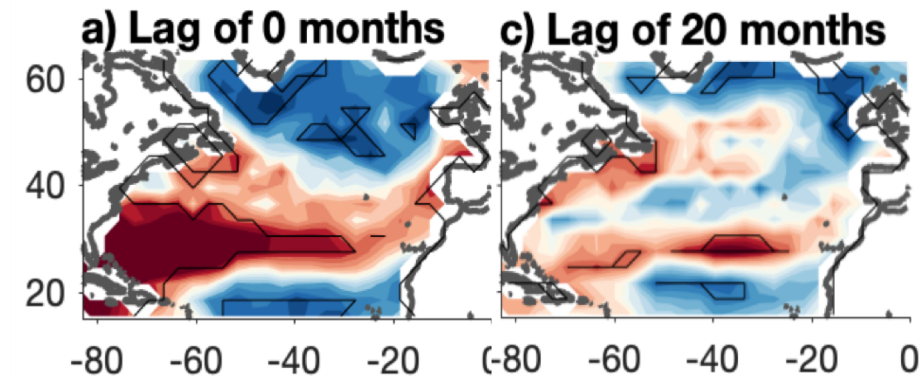
- **Claim:** MOC variability at 26°N is driven by wind.
- **Evidence:** Ekman + FC have weak interannual variability. **UMO** variability is captured in a 2-layer wind-forced model, explained by Rossby waves. (Zhao & Johns 2014)
- **Tested here:** Lagged relationship between **UMO**, **Gyre** and Western Boundary Current (**WBC**) vs Sverdrup relation.
- **What we found:** Gyre (= **UMO** – Antilles) satisfies Sverdrup relation, until Sep 2016 + with a 2-year lag. **UMO** does not.
- **What's next:** Sources of WBC variability?
Why does Sverdrup relation break down since 2016?



Lagged Sverdrup transport explains 30% of measured Gyre



Adjustment can be visualized with satellite altimetry.



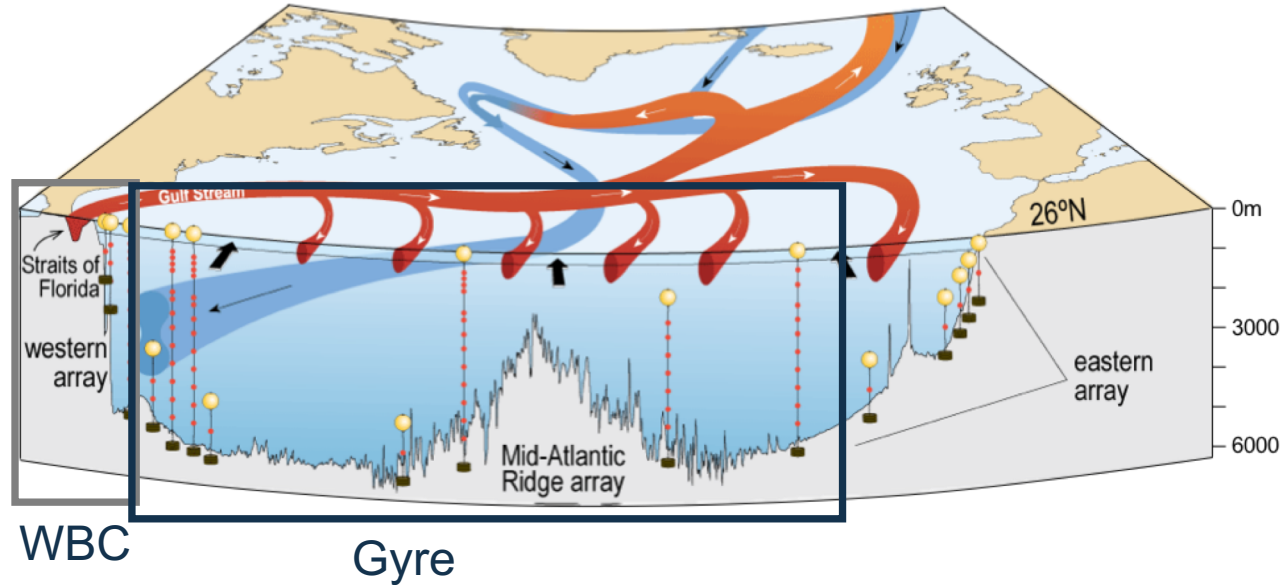
The Antilles and wind-driven gyre circulation at 26°N

How does the gyre strength at 26°N respond to wind forcing?

1. Re-decompose the MOC – instead of upper mid-ocean, calculate a ‘gyre’ (slide 3 & 4)
2. Identify the expected response to wind-forcing: Sverdrup balance

$$\beta V_s = \frac{\hat{k} \cdot \nabla \times \vec{\tau}}{\rho}$$

3. Consider adjustment timescales: How quickly should the large-scale circulation ‘feel’ the wind stress curl forcing? (slide 5)
4. Compute lagged correlations between expected Sverdrup transport and measured gyre transport (slide 6)
5. Calculate a predicted Sverdrup transport and compare to the gyre transport (slide 6)
6. Visualise the adjustment with satellite altimetry (slide 7)

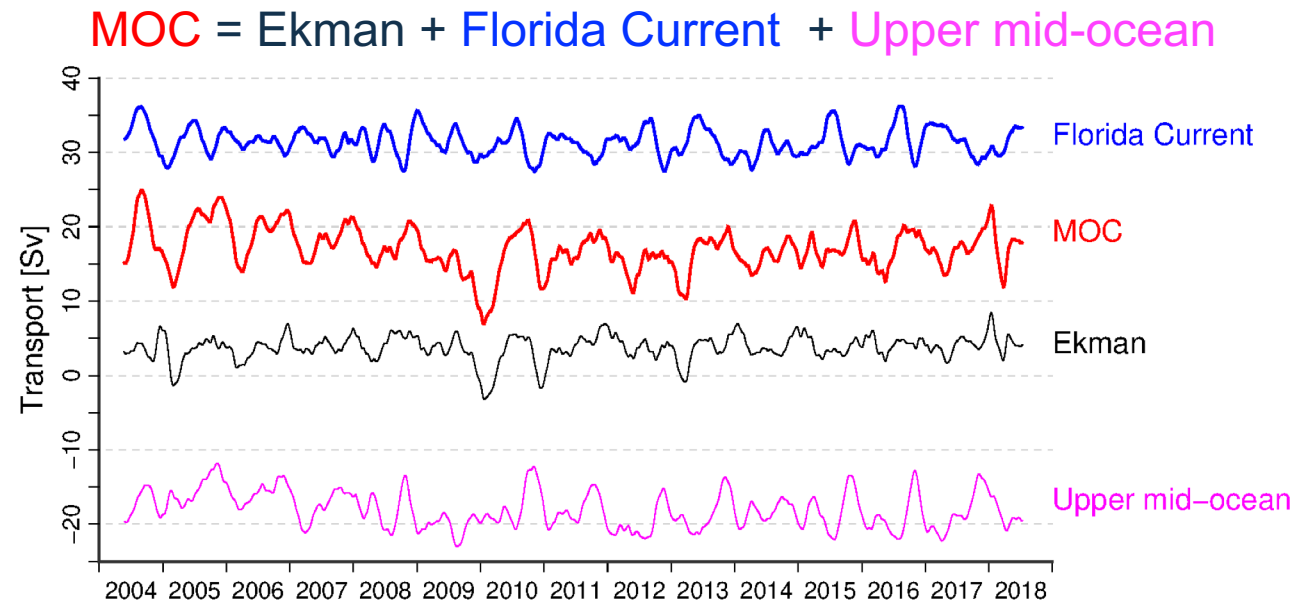
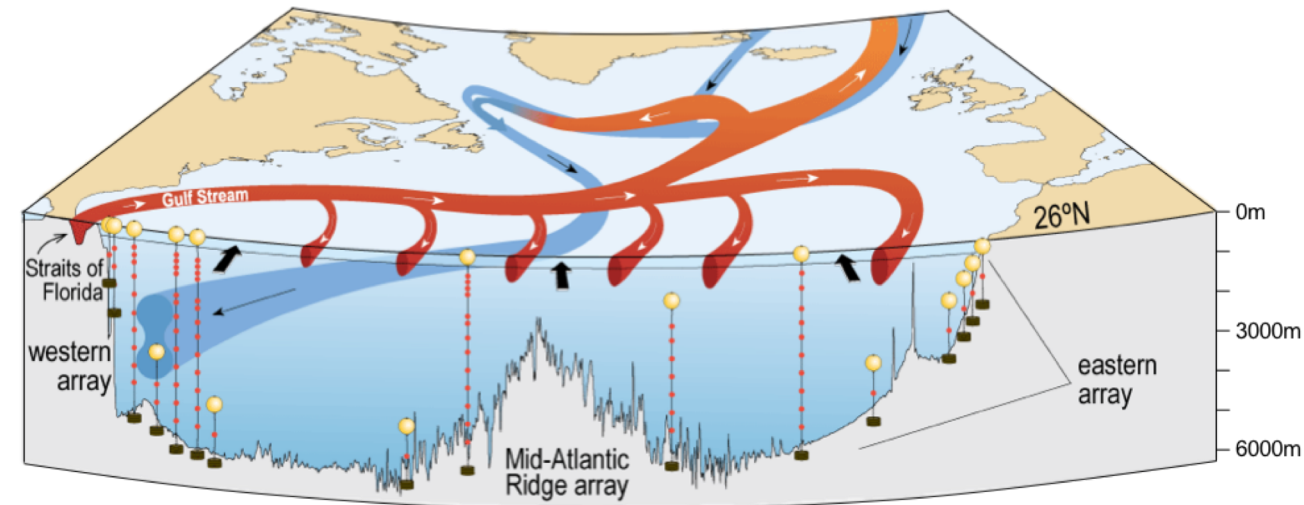


RAPID / MOCHA / WBTS array at 26°N NERC, NSF, NOAA funded

- The 26°N array measures the meridional overturning circulation (MOC) strength.
- Individual components are
 - Meridional **Ekman transport** from reanalysis winds
 - **Florida Current** from a cable
 - **Upper mid-ocean** (Bahamas to Canaries) from moored observations
- The overturning is equal to the total transport <1100m and opposite to the transport >1100m ("what goes north must go south").

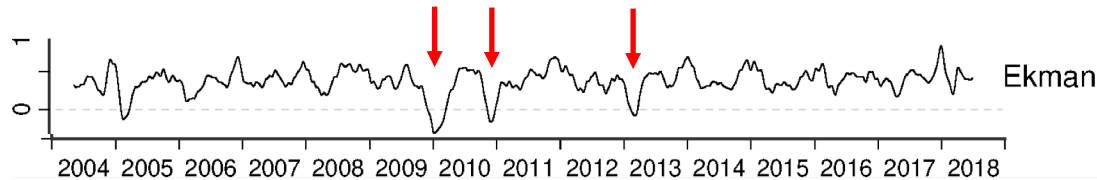
See McCarthy et al. 2015 Progr.

However, the 26°N decomposition into components by their measurement method doesn't match ocean dynamics.



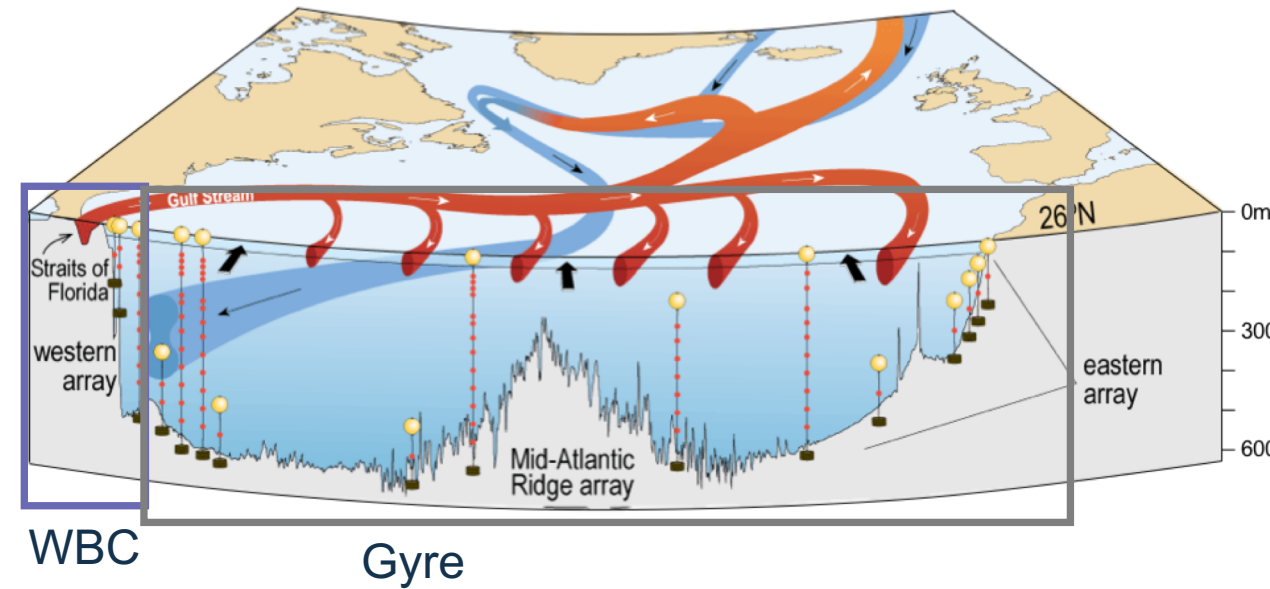
Re-decomposing the 26°N circulation

- **Upper mid-ocean vs subtropical gyre:**
The gyre is forced by wind stress curl.
- **Florida Current vs western boundary current (WBC):** Only some of the WBC flows through the Florida Straits; the remainder is east of the Bahamas in the Antilles Current.
- Ekman contributes little to the interannual variability apart from a few big events.



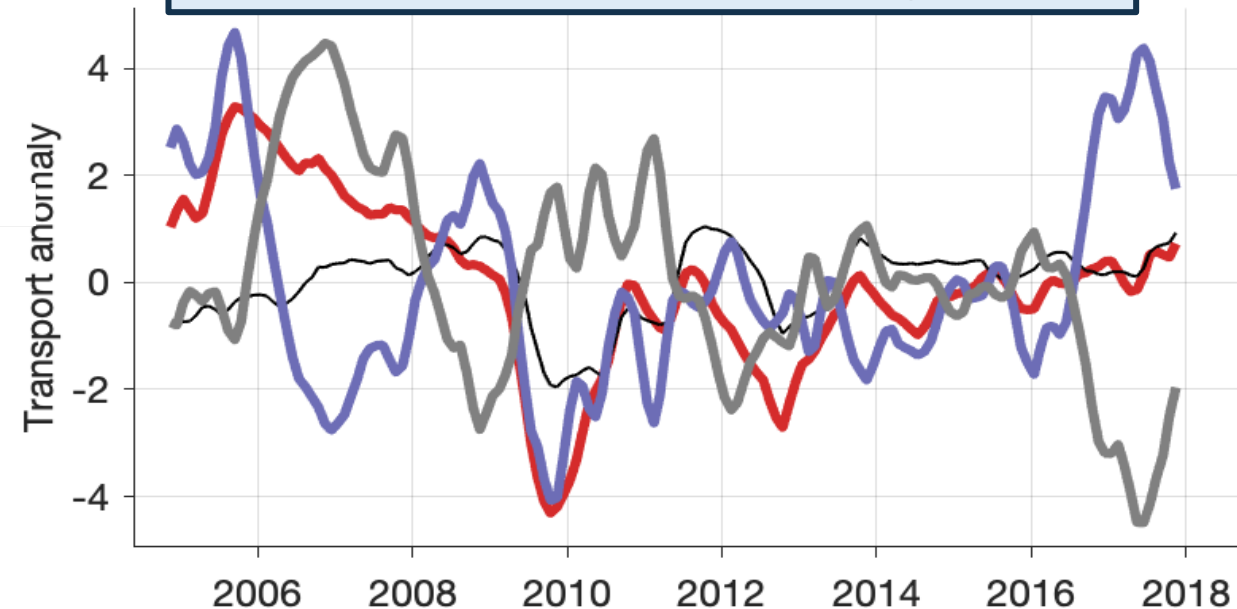
- The Gyre and western boundary current (WBC) are largely *compensating* (anti-correlated) on shorter timescales.

See Frajka-Williams et al. 2016 OcSci



New decomposition:

$$\text{MOC} = \text{Ekman} + \text{WBC} + \text{Gyre}$$

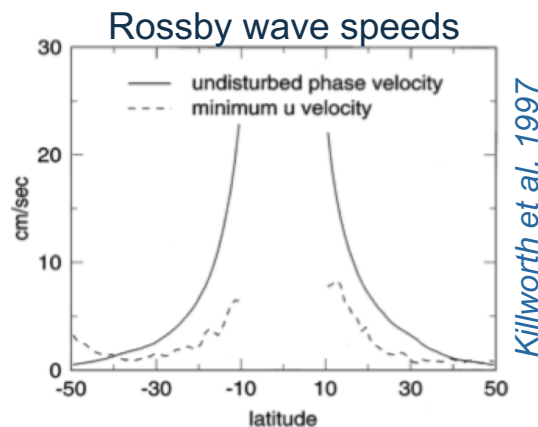


Wave adjustment of the subtropical gyre

How does the ocean respond to wind-stress curl? Large-scale circulation responds through wave-adjustment.

- East of the Mid-Atlantic ridge, the ocean response is *barotropic* (near-instantaneous)
- West of the Mid-Atlantic ridge, the ocean response is *baroclinic* (through long Rossby waves)

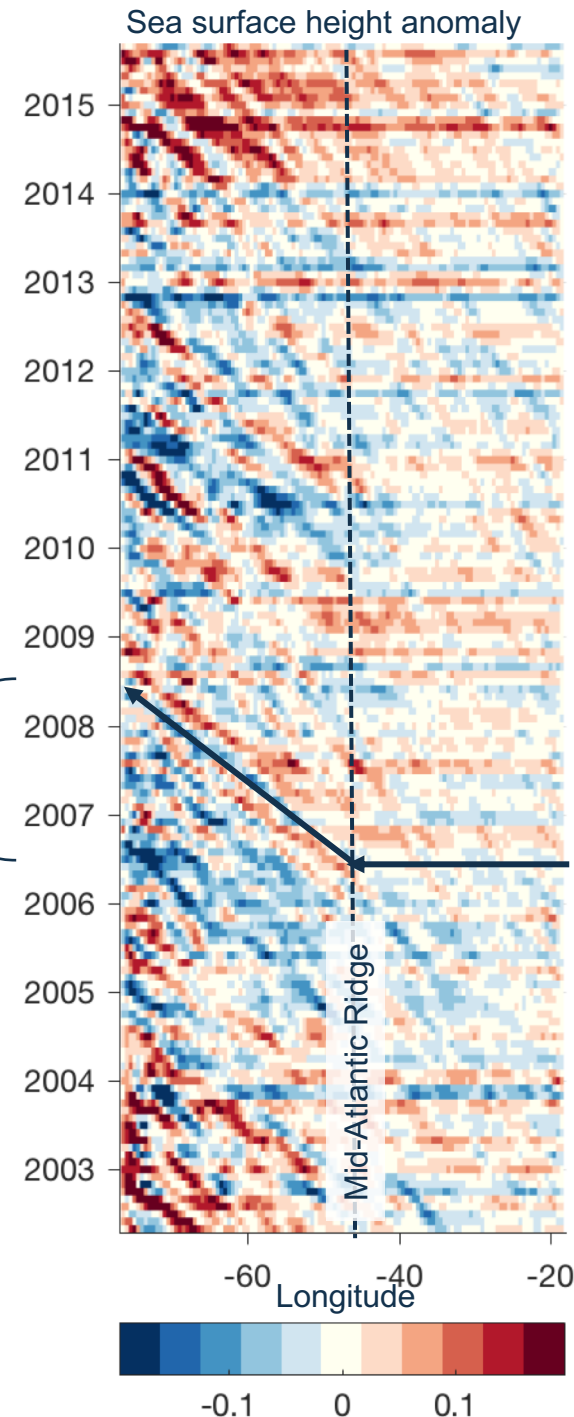
See Andres et al. (2012), Journal of Marine Research



At 26°N, speed ≈ 4.5 cm/s

These waves carry the signal of upwelling/downwelling to the boundary, where the large-scale (transbasin) circulation then 'adjusts' to a new value.

Gyre circulation adjusts ~ 2 years after forcing.

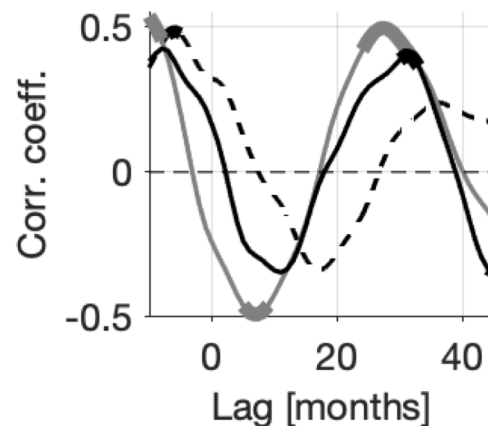


Evaluating Sverdrup balance

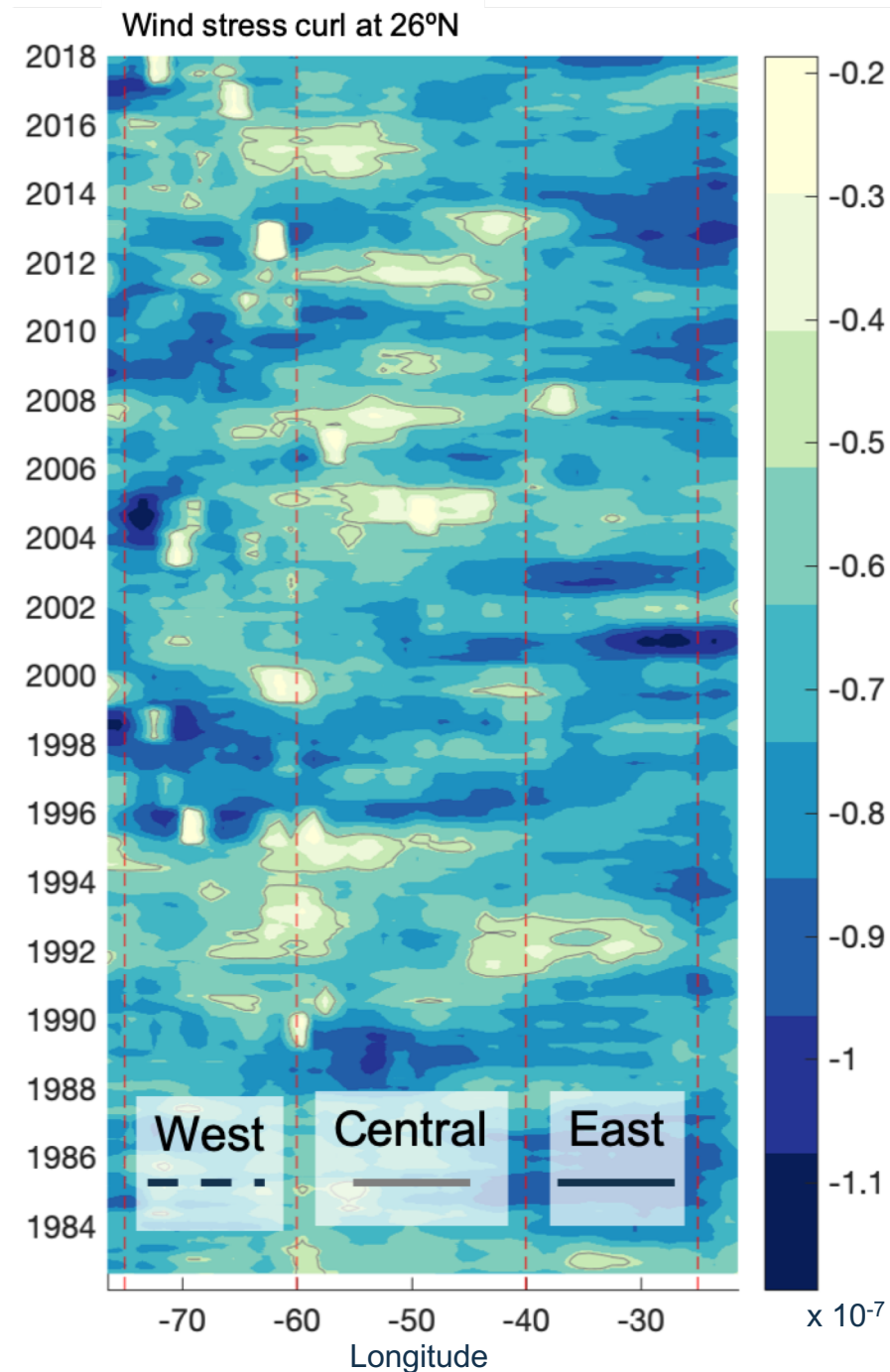
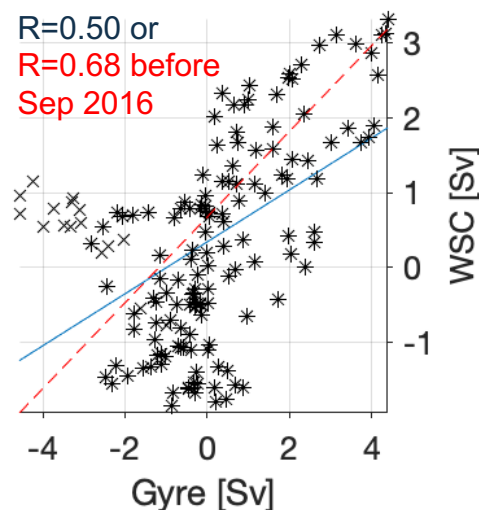
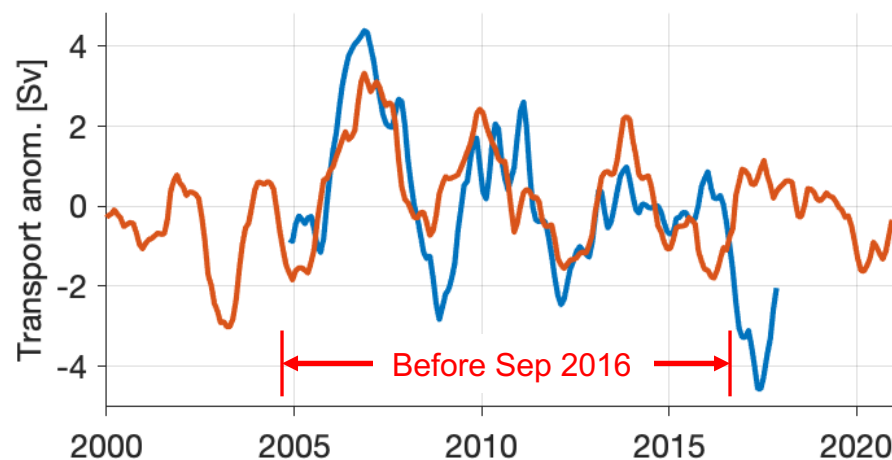
- Calculate expected Sverdrup transport from wind stress curl (ERA5) + integrate within regions (west, cent., east)

$$\beta V_s = \frac{\hat{k} \cdot \nabla \times \vec{\tau}}{\rho}$$

- Compute lag correlation between Gyre (upper mid-ocean minus Antilles Current) and WSC
- Identify lag of maximum correlation (27 months)



Lagged V_s explains 30% of measured Gyre strength

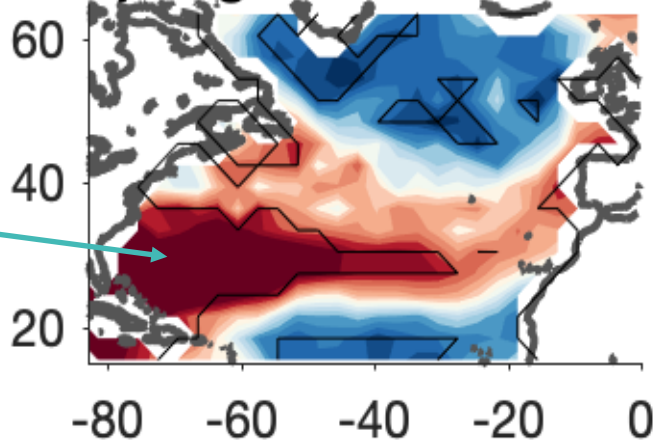


Watching the wave adjustment from space

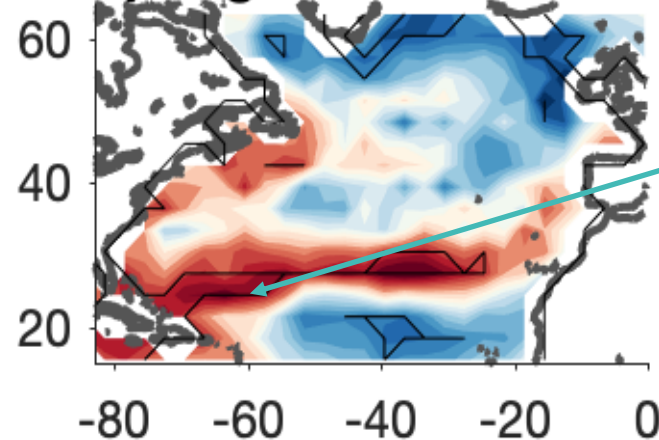
Wave adjustment can be visualized with lag correlations between Gyre and sea surface height anomaly.

When the gyre circulation is anomalous, SSHA correlation pattern shows a strong gyre circulation.

a) Lag of 0 months

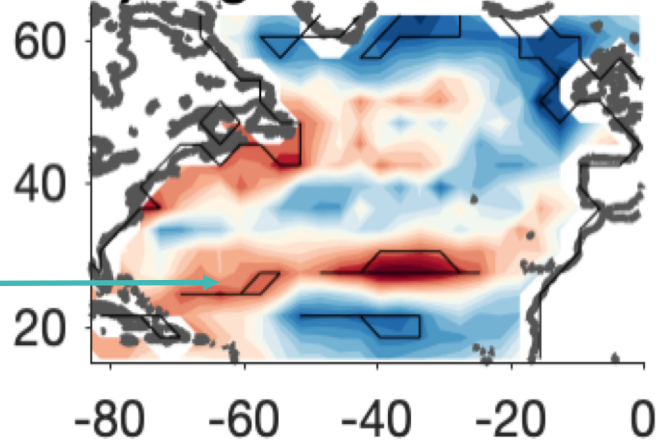


b) Lag of 15 months



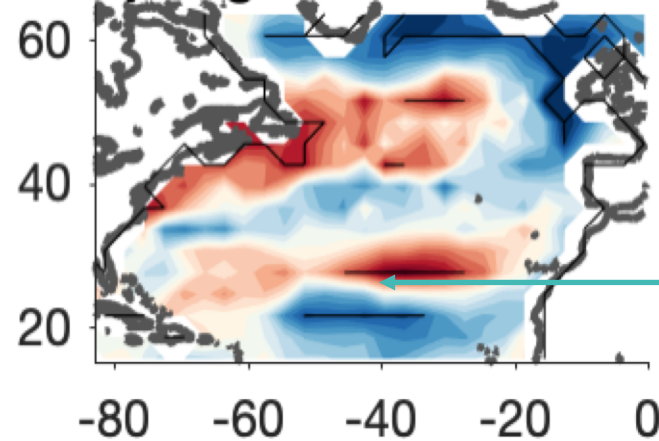
Preceding an anomalous gyre strength, the SSH anomaly is offshore

c) Lag of 20 months

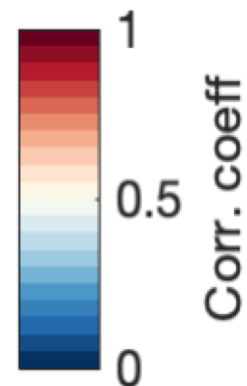


Transitional period – showing a westward movement of SSH anomalies (waves)

d) Lag of 25 months



Early in development, the SSH anomaly is primarily east of the Mid-Atlantic ridge



Lag 25 months is the SSH anomaly 25 months **before** the Gyre transport

More information?

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This was a presentation for the EGU 2021 General Assembly, April 2021.

Frajka-Williams et al. The Antilles Current and wind-driven gyre circulation at 26°N

The Antilles Current is a narrow, northward flowing boundary current in the western Atlantic just east of the Bahamas. Its role in the larger scale circulation has been debated: alternately thought to be part of the western boundary closure of the gyre circulation or the northward flowing limb of the meridional overturning circulation (MOC). From 19 years of moored current meter observations (1987--1991, 2004--2018), we define the strength of the Antilles Current by the net transport between the Bahamas and 76.5°W (spanning about 45 km zonally) and in the thermocline (0–1000 m). We find a mean northward transport of 3.5 Sv, substantial interannual variability, and no discernable trend since 1987. The interannual variability of the AC transport is independent of the variability of the Florida Current (the Gulf Stream through the Florida Straits). Instead, the Antilles Current contributes to the interannual variability of the MOC at 26°N, while the trend in the strength of the gyre circulation (defined as the transbasin thermocline transport minus the AC) is responsible for the trend in the MOC. In particular, the 2009/10 slowdown of the MOC resulted from a weaker northward AC transport, rather than an intensified gyre transport. Using the recent 14 years of in situ transport records, we compare the interannual variability of the gyre circulation to that of wind stress curl forcing via a Sverdrup transport calculation, identifying a potential role for wind stress curl (WSC) forcing at 26°N with a ~2 year lag until 2016. From 2016, the predicted gyre circulation using WSC diverges from the measured gyre strength.

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