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

Cheng Sun1, Jianping Li1 and Fei-Fei Jin2

1. College of Global Change and Earth System Science, Beijing Normal University, Beijing 100875, China
2. Department of Atmospheric Science, University of Hawaii-Manoa, Honolulu, USA

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

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 NAO index.

3. Modes of SST multidecadal Variability

Two modes of SST multidecadal variability revealed by the POP method

AMO NAT

NAO vs. NAT

The maximum correlation coefficients occur at a lag of 16 years (NAO leading DNHT) by 1-2 decades

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

4. Three key physical processes

#1 Direct effect of NAT on NAO

Atmospheric (SLP) responses to the AMO and NAT in the Ocean. The maximum correlation coefficients occur at a lag of 16 years (NAO leading DNHT) by 1-2 decades

#2 NAO forcing of AMO/AMOC

Lagged regression of the annual mean AMO/AMOC time series with respect to the normalized NAO index. The lagged coefficient is positive at 15 years, negative at 20 years, and significant at 25 years

#3 Negative feedback of AMO on NAT

The negatve NAO phase coincides with the AMO negative phase in the atmosphere, and the cycle proceeds, but in the opposite sense. Blue (black) text indicates oceanic (atmospheric) phenomena.

5. 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 increased AMOC continues to affect the heat transport and due to slow ocean adjustment, the North Atlantic Ocean shows a delayed response (about 18 years) to the preceding enhanced AMOC with an SST pattern that resembles the NAO negative phase. The NAO negative phase coincides with the AMO negative phase in the atmosphere, and thus the cycle proceeds, but in the opposite sense. Blue (black) text indicates oceanic (atmospheric) phenomena.

Selected publications:

Email: jianping.li@bnu.edu.cn
Cheng Sun: ncerg@bnu.edu.cn

6. NAO implicated as a predictor of NHT

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

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

7. NAO and Eastern Australian Rainfall

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

(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.