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Key Points:

- Western boundary dynamic height governs interannual variability of transports
- Sea level anomalies in the west anticorrelate transbasin transports at 26°N
- The MOC 1993–2014 weakened (-1 Sv) due to a weakening of the Florida Current

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Estimating the Atlantic overturning at 26°N using satellite altimetry and cable measurements

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Abstract Climate simulations predict a slowing of the Atlantic meridional overturning circulation (MOC), a key oceanic component of the climate system, while continuous observations of the MOC from boundary arrays demonstrate substantial variability on weekly to interannual time scales. These arrays are necessarily limited to individual latitudes. A potential proxy for the MOC covering longer time scales and larger spatial scales is desirable. Here we use sea surface height data from satellites to estimate the interannual variability of transbasin ocean transports at 26°N. Combining this estimate with surface Ekman transport and cable measurements of the Florida Current, we construct a time series of the MOC from 1993 to 2014. This satellite-based estimate recovers over 90% of the interannual variability of the MOC measured by the RAPID 26°N array. This analysis complements in situ observational efforts to measure the MOC at multiple latitudes and opens the door to a broader spatial understanding of the Atlantic circulation variability.

1. Introduction

The Atlantic meridional overturning circulation (MOC) is characterized by warm waters flowing northward at the surface and cool waters flowing southward at depth. Due to the temperature difference between these transports, heat is fluxed northward, with the MOC responsible for roughly 25% of the northward heat transport at 26°N [*Hall and Bryden*, 1982]. In a warming climate, numerical simulations suggest that the MOC will slow in the near future, with implications for regional climate changes across Europe and beyond [*Meehl et al.*, 2007]. Traditionally thought of as a slowly varying circulation, the overturning has been estimated from hydrographic sections. Using five sections at 26°N, the circulation was found to have slowed by 30% over the period 1957–2004 [*Bryden et al.*, 2005].

Since 2004, the RAPID/MOCHA (Rapid Climate Change/Meridional Overturning Circulation and Heatflux Array) observational program at 26°N (hereafter, RAPID 26°N) has been delivering depth-resolved estimates of the transbasin volume and heat transports across the North Atlantic [*Johns et al.*, 2011; *McCarthy et al.*, 2015]. These continuous observations at 26°N have been transformative in our understanding of the meridional overturning circulation, identifying, for example, that the 30% reduction calculated from hydrographic sections over 1957–2004 [*Bryden et al.*, 2005] was not significant, due to large variability on subannual [*Cunningham et al.*, 2007] and seasonal time scales [*Kanzow et al.*, 2010]. More recently, the RAPID observations have identified a reducing trend of the MOC, at a rate of −0.5 sverdrups per year (Sv/yr) [*Smeed et al.*, 2014]. However, numerical simulations call into question the relevance of this slowing amidst substantial lower frequency variability [*Roberts et al.*, 2014]. Due to the present length of records from RAPID (10 years), it is not yet possible to directly assess the lower frequency variability of ocean transports.

While RAPID 26°N provides the most comprehensive measurements of the MOC, it is necessarily limited in space (to 26°N) and time (since 2004). Numerical studies have suggested that sea level anomalies (SLA) may be a useful proxy for oceanic transports. *Bingham and Hughes* [2009] found that SLA along the East Coast of North America are a good proxy for the MOC between 40 and 50°N. *Willis* [2010] used altimetry along with Argo float profiles to calculate transport at 41°N, based on model simulations indicating that the methodology only works around 41°N. At 26°N, transbasin transports were found to covary with the differences in SLA between the west and east of the basin [*Hirschi et al.*, 2007]. However, the correlation was degraded somewhat in observations by the absence of steric height measurements (related to density) in the top 200 m [*Ivchenko et al.*, 2011]. SLA and bottom pressure can be related to depth-dependent (baroclinic) and depth-independent (barotropic) transports in the ocean. Model studies have found that SLA is mirrored by bottom pressure fluctuations on shorter time scales, at higher latitudes and over shallower regions; on longer time scales, at lower