Shell growth and geochemistry in northern Norway provide insight into North Atlantic climate dynamics

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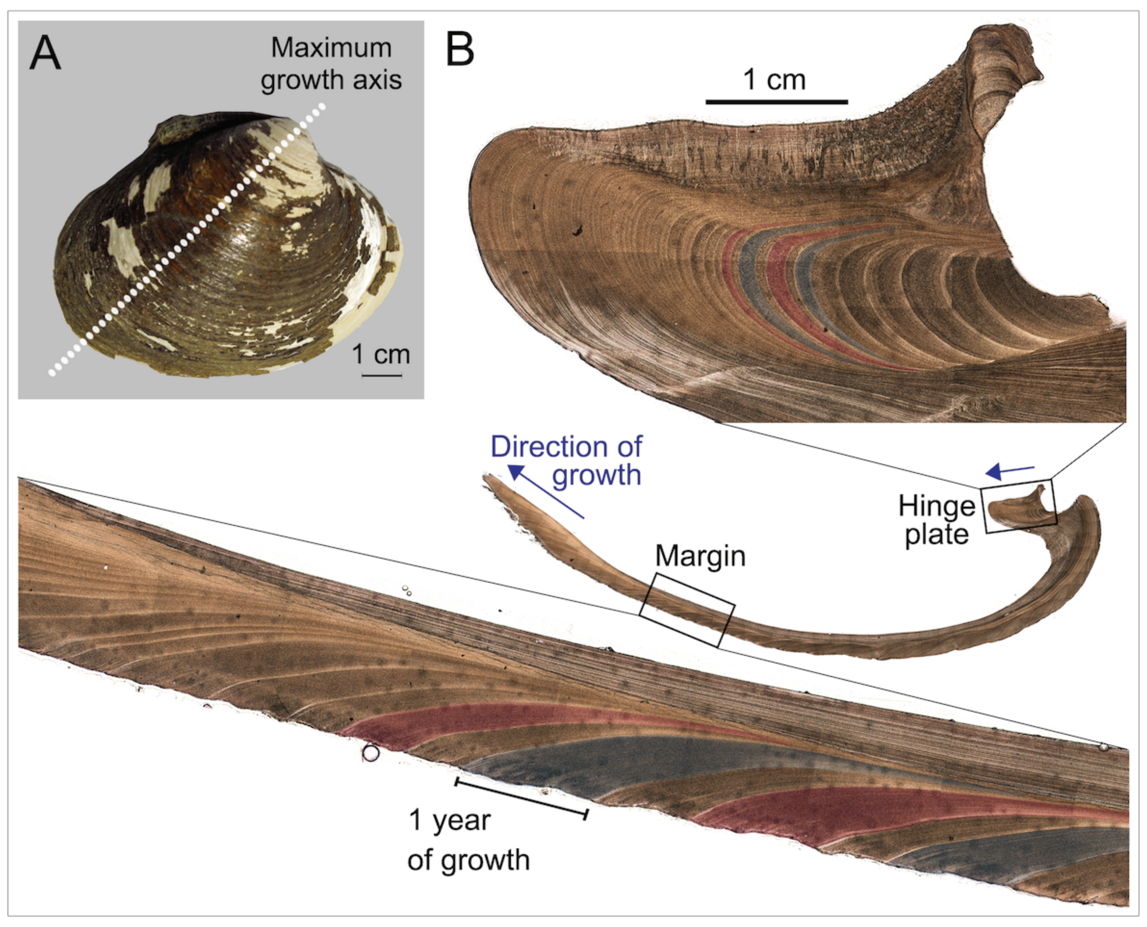

Figure 1. *A. islandica* growth patterns. (A) Left valve of a shell showing the idealized axis of maximum growth. (B) Digitized photomicrograph of an Ingøya sample showing annual increment lines in both the shell margin (bottom) and hinge plate (top). False colors were added to show same relative growth patterns in both the hinge and margin records.

PROJECT SUMMARY

Few high-resolution resolution paleoclimate records exist from the oceans, especially at high latitudes. We developed an annually resolved shell growth and geochemical proxy from the marine bivalve, *Arctica islandica* from northern Norway (Figure 1). The study site is located proximal to one of the main pathways of Atlantic water entering the Barents Sea, namely, the eastern branch of the North Atlantic Current (Figure 2). Shell growth rates and oxygen isotope ratios show an inverse relationship with sea surface temperatures across a broad swath of the North Atlantic region (Figure 2), suggesting the records may provide useful records for past climate dynamics in this region. The combined shell-growth and d18O record shows a strong negative relationship with the Atlantic Multidecadal Oscillation (AMO; Figure 4), a climate mode hypothesized to be forced in part by surface components of the Atlantic meridional overturning circulation. While the record provided here is not used to test this hypothesis, largely due to a lack of high-latitude instrumental records of ocean dynamics, it can be compared with existing records of North Atlantic sea surface temperatures and dynamics to address a variety of hypotheses, some of which are described detailed below.

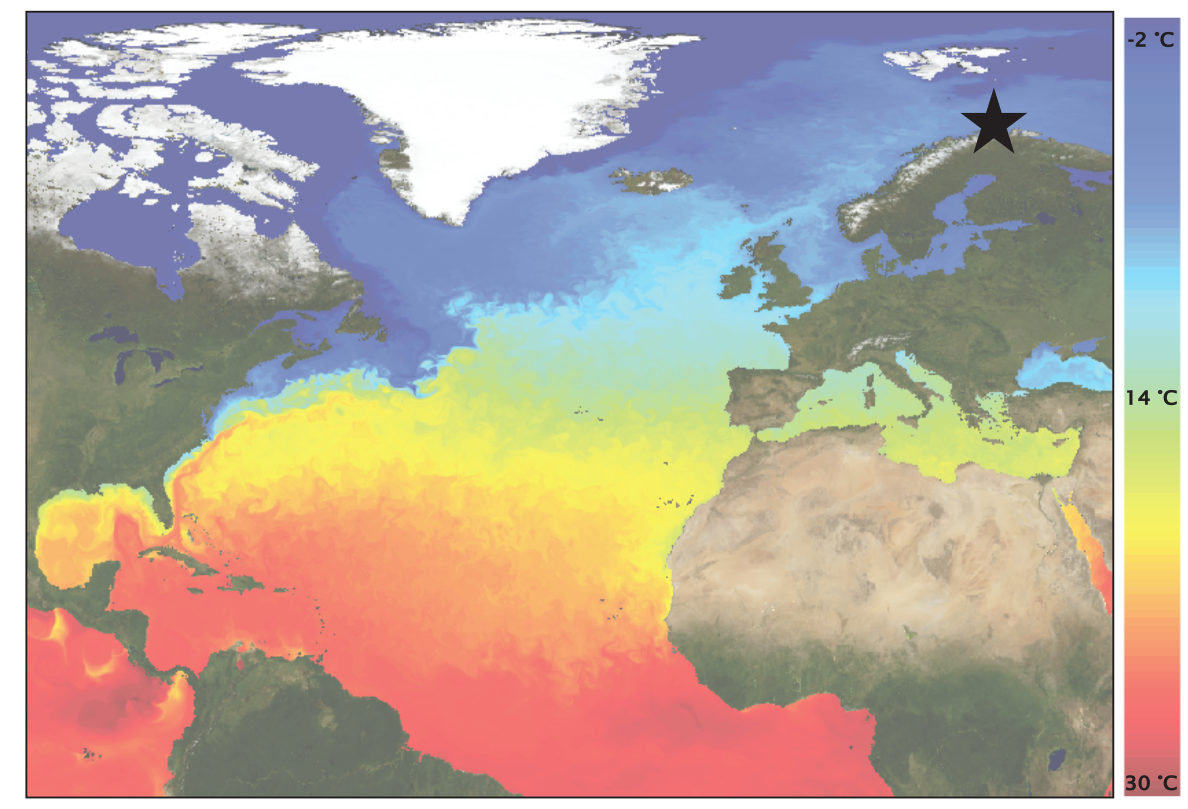

Figure 2. North Atlantic Ocean showing sea surface temperatures during February, 2016. Location of the present study indicated by a star. Background image from http://marine.copernicus.eu/.

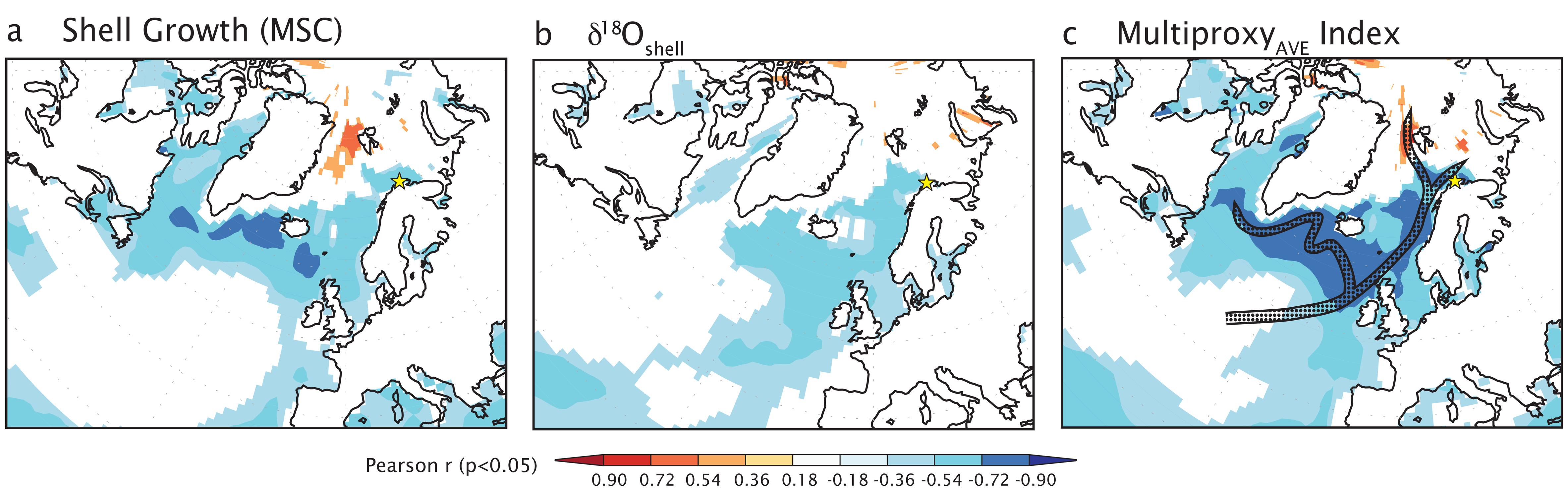

Figure 3. Spatial correlation plots showing the relationship between Sea Surface Temperature (OISST) and the (a) MSC, (b) d18Oshell record, and (c) MultiproxyAVE Index for the years 1982–2012. Colored regions indicate p<0.05. Yellow star indicates location of study site. The approximate path of the North Atlantic Current (stipple) is shown in 5C (Figure 5 from Mette et al., 2016).

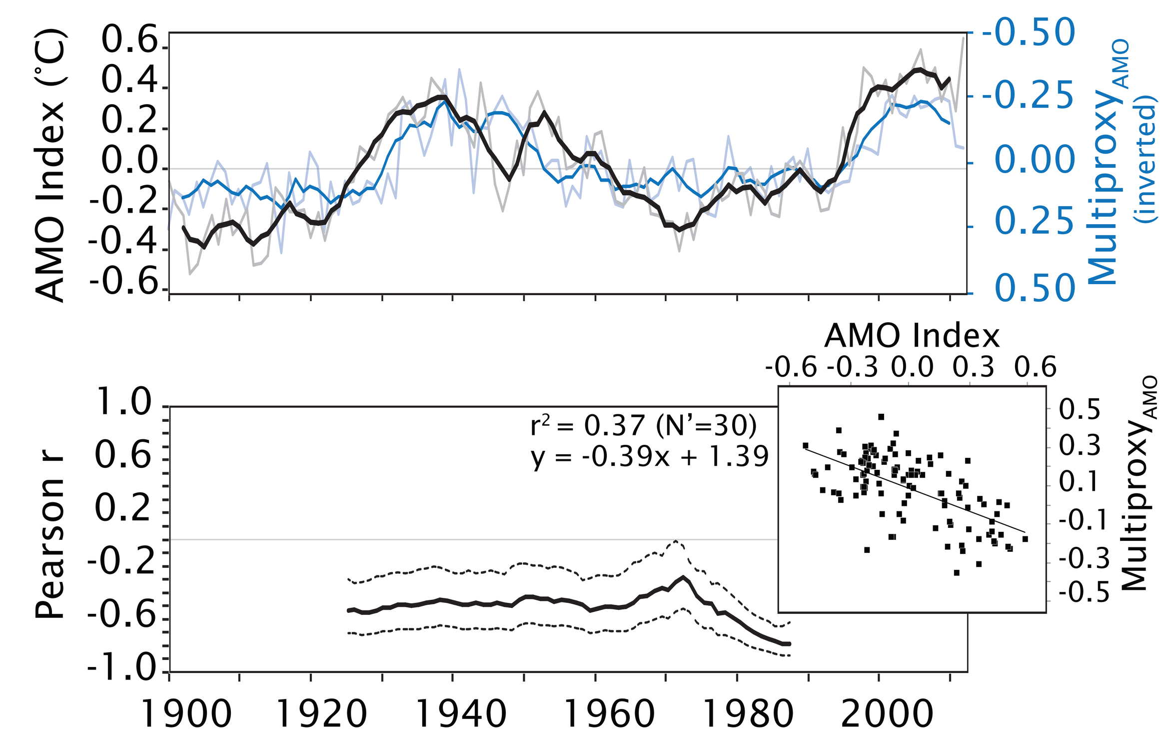

Figure 4. Relationship between the shell based Multiproxy$_{AMO}$ Index and AMO Index. (top) Standardized time series of the Multiproxy$_{AMO}$ Index (blue) and AMO Index (black) both smoothed and unsmoothed (light blue; gray). (bottom) 51-yr running correlations between the AMO and Multiproxy$_{AMO}$ Index. (bottom inset) Biplot showing relationship between the total length of both unsmoothed records. (Figure 6 from Mette et al., 2016)

CURRENT PROGRESS

Current and future work is focused on extending the lengths of the shell growth and geochemical records. Radiocarbon dating of dead-collected material is being used to range-find appropriately aged material that can then be crossdated into the modern chronology. ~10 long-lived dead-collected (>150 years) shells have been found to be dated at death between AD 1700-1900. These shells will be integral in extending the chronologies to span the transition between the Little Ice Age and Modern Climate intervals. Decadal radiocarbon data will also be collected from the chronologies to assess whether changes in the radiocarbon reservoir effect are detectable and related to water mass variability.

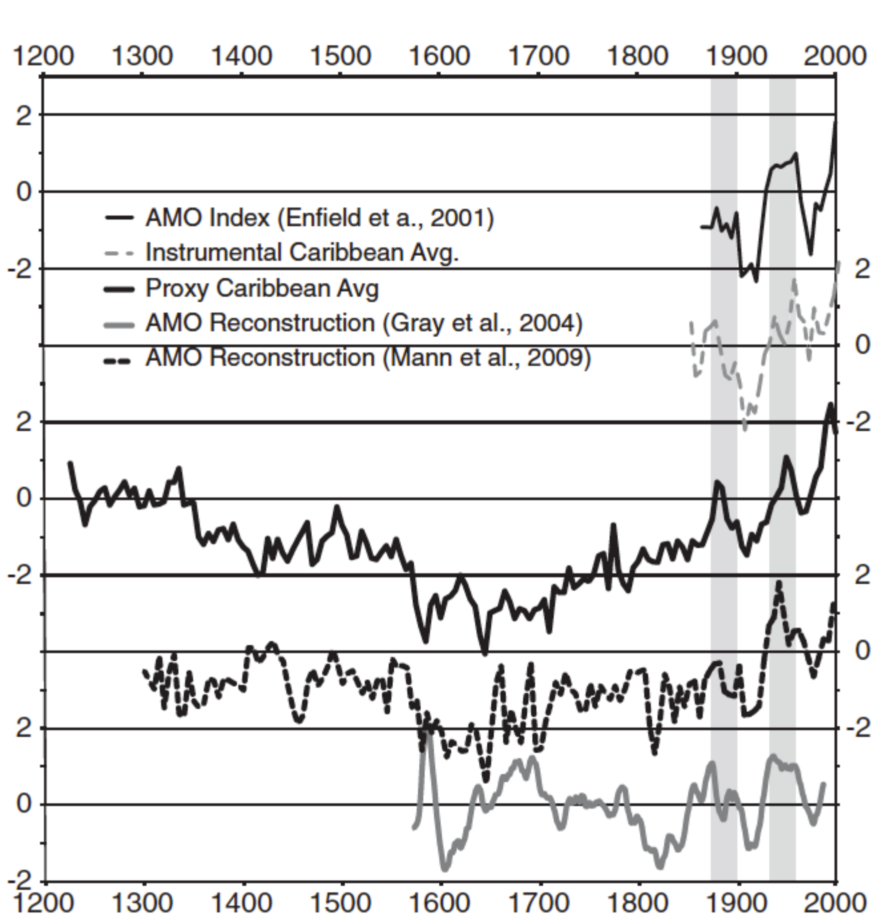

Figure 5. From Kilbourne et al., (2013) Figure 5. Proxy reconstructions of Atlantic multidecadal variability correlate to instrumental records of SST during the modern period, but do not show coherent multidecadal-scale variability during the pre-instrumental period. All y-axis values refer to standard deviation units.

APPLICATIONS OF THE RECORDS

Multicentury, high-latitude, annually resolved proxy records from the oceans are extremely rare, and thus provide unique opportunities for application (Jones et al., 2009). Previous studies have laid the groundwork and suggested future directions for research and need for such proxies. Several examples are outlined below:

Contributing to AMO reconstructions

The two most commonly cited AMO reconstructions (Figure 5) have major drawbacks. Gray et al. (2004) constructed a proxy network utilizing mid-latitude multicentury tree-ring chronologies, which may not account for variation of the centers of SST influence through time (Knudsen et al., 2014). Mann et al., 2009 analyzed global proxy records of temperature to construct an AMO index, however, these records suffer from inconsistent age control. Both reconstructions are obtained from predominantly atmospheric proxy archives. An attempt at a low latitude, ocean-based reconstruction of the AMO was recently compiled by Kilbourne et al. (2013) using coral records. These authors called for development of a spatial network of high resolution proxy SST records with both low and high latitude contributions to gain understanding of the forcing mechanisms of the AMO.

Forcing mechanisms of the AMO through time

Recent work by Knudsen et al. (2014) suggests the influence of solar and volcanic forcing on the AMO predominated after termination of the Little Ice Age (LIA). This conclusion was reached through comparison of two major AMO reconstructions with records of solar variability and volcanic forcing, finding a significantly strong correlation after the LIA and ambiguous results prior (Figure 6). The authors note the limitations of the proxy records, implying the need for proxies less sensitive to shifts in atmospheric climate modes. The shell-based record from Ingøya provides such an opportunity to help separate atmospheric versus ocean forcing of North Atlantic SSTs.

High latitude ecosystem impacts of the AMO

Sea surface temperature variability in the Barents Sea has been shown to parallel that of the AMO (Skagseth et al., 2008; Levitus et al., 2009). Therefore, impacts of this ocean climate mode are hypothesized to extend into the Barents Sea, impacting ecosystems at all levels. Evidence for this linkage is shown through correlations between shell growth records at Ingøya and the AMO index (Figure 4). The cascade effects of high-latitude SST variability from primary production to the benthic ecosystem can be detailed by developing long records of shell growth and geochemistry from northern Norway.

Other modeling studies

Proxy records of the AMO are often used as benchmarks for comparison in modeling studies. The limitations of the existing proxy records are a potential weakness in such studies (e.g., Otterå et al., 2010). The record from Ingøya provides data from a region where few long-term instrumental records exist and appears to reflect larger-scale processes. Shell-based proxies may provide useful calibration tools for climate modelers characterizing northern North Atlantic ocean dynamics.

North Atlantic Current dynamics

SST and shell-based records at Ingøya appear to be related to NAC variability. This hypothesis, however, is difficult to test due to the lack of records for verification of the proxy.

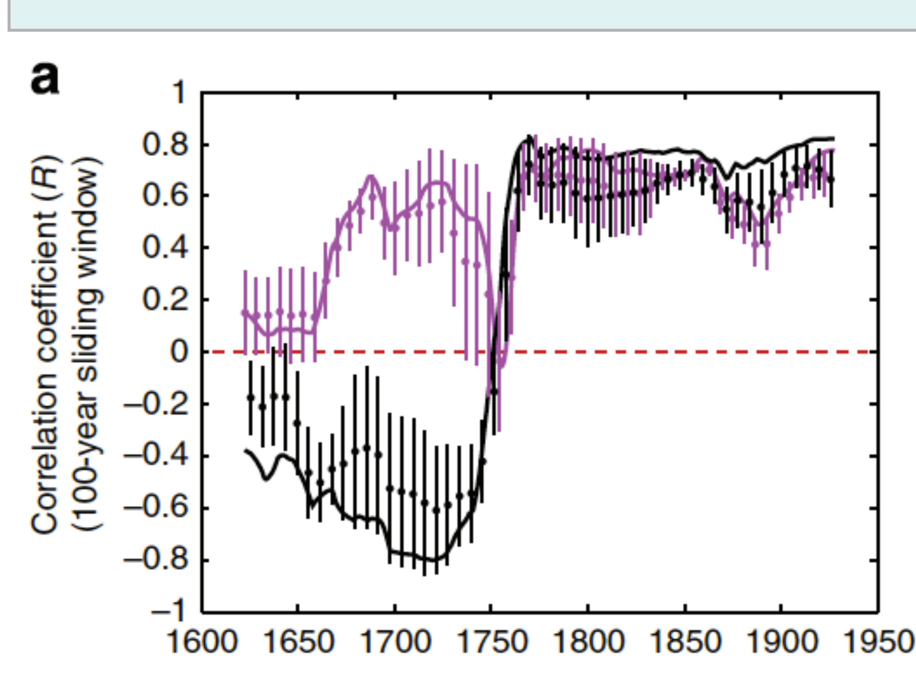

Figure 6. From Knudsen et al. (2014) Figure 2. Changes in the Pearson correlation between the combined solar and volcanic forcing and the two AMO reconstructions for data in 100-year sliding windows. All data were smoothed using 11-year running means, and the black and magenta lines/dots/triangles denote the tree-ring and multiproxy AMO reconstructions, respectively.

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Gray et al., *Geophysical Research Letters* **31**, L12205 (2004); Kilbourne et al., *Journal of Marine Systems* **133** (2013); Knudsen et al., *Nature Communications* **5**, 3323 (2014); Levitus et al., Geophysical Research Letters **36** (2007); Mann et al., *Science* **326**, 1256 (2009); Mette et al., *Limnology and Oceanography* **61** (2016); Otterå et al., *Nature Geoscience* 3 (2010).; Skagseth et al., *Geophysical Research Letters* **35** (2008).