Reconstructing Late Holocene Atlantic Meridional Overturning Circulation strength using oxygen isotopes from an annually resolved *Arctica islandica* shell-based record

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Motivations

The scarcity of long-term, highly resolved, precisely dated marine records makes it difficult to reconstruct and model Atlantic Meridional Overturning Circulation (AMOC) strength, a necessity for understanding both the natural variability of this system and the exact mechanisms by which the AMOC regulates North Atlantic and global climates. Recent modeling studies suggest that the Gulf of Maine, situated in the western North Atlantic, may be an ideal location for AMOC strength reconstructions due to the influence that the AMOC has on hydrographic properties in this region[1,2,3].

Introduction and Methods

Study Site: The Gulf of Maine

The Gulf of Maine's hydrographic properties are influenced by warm slope waters brought up from the tropics by the Gulf Stream and colder slope waters brought down from the Labrador Sea by the Labrador Current. Recent research suggests that the path of the Gulf Stream shifts northward (southward) with decreased (increased) AMOC strength[1,2], bringing warmer waters closer to (farther away from) the Gulf of Maine.[3] Therefore, Gulf of Maine seawater temperatures are likely inversely related to AMOC strength and reconstructions of these seawater temperatures in the Gulf of Maine have the potential to lead to valuable insights into past AMOC behavior.

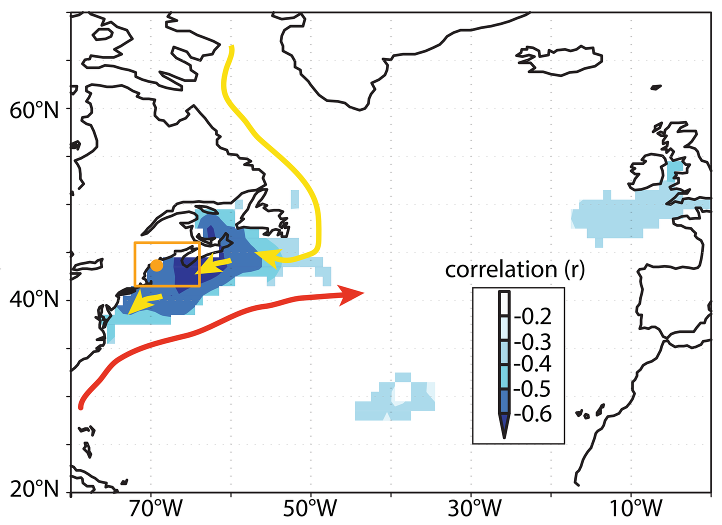

Figure 1. Map of the correlation (r, shaded regions indicate correlations with p<0.05) between modeled AMOC (ECMWF S3) and sea surface temperatures (SSTs, HadISST) in the North Atlantic. The orange box outlines the Gulf of Maine. The orange marker denotes the study site for this research. Major ocean currents in the western North Atlantic, the Labrador Current (yellow) and the Gulf Stream (red), are marked.

Hydrographic Reconstruction

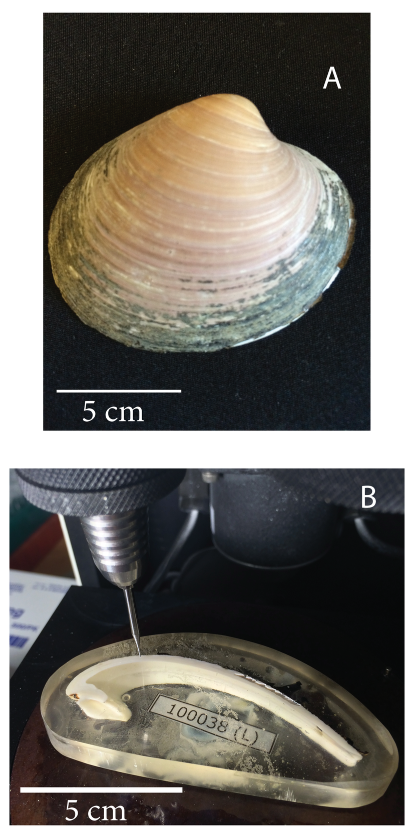

Figure 2. An *A. islandica* shell (A) and a shell cross-section being milled for isotope analysis (B).

To reconstruct Gulf of Maine hydrographic conditions, we used *Arctica islandica* shells, which:

- Precipitate in oxygen isotopic equilibirum with seawater, enabling seawater temperature reconstructions[4].
- Deposit annual increments, enabling the collection of precisely dated and annually resolved data.

A master chronology of fossil and live-caught shells from near Seguin Island, western Gulf of Maine, was built using crossdating techniques. Shells were sampled using a Merchantek micromill and oxygen isotopes were analyzed using a ThermoFinnigan MAT Delta Plus XL mass spectrometer coupled with a GasBench II.

Results

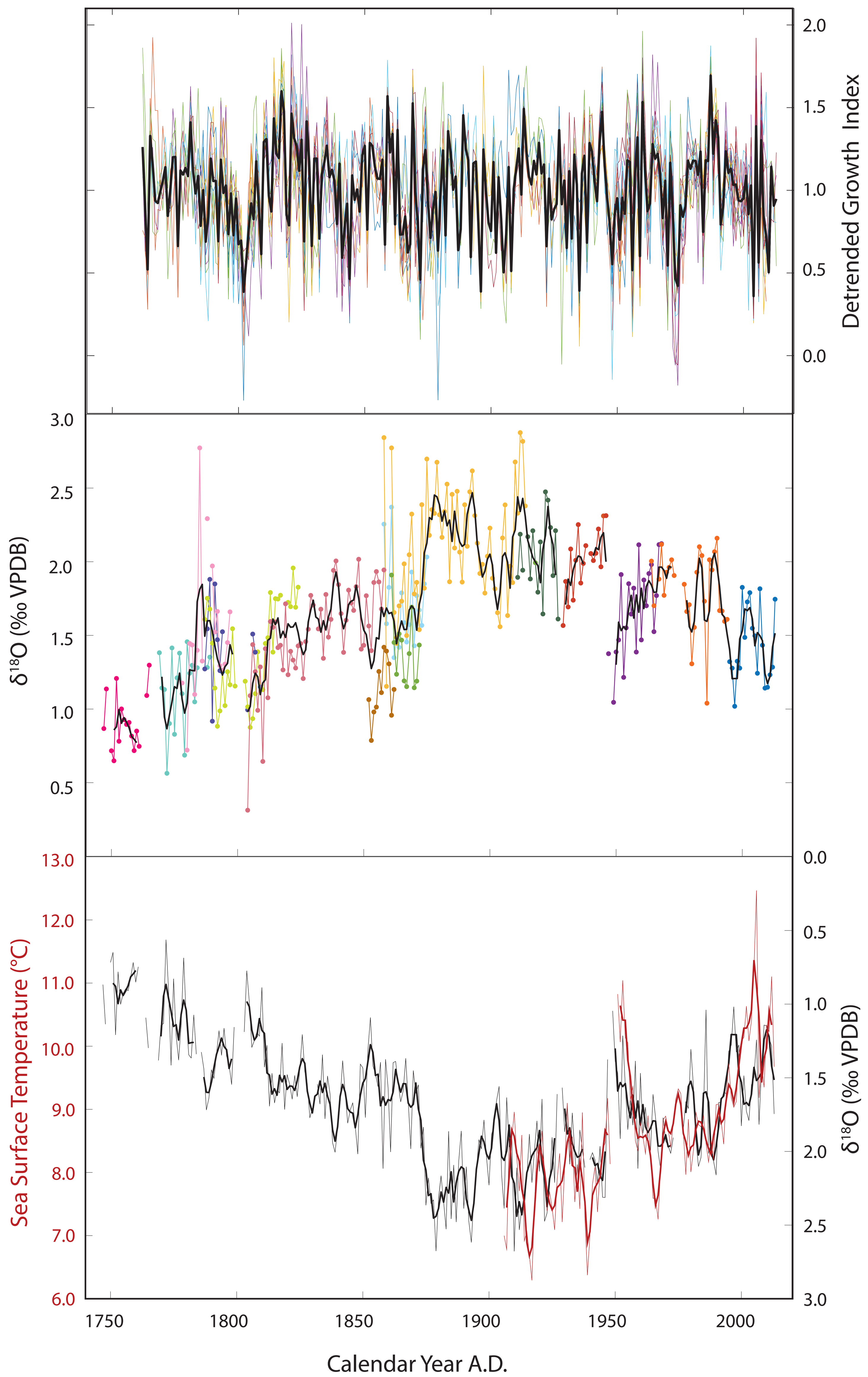

Figure 3. The top and middle panels are the Gulf of Maine master chronology (black line; units are standard deviations) and oxygen isotope record (black line is three-year running average), respectively. Colors denote individual shells for both panels. The bottom panel is the time series of the average Gulf of Maine oxygen isotope record (black, right axis; note reversed axis) and the Boothbay Harbor SST instrumental record (red, left axis, ~17 km away from shell collection site). Thicker lines are three-year running averages. Average uncertainty in $\delta^{18}O$ is ~±0.10‰.

Proxy Analysis

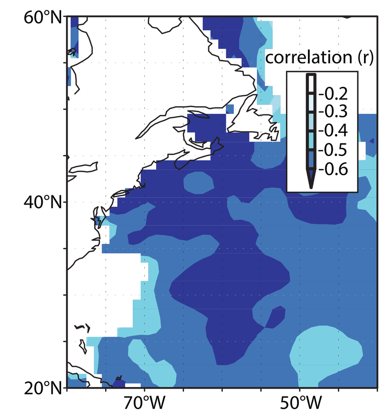

Figure 4. Correlation (r, shaded regions indicate correlations with p<0.05) between the Gulf of Maine isotope record and the HadISST SST reconstruction (data are three-year running average) from 1872-2013.

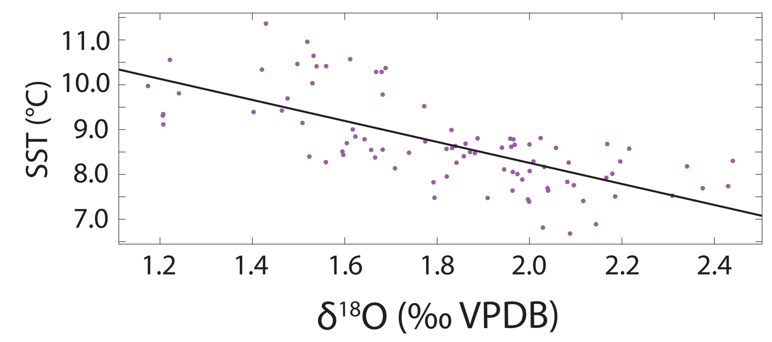

Figure 5. Boothbay Harbor, Maine instrumental SSTs data versus the Gulf of Maine isotope record (data are three-year running average). Years of comparison: 1906-2013. $SST = -2.34 * \delta^{18}O + 12.94$. $r^2 = 0.48$.

Climate Parameter	Running Average	Isotopes Lagged	Part of Year	Years	# Years	Correlation (r)	p Value
AMOC (EMCWF S3)	0 yr	-3.5 yr ($\delta^{18}O$ lead)	Jan.-Dec.	1961-2010	41	**0.33**	<0.05
AMOC (EMCWF S3)	0 yr	5 yr	Jan.-Dec.	1961-2010	42	**0.37**	<0.05
AMOC (EMCWF S3)	3 yr	4.5 yr	Apr.	1962-2010	38	**0.72**	<0.015
AMOC (EMCWF S3)	3 yr	4 yr	Oct	1962-2010	38	**0.70**	<0.03
Florida Current	0 yr	4 yr	Jan.-Dec.	1984-2010	17	**0.75**	<0.015
Florida Current	3 yr	4 yr	Jan.-Dec.	1984-2010	14	**0.92**	<0.015

Table 1. Correlation coefficients (r) and related dated for the Gulf of Maine isotope record and select climate parameters (p-values adjusted for smoothing). AMOC modeled data from https://-climatedataguide.ucar.edu. Florida Current instrumental data from http://www.aoml.noaa.gov.

Discussion and Future Work

- Oxygen isotopes measured in *Arctica islandica* shells show a strong correlation with the nearby (~17 km) instrumental record of SSTs from Boothbay Harbor, Maine (Figure 5), indicating that these data are a valid proxy for Gulf of Maine SSTs.
- Based on previous modeling work that suggests that Gulf of Maine SSTs are influenced by AMOC strength[1,2,3], we would expect our SST proxy record to represent a reconstruction of AMOC variability.
- The $\delta^{18}O$ record has strong but variable correlations with modeled AMOC strength (EMCWF S3) and the instrumental record of Florida Current strength (a component of surface AMOC) at various lags and times of the year (Table 1). Further investigation into the appropriate model for AMOC strength is needed to more comprehensively analyze these complex relationships.
- While the Gulf of Maine oxygen isotope record is a promising proxy for AMOC strength variability over the last several centuries, additional modeling work is necessary in order to fully assess this proxy and utilize it to reconstruct (components?) of AMOC strength.

Acknowledgements

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References

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