Salt transport and salinity changes in the Florida Current, and implications for Atlantic Circulation

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1. Introduction

On long time scales, the ocean adjusts to atmospheric forcing by advecting density anomalies. In the subtropical North Atlantic, the Florida Current (FC) plays a central role. Salt transport determines the stability of Atlantic Meridional Overturning Circulation (AMOC) (Warren, 1983), while salinity anomalies contribute to long period ocean-atmosphere feedback patterns (e.g. Buckley and Marshall, 2015). For the AMOC's upper branch, anomalies must transit the FC to reach the subpolar gyre. The average structure of the FC provides insight on where salty waters originate, while decadal changes reflect adjustment to long-term changes in forcing.

In the Florida Current, what controls advected salt anomalies?

2. Data

There are 9 sampling locations across the strait.

1982-1986 Transects from CTDs (N=9-11, WOD13) and Pegasus velocity (N=65, ~25 dofs, Molinari et al., 1985).

2000-2014 CTD/L ADCP transects collected 3-4 times per year by NOAA/AOML (N=51, (Hooper and Baringer, 2014).

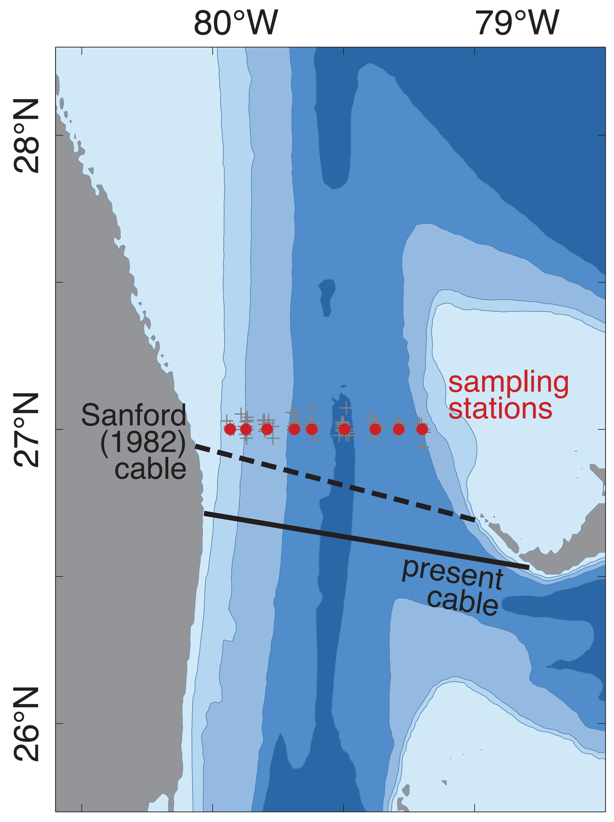


Figure 1 The Straits of Florida

Salt transport is calculated as

$$T_{sal} = \iint v(S - S_{ref})\, dx\, dz$$

where S_{ref} is
(1) an area-averaged constant (S_0=35.338 g kg^{-1}, McDonagh et al., 2015),
(2) an isopycnally-averaged profile $S(\sigma)$ (Hydrobase 3, Curry, 1996), calculated across 26°N.
These definitions match our general concept of AMOC as vertical circulation and gyre as horizontal circulation.

Welch's T-test at 95% confidence determines statistical significance of differences between the two time periods.

3. Transports

Integrated transports in water mass classes (see box 4): 2000-2014 average (top value), 2000-2014 minus 1982-1986 (bottom value). Confidence limits are standard deviations. Small changes (<std) are in gray, larger changes are in black.

		volume transport (Sv)	salinity transport (Sv g kg^{-1}) $S_{ref} = S_0$	$S_{ref} = S(\sigma)$
SW	2000s	8.5±0.3	-0.11±0.11	10.7±0.4
	2000s-1980s	0.0	0.27	0.3
IWW		4.5±0.2	-0.77±0.09	5.6±0.2
		2.2	0.11	2.8
IWE		14.3±0.3	-0.64±0.13	20.3±0.4
		-3.0	1.87	-2.7
AAIW		4.5±0.2	-1.46±0.09	0.8±0.03
		0.0	-0.01	0.1
total		31.9±0.4	-2.97±0.29	37.5±0.5
		-0.7	2.25	0.5

Bibliography

MW Buckley and J Marshall. 2016. Observations, inferences, and mechanisms of Atlantic Meridional Overturning Circulation variability: A review. duction. *Science*, **227**: 292–295.
R Curry. 1996. HYDROBASE: a database of hydrographic stations and tools for climatological analysis. *WHOI Tech. Rep. WHOI-96-01*, Woods Hole, MA.
JAV Hooper and MO Baringer. 2014. Hydrographic measurements collected aboard the UNOLS ship R/V Walton Smith, 2014: Western Boundary Time Series cruise: Florida Current. *NOAA Data Report OAR AOML 50*, Miami, Florida, USA, 2014.
E McDonagh, BA King, HL Bryden, P Courtois, ZB Szuts, MO Baringer, SA Cunningham, CP Atkinson, and G McCarthy. 2015. Continuous estimate of Atlantic oceanic freshwater flux at 26°N. J. *Climate*, **28**: 8888–8906.
M Rhein, K Kirchner, C Mertens, R Steinfeldt, M Walter, and U Fleischmann-Wischnath. 2005. Transport of South Atlantic water through the passages south of Gaudeloupe and across 16°N, 2000–2004. *Deep-Sea Res. II*, **52**: 2234–2249.
WJ Schmitz Jr and PL Richardson. 1991. On the sources of the Florida Current. *Deep-Sea Res.*, **3**: S379–S409.
WJ Schmitz Jr and MS McCartney. 1993. On the North Atlantic circulation. *Rev. Geophys.*, **31**: 29–49.
BA Warren. 1983. Why is no deep water formed in the North Pacific? *J. Mar. Res.*, **41**: 327-347

4. The Florida Current (FC) - structure and water masses

Water Mass Structure Sloping iopycnals (Schmitz and Richardson, 1991) separate surface water (**SW**, σ<24) from intermediate water (**IW**, 24<σ<27) from Antarctic Intermediate Water (**AAIW**, σ>27). The east-west axis of the FC is where potential vorticity changes sign, close to maximum velocity. For IW, east of the axis (**IWE**) is North Atlantic Salinity Maximum Water (NA-SMW) and Eighteen Degree Water (EDW), while on the west (**IWW**) is water of ambiguous origin with traces of influence from the equatorial Atlantic, subtropical South Atlantic (Rhein et al., 2005), or Gulf of Mexico (Schmitz and McCartney, 1993). AAIW is the only distinct water from the Southern Hemisphere.

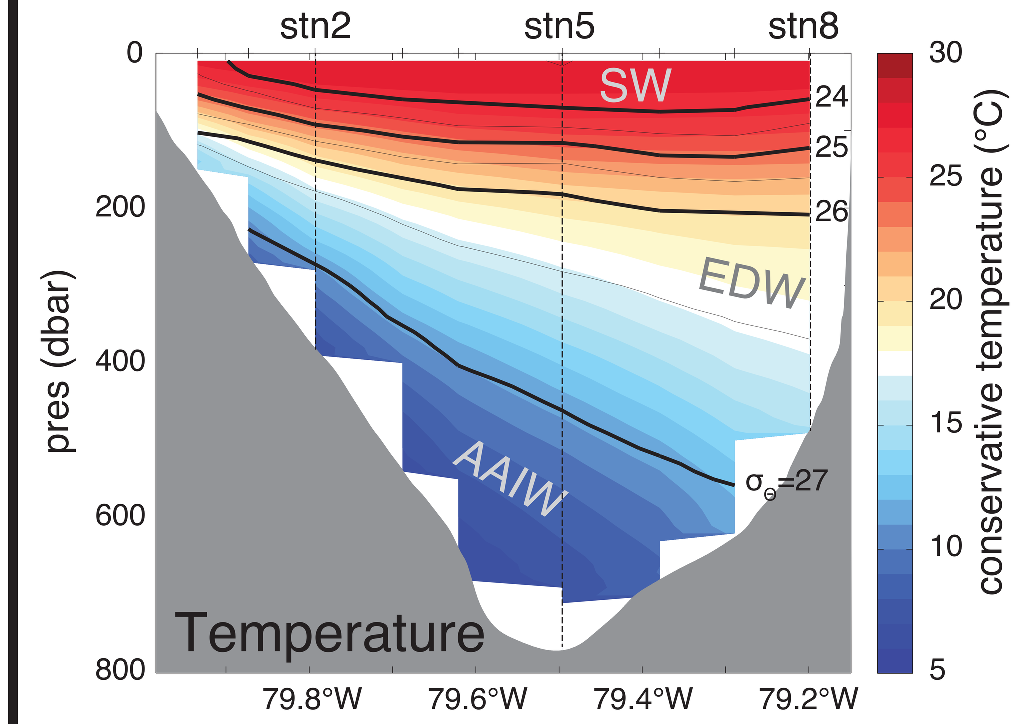
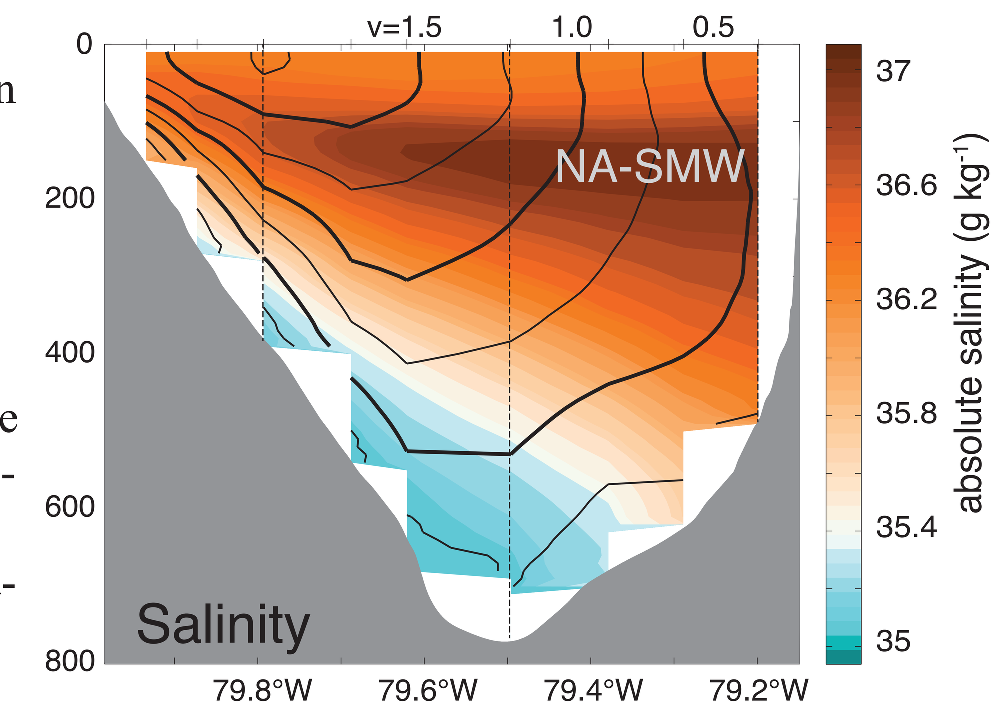


Figure 2 Average section in depth space, 2000-2014.

(left) Temperature (color) and isopycnals (labeled black lines, kg m^{-3}).

(right) Salinity (color, white at S_0=35.338 g kg^{-1}) and velocity (labeled black lines, m s^{-1}). Water masses are labeled.



5. Referenced Salinities

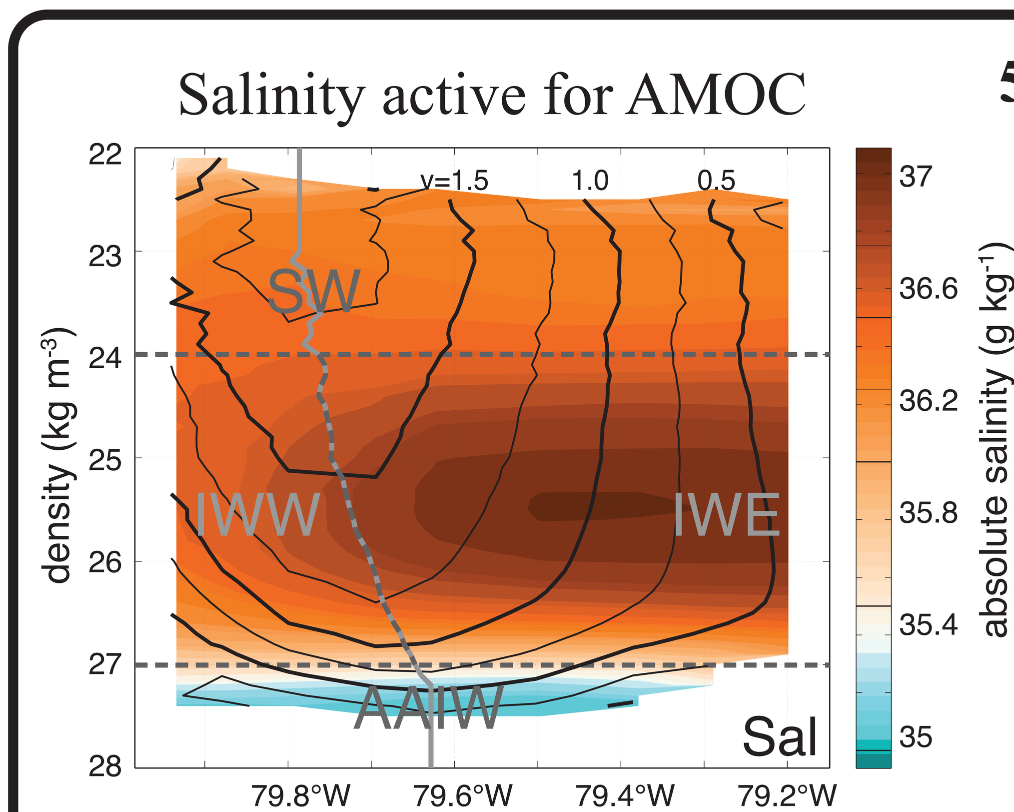
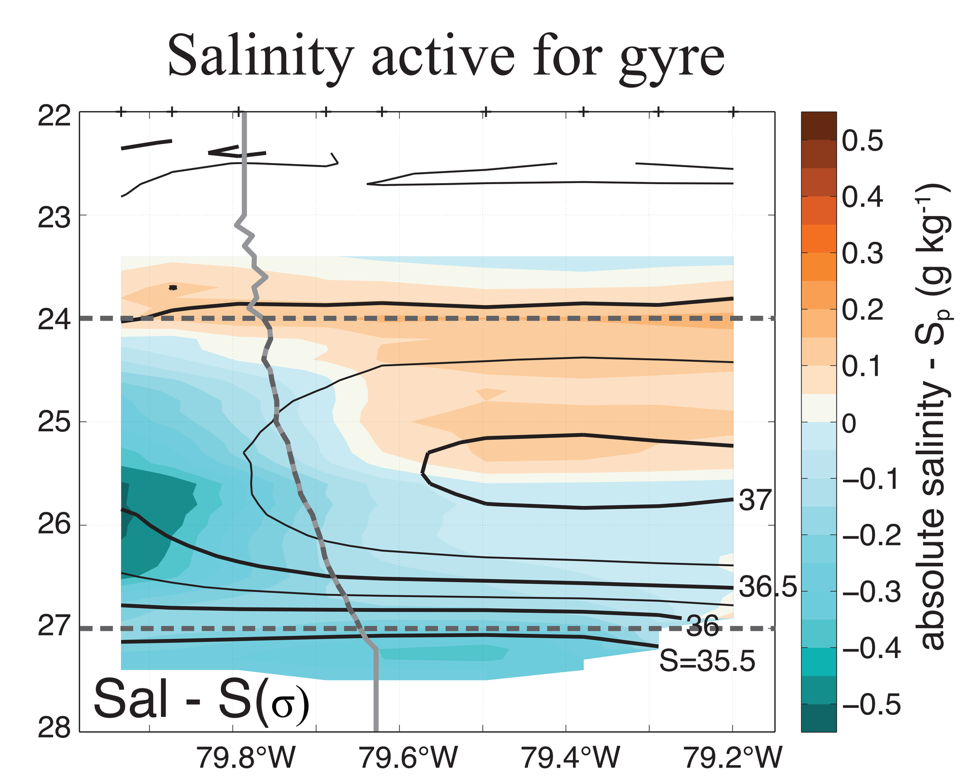


Figure 3 Average section in density space, 2000-2014. (left) Salinity (color, white at S_0=35.338 g kg^{-1}) and velocity (labeled black lines, m s^{-1}). (right) Salinity relative to average mid-ocean profile (color), average salinity (labeled black lines). Both show the FC axis (thick light grey line) and water mass divisions (dashed dark grey line).



6. Decadal Changes

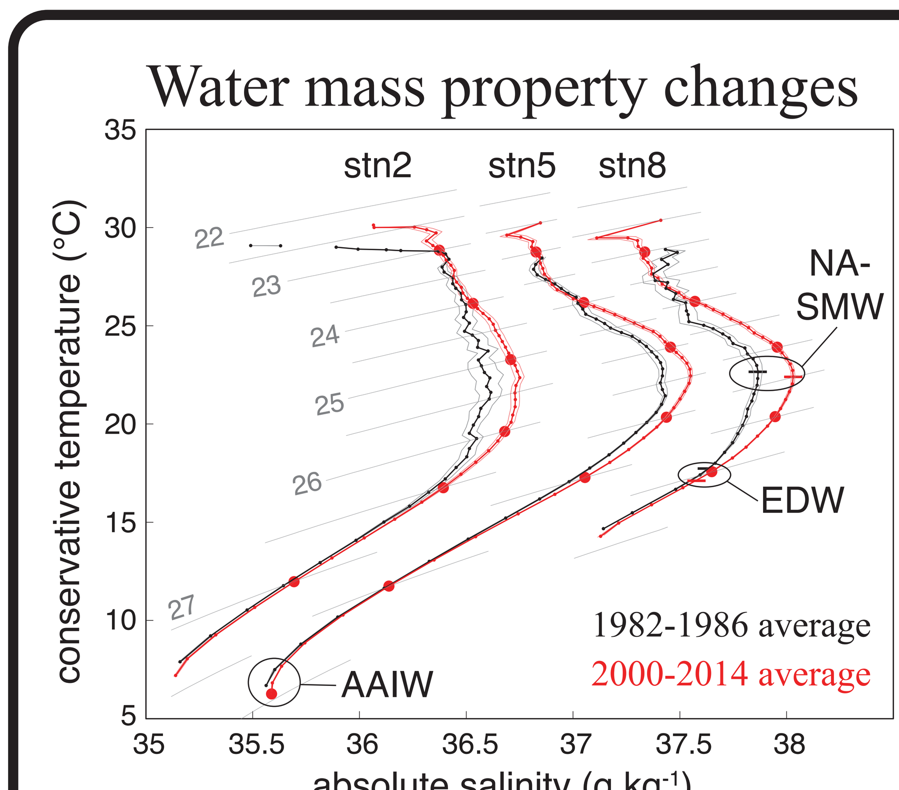
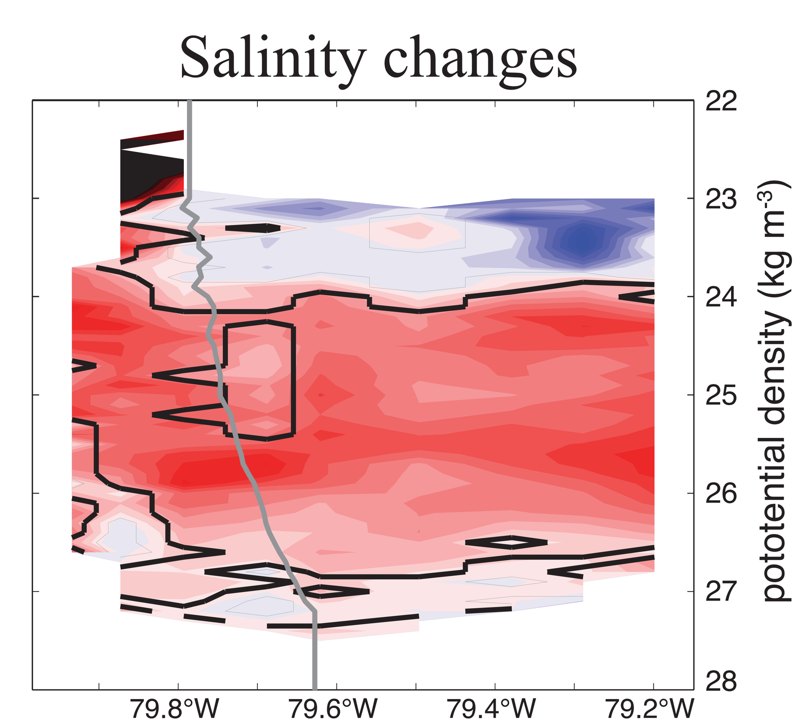


Figure 4 Changes from 1980s to 2000-2014.

(left) T/S profiles at 3 stations. Average (dark) and standard error (light) on isopycnals, with dots indicating potential density (large every 1 kg m^{-3}, small every 0.1 kg m^{-3})

(right) Salinity changes. Statistically significant changes are inside thick black lines.

Both figures show the FC axis (thick light grey line) and water mass divisions (dashed dark grey line).



6. Interpretations

Average Volume Transport
Which water masses constitute the 18 Sv of AMOC?
IWW+AAIW (=9 Sv) is too small, as are all densities west of the axis (8.7 Sv).
Thus, salty IWE must contribute about half by volume.

Average Salt Transport
- Gyre circulation (small and negative) is more sensitive than overturning (large and positive).
- A uniform increase of FC transport exports salt to AMOC and imports freshwater to gyre.
- AAIW dominates gyre because of its freshness.
- IWE dominates AMOC because of its volume.

Decadal Changes
- Saltier subtropical waters agrees with increased evaporation (Durack and Wijfels, 2010)
- Saltier AAIW must originate in subtropics, by changed mixing fractions or sources.
- Gyre freshwater transport has decreased by half, likely in balance with E-P forcing.
- AMOC salt transport is dominated by volume transport, with modest (13%) increases in deep transport.

6. Conclusions

- Overturning salt advection at 26°N is dominated by volume transport, with a large fraction carrying subtropical properties.
- The Southern Hemisphere contributes much freshwater to the gyre, but little salt to overturning.
- Decadal changes show a small increase in AMOC salt transport from saltier subtropical waters.

These findings imply that interior mixing and recirculation dominate throughput of salinity anomalies by the AMOC at 26°N.