Breakdown of The Link Between Arctic and North Atlantic Oscillations in a Warm Climate

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1 ABSTRACT

The North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO) are climate variability modes significantly affecting temperature and precipitation variability in the mid-latitudes. In this study, we use both reanalysis data and model historical and warmer climate simulations to show that the relation between the two oscillations may change in a different climate. In the current climate, these two climate modes are highly correlated, as both are strongly influenced by downward propagation of stratospheric anomalies into the troposphere. When considering a warmer climate scenario (RCP8.5 in the 23rd century), the correlation between NAO and AO drops significantly, revealing that they become two separate modes of variability. Surface Eurasian and Aleutian pressure anomalies precede polar vortex anomalies, and the typically anticipated NAO does not follow afterwards. The analysis suggests that the changes can be related to the strong reduction of land-sea thermal contrast in the Atlantic sector compared to that of the Pacific sector, associated with the limited temperature increase in the North Atlantic (known as the Atlantic warming hole), which is accompanied by limited Atlantic storm variability, and a more intense Pacific storm track.

2 DATA & METHOD

- **Observation data:** NOAA-CFSR reanalysis
  - **Observations period**:1979-2018.
- **Model data:** 5 models are obtained from the Coupled Models Intercomparison Project (CMIP5):
  1- MPI-ESM-LR. 2- CCSM4. 3- CNRM.
  4- HadGEM. 5- IPSL. 6- GISS.
  - **Historical period**: 1901-2000.
  - **RCP8.5 period**: 2201-2300.

Definitions:
Arctic Oscillation (AO): the first Empirical Orthogonal Function (EOF1) of sea level pressure for the hemisphere 20˚N-90˚N.
North Atlantic Oscillation (NAO): the first EOF of sea level pressure for (90 ˚W-40 ˚E, 20 ˚N-80 ˚N).
Weak Polar Vortex (WPV): when the principle component (PC) of the 90 days low-pass filtered 10 hPa geopotential height is equal to or less than 1.5. Composites of weak polar vortex are based on calculating EOF1 of geopotential height for each pressure level independently for 90-day low-pass filtered November-April data.

For land-sea contrast experiment, **SPEEDY AGCM** is used, which is an intermediate complexity model (Molteni & Kucharski).

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3 DECOUPLING OF ARCTIC OSCILLATION AND NORTH ATLANTIC OSCILLATION

➢ **Current climate:**
- AO is composed of Pacific, Arctic and Atlantic centers of action. (Fig1.a)
- AO and NAO are highly correlated (correlation coefficient≈0.9).

➢ **Warm climate (RCP8.5):**
- AO is composed only of Pacific and Arctic centers of action. The Atlantic center of action weakens/disappears. (Fig1.b)
- AO and NAO are decoupled.
- AO/NAO correlations drops significantly as shown in Fig2.
- NAO does not change significantly between current and warm climate.
- We notice that the Pacific warms up much faster than the Atlantic.

In a nutshell:
AO and NAO are currently the same oscillation, since the mutual forcing for both oscillations is the stratosphere. Therefore, both oscillations occur simultaneously.

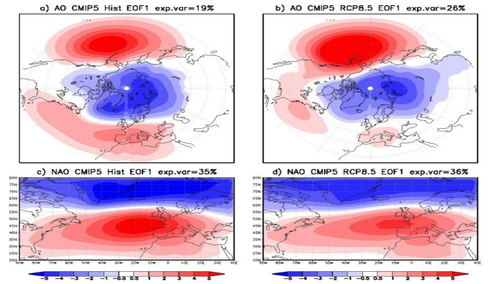


Fig1: Multi-model average of the 1st EOF mode for winter time (DJF) sea level pressure (hPa/σ)

4 LAND-SEA THERMAL CONTRAST

➢ The Pacific warms up faster than the Atlantic in warm climate. We force SPEEDY model by a warming in the Pacific (Pac_P), with respect to control simulation of the current climate (CTL). Fig.

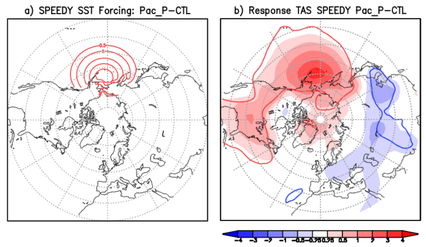
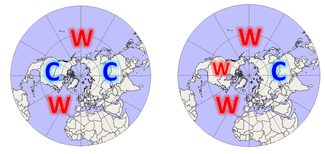


Fig.3: a) Forcing SST in the Pacific by +4 C. b) Near

➢ This forcing strengthens baroclinicity of the Pacific, and weakens it in the Atlantic, due to the warm air advected to North America.
➢ Storm activity is favored in the Pacific more than in the Atlantic.



Current Climate Warm Climate

5 STRATOSPHERIC POLAR VORTEX ROLE

➢ **Current climate:**
- Weak Polar Vortex starts in the stratosphere and propagates to the surface to initiate a negative AO within 2-3 weeks. (Fig3.a,b)

➢ **Warm climate (RCP8.5):**
- Weak Polar Vortex does not start at the stratosphere.
- Negative AO event starts on the surface and propagates towards the stratosphere initiating a weak polar vortex event within 2-3 weeks.
- The signal that starts from the surface corresponds to a Aleutian low pressure over the Pacific, and a Eurasian high pressure anomalies.
- NAO events does not necessarily follow polar vortex anomalies.

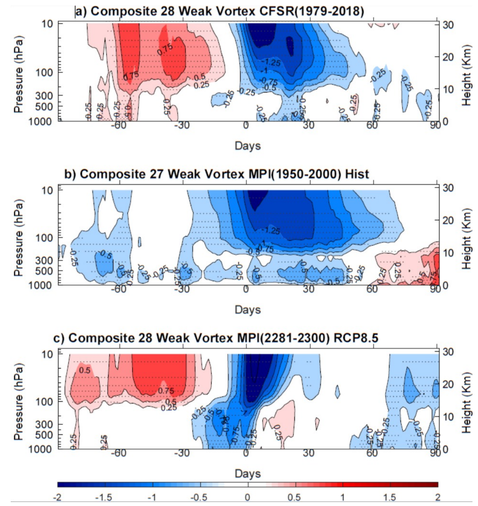


Fig 3: Time-height development of weak polar vortex (WPV) events of a) NOAA-CFSR reanalysis, b) Historical, c) RCP8.5.

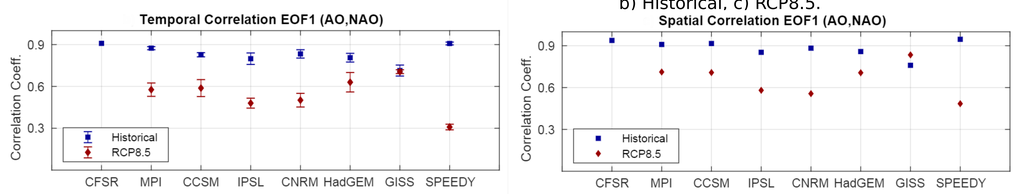


Fig 4: Temporal and Spatial correlation between AO and NAO of mean sea level pressure PC time series for Hist and RCP8.5.

6 CONCLUSION

- The AO and NAO are currently highly correlated due to the forcing of the stratospheric polar vortex.
- In a warm climate, AO and NAO become two different mode of variability.
- Land-sea thermal contrast controls the variability in the Pacific and the Atlantic.
- Storm variability in the current climate is equally distributed between the Pacific and the Atlantic sectors.
- In a warm climate, more storm activity is found in the Pacific due to the sharp temperature gradient with Asia in winter.
- Stratospheric Polar Vortex forces AO and NAO phases on the surface, in the current climate.
- While in warm climate, surface anomalies precede stratospheric polar vortex anomalies.