A Potential Method to Evaluate the Relative Contribution of Arctic Sea Ice Loss to Mid-Latitude Climate in CESM Large Ensemble Project

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Background

Midlatitude weather is known to be influenced by the tropics, but there is increasing evidence that it is also affected by Arctic amplification, including melting Arctic sea ice and increasing snow cover. Due to the short time period of Arctic amplification, high atmospheric internal variability, and conflicting model results, it is difficult to determine the impacts of Arctic sea ice and snow cover on the atmosphere using observational data. **To address these limitations, we explore the potential of a statistical method, GEFA, to reveal the impacts of Arctic sea ice and snow cover on the atmosphere.**

Motivation

- Both Cohen (2016) and Lee et al. (2015) show that changing Arctic surface conditions affect midlatitude weather in the Arctic amplification period (1989 – 2015).
- A multivariate statistical method, Generalized Equilibrium Feedback Assessment (GEFA), can extract the impact of slowly-evolving environmental variables, such as sea surface temperature, on the rapidly-responding atmosphere (Liu et al. 2008; Wang et al. 2013, 2014). By decomposing different oceanic or terrestrial forcings, GEFA can extract the influence of individual oceanic regions on the atmosphere.
- As required for GEFA, the forcings of Arctic sea ice and snow cover used here possess long memory (Fig. 1).

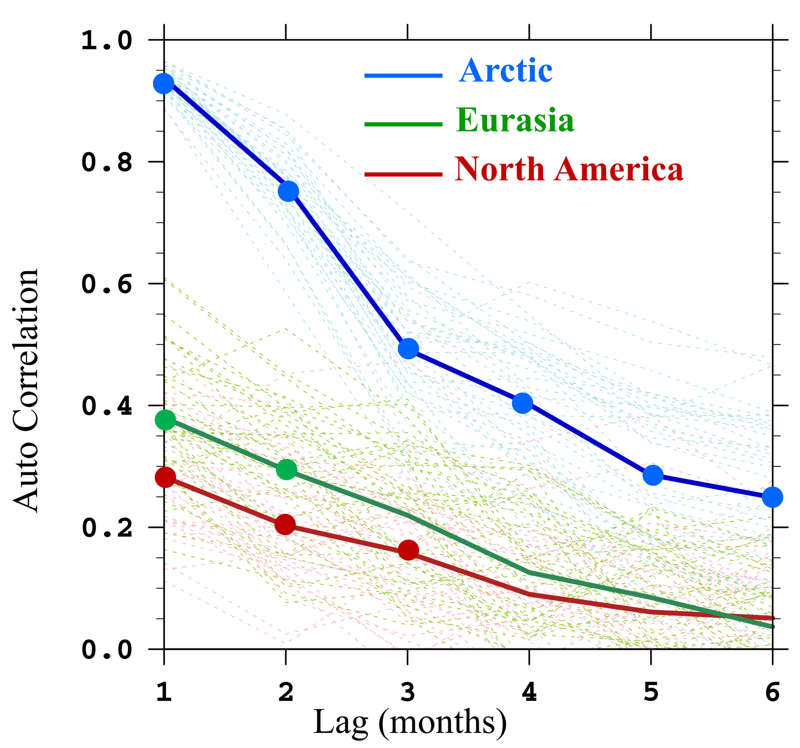

Fig. 1. Monthly lagged correlations of total Arctic sea ice area (blue), area averaged snow cover fraction over Eurasia (green), and North America (red) for September during 1920 – 2000 in CESMLENS. Thin dash lines represent each ensemble member. Thick solid lines indicate ensemble mean. Filled dots indicate the correlation coefficient is significant at confidence level 90%.

Data

CESMLENS:
National Center for Atmospheric Research (NCAR) Community Earth System Model (CESM) Large Ensemble Community Project (LENS)

Time period: Historical: 1920 – 2005, RCP8.5: 2006 – 2100

Ensemble member used: 40

Variables analyzed: sea ice fraction (aice), sea surface temperature (SST), snow cover fraction (FSNO), 850hPa geopotential height (Z850)

Method

Stochastic climate theory: *(Hasselmann 1976; Frankignoul and Hasselmann 1977)*
The coupled climate system, based on time scale, can be divided into a rapidly varying "weather" system (e.g. atmosphere) and a slowly responding "climate" system [e.g. sea surface temperature, sea ice fraction, snow cover fraction, etc.].

GEFA method: *(Liu et al. 2008; Liu and Wen 2008)*
Based on stochastic climate theory, and since the memory of atmosphere (≈ 1 week) is shorter than that of SST, sea ice area and snow cover fraction, the response of an atmospheric variable at time t A(t), to a slowly-evolving variable O(t), can be deduced as the feedback matrix B:

$$B = \frac{\langle A(t), O(t-\tau)^T \rangle}{\langle O(t), O(t-\tau)^T \rangle}$$

Where τ is the time lag, and here $\tau = 1$. $< a, b >$ represents the covariance between a and b. Superscript "T" indicates a transpose.

Forcings: *(Wen et al. 2010; Wang et al. 2013)*

SST: Principal component (PC) of the first EOF SST mode from tropical Pacific (TP1), tropical Indian (TI1), tropical Atlantic (TA1), N. Pacific (NP1), and N. Atlantic (NA1).

Sea ice: Time series of area-averaged sea ice area over Arctic (80°N – 90°N, 180°W – 180°E), Chukchi-Beaufort Sea (CB, 65°N – 80°N, 120°W – 170°E), and Barents-Kara Sea (BK, 65°N – 80°N, 10°E – 100°E).

Snow: Time series of area-averaged snow cover fraction over Eurasia (30°N – 80°N, 0°E – 180°E) and North America (30°N – 80°N, 50°W – 160°W).

Forcing set 1: [TP1 TI1 TA1 NP1 NA1 Arctic CB BK Eurasia NAmerica]
Forcing set 2: [TP1 TI1 TA1 NP1 NA1]
Forcing set 3: [Arctic CB BK Eurasia NAmerica]

Explained variance (linear part): *(Wonnacott and Wonnacott 1972)*
The percent variance in a select response variable, as explained by ocean, sea ice, or snow forcing, is calculated similarly to the Analysis of Variance (ANOVA) approach in multiple linear regression. The explained variance of each forcing set is calculated by the square of the correlation between A(t) and B × O(t).

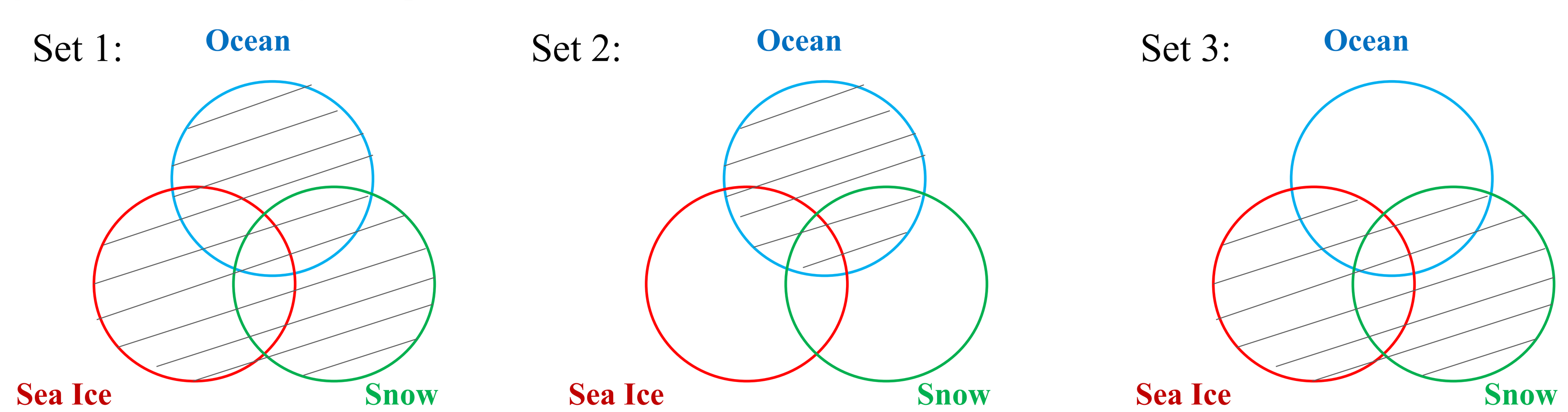

Fig. 2. Schematic diagram of the atmospheric variability explained by each forcing set (hatching means the atmospheric variability explained by ocean, sea ice, or snow). The difference of explained variance between Set 1 and Set 2 is the part of atmospheric variability explained by sea ice and snow together, and the difference between Set 1 and Set 3 is the part explained by the ocean alone.

Next Steps

- ❑ Systematic GEFA analysis will be done to other atmospheric variables and index to understand how arctic sea ice and land snow cover change affect the atmosphere in CESMLENS.
- ❑ The length of data record needed to get stable GEFA results will be examined using CESMLENS.
- ❑ Will apply this method to observational data if available observational data record is long enough.
- ❑ Check the impacts of Arctic sea ice and land snow cover on the atmosphere using different climate models and dynamic experiments to understand the conflictions among previous modeling studies.

Preliminary Results

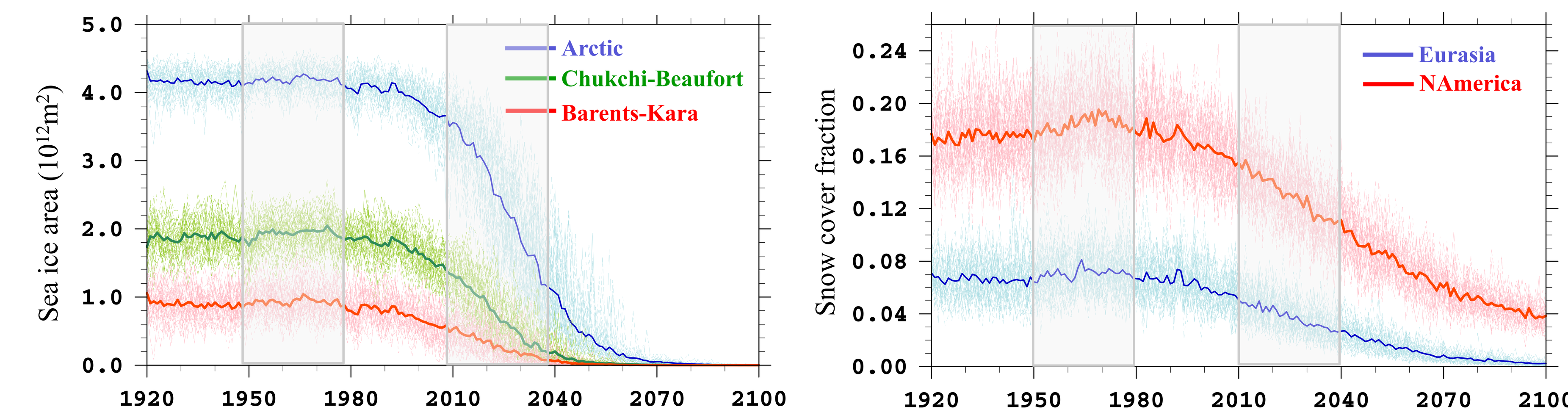

Fig. 3. Time series of September (a) sea ice area averaged over Arctic (blue), Chukchi-Beaufort Sea (green), and Barents-Kara Sea (red) and (b) snow cover fraction over Eurasia (blue) and North America (red) in CESMLENS during 1920 – 2100. Thin lines represent each ensemble member, and thick lines represent ensemble mean. Gray boxes indicate the two time period discussed below.

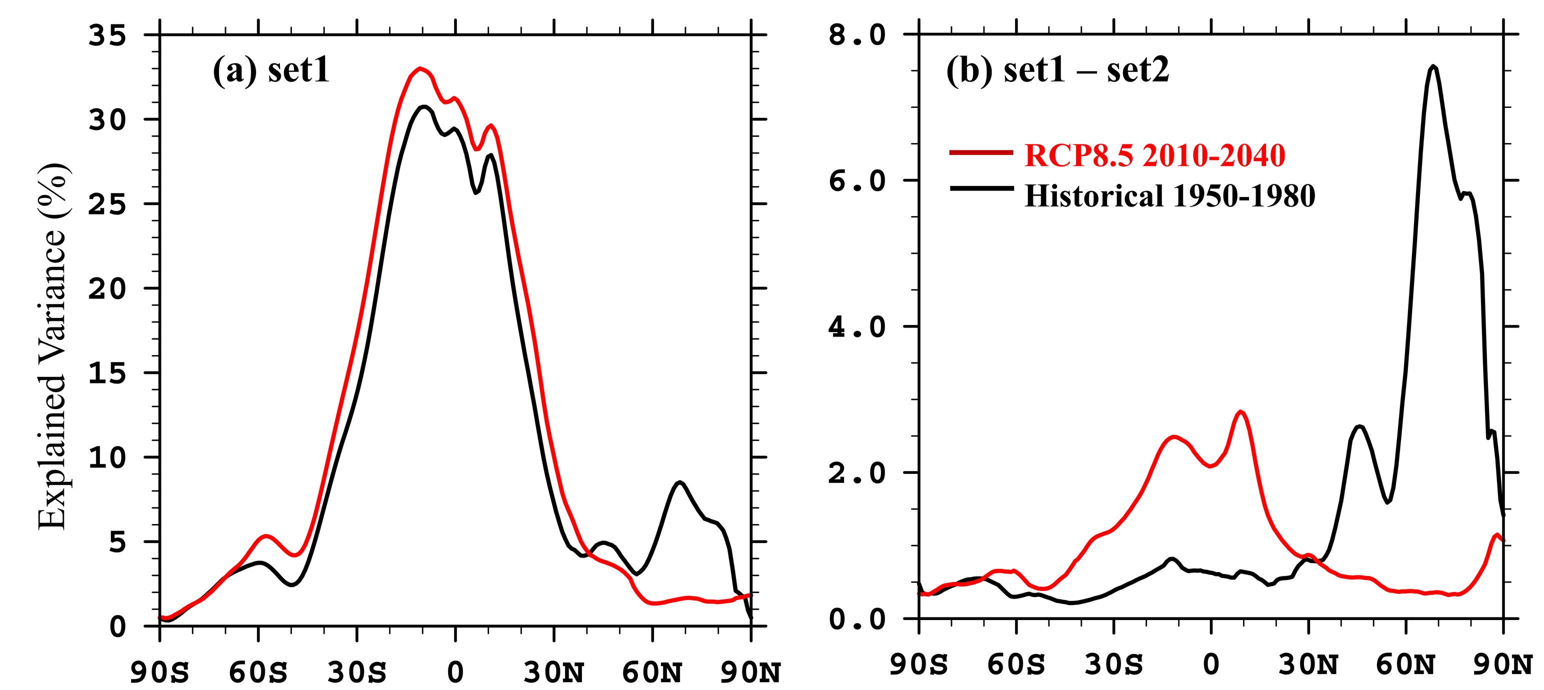

Fig. 4. Zonal mean percentage of total variability of September 850hPa geopotential height explained by (a) ocean, sea ice, and snow cover combined and (b) sea ice and snow cover combined during 1950 – 1980 (black) and 2010 – 2040 (red).

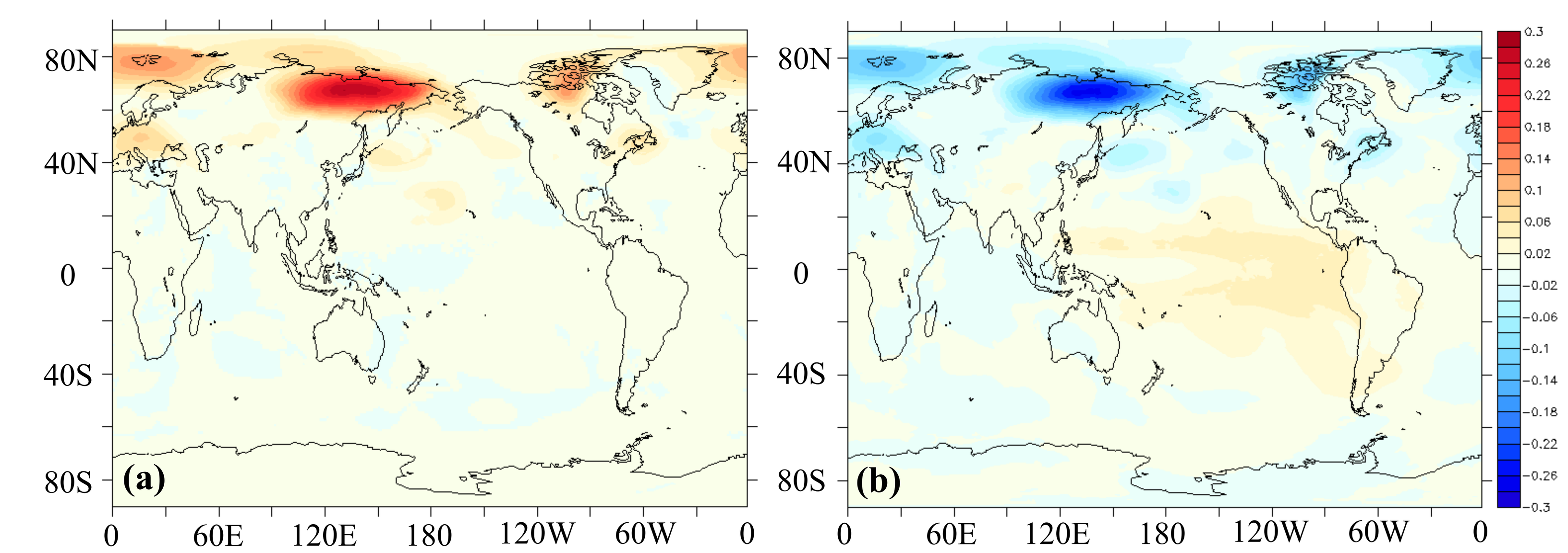

Fig. 5. (a) The atmospheric variability explained by sea ice and snow cover in historical. (b) The change of sea ice and snow cover explained variance between period 2010 – 2040 and 1950 – 1980.

Conclusions

- ➢ The total variance (linear part) can be explained by ocean, sea ice, and snow together is small compared with atmospheric internal variability, which is small at tropics and large at mid-high latitudes.
- ➢ In the tropics, global SST accounts for most of the explained variability, while at mid- and high-latitudes, sea ice and snow cover explain the most.
- ➢ Statistical GEFA can be used as a tool to study the relative contribution of ocean, Arctic sea ice, and snow cover to the atmospheric variability.
- ➢ The impacts of Arctic sea ice and land snow cover on the atmosphere in September is changing. Compared with the historical time period, sea ice and snow cover have more impact on low latitudes atmosphere rather than on high latitude.