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Modulators of Arctic summer climate modes : from storm to global teleconnection

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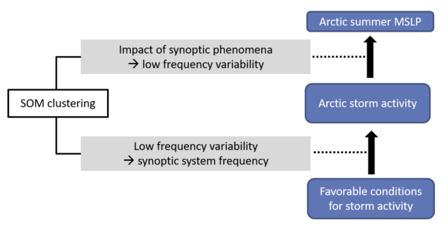
1. Introduction

- Recently, with regard to sea-ice variation over Arctic, the importance of the atmospheric circulation in summer has been getting more attention.
- Unlike the mid-latitude, in Arctic, due to the small east-west distance of Arctic, the specific aspects of the high/low pressure system on the synoptic scale itself could make a significant contribution to the formation of the regional climate pattern in Arctic.
- Arctic summer is most synoptically active season in the year. Indeed, the summer storm can be generated in the Arctic Ocean itself while the winter storm is mainly originated from the mid-latitude. Therefore, summer storm can affect the variation of mean sea-level pressure (MSLP) over Arctic by modulating the distribution of high/low pressure field.



- 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.
- For identifying the summer Arctic circulation pattern, we adopted the self-organizing map clustering (SOM) method which can sufficiently distinguish the representative patterns with the physical meaning from the large climate data set.

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

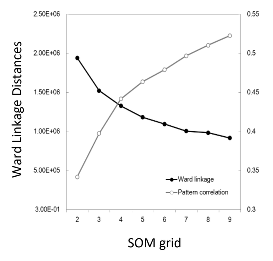
- SOM clustering method
  - one of clustering method which is originated from the neural networks
    i) classify the data into a specified number of pattern
    ii) relocate the resultant patterns according to the similarity between the patterns
  - more accurate and linearly independent than the patterns from other clustering & empirical orthogonal function (EOF) method
- Storm detection & tracking 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.

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



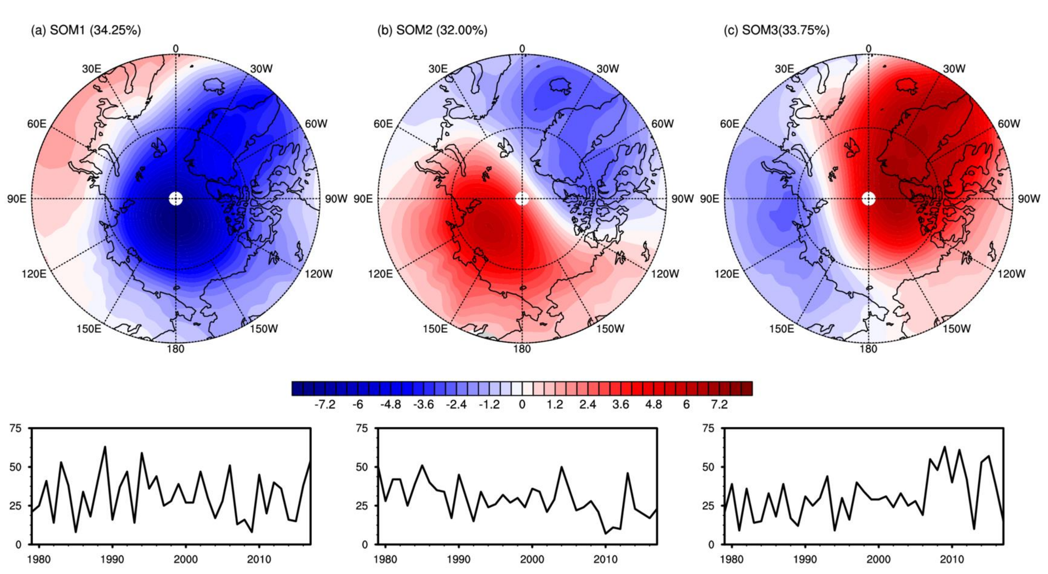
$$d(r,s) = \sqrt{\frac{2n_r n_s}{(n_r+n_s)}}\,\|\bar{x}_r - \bar{x}_s\|_2$$

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) (that is, 3 row by 1 column).

b. Representative modes of Arctic summer MSLP from SOM

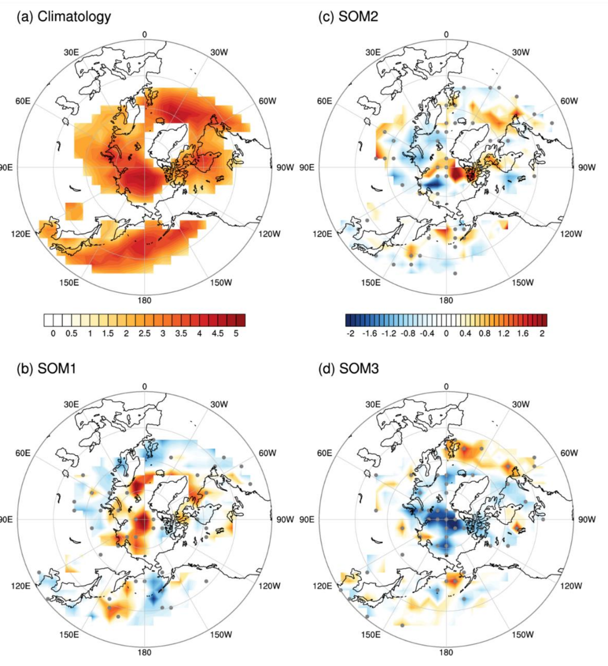
- MSLP SOM pattern & their annual frequency of occurrence (days/JJA)



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

c. Associated storm activity with each SOM pattern

- Composite of storm frequency



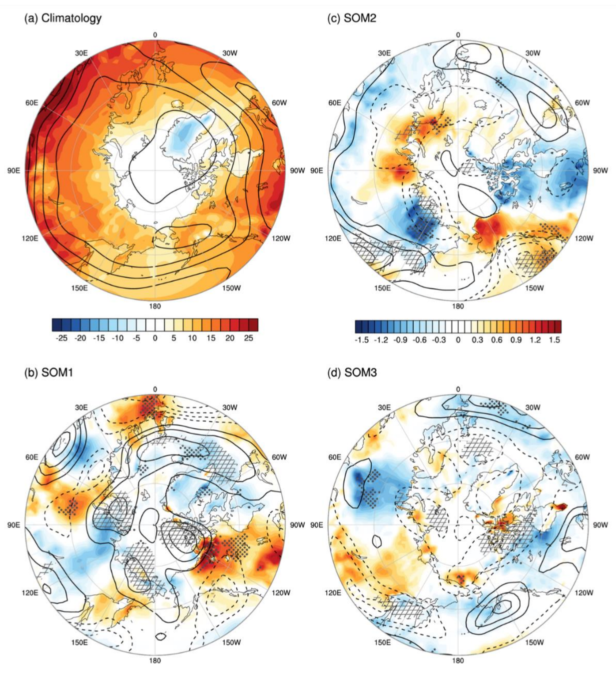
- Correlation (MSLP, storm activity)

SOM	Phase	Freq.	Dur.	CentP	ACE
1	High	-0.23	-0.33	0.6	-0.39
	Low	-0.6	-0.72	0.87	-0.55
2	High	-0.48	-0.58	0.75	-0.42
	Low	-0.39	-0.42	0.54	-0.48
3	High	-0.65	-0.69	0.82	-0.49
	Low	-0.15	-0.23	0.47	-0.25

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

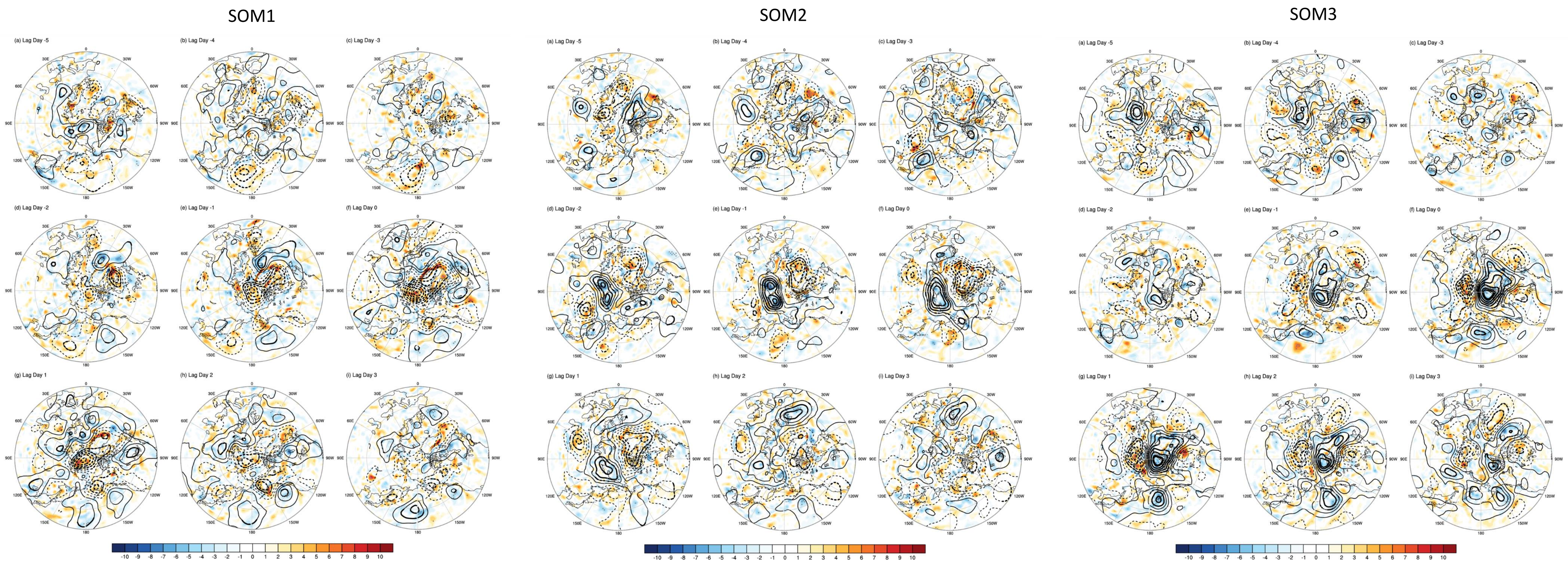


SOM1: warm coastal line & cold Arctic Ocean → increase in U200 & EGR over Arctic Ocean
SOM2: relatively warm in Pacific sector and cold in Atlantic sector → increase (decrease) in U200 & EGR over Atlantic (Pacific) sector
SOM3: warm Arctic ocean & cold Eurasian continent → decrease in U200 & EGR over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

Area averaged EGR over core area for each SOM show the consistently related to the storm activity for the region

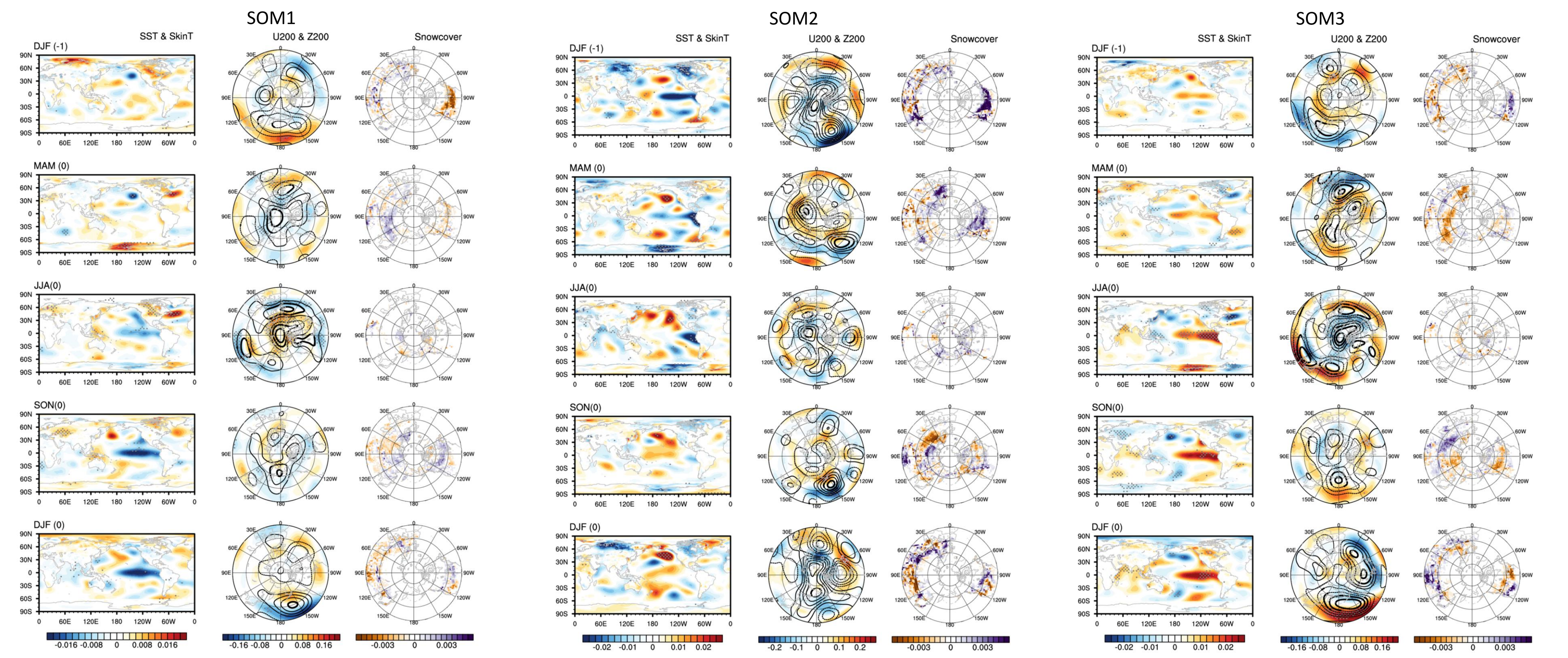
e. Daily evolution of atmospheric fields in SOM event

- Lag composite of Z500 (contour) and U200 (shading) from -5 to 3 days for each SOM events
  - 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.



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

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

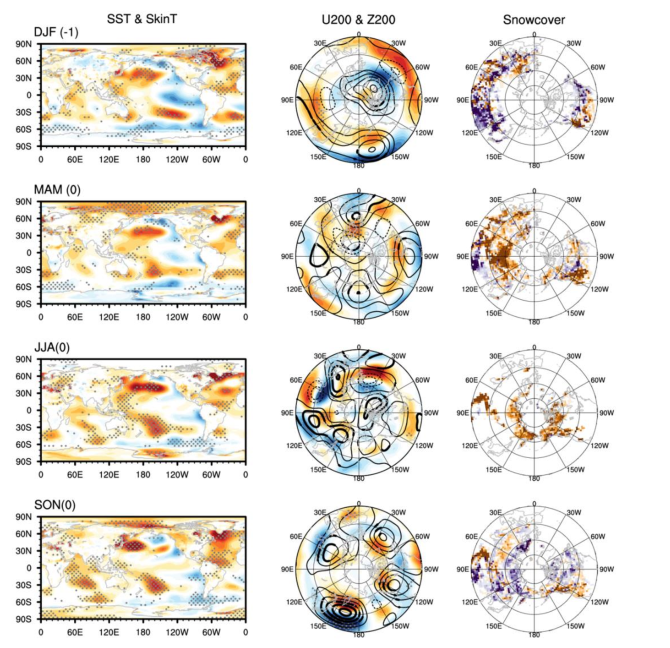


SOM1:
- Developing phase of La-Nina
- Positive snow extent anomaly over cold Eurasian continent from spring to summer
- Positive AO-like pattern with reduced Aleutian Low in the following winter
- Negative snow anomaly over warm Eurasian continent in the following fall and winter

SOM2:
- 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

SOM3:
- 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
- Positive NAO-like pattern with strong Aleutian Low in following winter

- 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.
- In association with low frequency variability of SOM3 occurrence frequency, a La-Nina like pattern with warm northwestern Pacific and cold eastern Pacific SST anomalies occurred thorough whole year. This may have a linkage with recent large climate change such as the global/Arctic warming.
- High geopotential anomalies are persistently observed in the mid-latitude region of 30°N (DJF) - 50°N (JJA) during all season, which may attributes to the extreme hot/cold temperatures over mid-latitude region of Northern Hemisphere during summer/winter in recent years.

극지역 여름철 기후모드의 조절자들; 스톰부터 전구 규모 원격상관까지
Modulators of the Arctic summer climate modes; from storm to global teleconnection

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In this study, we investigate several factors to modulate the summer Arctic circulation which has a significant linkage with the sea-ice variation. Using self-organizing map (SOM) clustering, the daily Arctic (north of 60 °N) mean sea level pressure (MSLP) during 1979-2017 is classified to three SOM modes through the procedure finding the optimal number. The resultant patterns are characterized by the negative Arctic mode, the dipole mode between Pacific (positive) and Atlantic (negative) sides, and the positive Arctic mode with weak negative Russia for SOM1, SOM2, and SOM3, respectively. The occurrences of the frequency of each SOM pattern computed by counting the number of days that are matched to each SOM in a year show not only the large interannual variation but also the decadal shift. Since Arctic summer is well known as the most synoptic period with the frequent storm occurrence in Arctic central Ocean, we first check the influence of storms on these variabilities in SOM occurrences. All spatial and temporal changes in Arctic MSLP are largely explained by the storm distributions in the interannual time scale. Considering the short scale of e-folidng time of all three SOM mode, we also analyze the daily evolution of atmospheric condition in the synoptic scale, and obtain the consistent results with the unfiltered daily SOM pattern and the associated storm distribution. From these, we can conclude that the Arctic summer MSLP variability is attributed to the accumulated effect of the spatio-temporal distribution of synoptic storms.

Further, the possible factors to modulate summer Arctic MSLP via affecting the storm distribution in the longer time scale are investigated. Basically, it is well known that the activity of storm is strongly related to the baroclinic instability. Indeed, the storm activity related to each SOM pattern are all significantly linked with the baroclinic instability which is determined from the surface temperature distribution. Since the Arctic surface condition can be modulated by the snow cover or sea-ice condition from the preceding season, we also investigated the snow cover, sea-ice, and the SST teleconnection from the preceding winter to the following winter.