# Seasonal overturning of the Labrador Sea as observed by Argo floats

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## Abtract

The Labrador Sea overturning is difficult to measure because it is a relatively small signal superimposed on a large horizontal circulation and because basin-wide observations during winter are limited. These factors have made it difficult to constrain the seasonal and interannual variability of the overturning or to deduce relationships between Labrador Sea overturning, Labrador Sea Water formation, and the Atlantic Meridional Overturning Circulation (Lazier et al. 2002; Schott et al. 2006; Straneo 2006; Pickart and Spall 2007; Lozier 2012).

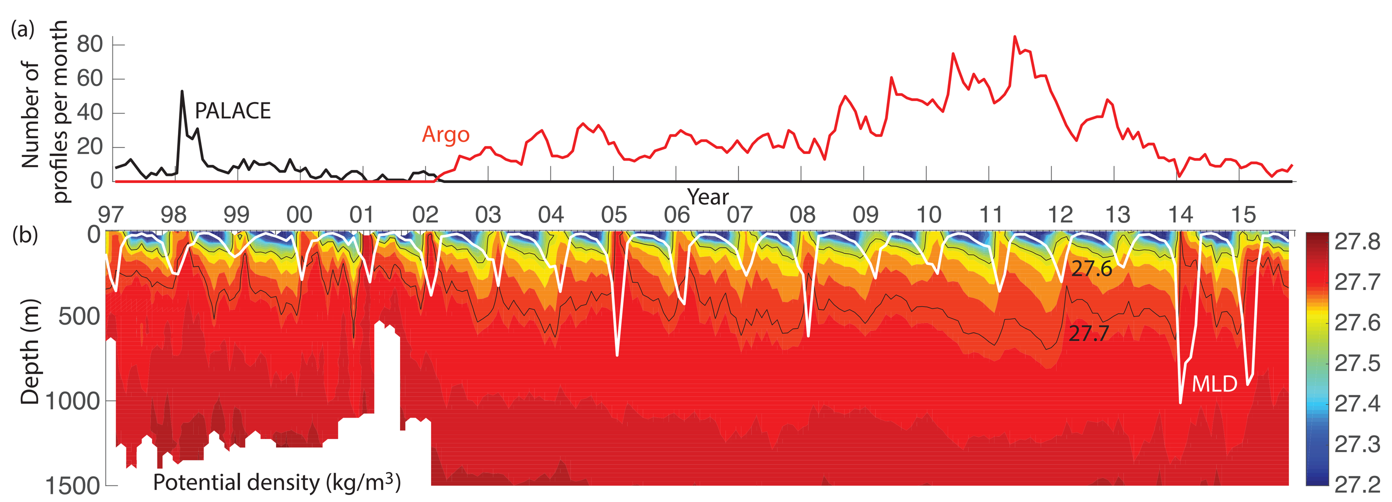




Figure 1: Time series of (a) number of profiles and (b) potential density in the central Labrador Sea (profiles collected over bathymetry deeper than 2200 m) from PALACE and Argo float profiles.


We use Argo floats to investigate Labrador Sea overturning and its variability on seasonal timescales. The overturning exhibits a pronounced seasonal cycle; it doubles in depth space and triples in density space. The largest overturning (1.2 Sv in depth space and 3.9 Sv in density space) occurs in spring and corresponds to the outflow of recently formed Labrador Sea Water. The overturning decreases through summer and reaches a minimum in winter (0.7 Sv in depth space and 1.3 Sv in density space).


## Data

Argo profiles and trajectories (ANDRO and YoMaHa) collected 2002 - 2016

PALACE float trajectories collected 1995 - 2002

11 AR7W crossings occupied 2001 - 2013

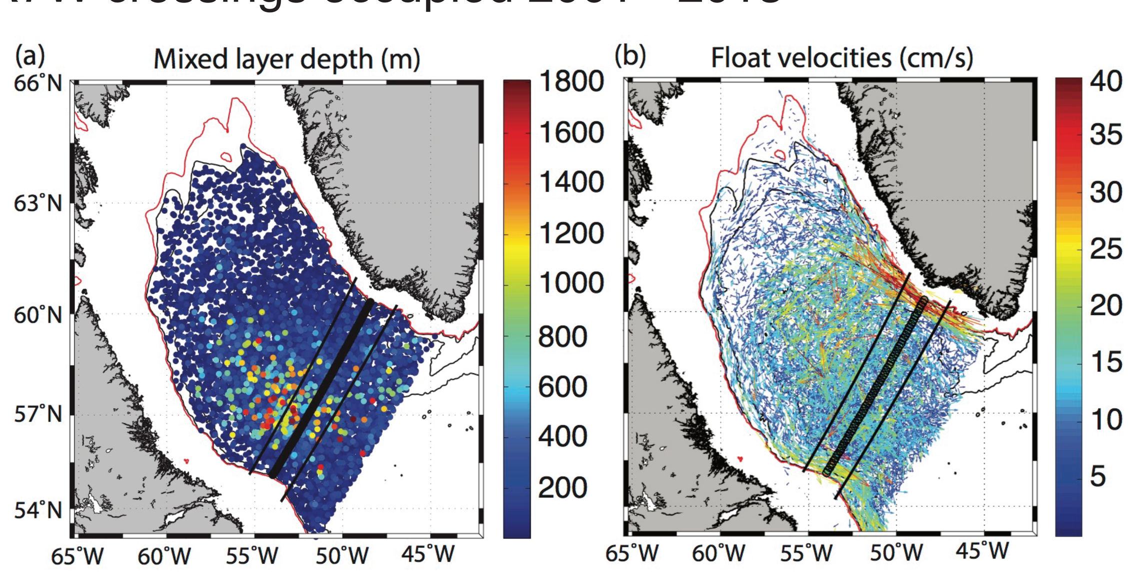



Figure 2: Maps of PALACE and Argo float (a) mixed layer depths and (b) trajectories in the Labrador Sea. The bold black line denotes the AR7W repeat hydrography line, along which the float composite sections are constructed; the thin black lines denote distances of 75 km from AR7W.

## Methods

We assemble composite potential density and absolute geostrophic velocity sections across the mouth of the Labrador Sea from float profiles and trajectories at 1000 m. The overturning is calculated by decomposing the velocity following Fanning and Weaver (1997) and Pickart and Spall (2007):

$$v(x,z) = \overline{v(z)}^{x} + v'(x,z),$$

This averaging is performed in depth space to diagnose the sinking and in density space to resolve the water mass transformation.

## Mean composite section

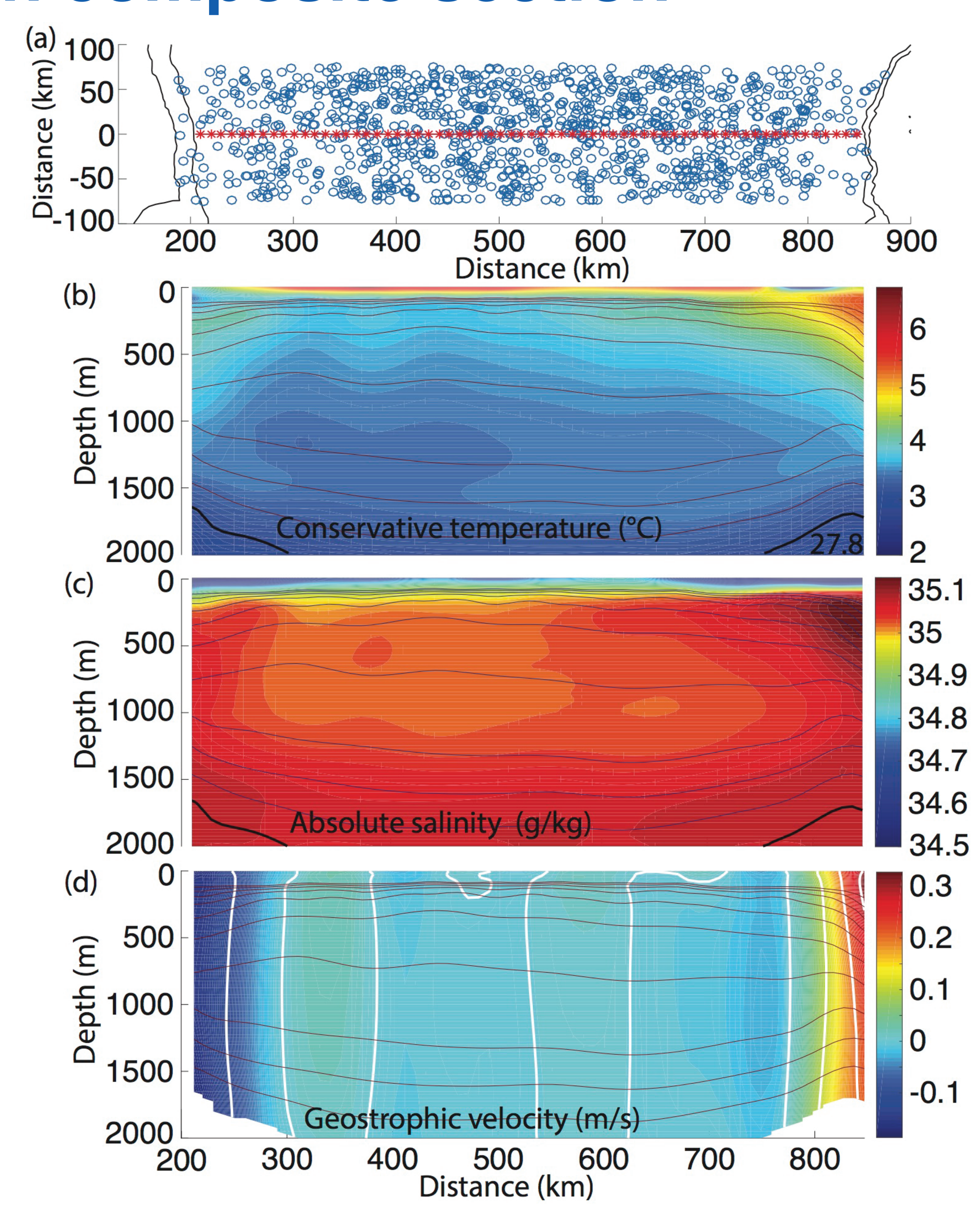



Figure 3: (a) Locations of 1157 Argo profiles (circles) within 75 km of the AR7W line and composite sections of (b) conservative temperature, (c) absolute salinity, and (d) geostrophic velocity. In (a), the 1000m and 2000 m isobaths are plotted (black lines), as well as the x coordinate for the composite sections (red stars). In (b,c,d) potential density is contoured at 0.02 kg m$^{-3}$ intervals (black lines). In (d), the white lines denote 0.1 m s$^{-1}$ velocity contours.

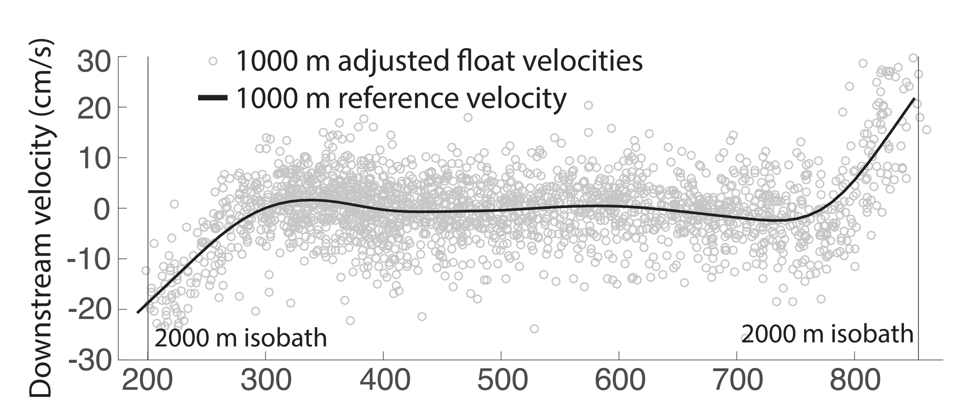



Figure 4: Downstream velocity at 1000 m (grey circles) from 2120 float trajectories collected within 75 km of the AR7W line. The velocities have been rotated into a downstream reference frame normal to the AR7W line. A thermal wind field derived from 21 AR7W sections was used to adjust the velocities to a uniform depth of 1000 m. The reference velocity fit to the float velocities (black line) is also plotted.

## Mean overturning

- 0.9 ± 0.5 Sv in depth space
- 2.5 ± 0.75 Sv in density space
- Horizontal transport balances to within -0.1 Sv

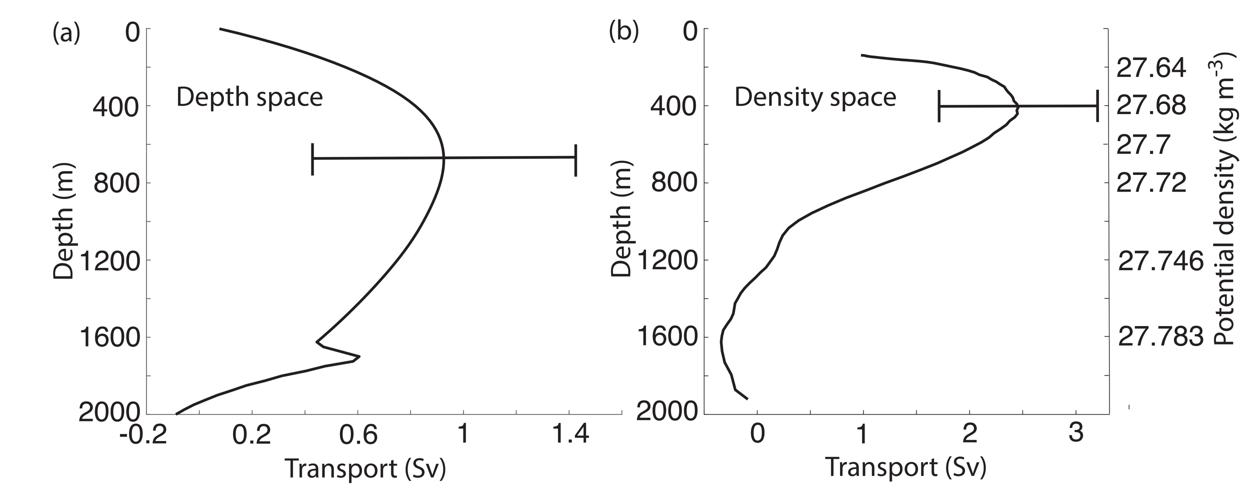



Figure 5: Mean overturning during the Argo period in (a) depth and (b) density space. The error bars are derived from 1000 siumulated overturning estimates that use subsets of the data.

## Seasonal overturning

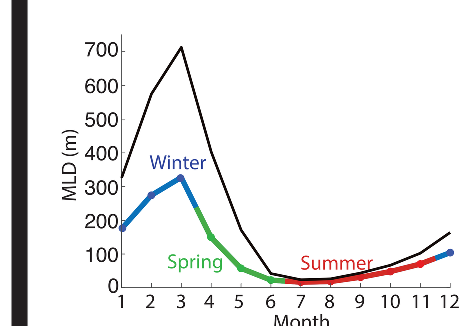



Figure 6: Mean annual cycle of mixed layer depth (colored line) in the interior Labrador Sea and the standard deviation (black line). The colors represent the breakdown of the seasonal overturning estimate: blue (winter, corresponding to mixed layer deepening), green (spring, corresponding to restratification and mixed layer shoaling), and red (summer, during which the mixed layer remains fairly shallow).

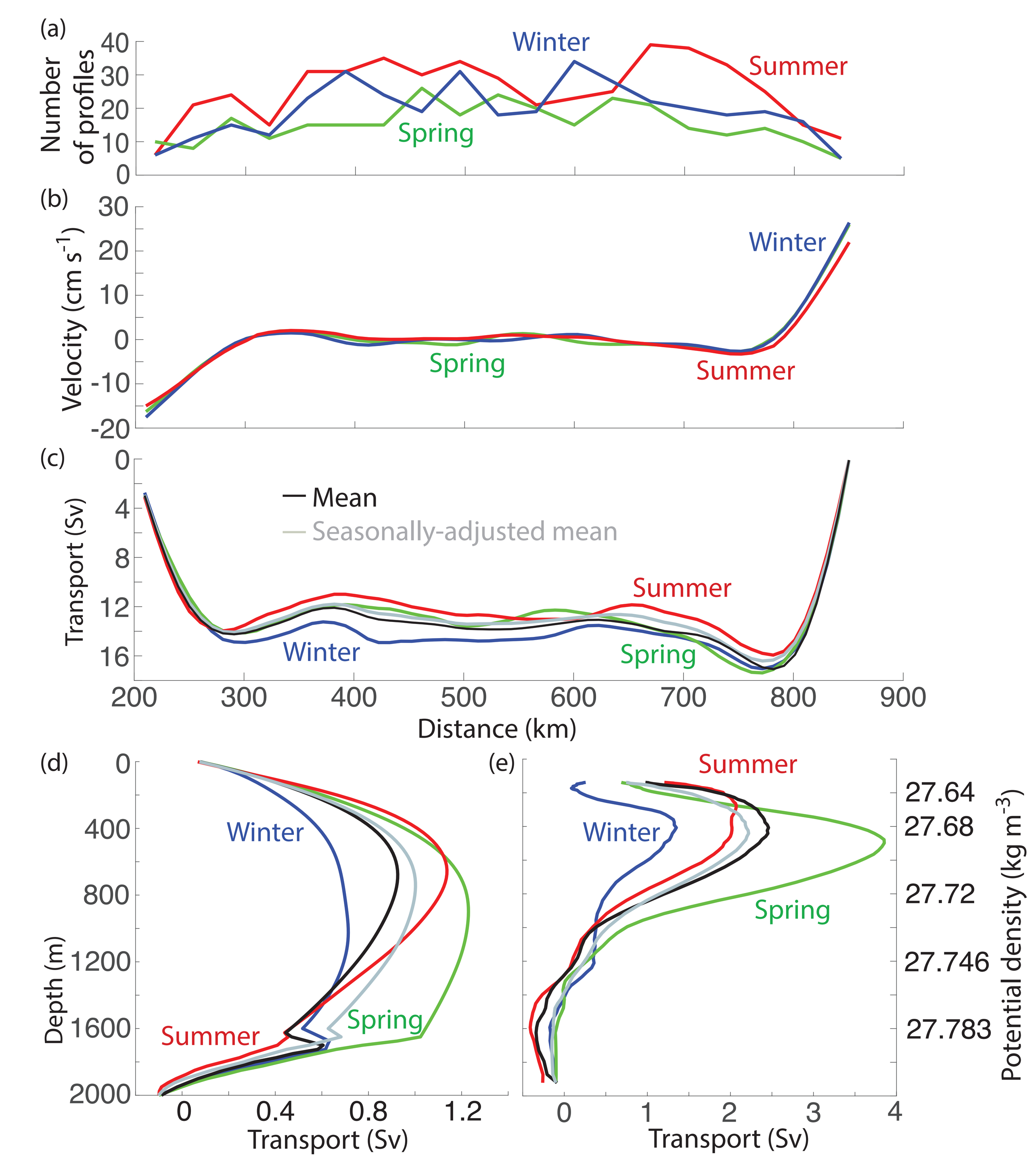



Figure 7: Seasonal (a) number of profiles in 20 km bins, (b) 1000 m reference velocity, (c) horizontal transport, (d) overturning in depth space, and (e) overturning in density space. The overall Argo means (black lines) and the mean calculated by averaging the seasonal estimates (grey lines) are also plotted.

- In depth space, the largest overturning (1.2 Sv) occurs in spring. The overturning shrinks and shoals through summer reaching a minimum in winter (0.7 Sv)
- In density space, the largest overturning occurs in spring (3.9 Sv). The overturning is smaller in summer (2.1 Sv) and winter (1.3 Sv ) and centered at lighter densities
- The largest maximum horizontal transports in the boundary currents occur in winter and spring
- The large spring overturning corresponds to the outflow of recently formed Labrador Sea Water

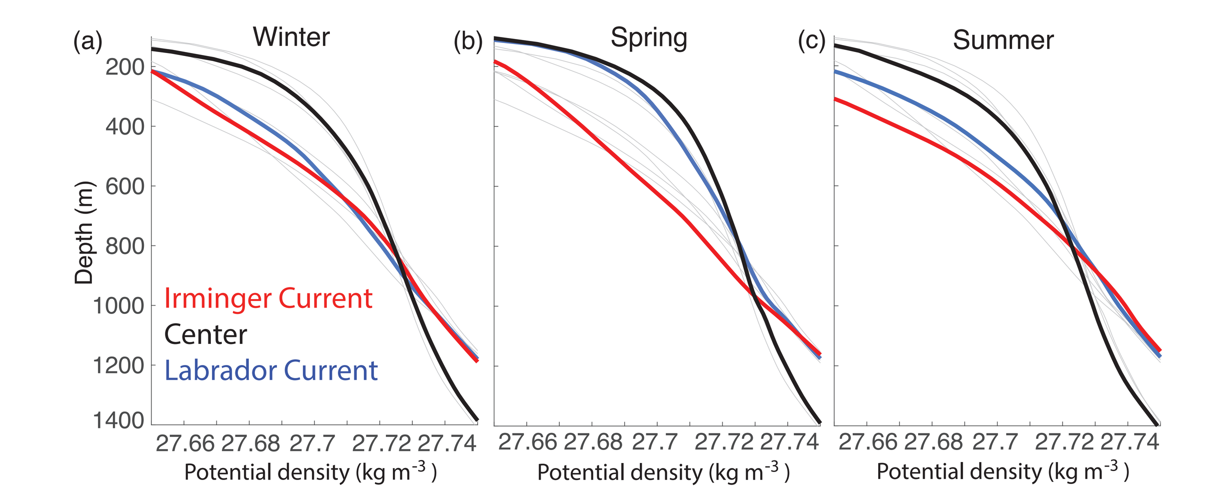



Figure 8: Average seasonal potential density profiles for inflowing water in the Irminger current (red lines), outflowing water in the Labrador Current (blue lines), and in the Labrador Sea interior (black lines).

## AR7W comparison

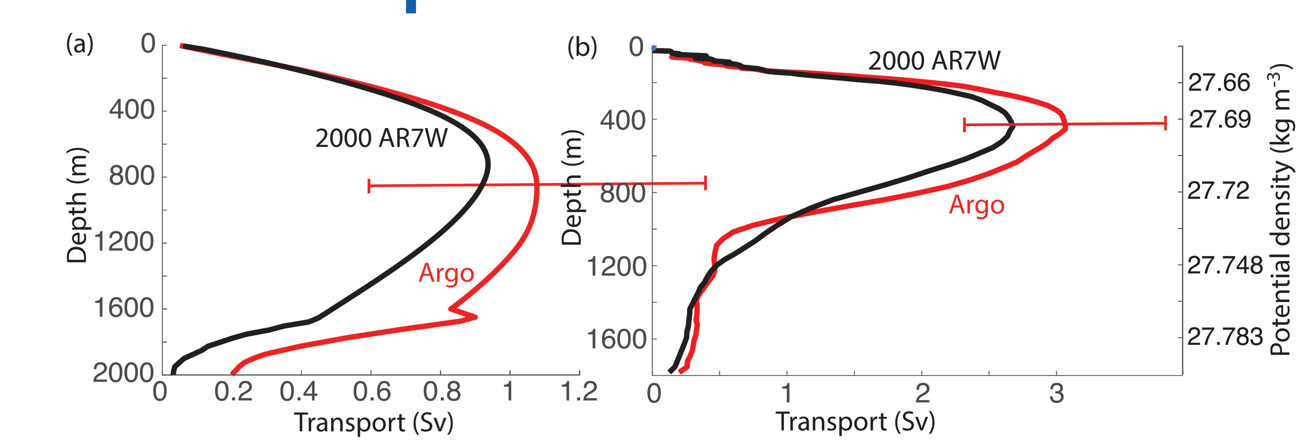
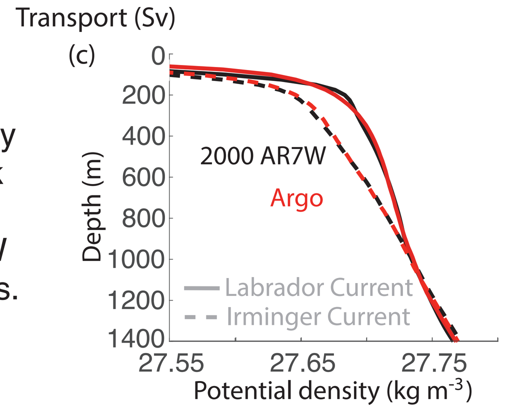



Figure 9: Overturning in (a) depth and (b) density space and (c) mean density profiles in the boundary currents for AR7W crossings from the 2000s (black lines) and Argo (red lines). The overturning is calculated for May, June, and July, as the 11 AR7W crossings were collected during these three months.




## Conclusions

The Labrador Sea overturning exhibits a substantial seasonal signal. The overturning is largest in spring (3.9 Sv in density space), shrinks through summer, and reaches a minimum in winter (1.3 Sv). The large spring overturning is associated with the export of Labrador Sea Water in the Labrador Current.


## Acknowledgements

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## Works cited


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