MERIDIONAL TRANSPORT ESTIMATES FROM THE RAPID-WAVE ARRAY

Shane Elipot, Chris Hughes, Miguel Maqueda
National Oceanography Centre (Liverpool), UK
Ric Williams
University of Liverpool, UK

In collaboration with:
Bedford Institute of Oceanography (John Loder et al.)
Woods Hole Oceanographic Institution - Line W program (John Toole et al.)
Outline

1. Principle: pressure and transport on the western boundary
2. The “step” method to measure pressure
3. Application at the Rapid Scotia (RS) line (2008 ...)
4. Application at line W (2004 - ...)

[Map of ocean with arrows indicating measurement lines]
1. The measurement principles

Geostrophy:

$$-\rho_0 f v(x, z) = -\frac{\partial p}{\partial x}(x, z)$$

Define transport per unit depth:

$$\int_{W}^{E} v \, dx = Q(z)$$

Zonal integral gives:

$$\rho_0 f Q(z) = p_E(z) - p_W(z)$$

Transport per unit depth is the difference of pressure between East and West boundaries.
“Western” and “Eastern” contribution to zonally-integrated meridional transport

\[ T = \int_{-H}^{0} \frac{-p_W(z)}{\rho_0 f} \, dz + \int_{-H}^{0} \frac{p_E(z)}{\rho_0 f} \, dz \]

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“Western boundary contribution”

“Eastern boundary contribution”
Measuring from top to bottom? 1000 m down?

Meridional transport per unit depth $Q(z)$ at 42°N in Ocean Circulation and Climate Advanced Modelling project model (OCCAM), run at NOC (Southampton). From Bingham and Hughes (2008)

Zero crossing of $Q(z)$ is at ~ 1000 m

From 26.5°N data; 3-month averaging window.
2. The “step” method: (because bottom pressure recorders are unreliable on climatic time scales)

a. Measure pressure along slope from in-situ velocity and density data

\[ \Delta p = \frac{\partial p}{\partial x} \Delta x + \frac{\partial p}{\partial z} \Delta z \]

\[ = \rho_0 f v \Delta x + \rho' g \Delta z \]

Pressure gradient from geostrophic velocity
Pressure gradient from density anomalies

b. Use pressure differences to step along the slope to obtain pressure anomalies relative to first depth (here 1000 m):

\[ p'_1 = 0, \quad p'_2 = p'_1 + \Delta p_{12}, \quad p'_3 = p'_1 + \Delta p_{12} + \Delta p_{23}, \ldots \]
3. The Rapid Scotia (RS) line

Short mooring diagram:

- Microcat CTD
- Upward-looking ADCP (100 m range)
- Bottom Pressure Recorder (BPR)

Bottom pressure recorder (Δ), microcat CTD (+) and ADCP (||)
RS line velocity data

- Mean flow
- Bathymetry gradient
- Variance ellipses

Velocity component perpendicular to gradient of bathymetry
Validation of the “step” method at RS line

\[ \Delta p = \frac{\partial \rho}{\partial x} \Delta x + \frac{\partial \rho}{\partial z} \Delta z \]

\[ = \rho_0 f v \Delta x + \rho' g \Delta z \]

100 Pa = 1 mbar
BPRs (—) and step-derived (---) pressure differences

Band-passed between 50- and 2-day periods

100 Pa = 1 mbar
Transport at RS line (42°N)
(below and relative to ~1100 m)

\[ T'_W = \int_{z=-4000}^{z=-1000} \frac{-p'_W(z)}{\rho_0 f} \, dz \]

Standard deviation: 2.7 Sv
peak-to-peak: 16.9 Sv
Trend: 2.4 Sv/year
Line W (2004 - ongoing)

- Mean bottom flow
- Bathymetry gradient
- Variance ellipses

• Bottom pressure recorder (Δ), microcat CTD (+), VACM (x), MacLane profiler (|)
Transport at line W (below and relative to \( \sim 1000 \) m)

\[
T'_W = \int_{z=-4000}^{z=-1000} \frac{-p'_W(z)}{\rho_0 f} \, dz
\]

Standard deviation: 6 Sv  peak-to-peak: 36 Sv
Vertical structure of transports: layers and EOFs

- **RS**: Mode 1: 92%, Mode 2: 6%
- **W**: Mode 1: 86%, Mode 2: 11%
Comparison with Willis (2010) ARGO+Altimetry upper 1000 m geostrophic transport anomalies (40 – 41.5°N)

Willis (2010)’s northward geostrophic total transport anomaly

Southward geostrophic “western contribution” transport anomaly (3-month)

1-month average

With W transport, correlation is 0.30, significant at 95%
Summary

• Step method is shown to work for reconstruction of pressure on sloping boundary;
• Transport vertical structures are comparable at lines W and RS;
• Estimates are comparable to Willis (2010)’ overturning;
• Affordable method for long-term monitoring of MOC variability
What’s next?

• Uncertainty estimates;
• Assess importance of pressure on Eastern boundary at 42°N (RAPIDO program); link to 26.5°N
• Coherence with transport at 26.5°N? Model studies show that MOC inter-annual (or more) variability differs between North Atlantic subtropical and subpolar gyres (see Bingham et al. 2007)
• This method is an option for MOC monitoring; it is a simple add-on to DWBC monitoring systems
• Involvement in US AMOC subpolar gyre initiative?
“Step” method between RS5 (3400 m) and RS6 (3900 m)

100 Pa = 1 mbar
Step method applied at line W

- Validated between sites W0 and W1
- Extended from 1000 m to ~4000 m
In-situ density anomalies at RS line along the slope and east of slope
Transport spectra

26.5 N line (MOC)
W line (western contribution)
RS line (western contribution)
Willis (geostrophic, --, AMOC —)

Multi-taper spectral estimates
Figure 1. Locations and depths of the four BPR moorings deployed during RADPROF0809. Red: BPR deployments in the Santander line. Green: BPR deployments in the Finisterre line.
The vertically integrated pressure signal

\[ \bar{p} = \frac{1}{H} \int_{z=-H}^{z=0} p(z) \, dz \]

\[ p'(z) = p(z) - \bar{p} \quad \text{Residual pressure} \]

Subtracting \( \bar{p} \) removes mean hydrostatic pressure, high frequency basin modes and uniform net flow which is not an overturning
Intervening topography

In Determining North Atlantic meridional transport variability from pressure on the western boundary: A model investigation
R. J. Bingham and C. W. Hughes (2008)