Evidence of reduced formation of NADW in recent decades

- Historical atmospheric state fields (CORE-II data) spanning 1948-2013 are paired with monthly observed sea surface temperatures (SST) and daily observed sea ice fraction to generate an historical air-sea flux data set.
- Using monthly climatological sea surface salinity (SSS), estimates of historical high latitude North Atlantic surface density flux ($D_N$) are computed from net air-sea heat ($Q_{air}$) and freshwater ($Q_{f$}) contributions as follows:

$$D_N = \frac{Q_{air}}{C_v} - \beta \frac{SSS - 34}{1 - SSS}$$

- Monthly water mass transformation (WMT) rates (Sv) are computed as spatial integrals of $D_N$ over pre-defined outcrop areas in each of four North Atlantic regions. Corresponding water mass formation (WMF) rates are given by the density convergence of WMT:

$$WMF(\rho) = \frac{1}{\Delta \rho} \int D_N d\Delta \rho$$

- In the adiabatic limit, the surface WMT over the high latitude North Atlantic suggests a mean subduction rate of NADW of ~19 Sv.
- Interannual variations in formation of NADW correlate highly with the winter NAO index (F3). The extreme NAO- of 1996 subduced in a 15-year period of normal-to-weak NADW formation, in sharp contrast to the 1980-1995 period. The extreme NAO- of 2010 was associated with very weak NADW production, but has since recovered to normal levels.

Predicting Atlantic Circulation Changes

- Temporal variations in the surface formation of NADW explain most of the large decadal AMOC changes in a COREII-forced ocean-ice simulation of the 1948-2013 period. The large increase in AMOC strength between 1970-1993 and decrease since 1995 (F4, panel a) is in line with observed “WFM” variability (F3).
- Now consider a suite of CMIP5 fully-coupled decadal prediction (DP) experiments (10 member ensembles) initialized from the COREII ocean-ice state every January between 1955-2014. There is little skill in predicting the WFM which sets Labrador Sea density anomalies (F5, left); however, there is high skill in predicting the southward propagation of pre-formed water mass anomalies into the Grand Banks shelf region (F5, right).

Impacts on North Atlantic surface temperature and sea ice extent

- Annual SST anomaly time series from 1948 to 2013 of net positive WMT (black curve, left axis) binned over the density range corresponding to NADW (≥978 kg/m³) for various N. Atlantic regions. The observed winter (DJFM) NAO index is also shown (red curve, right axis).

Summary

- Historical changes in the rate of NADW formation explain the large, buoyancy-driven decadal variations in AMOC and gyre flow in the COREII ocean-ice state estimation used to initialize fully-coupled CESM decadal prediction ensembles. The recently observed AMOC cooling resulting from much reduced NADW formation can be skilfully predicted as a manifestation of the large-scale atlantic circulation. DP ensembles can still skillfully predict the dynamical consequences of pre-formed NADW anomalies, but not the actual formation processes. The return of normal NADW formation rates suggests that AMOC cooling trends will weaken.

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