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Arctic autumn sea ice decline and Asian winter temperature anomaly

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Abstract

Associations between the autumn Arctic sea ice concentration (SIC) and Asian winter temperature are discussed using the singular value decomposition analysis. Results show that in recent 33 years reduced autumn Arctic sea ice is accompanied by Asian winter temperature decrease except in the Tibetan plateau and the Arctic Ocean and the North Pacific Ocean coast. The autumn SIC reduction excites two geopotential height centers in Eurasia and the north Arctic Ocean, which are persistent from autumn to winter. The negative center is in Barents Sea/Kara Sea. The positive center is located in Mongolia. The anomalous winds are associated with geopotential height centers, providing favorable clod air for the Asian winter temperature decreasing in recent 33 years. This relationship indicates a potential long-term outlook for the Asian winter temperature decrease as the decline of the autumn sea ice in the Arctic Ocean is expected to continue as climate warms.

Key words: Arctic sea ice decline, Asian, winter temperature

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1 Introduction

World Meteorological Organization Statement on the Status of the Global Climate (http://www.wmo.int/pages/prog/wcp/wcdmp/statement.php) during the past few winters all show that Asia along with North America and Europe has experienced anomalously cold conditions. In fact, in recent 33 years, the Asian winter temperature exhibits a cold trend that temperature reduction almost everywhere of Asia. In this period, the temperature declines gradually. Until recent years, cold temperature associated with persistent snow freezing rain resulted in disruptions in transport, energy supply, and power transmission and damage to agriculture. The causes of the recent severe cold winters are unclear, particularly in context of the amplified warming in the Arctic (Intergovernmental Panel on Climate Change, 2007; Symon et al., 2004). Understanding forcings and mechanisms responsible for such clod events are important for long range weather and climate forecasts.

Arctic sea ice cover has been shrinking since the 1970s, which has shrunk to its smallest extent ever recorded, smashing the previous record minimum and prompting warnings of accelerated climate change (Honda et al., 1996; Rigor et al., 2002; Alexander et al., 2004; Deser et al., 2000, 2004; Magnusdottir et al., 2004; Singarayer, 2006; DeWeaver et al., 2008; Kumar et al., 2010). A record low in 2007 of 41 700 km^2 was broken on 27 August 2012; Satellite images show that the rapid summer melt has reduced the area of frozen sea to less than 3.5 million km^2 in 2012—less than half of the area typically occupied four decades ago. Corresponding to the sea ice melting in summer, the recovery of autumn sea ice also shows an anomalous change. The loss of sea ice in autumn is particularly pronounced in the East Siberian, northern Chukchi, western Beaufort, Barents, and Kara Seas from 1979 to 2011.

Recently, declining autumn Arctic sea ice and its potential climatic impacts on these severe weathers have received increasing attention (i.e., Holland et al., 2006; Honda et al., 2009; Serreze et al., 2007; Wang and Overland, 2009; Ghatak et al., 2010; Liu et al., 2012). The results of Honda et al. (2009) and Ghatak et al. (2010) both show that cold conditions and increased snow cover over Siberia in autumn are correlated with reduced September sea ice cover in the Pacific sector of the Arctic. Liu et al. (2012) concluded that the recent decline of autumn Arctic sea ice has played a critical role in recent cold and snowy winters. In the present paper, the association of Arctic autumn sea ice concentration variation with Asian winter temperature is investigated during the past sea ice rapid decline 33 years.

2 Data and method

The Arctic sea ice concentrations (SIC) is retrieved from the Scanning Multichannel Microwave Radiometer and the Special Sensor Microwave/Imager based on a bootstrap algorithm

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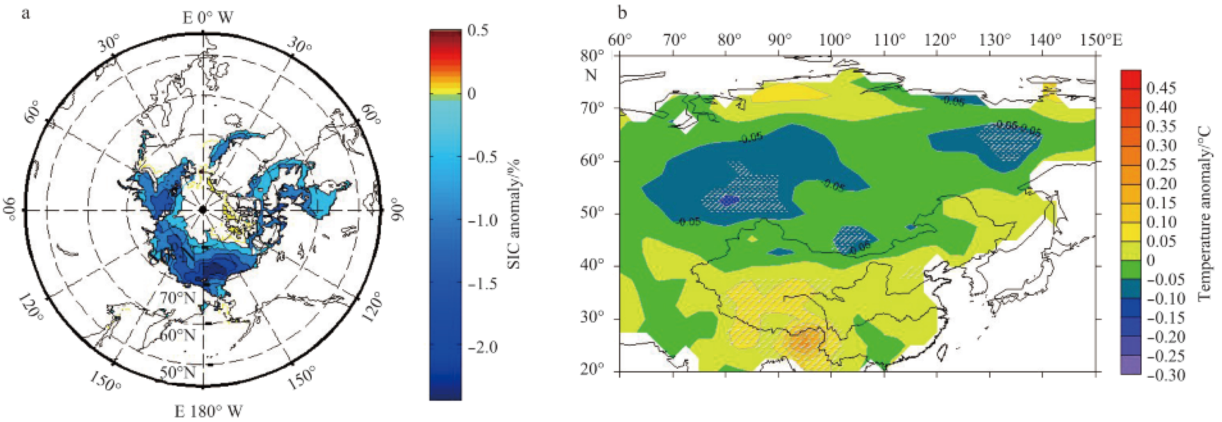

Fig. 1. Linear trends of the Arctic autumn (September–November) SIC (% per year) (contours show the trends that are significant at the 90% confidence level) (a), and linear trends of the Asian winter (December to the following February) temperature from 1979 to 2011 (b). Regions within oblique lines denote the regression above 90% confidence level.

(http://nsidc.org/data/docs/daac/nsidc0079 bootstrap seaice.gd.html for details), which provide the longest quality-controlled record for studying interannual and decadal sea ice variabilities. The surface air temperature, 5×10^4 Pa geopotential heights, 7×10^4 Pa zonal and meridional winds are obtained from the National Centers for Environmental Prediction (NCEP) reanalysis Ⅱ (Kanamitsu et al., 2002). The time period for all the datasets is from January 1979 to February 2012.

In this study, we focus on interannual variability of the sea ice seasonal means, averaged for three autumns (September–October–November) and there winter (December–next year January and February) months. Anomalies were calculated by subtracting the climatology. To reveal the dominant modes of co-variability between Arctic autumn SIC and Asian winter temperature, we used the singular value decomposition (SVD) method (Bretherton et al., 1992) .

3 A statistical linkage between Arctic autumn SIC and Asian winter temperature

Figure 2 shows the time series and corresponding spatial distributions of the leading SVD between the Arctic autumn SIC and Asian winter temperature, which accounts for 49.7% of their covariance. The spatial distribution of Asian winter temperature (hereafter referred to as SVD1-AWT, Fig. 2a) exhibits negative values almost everywhere in Asia land except positive values in the Tibetan plateau and the Arctic Ocean coast and the North Pa-

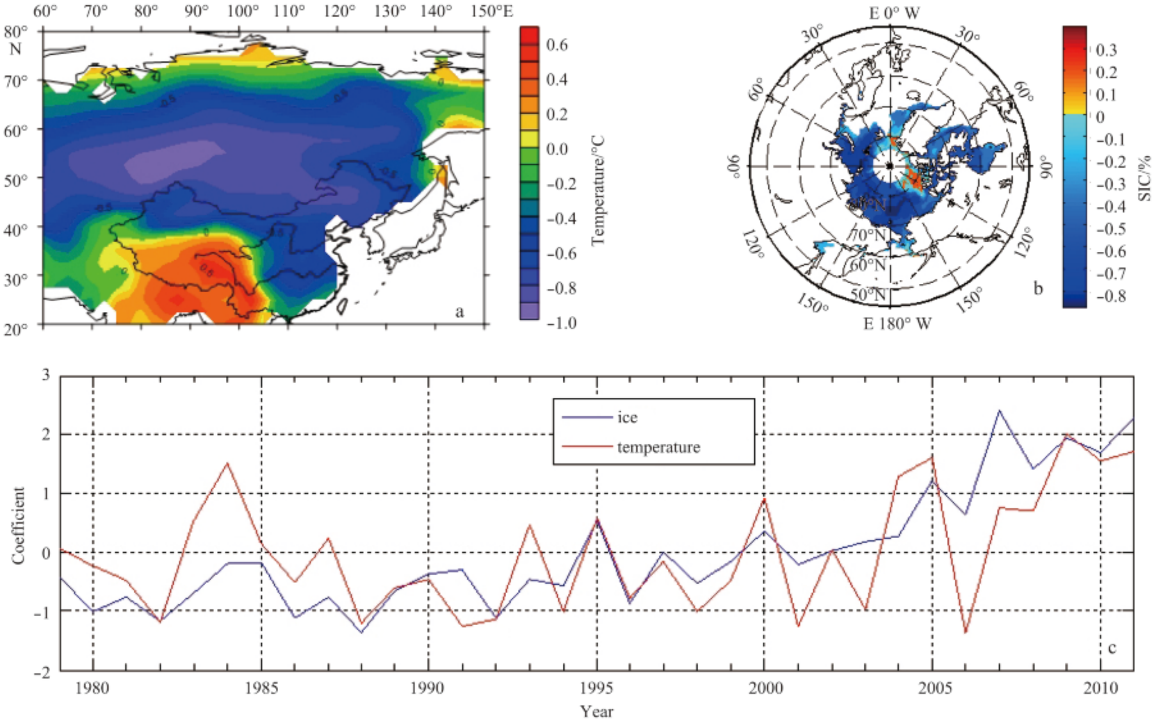

Fig. 2. First SVD mode of the Arctic autumn SIC (SVD1-SIC) and Asian winter temperature (SVD1-AWT) for the period 1979–2011. a. The spatial pattern of SVD1-AWT, b. SVD1-SIC (the units are arbitrary), and c. the standardized temporal coefficients of SVD1-SIC (solid blue line) and SVD1-AWT (red line).

cific Ocean coast, which is also similar to the linear trend of the Asian winter temperature for the period of 1979–2011 (Fig. 1b). The spatial distribution of the Arctic autumn SIC (hereafter referred to as SVD1-SIC, Fig. 2b) shows negative values almost everywhere (the Baffin Bay/the Davis Strait, the Greenland Sea, the Kara Sea the northern Barents Sea, the northern Chukchi Sea, the East Siberian Sea and Laptev Sea) except positive values in the northern Greenland Sea and the Canada Basin, which is similar to the linear trend spatial pattern of the autumn Arctic SIC for the period of 1979–2011 (Fig. 1a).

The corresponding temporal coefficients of both SVD1-SIC and SVD1-AWT are shown in Fig. 2c. The correlation coefficient between the Arctic SIC and SVD1-AWT time series is 0.68, which indicates coherent variations between them. Besides strong year-to-year variability, there is a statistically significant upward trend for both SVD1-SIC temporal coefficients for the period of 1979–2011, which underwent a change from one of negative phase to one of positive phase. That is, there is a tendency toward less autumn SIC (the Baffin Bay/the Davis Strait, the Greenland Sea, the Kara Sea, the northern Barents Sea, the northern Chukchi Sea, the East Siberian Sea and the Laptev Sea) and more autumn SIC in the northern Greenland Sea and the Canada Basin from 1979 to 2011. Associated with the time series of SVD1-SIC, there is also an upward trend of SVD1_AWT. That is, there is a tendency toward cold winter temperature conditions almost everywhere in Asia land except warm winter temperature conditions in the Tibetan plateau and the Arctic Ocean coast and the North Pacific Ocean coast from 1979 to 2011.

Further, we performed a composite analysis to conform the covariations of Arctic autumn SIC and Asian winter temperature. Based on the temporal coefficients of SVD1-SIC and SVD1-AWT shown in Fig. 2c, the year 2003 was selected as the turning point. The results of the composite average for the period 1979–2003 and 2004–2011 are shown in Fig. 3. Figures 3a and b show that the Arctic autumn SIC spatial pattern and the temporal changes it undergoes during 1979–2011 are similar to the results for SVD1-SIC. Similarly, the composite average results shown in Figs 3c and d show that the spatial pattern of winter temperature in Asian and the temporal changes it undergoes during 1979–2011 are also in good agreement with the results for SVD1-AWT. Additionally, the spatial pattern of SVD1-SIC is similar to the linear trend of autumn Arctic SIC (winter temperature in Asia) for the period 1979–2011 (Fig. 1). Thus, sea ice (temperature) variability in SVD1-SIC (SVD1-AWT) reflects the dominant spatiotemporal variability of the autumn Arctic SIC (Asian winter temperature). All the above analyses suggest that the relationships between the autumn Arctic SIC and Asian winter temperature possibly arise from the forcings by the decline of sea ice due to global-scale warming and as well as fluctuations in SIC.

Liu et al. (2016) discusses the early winter large-scale atmospheric circulation response to autumn Arctic sea ice decrease. It suggests that, over Asian region, there is a weakening of the westerly wind (20°–40°N), and a strengthening of the zonal wind to the north (40°–60°N) at upper levels. Over the north of China, Mongolia and Japan, there is a positive 5×10^4 Pa geopotential height anomalous center. These anomalous atmospheric circulations tend to encourage the movement of cool air from Arctic to Asia. To further address how the Arctic sea ice decrease SVD1-SIC linked to temperature variability in SVD1-AWT, we examined the regression patterns of the NCEP 5×10^4 Pa geopoten-

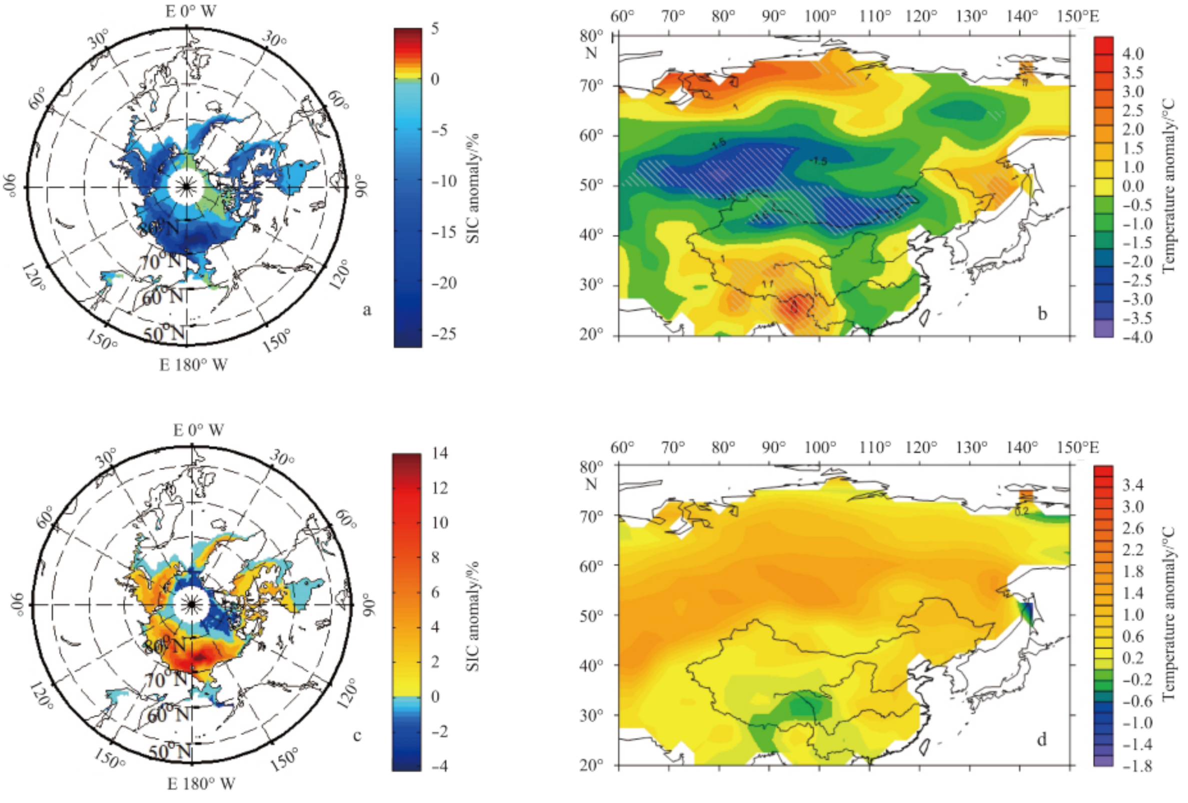

Fig. 3. Composite average of autumn (September–November) Arctic SIC anomalies (a and c) and winter (December to the following February) temperature anomalies (b and d). Figures 3a and b are during the period 2004–2011. Figures 3c and d are during the period 1979–2003.

tial height, 7×10^4 Pa zonal and meridional winds in winter (Note the winter fields being analysed are for winter following autumn used for the SVD-SIC/NAR analysis) with respect to the standardized time coefficients of SVD1-SIC. Considering the decline of the Arctic autumn sea ice, the resulted regression coefficients are multiplied by –1 which corresponding to the negative change in the time coefficients of SVD1-SIC.

The 5×10^4 Pa geopotential height anomalies show two centers (Fig. 4a). One negative center is in Barents Sea/Kara Sea. One positive center is located in Mongolia. Associated with the negative center of 5×10^4 Pa geopotential height, at low levels, there is a large-scale anomalous cyclonic circulation at 7×10^4 Pa centered in Europe and Barents Sea/Kara Sea. Associated with the positive center of 5×10^4 Pa geopotential height, at low levels, there is an anomalous anti-cyclonic circulation over much of Asian (Fig. 4c). The anomalous south-westerlies in the southern flank of the anomalous cyclone impinge on eastern Asian, which converge with the anti-cyclonic circulation, across Russian and northeastern China to southern China. The winter cold of the North Asia is coincident with the anomalous northern winds from the Arctic Ocean, which carrying cold air from the cold Arctic Ocean into North Asian, and decreases temperature there. The winter clod conditions over China stem from the effects of the anomalous cyclonic over Mongolia associated with the Arctic sea ice decline which lead to the anomalous cold air from the Siberia invades China.

It is worth mentioning that the aforementioned atmospheric anomalies in the 5×10^4 Pa geopotential height, and 7×10^4 Pa wind not only pronounced (with more statistically significant grid points) in winter, in fact, the anomalous atmospheric circulation structures start to emerge in autumn with strengthening anomalies from autumn to winter (Figs 4b and d). The locations of the anomalous 5×10^4 Pa geopotential height and 7×10^4 Pa wind centers do not change much (Figs 4a and b), with slight changes of the negative 5×10^4 Pa geopotential height and the associated 7×10^4 Pa anti-cyclonic wind circulation centers southwestward from autumn to winter.

What is the mechanism that helps the atmosphere maintain the memory from autumn to winter? Blanchard-Wrigglesworth et al. (2011) analyzed the lagged correlation of the Arctic sea ice in observations and a GCM ensemble. They showed a persistence of total sea ice area anomalies for the 1–5 months time scale, longer in winter and summer months. Figure 5a shows the regression pattern of the Arctic winter SIC on the standardized time series of SVD1-SIC. It shows that the reduction of the autumn SIC in the Arctic Ocean also occurs in winter, although sea ice increases in

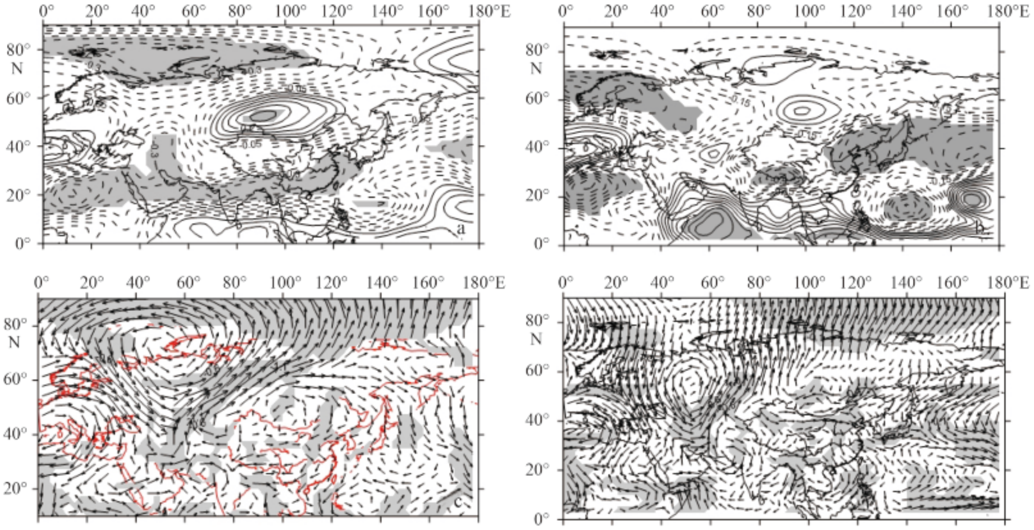

Fig. 4. Regression coefficients of the 5×10^4 Pa geopotential height in winter (December to next February) (a) and autumn (September to November) (b), and regression coefficients of the 7×10^4 Pa winds in winter (c) and autumn (d) on the standardized time series of SVD1-SIC. Regions within contours denote the regression above 90% confidence level.

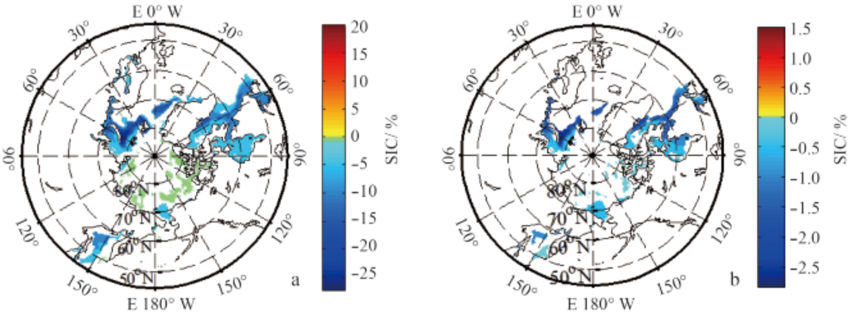

Fig. 5. Regression coefficients of the winter Arctic SIC corresponding to the time series of SVD1-SIC (a), and linear regression trend of the winter Arctic SIC (per decade) (b). The colour shading gives anomalies and trends that are significant at the 95% confidence level.

the Arctic Ocean. This also closely resembles the linear trend of the Arctic winter SIC for the period of 1979–2011 (Fig. 5b). We speculate that the autumn SIC anomalies are persistent in the next winter. As a result, the accumulated impacts of the anomalous SIC persistency from autumn and winter influence the large-scale atmospheric circulation through changing surface fluxes between the atmosphere and the ocean, which further modulates distribution of the atmosphere circulation.

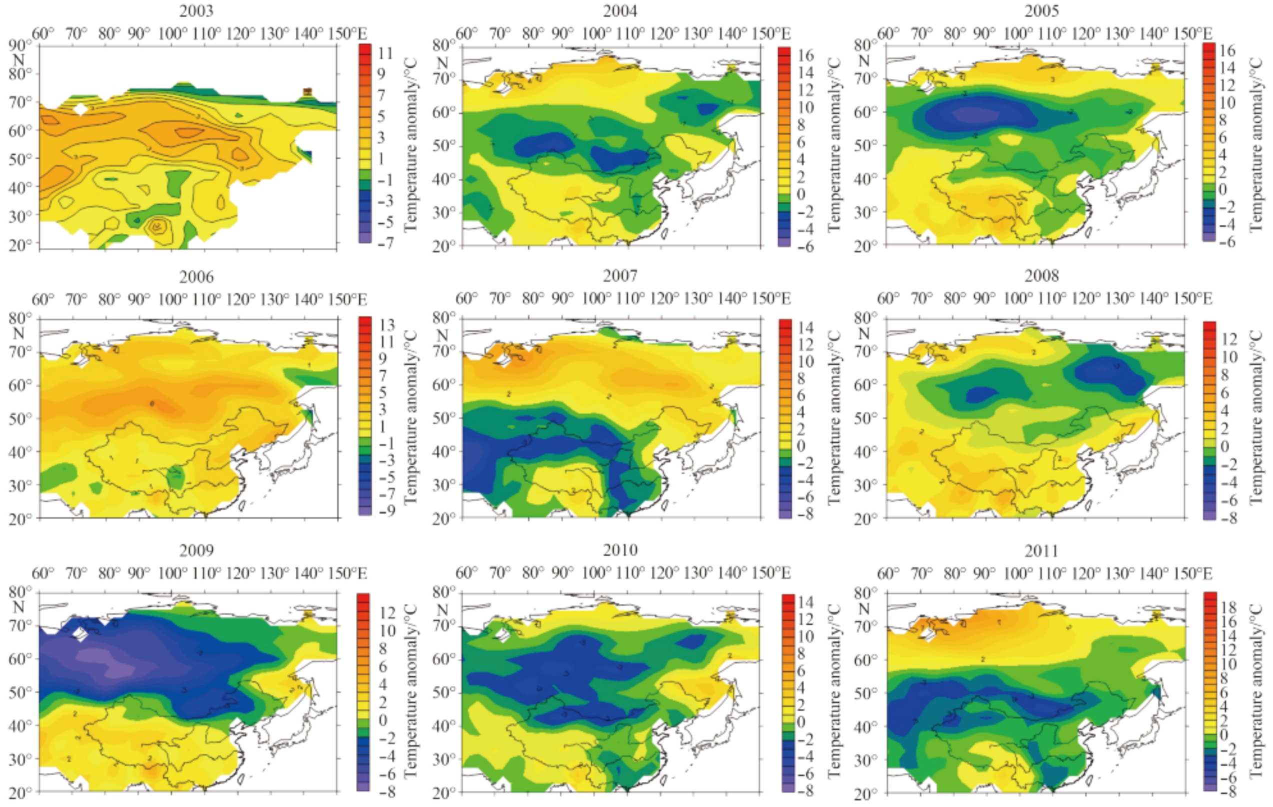
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Fig. 6. The Asian winter temperature anomalies from 2003 to 2011.

4 Conclusions and discussion

In this study, we found that the anomalous atmospheric circulation pattern which persistent from autumn to winter associated with the decrease of the Autumn SIC in the Arctic Ocean contributes to the Asian winter cold in recent years. Recognition of the associations between the Arctic autumn SIC and Asian winter temperature might provide us a useful long-term outlook of clod anomalous distribution for Asian winter. As the decline of the autumn sea ice in the Arctic Ocean have begun (Fig. 1a), which is expected to continue associated with increased greenhouse gases in the atmosphere (e.g., Arzel et al., 2006; Stroeve et al., 2007; Serreze et al., 2007), our results suggest that the temperature for winter might be strengthened in Asian in the 21st century.

It is deserved to say that from Fig. 2c we can see that after the year 2003, when the standardized time series of SVD1-SIC start to change to positive phase, the SVD1-AWT does not change to positive phase immediately. From 2004 to 2007 the SVD-AWT variability fluctuates around zero although SVD1-AWT shows significant correlation with SVD1-SIC in this period. Figure 6 shows the Asian winter temperature anomalies in each year from 2003 to 2011. In these winters, Asian winter is warm in most of Asia than the temperature climatology in 2003 and 2006 which is consistent with the negative year shown in Fig. 3c. From 2003 to 2011, Asian winter is cold in most of Asia than the temperature climatology in 2004, 2005, 2009, 2010 and 2011 which is consistent with the positive year shown in Fig. 3c. In 2007, North Asia is warm but the South Asia is cold. In 2008, South Asia is warm but the North Asia is cold. In fact, the warm and cold winter appear nearly alternately from 2003 to 2008. After 2008, the cold winter occur persistently. This is an interesting result and it suggests an important hypothesis that Arctic sea-ice anomalies have been decreasing has been studied and partially supported in other studies, namely that autumn Arctic sea-ice cover can induce anomalous heat fluxes over the Arctic Ocean and impact Asian temperature in the next winter. Before 2003, shown as Fig. 3d, the Asian temperature is warm. During the 5–6 years around 2003, the Asian temperature decreasing associated with the Arctic sea ice decline. But in this period the Asian temperature decreasing does not surpass its own natural variability and it shows negative and positive alternately. During the recent years, the Arctic sea ice again and again to break the very low value. Maybe low Arctic sea-ice cover reached a particularly low threshold to trigger the Asian winter temperature response with associated atmospheric circulation.

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