The wind stress drives the coherence of the North Atlantic Meridional Overturning Circulation on seasonal and longer time scales

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Woods Hole Oceanographic Institution – Line W program (John Toole)
MOVE Project at Scripps Institution of Oceanography (Uwe Send)
MOC strength at two latitudes:

26°N (from RAPID MOC)

41°N (+15 sv) from Argo: in Willis (2010)

Total = Geo. + Ekman

Fits to annual frequency

Goals of study:

1. Derive a quantity from observations which is representative of the MOC in the North Atlantic ocean

2. Study the meridional coherence of overturning processes in the North Atlantic: role of wind forcing?
Eastern and western overturning transports below 1000 m

\[ T_g(z, y) = \int_{W}^{E} \rho v_g \, dx \quad : \text{zonally integrated meridional geostrophic transport} \]

\[ \frac{\partial}{\partial z} T_g(z, y) = \frac{1}{f} \frac{\partial}{\partial z} [p_E(z, y) - p_W(z, y)] = \frac{\partial}{\partial z} T_{E,g}(z, y) + \frac{\partial}{\partial z} T_{W,g}(z, y) \]

Western overturning

Eastern overturning

\[ T(z,y) = 0 \text{ at } Z_1 = 1000 \text{ m} \]

\[ Z_2 = 4000 \text{ m} \]
4 arrays to obtain western overturning transports below and relative to 1000 m:

RAPID WAVE array
Line B/Line RS
(NOC/BIO)
Hughes et al. (2013)
Elipot et al. (2013)

WHOI Line W array
Toole et al. (2011)

RAPID MOC/MOCHA array
RSMAS/AOML/NOC
Rayner et al. (2011)

MOVE array
(SIO)
Send et al. (2011)
Overturning transport below 1000 m and MOC at 26°N?

“MOC” transport

Correlation

Negative of overturning transport below and relative to 1000 m ($T_{26}$)

$\rho_{xy}(1/\nu_c)$

$>0.7$

$\sim 6$ months

In “Ocean bottom pressure data capture the North Atlantic Meridional Overturning Circulation and its meridional coherence” Elipot et al. 2013 (in revision for JPO)
So, 4 time series of overturning transport below 1000 m ... 

Correlation between B and W: 
0.18 (daily) 
0.32 (monthly) 

No correlation 

Study from 22 August 2004 to 8 April 2008 : 3.7 years

Evidence for boundary waves propagation at time scales < 3 months between Lines B and W at ~ 1 m s\(^{-1}\)

**Outstanding question:**

How does one explain overturning coherence at time scales longer than 3 months?

From RAFOS floats: NOT advection by DWBC
Analytic (complex) EOF analysis

First mode: AEOF1: 36% of the covariance

a) AEOF1: conjugate Eigen vectors

b) APC1: Absolute value

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Analytic EOF1: projection on time series

3-month lowpass
3-month lowpass AEOF1

Variance explained (12h-step):

<table>
<thead>
<tr>
<th>AEOF1(%)</th>
<th>$T_B$</th>
<th>$T_W$</th>
<th>$T_{26}$</th>
<th>$T_M$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19</td>
<td>48</td>
<td>56</td>
<td>21</td>
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</tbody>
</table>
Correlation of transports with wind stress
Cartesian components and wind stress curl:

\( \mathbf{\nabla} \times \mathbf{\tau} \)
Analytic correlation of transports with wind stress Cartesian components and wind stress curl:

\[ r_{x+y+}(0) = |r_{x+y+}(0)| e^{\phi_{x+y}} \]

\[ \nabla \times \tau \]
First mode of correlation between transports and wind stress: ASVD1

opposing oceanic overturning cells

Principal Component time series: APC1 (τ) APC1 (T)

Coupling coefficient: \( r = 0.50 \)

Sime et al. (2006): Mean seasonal anomaly in MOC diagnosed in HadCM3

Singular Vectors
Second mode of correlation between transports and wind stress curl: ASVD2

Principal Component time series:
APC1 (curl $\tau$) APC1 (T)

Coupling coefficient: $r = 0.53$

Correlation of mode with NAO index: 0.38
Wind stress and curl changes associated with ASVD2:

Composite anomalies of normalized wind stress curl (shading) and normalized wind stress vector (arrows)
Mechanism for deep overturning transport fast response to ASVD2?

Subpolar Gyre

Subtropical Gyre

inter-gyre “gyre”

e.g Marshall et al. 2001

NAO+

Re[APC2]+
Summary of wind covariance analysis: ASVD1 & ASVD2 for overturning transport time series

Total amount of variance explained by AEOF and wind stress curl modes:

<table>
<thead>
<tr>
<th></th>
<th>$T_B$</th>
<th>$T_W$</th>
<th>$T_{26}$</th>
<th>$T_M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEOF1 (%)</td>
<td>19.1</td>
<td>47.9</td>
<td>55.7</td>
<td>20.6</td>
</tr>
<tr>
<td>$\nabla \times \tau$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SVD1</td>
<td>9.4</td>
<td>20.7</td>
<td>45.7</td>
<td>59.4</td>
</tr>
<tr>
<td>SVD2</td>
<td>56.6</td>
<td>39.2</td>
<td>6.1</td>
<td>14.2</td>
</tr>
<tr>
<td>SVD1+SVD2</td>
<td>63.4</td>
<td>54.5</td>
<td>49.6</td>
<td>80.0</td>
</tr>
</tbody>
</table>
Summary

• 4 time series of western overturning transport below and relative to 1000 m at 42ºN, 39ºN, 26ºN, and 16ºN

• Time series are representative of geostrophic overturning processes on semi-annual and longer time scales

• Evidenced semi-annual and longer periods covariability between transports

• 1\textsuperscript{st} mode of variability with near annual & semi-annual phase cycle associated with basin-wide Ekman forcing

• 2\textsuperscript{nd} mode of variability related to large-scale NAO-like wind pattern

Thank you

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