Chinese Journal of Polar Science, Vol 15, No 2, 75− 84, December 2004

Spatial-temporal characters of Antarctic sea ice variation

Ma Lijuan(马丽娟), Lu Longhua(陆龙骅) and Bian Lingen(卞林根)
Chinese Academy of Meteorological Sciences, Beijing 100081, China

Received October 10, 2004

Abstract Using sea ice concentration dataset covering the period of 1968-2002 obtained from the Hadley Center of UK, this paper investigates characters of Antarctic sea ice variations. The finding demonstrates that the change of mean sea-ice extent is almost consistent with that of sea-ice area, so sea-ice extent can be chosen to go on this research. The maximum and the minimum of Antarctic sea ice appear in September and February respectively. The maximum and the maximal variation of sea ice appear in Weddell Sea and Ross Sea, while the minimum and the minimal variation of sea-ice appear in Antarctic Peninsula. In recent 35 years, as a whole, Antarctic sea ice decreased distinctly. Moreover, there are 5 subdivision characteristic regions considering their different variations. Hereinto, the sea-ice extent of Weddell Sea and Ross Sea regions extends and area increases, while the sea-ice extent of the other three regions contracts and area decreases. They are all of obvious 2− 4 years and 5 − 7 years significant oscillation periods. It is of significance for further understanding the sea-ice-air interaction in Antarctica region and discussing the relationship between sea-ice variation and atmospheric circulation.
Key words Antarctic sea ice, mathematical diagnostic, spatial-temporal variation, global change.

1 Introduction

Nowadays global climate change has been an important issue in the world. Antarctic area is just the key and sensitive region, from which scientists are trying their best to find the omen of global climate change. And for the revolving global atmosphere, Polar Regions are cold source. The oceanic and atmospheric condition of Polar Regions is important to global atmospheric circulation and climate change. Antarctic area is one of the cold sources of global earth-atmosphere system, while equatorial area is its main heat source (see Zhou and Lu *et al.* 1996). And the non-even distribution of cold and heat sources on the rotating earth is just the direct reason that causes atmospheric circulation.

Sea-ice is one of the most important characters of atmospheric environment in Antarctic area. Its being and seasonal and interannual change are the most distinct characters of polar marine regime. Its high reflectivity, its restraining to the exchange of heat and vapor between ocean and atmosphere and the variation of latent heat accompanying with its growing and disappearing are all of great importance to the atmosphere heat balance in polar and high latitude regions, and consequently affecting the intensity of atmospheric cold source in

Polar Regions. Therefore, the covered area variation of polar sea ice can influence the atmospheric circulation by influencing the intensity of polar atmospheric cold source. On the other hand, the effect of sea ice in different polar areas has obvious spatial and seasonal difference on atmospheric circulation due to the non-uniformity of sea ice geographical distribution caused by land-sea distribution and ocean flow (see Zhou and Lu *et al.* 1996). The anomalous variation of Antarctic sea ice can affect on not only the local energy balance, but also on the stability and variability of global climate system including sea, air and polar ice. National Aeronautics and Space Administration (NASA) and US Navy have analyzed the climatic characteristics of sea ice earlier and done global ice analysis and forecast (Zwally *et al.* 1983; O'Lenic 1978). WMO climate annual report and IPCC assessment report also emphasize the importance of Antarctic sea ice variation (WMO 2002; IPCC 2001). And Yuan and Martinson (2000) studied not only the Antarctic sea ice and its global connectivity, but also the correlation between sea ice and ENSO and the coupling oscillation between sea ice in South Pacific and atmosphere (Yuan and Martinson 2000; Kwok and Comiso 2002; Silvia *et al.* 2001). Many domestic scientists investigated the possible relation of Antarctic sea ice, plum rain in Yangtze River Basin and West Pacific Subtropical High (Fu 1981; Peng and Wang 1989); discussed short-term climate characters in Antarctica and the possible relation between sea ice oscillation and ENSO and the temperature of Antarctic Peninsula (Zhou *et al.* 1999; Cheng *et al.* 2003); investigated the effect of Antarctic snow-ice variation on global atmospheric circulation using numerical models (see Zhou and Lu 1996). These works demonstrate that there is a close correlation between Antarctic sea ice variation and global climate change.

In the recent years, domestic and foreign scientists have done many researches on the changing characters of Antarctic sea-ice and its response and feedback to global climate change. The research on Spatial-temporal characters of Antarctic sea ice variation is of great importance in many ways, such as further understanding the interaction of sea-ice-air and its physical process in Antarctic area, discussing the effect of sea ice variation on local circulation and global atmospheric circulation, especially on the circulation in East Asia and synoptic climate in China. The spatial-temporal characters of Antarctic sea ice variation in recent 35 years are researched in this paper by the means of diagnostic analysis using the ice concentration coming from Hadley center. The effect of sea ice variation on atmospheric circulation in East Asia and the synoptic climate in China will be discussed in another paper.

2 Data and methods

Using global mean monthly sea ice concentration dataset covering the period Jan. 1871-Dec. 2002, totally 132 years, obtained from the Hadley Center of UK (http://badc.nerc.ac.uk/cgi-bin/data_browser/data_browser/badc/ukmo-gosta//data/gice), 89.5°N to 89.5°S in latitude, 179.5°W to 179.5°E in longitude and 1°×1° spatial resolution, i.e. the total number of grids for each month is 180×360. Hereinto the area between 40.5°S and 89.5°S, 179.5°W and 179.5°E in the southern hemisphere is selected in this paper, i.e. 50 grids in latitude and 360 grids in longitude, which we take as the original sea ice concentration data of Antarctic region. Systemic observation for the sea ice concentration of

Antarctic region started at the end of 60s 20th century by satellite observation. So in this data, before 1968, it only gives long term mean value (figure 1) for lack of actual observation data. And among them, from 1871 to 1942 the mean extent of Antarctic sea ice is 64°S, and from 1943 to 1967 it is 64.1°S, both of no interannual change. So here we only select the data from Jan. 1968 to Dec. 2002, totally 35 years, when there were plenty of satellite observation data, to do further research.

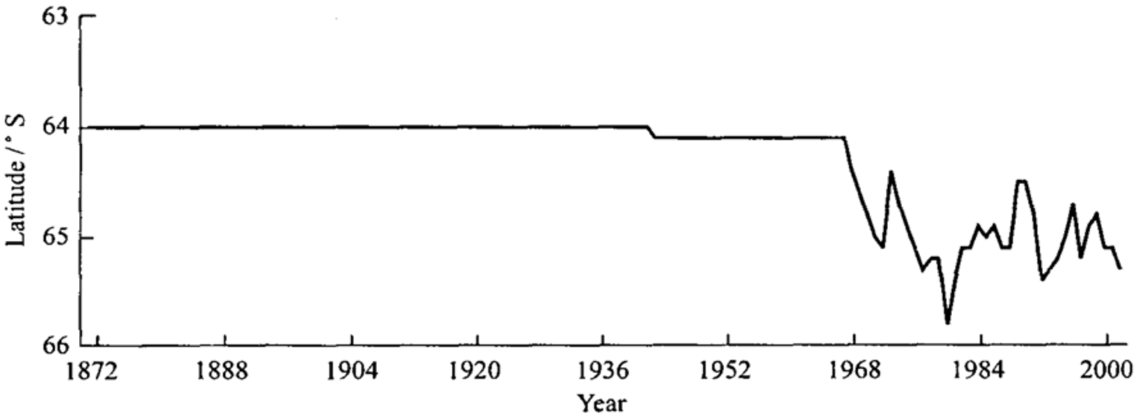
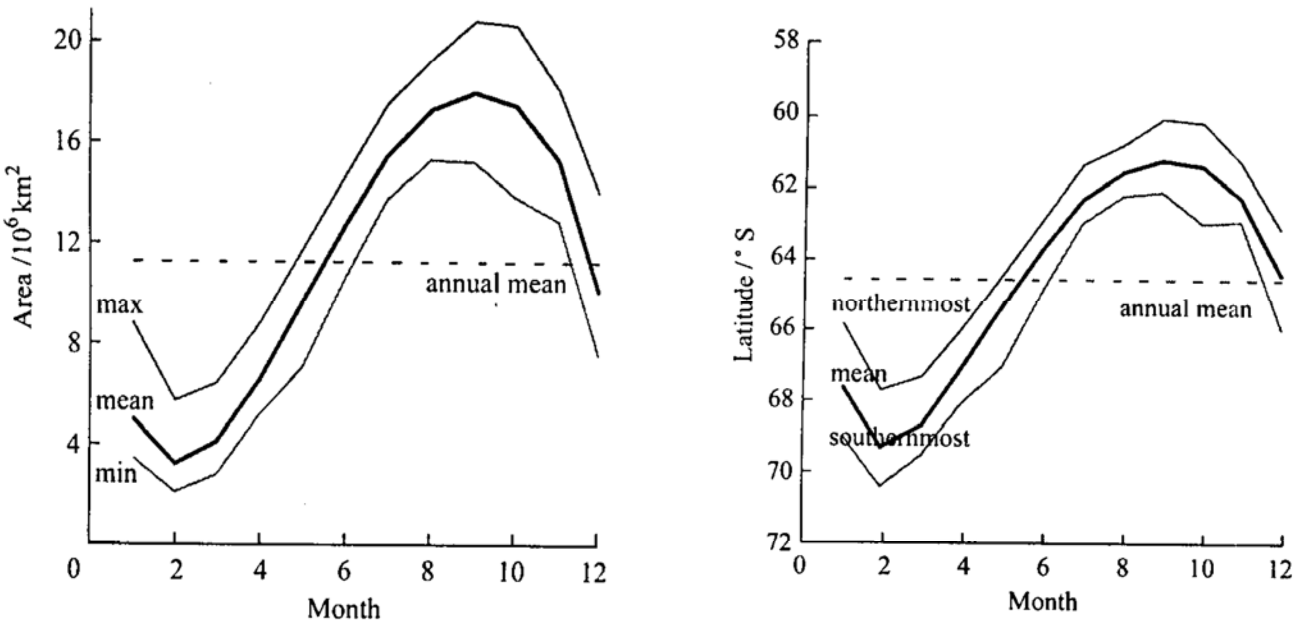


Fig. 1 The interannual variation of Antarctic mean sea ice extent



(a) Sea ice area (b) Sea ice extent

Fig. 2 The seasonal variation of total Antarctic sea ice area and extent (1968-2002).

For the large data content of sea ice concentration, mean sea ice extent of some longitude or corresponding sea ice area is usually taken as the characteristic parameters to investigate the variation of sea ice. In this paper, we defined the latitude in which its concentration is larger than or equal to 0.2 and nearest to the equator in each longitude as the sea ice extent (SIE). And when calculating the sea ice area, not only the sea ice concentration in each unit, but also the different area of each unit grid due to the different latitude were considered hereof.

Figure 2 shows the seasonal variation of total Antarctic sea ice area and extent, and it is of the same characters as that experts revealed before (O'Lenic 1978; Zhou and Lu 1996). When the value of SIE is higher, the corresponding area is smaller, and vice versa. So in order to make the expression of SIE be consistent with the sea ice area, we reverse the X-coordinate for SIE, i.e. from maximum to minimum. And for all of the similar situations occurred in this paper below, we deal with them similarly. The result demonstrates that both of them are of distinct seasonal variation. In February the sea ice area is the smallest and the location of SIE lies in the southernmost, while in September they are the largest, the northernmost and the smallest respectively. It is obvious that the seasonal variation of sea ice area and mean extent goes all the way. Figure 3 shows that there is distinct linear correlativity between area and extent of Antarctic sea ice. The correlation coefficient is up to 0.9859 and passes a significance test at 99.9%. So we unify the expression, take the SIE as the index to do regression analysis, cluster analysis and spectral analysis to analyze synthetically the spatial-temporal characters of Antarctic sea ice variation in recent 35 years because it is more convenient than sea ice area when calculating.

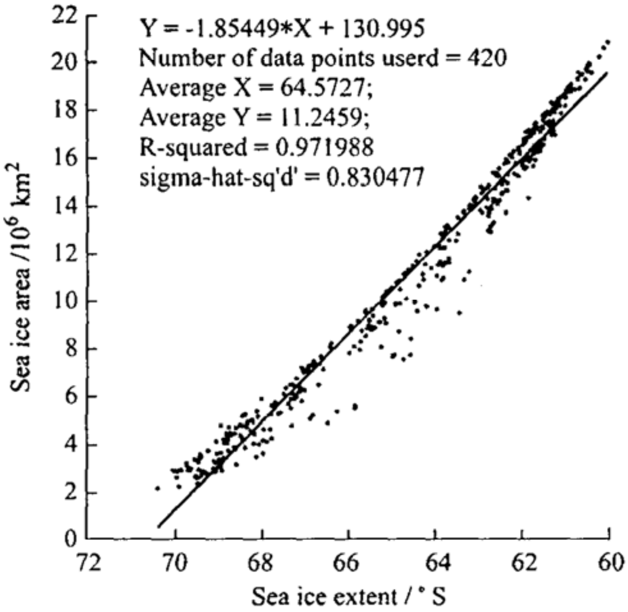


Fig. 3 The corresponding relation between area and extent of Antarctic sea ice

3 The mean character (*Distribution and temporal variation*) of Antarctic sea ice variation

3.1 *The spatial distribution and seasonal variation*

Figure 4 shows the seasonal variation of Antarctic average SIE. The dashed just outside the shadow represents the coastline of Antarctic continent and filaments represent the average SIE of each month. It indicates that although the location of extent is the nearest to the equator in East Antarctica (E), the most sea ice doesn't exist there but in Weddell Sea (W) and Ross Sea (R) due to the influence of terrain, while the least lies in the Antarctic Peninsula (P), and next the west of Ross Sea which is near to the East Antarctica (E). Besides, it demonstrates that in February the location of SIE is the lowest and the sea ice area is the smallest, while in September it is the highest and the largest respectively. From summer to winter, the freezing time is 7 months, while from winter to summer, the melting time is only 5 months. This indicates that melting rate of sea ice is quicker than freezing rate. And the biggest seasonal changing rate of Antarctic sea ice lies in Weddell Sea and Ross Sea, while the smallest lies in Antarctic Peninsula. Furthermore, it is relatively small in the west of Ross Sea.

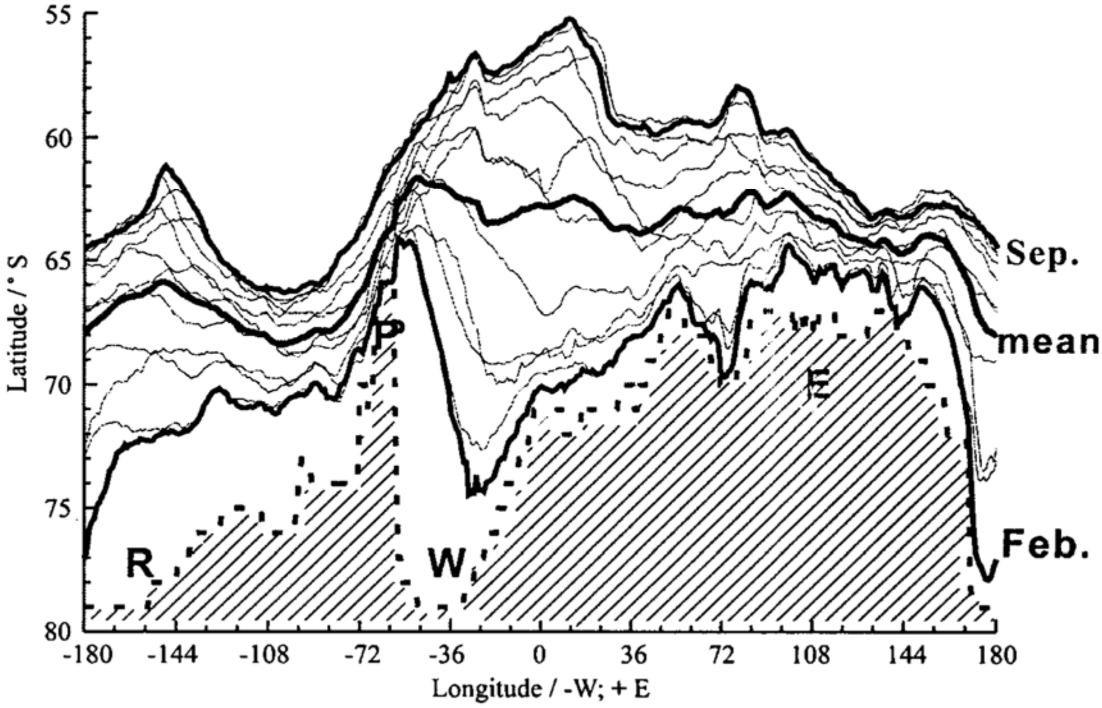


Fig. 4 The variation of Antarctic sea ice extent in longitude

3.2 *The interannual change of Antarctic sea ice*

Figure 5 gives the interannual variation of mean Antarctic SIE. As a whole, the Antarctic SIE has a trend of contraction towards South (0.1°/10a). And hereinto, it extends towards North in 80s but contracts towards South in 70s and 90s. The turning point occurred about in 1980 and 1991. Yuan *et al.* (2000) have discussed the variation of Antarctic SIE using the data from Oct. 1978 to Dec. 1996 and pointed out that the mean extent of sea ice had a trend of expanding towards the equator. But it isn't incompatible with the result of this paper. Because during different period, the extent of sea ice has different changing trend and this also can be found in figure 5.

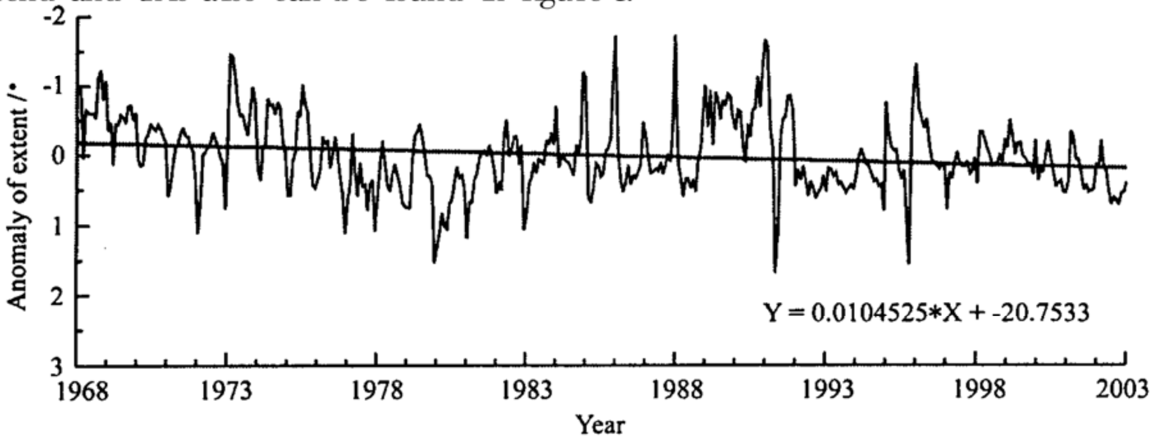


Fig. 5 The interannual variation of mean Antarctic sea ice extent

3.3 *The interannual variation of sea ice in each longitude*

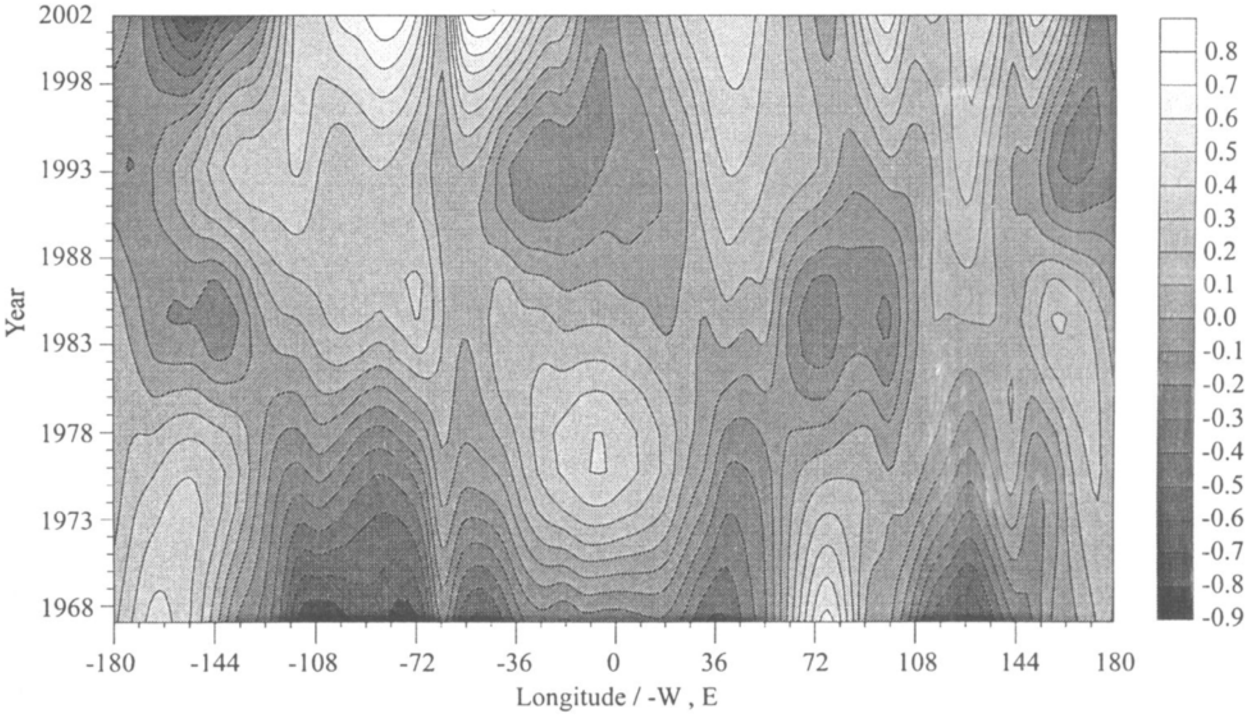


Fig. 6 The temporal-latitudinal section drawing of Antarctic sea ice extent anomalies

Figure 6 gives the interannual variation of SIE anomalies. The negative value (black) represents the SIE is partial to the north and the corresponding sea ice area is larger than average, while things reverse for the positive value (white) and the corresponding sea ice area is smaller than average. It indicates that it is of large regional difference for the interannual variation of Antarctic sea ice and there is distinct oscillation character between the Antarctic Peninsula and Ross Sea area. In 70s, when the sea ice of Ross Sea was less than average, the sea ice of Antarctic Peninsula was more than average. While in 80s, things reversed, less in Antarctic Peninsula and more in Ross Sea. This is consistent with the result pointed out by Cheng Yanjie in 2002 which said " there is special relation for the sea ice between the periphery of Ross Sea and the Bellingshausen Sea which is near the Antarctic Peninsula, just like a teeterboard". Meanwhile we can also see from figure 6 that there are all 2 to 3 interphase positive and negative anomalies centers during the same period and a trend propagating towards east.

4 The divisions of Antarctic sea ice and their variation characteristics

4.1 *The characteristic regions of Antarctic sea ice*

There is different variation for sea ice in different longitude because of its large regional difference. In order to compartmentalize its spatial distribution externally, cluster analysis of mean monthly extent anomaly is adopted in this paper (Lu Longhua 1984). The result (at 95% confidence level) demonstrates that there are 5 subdivision regions totally as considering their different variations (figure 7), i.e. iv: 164°E-132°W (Ross Sea); ㊆ 131°W-49°W (Antarctic Peninsula), ㊃ 48°W-23°E (Weddell Sea and its downstream); ㊄ 24°E-95°E (west of East Antarctica), ㈨ 96°E-163°E (east of East Antarctica). This is the same by and large to the cluster result compartmentalized by Zhou Xiuji and Lu Longhua in 1996 using data covering 1973-1992, totally 20 years and 10° spatial resolution. This indicates that this kind of regional division is stable and just the borderline is more subtle when using data of 1° resolution.

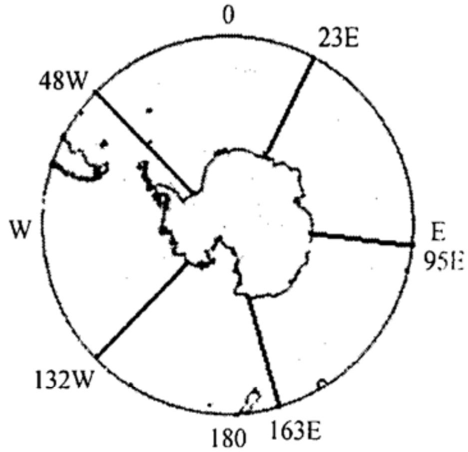


Fig 7 The five diagnostic regions for Antarctic sea ice

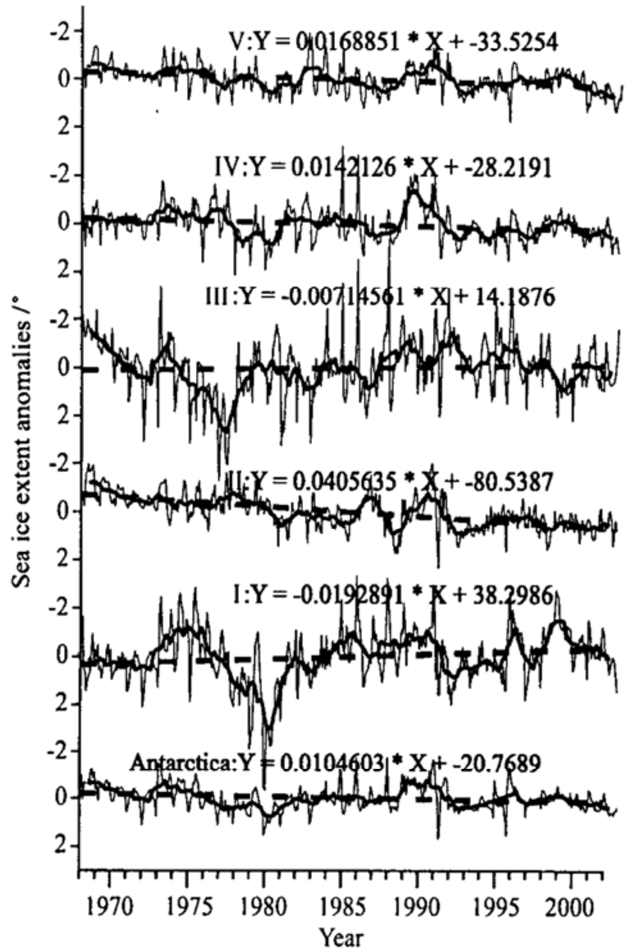


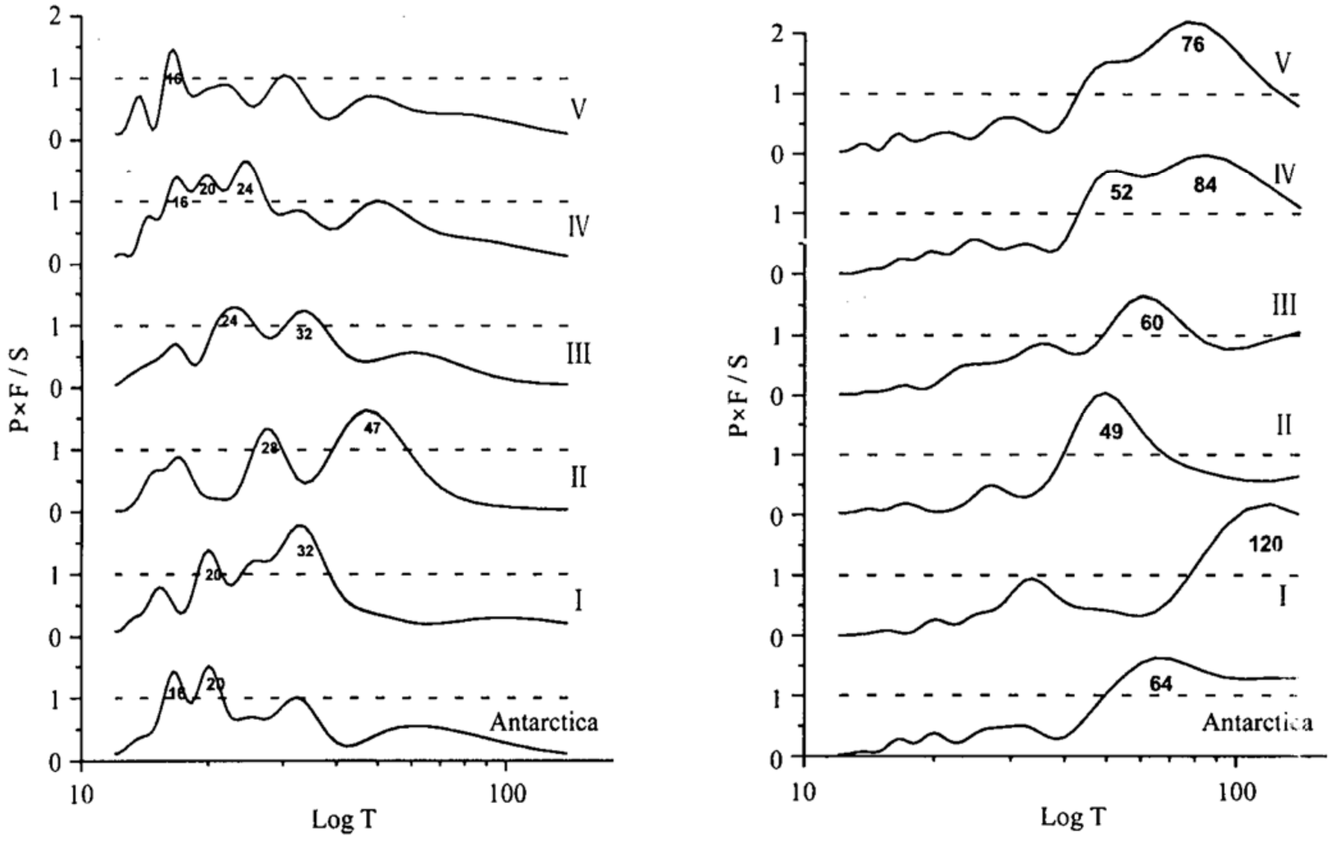
Fig 8 the interannual variation of Antarctic sea ice extent anomalies in each region

4.2 *The spatial-temporal variation characters of each subdivision region*

Figure 8 gives the changing curve of Antarctic SIE anomaly in each subdivision region.

The thick real lines represent the running mean of 13 months and the broken lines represent linear regression of sea ice variation in each region and corresponding regression equation are given respectively. It can be seen that there are different variation trends in different regions. The most distinct variation occurs in region ⅳ and region ㊃ where there are the most sea ice. Seeing from general trend, the sea ice in region ⅳ and ㊃ are increasing. In region ⅳ, the expanding rate of SIE is about 0.19°/10a and it is the most. The sea ice in region ㊆, ㊄ and ㈨ are all decreasing and it is the most distinct in region ㊆, i.e. Antarctic Peninsula region, and the contracting rate of SIE is 0.4°/10a.

The auto-spectrum of Antarctic SIE in each region is shown in figure 9. The Y-coordinate represents P × F / S, herein P represents the estimate value of power spectrum, F expresses the power and S represents the standard spectrum of non-dominant period assumption test. For some fluctuation if the ratio reaches 1, it means that this period is significant (at 95% confidence level). While at 99% and 99.9% confidence level, this ratio is 1.2295 and 1.6847 respectively (Lu *et al.* 1997). Figure 9a is the situation after band pass filter, i.e. the auto-spectrum by running mean of 12 months and difference. An significant oscillation period of 2-4 years is presented for sea ice variation. Figure 9b is the situation after low pass filter, i.e. the auto-spectrum only by running mean of 12 months. It shows that in low frequency part, there is significant oscillation period of 5-7 years. What's more, the coherence between Antarctic sea ice and some characteristic circulations such as ENSO is still waiting for further research.



(a) band pass filter (b) los pass filter

Fig 9 the auto-spectrum characteristics of Antarctic sea ice extent for each region

5 Epilogue

The spatial-temporal characters of Antarctic sea ice variation are researched in this paper by the means of diagnostic analysis using the ice concentration obtained from Hadley center. The results demonstrate: there is almost the same variation between Antarctic sea ice extent and area in different longitude. And Antarctic SIE can be used as the characteristic parameter for investigating the sea-ice spatial-temporal variation. In general, the Antarctic sea ice has decreased during the last 35 years, i. e. the extent is contracting Southtowardly. But the sea ice has different changing trend in different periods. It decreased in 70s, while increased in 80s and decreased again in 90s. Obvious seasonal variation also can be seen. It is up to the maximum in September and down to the minimum in February. The freezing rate of sea ice is much less than melting rate. And the sea ice in Weddell Sea and Ross Sea is the most and the seasonal variation is also the most obvious, while in Antarctic Peninsula it changes the least. There is large regional difference for the interannual variation of Antarctic sea ice. Distinct oscillation character exists between the Antarctic Peninsula and Ross Sea area. There is 2 to 3 interphase positive and negative anomalies centers during the same period and the fluctuations propagate eastwardly.

For the variation of Antarctic sea ice, spatial-temporal diversification obviously. There are 5 subdivision characteristic regions spatially. Although the mean SIE generally has a decreasing trend, it is quite different in different regions. Herein in region ⅳ and ㊃ the changing range is larger and the sea ice in both of the regions has an increasing trend. While in region ㊆, ㊄ and ㈨ it is all of decreasing trend. And all are of significant oscillation periods of 2 to 4 and 5 to 7 years temporally.

This systemic research on spatial-temporal characters of recent Antarctic sea ice variation can help better to understand the interaction between the Antarctic underlying surface and atmospheric circulation and offer clue for further studying the interaction between Antarctic sea ice and global climate. Meanwhile it lays the foundation for further analyzing the effect of Antarctic sea ice upon the Northern Hemisphere, especially the atmospheric circulation in East Asian Area and considering the Antarctic sea ice-underlying surface in numerical simulation, *et al*.

Acknowledgements This work was supported by the basic works of National Science and Technology Department. The authors take this chance to thank Dr. Wu Bingyi for his great help to this study.

References

Cheng YJ, Bian Lg, Lu LH (2002): The relation between Antarctic sea ice oscillation and ENSO. Quarterly Journal of Applied Meteorology, 13(6): 711–717(in Chinese).

Cheng YJ, Lu LH, Bian LG(2003): The relation among temperature in Antarctic Peninsula, Antarctic sea ice oscillation and ENSO. Chinese Journal of Polar Science, 15(2): 121–128 (in Chinese).

Fu CB(1981): The possible connectivity between the alteration of mold rain in Changjiang River basin and the Antarctic snow-ice situation. Chinese Science Bulletin, 26: 484–486(in Chinese).

IPCC(2001): Climate change 2001: The Science Basis. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881.

Kwok R, Comiso JC (2002): Southern Ocean Climate and Sea Ice Anomalies Associated with the Southern Oscillation. Journal of Climate, 15(1): 487–501.

Lu LH (1984): The cluster analysis and fuzzy classification of vector field. ACTA Meteorological Sinica, 42 (2): 189–197 (in Chinese).

Lu LH, Zhou XJ, Bian LG, Zhang ZQ, Zheng XD (1997): Characteristics of atmospheric oscillation in the region of Prydz Bay during the Ozone Hole in 1993. Chinese Science Bulletin, 42(10): 842–845.

O Lenic EA (1978): US Navy global ice analysis and forecasting. Glaciological data, GD 2, 43–46.

Peng GB, Wang BG (1989): The effect of Antarctic sea ice upon North-west Pacific Subtropical High and its background of oceanic-atmospheric general circulation. Chinese Science Bulletin, 34: 1–6 (in Chinese).

Silvia AV, Mark RD, Shaffer G (2001): Coupled oscillations in Antarctic sea ice and atmosphere in the South Pacific sector. Geophysical Research Letters 28(17): 3301–3304.

World Meteorological Organization (2002): WMO Statement on the status of the global climate in 2001. ISBN 92–63–10940–0. WMO-No. 940.

Yuan XJ, Martinson DG (2000): Antarctic Sea Ice Extent Variability and Its Global Connectivity. See: Lamont-Doherty Earth Observatory and Department of EARTH AND environmental Sciences, Columbia University, Palisades, New York. 1697.

Zhou XJ, Lu LH (1996): The research on interaction and influence between Antarctic and global climatic environment. Beijing: China Meteorological Press (in Chinese).

Zhou XJ, Lu LH, Bian LG, Jia PQ, Zhang ZQ (1999): Recent variation of Antarctic temperature, sea-ice and ozone. Chinese Journal of Polar Science, 10(1): 1–9.

Zwally HJ, Comiso JC, Parkinson CL *et al.* (1983): Antarctic Sea Ice, 1973–1976. Satellite Passive-Microwave Observations. Washington, NASA, SP–459, 206.