A Possible Mechanism for Winter Sea Ice Decline over the Bering Sea and Its Relationship with Cold Events over North America

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ABSTRACT

In this study, the mechanism for the sea ice decline over the Bering Sea and its relationship with cold events over North America are investigated based on the daily ERA-Interim data during the winter (December–February) of 1979–2016. The results show that the sea ice decline over western (eastern) Bering Sea is mainly contributed by (1) the strengthened southerly (southeasterly) wind near the surface, which possibly pushes the sea ice to move northward, and (2) the intensified downward infrared radiation (IR), which is closely related to the local increasing surface air temperature (SAT) and the intensified moisture convergence mostly induced by the anomalous southeasterly wind associated with an anticyclonic anomaly over the Alaska Bay. During the sea ice decline over the Bering Sea, a cold SAT anomaly is simultaneously found over North America. It is proved that the occurrence of such a cold event is driven by the atmospheric internal variation, but not the forcing of sea ice decline over the Bering Sea. This study deepens our understanding of sea ice decline and its relationship with contemporary cold events in winter.

Key words: sea ice decline, cold events, the Bering Sea, North America

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1. Introduction

In recent years, Arctic sea ice has shown a retreating trend (Vaughan et al., 2013; Wu and Wang, 2018), which is regarded as a direct reason for Arctic amplification of near-surface warming (Screen and Simmonds, 2010; Serreze et al., 2011; Wei et al., 2018). The most notable aspect of 2017/2018 winter ice extent is the persistent low ice extent in the Bering Sea (Cornwall, 2019). Though the sea ice concentration (SIC) can appear to change slowly throughout the seasons, a closer look at observations indicates that rapid changes occur over relatively large areas on a daily basis, especially over marginal seas during December–February (Dammann et al., 2013). In addition, the warming in the Barents–Kara Sea (BKS) is identified as a main contributor to cold winters over East Asia based on observation data and CMIP5 (Coupled Model Intercomparison Project Phase 5) multi-model simulations (Petoukhov and Semenov, 2010; Yang and Christensen, 2012; Mori et al., 2014), and the East Siberian–Chukchi Sea region is found closely related to the severe cold winters over North America (Kug et al., 2015). Tachibana et al. (2019) indicated that the Bering Strait sea ice anomaly and Pacific atmospheric rivers in late autumn are partially responsible for the cold winter in Asia and North America. It seems that Arctic sea ice decline is connected with cold events in different geographical regions (Screen, 2017). Therefore, a better understanding of the process responsible for the transient sea ice decline is essential for assessing the potential risk of extreme weather events and improving the predictability for intraseasonal to seasonal forecasts in the Northern Hemispheric extratropics.

Numerous studies have investigated the causes of Arctic sea ice decline and its variability. Zhang and Li (2017) found that the positive cloudiness and weakened
surface wind speed will reduce Arctic sea ice concentration through changes in the surface latent heat flux and the downward longwave radiation in autumn. In winter, strong positive ice–temperature feedbacks have been regarded as an important factor increasing the chances of further rapid warming and sea ice decline (Screen and Simmonds, 2010). Some works revealed that the Arctic sea ice tend to be organized into large-scale geographical patterns that are strongly associated with the dominant mode of atmospheric variability in winter (Fang and Wallace, 1994; Deser et al., 2000). For the dipole pattern with opposing centers of action in the Davis Straits/Labrador Sea region and the Greenland and Barents Seas, its temporal variability is strongly coupled to the atmospheric North Atlantic Oscillation (NAO), especially when the atmosphere is leading the ocean by two weeks (Fang and Wallace, 1994). Sørterberg and Kvingedal (2006) emphasized the influence of atmospheric forcing on the BKS ice extent loss during winter, and pointed out that the activity of northward-moving cyclones over the western Nordic Seas strongly influences the BKS particularly on decadal timescales. However, Park D.-S. R. et al. (2015) showed that a positive trend of downward infrared radiation (IR) may account for nearly half of the sea ice decline over the Atlantic sector during 1979–2011 winters on a weekly timescale. Furthermore, the Arctic downward IR increase is driven by horizontal atmospheric moisture flux and warm air advection into the Arctic (Park H.-S. et al., 2015). Zhong et al., 2018 derived that the external moisture sources transported poleward to the BKS explain 57.3% and local evaporation explains 35.4% in winter during 1979–2015. Luo and Yao (2018) indicated that the strong downward IR is seen to occur together with the quasi-stationary and persistent Ural blocking (UB) because of the accumulation of more water vapor over the BKS and further favors sea ice decline. The positive NAO–UB combination is an optimal circulation pattern that significantly increases the BKS water vapor, which plays a major role in the BKS warming and sea ice reduction (Luo et al., 2017).

Till now, the dynamic and thermodynamic roles played by the atmosphere on the BKS sea ice decline are stressed, respectively. For the winter sea ice variability over the Bering Sea, previous work mostly emphasizes the atmospheric dynamical roles. Francis and Hunter (2007) showed that the ice-edge location in winter over the Bering Sea appears to be governed completely by anomalies in easterly winds associated with the Aleutian low. Sasaki and Minobe (2005) indicated that the positive SIC anomalies in the northeastern (northwestern) Bering Sea is related to the local northwesterly (northeast) wind anomalies in the winter season. Zhang et al. (2010) found that the main interannual variation of marine ice cover in the Bering Sea is due to the anomalous northeasterly wind-driven ice mass advection and the ocean thermal front at the ice edge, by using a sea ice–ocean model in the winter and spring seasons. Yao et al. (2018) focused on the synoptic impact on the sea ice variation associated with the blocking circulation and found that the blocking process can reduce the SIC by 49.5% for the Bering Sea.

Based on the above investigations, we are not sure yet whether the downward IR plays a role to the sea ice decline over the Bering Sea. If it does, how much contributions of the atmospheric dynamics and thermodynamics make respectively? In addition, considering the inconsistency of previous results about the favorable atmospheric circulation in the troposphere related to the sea ice decline over the Bering Sea, it is worthwhile for us to further explore this issue based on the composites of sea ice decline events in winter, which may help us better capture the characteristic atmospheric evolutions associated with sea ice decline and further reveal the possible mechanism. At last, the relationship between sea ice decline over the Bering Sea and cold events over North America is explored.

The rest of the paper is organized as follows. Section 2 describes the data and methods. The composites of atmospheric anomalous fields are presented and analyzed to explain the mechanism for the sea ice decline over the Bering Sea in Section 3.1. Section 3.2 shows a possible relationship between the sea ice decline over the Bering Sea and the cold events over North America. The conclusions and discussion are given in Section 4.

2. Data and methods

2.1 Data

In this study, the daily mean ERA-Interim (ECMWF Interim Reanalysis) data during the boreal winter (December–February; DJF) of 1979–2016 (Dee et al., 2011) are used. The dataset includes 2-m surface air temperature (SAT), 500-hPa geopotential height, total column water vapor (TCWV), vertical integral of water vapor flux and its divergence, downward IR, zonal (U10m) and meridional (V10m) wind at 10 m, and surface turbulent (sensible plus latent) heat flux (THF) on a horizontal resolution of $1^\circ \times 1^\circ$. SIC of daily ERA-Interim data is also used and verified to agree well with that from the US National Snow and Ice Data Center (Park D.-S. R. et al., 2015).
2.2 Methods

To identify the sea ice decline events over the Bering Sea, a standardized sea ice index is constructed by averaging the SIC anomalies over this region. To locate the specific region, we firstly perform an Empirical Orthogonal Function (EOF) analysis of the daily SIC anomaly in winter. The first EOF mode is illustrated in Fig. 1a, which accounts for 33.8% of the total variance. A unanimous variation of SIC can be seen over the Bering Sea. Combined with the standard deviation of SIC in winter (Fig. 1b), the region (55°–68°N, 165°E–155°W; labelled in Fig. 1b) is chosen to define the sea ice index, which also has the largest variability. Anomalies are calculated by subtracting the seasonal cycle (calendar-day mean) at each grid point. A sea ice decline event is defined over a time period when the sea ice index value exceeds −1.0 standard deviation for 3 or more consecutive days. If the beginning of an event occurs within 10 days at the end of the preceding event, the latter event is regarded as the continuation of the former one. In this way, 31 sea ice decline events are identified during 1979–2016 (Table 1). Lag 0 for a sea ice decline event is defined as the onset day when the sea ice index first reaches the criterion. Composite calculations are conducted to investigate the evolution of atmospheric variables associated with sea ice decline over the Bering Sea. Other indices of the atmospheric variables (SAT, TCWV, downward IR, THF, V10m, etc.) are obtained in a similar way. The Student’s t-test is used to evaluate the statistical significance of our composite calculations.

To better assess the atmospheric dynamic and thermodynamic roles on the sea ice decline over Bering Sea, we utilize an approach similar to Park D.-S. R. et al. (2015), but based on the perspective that the trend of the composite SIC decline events may be realized through composite evolving weather anomalies. We express the SIC anomaly at each grid point as a function of the anomalous downward IR and 10-m wind vector: \( f \approx f(R, V) \), where \( f \) is the composite anomalous daily SIC, \( R \) is the composite anomalous daily downward IR, and \( V = (u, v) \) is the composite anomalous daily 10-m wind vector, in which \( u \) (\( v \)) represents the zonal (meridional) wind component. Then, the trend in \( f \) by the trend in \( R \) can be expressed as \( (\delta f/\delta R) \Delta R \), where \( \delta f/\delta R \) can be estimated by calculating a linear regression coefficient at each grid point between \( f \) and \( R \) using the composite daily anomalous fields, and \( \Delta R \) is the linear trend in \( R \).

In addition, to explore the relationship between the sea ice decline over the Bering Sea and cold events over North America (30°–60°N, 130°–60°W), 20 extreme cold events are identified over North America during

![Fig. 1](image-url)

**Table 1.** The onset date and life cycle (day) of 31 sea ice decline events over the Bering Sea

| Onset date (yyyy-mm-dd) | Life cycle | Onset date (yyyy-mm-dd) | Life cycle | Onset date (yyyy-mm-dd) | Life cycle |
|-------------------------|------------|-------------------------|------------|-------------------------|------------|
| 1982-02-01              | 27         | 1996-02-12              | 8          | 2005-01-28              | 8          |
| 1983-12-18              | 37         | 1997-01-23              | 8          | 2005-02-21              | 7          |
| 1985-01-05              | 54         | 2000-02-14              | 6          | 2006-02-20              | 3          |
| 1985-12-13              | 26         | 2000-12-11              | 28         | 2007-02-09              | 7          |
| 1986-02-11              | 11         | 2001-01-28              | 31         | 2007-12-01              | 18         |
| 1988-01-29              | 16         | 2002-12-08              | 19         | 2011-02-25              | 3          |
| 1989-02-07              | 21         | 2003-01-17              | 21         | 2014-01-07              | 6          |
| 1993-02-18              | 10         | 2004-01-01              | 11         | 2014-01-28              | 31         |
| 1994-02-02              | 26         | 2004-01-25              | 11         | 2016-01-08              | 51         |
| 1996-01-01              | 5          | 2004-02-14              | 6          | —                       | —          |
| 1996-01-28              | 9          | 2005-01-03              | 10         | —                       | —          |
winters of 1979–2016 (Table 2). A cold event is defined over a period when the domain-averaged SAT reaches the criterion of the probability of occurrence less than 5% (namely, 266.59 K or −6.56°C) and persists for more than 3 days. Besides, the interval between two cold events needs to exceed 15 days (Wu et al., 2017). Lag 0 for a cold event is defined as the onset day when the domain-averaged SAT first reaches its criterion.

### 3. Result

#### 3.1 The contributors to the SIC decline

Before we check the atmospheric circulations related to the sea ice decline, lead–lag composites of anomalous SIC based on 31 sea ice decline events are shown in Fig. 2. It is revealed that the SIC anomaly begins to appear weakly negative over northern Bering Sea on lag −8 days (Fig. 2a), and then strengthens and becomes significant on lag −4 days (Fig. 2c). The negative anomaly of SIC reaches its maximum absolute value around lag +6 days (Fig. 2h), and then weakens gradually afterwards.

To better see the relationship between sea ice decline and atmosphere, various variable indices based on sea ice decline events are presented in Fig. 3. It is shown that the sea ice index begins to appear significantly negative on lag −6 days and reaches its minimum value of −1.8 standard deviation around lag +6 days, which is basically consistent with Fig. 2. Afterwards, it decays to about −1.0 standard deviation and persists until lag +30 days. This means that the sea ice decline is a slow process. Comparatively, SAT index appears significantly positive on lag −6 days, and reaches its maximum on lag 0 day. Both TCWV and downward IR indices also appear significantly positive on lag −6 days, and reach their maximum on lag −1 day. The THF index appears significantly positive on lag −5 days and reaches its maximum on lag −2 days (note that the ECMWF sign convention for surface sensible/latent heat flux is that positive values indicate a downward surface heat flux), which indicates that the melt of sea ice is primarily driven by the atmosphere (Blackport et al., 2019).

These four indices (SAT, TCWV, downward IR, and THF) show great signals before the sea ice decline, implying obviously that atmospheric thermodynamics may play an important role in the sea ice decline over the Bering Sea.

In addition, we notice that the 10-m meridional wind index appears significantly positive around lag −5 days and reaches its maximum amplitude around lag 0 day. In addition, the 10-m zonal wind index appears significantly negative between lag −5 days and lag 0 day. That is to say, wind-driven sea ice motion may also play an important role in the sea ice decline over the Bering Sea.

Furthermore, Fig. 4 shows the comparative contributions of 10-m meridional wind, 10-m zonal wind, and downward IR to the sea ice decline; linear regressions against the SIC anomaly; and the linear trends of atmospheric variables between lag −14 days and lag 0 day. It is seen that the sea ice decline contributed by anomalous southerly wind near the surface exceeds 60% (Fig. 4a), especially in the mid–northern Bering Sea. However, the sea ice decline contributed by anomalous zonal wind near the surface is extremely weak, which only account for 10% over most mid–northern Bering Sea, and reaches nearly 20% over northeastern Bering Sea (Fig. 4b). Comparatively, the sea ice decline induced by anomalous downward IR is concentrated over northwestern Bering Sea (Fig. 4c), which is less than that by anomalous meridional wind but larger than that by anomalous zonal wind near the surface, accounting for about 40%. The regression coefficients between sea ice and meridional (zonal) wind anomalies are significantly negative over northern Bering Sea (positive but limited to northeastern Bering Sea (Figs. 4d, e), which means that the southerly (easterly) wind anomalies contribute to the sea ice decline. The trend in wind vector near the surface against sea ice decline indicates that there are two branches of southerly flows into the Bering Sea (Fig. 4g). One branch from northeastern Pacific Ocean is associated with an anticyclonic anomaly over Gulf of Alaska, and the other is the cyclonic turn of southerly and southwesterly from mid–western North Pacific Ocean. Combined with Figs. 4d–g, it is inferred that the sea ice decline over northwestern Bering Sea is mainly associated with the anomalous southerly, while the sea ice decline over northeast-

### Table 2. The onset date and life cycle (day) of 20 cold events over North America

| Onset date (yyyy-mm-dd) | Life cycle | Onset date (yyyy-mm-dd) | Life cycle | Onset date (yyyy-mm-dd) | Life cycle |
|-------------------------|------------|-------------------------|------------|-------------------------|------------|
| 1980-01-28              | 4          | 1988-02-03              | 5          | 1996-01-29              | 4          |
| 1982-01-07              | 7          | 1989-02-02              | 5          | 2004-01-25              | 3          |
| 1982-02-04              | 3          | 1989-12-18              | 6          | 2005-01-15              | 3          |
| 1983-12-17              | 10         | 1990-12-20              | 3          | 2008-12-20              | 3          |
| 1984-01-17              | 6          | 1991-01-06              | 4          | 2008-12-20              | 3          |
| 1985-01-30              | 10         | 1994-02-07              | 6          | 2013-12-31              | 11         |
| 1988-01-05              | 5          | 1994-01-15              | 8          | —                       | —          |
ern Bering Sea is mainly associated with the anomalous southeasterly. The regression coefficients between sea ice and downward IR anomalies are weakly negative (Fig. 4f), combined with the strong positive trend over the Bering Sea and Chukchi Sea, centered at Bering Strait (Fig. 4h), which contributes to the sea ice decline over the whole Bering Sea.

The results hitherto suggest that both the atmospheric dynamics and thermodynamics play important roles in the sea ice decline. Next, we try to illustrate what kind of circulation in the troposphere locally and beyond the Bering Sea is associated with enhanced water vapor convergence and then the intensified downward IR, together with strengthened southerly/southeasterly winds near the surface, over the Bering Sea. Lead–lag composites of the anomalous 500-hPa geopotential height and SAT fields

![Fig. 2. Lead–lag composites of anomalous SIC based on 31 sea ice decline events for (a) lag −8 days, (b) lag −6 days, (c) lag −4 days, (d) lag −2 days, (e) lag 0 day, (f) lag 2 days, (g) lag 4 days, (h) lag 6 days, (i) lag 8 days, and (j) lag 10 days. Dotted areas indicate that the anomaly of SIC exceeds the 90% confidence level according to the Student’s t-test.](image-url)
Fig. 3. Lead−lag composite of the indices over the Bering Sea (55°–68°N, 165°E–155°W) based on 31 sea ice decline events. The dots indicate that the value of the index exceeds the 90% confidence level according to the Student’s t-test.

Fig. 4. Contributions (%) of anomalous (a) 10-m meridional wind, (b) 10-m zonal wind, and (c) downward infrared radiation (IR) to the SIC trend; linear regressions of anomalous (d) 10-m meridional wind, (e) 10-m zonal wind, and (f) downward IR; and linear trends of (g) 10-m wind vector and (h) downward IR against the SIC anomaly based on the composite daily anomalous fields from lag −14 days to lag 0 day. The shaded colors in (d, e, f, h) and vectors in (g) are statistically significant above the 90% confidence level based on the Student’s t-test.
based on the sea ice decline events are given in Fig. 5. It is shown that at 500 hPa, there is an anticyclonic anomaly over the North Pole, extending to the Alaska in the southeastern direction on lag −8 days (Fig. 5a), which implies a weakened polar vortex. Then, this anticyclonic anomaly strengthens gradually and moves southward to the Bering Strait on lag −2 days (Fig. 5d), accompanied with two cyclonic anomalies over the northwestern Pacific and North America, respectively. Afterwards, the atmospheric pattern bears some resemblance to the negative phase of North Pacific Oscillation/western Pacific pattern, which reaches its maximum amplitude on lag 0 day and then decays (Figs. 5e-h).

In addition, we notice that during the sea ice decline, there is a weak warm center, which first appears around the Bering Strait on lag −8 days (Fig. 5a), and then strengthens and spreads. On lag 0 day (Fig. 5e), the warm center reaches its maximum, about 5 days ahead of the minimum value of the sea ice decline (Fig. 2). Afterwards, the warm center decays gradually. It is also worth mentioning that during the sea ice decline, there is a significant cooling anomaly, which appears over North America on lag −2 days (Fig. 5d), reaching its minimum on lag +2 days, and persists until lag +6 days (Fig. 5h). So far, there are two contradicting viewpoints about this warm Arctic–cold continent pattern, one of which is that the Arctic warming is the cause of cold winters over midlatitude continent (Overland et al., 2011; Kug et al., 2015), and the other of which is that the reduced sea ice has a minimal influence on severe midlatitude winters (McCusker et al., 2016; Blackport et al., 2019). In the next subsection, we will further explore the relationship.

**Fig. 5.** Lead–lag composites of anomalous surface air temperature (SAT; color shaded; K) and 500-hPa geopotential height (gpm; contour interval 20 gpm) fields based on 31 sea ice decline events for (a) lag −8 days, (b) lag −6 days, (c) lag −4 days, (d) lag −2 days, (e) lag 0 day, (f) lag 2 days, (g) lag 4 days, and (h) lag 6 days. The thick line and shaded area denote that the anomaly is statistically significant at the 90% confidence level for the Student’s t-test.
between sea ice decline over the Bering Sea and cold events over North America in winter.

To further analyze the water vapor source to the Bering Sea, lead−lag composites of vertically integrated moisture flux and its divergence are provided in Fig. 6. Significant moisture convergence centered over the Bering Strait appears on lag −4 days (Fig. 6b) and reaches its maximum on lag −2 days (Fig. 6c). The convergence persists until lag +4 days (Fig. 6f). The main water vapor source is over south of the Alaska Bay, where the water vapor is transported westward at first and then northwestward into the Bering Sea. That is to say, the transport of water vapor to the Bering Sea is mostly due to airflows from northeastern Pacific Ocean, which further emphasizes the important role played by the southeasterly wind (Fig. 4g).

3.2 Relationship of the sea ice decline over the Bering Sea to cold events over North America

Before exploring the relationship between the sea ice decline over the Bering Sea and cold events over North America, we first show the atmospheric circulation associated with the cold events. The lead−lag composites of anomalous SAT and 500-hPa geopotential height fields based on cold events are presented in Fig. 7. It is seen that a weak cooling first appears over northeastern America on lag −8 days (Fig. 7a), and then it strengthens, reaches its maximum amplitude over central North America on lag +2 days (Fig. 7f), and weakens after lag +4 days (Fig. 7g). Accompanied with the cold events, there is also a significant warming anomaly over the Bering Sea and Chukchi Sea, which almost synchronizes with the cooling over North America. At 500 hPa, an anticyclonic anomaly appears over the Bering Sea, with a cyclonic anomaly downstream over North America, which bears resemblance to the circulation related to the severe 2013/2014 cold winter in North America (Yu and Zhang, 2015). This atmospheric structure is favorable for the warm (cold) temperature advection to the Bering Sea (North America), which accordingly induces the opposite temperature anomalies of warming and cooling in these two regions. Especially, we notice that this structure related to the cold events in North America also shows resemblance to that with the sea ice decline over the Bering Sea (Fig. 5). The first is the appearance of positive geopotential height anomaly over the North Pole.
Fig. 7. As in Fig. 5, but for 20 cold events over North America (30°–60°N, 130°–60°W).

during the onset stage, which implies a weakened polar vortex. The second is the persistent meridional positive over negative centers over the North Pacific Ocean, which resembles the negative phase of North Pacific Oscillation/western Pacific pattern. The third is a strong anticyclonic anomaly over the Bering Sea with a downstream cyclonic anomaly over North America, which is closely associated with the warm Arctic–cold midlatitude continent. All these common characteristics seemingly suggest that there must be a close relationship between the sea ice decline over the Bering Sea and the cold events over North America.

To further illustrate the causal relationship between the sea ice decline and the extreme cold events, the various standardized indices over the Bering Sea plus SAT index over North America based on 20 cold events over North America are plotted in Fig. 8. A very interesting thing is that the result in Fig. 8 is very similar to that in Fig. 3, displaying that the meridional wind at 10 m, THF, and downward IR indices reach their maximums on lag –1 day, about 5 days ahead of the minimum sea ice. Though the maximum cooling over North America lags the maximum warming over the Bering Sea about 1 day, it still appears ahead of the minimum sea ice over the Bering Sea for about 3 days. Thus, we may conclude that the cold events over North America are not the results of the sea ice decline over the Bering Sea during winter. The sea ice decline and the cold events downstream are both triggered by the internal atmospheric variability. However, whether the sea ice decline will have a positive feedback on the cold events needs to be further explored in the future.

4. Conclusions and discussion

In this paper, a possible mechanism for the sea ice decline over the Bering Sea in winter is explored by composite analysis. This study illustrates the relative contri-
butions by the atmospheric thermodynamic and dynamic factors to the sea ice decline. It is revealed that the anomalous southeasterly (southerly) wind at 10 m over northeastern (northwestern) Pacific Ocean accounts for nearly 60% to the sea ice decline, which may push the sea ice to move northward. At the same time, the intensified moisture convergence mostly induced by the southeasterly wind and the increasing surface temperature accordingly strengthen the downward IR, which explains about 40% to the sea ice decline. We conclude that the sea ice decline over the Bering Sea is mainly due to the atmospheric dynamics, which is consistent with previous studies (Francis and Hunter, 2007; Zhang et al., 2010). Moreover, our results further illustrate the importance of southeasterly wind near the surface over the northeastern Pacific Ocean.

Meanwhile, we also performed a composite analysis of the selected cold events over North America, to verify the relationship between sea ice decline over the Bering Sea and the accompanied cooling over North America. It is found that the cooling over North America is usually accompanied with the warming over the Bering Sea. The positive–negative temperature anomaly over the Bering Sea–North America is closely related to the anticyclonic anomaly over the Bering Strait and its downstream cyclonic anomaly. This atmospheric pattern shows resemblance to that associated with the sea ice decline over the Bering Sea, which includes the weakened polar vortex and the North Pacific Oscillation/western Pacific pattern. Furthermore, we examined the 20 cold events over North America individually. It is found that 12 (8) cold events were accompanied with negative (positive) sea ice anomaly over the Bering Sea. However, a negative sea ice tendency and a dipole structure with an anticyclonic anomaly over the Bering Sea and a cyclonic anomaly over North America can both be observed. The difference is that the anticyclonic anomaly with negative sea ice anomaly is more persistent and northward. We conclude that the studied cold events over North America are not the results of sea ice decline over the Bering Sea during the winter. They are both induced by the internal atmospheric variability, which supports Blackport et al. (2019) though their work is on the interannual timescale. It is believed that our work may provide a better understanding of the process responsible for the Arctic sea ice decline and the contemporary cold events over mid–high latitude continent, which will benefit the extreme weather prediction.

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