θ-S structure of the North Atlantic circulation and the associated heat/freshwater transports

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Motivations

We know the North Atlantic circulation well: basin scale AMOC that is mostly vertical/diapycnal and sub-basin scale gyres that are mostly horizontal/isopycnic. Yet, there are uncertainties regarding the partition of the meridional heat transport (MHT) between the AMOC and gyres. For example, at 25°N,

- Classical vertical-horizontal decomposition suggests that 90% MHT is due to the AMOC and the remaining 10% is due to the subtropical gyre (e.g., Bryden and Imawaki 2001; Johns et al., 2011; McCarthy et al., 2015)
- 0.1-0.4 PW (10-30%) by the subtropical gyre (Talley, 2003)
- 40% by the subtropical gyre (Ferrari and Ferreira, 2011)

The meridional freshwater transport (MFWT) is less well-known, so are the AMOC and gyre contributions:

- Vertical-horizontal decomposition of the RAPID data based transports suggests that -0.78 Sv MFWT is due to the AMOC, 0.35 Sv due to the subtropical gyre (McDonagh et al. 2015)
The purpose here is to examine the circulation structure to clarify the differences, using high-resolution model results. A simple (natural) approach of summarizing the essential of the meridional flows (of different water masses) across a zonal section is to project the meridional transports on a θ-S plane. For example, the **Northward** and **Southward** transports across 26°N
From a different angle...

Model meridional transport on θ-S plane for three ΔθxΔS

- diapycnal AMOC (warmer, saltier water northward)
- diapycnal subtropical gyre (warmer, saltier water northward)
- isopycnic subtropical gyre (colder, fresher water northward)
In the basin-scale perspective

- Different meridional overturning circulation projected on depth and density spaces: the later shows sub-basin scale diapycnal overturning cells (in both the subtropical and subpolar NA), which are not part of the basin-scale AMOC. How does this difference impact the MHT/MFWT?
Overturning (vertical vs. diapycnal)

MHT: 1.10 PW [total 1.24 PW]
MFWT: -0.71 Sv [total -0.37 Sv]

1.29 PW (0.06 PW)
-0.53 Sv (-0.03 Sv)
Gyre (horizontal vs. isopycnal)

0.14 PW [total 1.24 PW]
0.34 Sv [total -0.37 Sv]
Gyre vs. AMOC in the MHT/MFWT

• The subtropical gyre (including a large isopycnic circulation and a small diapycnal overturning) contributes near 0 PW MHT and about 0.13 Sv MFWT northward;

• The zero gyre MHT is even lower than the 10% contribution based on the classical vertical-horizontal decomposition, let alone the higher gyre contributions in by Talley (2003) and Ferrari and Ferreria (2011);

• The northward gyre MFWT, also lower than the contribution based on vertical-horizontal decomposition, is opposite of that by the diapycnal AMOC: one corresponds to the positive E-P within the subtropical gyre, the other to the overall negative E-P in the northern North Atlantic that forms the NADW.
Why not higher gyre MHT?

- 0.4 PW gyre contribution in Talley (2003) comes from using the upper part of the Florida Current (and Ekman) transports to balance the returning component of the subtropical gyre

\[(a)\) Atlantic 24°N (Reid, 1994 velocities with Ekman adjustment)

\[
\begin{array}{|c|c|}
\hline
 & 5.9 \text{ Sv}/0.56 \text{ Sv} \\
\hline
13.0 \text{ Sv}/1.40 \text{ PW} & (\text{Ekman}) \\
25.845 \sigma_\theta \\
16.0 \text{ Sv}/1.03 \text{ PW} & (-19.0 \text{ Sv}/-1.56 \text{ PW}) \\
\text{(Gulf Stream)} & (\text{Interior}) \\
27.3 \sigma_\theta \\
\hline
\end{array}
\]

Total heat transport = 1.28 PV
Shallow gyre heat transport = 0.40 PW
Int./ deep heat = 0.88

Figure 3 from Talley (2003)
However, T/S in the WBC (FC)
It is thermocline water that constitutes the subtropical gyre, and the near-surface water and AAIW are the (basin-scale) AMOC components. If we refine the Talley (2003) calculation (using the thermocline water only), we obtain ~0 PW MHT and 0.13 Sv MFWT, consistent with the results of diapycnal-isopycnal decomposition.
Why not higher gyre MHT?

- 40% gyre contribution in Ferrari and Ferreira (2011) is based on two experiments: One with AMOC (0.8 PW); the other without AMOC (0.3 PW). However, subtropical gyre differs significantly between these two models: 0.3 PW represents the gyre MHT in the experiment without AMOC, not the one with AMOC.

Figures 6a, 12a in Ferrari and Ferreira (2011)
Summary

• The (basin-scale) AMOC is responsible for virtually all the MHT across the subtropical North Atlantic at 26°N;

• The subtropical gyre contributes quite significantly to the MFWT (0.13 Sv, northward), opposite to that contributed by the AMOC (-0.50 Sv, southward).

For more details of this work, see J. Climate; 2016 (DOI: 10.1175/JCLI-D-15-0798.1)
On-going work

2-D Diapycnal transformation

3-D maps of WMT
On-going work

2-D Diapycnal transformation

Surface buoyancy forcing
On-going work

2-D Diapycnal transformation

(difference: interior mixing)