On the role of the Gulf Stream in the changing Atlantic nutrient circulation during the 21st century

Daniel B Whitt

Outline

A large-scale observational description of the Gulf Stream nutrient stream

Projected decline of Gulf Stream nutrient flux in simulations with CESM, and implications

How small-scale processes modify AMOC and associated Gulf Stream nutrient transport
What we usually talk about when we talk about the Gulf Stream

- Western boundary current of subtropical gyre
- Prominent surface front, steeply sloping isopycnals
- Key pathway of Atlantic meridional overturning circulation
- Large heat, salt and water transports
Nutrients depleted at surface, maximum in the main pycnocline

Isopleths of nutrient align with sloping isopycnals across the Gulf Stream

Williams et al. (2011)
NO₃ is elevated in the Gulf Stream on subsurface isopycnals

Whitt (2018)
Gulf Stream transports vast quantities of nutrients below the surface

\[ \sigma_g = 27.5 \text{ kg/m}^3 \]

Separated Gulf Stream

Nutrient transport highly correlated with volume transport

Williams et al. (2011)

Whitt (2018)
Fate of Gulf Stream nutrients depends strongly on their depth/density class. Deeper waters irrigate subpolar gyre, shallower waters irrigate gyre boundary. Williams et al. (2006)
Scaling key terms in the mean nitrate budget of the subpolar gyre above $\sigma_\theta = 27.5$ kg/m$^3$:

- Gulf Stream NO3 flux 300–800 kmol/s
- AMOC NO3 flux 350 kmol/s at 36 N
- Interior diapycnal nitrate flux < 10 kmol/s
- Entrainment 50–75 kmol/s

Whitt (2018)
Upper-ocean ($\sigma_\theta < 27.5$ kg/m$^3$) NO$_3$ sourced from south via AMOC (~80%) and entrainment via deep convection (~20%) in the subpolar N. Atl.

How much will 21st century declines in (1) AMOC and (2) deep convection drive declines in nutrient supply to the euphotic zone and export via sinking organic particles during the 21st century?

Can we separate the two effects?

Whitt (2018)
CESMLE projects that AMOC nutrient and volume transport decline by \( \sim 0.5\% \) per year on average between 2006 and 2080.

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Changes in AMOC associated with changes in Gulf Stream

Ensemble means (34 members)

Whitt (2018)
Changes in AMOC associated with changes in Gulf Stream

### Zonal integrals across Atlantic at 48 N, $\sigma_\theta < 27.5$ kg/m$^3$

<table>
<thead>
<tr>
<th>Year</th>
<th>AMOCN</th>
<th>AMOCV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kmol/s</td>
<td>Sv</td>
</tr>
<tr>
<td>2006</td>
<td>[303,313]</td>
<td>[18.3,19.3]</td>
</tr>
<tr>
<td>2080</td>
<td>[169,184]</td>
<td>[10.9,12.0]</td>
</tr>
</tbody>
</table>

- percent change: -43% - 39%
- rate of change: -1.8 /yr -0.10 /yr

*Ensemble IQRs (34 members)*

### Sections across the Gulf Stream

<table>
<thead>
<tr>
<th>GS,64°W,N</th>
<th>GS,30.5°N,N</th>
<th>GS,64°W,V</th>
<th>GS,30.5°N,V</th>
</tr>
</thead>
<tbody>
<tr>
<td>kmol/s</td>
<td>kmol/s</td>
<td>Sv</td>
<td>Sv</td>
</tr>
<tr>
<td>[521,547]</td>
<td>[507,528]</td>
<td>[35.9,37.6]</td>
<td>[36.8,38.8]</td>
</tr>
<tr>
<td>[337,366]</td>
<td>[330,347]</td>
<td>[26.6,28.5]</td>
<td>[28.7,30.0]</td>
</tr>
</tbody>
</table>

- -34% -35% -25% -22%
- -2.4 /yr -2.4 /yr -0.13 /yr -0.11 /yr

*Whitt (2018)*
CESMLE projects near collapse of entrainment across 27.5 by 2080 in RCP8.5
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Atlantic, north of 48 N

<table>
<thead>
<tr>
<th>Year</th>
<th>EN275</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>[27.7, 42.7]</td>
</tr>
<tr>
<td>2080</td>
<td>[0.8, 2.4]</td>
</tr>
</tbody>
</table>

percent change -95%
rate of change -.44 /yr

Reduced entrainment of NO3 is about 4x smaller than reduced AMOC advective NO3 flux

Whitt (2018)
Declines in NO3 supply are associated with declines in export.

Pattern of reduced PON flux across 27.5 differs qualitatively from pattern of reduced NO3 entrainment across 27.5

Whitt (2018)
Declines in NO₃ supply are associated with declines in export

<table>
<thead>
<tr>
<th>Year</th>
<th>PON275</th>
<th>PON100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kmol/s</td>
<td>kmol/s</td>
</tr>
<tr>
<td>2006</td>
<td>[76.8, 81.9]</td>
<td>[118,123]</td>
</tr>
<tr>
<td>2080</td>
<td>[32.6,40.2]</td>
<td>[85,90]</td>
</tr>
<tr>
<td>percent change</td>
<td>-54%</td>
<td>-27%</td>
</tr>
<tr>
<td>rate of change</td>
<td>-.57 /yr</td>
<td>-.44 /yr</td>
</tr>
</tbody>
</table>

Reduction in export across 27.5 (~42 kmol/s) is greater than reduction in entrainment across 27.5 (~32 kmol/s)
Nutrient transport highly correlated with volume transport; CMIP5 models predict 15–60% reductions in AMOC over 21st century, so results are uncertain at an $O(1)$ level.

$O(1)$ uncertainties associated with ocean circulation could arise from missing mesoscale dynamics, for a variety of reasons.

However, uncertainties about boundary layer and interior mixing processes are more likely smaller $O(<10\%)$ uncertainties, but non-negligible
Thanks

danielwhitt.github.io
Future projections of global export of POC in CESM1

In RCP8.5, CESM1 predicts:
- enhanced export at subpolar latitudes
- reduced export at subtropical latitudes

However, subpolar North Atlantic experiences largest regional reduction in export
Dramatic reductions in phytoplankton during the North Atlantic spring bloom in RCP8.5

There are implicit implications for higher trophic levels, which depend on timing and magnitude of bloom.
Source water for subpolar gyre water is largely sourced from deeper depths in the subtropics and is nutrient rich.

4-year back trajectories, 50 m depth

Modeled Lagrangian float trajectories in eddy-resolving model (FLAME)

Burkholder and Lozier (2014)
CESMLE projects almost complete collapse of wintertime entrainment across 27.5 by 2080 in RCP8.5

Whitt (2018)
Gulf Stream nutrient transport key component of Atlantic nutrient circulation: observations

Characteristics of the nutrient distribution:
• Vertical profiles are very different north and south of the Gulf Stream
• But nearly identical when plotted as a function of density

Whitt (2018)
Changes in AMOC associated with changes in Gulf Stream

Ensemble means (34 members)

Whitt (2018)