The Surface-Forced Overturning of the North Atlantic: Estimates from Modern Era Atmospheric Reanalysis Datasets

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Outline

1. The Surface-Forced Overturning and the AMOC
2. Estimates of the Mean Surface-Forced Overturning
3. Estimates of the Time Varying Surface-Forced Overturning
Surface-Forced Overturning

Marsh (2000) described (but did not test) a method that might allow ‘the meridional stream function to be largely inferred from surface fluxes alone’.

We’ve examined this possibility using output from:

1) Three IPCC coupled climate models. (100-400 years of GFDL2.1, BCM, HadCM3) (Grist et al. J. Climate 2009; Josey et al. 2009).

2) Eddy-permitting (1/4 °) ocean only model (88 years of ORCA-025, ‘NEMO’) (Grist et al., JGR-Oceans 2012).
Net diapycnal volume flux, \( G(\Theta, \rho) \) and diapycnal density fluxes \( D(\Theta, \rho) \) in an idealized North Atlantic.

Walin (1982), Nurser et al. (1999), Marsh (2000)
Surface-Forced Overturning

Walin (1982), Nurser et al. (1999), Marsh (2000)

Net diapycnal volume flux, $G(\Theta, \rho)$ and Diapycnal density fluxes $D(\Theta, \rho)$ in an idealized North Atlantic.

\[
G(\Theta, \rho) = F(\Theta, \rho) - \frac{\partial D_{\text{diff}}(\Theta, \rho)}{\partial \rho} + C(\Theta, \rho)
\]

\[
F(\Theta, \rho) = \frac{\partial D_{\text{in}}(\Theta, \rho)}{\partial \rho}
\]
Net diapycnal volume flux, \( G(\Theta, \rho) \) and diapycnal density fluxes \( D(\Theta, \rho) \) in an idealized North Atlantic.

Assuming incompressibility and steady state of water masses, the meridional streamfunction then:
\[
\psi(\Theta, \rho) = G(\Theta, \rho)
\]
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Assuming incompressibility and steady state of water masses, the meridional streamfunction then:

$$\psi(\Theta, \rho) = G(\Theta, \rho)$$

$\psi(\Theta, \rho)$ lags $G(\Theta, \rho)$

Greatest agreement if AMOC related to average Surface Forced signal over previous 10 years.

Grist et al. (J. Climate, 2009; JGR-Oceans, 2012)
Fraction AMOC(σ) Explained by Surface-Forced Overturning: ¼º NEMO Ocean Model

Grist et al. (JGR – Oceans, 2012)
Fraction AMOC(σ) Explained by Surface-Forced Overturning: 
$\frac{1}{4}^\circ$ NEMO Ocean Model

Grist et al. (JGR – Oceans, 2012)
Mean Surface-Forced Overturning: ¼° NEMO
Mean Surface-Forced Overturning:

$\frac{1}{4}^\circ$ NEMO

\[ \text{AMOC}(\sigma, \theta) \]

\[ G(\sigma, \theta) \]

12 Estimates:
6 Reanalysis products
2 Salinity Products (WOA & EN3)
Mean Surface-Forced Overturning: Atmospheric Reanalysis Products

1979-2007
SSS from WOA
Mean Surface-Forced Overturning: Atmospheric Reanalysis Products

Maximum overturning (Sv) for density range:

**Bold line with WOA SSS**, thin line with EN3 SSS

Subtropical cell

Subpolar cell
Mean Surface-Forced Overturning: Estimates of Total Surface Density Flux

$D_{TOT} \text{ (kg m}^{-2} \text{s}^{-1}) \text{ JRA}$

$D_{TOT} \text{ (kg m}^{-2} \text{s}^{-1}) \text{ MERRA}$
Mean Surface-Forced Overturning: Estimates of Thermal Surface Density Flux
Mean Surface-Forced Overturning: Sub-Tropical Transformation Rate vs Bias in Global Ocean Heat Budget

- JRA: -13 Wm\(^{-2}\)
- MERRA: +19 Wm\(^{-2}\)
Surface-Forced Overturning:
Correlation (r) Between Time Series from Different Reanalysis Estimates

![Histogram showing frequency of correlation values](image)
Surface-Forced Overturning: Correlation ($r$) Between Time Series from Different Reanalysis Estimates

- Estimate STMW Formation Rate
- Inferred change STMW Volume
- Compared to Observations

Only 2 estimates significantly Correlated with observations.
Surface-Forced Overturning: Correlation (r) Between Time Series from Different Reanalysis Estimates

![Graph showing correlation (r) distribution for Subtropical cell]
Surface-Forced Overturning: Correlation (r) Between Time Series from Different Reanalysis Estimates

![Graph showing correlation (r) between time series from different reanalysis estimates for Subtropical and Subpolar cells.](image)
Surface-Forced Overturning: Subpolar Time Series from Different Reanalysis Estimates

Max Strength Subpolar Cell

Sv

JRA
NCEP1
NCEP2
ERA-I
CFS
MERRA
Surface-Forced Overturning: Subpolar Time Series from Different Reanalysis Estimates

![Graph showing time series for different reanalysis estimates from 1980 to 2010. The x-axis represents years, and the y-axis represents the 10-year past-average values. The graph includes lines for JRA, NCEP1, NCEP2, ERA-I, CFSR, and MERRA, each with a different color. The lines show fluctuations over time.]
Surface-Forced Overturning: Subpolar Time Series from Different Reanalysis Estimates

10 Year Past-Average

Composite Means of 10 Year Past-Average
Summary

- In ¼° NEMO ocean model, the water mass transformation method can be used to estimate AMOC variability.
- The method shows greatest potential between 33°N and 54°N where 70-84% of the AMOC (σ) variance is explained.
- As the method relies only on surface observations, estimates of AMOC variability can be made for the reanalysis era.
- **Sub-tropics:** Reanalyses yield a large range in transformation rates. Influenced by biases in Global Ocean heat budget.
- Some estimates poorly correlated with each other. Only 2 capture significant fraction of observed STMW variability.
- **Sub-polar region:** Reanalysis products show mean surface-forced sub-polar overturning 12-18 Sv.
- Better temporal agreement than in sub-tropics: Common features of inferred AMOC change: High 1990s, low or normal since 2005.
- Grist et al. 2013 (submitted to J. Climate).