A coupled decadal-scale air-sea interaction theory: the NAT-NAO-AMOC-AMO coupled mode and its impacts on global and regional climate

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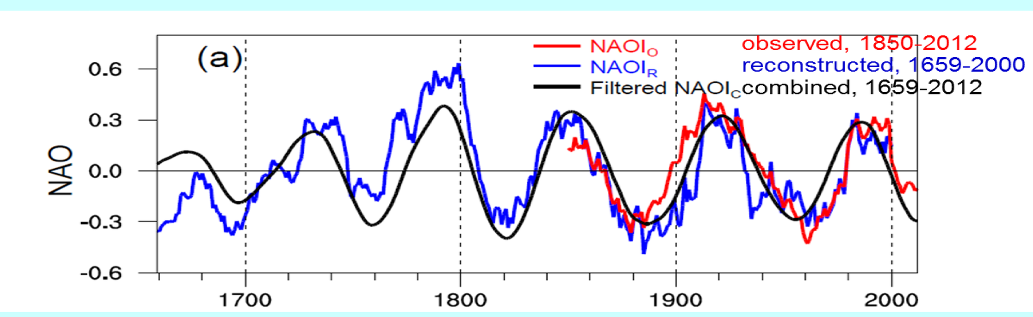
1. Introduction

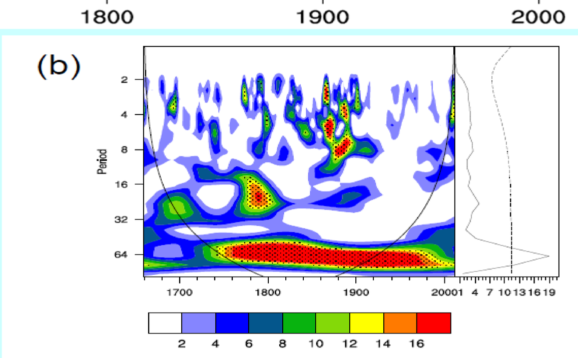
It has been well documented in the literature that over interdecadal timescales the NAO has important impacts on regional and hemispheric climates in the NH. The NAO shows a remarkable upward trend over the second half of the twentieth century. This upward trend explains much of the observed warming trend over Eurasia and North America, and has been linked to the interdecadal variations of Asian winter monsoon. However, since the 1990s, the NAO has shown a significant decreasing trend.

Several factors, such as greenhouse gas emissions and warming in tropical oceans, have been suggested to account for the NAO interdecadal variations, but neither of them could explain the NAO downward trend during the two most recent decades.

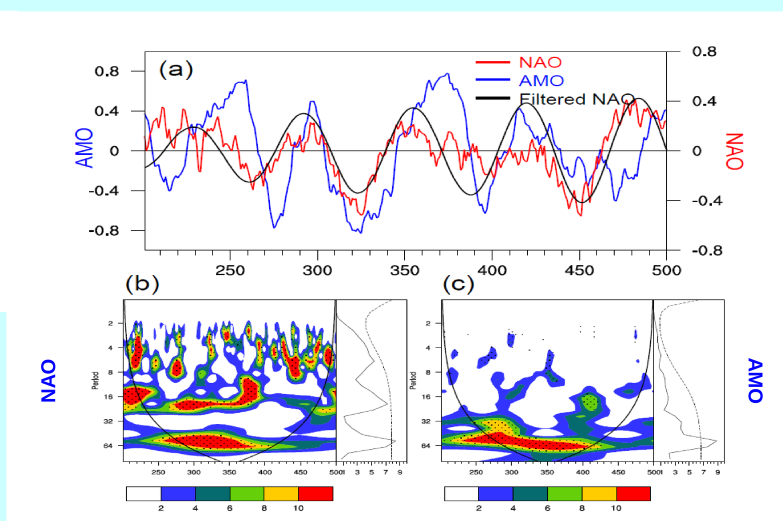
Mechanisms and physical processes involved in the multidecadal air-sea interaction over the North Atlantic basin remain to be elucidated.

2. Quasi-60 year cycle in the NAO





Observed and reconstructed NAO indices; Wavelet analysis

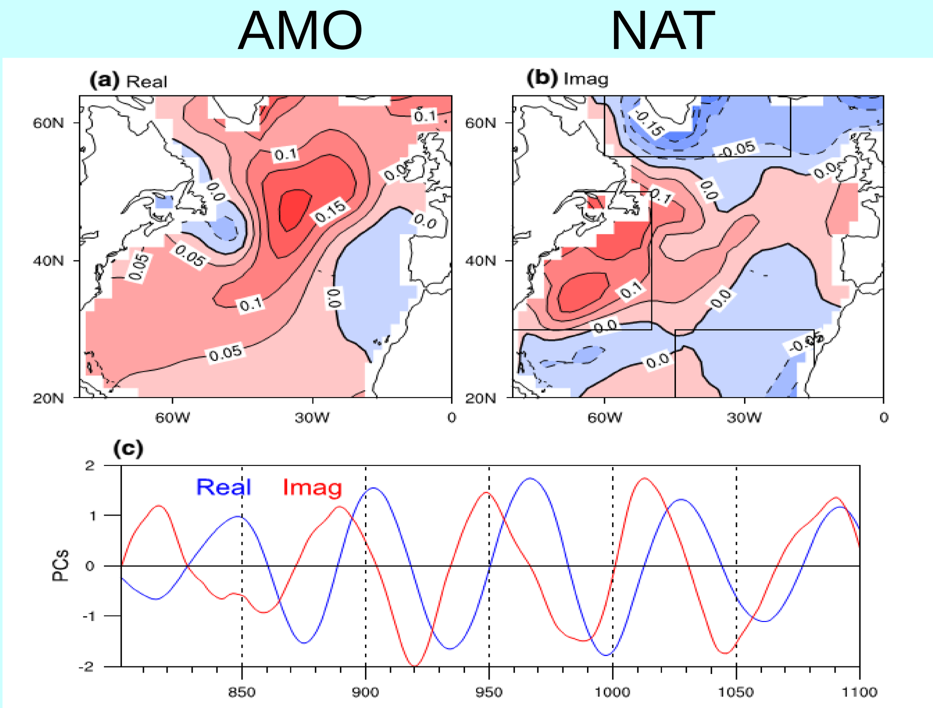


Simulated AMO and NAO indices in the 300-yr CCSM4 simulations.

3. Modes of SST multidecadal Variablity

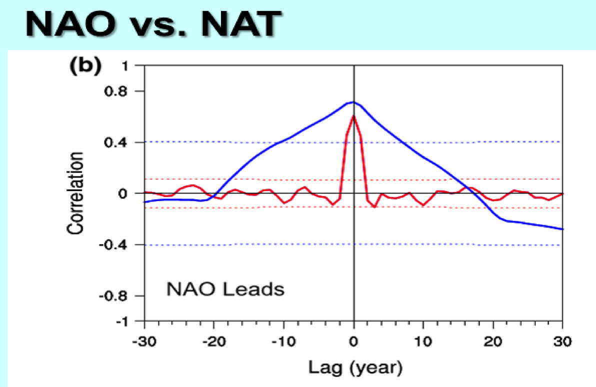
Two modes of SST multidecadal variability revealed by the POP method

AMO NAT



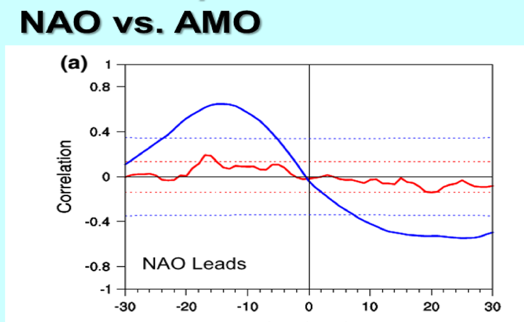
The first leading POP mode of band-pass (50–70 years) filtered annual SST anomalies over the North Atlantic Ocean: (a) real-part pattern of POP1; (b) imaginary-part pattern of POP1; and (c) their corresponding PCs. The POP patterns are shown as the SST anomaly (in K) regressions onto the normalized PCs. The boxes marked in (b) indicate the regions used to define the NAT index.

NAO vs. NAT



NAT is in phase with NAO

NAO vs. AMO

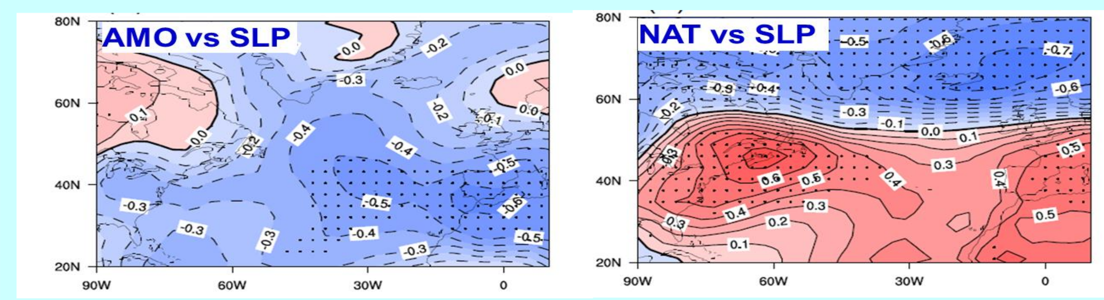


NAO leads AMO, while AMO has a negative feedback on NAO

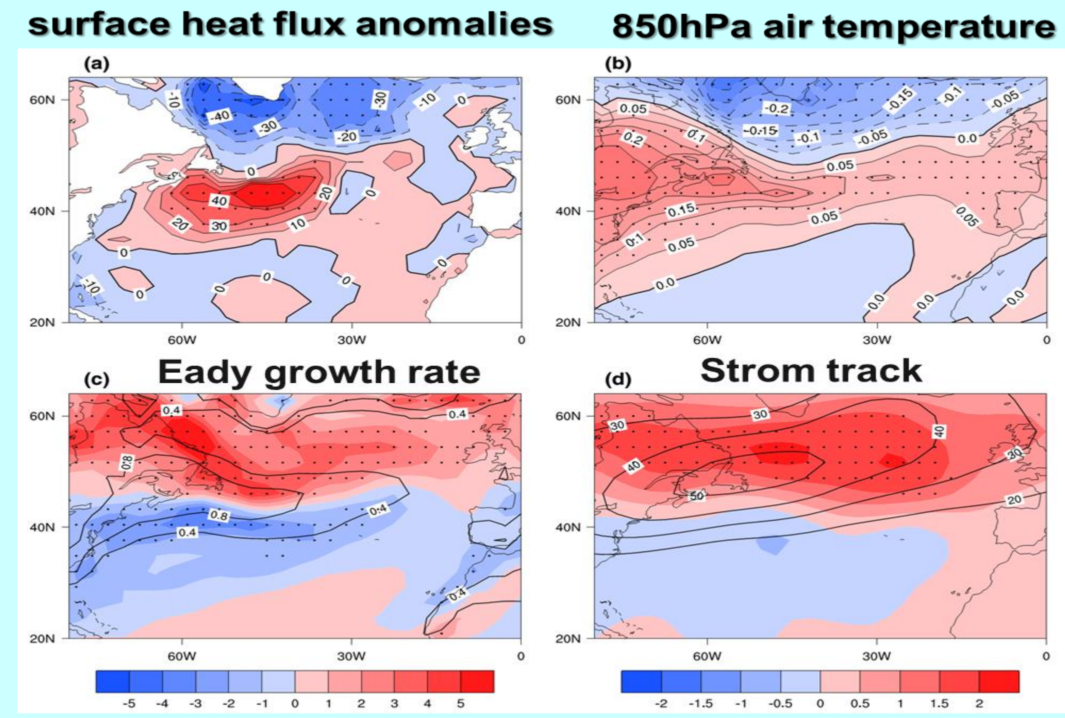
Lead–lag correlation between the NAO and NAT (upper) and AMO (bottom)indices in the CCSM4 simulations.

4. Three key physical processes

#1 Direct effect of NAT on NAO

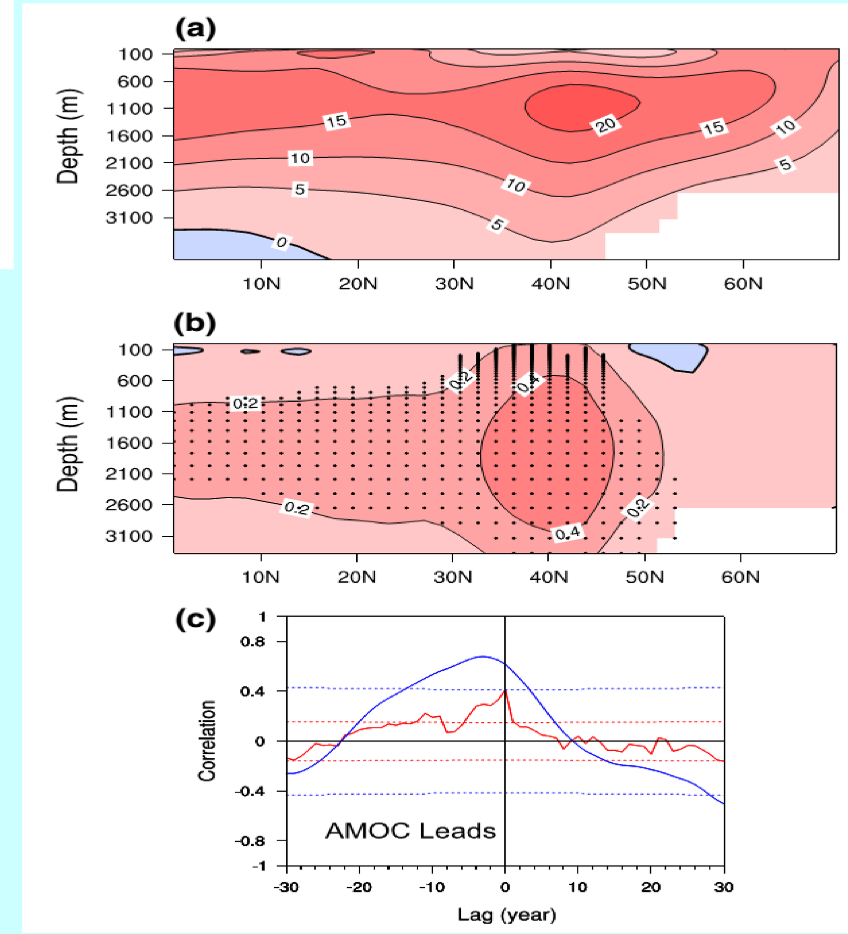


Atmospheric (SLP) responses to the AMO and NAT in CCSM4



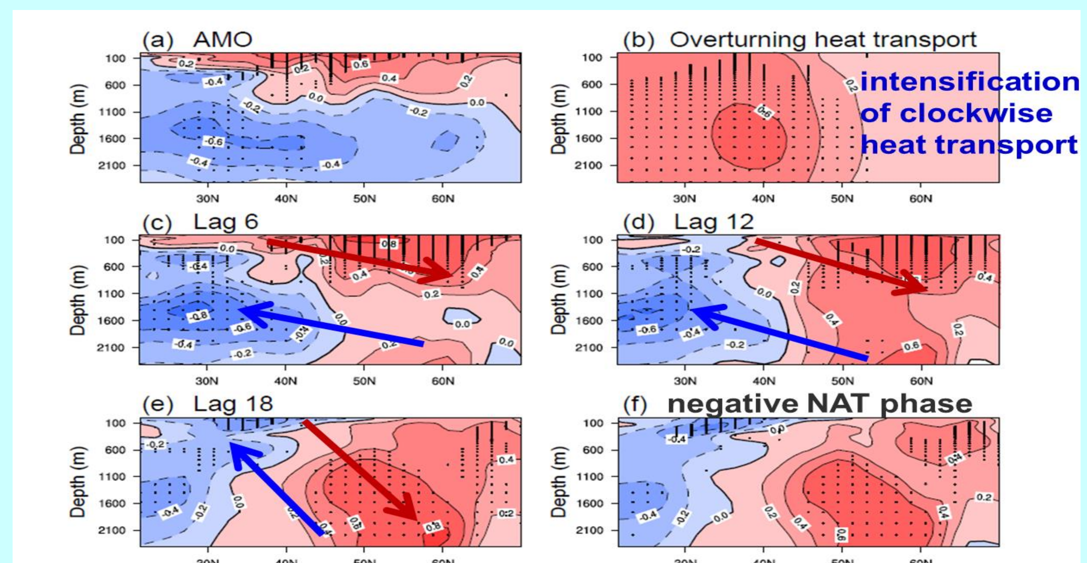
Physical process of the NAT effect on NAO

#2 NAO forcing of AMO/AMOC



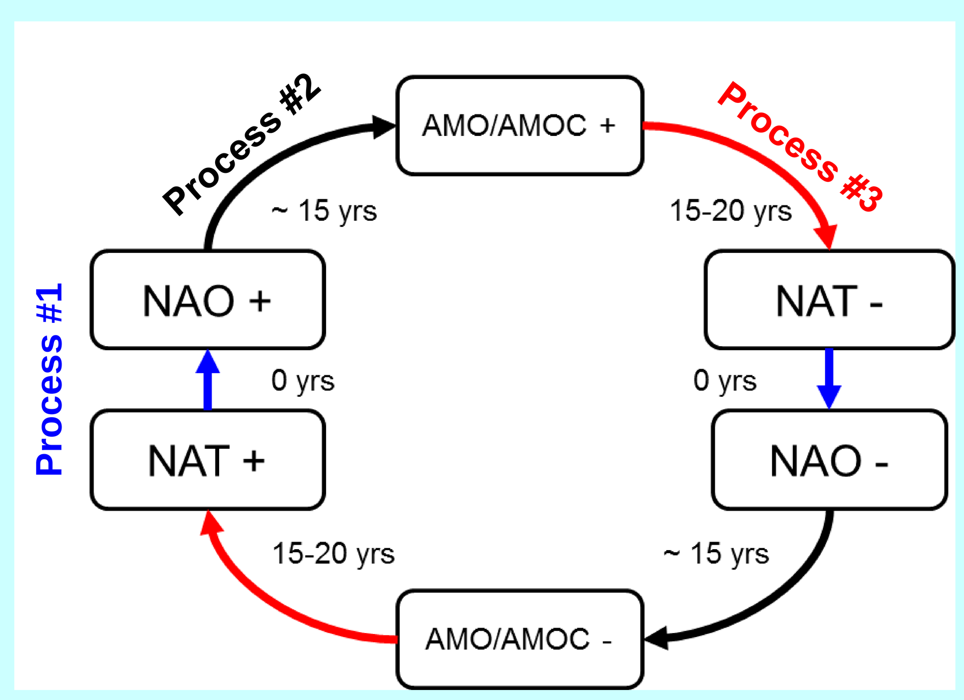
(a) Long-term mean AMOC streamfunction (Sv) in the CCSM4 simulations. (b) Lagged regression of the annual mean AMOC streamfunction (Sv) with respect to the normalized NAO index based on 21-yr running mean data, with the NAO leading by 15 years. (c) Cross-correlations of the simulated AMO index with the AMOC index

#3 Negative feedback of AMO on NAT



The positive correlations are at first located in the upper North Atlantic and then propagate into the subpolar region, expanding downward; the negative correlations are shifted southward.

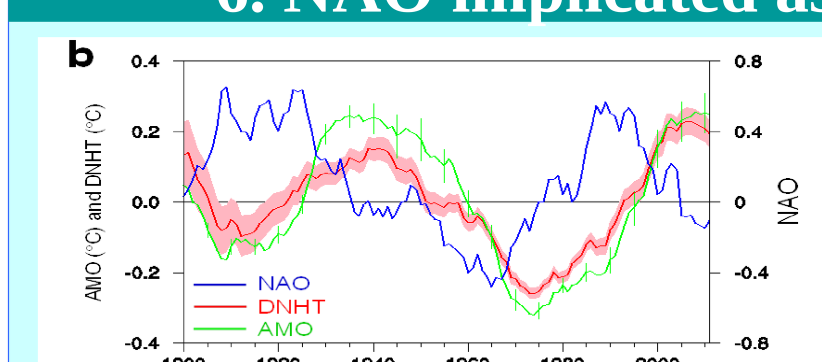
5. Summary of the mechanisms



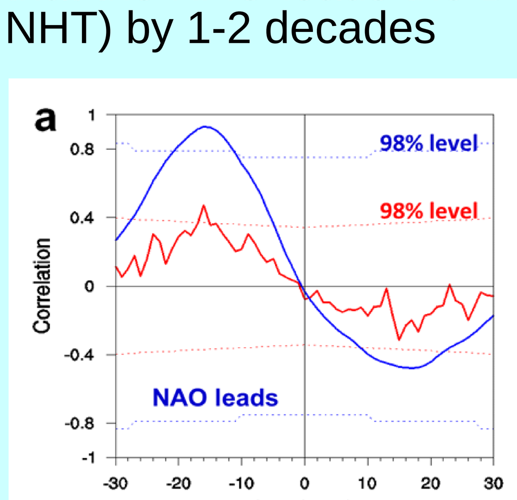
Schematic diagram of the physical processes for the quasi-60-yr cycle

The positive NAO forces the enhancement of the AMOC, and leads to the AMO positive phase. The forcing effect is delayed by about 15 years, possibly due to the large inertia associated with slow oceanic processes. The enhanced AMOC continues to affect the heat transport, and due to slow ocean adjustment, the North Atlantic Ocean shows a delayed response (after about 18 years) to the preceding enhanced AMOC with an SST pattern that resembles the NAT negative phase. The NAT negative phase coincides with the NAO negative phase in the atmosphere, and thus the cycle proceeds, but in the opposite sense. Blue (black) text indicates oceanic (atmospheric) phenomena.

6. NAO implicated as a predictor of NHT

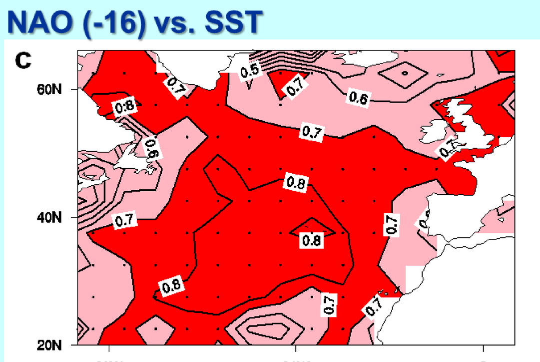


The above multidecadal dynamical theory can explain the observational fact that the NAO leads the DNHT (detrended NHT) by 1-2 decades



The maximum correlation coefficients occur at a lag of 16 years (NAO leading DNHT)

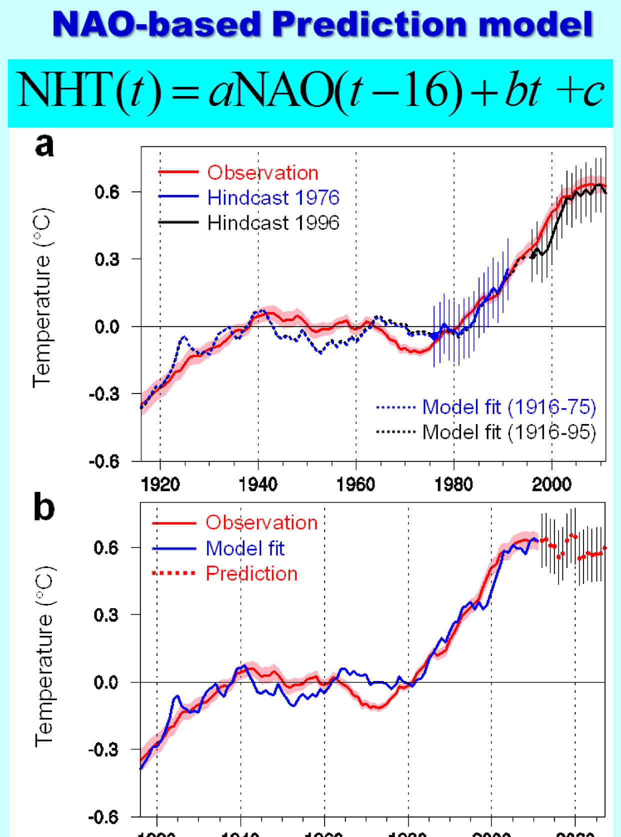
NAO (-16) vs. SST



The correlations between SSTs over the extratropical North Atlantic and the NAOI 16 years earlier are significantly positive with a basin wide homogeneous pattern resembling the AMO

NAO-based Prediction model

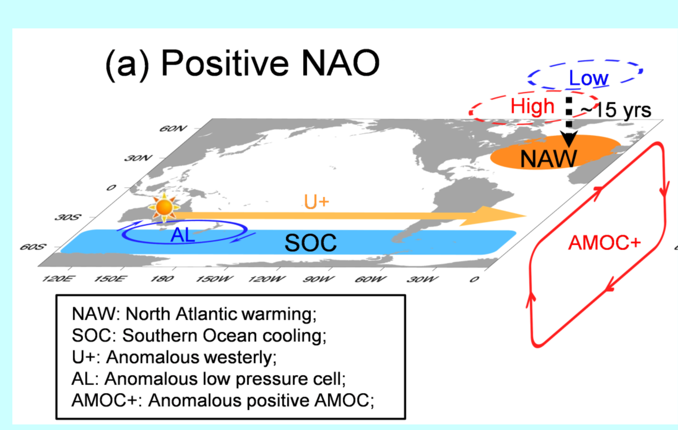
$$NHT(t) = a\mathrm{NAO}(t-16) + bt + c$$

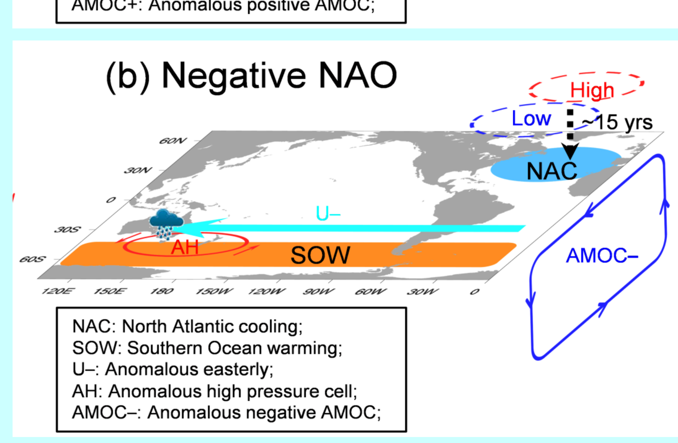


The prediction shows NHT will fall slightly over the next decade (2012-2027).

7. NAO and Eastern Australian Rainfall

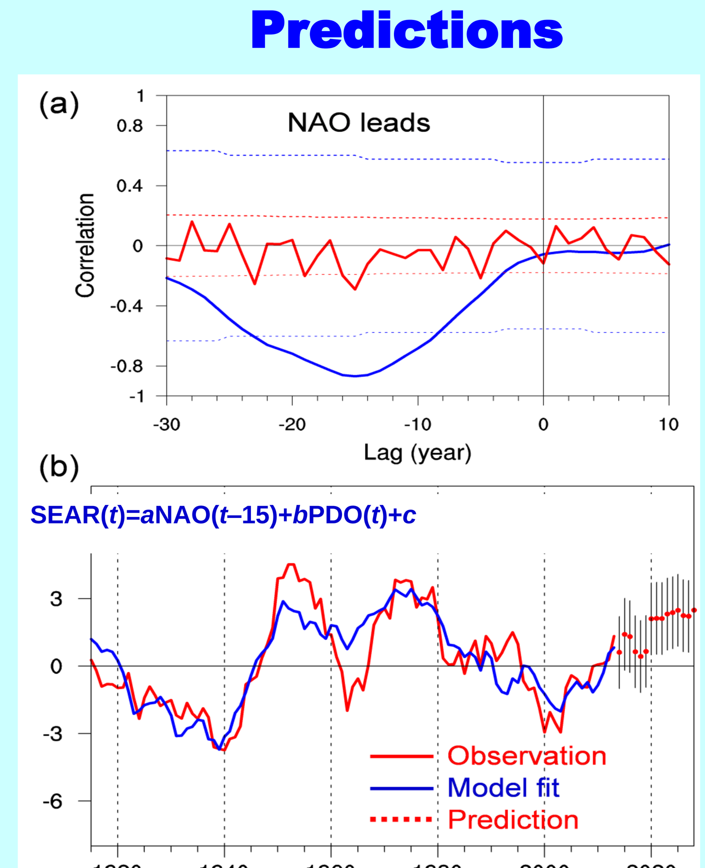
Mechanisms





Schematic diagram of the variations of the AMOC, subpolar interhemispheric SST seesaw, The SH low-level atmospheric circulation and SEAR following the (a) positive and (b) negative NAO phases, with the NAO leading by around 15 yr.

Predictions



(a) Lagged correlation between NAO and SEAR (b) The observed decadal SEAR from 1915 to 2013 (red), the linear model fit of SEAR (blue), and the predicted SEAR between 2014 and 2028 (red dots) assuming a fixed negative PDO phase over the next decades.

Selected publications:

1. Li, J., C. Sun, and F.-F. Jin, 2013: NAO implicated as a predictor of Northern Hemisphere mean temperature multidecadal variability. Geophys. Res. Lett., 40, 5497–5502.
2. Sun, C., J. Li, F.-F. Jin, 2015: A delayed oscillator model for the quasi-periodic multidecadal variability of the NAO. Climate Dynamics, DOI: 10.1007/s00382-014-2459-z.
3. Sun, C., et al., 2015: A decadal-scale teleconnection between the North Atlantic Oscillation and subtropical eastern Australian rainfall. Journal of Climate, doi:10.1175/JCLI-D-14-00372.1.
4. Sun, C., J. Li, F.-F. Jin, and R. Q. Ding, 2013: Sea surface temperature inter-hemispheric dipole and its relation to tropical precipitation. Environmental Research Letters, 8, doi:10.1088/1748-9326/8/4/044006.
5. Sun, C. et al., 2015: Remote influence of Atlantic multidecadal variability on Siberian warm season precipitation. Scientific Reports, doi: 10.1038/srep16853.
6. Sun, C. et al., 2016: Cold season Africa–Asia multidecadal teleconnection pattern and its relation to the Atlantic multidecadal variability. Clim Dyn, doi:10.1007/s00382-016-3309-y.

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