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A coupled decadal-scale air-sea interaction theory: the NAO-AMOC-AMO coupled mode and its impacts

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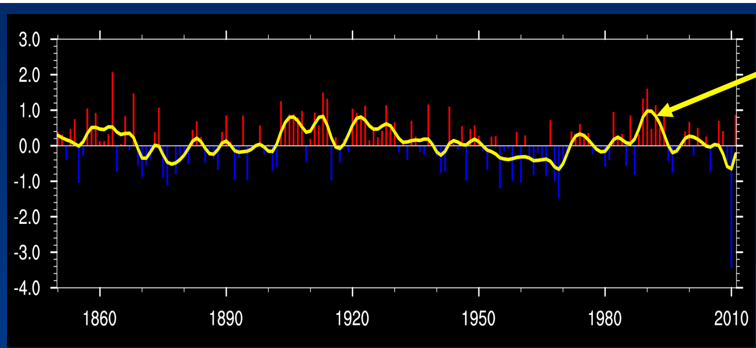
Li, Sun and Jin, 2013, *GRL*
Sun, Li and Jin, 2015, *CD*
Sun, Li, Feng and Xie, 2015, *JC*

A delayed oscillator model for the quasi-periodic multidecadal variability of the NAO

Cheng Sun · Jianping Li · Fei-Fei Jin

(Sun, Li, & Jin, 2015, *Clim Dyn*)

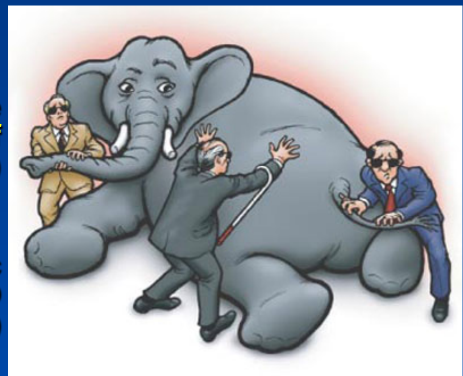


Multidecadal variability of the NAO and recently decadal weakening

(Li and Wang, 2003, *AAS*)

Decrease of Artic sea ice leads to strengthening of NAO (Deser et al. 2004)

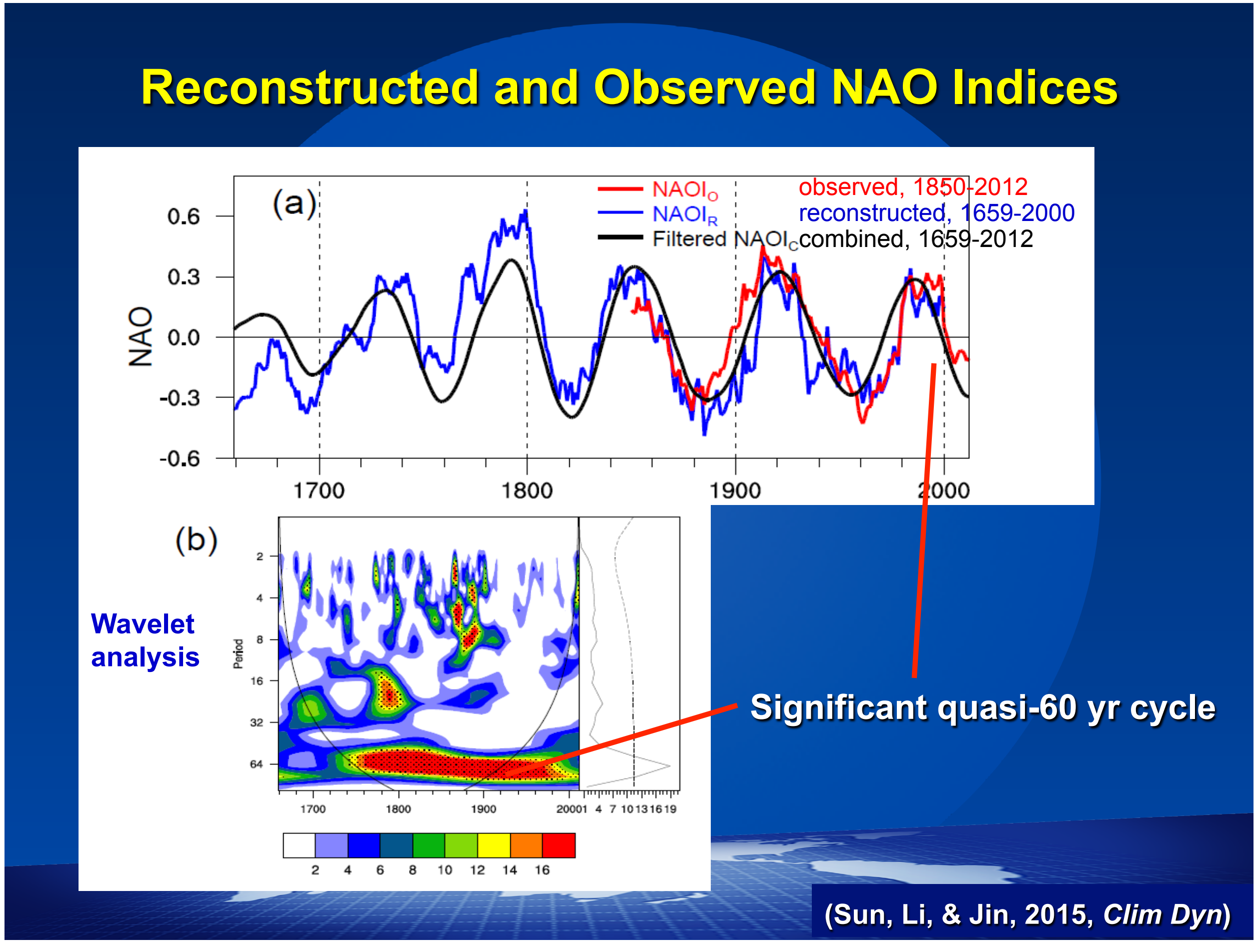
Warming of Indo-Pacific warm pool enhances NAO (Hoerling et al. 2001)



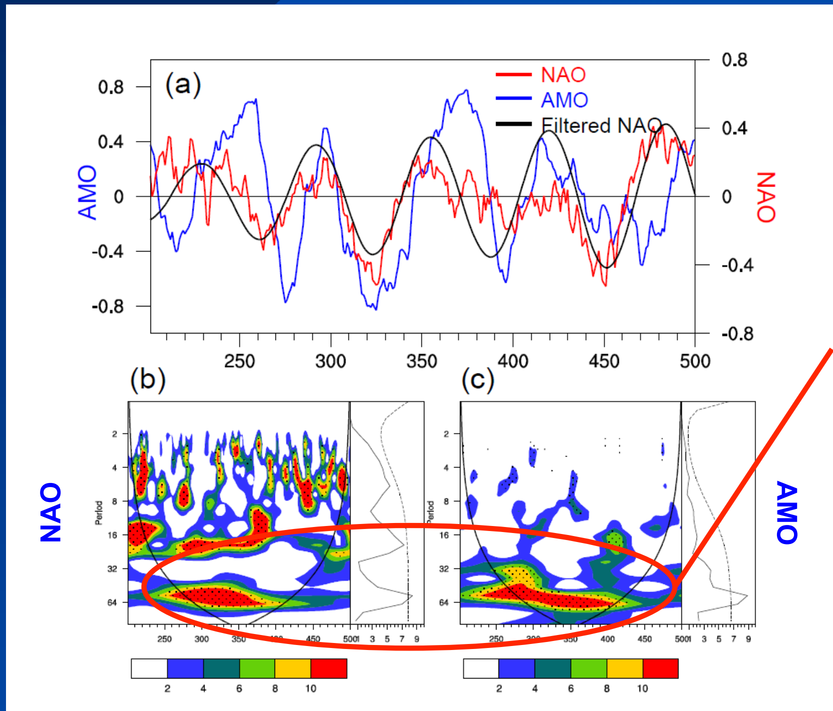
Greenhouse gas increase forces NAO upward trend (Shindell et al. 1999)

Questions:

- **Quasi-60 yr cycle**
- **The weakening trend over the past decades**


Reconstructed and Observed NAO Indices
(a)
NAOI_O
observed, 1850-2012
NAOI_R
reconstructed, 1659-2000
Filtered NAOI_C combined, 1659-2012
NAO
0.6
0.3
0.0
-0.3
-0.6
1700
1800
1900
2000
(b)
Wavelet analysis
Period
2
4
8
16
32
64
1700
1800
1900
2000
1 4 7 10 13 16 19
2 4 6 8 10 12 14 16
Significant quasi-60 yr cycle
(Sun, Li, & Jin, 2015, Clim Dyn)

NAO in the coupled model NCAR CCSM4

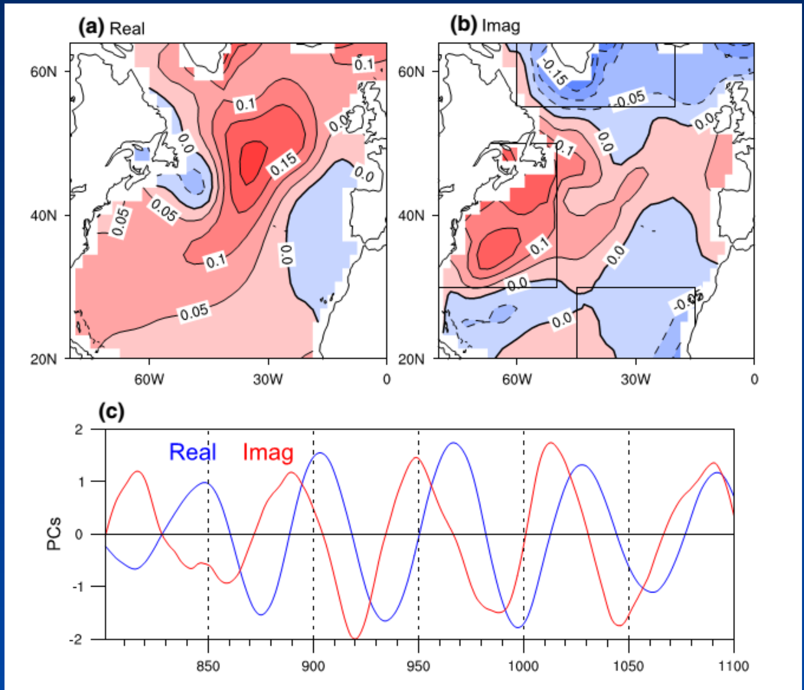


Significant quasi-60 yr cycle is reasonably well simulated

(Sun, Li, & Jin, 2015, *Clim Dyn*)

Dominant patterns of SST multidecadal variability

Principle oscillation pattern (POP) analysis:



AMO and North Atlantic Tripole (NAT)

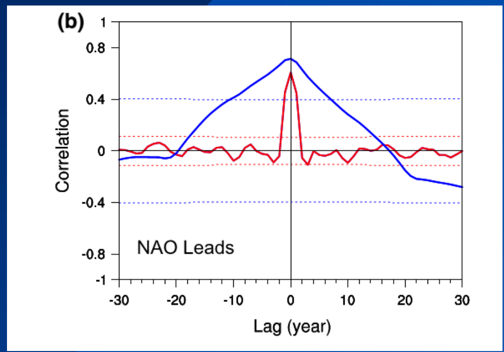
The oscillatory sequence of POPs

+NAT → + AMO → -NAT

(Sun, Li, & Jin, 2015, *Clim Dyn*)

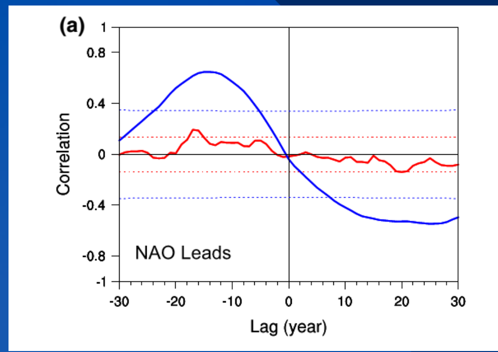
NAO vs. AMO and NAT

NAO vs. NAT



NAT is in phase with NAO

NAO vs. AMO



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

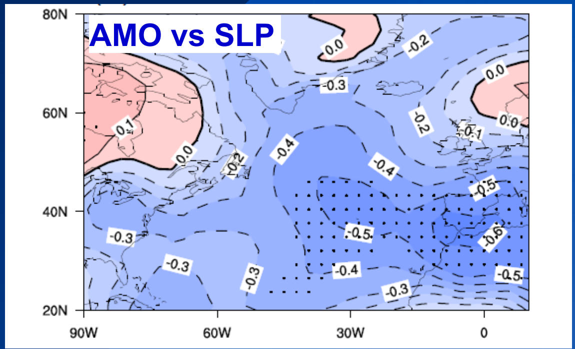
Hypothesize three possible mechanisms involved in the quasi-60-yr cycle

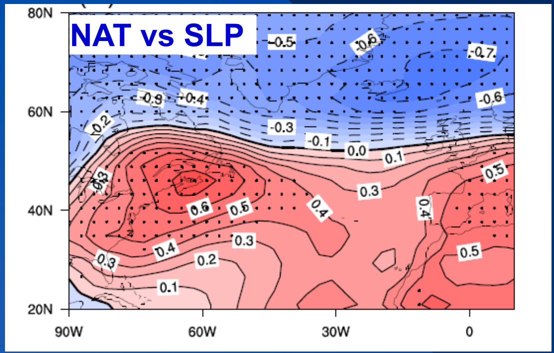
1. NAT has a direct effect on the NAO；
2. NAO exerts some wind stress forcing on the AMO；
3. AMO in turn provides some negative feedback on NAT.

(Sun, Li, & Jin, 2015, *Clim Dyn*)

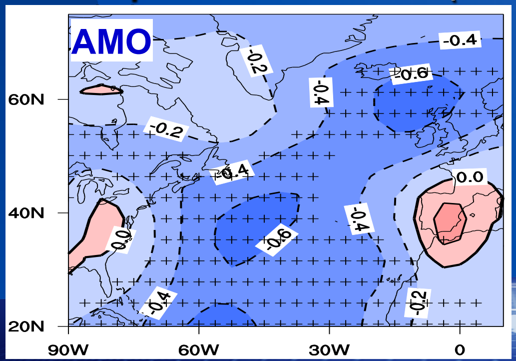
1. Direct effect of NAT on NAO

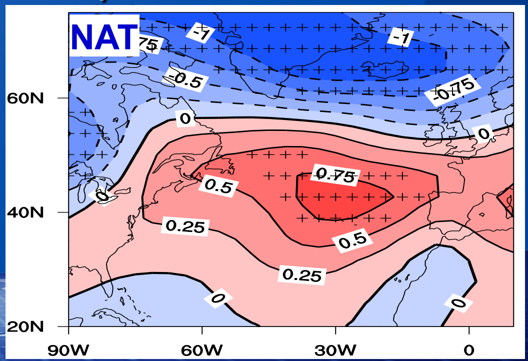
Atmospheric (SLP) responses to the AMO and NAT in CCSM4





SLP response in an AGCM (SPEEDY model) to

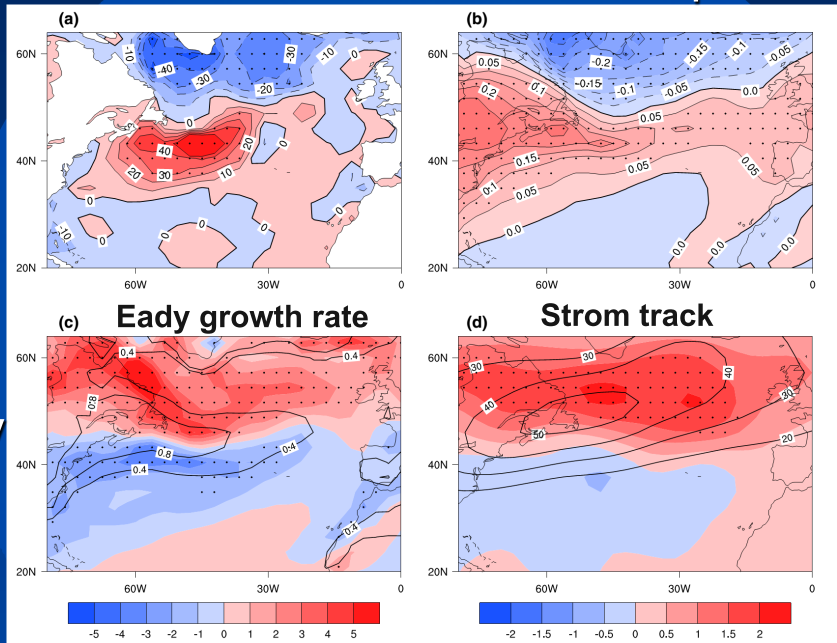




Physical processes for +NAT ➔ +NAO

upward surface heat flux anomalies

850hPa air temperature



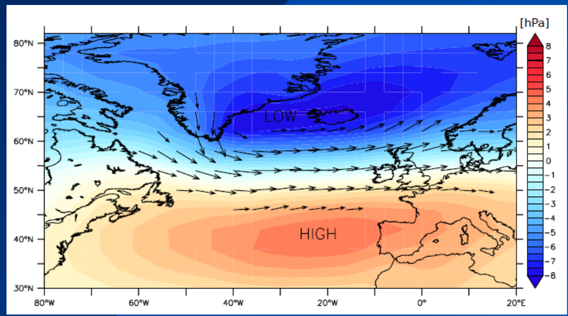
atmosphere acts to damp the SST anomalies

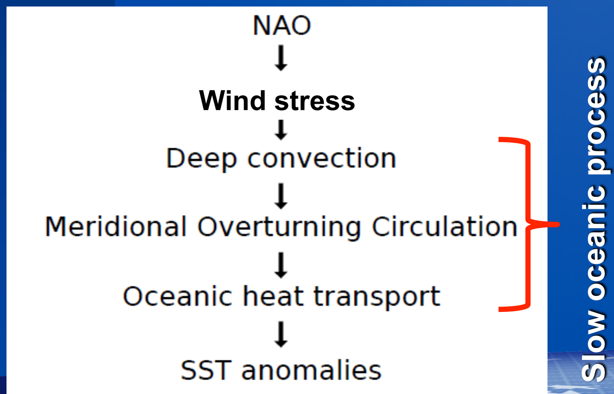
baroclinicity

increase storm track intensity and shift northward

NAT contributes to the increase of the storm track intensity and shifts the storm track northward, leading to a positive NAO phase.

2. NAO forcing on the AMO, +NAO → +AMO

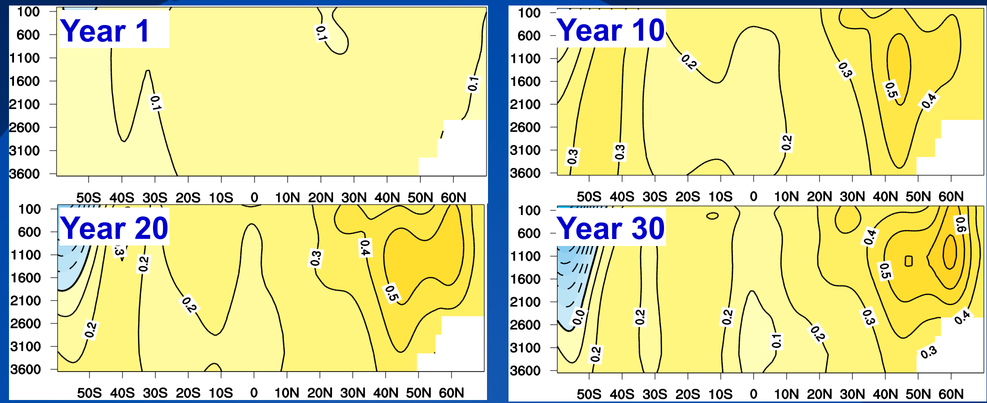




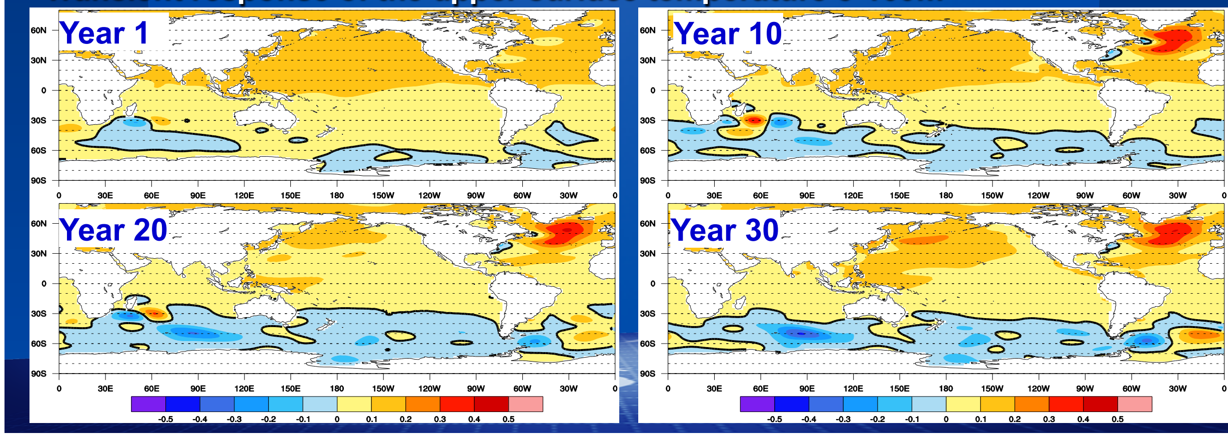
There is substantial modeling evidence that NAO-related wind stress anomaly can lead to multidecadal variations of the AMOC, which in turn produce the SST pattern of the AMO (Visbeck et al., 1998; Delworth and Greatbatch, 2000; Eden and Jung, 2001; Latif et al. 2006).

AMOC response to NAO in the MOM5 model

Transient response of the AMOC

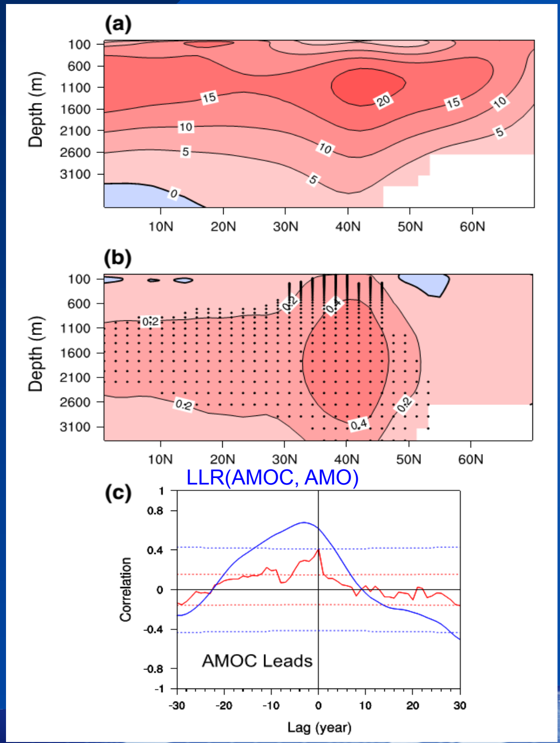


Transient response of the upper surface temperature 5-100m



NAO ➔ AMO

CCSM4 simulation



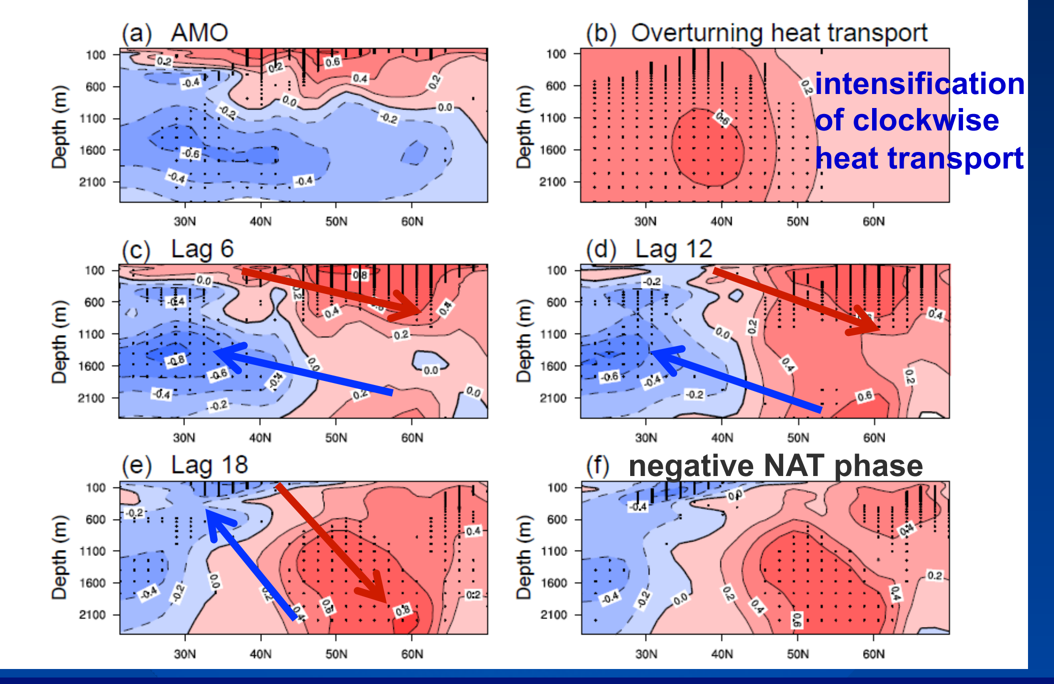
Simulated long-term mean AMOC

NAO leads the AMOC by 15 years
+NAO ➔ AMOC strengthening
-NAO ➔ AMOC weakening

AMOC in phase the AMO

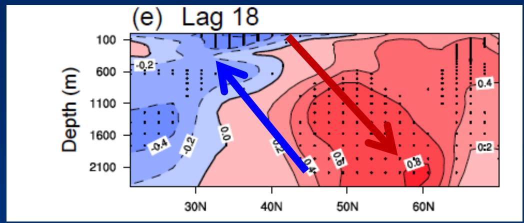
(Sun, Li, & Jin, 2015, *Clim Dyn*)

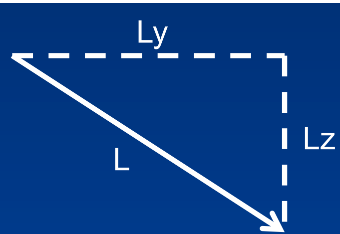
3. Negative feedback of AMO on NAT, +AMO → -NAT



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.

Theoretical explanation for the time delay





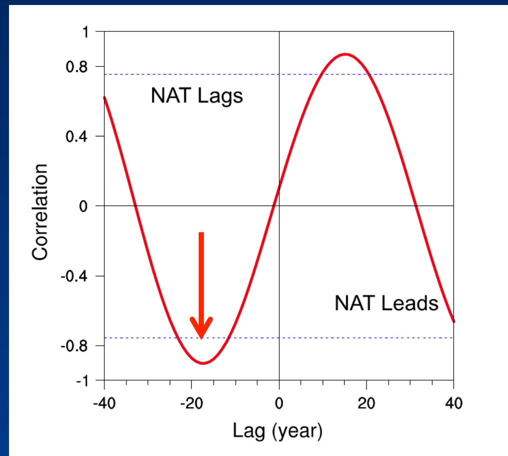
Time it takes for transport along the OHT pathway $\frac{L}{V}$

$$\frac{L}{V} \approx \frac{L_y}{V_y} \approx \frac{L_z}{V_z}$$

$$Vy = \frac{\Psi}{W \cdot D}$$

$$\frac{L_y \cdot W \cdot D}{\Psi}$$

The theoretical time delay is ~16 years.

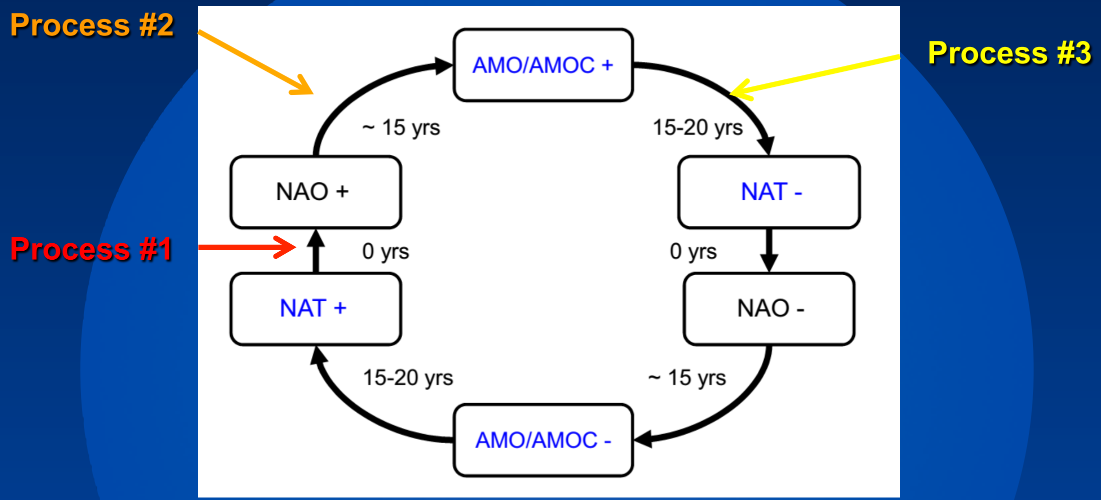


Very close to the time lag of the NAT relative to the AMO

The advection plays a key role in the SST evolution from positive AMO to negative NAT.

(Sun, Li, & Jin, 2015, *Clim Dyn*)

Summary of the mechanisms



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.

(Sun, Li, & Jin, 2015, *Clim Dyn*)

A delayed oscillator model for NAO multidecadal variability

Normal mode analysis

Frequency:
Growth rate:

$$\sigma_R = -\frac{1}{\beta C} - \frac{\alpha}{C} e^{-\sigma_R \tau} \cos(\sigma_I \tau),$$

$$\sigma_I = \frac{\alpha}{C} e^{-\sigma_R \tau} \sin(\sigma_I \tau).$$

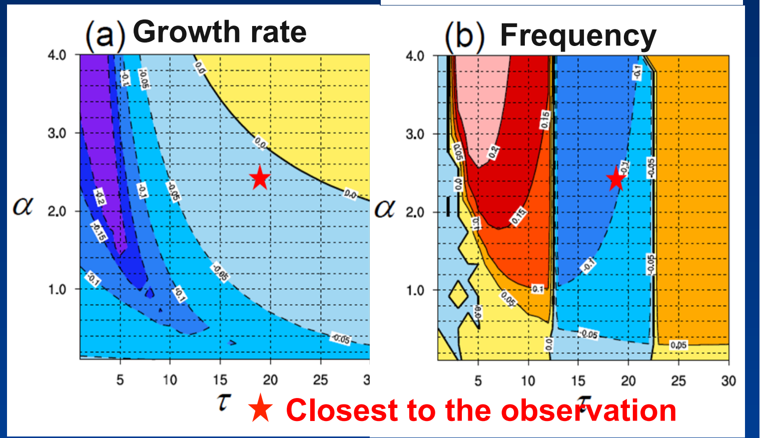
$$\mathrm{NAO}(t) \approx \mathrm{NAT}(t),$$

$$C\frac{d\mathrm{AMO}}{dt} = \alpha \mathrm{NAO} - \frac{\mathrm{AMO}}{\beta},$$

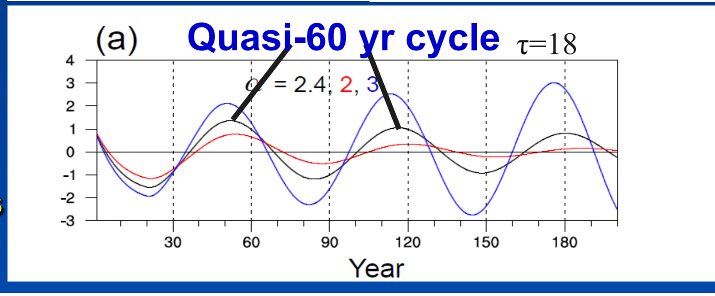
$$-\mathrm{NAT}(t+\tau) \approx \mathrm{AMO}(t),$$

$$\frac{d\mathrm{NAT}(t)}{dt} = -\frac{\alpha}{C}\mathrm{NAT}(t-\tau) - \frac{\mathrm{NAT}(t)}{\beta C},$$

$$\mathrm{NAO}(t) \approx \mathrm{NAT}(t).$$



Numerical solutions

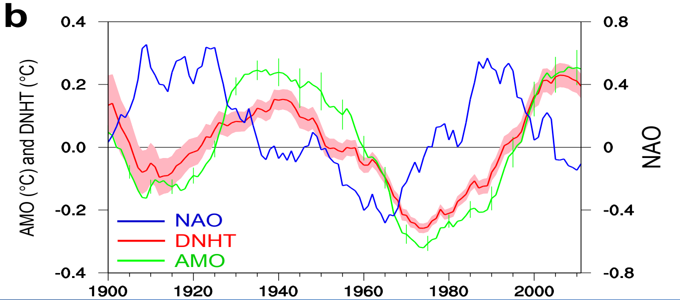


NAO implicated as a predictor of Northern Hemisphere mean temperature multidecadal variability

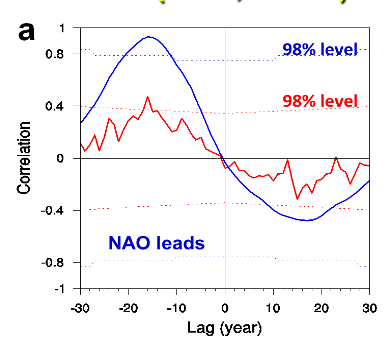
Jianping Li,[1] Cheng Sun,[1] and Fei-Fei Jin[2]

(Li, Sun, and Jin, 2013, *GRL*)

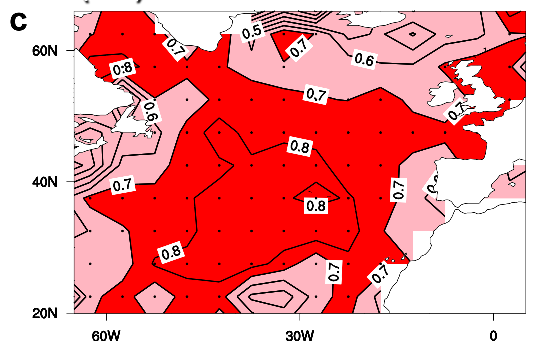
The above multidecadal dynamical theory can explain the observational fact that the NAO leads the DNHT (detrended NHT) by 1-2 decades



LLR (NAO, DNHT)



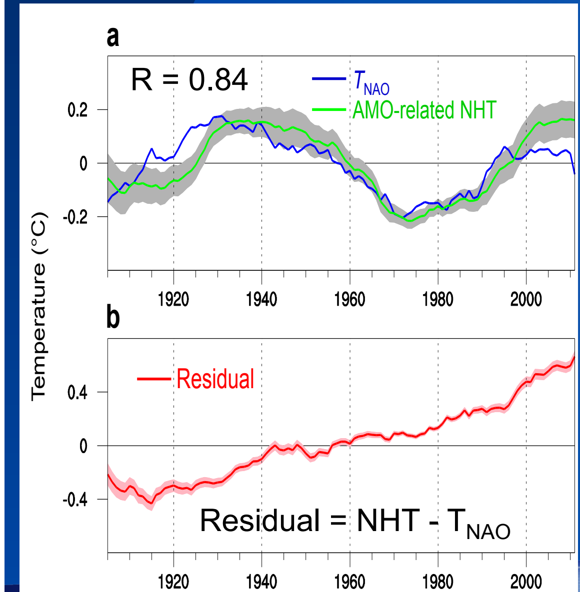
NAO (-16) vs. SST



The maximum correlation coefficients occur at a lag of 16 years (NAO leading DNHT)
Red: unfiltered data
Blue: 11-yr running means

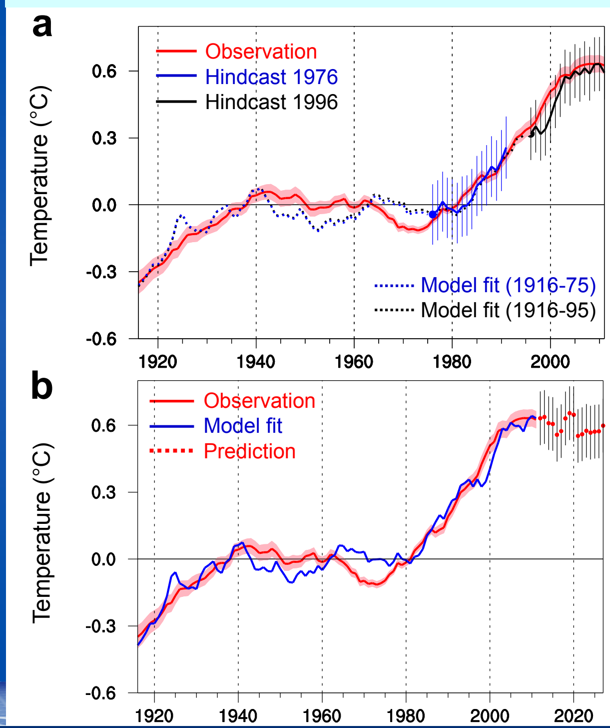
Modeling DNHT using NAO signal

$$C\frac{dT_{NAO}}{dt} = \alpha \mathrm{NAO} - \frac{T_{NAO}}{\beta}$$



NAO-based Prediction model

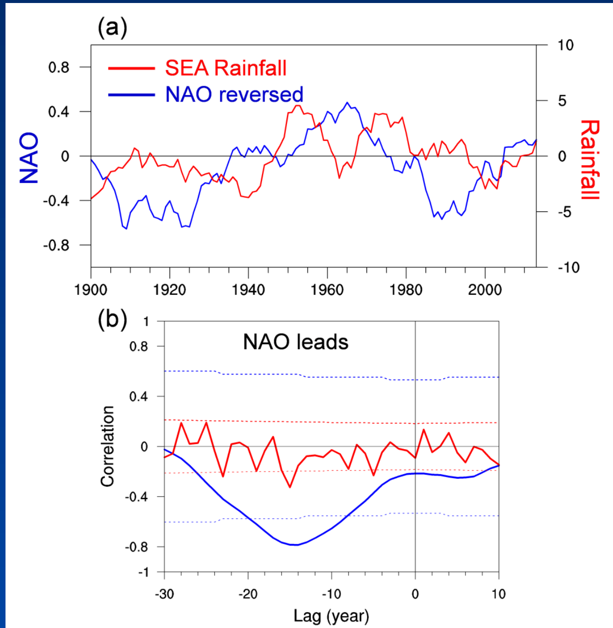
$$\mathrm{NHT}(t) = a\mathrm{NAO}(t-16) + bt + c$$

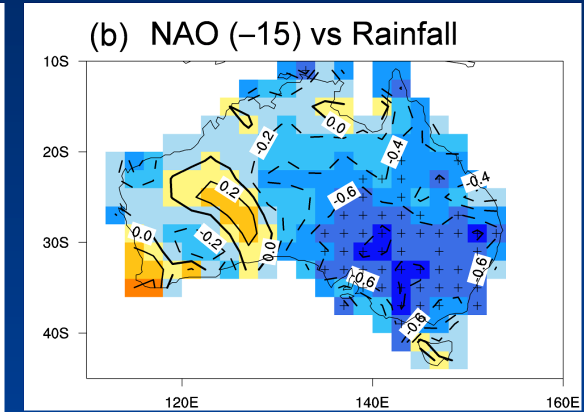


The prediction shows NHT will fall slightly over the next decade (2012-2027).

A Decadal-Scale Teleconnection between the North Atlantic Oscillation and Subtropical Eastern Australian Rainfall

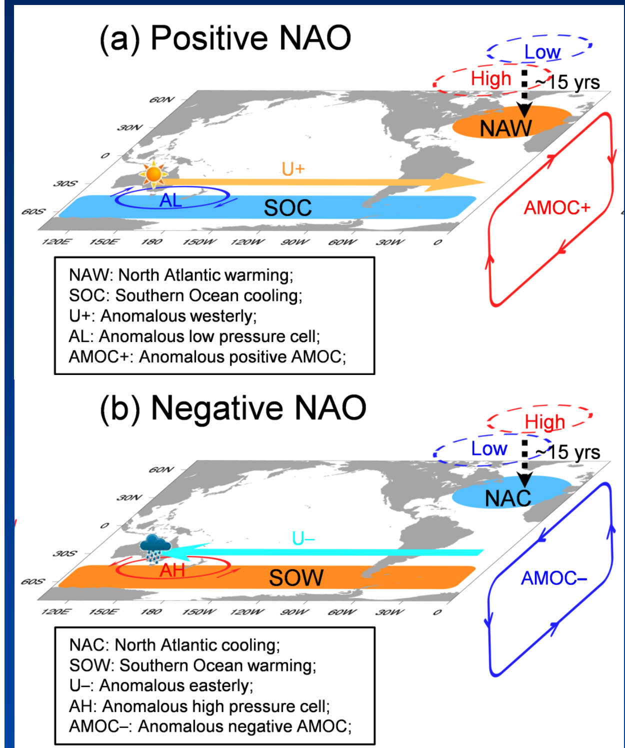
(Sun, Li, Feng and Xie, 2015, *JC*)



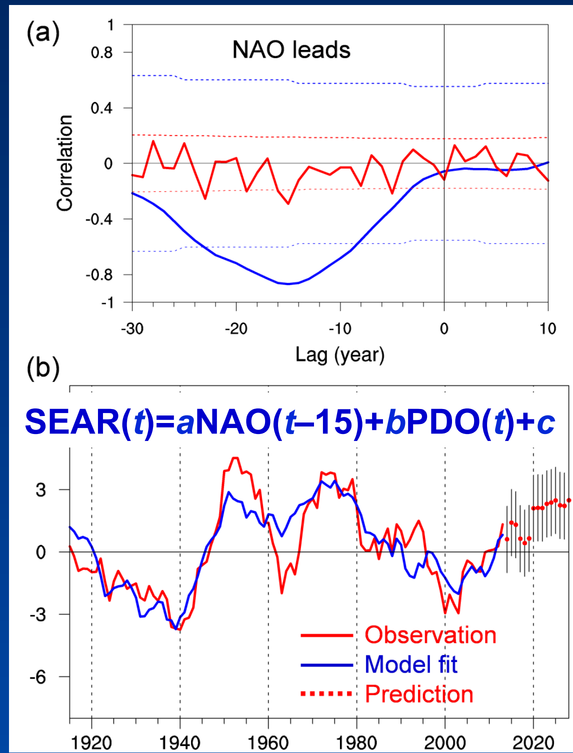


Based on observations, SEAR is connected with NAO, with NAO leading by ~15 years.

Mechanisms



Predictions



(Sun, Li, Feng and Xie, 2015, *JC*)

Conclusions

- A coupled decadal-scale air-sea interaction theory: the NAT-NAO-AMOC-AMO coupled mode

A delayed decadal oscillator model

- The coupled decadal mode leads to DNHT multidecadal variability and an accelerator/decelerator of NHT multidecadal warming/cooling, and may be an important factor of hiatus.
- The coupled decadal mode also exerts an influence on SH climate, esp. the Australian rainfall variations.

感谢聆听

Thank you！