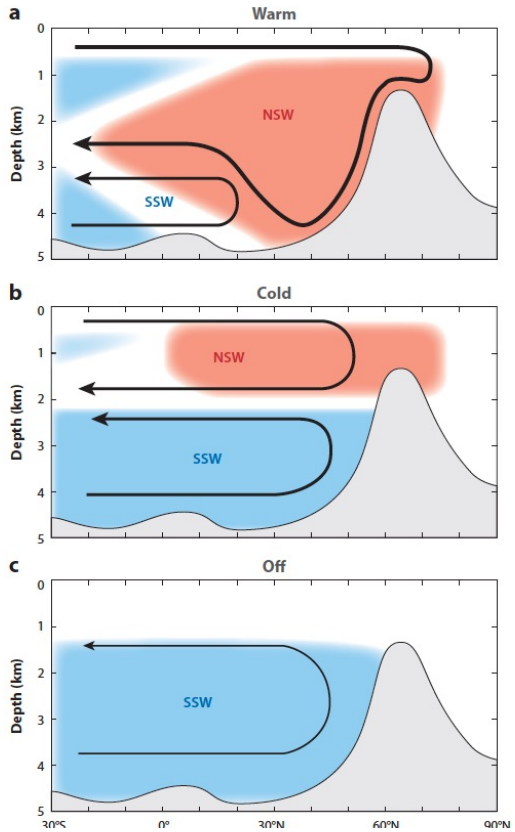
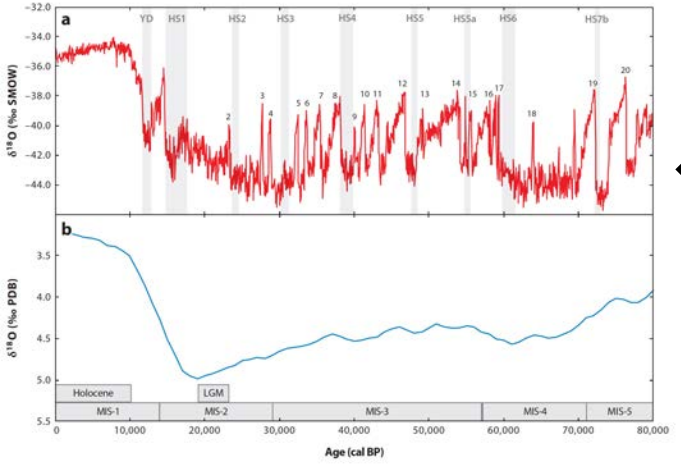
Conceptual Diagram of AMOC



Holocene (Modern) and millennial-scale warm events (DO interstadials) recorded in Greenland

Glacial Maximum AMOC Shallow Southern Source water (AABW) filled the basin

Heinrich Events; AMOC Off due to iceberg inputs



Some "recent" things we have learned about AMOC

The Pacific/Arctic sector maybe more important than we thought for abrupt changes:

- Younger Dryas may have been triggered by outflow from Makenzie River in Alaska (Keigwin 2018).
- Pacific ice discharge and ocean ventilation events precede Atlantic Heinrich events, Pacific trigger? (Walczak et al., 2020)

Simulated AMOC is potentially biased towards mono-stable state

- Salinity stratification in the South Atlantic is a major determinant of stability during deglaciation and is also likely to be distorted due to common biases in models (Liu et al. 2013, 2015).

Glacial AMOC was definitely shallow, changing global MOC

- Glacial Maximum AMOC Shallow - carbon isotopes (^{13}C and ^{14}C) are great for indicating depth of overturning, but cannot *constrain glacial overturning strength* (Muglia et al., 2021).
- Observational and modeling evidence that a shallow AMOC does not participate in global MOC through the southern ocean (Lund et al., 2015, Sikes et al., 2017, Nadeau and Jansen 2020).

Heinrich Events are not all the same

- AMOC did not shut off (or at least not for long) during the most recent (H1) event (Repschlaeger et al., 2021).
- AMOC may not have shut off during H2 and H3 (Lynch-Stieglitz 2017 review, and refs therein).

(Figures from Lynch-Stieglitz 2017)

Ideas about recent AMOC behavior and mechanisms

AMOC Fingerprints to investigate past AMOC changes, possible (but with caveats):

- Cold tropical subsurface and warm surface temperatures off Brazil associated with the weak AMOC during the Younger Dryas as expected from Zhang 2007 fingerprint (Schmidt et al., 2012)
- Subsurface Temperature contrast between the Gulf Stream and Subpolar gyres used to propose recent AMOC slow down based on Zhang 2008 fingerprint (Thornalley et al., 2018)
- Some AMOC Fingerprints may not be time stable, especially surface manifestations (preindustrial versus industrial - Little et al., 2020; Moffa-Sanchez et al., 2019); alternate metrics for AMOC dynamics are needed

AMOC *may* have slowed down in recent centuries (but conflicting evidence):

- The subpolar gyre has not warmed with the rest of the ocean and it may be associated with AMOC slowdown (Rahmstorf et al 2015, Caesar et al. 2018, Thornalley et al., 2018, Caesar et al., 2020, Caesar et al., 2021), but see comment by Kilbourne et al. (2022)
- Hydrographic data since 1900 from Nordic Seas do not support a modern slow down (e.g., Rossby et al., 2020)

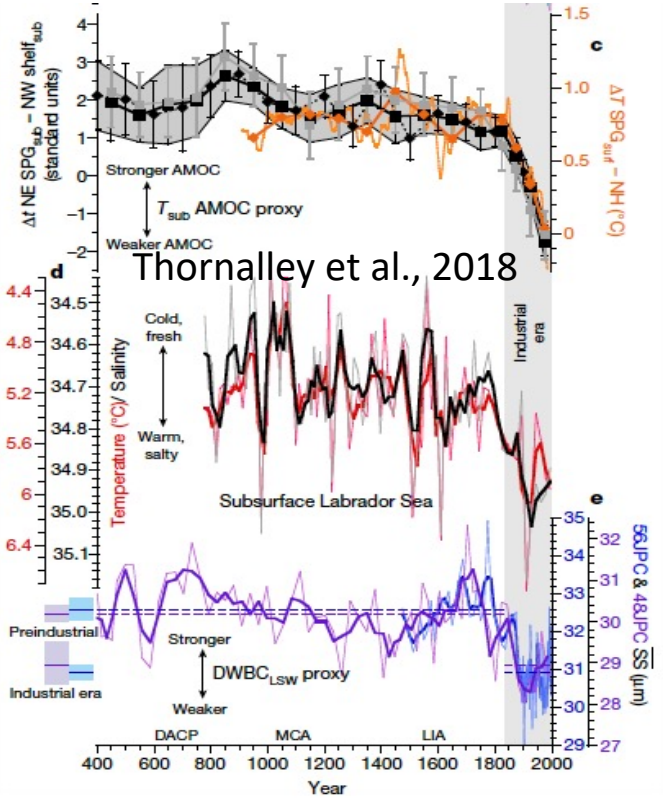
The link(s) between AMV and AMOC – is/are still unresolved

- AMV could be just red noise from atmosphere (Clement et al., 2015) or a dynamic ocean response (Zhang et al., 2016)
- Mann et al. (2020) argue that AMO/AMV is not significant– explained by aerosols and GHG in last 150 yrs
- Paleo data often maps on modern multidecadal variability (e.g., low latitude example - Kilbourne et al., 2014; high latitude example - Mette et al., 2021), but they don't always match in the earlier portions of the records for a variety of reasons – is it because they are really moving independently, or because small signals, sparse data, and age-model errors inhibit detection? **Nonetheless – AMV is persistent and intense before last 150 yrs in many recent paleo records.**

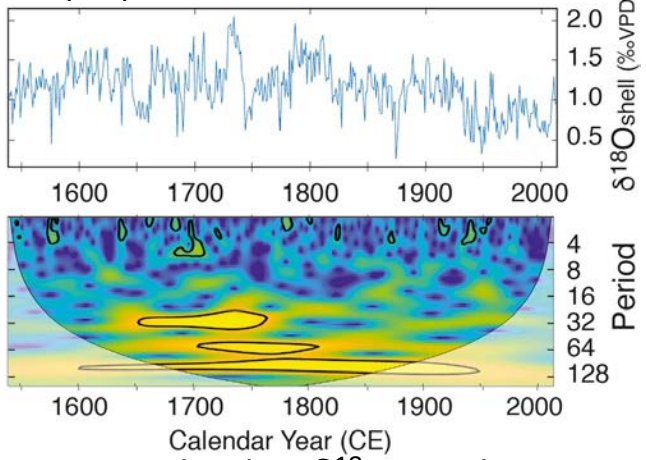
Key Messages and Challenges

- Decadal to centennial timescales components of the AMOC system may behave differently, which may explain some of the discrepancies in the proxy data.
- We need to be careful to deconvolve the un-forced signals from anthropogenic forcing on AMOC and ocean variability and recognize the relatively small signal/noise ratio of the AMOC in the late Holocene.
- Collaborations of observational oceanographers and paleo folks is still needed (Paleo-Modern AMOC workshop 2015)

Subsurface temperature anomalies indicate AMOC decline



Example persistent multidecadal variability



Arctica islandica $\delta^{18}O$ Southern Barents Sea, Mette et al., (2021).