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Formation of Arctic summer circulation patterns : the role of synoptic cyclones under different phase of ENSO evolution

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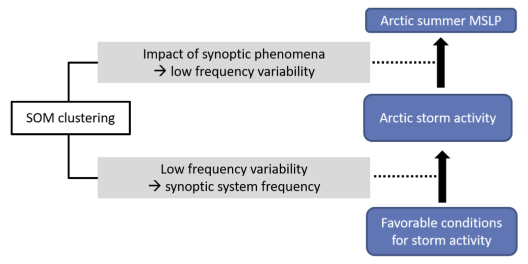
1. Introduction

- Low-frequency atmospheric circulation modes in the Arctic have attracted much attention owing to their role as controlling factors in the spatiotemporal sea-ice variability. Among the different seasons, the summer circulation pattern has received research focus because of its temporal proximity to the September sea-ice minimum.
- The summer season is known to be the most synoptically active in the Arctic Ocean with the large variability of baroclinic frontal zone along the land-ocean boundary. As a result, summer in the Arctic Ocean is stormier than the winter, which manifests as local cyclogenesis, as well as migratory mid-latitude cyclones.
- Therefore, Arctic cyclones and their role in controlling sea-ice have been critical topics in understanding the Arctic summer.
- From a scale interaction perspective, the Arctic is a singular region, where the zonal scales from synoptic to planetary merge, due to the reduced length of latitudinal circles. So, if a strong synoptic system persists or frequently passes near the pole, it can directly contribute to a low-frequency circulation pattern



- In this study, we want to show

1) the impact of storm as the synoptic event which make up the seasonal averaged circulation in Arctic

2) the possible low-frequency teleconnection that can be a favorable condition for the storm activity.

2. Data & Method

a. Data

- Daily MSLP, skin T, U, V, T, q, RV from ERA-Interim reanalysis
- NOAA Extended Reconstructed SST (ERSST) version 4
- NOAA NCDC Snow cover extent
- Period : boreal summer (JJA) for 1979-2017
- Domain : 60°N- 90°N

b. Method

- SOM clustering method
  - one of clustering method which is originated from the neural networks
    - i) classify the data into a specified number of pattern
    - ii) relocate the resultant patterns according to the similarity between the patterns
  - more accurate and linearly independent than the patterns from other clustering & empirical orthogonal function (EOF) method
- Cyclone tracking and gridding method
  - Detection
    - i) A local $RV850_{max}$ (> 2.0×10^{-5} s^{-1}) in each 11×11 grid window.
    - ii) The closest local $MSLP_{min}$ within a 400 km radius of the local $RV850_{max}$.
    - iii) MSLP which increases by at least 15 Pa in all directions within a 500 km distance from the local $MSLP_{min}$
    - iv)The equatorward limit of detection : 30°N for Northern Hemisphere extratropical storms.
  - Tracking
    - i) For a given storm, a circular tracking boundary with a 750 km radius is set at each 6-hourly time step, and the location of the storm at that time step is set as the center of the circle. Then, the storm centers at the next time step are examined within the boundary.
    - ii) If one storm center is found within the boundary, it is determined as the next storm position. In case of multiple storm centers, priority is given to the closest storm center located in the front half of the circle, towards the direction of the storm's movement. If there is no such storm center at the front half of the circle, the closest one is selected as the next position. If no storm appears within the boundary, the tracking of that given storm stops.
    - iii) Finally, only storms with lifetimes equal to or greater than 1days are considered.
  - Gridding

    Cyclone tracks is transformed into grid-cell counts. Due to singularity near the pole, we constructed equidistant grid-cells that were 500 km x 500 km and centered on the pole, rather than the conventional latitude-longitude grid cells.

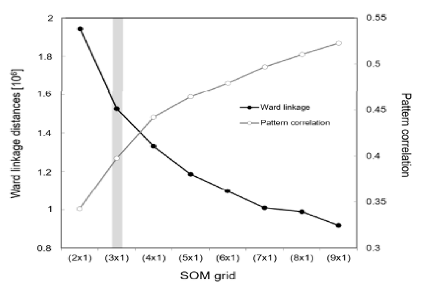
3. Results

a. Determination of optimal SOM number

- The optimal number should be
  - i) large enough to accurately capture the daily pattern
    → large pattern correlation between daily fields & SOM pattern
  - ii) sufficiently small that the clusters are distinctive from each other
    → large distances among each SOM patterns

$$d(r,s)=\sqrt{\frac{2n_r n_s}{(n_r+n_s)}}\|\bar{x}_r-\bar{x}_s\|_2$$

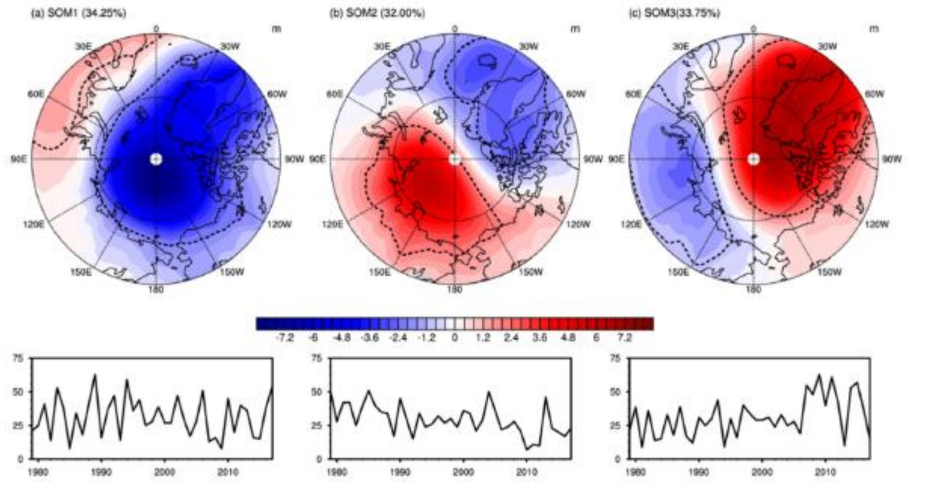
where n_r and n_s are the number of elements in clusters r and s, respectively, and $\bar{x}_r$ and $\bar{x}_s$ are the centroid patterns of clusters r and s, respectively.



- As the number of SOMs exceeds 3, it can be seen that the increasing tendency of pattern correlation and the decreasing tendency of the distance are both slowed down.
- We therefore set an appropriate number of SOM pattern for the MSLP variation over Arctic to a (3x1)

b. Representative modes of Arctic summer MSLP from SOM

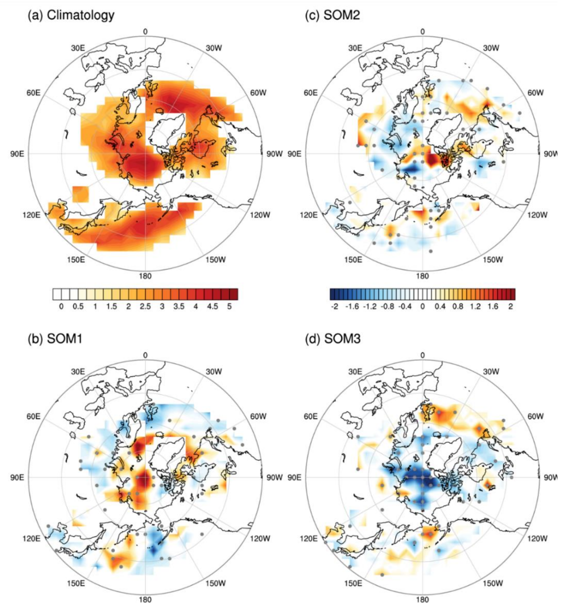
- MSLP SOM pattern & their annual frequency of occurrence (days/JJA)



- SOM1: Positive AO-like pattern, negative MSLP anomaly at Arctic Ocean, Greenland, large interannual variation, slightly low variability & frequency in 2000s
- SOM2: Dipole mode between positive Kara/Laptev Sea/ negative Greenland/Iceland slightly small interannual variation in 1990s, decreasing trend
- SOM3: Negative AO-like pattern, positive in Arctic Ocean near Greenland vs. negative Eurasian, recent shift of frequency after 2007

c. Associated storm activity with each SOM pattern

- Composite of storm frequency



- Correlation (MSLP, storm activity)

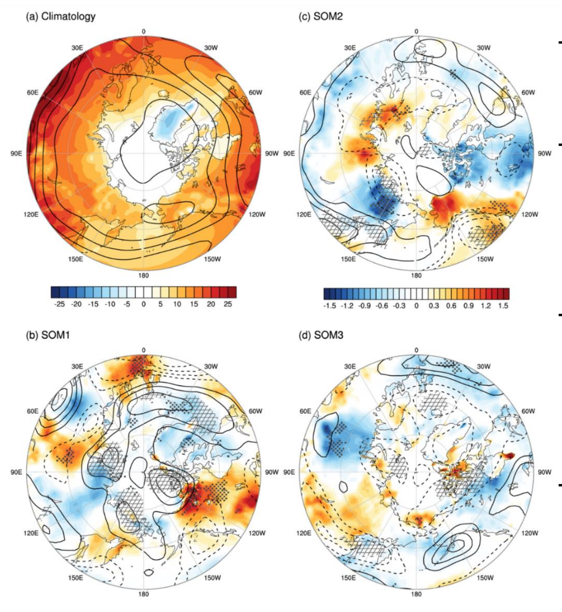
SOM	Activity Cire	Freq.	Dur.	CentP	ACE
1	Positive	-0.23	-0.33	0.6	-0.39
	Negative	-0.6	-0.72	0.87	-0.55
2	Positive	-0.48	-0.58	0.75	-0.42
	Negative	-0.39	-0.42	0.54	-0.48
3	Positive	-0.65	-0.69	0.82	-0.49
	NEgative	-0.15	-0.23	0.47	-0.25

- Most area-averaged MSLPs over core area for each SOM pattern are significantly related to the cyclone activity

- SOM1: increase in Arctic Ocean, more storms from Greenland Sea
- SOM2: increase (decrease) in Canada (along Eurasian coastal line)
- SOM3: decrease (increase) in Arctic Ocean (Norwegian Sea, Bering Sea, Eurasian continent)

d. Baroclinic instability

- Composite difference of U200 (contour) and Skin T (shading)



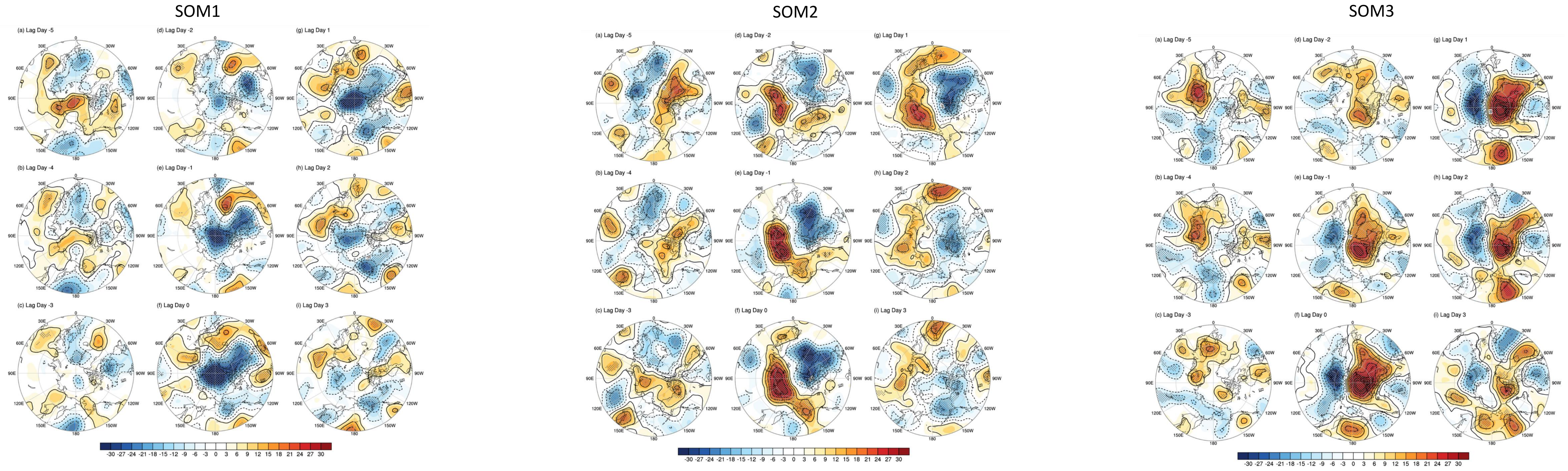
- SOM1: warm coastal line & cold Arctic Ocean → increase in U200 & EGR over Arctic Ocean
- SOM2: relatively warm in Pacific sector and cold in Atlantic sector → increase (decrease) in U200 & EGR over Atlantic (Pacific) sector
- SOM3: warm Arctic ocean & cold Eurasian continent → decrease in U200 & EGR over Arctic Ocean

Area averaged EGR over core area for each SOM show the consistently related to the cyclone activity for the region (figure not shown).

e. Daily evolution of atmospheric fields in SOM event

- Lag composite of Z500 (contour) and U200 (shading) from -5 to 3 days for each SOM events
  - Although all 3588 days had to be classified into one of the SOM patterns, the similarity between the daily anomaly field and the SOM pattern varied from day to day. Therefore, if there are consecutive days with one SOM pattern, the best matching day need to be determined as lag 0 days. We selected the days with the smallest RMSE between daily anomaly and the SOM pattern.
  - Consistent with the composite of storm frequency for each SOM, the low pressure system developed at the high baroclinicity zone and moved to the region of negative core in each SOM pattern.

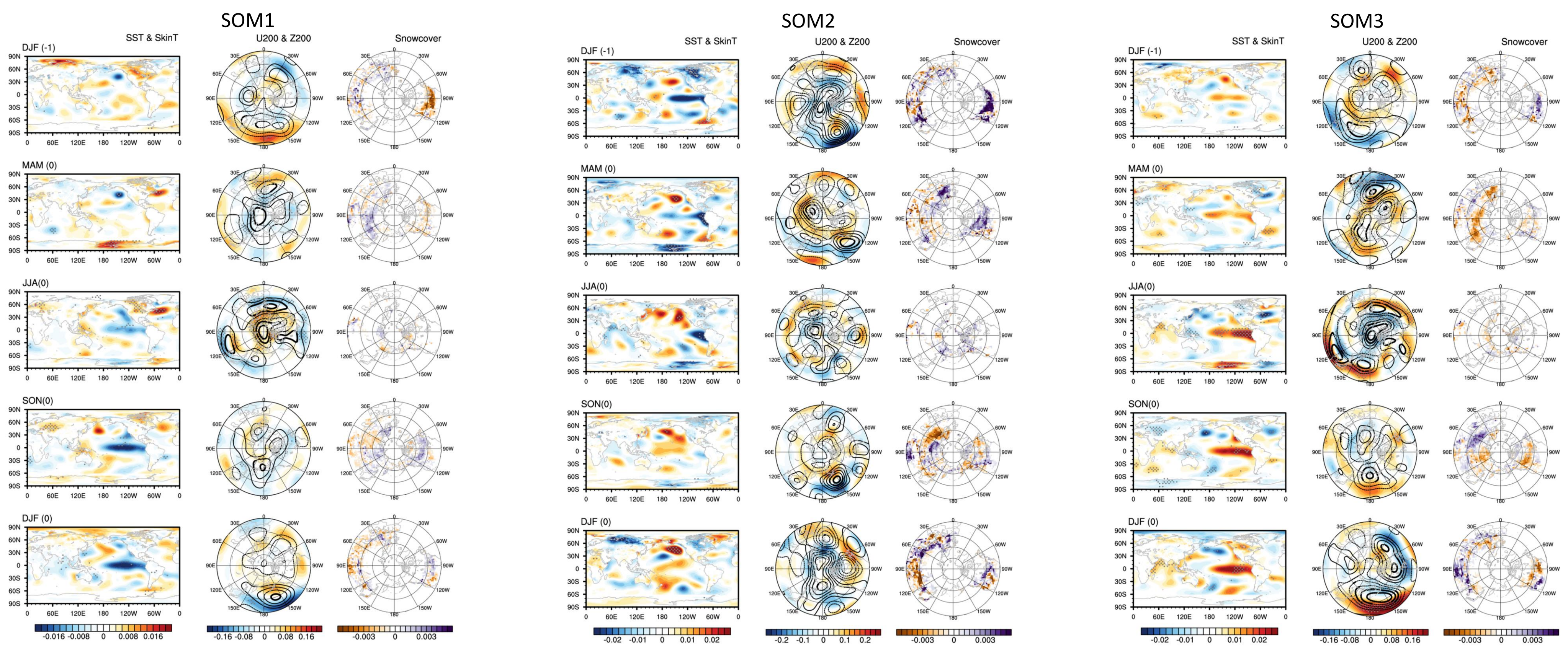
SOM1 SOM2 SOM3



f. Possible global teleconnections as the favorable conditions for the baroclinicity

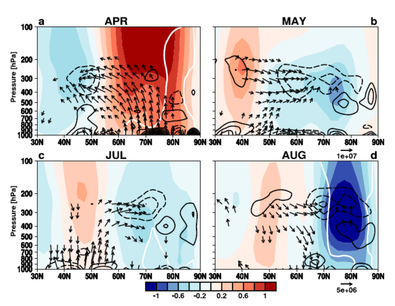
- Composite against high pass (< 10 yr) filtered SOM frequency

SOM1 SOM2 SOM3



Low Eurasian snow cover
→ Spring Arctic Low vs. mid-latitude High(+NAO)

→ Summer Arctic High vs. mid-latitude Low (-NAO)



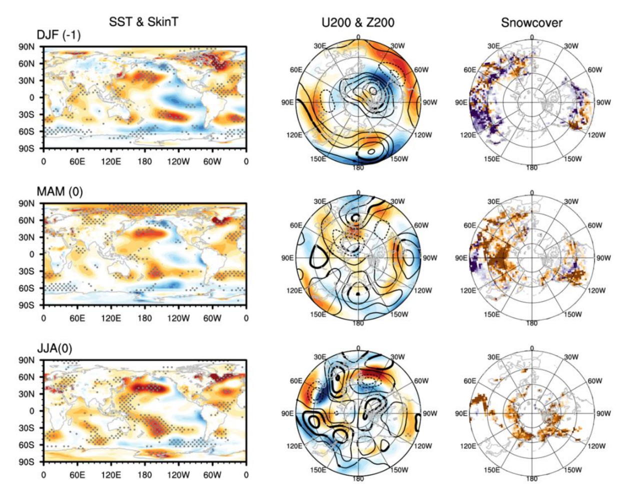
Matsumura et al. (2014)

- Developing phase of La-Nina
- Positive snow extent anomaly over cold Eurasian continent from spring to summer
- Positive AO-like pattern with reduced Aleutian Low in the following winter (Li et al., 2014; Deser et al., 2017)
- Negative snow anomaly over warm Eurasian continent in the following fall and winter

- Decaying phase of La-Nina
- Positive snow extent anomaly over high latitude except northeast Russia from the preceding spring
- Negative NAO-like pattern in the following winter

- Developing phase of El-Nino
- Negative (positive) anomaly in snow over warm Eurasian continent (America) from winter to summer
- Positive (negative) snow anomaly in Eurasian (America) in following fall & winter (Wegmann et al., 2015; Seagar et al., 2010)
- Positive NAO-like pattern with strong Aleutian Low in following winter (Li et al., 2014; Deser et al., 2017)

- Composite against low pass (> 10 yr) filtered SOM3



4. Summary and Discussion

- Summer Arctic daily MSLP fields can be partitioned to the three representative patterns by using SOM clustering method.
- The spatial patterns for MSLP SOMs are characterized by a negative anomaly over Arctic Ocean for SOM1, a dipole mode between positive Eurasian and negative Greenland for SOM2, and a positive pattern over Arctic Ocean for SOM3.
- All three patterns are significantly related to the storm spatial distribution and temporal variation.
- The storm has frequently developed in the large baroclinic instability zone.
- Considering that the summer baroclinic instability is also influenced by the preceding spring snow cover and SST evolution, it can be predictable on seasonal time scale in the same year.
- Low frequency variability of SOM3 occurrence frequency may have a linkage with recent large climate change such as global/Arctic warming, which brings to the extreme temperature over mid-latitude region of Northern Hemisphere in recent years.

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Formation of Arctic summer circulation patterns: the role of synoptic cyclones under different phases of ENSO evolution

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Abstract Text:

We investigate the contribution of synoptic cyclones to the formation of summer-mean circulation patterns in the Arctic and then understand their linkage in terms of global teleconnection to different phases of El Nino-Southern Oscillation (ENSO) evolution. The optimal number of Arctic summer circulation patterns is obtained by the self-organizing maps (SOMs) applied to the daily mean sea level pressure in the Arctic domain (≥ 60°N). Three SOM patterns are identified: one with prevalent low pressure anomalies in the Arctic Circle (SOM1) and two opposite dipoles with primary high pressure anomalies covering the Arctic Ocean (SOM2 and SOM3). The relevant analyses with produced cyclone track data confirm the vital contribution of synoptic cyclones for all patterns. The overall Arctic cyclone activity is enhanced for the SOM1 because the meridional temperature gradient increases over the land–Arctic Ocean boundaries co-located with major cyclone pathways. The SOM1 is prevalent during the developing year of La Nina in following autumn and winter. In preceding spring, the snow extent anomaly is weakly negative over the surrounding land areas of the

Arctic Ocean, leading to stronger baroclinicity along the pan-Arctic land-ocean boundaries in following summer. The SOM2 tends to occur during the decaying year of La Nina. The high-latitude land areas of northern Europe are more snow-covered in preceding spring, which results in weaker baroclinicity therin in following summer. The SOM3 is the prevalent pattern during the El Nino developing year. The northern mid-latitude Eurasia is less snow-covered in preceding spring, leading to more baroclinicity over northern Siberian continent. Though the springtime snow extent anomaly is negligible over the surrounding land areas of the Arctic Ocean, weaker baroclinicity is induced along the pan-Arctic land-ocean boundaries in following summer, which leads to the dominating high pressure anomaly over the central Arctic Ocean. Based on these relationships, we suggest that the ENSO-related evolution of the sea surface temperature in the tropical Pacific and continental snow cover extent could be used to outlook the summer-mean circulation pattern in the Arctic Ocean.

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