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The coupled characteristics of the physical process between sea ice of two poles and Tibetan land surface

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Abstract In order to discuss the characteristics of sea ice change of strong signal area on Antarctic and Arctic and the correlation between the thermal state on the land surface of Tibetan Plateau and the atmosphere circulation of North Hemisphere or the climate changes in China, and to study the feedback mechanism among "three-pole" factors, the earlier stage "three-pole" strong signal characteristics by using statistic methods such as teleconnection, which affect the regional climate changes in China and East Asia. The cross-correlation feature and coupling effect between ice caps of North and South pole and water-thermal state on Tibetan Plateau surface are discussed as well. The contribution of three-pole's earlier stage factors to China's summer climate change and the influence of its dynamic structure are compared here. The formation mechanisms of global climate change and regional climate change of China are investigated from the aspect of qualitative correlation mode of global sea-land-air-ice.
Key words Antarctic, Arctic, cryosphere, sea-ice, plateau, climate change.

1 Introduction

Cryosphere is an important active member of climate system. Antarctic, Arctic and Tibetan Plateau are called "three-pole". The changes of ice area on Antarctic and Arctic surface and the state of water-thermal on Tibetan Plateau surface contribute not only to the formation of global climate but also to the maintaining and development of abnormal phenomena. The effects of cryosphere on the balance of moisture and energy and their cycle in global climate system are notable. It can be seen from the following calculation that, in time scale, the most obvious change is the seasonal change of ice cover and its largest monthly change area has the same order as the total area of sea ice and surface. Those area with significant seasonal change is called strong signal area. The characteristics of ice cover process and its water-thermal process on Antarctic, Arctic and Tibetan Plateau, (or so-called as "three-pole"), are analyzed in this paper. The teleconnection characteristics among ice cover change on "two-pole" (Antarctic and Arctic), thermal state on Tibetan Plateau, atmosphere circulation system on North Hemisphere and climate change in China are also discussed. Moreover, the effects of "three-pole" factors on the regional climate change in winter and summer of North Hemisphere are emphasized.

2 Strong signal characteristics of the temporal and spatial variations of sea ices of two-pole

The influence of large-scale ice cover of two-pole on the global climate and the long-term climate change in China are disclosed by a quantity of statistic facts and climatic analysis. Sukla (1968) considered that though the area of ice cover is only a small proportion of the whole global surface, the effect of ice cover on atmospheric circulation in polar region is remarkable. Moreover. the effect can propagate to mid-latitude and subtropical belt under the good dynamical condition of synoptic stream. The difference of the regional characteristics between two-pole are notable.

It is the polar strong signal area which probably affect the global climate that needs us to study. We have a statistic study on monthly database of Antarctic and Arctic from January 1973 to September 1990 provided by Walsh. As shown in Fig. 1a and Fig. 1b, we divide Antarctic and Arctic area into 36 regions according to their azimuth and calculate the ice cover of them month by month. We divide Antarctic into 4 regions (Fig. 2a) according to the distribution of variance extreme value. The interannual change of the fourth region is the most obvious (Fig. 1a). We divided Arctic into three regions (Fig. 2b) and the interannual change of the third region is the most obvious, which is the same as calculation of Peng *et al*. (1992). Moreover, Peng *et al*. (1992) pointed out that the main reasons for the difference of interannual change are: (1) the distribution of sea and land in each region is different and the third region has larger area of sea; (2) influence of ocean current on the spreading and withdraw of the sea ice. The regions that have extreme value of interannual change in Antarctic and Arctic are strong signal regions where poles affect global climate. There are remarkable differences between interannual change extreme regions in Antarctic and Arctic and the diversification in Antarctic is further more obvious than that in Arctic. The characteristics of strong signal in Antarctic are especially remarkable.

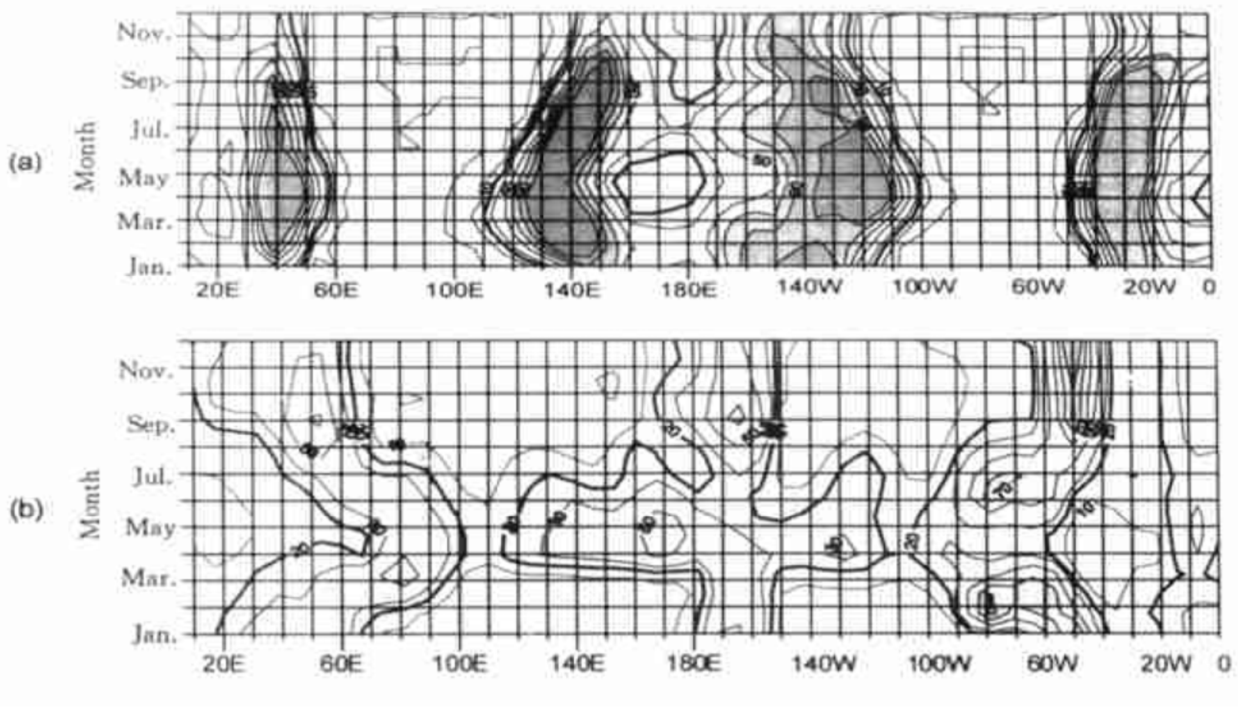

Fig. 1. Variance of Antarctic (a) and Arctic (b) sea ice distribution in 36 regions.

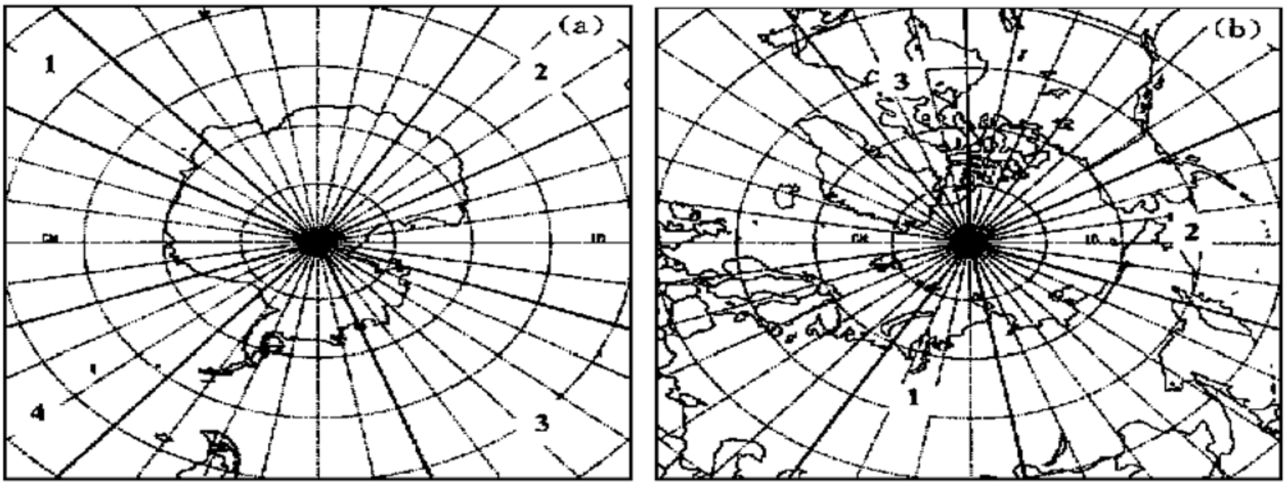

Fig. 2. Distribution of Antarctic (a) and Arctic(b) regions.

The correlation coefficient among the sea ice area index number of all regions in Antarctic and Arctic in all months is listed in Table 1. It is disclosed in Table 1 that the most obvious durative region in all months, which is the forth region in Antarctic and the third region in Arctic in turn has the biggest interannual change. Moreover, the durative characteristic of continuous months in Antarctic is more obvious than that in Arctic. The above statistic studies indicate that the interannual change extent and its durative characteristic in Antarctic strong signal region is more obvious than that in Arctic, which affects global climate.

Table 1. Correlation coefficient of Antarctic and Arctic sea ice areas between adjacent months

Antarctic sea ice	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	Average
30℃E–50℃E	0.47	0.79	0.77	0.25	0.79	0.62	0.49	0.79	0.67	0.59	-0.11	0.58
120℃E–150℃E	0.5	0.8	0.81	0.56	0.83	0.76	0.68	0.82	0.5	0.52	0.41	0.65
160℃W - 110℃W	0.69	0.71	0.8	0.66	0.89	0.65	0.78	0.83	0.22	0.48	0.53	0.66
50℃W - 20℃W	0.85	0.74	0.76	0.64	0.94	0.67	0.82	0.74	0.34	0.58	0.44	0.68
Total area	0.77	0.79	0.7	0.71	0.92	0.72	0.8	0.71	0.33	0.65	0.42	0.68
Arctic sea ice	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	Average
60℃E - 100℃E	0.3	0.59	0.44	0.6	0.25	0.84	0.71	0.89	0.45	0.7	0.12	0.54
160℃E - 150℃W	0.22	0.47	0.64	0.89	0	0.65	0.69	0.71	0.18	0.63	0.5	0.51
90℃W - 60℃W	0.08	0.49	0.72	0.92	0.15	0.83	0.65	0.62	0.19	0.86	0.56	0.55
Total area	0.02	0.42	0.64	0.85	0.36	0.86	0.63	0.38	0.41	0.86	0.68	0.56

3 Strong signal stations in Tibetan Plateau in spring

Just like regional characteristics in Antarctic and Arctic strong signal regions, it is disclosed that Shiquanhe in western Tibetan Plateau is the strongest signal station of spring vapor pressure in Tibetan Plateau and Zeku is the second one according to Xu´s results(1995). Zeku is the strongest signal station of spring relative humidity and Lhasa is the second strongest as shown in (Fig. 3a) and (Fig. 3b).

4 The effects of strong signal factor in three-pole on the precipitation and temperature in China in summer and its comparison of correlation and interaction chracteristics

We calculated correlation among five stations of Tibetan Plateau, four regions of

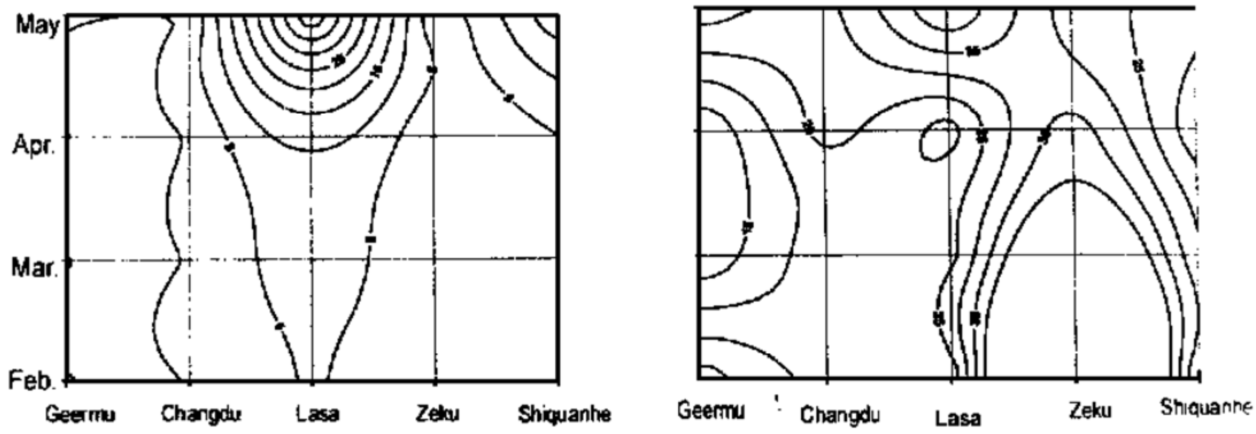

Fig. 3. (a) Vapor pressure variance of Tibetan Plateau; (b) Relative humidity variance of Tibetan plateau.

Antarctic, three regions of Arctic and precipitation of 160 stations of China in summer. It is disclosed that strong signal regions of three-pole have the most obvious correlated characteristics about the precipitation of China in summer. In addition, Antarctic, Arctic and Tibetan Plateau differ in the correlation field with high correlation coefficient for precipitation of China.

Fig. 4a is correlation diagram between surface vapor pressure of Shiquanhe in spring and precipitation of China in summer. The figure indicates that the vapor pressure of Shiquanhe in the strong signal region of Tibetan Plateau has high correlation coefficient with the precipitation of the middle and lower reaches of the Changjiang River of China in summer with the center value of 0.59. Fig. 4b is correlation diagram between sea ice area index of strong signal region of Arctic (the third region) in spring and precipitation of China in summer. Fig. 4b indicates that the correlation is obvious. Large scale regions of Hetao and the east of it have high correlation coefficient and the center value is − 0.71. Fig. 4c is correlation between sea ice area index of strong signal of Antarctic (the fourth region) in spring and precipitation of China in summer. It is notable that Guanzhong plain and the middle and lower reaches of Changjiang River have high negative correlation coefficient and the center value is − 0.61. Northeast plain have high positive correlation coefficient and the center value is 0.62.

5 Respondence of the characteristic of atmospheric circumfluence of Northern Hemisphere in summer to the earlier stage factor of three-pole

It is disclosed by Peng *et al*. (1992) that atmosphere, ocean and sea ice are three important members in climate system. They are interacting and restricting each other and their effects on global climate system are more obvious in winter than that in summer. Unconventionality of atmospheric circulation responses to abnormal increase of sea ice of Arctic both in synchronization and with lag effect, moreover, the latter is more obvious. The correlation coefficient field between sea ice of Antarctic and Arctic in spring and in winter, relative humidity and vapor pressure of five stations of Tibetan Plateau and height field on 500 hPa of Northern Hemisphere in summer (Fig. 5) are calculated. The results of calculation further prove the issue of Peng *et al*. (1992). In details, there is stronger correlation between the Arctic second area where Bering Strait lies and height

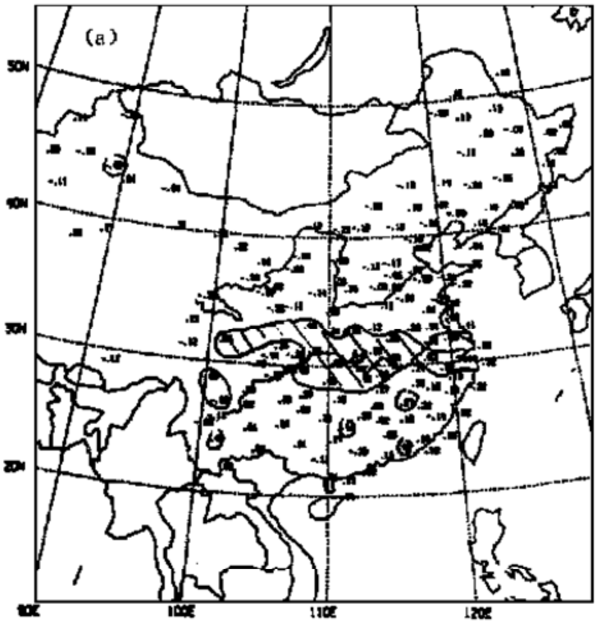

Fig. 4a Correlation field between vapor pressure of Shiquanhe in spring and precipitation of 160 stations of China in summer.

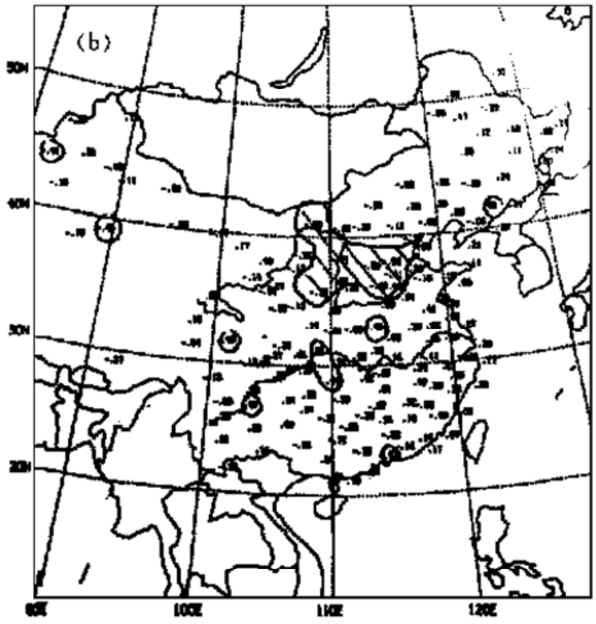

Fig. 4b Correlation field between Arctic sea ice (90°W - 60°W) in spring and precipitation of 160 stations of China in summer.

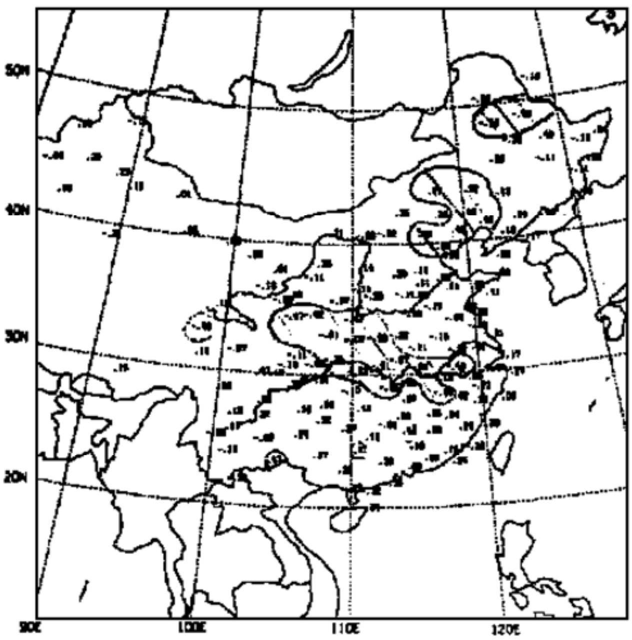

Fig. 4c. Correlation field between Antarctic sea ice (50°W - 20°W) in spring and precipitation of 160 stations of China in summer.

field on 500 hPa of Northern Hemisphere and significant negative correlation exists in Tibetan Plateau and its northern part. The calculated results show that the third area of Arctic also has influence on rainfall of China area besides the second area of it. Peng *et al*. (1992) also pointed out that not only the sea ice of Arctic has influence on subtropical high pressure system of western North Pacific, but also the sea ice of Antarctic has influence on the westerly winds atmosphere of Southern Hemisphere through the cooling ability of Antarctic atmosphere to cause abnormal cyclone in pole area. Furthermore, the sea ice of Antarctic can also change characteristics of subtropical high pressure system on Southern Pacific and meridional exchange extent of heat, and it has also influence on the extent and position of subtropical high pressure on eastern North Pacific. Compared to Fig. 5, it is disclosed that the sea ice of Antarctic has negative correlation with height field on 500 hPa of Northern Hemisphere and Tibetan Plateau, so it is concluded that Antarctic has more influence on Northern Hemisphere than Arctic does. The sea ice of Antarctic and Arctic in spring and in winter has influence on height field of Northern Hemisphere and it appears significant in phase or out phase difference among many areas. These disclosed the regional characteristics of climate activity of height field on 500 hPa of Northern Hemisphere corresponding to the sea ice of Antarctic and Arctic in spring and in summer. In detail, there exists resonance characteristic on some areas and weak characteristic on the others as well.

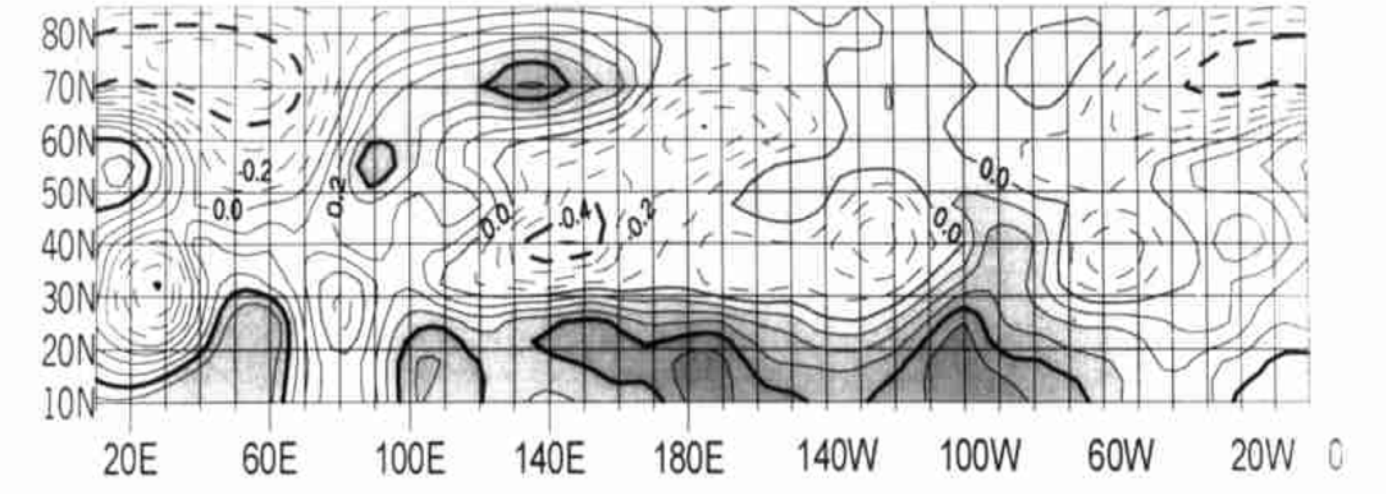

Fig. 5a. Correlation field between Shiquanhe relative humidity in spring and field of 500 hPa height in summer.

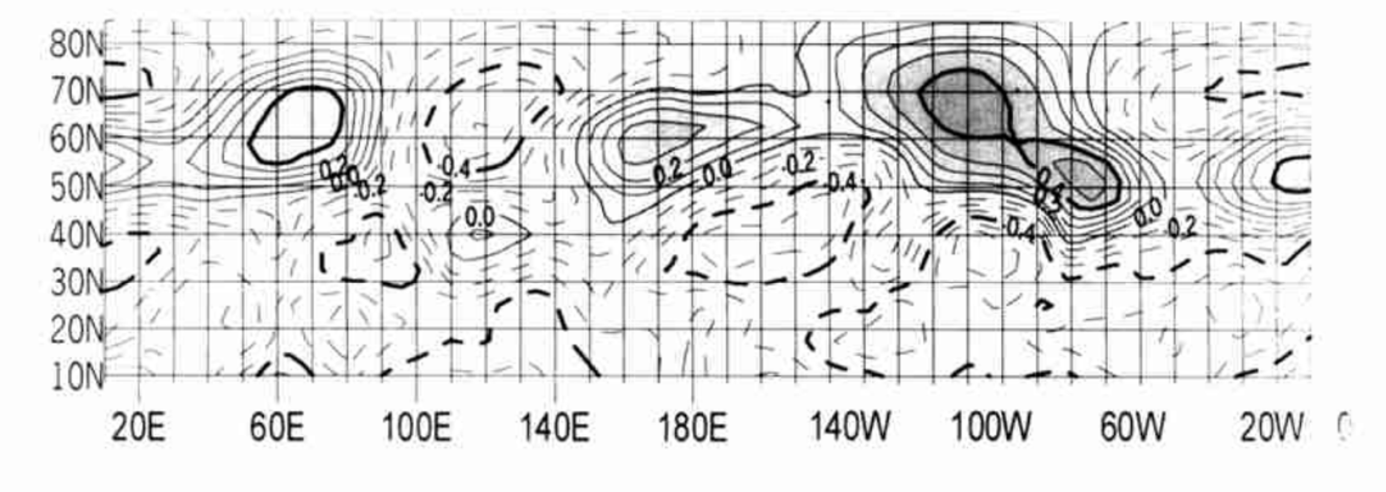

Fig. 5b. Correlation field between Antarctic sea ice (120°E - 150°E) in spring and field of 500 hPa height in summer.

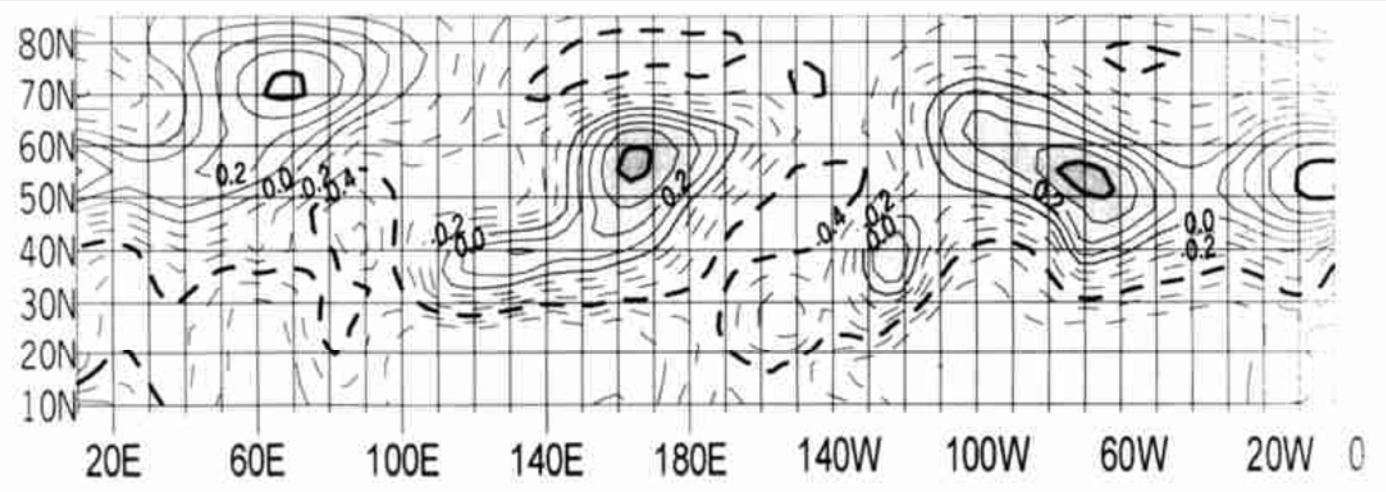

Fig. 5c. Correlation field between Antarctic sea ice (120°E - 150°E) in winter and field of 500 hPa height in summer.

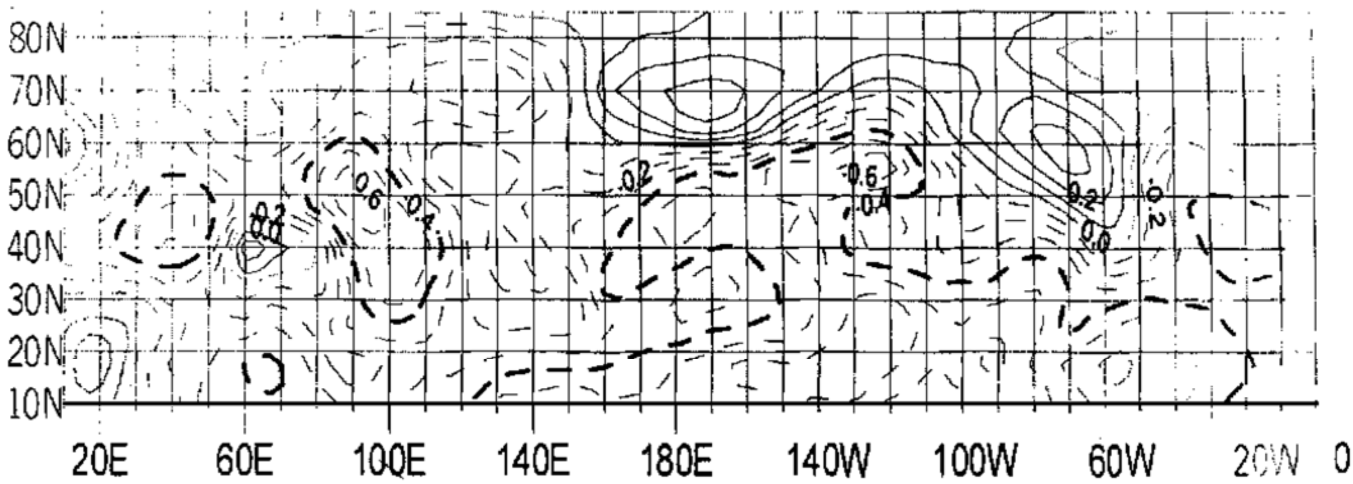

Fig. 5d. Correlation field between Arctic sea ice (160°E – 150°W) in spring and field of 500 hPa height in summer.

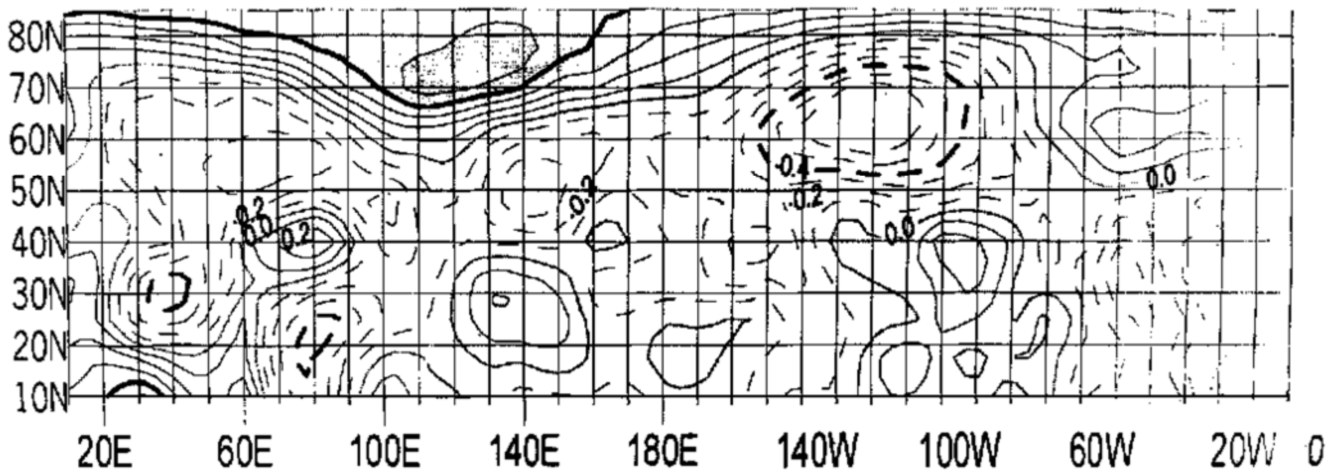

Fig. 5e. Correlation field between Arctic sea ice (160°E – 150°W) in winter and field of 500 hPa height in summer.

6 Correlation of feedback of ice-atmosphere condition among three-pole

Cryoshpere has significant influence on equalization of heat and moisture of global climate system. Feedback between heat and moisture on Tibetan Plateau and sea ice of Antarctic and Arctic reflects interaction among three global cold sources in winter. It also reflects feedback effect of ice-atmosphere-ice whose atmosphere is a medium for these cold source. The correlation matrix (Table 2 – 6) between monthly average coefficient of sea ice of Antarctic and Arctic with precipitation and temperature on Tibetan Plateau are calculated in this paper.

According to lag-correlation degree in Table 2 and Table 6, there exists significant seasonal lag-correlation among three-pole. Form Fig. 6, we can see that the characteristics of lag-correlation between two areas are different. The arrow A – > B shows that A surpasses B. Namely, the earlier stage factor A has influence on later stage factor B. According to the above statistic analysis, it is noticeable that the sea ice of Antarctic has opposite correlation with that of Arctic and it may reflect that the global cryospheres restrict each other.

Table 2. Correlation coefficient between Antarctic sea ice and Arctic sea ice

Antarctic \ Arctic	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Spring	− 0. 07	− 0. 50	− 0. 04	− 0. 49	0. 17	− 0. 13	0. 25
Summer	− 0. 18	− 0. 38	− 0. 05	− 0. 32	0. 18	− 0. 05	0. 13
Autumn	− 0. 13	− 0. 13	− 0. 19	− 0. 60	− 0. 13	0. 07	− 0. 25
Winter	0. 61	0. 00	0. 09	− 0. 26	0. 17	0. 19	0. 16
Spring	− 0. 19	− 0. 26	0. 51	0. 00	− 0. 10	− 0. 44	0. 03
Summer	− 0. 28	− 0. 15	0. 30	− 0. 03	− 0. 16	− 0. 27	− 0. 01
Autumn	− 0. 14	0. 10	0. 21	0. 04	− 0. 06	0. 10	− 0. 12

Table 3. Correlation coefficient between temperature in Tibetan Plateau and Arctic sea ice

Arctic \ Tibetan Plateau	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Spring	− 0. 13	− 0. 39	− 0. 39	0. 10	− 0. 21	0. 28	− 0. 21
Summer	− 0. 19	0. 22	− 0. 19	0. 21	− 0. 33	0. 33	− 0. 31
Autumn	− 0. 02	− 0. 09	0. 28	0. 22	− 0. 03	− 0. 10	0. 31
Winter	0. 02	0. 47	− 0. 08	− 0. 34	− 0. 09	0. 19	0. 16
Spring	− 0. 46	0. 00	− 0. 20	− 0. 27	− 0. 03	− 0. 15	− 0. 30
Summer	− 0. 23	0. 09	− 0. 61	− 0. 42	− 0. 01	0. 38	− 0. 09
Autumn	0. 47	0. 08	− 0. 20	− 0. 52	0. 02	− 0. 08	0. 28

Table 4. Correlation coefficient between temperature in Tibetan Plateau and Antarctic sea ice

Antarctic \ Tibetan Plateau	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Spring	0. 26	− 0. 28	0. 40	− 0. 04	0. 09	− 0. 43	0. 21
Summer	0. 17	0. 08	0. 56	− 0. 10	− 0. 04	− 0. 13	0. 33
Autumn	0. 01	− 0. 08	0. 30	0. 15	0. 03	0. 10	0. 42
Winter	− 0. 13	− 0. 12	− 0. 01	0. 18	0. 02	0. 10	0. 33
Spring	0. 02	− 0. 20	0. 47	0. 10	0. 17	− 0. 23	0. 49
Summer	0. 01	− 0. 11	0. 29	− 0. 04	0. 11	0. 15	0. 62
Autumn	− 0. 28	0. 18	− 0. 22	− 0. 01	− 0. 13	0. 12	0. 46

Table 5. Correlation coefficient between precipitation in Tibetan Plateau and Arctic sea ice

Arctic \ Tibetan Plateau	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Spring	− 0. 10	0. 16	0. 08	− 0. 08	0. 11	− 0. 47	− 0. 03
Summer	− 0. 19	− 0. 31	0. 16	− 0. 09	− 0. 26	− 0. 14	0. 44
Autumn	0. 22	0. 05	− 0. 27	0. 04	0. 22	0. 10	− 0. 20
Winter	− 0. 03	− 0. 37	0. 01	0. 25	− 0. 15	− 0. 01	0. 00
Spring	− 0. 39	− 0. 43	− 0. 35	0. 33	− 0. 18	− 0. 06	− 0. 14
Summer	− 0. 22	− 0. 22	0. 00	− 0. 07	− 0. 27	− 0. 47	− 0. 17
Autumn	− 0. 33	0. 08	0. 31	0. 23	0. 20	0. 03	− 0. 27

Table 6. Correlation coefficient between precipitation in Tibetan Plateau and Antarctic sea ice

Antarctic \ Tibetan Plateau	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Spring	− 0. 22	0. 17	− 0. 14	0. 01	0. 12	0. 19	− 0. 25
Summer	− 0. 32	− 0. 08	− 0. 29	− 0. 06	− 0. 14	− 0. 12	− 0. 40
Autumn	0. 12	0. 18	− 0. 26	− 0. 26	− 0. 05	− 0. 10	− 0. 14
Winter	0. 01	0. 01	0. 03	− 0. 28	0. 05	− 0. 24	− 0. 12
Spring	0. 43	0. 00	− 0. 41	− 0. 10	− 0. 20	0. 16	− 0. 07
Summer	0. 29	0. 07	− 0. 47	− 0. 05	− 0. 31	− 0. 12	− 0. 26
Autumn	0. 03	− 0. 21	− 0. 42	0. 08	0. 16	− 0. 05	− 0. 32

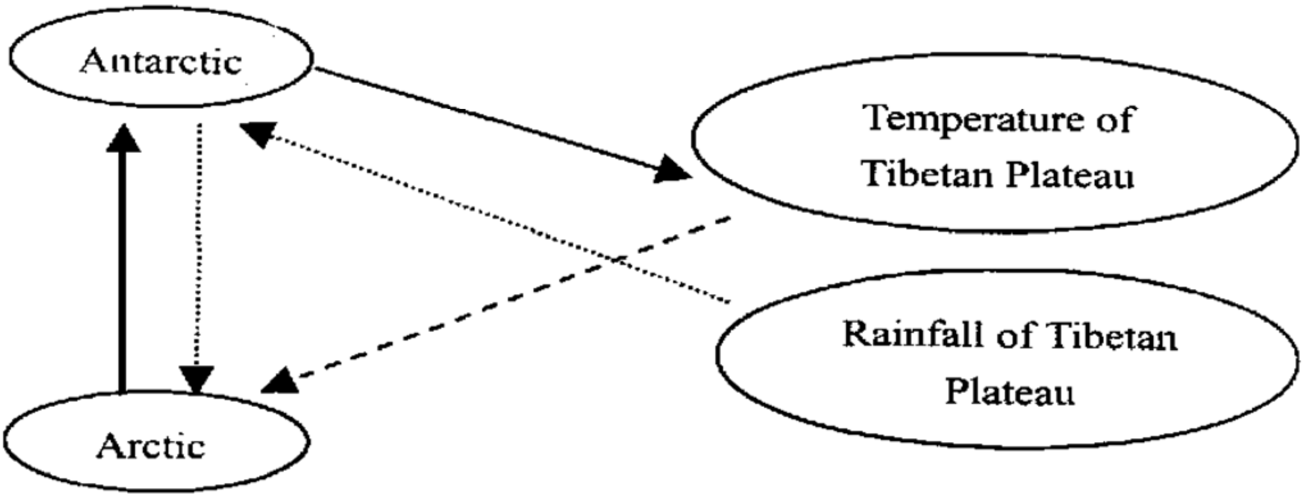

Fig. 6. Connection among three-pole.

The correlation of feedback among three-pole, to some extent, describes physical characteristics of global energy and moisture among Antarctic, Arctic and Tibetan Plateau.

7 The influence of sea ice of two poles in winter on moist structure over Tibetan Plateau in spring

Balance of moisture and energy among three-pole is realized through transmitting of atmosphere energy and moisture circulation. The correlation characteristics among sea ice of two poles in winter and moisture structure over Lhasa in Tibetan Plateau in spring are

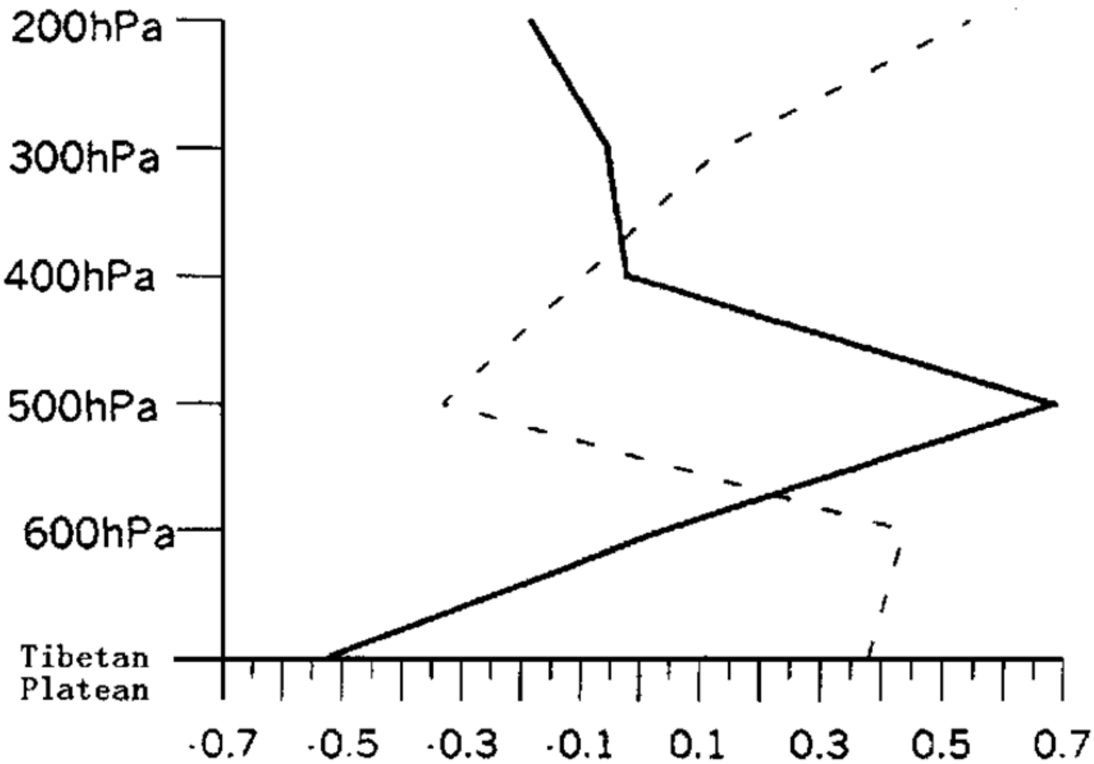

Fig. 7. Correlation coefficient between Lhasa T-Td and Antarctic sea ice(50°W − 20°W) in winter and Correlation coefficient between Lhasa T-Td and Arctic sea ice(90°W − 60°W) in winter. - : Arctic; —: Antarctica.

described in this paper. The correlation of strong signal area of Antarctic sea ice in winter and that of Arctic with Lhasa's T-Td vertical structure in spring is shown in Fig. 7. Through Fig. 7, it is disclosed that the effect of Antarctic, winter sea ice on the content of moisture over Lhasa in spring is significant different from that of the Arctic one. Moreover, it shows opposite characteristics between Antarctic and Arctic. Especially, the correlation of lower and middle levels on 500 hPa and 600 hPa is more significant than that of higher levels and the most obvious correlation level is 600 hPa in Antarctic and 500 hPa in Arctic and on the surface. In addition. the correlation extent between sea ice and Plateau is greatly different on vertical structure in Arctic strong signal area, but the influence of that in Antarctic and Tibetan Plateau is obvious only on specific levels. It reflects the difference of three-dimensional characteristics between Antarctic and Arctic in moisture circulation and energy spreading.

8 Conclusion

(1) There are strong signal areas with seasonal change in three-pole and the change extent of Antarctic sea ice is more obvious than that of Arctic.

(2) For correlation on rainfall of China area, the strong signal area of three-pole is also the most significant area of correlation. Moreover, the area with high correlation coefficient is different on Antarctic, Arctic and Tibetan plateau.

(3) Antarctic and Arctic sea ice has lag effect correlation with atmosphere circulation on Northern Hemisphere. Moreover, some areas show the resonance characteristic while other areas show weaken characteristic.

(4) The extent of the correlation characteristic on three-pole has significant difference.

(5) The strong signal areas of Antarctic and Arctic have influence on Tibetan Plateau and the vertical structure of influence is significantly different. The influence of Antarctic on Plateau is opposite to that of Arctic.

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