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Recent variations of Antarctic temperature, sea-ice and ozone

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Abstract A diagnostic study is made on the characteristics of regional difference of the Antarctic climatic change and the temporal and spatial multiplicity of the climatic change trend by using the temperature data for 1957 - 1993 from Antarctic and its vicinity, the data of sea ice northern boundary for 1973 - 1992 and the data of Antarctic total ozone for 1957 - 1992. The results show that there exists obvious regional difference for Antarctic climatic change, the climatic system is very complicated, and there were spatial and temporal multiplicity for temperature and ozone during the last 35 a and for Antarctic sea ice during the last 20 a. In recent years, the change of Antarctic temperature is not the same as global temperature. This kind of change and difference can not be easily explained by global greenhouse effect.

Key words Antarctic, temperature, sea ice, ozone, climatic change.

1 Introduction

Antarctic region, including Antarctic continent, sub-Antarctic islands and south ocean encircling the Antarctic Continent, has been considered to be one of the key regions as proposed in studying global change by the Global Atmospheric Research Program (GARP), World Climate Research Program (WCRP) and International Geosphere Biosphere Program (IGBP). Global atmosphere is a whole entity of interactions. To understand global climate change, it is necessary to study Antarctic region. Antarctic region with its particular geographical location and its special bioecological environment plays an important role in the research on global change.

Temperature, sea ice and ozone are important factors in the Antarctic climatic and environmental changes. In this paper, the recent temperature, total ozone and sea ice data obtained from Antarctic and its vicinity was used. The characteristics of regional difference of the Antarctic climatic change and the temporal/spatial multiplicity of the climatic changing trend was presented by using the methods of cluster and regression analyses, etc..

2 Data and method

Antarctic is one of the regions with sparse meteorological data. Antarctic weather observation systematically began in the International Geophysical Year (IGY) of 1957, but due to the limitation of the observing environment and large financial cost, only 25 stations have the accumulating data record for more than 360 months among 130 weather stations to the south of 50°S. The main data used in this paper is based on the monthly temperature average from the 25 stations (Lu *et al.* 1996a).

Global ozone satellite measurement began in 1978, but the network of ground observation of ozone has been established since IGY in 1957 (Canada Environment, Atmospheric Environment Sevice 1960 – 1993; Lu *et al.* 1995). A comparative analyses (Lu *et al.* 1996b) for these two kinds of ozone data show that the data from ground ozone observation station can be used to study on the characteristics of Antarctic total ozone variation. During the period from 1957 to 1992, there are totally 14 stations south of 60°S in which total ozone amount was observed on the ground base. But only Faraday, Syowa, Halley Bay and Amundsen-Scott Stations have the observation record longer than 200 months. According to the appraisal of WMO, the data of these four stations have high reliability (Lu *et al.* 1996b). In this study the ozone variation data from these four stations was used.

The Antarctic sea ice variations was first recorded in 1973 from satellite observation (Jacka 1983; US Navy 1985). Due to the similarity between Antarctic sea ice northern boundary and sea ice area variations, in this paper, the sea ice northern boundary data from 1973 to 1992 have been used.

3 Regional feature of the Antarctic climatic change

The Antarctic could be divided into different regions due to different climatic features. The cluster analysis method was used on the temperature and sea ice series for each station and sections to divide objectively the spatial distribution of temperature and sea ice in the Antarctic (Lu 1984).

3.1 Temperature variations

The results from cluster analysis (confidence $\alpha = 0.001$) of monthly mean temperature series of 25 weather stations during 1957 – 1993 show that, there are five regions with different temperature variation character. They are the Ross Bay (Section Ⅰ), the Antarctic Peninsula (Section Ⅱ), West part of Eastern Antarctic (Section Ⅲ), Eastern Antarctic (Section Ⅳ) and South Pacific (Section Ⅴ). All stations in each group locate in the same geographical area as indicated in Fig. 1a.

The distance averaged for each station in the same region is less than the critical distance with bigger correlative coefficient and the similar variation, while the distance to the other regions is greater than the critical distance with the opposite or small value correlative coefficient. Taking Orcadas station as an example, its temperature normalized series is obviously correlated with the mean series of the region in which it located (correlative coefficient 0.748), and the correlative coefficient with the Ross Bay and East Antarctic are negative (−0.138 and −0.124), the confidence reaching or close to 0.01 ($\gamma_{\alpha} = 0.129$); the correlative coefficient is quite small with the west part of Eastern

Antarctic ($\gamma_a = -0.043$). In addition, for different regions, their yearly mean temperature is different.

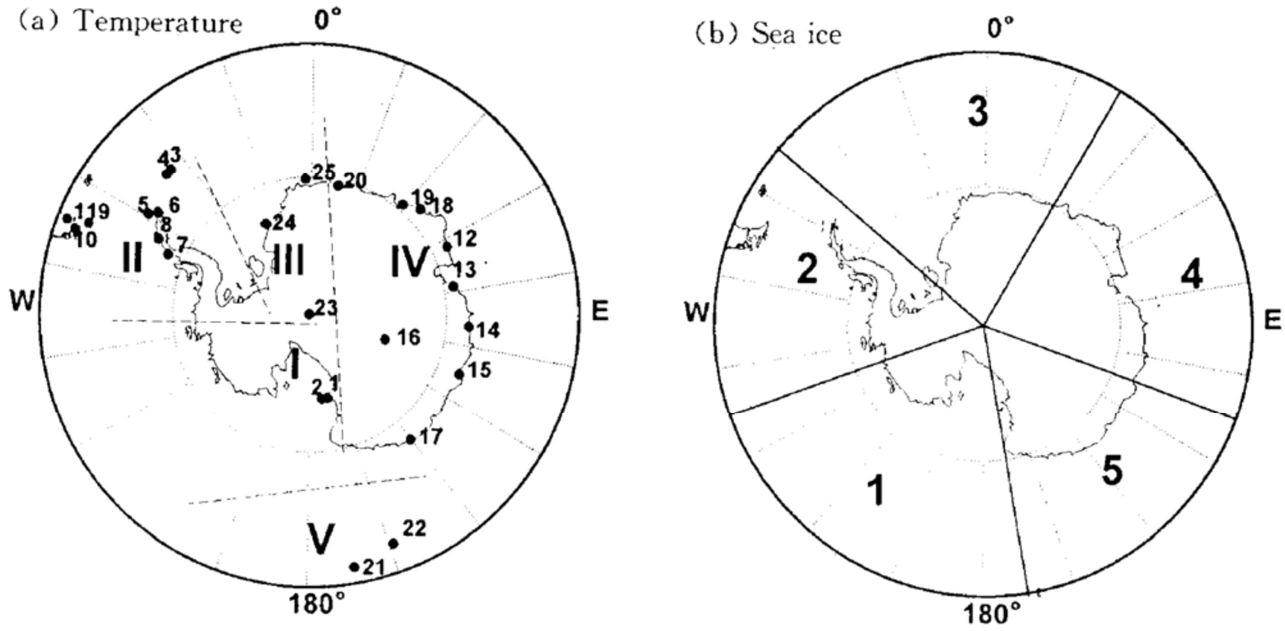

Fig. 1. The results of cluster division for temperature (a: I - V) and sea ice variation (b: 1—5). Black points indicated by the number 1-25 reprent locations of the station with the accumulating data of more than 30 a.

3. 2 Sea ice variation

The results from the cluster analysis on the series of monthly of northern sea-ice boundary show that, Section 1 (170°E - 110°W) is located in the Ross Sea and its lower reach; Section 2 (110°W - 150°W) covers the region of the Bellingshausen Sea and the sea around the Antarctic Peninsula; Section 3 (50°W - 30°E) lies in the Weddell Sea and its lower reach; Section 4 (30°E - 110°E) situated in the Prydz Bay and its upper and lower reaches and Section 5 (110°E - 170°E) control the upper reach of the Ross Sea (Fig. 1b) There is an obvious difference in climatic characteristics of sea ice spatial variation for each section, the maximum of yearly amplitude occurring both in the Weddell Sea and its lower reach and in the Ross Sea and its lower reach with the greatest variation. The sum of real area of sea ice for the two sections occupies more than half of the total of real sea ice area for the whole South Ocean, playing an important role in the distribution of Antarctic sea ice (Bian *et al.* 1995). The division in this paper mainly corresponds with that of Gloersen *et al.* (1992), but the latter is done much more geographically, having no objective standards. The division in this paper is more objective since it based on a quantitative and statistical standards. In addition, comparing Fig. 1a and Fig. 1b, the division for sea ice variation is similar to that for the temperature. The only difference occurs in East Antarctic. There are two regions for sea ice variation while only one for temperature variation.

The objective divisions of temperature and sea ice variations lay the foundation for further research on the characteristics and trend of climatic variation in each Antarctic region.

4 The trend of climatic change in the Antarctic

4.1 The temporal variation of temperature in the Antarctic in the last 35 a

Fig. 2 gives out the curves of temperature variation of standardized series after moving average of four years for each section to the south of 50°S through 1957 to 1993. It can be seen in Fig. 2 that there are different degrees of temperature warming trends for the sections south of 50°S during the last 30 a, the mean trend 0.2℃·$(10\ a)^{-1}$ between 50° – 90°S (obtained from temperature anomaly of each station, the following is the same), where the trend is the most obvious in the Antarctic Peninsula and the Ross Bay,

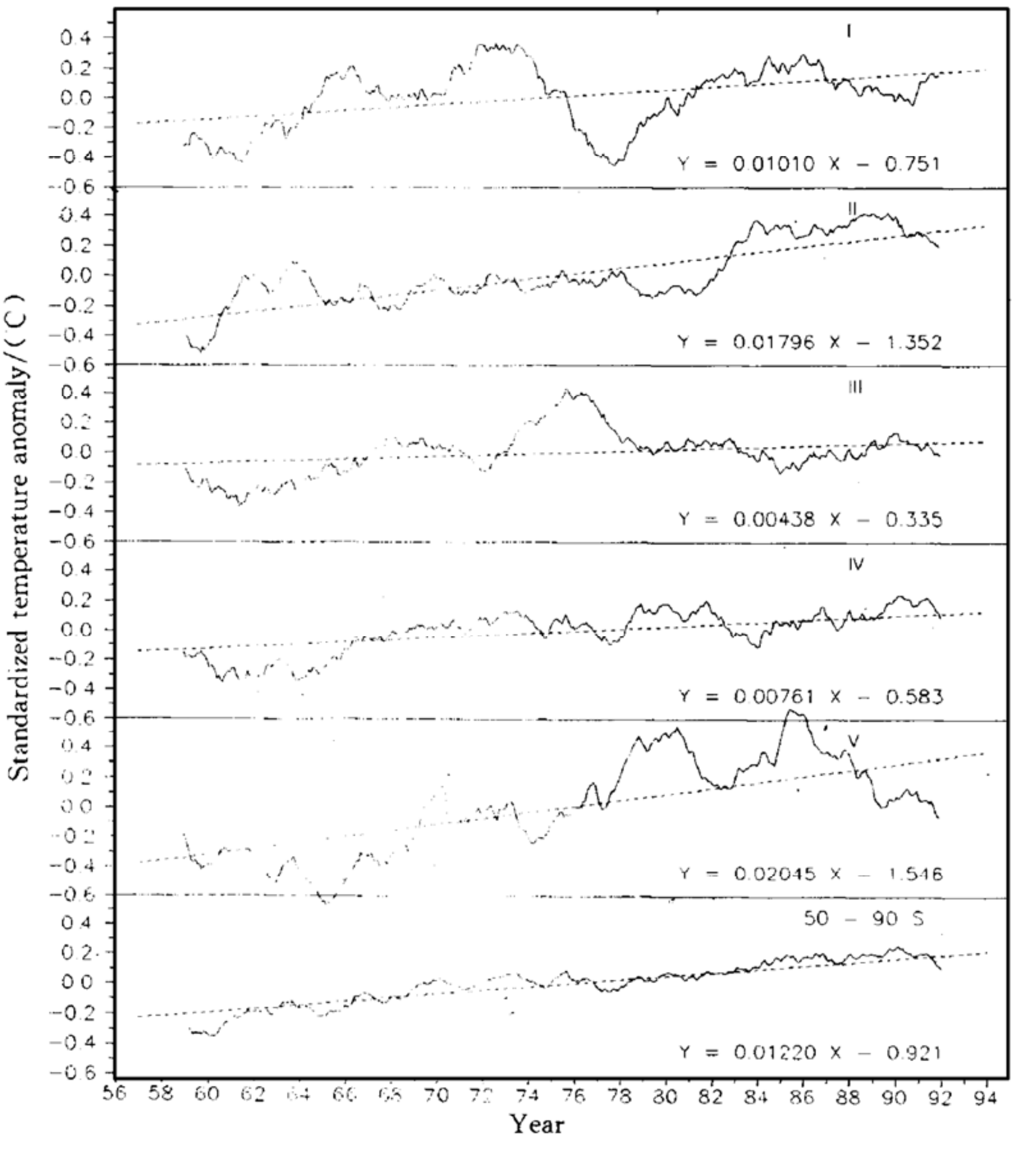

Fig. 2. Temperature variations of standardized series for the south of 50°S during 1957 and 1993. Bold lines represent the variation of temperature standardized series for each section by moving average values of 4 a, dotted oblique lines represent the one of linear regression relative to the time (year, month), the corresponding regression equation is given below the curve.

the mean trends are 0.4℃·(10 a)$^{-1}$ and 0.3℃·(10 a)$^{-1}$ respectively; while in the East Antarctic and its western part, the mean warming trend is less than 0.1℃·(10 a)$^{-1}$. This corresponds with that in IPCC reports (1996) pointed out by King (1994) that, significant warming since the 1950's along the west coast of the Antarctic Peninsula is not representative for the whole Antarctic area.

During the last 35 a there is greater difference in temperature variation features for the Antarctic and for the whole world (IPCC 1996). Although the Antarctic temperature has a warming trend since 1957 with a rate of 0.2℃·(10 a)$^{-1}$ in the last 40 a, similar as the global warming rate, the Antarctic temperature trend reached 0.25℃·(10 a)$^{-1}$ during 1957 - 1979 when there was no obvious global warming. Since 1980, however, the Antarctic temperature changed little, while the global average temperature experiences rapid increasing. The details of the Antarctic temperature change indicate that only in the section of the Antarctic Peninsula had a strong warming (0.81℃·(10 a)$^{-1}$), the other four sections were cooling with East Antarctic cooling most (−0.45℃·(10 a)$^{-1}$). Generally speaking, in recent years, the change of Antarctic temperature is not the same as that for the global temperature. This kind of change and difference can not be easily explained by global greenhouse effect. Meanwhile it is difficult to say that Antarctic is the region with the strongest greenhouse effect in the world. We should pay attention to the climatic meanings of the difference of short-term climatic change trend between South and North Hemispheres and the cooling trend in the several regions if Antarctic except the Antarctic Peninsula during the last 10 a.

4.2 Short-term climatic change of the sea ice in the Antarctic

Fig. 3 illustrates the variations of sea ice anomaly for each section in 1973 - 1992. Since 1973, Antarctic sea ice has a decrease trend of about 0.17 latitudinal degree·(10 a)$^{-1}$. Just like the temperature variation, the variation trend for different sea ice sections is also different. Except the Wedell Sea and its lower reach where sea ice variation is increasing (0.23 latitudinal degree·(10 a)$^{-1}$), the sea ice decreased in the other sections. The most obviously decrease occurred in the section from Southeast Pacific to the Antarctic Peninsula, while the biggest value of the decreasing rate is 0.62 latitudinal degree·(10 a)$^{-1}$ for the Ross Sea and its lower reach decreased. From the whole the South Indian Ocean to the West-South Pacific, the sea ice decrease trend is not obvious. In the Prydz Bay, the sea ice decreases at the minimum rate of 0.08 latitudinal degree·(10 a)$^{-1}$.

The correlative analysis of sea ice for each section during 1973 - 1992 and the temperature for each section at the same period show that, although there is no obvious statistical relation between the Antarctic mean sea ice and the temperature variations (correlative coefficient −0.01), corresponding with the result of Jones (1995), there is obvious negative correlation in some climatic regions. For example, when the temperature in the west part of Eastern Antarctic has the trend of cooling (−0.02℃·(10 a)$^{-1}$), the sea ice in the Wedell Sea and its lower reach has the trend of increasing, correlative coefficient is −0.25, and the correlation is obvious (confidence $\alpha = 0.01$, critical correlative coefficient $\gamma_a = 0.17$). When the temperature in Antarctic region such as the Antarctic Peninsula increased, the sea ice of the corresponding region decreased. Noticeably, except for the temperature and sea ice variation correlation in the Ross Bay section is not obvious (correlative coefficient only -0.04), in the other regions the temperature and sea ice had manifest negative correlation with confidence reaching to 0.05 (critical correlative coefficient is 0.15). The closest correlation between temperature and sea ice occurred appear in the section between the South Atlantic and the South Indian Ocean.

4.3 Trend of the Antarctic total ozone change

Fig. 4 shows the monthly variation of total ozone percentage in the four stations and the Antarctic as a whole (60° – 90°S). The total ozone has obvious decreasing trend during 1957 – 1992 both for each station and for the whole area of 60° – 90°S. The meandecreasing rate is $2.9\% \cdot (10\ a)^{-1}$ and the most and least rate are $-6.0\% \cdot (10\ a)^{-1}$ in South Pole and $-1.5\% \cdot (10\ a)^{-1}$ in Faraday respectively. In the Antarctic the total ozone decreasing trend corresponds with the temperature variation in middle and lower stratosphere (Lu *et al.* 1996b).

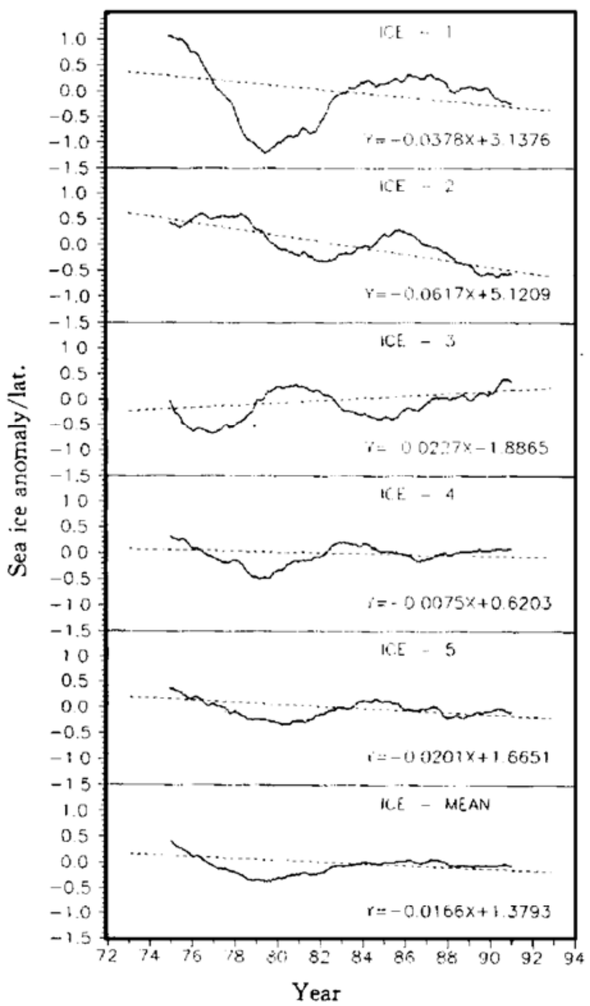

Fig. 3. Antarctic sea ice anomaly variation curves in 1973 – 1992, bold line represents the variation of sea ice anomaly for each section by moving average values of 4 a, dotted line represents the one of linear regression relative to the time (year, month), the corresponding regression equation is given below the curve.

For different periods, there are different trends for the Antarctic total ozone change with an obvious turn around 1970. During the period from 1970 to 1992, Antarctic total ozone has an obvious decrease for all 4 stations. The mean decreasing trend for these stations was $(9\% - 10\%) \cdot (10\ a)^{-1}$, and it is $-4.0\% \cdot (10\ a)^{-1}$ for whole area of 60° – 90°S, which corresponds with the results obtained by Bojkov *et al.* (1994). In contrast, during the period from 1957 to 1969, there were increasing trend for all stations except Halley with the confidence of 0.10. The total ozone increased mostly in Faraday at the rate $10.2\% \cdot (10\ a)^{-1}$, passing the statistical test of confidence 0.001. In Halley, it had no obvious variation at this period. Generally speaking, the Antarctic ozone

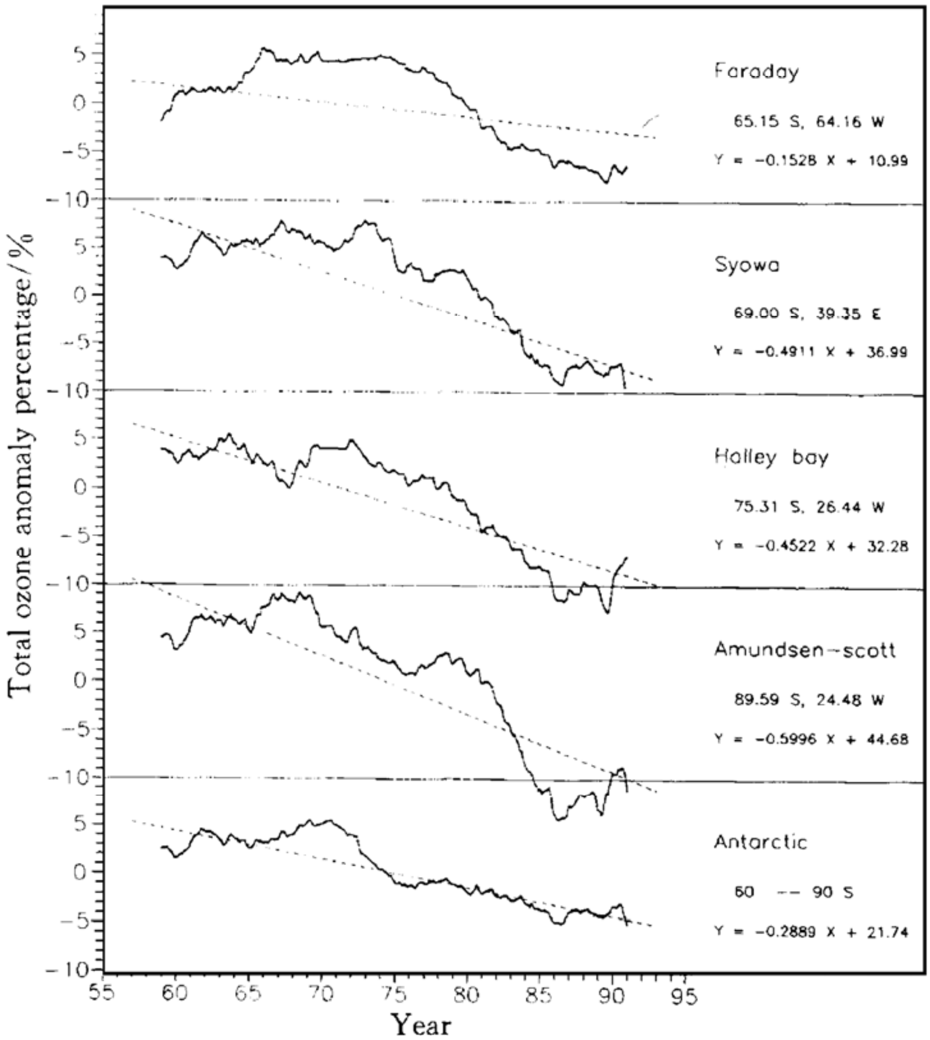

Fig. 4. Monthly change of the Antarctic total ozone anomaly percentage during 1957 and 1992. The bold line represents the monthly change of Antarctic total ozone anomaly percentage for each section by moving average values of 4 a, dotted oblique line represents the one of linear regression relative to the time (year, month), the corresponding regression equation is given below the curve.

discrepancy had an increasing trend during 1957 − 1992.

Fig. 5a shows the yearly variation trend for monthly total ozone in the Antarctic region (60° − 90°S). As shown in Fig. 5a, for the last 35 a the reduction of ozone occurred mainly in July to January, the maximum decrease rate value appear in October ($-9.1\% \cdot (10\ \text{a})^{-1}$). From February to June, the ozone varies at the rate less than $0.7\% \cdot (10\ \text{a})^{-1}$ for the last 35 a, almost being invisible. Fig. 5b shows the variations of mean total ozone for Feb. — June and Aug. — Dec.. As shown in this figure, it is more clear to see that, Antarctic ozone amount is almost the same in autumn (February to June) for the last 35 a, while the amount decreases rapidly in spring (August to December). This indicates that recent ozone discrepancy in Antarctic was caused by the formation and development of Antarctic ozone hole. In the North America, Europe, Far East, lower latitudes and South Hemisphere, etc., although there is the greatest discrepancy for total ozone in spring, there is also the decreasing trend in autumn (WMO 1992), which is different from that in Antarctic.

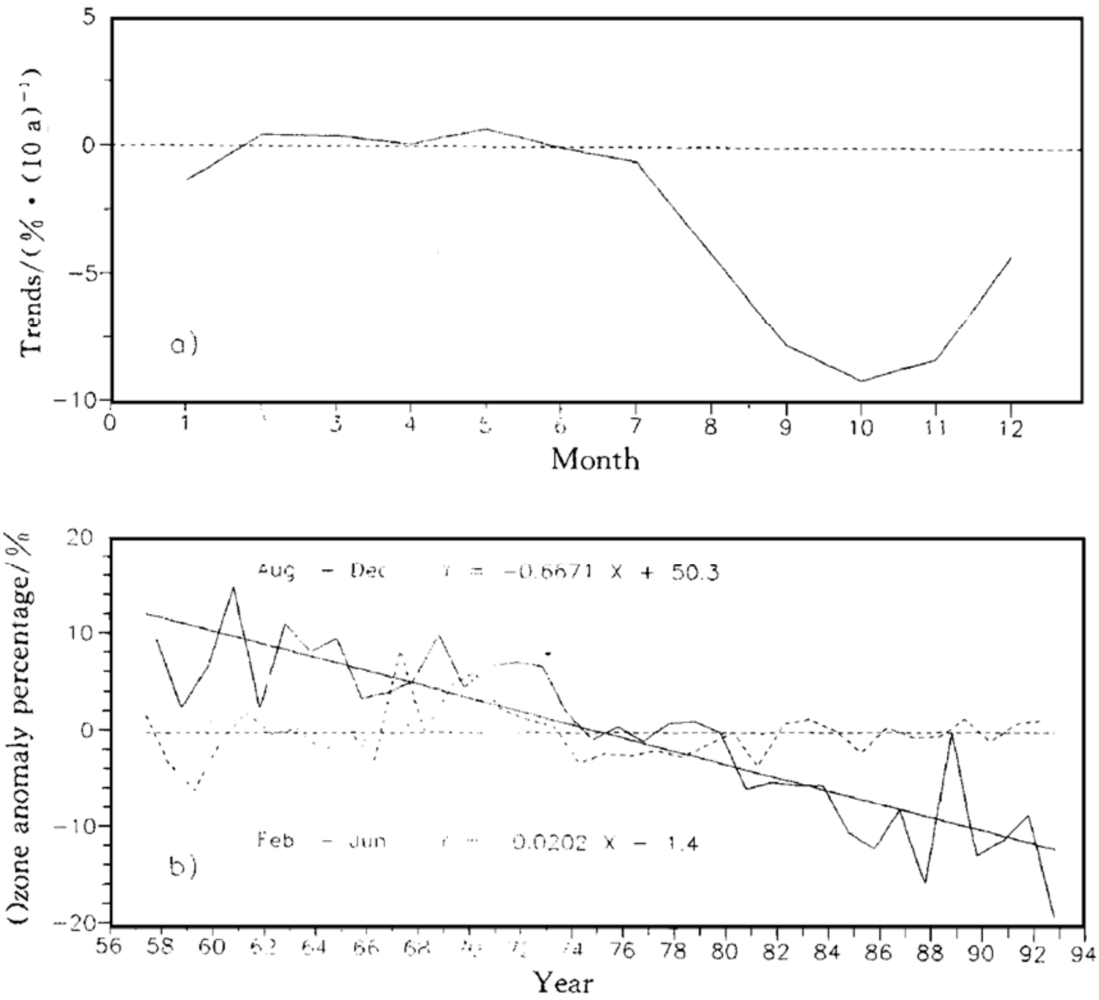

Fig. 5. Characteristics of Antarctic total ozone variation during 1957 – 1992. (a) Variation of trend for monthly total ozone. (b) Variations for the mean total ozone for Feb. – Jun. (dotted line) and Aug. – Nov. (straight line).

5 Conclusions

In summary, the results in this paper show that, the short-term climatic change in Antarctic has its regional feature. Although the climate changes are basically the same for the same region, but the variations in different regions have little correlation or have the opposite phases. The climatic system in Antarctic is very complicated. The temporal and spatial multiplicity exist for the atmospheric temperature and ozone in the Antarctic in the last 35 a and for Antarctic sea ice variation trend in the last 20 a. Some variations are difficult to be explained simply with human activities. For the last 30 a, Antarctic warming mainly occurred in the Antarctic Peninsula, while it is not so obvious for each region of the main Antarctic continent. At present, there is no evidence enough to say that, the temperature variation in the Antarctic for the last 30 a resulted from the forcing of greenhouse effect. This kind of change, to some extent, could result from the change within climatic system. Since there are large differences in the temperature variation characteristics for different regions, different periods, different seasons and different stations, it should be careful trying reconstruct the temperature change series for the

Antarctic. It is still one of important topics of research on global change to further conduct international cooperation in Antarctic and further make observations of atmospheric change including ground temperature to obtain scientific data.

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