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Relationship between Antarctic sea ice and the climate in summer of China

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Abstract The variations of sea ice are different in different regions in Antarctica, thus have different impacts on local atmospheric circulation and global climatic system. The relationships between the sea ice in Ross Sea and Weddell Sea regions and the synoptic climate in summer of China are investigated in this paper via diagnostic analysis methods by using global sea ice concentration gridded data covering Jan. 1968 through Dec. 2002 obtained from Hadley Center, combined with Geopotential Height on 500hPa and 100hPa over North Hemisphere and monthly precipitation and air temperatures data covering the corresponding period over 160 meteorological stations in China obtained from CMA (China Meteorological Administration). Results disclose that both these two regions are of indicative meanings to the climate in summer of China. The Ross Sea Region is the key sea ice region to the precipitation in Northeast China in summer. More sea ice in this region in September will result in less precipitation in Northeast China in the following June. Weddell Sea Region is the key sea ice region to the air temperature in Northeast China in summer. More sea ice in this region in September will contribute to lower air temperature in Northeast China in the following June.

Key words Antarctic Sea-ice, Correlation Analysis, Teleconnection, Climate Change.

1 Introduction

In the process of global heat balance, the huge ice sheet in Antarctica and the surrounding South Ocean are tremendous cold sources. Satellite observation indicated that the Antarctic sea ice ever underwent a remarkable interannual change over its normal annual cycle. This resulted in intensive variations of heat balance over the South Ocean. The redistribution of local cold source can alter the large scale circulation and, as a result, influence the climate in the region far away from Antarctica (Xue *et al.* 2003).

Sea ice is of many actions in global climatic system. Firstly, it is an effective insulator for heat, mass, momentum and chemical elements lying between ocean and atmosphere. Secondly, it influences the surface albedo. Basically, the albedo on ice-free sea surface is 0.1-0.5, while the albedo of sea ice can get up to 0.8 on average. Even, the albedo will increase to 0.98 on the ice surface covered with fresh snow, while it will decrease to 0.2-0.6 on melting ice pits. Since the albedo of sea ice is relatively higher than that of ice-free sea surface, the solar radiation absorbed by earth surface decreases considerably due to the existing of sea ice. The insulation and albedo of sea ice are of important impacts and indicative meanings on climate change.

Furthermore, the position of sea ice extent will influence regional climate, thus impacting the global climate system. In winter, the existing of obvious heat and pressure borderlines between sea ice and expansive ocean evokes intensive synoptic situation, like polar low. The remarkable variations occurring in the heat exchange of sea ice extent can inspire the polar low vortex storm under appropriate atmospheric conditions (Gloersen *et al.* 1992). Recently, more researches argue that the variations of sea ice can influence the stratification and stability of planetary boundary layer, thus bringing dynamic effect on it (Alexander *et al.* 2004; Deser *et al.* 2000, 2004; Wu *et al.* 2004). Therefore, the different variations of Antarctic sea ice in each region will consequentially influence the local atmospheric circulation via dynamic process, thus impacting the atmospheric circulation over North Hemisphere (NH), even the synoptic climate in China. Cheng *et al.* (2002, 2003) defined the Antarctic Sea-ice Oscillation Index (ASOI) in terms of the teetertotter characteristics of sea ice concentration between the peripheries of Ross Sea and Bellingshausen Sea in Antarctic and investigated its impacts on climate in China. Some new cognitions and opinions were obtained from the special topic "investigation on the interaction between Antarctica and global climate and environment" masterminded by Academician Xiuji Zhou covering 1991 through 1995, which is under the National Scientific and Technological Item "Chinese investigation and research on Antarctica". The main production was that the abnormal distribution of sea ice and sea surface temperature impacts on Chinese continent via the abnormal zonal circulation on the equator resulting in a series of wave trains on Northeast Pacific Ocean, which was disclosed by the numerical simulation about the effect of Antarctic continent on the atmospheric circulation (http://www.coi.gov.cn/jdkc/chengguo.htm#5).

There are two atmospheric circulations in NH that are of important impacts on the dryness and wetness in summer of China, which are the abnormality of the position, intensity and the co-configuration of West Pacific Subtropical High and South Asia High (SAH). Since the Pacific Subtropical High lies in the high pressure belts of SH and NH, it is called Subtropical High for short. It often splits into some high pressure monomers with a close center affected by different distribution of oceans and continents. In some isobaric surface, the isohypse shows in ellipse and the long axis is almost parallel to the latitude circle. The monomers of Subtropical High are often named after the geographical locations. What impacts the climate in China is mainly the west part of Pacific Subtropical High and is called, generally, West Pacific Subtropical High (WPSH). Usually, it presents zonal form and stretches east and west. Dryness and wetness variations in large scale have close relation to do with its activities. In summer, in the regions controlled by WPSH arid climate prevails, while in the northwest edge of this region, southwest wind prevails due to the interaction of WPSH and fluctuations in westerlies. This is the main water vapor channel of Chinese summer monsoon and the main rain belt in summer of China, where there are many low-pressure systems, such as shear lines and cyclonic waves, etc. There are obvious seasonal variations for the latitude of ridge line and the intensity of WPSH, and the seasonal shift of Chinese main rain belt has close relationship with this, but the interannual discrepancies are very large. Besides advancing and retreating in south-north direction, WPSH also swings west and east, which results in an extremely uneven distribution of dryness and wetness and complicatedly changeful weather phenomena in China annually. In summer, the variations of position and intensity of SAH have considerable effects on the precipitation in vast areas. Similarly, it has not only seasonal variations, but also inner-season oscillations eastward and westward. It is called East Type when the center of SAH lies in the east of 100°E, and West Type when lies in the west of 100°E in summer. The corresponding weather types resulting in these two types of SAH are right on the contrary. When it is West Type, it is not easy for the ridge of WPSH to stretch toward Chinese continent, while it is East Type, there are almost simultaneous processes for WPSH to jump towards north and advance westward.

Therefore, these two atmospheric circulation systems interact with each other and are both the key factors impacting on the precipitation in summer of China. The first and third regions of Antarctic Sea ice regions based on the research of Ma *et al.* (2004), which are Ross Sea Region and Weddell Sea Region covering 163°E – 132°W and 48°W – 23°E respectively, are of relatively obvious seasonal variations. So, what changes the variations of sea ice in these two regions will bring to the atmospheric circulation systems in NH mentioned above and the influence on the synoptic climate in China are discussed in this paper.

2 Data and Methodology

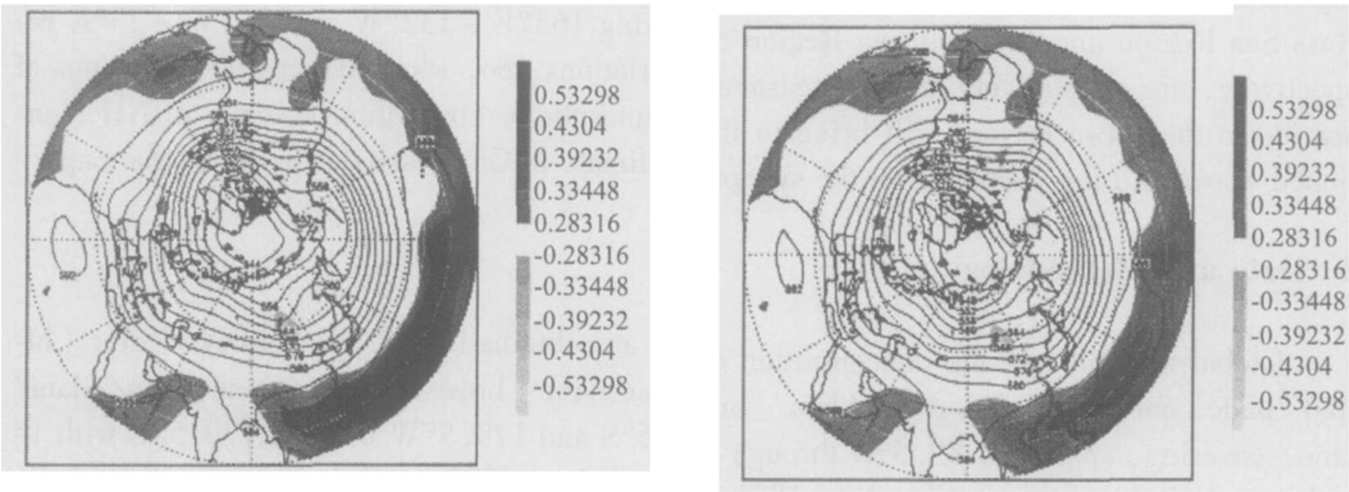
Global monthly sea ice concentration data are obtained from UK Hadley Center (http://badc.nerc.ac.uk/cgi-bin/data_browser/data_browser/badc/ukmo-gosta//data/gice) covering spatially, 89.5°N through 89.5°S and 179.5°W through 179.5°E with 1° × 1° resolution and temporally, Jan. 1871 through Dec. 2002, and the data precision is 0.1. Since the data before Dec. 1967 have no interannual change (Ma *et al.* 2004), the final dataset used in this paper covers 40.5°S through 89.5°S and 179.5°W through 179.5°E spatially and Jan. 1968 through Dec. 2002 temporally.

Geopotential Height in NH and monthly precipitation and air temperature data in China obtained from CMA which including monthly NH Geopotential Height over 500 hPa covering Jan. 1951 through Dec. 2002 with 5° × 10° spatial resolution and 100 hPa covering Jan. 1956 through Dec. 2002 with 10° × 10° spatial resolution, monthly total precipitation and average air temperatures over 160 meteorological stations in China covering Jan. 1951 through Dec. 2002.

The correlation coefficients between variations of Antarctic sea ice extent and the meteorologic elements in summer of China, such as precipitation and air temperatures, are calculated via synoptic correlation analysis method (Lu *et al.* 1983). The regions where the coefficients are more significant than critical correlation coefficient are marked off, labeled as significant correlation regions and made synoptic analysis. The distribution of lag correlation is well explained by searching the synoptic systems corresponding to significant correlation regions via synoptic analysis method. Usually, there are a mass of significant correlation regions seen from the correlation fields of Antarctic sea ice and some circulation feature, like 500 hPa and 100 hPa Geopotential Height or meteorological elements, like precipitation and air temperature. The corresponding synoptic systems can be found out under the multi-year average chart of this synoptic situation and are consistent with the composite chart of synoptic situation under the analogous weather conditions. Therefore, these kinds of significant correlation fields not only are of statistical meaning but also can help us seeking the relationship between weather or circulation systems and some elements.

3 Sea ice in Ross Sea Region and the Climate in summer of China

The sea ice in Ross Sea Region is of relatively great seasonal variations (Ma *et al.* 2004). In order to disclose if there is any teleconnection between the variations of sea ice extent in this region and the atmospheric circulation in NH and the summer climate in China, the superimposed fields on correlations of prophasic mean Antarctic Sea ice extent and Geopotential Height fields over 500 hPa and 100 hPa in summer of NH and the situation of precipitation and air temperature fields in China when in significant correlation are made in this paper (figures are omitted).



a higher index   b lower index

Fig. 1 The superimposed field of 500 hPa atmospheric circulation in Northern Hemisphere in the following June when Ross sea ice extent index was higher and lower in the previous September and their correlation field in the corresponding period

Figure 1a and 1b shows the situation of 500 hPa Geopotential Height field in NH in the next June when the sea ice extent index in Ross sea region is on the high and low side in September respectively and also the distribution of correlation field between them. The curve represents 500 hPa Geopotential Height field, and the regions shown in shade are those of significant correlations. The smallest significant level is 0.1, and the critical values are ±0.28316. The other critical values represent the level of 0.05, 0.02, 0.01, 0.001 respectively, and the deeper the color, the better positive correlation, and the shallower the better negative correlation. What notable is that in South Hemisphere (SH), the higher is the sea ice extent index, the less sea ice there is. We can see that there is obvious positive correlation between the sea ice extent index in this region in September and the 500 hPa Northwest Pacific High (NPH) in the next summer. That is to say, NPH will be stronger when the sea ice in Ross sea region is less than normal. There are consistent exhibitions in the correlation field of Figure 1a, which behaves as the point of ridge extending to west and its area expanding comparing with Figure 1b, which is the situation with low sea ice extent.

Figure 2 shows the superimpose field of the difference field of precipitation in China in the following summer when there was less and more sea ice in Ross sea region and the correlation field between them in the corresponding period. The regions with shade represent the precipitation difference, and the deeper the color is, the more precipitation there is. See from the correlation field, which is shown in curve, there are flaky positive correlations in the Northeast China, while it is negative in Sichuan and the coastland of South China. In the corresponding precipitation field, when the sea ice in Ross sea is less than normal, the precipitation in Northeast China, most of North China and part of Xinjiang is more than normal in the following June. However, the situation in South China is relatively complicated. Possible reason is that the strengthened NPH enforced upon the weather posture of South China and made the precipitation belt there behaved as from northwest tending towards southeast alternating with positive and negative.

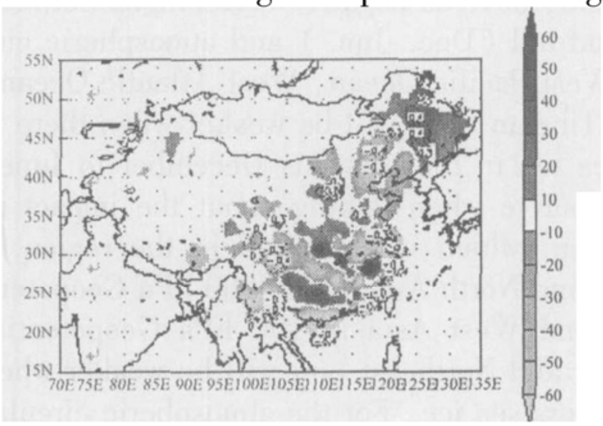


Fig 2 Superimposed field of rainfall dispersion in China in the following June when Ross sea ice extent index was in its high and low side in the previous September and their correlation field at the corresponding period

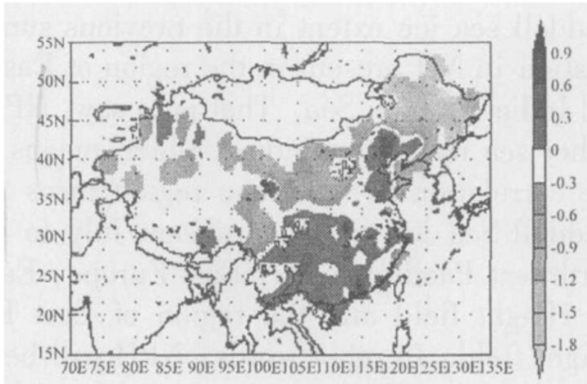


Fig 3 Superimposed field of air temperature in China in the following June when Ross sea ice extent index was higher and lower int he previous September and their correlation field in the corresponding period

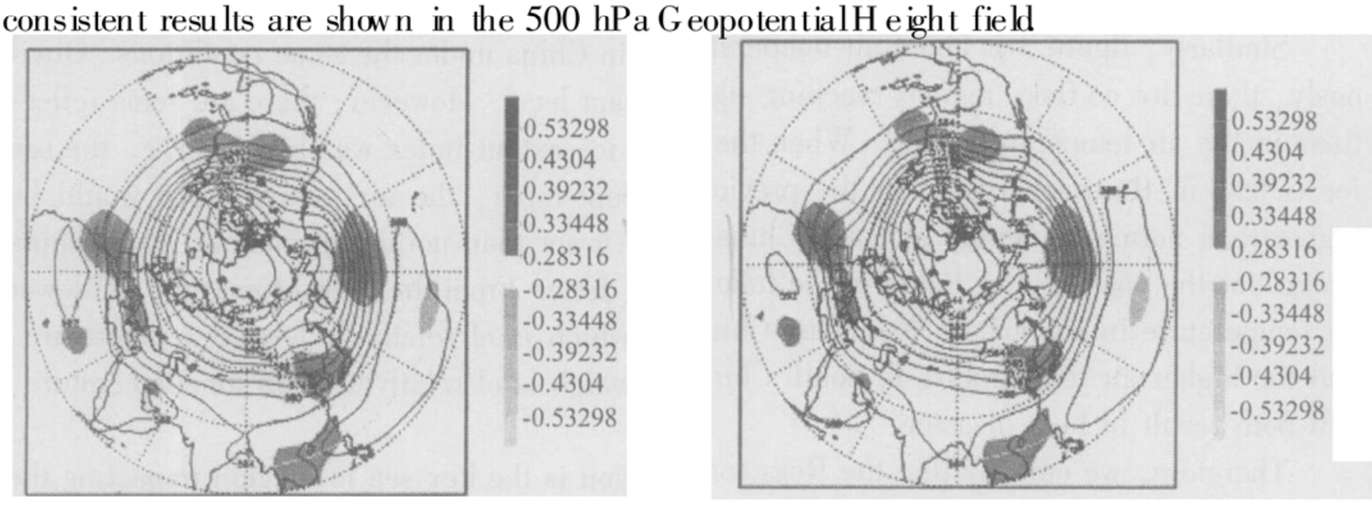
Similarly, figure 3 is about air temperature in China under the same conditions. Obviously, there are no flaky regions reaching significant level. However, there are some reflections in the air temperature field. When the sea ice extent index was higher, i. e. the sea ice is less in Ross sea region in the previous September, the air temperatures would be higher than normal generally in South China and lower than normal in most of North China except for the coastland of Bohai in the following June. From the view of energy, the lower air temperature in summer in Northeast China, which is of relatively low air temperature, and the higher air temperature in South China, which is of relatively high air temperature, will both result in heat disaster.

Therefore, we can say that the Ross sea region is the key sea ice region impacting the precipitation in Northeast China in summer. As we know, there is apparent increase in the interannual variations of Ross sea ice (Ma *et al.* 2004), and if the sea ice in this region increased in the previous September, the precipitation in Northeast China in the following June will be less than normal.

4 Sea ice in Weddell Sea Region and the climate in summer of China

As analyzed above, there is good remote correlation between the sea ice in Ross Sea region and the synoptic climate in summer of China. Ross Sea region can be taken as a key region of sea ice to the summer climate of China. So, what is the situation for the sea ice in Weddell Sea region, which is also of great seasonal variations? What impacts it will bring to the summer climate of China? Similar analyses were done (figures are omitted).

The results showed that the good correlation between sea ice extent of Weddell Sea region and atmospheric circulation in NH will first show up in the East Pacific Ocean and West Atlantic Ocean, which behaves as large-scale negative correlation, and then behaves as positive correlation in part of East Europe and East Asia. That is to say, the influence of Weddell Sea ice on atmospheric circulation of western hemisphere (WH) is earlier than on that of eastern hemisphere (EH), which is the hemisphere China locates. In June, no matter on 500 hPa or 100 hPa Geopotential Height field, obvious negative correlations between Weddell sea ice extent in the previous summer and fall (Dec.-Jun.) and atmospheric circulation in NH present in the region of East and West Pacific Ocean, West Atlantic Ocean, and India-Arabian Sea. That is to say, NPH and Tibetan High will be weaker when there is higher sea ice extent index, which means less sea ice in the previous December to June. The correlation in the same region turns to be positive when talking about the impact of Weddell Sea ice in the previous July to November, which is embodied in the region of Northwest Pacific Ocean, East Europe, East Asia and North America in 500 hPa Geopotential Height field and the region of East Europe and West Asia in 100 hPa Geopotential Height field. In other words, NPH will be stronger and Northeast Low will be weaker when there is higher sea ice extent index, which means less sea ice. For the atmospheric circulation in NH in July, it is the similar to that in June. In order to show in detail, the superimposed field of 500 hPa Geopotential Height in Northern Hemisphere in June when Weddell Sea ice extent index is higher and lower than normal in the previous September and their correlation field in the corresponding period are listed, as shown in Figure 4a and 4b. We can see that there is apparent positive correlation in the region of Northeast China and the coast of Southeast China. This indicates that the higher Weddell Sea ice extent index will cause the ridge point of NPH moving westward and East Asian Trough to be weaker. The consistent results are shown in the 500 hPa Geopotential Height field.



a. higher index   b. lower index

Fig. 4 The superimposed field of 500 hPa Geopotential Height field in Northern Hemisphere in June when Weddell Sea ice extent index is higher and lower than normal in the previous September and their correlation field in the corresponding period

Correspondingly, the superimposed field of precipitation in China in June due to the anomaly of Weddell Sea ice extent index in the previous September and their correlation field in the corresponding period are shown in Figure 5. Although there is no large pack of significant correlation in the correlation field showing as curve, there are still some reflections in the precipitation field. More and less precipitation will occur in the region of Yangtze River and Northeast China respectively.

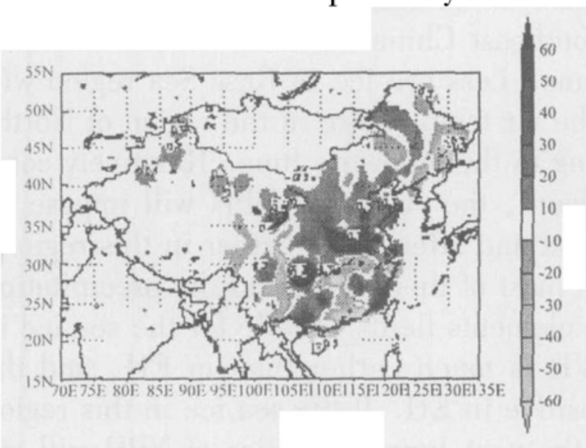


Fig. 5 Superimposed field of precipitation in China in June due to the anomaly of Weddell Sea ice extent index in the previous September and their correlation field in the corresponding period

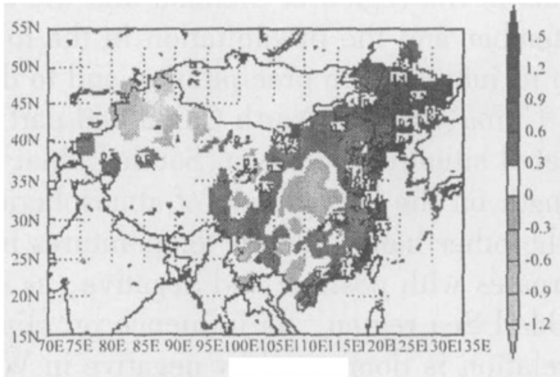


Fig. 6 Superimposed field of air temperature in China in June due to the anomaly of Weddell Sea ice extent index in the previous September and their correlation field in the corresponding period

Similar to figure 5, Figure 6 shows the variations of air temperatures in the same conditions. It indicates that there is flaky area of positive correlations in Northeast China and the coast of Southeast China, and the increases of air temperature in these regions are the greatest. However, although there is no apparent correlation in the region of northern Xinjiang, Qinghai and Middle China, the air temperature decreases in these regions, as shown in the air temperature field (shaded area).

So, the influence of sea ice in Weddell Sea region on the atmospheric circulation in East Asia in EH is much later than in WH, and the negative correlation dominate in WH, while in East Asia the positive correlation dominate. Although the impact of Weddell Sea ice on the summer climate in China is not as strong as that of Ross Sea ice, as indicated from correlation field, it can be still taken as the key sea ice region to the air temperature in Northeast China. The more sea ice in this region in the last September will cause the lower air temperature in Northeast China in the following June.

5 Conclusion and Discussion

Different sea ice regions in Antarctica are of different trend of sea ice variations, and different Antarctic sea ice variations must have different influence on the atmospheric circulation in NH. Research on the variations of sea ice extent in the recent 35 years indicates that there is obvious increasing trend for the sea ice in Ross Sea region and Weddell Sea region, while in Antarctic Peninsula the trend is decreasing (Ma *et al.* 2004). As a whole, the sea ice in both Ross Sea region and Weddell Sea region are of indicative meanings for the climate in summer of China.

In order to investigate the impacts of sea ice in Ross Sea region and Weddell Sea region on the climate in summer of China, 500 hPa and 100 hPa Geopotential Height, precipitation and air temperature in 160 meteorological stations in China are used besides the sea ice concentration data. Results disclose that the sea ice in Ross Sea region, which is of obvious seasonal variations, is the key to the precipitation in Northeast China in summer. There are significant positive correlations in Northeast China and significant negative correlations in the region of Sichuan and the coast of Southeast China between sea ice extent in September and the precipitation in the following June. Less sea ice in Ross Sea region will help to increase the precipitation and to decrease the air temperature in the region of Northeast China, most of North China and part of Xinjiang in the following June. Relatively complicated situation occurs in South China. On one hand, the enhanced NPH will impose its strength on the background of atmospheric circulation and affect the weather in this region; on the other hand, the air temperatures increase in most of this region and the precipitation alternates with positive and negative, as seen from elements fields. While for the sea ice in Weddell Sea region, its influence on climate in WH is much earlier than in EH, and the correlation is dominated by negative in WH and positive in EH. If the sea ice in this region is less than normal about 7 to 10 months ahead of the next June, the ridge of NPH will extend westward than normal and the Northeast Low will be weaker in June. Weddell Sea region is the key sea ice region to the air temperature in Northeast China. There is good positive correlation between the sea ice in September and the air temperature in Northeast in the following June. If the sea ice is less than normal in September, the air temperature and precipitation in the following June will be higher and less respectively in Northeast and South China; by contraries, the air temperature and precipitation will be lower and more in the northern Xinjiang and Middle China.

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