A decade of Atlantic Ocean Heat Transport estimates from the RAPID-MOCHA Array

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Estimating heat transport from the array

Meridional Heat Transport: \( Q_{\text{net}} = \int \int \rho c_p v \theta \, dx \, dz \)

\( Q_{\text{net}} = Q_{\text{FC}} + Q_{\text{EK}} + Q_{\text{WB}} + Q_{\text{INT}} + Q_{\text{EDDY}} \)

\( Q_{\text{FC}} \rightarrow \text{Cable transport} \ast \text{Seasonally varying flow-weighted FC temperature (updated from Shoosmith et al., 2005)} \)

\( Q_{\text{EK}} \rightarrow \text{CCMP/ERA wind stresses} \ast \text{Argo Ekman layer temperature} \)

\( Q_{\text{WB}} \rightarrow \text{Directly calculated from moored current meters/thermistors in Abaco western boundary array} \)

\( Q_{\text{INT}} \rightarrow \text{Zonally-averaged interior transport profile from endpoint geostrophic moorings} \ast \text{Zonally-averaged interior ocean temperature (Argo in top 2000 m merged with seasonal Hydrobase climatology below 2000 m)} \)

\( Q_{\text{EDDY}} \rightarrow \text{Contribution due to spatially correlated v,T variability across the interior (from Argo)} \quad Q_{\text{EDDY}} = \int \int \rho c_p v' \theta' \, dx \, dz \)

*Johns et al., J.Clim. (2011)*
What’s New?

1. **Weekly Argo/Rapid OI for interior, used in:**
   - $Q_{\text{INT}}$ (replaces Hydrobase seasonal temperature climatology)
   - $Q_{\text{EDDY}}$ (replaces estimate from historical sections and widely-spaced geostrophic moorings)
   - $Q_{\text{EK}}$ (replaces Reynolds SST)

2. **Updated Florida Current seasonal flow-weighted temperature (more sections)**

3. **Other improvements (McCarthy et al. 2014, Prog. Oceanogr.)**
   - better surface extrapolation of interior geostrophic velocities
   - TEOS-10 equation of state
Meridional Heat Transport and Components

![Graph showing temperature/heat transports (PW) over years from 2004 to 2014. The graph displays different components such as Florida C., Interior, Ekman, WB Abaco, Eddy, and Total. Each component is represented by a different line color. The x-axis represents the years from 2004 to 2014, and the y-axis represents the temperature/heat transports in PW.]
Low-frequency Variability of Gulf Stream, Ekman, Mid-ocean, and total Heat Transport

2004-2013 mean heat transport: 1.24 PW

5-yr means:
2004-2008 1.34±0.04 PW
2009-2013 1.14±0.08 PW
Geostrophic (non-Ekman) Heat Transport Variability

\[ Q_{\text{tot}} (\text{PW}) = 0.077 \times \text{MOC} - 0.08 \]

\[ Q_{\text{geo}} (\text{PW}) = 0.064 \times \text{MOC} + 0.14 \]
Overturning and Gyre Heat Transports

\[ Q_{OT} = \int \rho C_p \langle V \rangle \langle \theta \rangle dz \]
\[ Q_{GYRE} = \iint \rho C_p v^* \theta^* dx dz \]

Mean Overturning HT = 1.11 PW  Mean Gyre HT = 0.13 PW
What are the impacts of these heat transport changes?

\[ \Delta OHC = \int \Delta Q_{26N} \, dt \]

- \( \Rightarrow \) **Significant cooling occurred in the N. Atlantic following the heat transport reduction in 2009**

- \( \Rightarrow \) **A decrease in heat transport of 0.2 PW is equivalent to a 7 W/m\(^2\) change in surface heat flux over the entire Atlantic north of 26°N.**

*Bryden et al. (2014)*
A longer term perspective on N. Atlantic heat storage

North Atlantic heat content (30-65°N; 0-700m)
http://www.nodc.noaa.gov

⇒ Heat content in the N. Atlantic peaked during the first half of the RAPID period

⇒ The N. Atlantic may have contributed to net global ocean heat storage during the initial phase of the global warming "hiatus" (Chen and Tung, 2014)
Summary

• The northward heat transport across 26.5°N has decreased during the RAPID-MOCHA observation period. The last 5 years show a reduction of 0.2 PW from the first 5 years.

• Interannual HT variability is dominated by the geostrophic circulation, and mostly by the mid-ocean HT. Both Ekman and Gulf Stream variability contribute to “extreme” events (including short-term HT reversals).

• Ocean heat content in the N. Atlantic has decreased since 2008, coinciding with the drop in HT across 26.5°N. The magnitude and timing of the OHC change is consistent with the observed HT reduction, suggesting surface cooling is playing a lesser (but possibly complementary) role.

• Key questions:
  - How do these heat transport anomalies move/spread into the N. Atlantic?
  - On what time scale?
  - What are the associated OHC tendencies resulting from ocean heat advection/divergence?
  - What OHC patterns are set up?

-> Data is available online! [http://www.rsmas.miami.edu/users/mocha/](http://www.rsmas.miami.edu/users/mocha/)