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Interdecadal oscillations of temperatures in 1903 – 2002 over the Antarctic Peninula

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Abstract In the paper, by use of the monthly mean temperature data of 12 stations in the vicinity of Antarctic Peninsula, the temperature series during 1903 - 2000 is founded and the interdecadal oscillation of the temperature are discussed. The results indicate that 1) There are three jumps during 1919 - 1923, 1947 - 1953 and 1976 - 1982 in recent hundred years and the stable climate step between two jump points lasted about 30 years. 2) Annual mean temperature is increased by 0.730℃ in an echelon during 1903 - 2000, the warming extent is dissimilarity in each season, the maximum of warming is in the winter and the minimum of warming is in summer. 3) The ice decline trend is presented in the index of Ice concentration in the vicinity sea of Antarctic Peninsula, which shows a −0.2053/10a drop, and the decrease trend of the ice concentration index in summer half year (Dec-May) is found much more obviously than that in winter half year (Jun-Nov). 4) There is better negative relationship between the temperature and the Ice concentration index in Antarctic Peninsula and its vicinity sea, which correlation coefficient of is exceed the significance level of 5% in summer, autumn and annual.

Key words Antarctic Peninsula, temperature, sea ice, oscillation.

1 Introduction

Global atmosphere is a system with inter-actions inside such that for understanding global warming in the past century or so it is necessary to undertake research of temperature variation in the Antarctic continent. Many studies have been devoted to temperature change in the Antarctic and its vicinity. Schwerdtfeger (1984) addressed 1904—1981 temperatures at Orcadas Station. Raper (1984) sorted monthly mean temperatures for 1957—1982 in this study area, converting station data to gridded ones, leading to the related values south of 60°S, with which to investigate the inter-annual variation in the last 30 years. Using an area-weighing technique, Jones *et al.* (1990; 1995) extended the 1957—1982 temperature sequence as from 1900. These authors drew on data prior to the 1980s but global warming happened mostly thereafter, so that posterior observations are needed as supplementary series for the problem in order to use our conclusions to improve theirs if necessary. Before the 1950s in the Antarctic there were very few observations on a continuous basis, which, when used to investigate climate change over the extensive land, pose a problem as to their soundness and representativeness.

In recent years, King (1994) has discussed climate change in the Antarctic Peninsula and its vicinity, and Lu *et al.* (1996; 1997) investigated space/time temperature features in the Antarctic and its neighbor area, indicating the space/time multiplicity of temperature variation over the last 35 years. The warming tendency occurs mainly in the Peninsula, with little variation in the main body of the land during the past 30 years. In their study on the space/time features of Antarctic temperature, sea ice cover and the inter-correlations, Bian *et al.* (1997) reveal a remarkable warming trend on the land for the past ~30 years, which differ more greatly on a temporary and spatial basis, particularly in the Antarctic Peninsula and Ross Bay, and the latter has been less studies till now. Besides, with the long-range trend from data, Cheng *et al.* (2002) made empirical orthogonal function (hereinafter, referred to as EOF) and singular-value decomposition (hereinafter, referred to as SVD) analysis of the sea ice concentrations in the past~30 years, discovering that the trend of Antarctic sea ice oscillation (hereinafter, referred to as ASIO) in the outer regions of the Ross Sea is opposite to that of the Peninsula temperature and corresponds to the dipole-like sea-level temperature field, thus proposing a possible linkage between ASIO and ENSO. All these studies indicate that the Peninsula occupies an important position in climate change of the vast land.

In the context of 12 different-length measurements for the Peninsula (35—70° W, south of 50°S) we get the 1903—2000 timeseries of temperature on a statistical basis, whereby the interannual variation is discussed and compared to the conditions during the study period. Results suggest that climate jump points occur, i. e. , 1919—1923, 1947—1953 and 1976—1982, with phase length of roughly 30 years in between, and temperature rising in a stepwise manner; the rise is 0. 730°C for 1903—2000, differing in range on a seasonal basis and maximizing (minimizing) in winter (summer).

2 Materials

One of the data-deficient regions in the world is the Antarctic where a systematic observation project was launched in 1957 during the International Geophysical Year (IGY) and 62 scientific stations were set up in the continent and sub-Antarctic. Limited by the severe climate and considerable financial support, a number of the stations were closed after the IGY, leaving only 18 points kept on observing till now. After the 1970s data from weather satellites, telemetric equipment and automatic meteorological stations have found their widespread applications in meteorology and the number of stations established by newcomers is growing, leading to substantial improvement of observational methods and data quality for the land. Nowadays we have only 25 stations providing data covering a period >30 years although there were more than 130 stations engaging in systematic observation in the continent and its neighboring areas south of 50°S.

Many of the previous studies have noticed that temperature varies differently on a local basis in the Antarctic, indicating that the Peninsula with its vicinity is a single climate region as demarcated via cluster analysis (Lu *et al.* 1997), and the same is true for sea ice regionalization (Bian *et al.* 1997). 12 stations with less missing data were chosen from the Peninsula and its surroundings (30-70°W, south of 50°S) to investigate the temperature development (see Table 1) and most of these stations began observation in the 1950s to 1960s, keeping 30 to 50 year records but Orcadas was set up in 1903 whose temperature records cover nearly 100 years; Grytviken started its measurement in 1905 but no data were found after 1988; other stations including Great Wall founded by Chinese meteorologists keep shorter, yet continuous records. The climate on the land is harsh enough for observation failure frequently, leading to poor representativeness for some of monthly means data, particularly for those prior to the 1970. As a result, it is necessary to reconstruct a climate sequence for the region in a particular way. Two climate series are considered to be able to replace each other if their correlation coefficients pass a test at significance level of 5%, suggesting that they fall into the same climate area. We calculated correlation coefficients between any two station annual mean temperatures (AMT) for the 12 stations, resulting in a 12×12 triangular matrix, yet only with the correlations of these stations at Orcadas (denoted as coefficient A) given in Table 1, where we see that for the correlations all stations but one have passed the test at 1% significance level, the exclusive exception being San-Matin with the coefficients not passing tests at 5% significance test, thus indicating that the 12 stations are in the same climate region.

To reduce errors in temperature measurements caused by diverse terrains, e. g., station height, we have calculated the mean over WMO-specified 1971—2000 data of 12 stations (based on the longest possible length of series of AMT available at these stations), and the resulted mean is utilized to get annual temperature anomalies (ATA) against AMTs, followed by averaging the 12-station ATA values of the same year. In this way we have gained a new sequence of ATAs for the study region. As shown in Table 1, the ATA series involves only two stations prior to 1947. To validate the representativeness of the ATA sequence, we compute the correlation coefficients of the ATA with station AMT series (coefficient B), showing that the correlations have all passed the tests at 0.1% significance level, and exceed the coefficients A by >10%, indicating that the ATA series can represent the change in AMT for each station concerned.

3 Results and discussion

3.1 Climate jump

Climate jump and interdecadal oscillation are concepts developed by contemporary researchers in their studies on climate analysis and diagnosis and are receiving great attention from the meteorological community at home and abroad due to the close association with non-linear theory. The concepts are now the leading topics in the climatological research.

Climate jump is defined as its transition from one stable phase to another, either of which is much longer than the transition. The so-called stable phase refers to insignificant difference in statistics, e. g. , mean and variance, during the phase or period. In other words, climate jump denotes a phenomenon of remarkable difference in statistics between stable phases over a short period (i. e. , transition). As a result, the jump is detected by statistical methods, the usual ones of which are Mann-Kendall Rank statistic (simply given as M-K) and moving T test.

Table 1. Distribution of stations with data length given in the Antarctic Peninsula and its vicinity where figures with superscript * , ** and *** denote the passage of tests at significance level 5%, 1% and 0.1%, respectively

Site	Name	Latitude	Longitude	Observation period	Correlation coefficient A	Correlation coefficient B	Number r of samples
88903	Grytviken	54.3S	36.5W	1905—1988	0.51***	71***	84
88963	Esperanza	63.4S	57.0W	1960—1999	0.72***	82***	41
88968	Orcadas	60.7S	44.7W	1903—2000	0.999	91***	98
88971	Almirante-Brown	64.9S	62.9W	1957—2000	0.41**	95***	44
89042	Signy	60.7S	45.6W	1947—1995	0.84***	95***	48
89050	Bellingshausen	62.2S	58.9W	1968—2000	0.75***	94***	33
89056	Marsh	62.4S	58.9W	1959—2000	0.65***	94***	32
89058	Great-Wall	62.2S	59.0W	1985—2000	0.82***	93***	16
89059	O-Higgins	63.3S	57.9W	1963—2000	0.76***	94***	38
89062	Rothera	67.5S	68.1W	1977—2000	.0.67***	93***	25
89066	San-Martin	68.1S	67.1W	1979—2000	0.25	93***	22
89075	Arturo-Prat	62.5S	59.7W	1966—2000	0.72***	94***	35

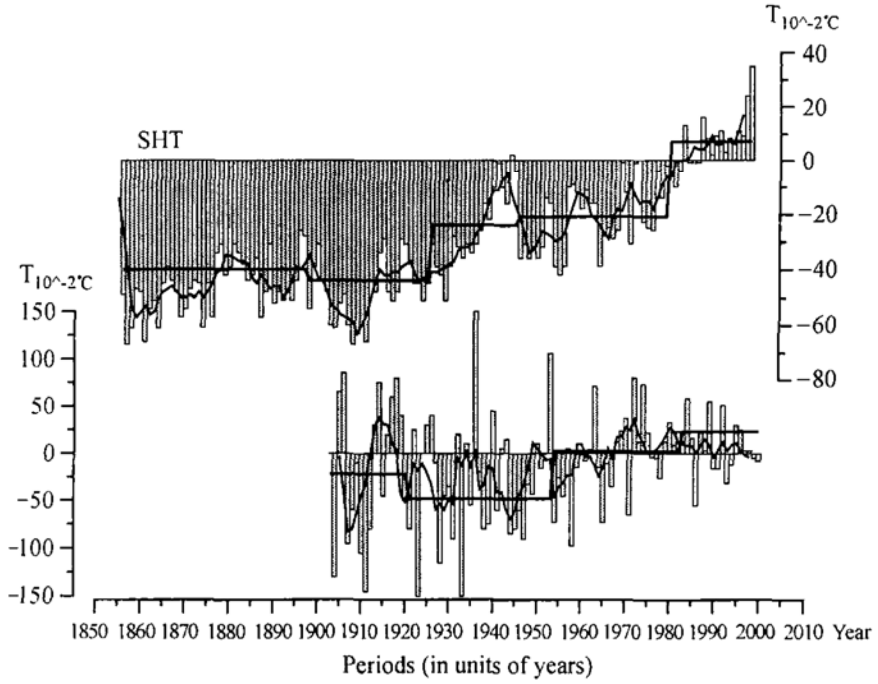

Fig. 1 Interannual variation in yearly temperature (bars), 5-year running mean (solid curve) and the average and jump point of phase annual temperature (full broken line) for the Southern Hemisphere and Antarctic Peninsula.

Fig. 1 presents AMT interannual variation (bars), 5-year moving mean (solid curve) and phase averaged AMT and jump points (full broken line) of temperature in the Southern Hemisphere and Antarctic Peninsula. It is seen therefrom that the Peninsula interannual temperature variations (a group of bars) show lower temperature for negative anomaly between 1903 to the 1920s, keeping on dropping till the end of the 1940s and turning to rise therefrom to end of the 1960s for positive anomaly; And the inter-annual temperature slightly decreases during the 1970s and keeps on increasing in the 1980s for strengthened positive
anomaly. On the whole, during the period 1903—2000 on the Peninsula, warming is dominant except insignificant drop between the end of the 1920s to that of the 1940s. Schwerdtfeger (1984) addressed the temperature change at Orcadas during 1904—1981, pointing out that 1903—1930 is a cold phase and 1931—1950 is a warm phase, followed by a somewhat colder phase lasted about 25 years, a statement that somewhat differs in annual temperature variation from the Peninsula counterpart mainly on account of temperature average, definition of cold/warm phase and data length.

Also, Fig. 1 depicts the wave-like rise in temperature for the research period (1903—2000) in the Peninsula, with positive anomaly, in the main, after the 1980s and interdecadal oscillations at 20—40 year scales. To further investigate the climate jump of oscillations, a 15—year running T test is chosen to detect the yearly and seasonal jump points of temperatures after multiple experiments. In the yearly cases three jump points are discovered for the Peninsula, which are in 1920, 1953 and 1982, each followed by an approximately 30 year phase, with mean temperature of −0.221°C in 1903—1919, −0.474°C in 1920—1952 (lower by −0.253°C compared to −0.221°C), −0.024°C in 1953—1982 (higher by 0.498°C compared to −0.474°C) and 0.256°C in 1983—2000 (higher by 0.280°C, compared to −0.024°C). The Antarctic Peninsula temperature rose by 0.730°C from 1920—1952 to 1982—2000 on a yearly mean basis. The tendency rate of the annual temperature reaches 0.07534°C/100a (refer to Table 2), or its rise of 0.7534°C/100a, both being quite close to each other (0.730°C/80a vs 0.7534°C/100a), indicating that the Peninsula rise in temperature is fulfilled via interdecadal jumps.

Fig. 2 presents the wavelet analysis of the Peninsula AMT, showing distinct inter-decadal oscillations on scales of 20—30 years, zero lines of which are very close to the locations of jump points mentioned above, indicating that the oscillations occur in a jumping manner. Besides, centurial oscillations (80—100 year time scales) and less than 10 year inter-annual oscillations are uncovered.

For comparative purposes Fig. 1 also gives the variation of AMT for the Southern Hemisphere (data from IPCC), indicating that the curve rises slowly from 1850 at the tendency rate of 0.0431°C/10a except for a slight drop in the beginning of the 20th century.

The detection by using a 15—year moving T test for the Southern Hemisphere (SH) yearly temperature reveals 4 jump points thereof during the past ~150 years, happening in 1898, 1926, 1946 and 1980, each with a phase of averaging about 30 years. The mean temperature is −0.40°C in 1850—1897, −0.44°C in 1898—1925 (a drop of −0.04°C compared to −0.40°C), −0.24°C in 1926−1945 (a rise of 0.20°C compared to −0.44°C), −0.21°C in 1946−1979 (a rise of 0.03°C compared to −0.24°C) and 0.07°C in 1980−2000 (a rise of 0.28°C compared to −0.21°C). Over 1903−2000 the SH annual temperature increases by 0.47°C and the tendency rate is 0.0431°C/10a. Based on the calculation the rise of the SH yearly mean temperature is 0.431°C, indicating both figures are close (0.47 vs 0.431°C in 1850−2000, which means the SH temperature increase is fulfilled on an interdecadal jump basis.

Table 2. Jump points of temperature evolution and phase means on an annual and seasonal basis for the Antarctic Peninsula.

	Phase mean temperature (℃)	Jump point (year)	Phase mean temperature (℃)	Jump point (year)	Phase mean temperature (℃)	Jump point (year)	Phase mean temperature (℃)
Spring(Sept.-November)	−0.217	1919	−0.576	1947	−0.005	1981	0.202
Summer (Dec.-Feb.)	−0.189	1920	−0.426	1950	−0.094	1976	0.144
Autumn (March-May)	−0.269	1919	−0.477	1950	0.054	1978	0.232
Winter(June-August)	−0.315	1923	−0.608	1953	−0.116	1982	0.496
Mean	−0.221	1920	−0.474	1953	0.024	1982	0.256

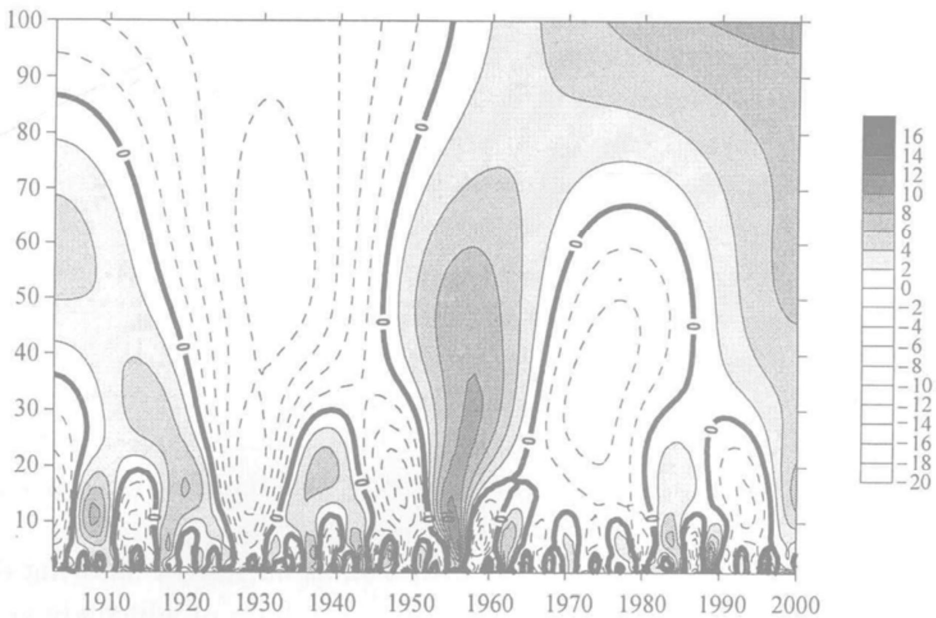

Fig. 2 Wavelet analysis of annual temperatures of the Antarctic Peninsula

It is apparent that variations in the Peninsula interannual temperature variations bear close similarity to those in the SH temperature. The jump points in the Peninsula case are in 1920, 1953 and 1982 compared to the points in 1926, 1946 and 1980 in the Southern Hemisphere case, showing the jump points to be very close respectively to each other. However, there is more remarkable difference in temperature change between both the cases. For the SH, a dominant feature is that the fluctuations on small scales are less than those on large scales and, in contrast, the curves for the Peninsula display quite a lot of smaller-scale as well as large-scale fluctuations. Besides, minimum SH yearly temperature occurs in 1898−1925 as a climate phase while minimum Peninsula temperature appears in 1920−1952, there is a climate phase difference.

From the foregoing discussion, we know that the tendency rate is 0.0431°C/10a (0.0753°C/10 a) for the SH (Peninsula) temperature evolution. Jacka and Budd (1991) investigated, independently, the temperature evolution over the Antarctic and southern Pacific for the past 30—40 years, indicating the tendency rate is, on average, 0.8°C/100a for the southern Pacific during 1949—1988 and 2.8°C/100a for the Antarctic in 1955—1988. Obviously, their results are by far bigger than ours presented above, maybe due to the difference in the data used.

Lin (1998) made use of a running T test to explore the climate jump of Northern Hemisphere (NH) mean temperature and sea-level pressure, 500 hPa height and North Pacific SST, revealing three greater jump events, separately in the 1920s, 1950s and from the end of the 1970s to the 1980s, indicating more significant differences in these index before and after the jumps. In the same way, study is undertaken of the climate jump of temperature recorded in China over the past ~100 years (Tang and Lin 1993; Lin 1995), discovering three jump points, separately in 1920, 1955 and 1978, a situation that is similar to that of the Antarctic Peninsula and Southern Hemisphere, demonstrating that it is likely to have experienced three climate jumps on a global basis in the 1920s, 1950s and from the end of 1970s to the early 1980s.

It should be noted that temperatures in the Northern hemisphere and China are higher in the 1920s to 1950s, i. e., the rise in the 1940s, and the drop from the 1950s to the end of the 1970s. In comparison, the temperatures in the Antarctic Peninsula and Southern Hemisphere (SH) exhibit a stepwise rise without the warming in the 1940s. It follows that the Peninsula and SH differ more greatly in temperature change from China and Northern Hemisphere, suggestive of natural evolution of their own, but both sides display distinct coincidence in temperature rise starting from the 1980s, implying that global warming shows up largely in this decade, which may be the result of anthropogenic activities (including the increased release of greenhouse gases).

The same 15—year moving T test is utilized to detect the jump points of temperature in spring (SON), summer (DJB), autumn (MAM) and winter (JJA) to reveal interdecadal variations in the Antarctic Peninsula AMT, with the results shown in Table 2. It is seen therefrom that for 1903—2000 all the seasonal temperatures exhibit 3 jump points, separately concentrated in 1919—1923, 1947—1953 and 1976—1982. Take for example, the winter jump points that occur in 1923, 1953 and 1982, with the phase length covering about 30 years and the mean of −0.315°C in 1903—1922, −0.608°C in 1923—1952 (a drop of −0.293°C compared to −0.315°C), −0.116°C in 1953—1981 (a rise of 0.492°C compared to −0.608°C) and 0.496°C in 1982—2000 (a rise of 0,612°C compared to −0.116°C). And from the minimum to the present temperature phase the Peninsula winter temperature rises by 1.104°C, which is more or less in concord with the tendency rate of 0.1067°C/10a. Also, the Peninsula summer temperature experiences three jump points in 1920, 1950 and 1976, with phase length covering about 30 years. The phase mean is −0.189°C in 1903—1919, −0.426°C in 1920—1949 (a drop of −0.237°C relative to −0.189°C), −0.094°C in

1950—1975 (a rise of 0.332°C relative to −0.426°C), and 0.144°C in 1976—2000 (a rise of 0.238°C relative to −0.094°C), indicating the summer temperature rises by 0.333°C in 1903—2000 which agrees roughly with the tendency of 0.0233°C/10a.

As shown in Table 2, Antarctic Peninsula seasonal temperatures vary in a similar way, with three jump points very closed to each other in three different years, and a stepwise rise for all the seasons, leading to the maximum after the 1980s. However, their tendency rates display apparent difference from a season to another (Table 3). The greatest rate is 0.1067°C/decade in winter months (JJA), 0.0852°C/10a in autumn (MAM), 0.0579°C/10a in spring (SON) and 0.0232°C/10a in summer (DJB). It is obvious that Peninsula winter temperature increases by 1.016°C in 1903—2000 while the summer temperature rises only by 0.333°C, less than 1/3 of the winter equivalent. This fact indicates the Peninsula rise in temperature occurs dominantly in winter months.

Table 3. Tendency rates of AMT and ice index at the Peninsula with its vicinity where correlation coefficients with superscript * and ** denoting the correlations passing tests at significance level 5% and 1%, respectively.

	Change trend of temperature (℃/10a)	Index of ice concentration (1/10a)	Correlation coefficient
Spring(Sept.-November)	0.0579	−0.0021	−0.274
Summer (Dec.-Feb.)	0.0233	−0.2302	−0.282*
Autumn (March-May)	0.0853	−0.2078	−0.594**
Winter(June-August)	0.1051	−0.0472	−0.154
Mean	0.0734	−0.2053	−0.297*

3.2 Variation in polar ice cover

Antarctic ice-capped area consists of snow-enveloped land and ice-covered sea area. The permanent ice cap is the decisive factor of the Antarctic climate and ice cover in seaboards and the southern oceans bears a close relation to the change in temperature. Budd (1975) pointed out that there is a relationship between coastal temperature and sea ice size, indicating that change of in 1°C station measurement will lead to a change in latitude by 2.50° for sea ice fringe. In the study on the relation of Syou Wa station annual mean temperature (AMT) to ice conditions, Kusunokit (1981) showed that in the presence of low (higher) AMT the ice packs are heavy (thinner), close together (scattered) and large (smaller) in size. Based upon 1973-1982 data, Raper *et al*. (1984) did not arrive at good result in the study on Antarctic temperature as a whole in relation to sea ice cover, asserting that their relationships are quite complicated so that further research is required when enough data are accumulated in the future.

Systematic satellite-sensed ice data began in 1973 for the Antarctic but difference in using expressions for retrieval leads to disparities in results. Early data are inappropriate due to greater errors. In the present work, we made use of NCEP reanalysis ice concentrations, marked by quite good continuity from a normalized scheme for reanalysis of the long-term data. The sea ice condition is expressed as a concentration in an either-choice way (0, 1) inside a grid whose mesh is in Gaussian form with the spacing of 1.8750 in a zonal and unequal length in a meridional dimension, i.e., the grid lengths consist of 1.905 ~ 1.8890 from the equator to the southern pole. We denote 1 and 0 for ice packs available and non-available, respectively. The ice concentrations averaged over 60—81°S, 30—70°W for the Antarctic Peninsula and its vicinity and normalized as a measure of the condition, denoted as the Peninsula ice concentration index (PICI).

Fig. 3 presents the interannual curve of yearly mean PICI, showing its greater variation, with positive anomaly in the late 1990s, but the general trend is decreased at the tendency rate of −0.0472°C/10a (Table 3). The correlation coefficient is −0.297 between Peninsula annual temperatures and PICIs passing test at significance level of 5%.

The PICI climate tendency rate displays pronounced seasonal variation (refer to Table 3), wherefrom we see the rate is bigger in summer (December to May) than that in the winter half year (June to November), with the values ranging in descending order: −0.2302°C/10a in summer (DJF), −0.2078°C/10a in autumn (MAM), and −0.0021°C/decade in spring (SON) as the minimum. In contrast, the temperature tendency rate is larger in the winter (June-November) than in the summer half year (November-May), with the maximum in winter (JJA) and minimum in summer (DJF). The difference arising between the tendency rates is likely to relate to the variability of their own. As a rule, temperature variability is bigger in winter than in summer as opposed to sea ice condition. Table 3 also gives the correlation coefficients for 30 years on a seasonal basis between temperature and sea ice index in the Peninsula, indicating all the coefficients are negative, meaning that sea ice size reduces when temperature rises. The correlations in yearly mean, summer and autumn have passed tests at significance level of 5% except the coefficients in winter and spring. This may be in relation to magnitudes of the tendency rate of PICI.

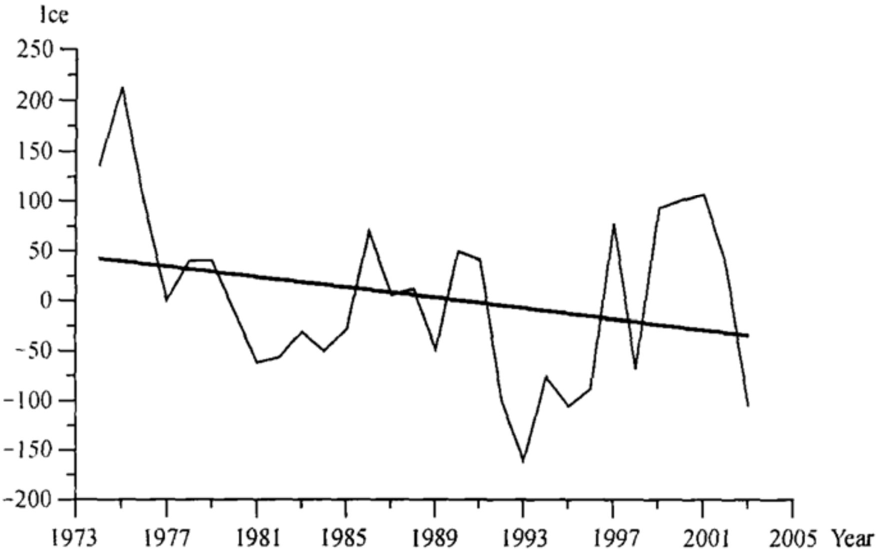

Fig. 3 The interannual curve of yearly mean PICIs.

4 Conclusion remarks

Selected from the Antarctic Peninsula and its vicinity (south of 50°S, 30—70°W) are 12 stations with better observations, most of which were set up in the 1950s—1960s, thus keeping observations for 30—50 years except Orcadas and Grytviken that have ~100 year records. For Great Wall station of China, data, although collected in relatively shorter in phase, are continuous in recording from its very beginning to present. With 1971—2000 mean over 12—station AMT, we calculate the temperature anomalies for each of the 12 stations, followed by averaging the anomalies of the same year over the 12 stations, thus constructing a ATA (annual temperature anomaly) series for 1903—2000. From study of correlativity between the ATA and station AMT (annual mean temperature) series we find their correlation coefficients passing tests at 0.1% significance level so that the 1903—2000 ATA series is able to depict the change in temperature at the Peninsula and its vicinity and used in investigating the temperature climate jump, interdecadal variation and the relation to sea ice condition, leading to the following conclusions.

1) Three AMT jump points occur in 1903—2000 for the study region, separately, in 1920, 1953 and 1982, with the phase duration covering ~30 years and temperature rising in a stepwise manner. The temperature rises by 0.730°C in 1903—2000, by means of interdecadal jump, equivalent to the tendency rate of 0.0734°C/10a.

2) There are three jump points in the change of four seasonal temperatures, appearing, separately, in 1919—1923, 1947—1953 and 1976—1982, with the phase length of ~30 years. The temperature rise ranges differ on a seasonal basis, with the maximum (minimum) of 1.104°C (0.333°C) in winter (summer) that is related to the tendency rate of 0.1067°C (0.0233°C)/10a, the temperature increase happens mainly in winter in the Peninsula.

3) The annual mean temperature in the research region has its tendency rate of −0.2053°C/10a, with the rate bigger in the summer (December-May) than that in the winter half year (June-November), maximizing at −0.2302°C/10a in summer (DJF) and minimizing at −0.0021°C/10a in spring (SON). There the temperature is in opposite correlation with sea ice index, with the correlation coefficients passing tests at significance level of 5% for the summer, autumn and annual means.

note that the temperature jump points for the Antarctic Peninsula and Southern Hemisphere, on one side, and for China and the Northern Hemisphere, on the other, occur in the 1920s, 1950s and from the end of the 1970s to the early 1980s, suggestive of three climate jumps on a global basis in 1903—2000. However, China and the Northern Hemisphere experience higher temperature in the 1920s to 1950s in relation to the 1940s warming and lowered temperature over the 1950s to the end of the 1970s in contrast to the stepwise ascendant in the Peninsula and Southern Hemisphere without the 1940s warming. This demonstrates greater difference in temperature development between the sides, displaying natural behaviors of their own. The only phenomenon is that both sides exhibit the warming starting in the 1980s on a synchronous basis possibly owing to human activities (including the increased release of greenhouse gases) that exert effects on global climate.

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