Interannual and Interdecadal Variability of East Asian Acas and Their Impact on Temperature of China in Winter Season for the Last Century①

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(Received July 31, 2000; revised March 1, 2001) P4 A

ABSTRACT

The interannual and interdecadal variability of the Siberian High (SH) and the Aleutian Low (AL) from aspects of strength and location for the past one hundred years as well as their possible relations with temperature changes over mainland China are investigated. The data sets used are the historical sea level pressure for 1871–1995 and surface air temperature (SAT) over China in the last 100 years. The results show that the SAT in different regions over China, central strength of the SH and the AL, the south-reaching latitude of the 1030 hPa contour of the SH and the pressure gradient between the SH and the AL experienced two obvious changes during this period. One occurred in the 1920s, with a more prominent one in the 1980s. These variations are closely linked with the change of winter temperature over China in the interdecadal timescale. In the last 50 years, there is a remarkable interannual correlation between the strength of Active Centers of Atmosphere (Acas) and the winter temperature of northern and eastern regions in China. The abrupt change of Acas in the 1980s is consistent with the rising of the SAT in China. Since the late 1980s, the atmospheric circulation is experiencing a remarkable modulation, which may cause the interdecadal transition of warming trend.

Key words: Siberian High, Aleutian Low, Sea level pressure, Surface air temperature, Climate change

1. Introduction

Recently, the climate change characterized by global warming has drawn the attention of scientists from all around the world. Investigations concerning interdecadal climate oscillation are among the core contents of the on-going CLIVAR project (CLIVAR, 1998). A number of studies indicate that since 1880 the mean surface air temperature (SAT) of the Northern Hemisphere has risen about 0.3–0.6°C (Houghton et al., 1996). Most investigators attribute this rising to a great increase of "greenhouse gases" like carbon dioxide in the atmosphere. Generally, the global climate change experienced in the twentieth century can be divided into two relatively warmer periods and two relatively colder periods. The first cold spell lasted from 1880 to 1920 with the second one 1951–1970 and the first warm spell

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This research was supported by the National Key Program for Developing Basic Sciences in China (No.G1999043405) and NSFC 49975023.

maintained from 1921 to 1950 with the second one currently progressing since 1971 (IPCC, Houghton et al., 1996). Besides the warming trend in the last century that may be concerned with the " greenhouse effects" , those transitions of colder and warmer periods should be linked with other factors, such as the change of atmospheric circulation that directly influenced the SAT. It may not be excluded that a coming colder period will appear accompanying the abrupt change of the atmospheric circulation.

During the last century, Chinese climate has been affected by this large background of warming and exhibited its own characteristics. The warm period 1920–1940 and the cold period 1960–1970 are well consistent with the variation in the global SAT. But the intensive warming starting from the 1980s is more prominent in the northern part of China. Obviously, the climate of China has received various effects coming from a relatively complex background. Chinese climatologists (Tu, 1936; Wang, 1962) have pointed out that climate oscillation in China, in both frequency and amplitude, has a close relationship with the variability of corresponding active centers of atmosphere (Acas). Based on this knowledge, Zhu et al. (1997) analyzed the trend of strength change of the Siberian High (SH) using the data of the last 100–year sea level pressure (SLP). Gong and Wang (1999) analyzed the long–term variability of the SH and the possible connection to global warming. Due to the different length of data used in the above studies, the trends of long–term change showed some differences. Because of limited length and accuracy of data sets, till now we lack definite knowledge about variation characteristics in location and strength of Acas as well as their impact on the climate change. Further studies on the activity of East Asian Acas will contribute to better understanding of Chinese climate change during the past 100 years and producing forecast by possible trends.

The Siberian High (SH) and the Aleutian Low (AL) are two main Acas in the Northern Hemisphere affecting Chinese winter seasons. As the strongest cold high pressure develops in winter, deepening and southward–moving of the SH always cause the cold air–break or the strong cold–surge weather. The AL is a cold vortex, which can also influence the East Asian climate. These two permanent Acas are directly related to the strength of the East Asian monsoon and possibly play a key role in triggering off the westerly wind anomaly over the western Pacific, which will result in the equatorial Kelvin wave and lead to an El Niño event (Li, 1988).

The present paper firstly investigates oscillation characteristics and possible changing trends of the SH and the AL, then discusses their relations with the SAT over China. Following this introduction will be a section describing methods and data used. The SAT change in different river basins over eastern China during the last 100 years will be described in Section 3. Sections 4 and 5 will discuss the interdecadal variability of the SH and the AL and their influences on the SAT over China. Section 6 focuses on the interannual relation between the SH index and the SAT of winter China depicted from observational data of 160 stations. Conclusions will be given in Section 7.

2. Data and method

2.1 *Data source*

In this paper, major data sets are monthly mean sea level pressure (SLP) in the Northern Hemisphere with a spatial resolution of $5^{\circ} \times 10^{\circ}$ (15°–85°N) and a time period from January 1873 to December 1995, provided by University of East Angela (Jone, 1987). This is a relatively reliable grid data set covering 123 years (Gong and Wang, 1999). Jones (1987) described the sources of this data and the handling process. Williams and van Loon (1976) compared this data with the historical SLP provided by National Center for Atmospheric Research (NCAR).

Two areas, the SH area (30°–150°E, 20°–65°N) and the AL area (130°E–130°W, 20°–65°N) have been demarcated, respectively. Some grid points in certain years, for example, in 1882 and 1915–1920 were lost so that we used a mean value of four points around the lost point to represent it.

Two SAT data sets are used in this paper. One is the annual surface air temperature anomalies (SATA) for ten regions (Northeast China, North China, East China, South China, Taiwan, Central China, Southwest China, Northwest China, Xinjiang, and Tibet) over China from 1880 to 1998, which were constructed and provided by Wang et al. (1998). Based on this data, regional area–averaged temperature series for the altogether 10 regions covering 1880–1998 are calculated. The other data set is an observational monthly mean SAT of 160 stations from 1951 to 1999, which was provided by China Meteorological Administration. Only the winter records of the observational SAT are used. A set of data including modern meteorological observations for recent 49 years in China are relatively accurate.

2.2 *Methods*

The "winter season" to be discussed in this paper is referred to three months from the last December to the present January and February. Parameters used to describe Acas included are the strengths and locations in the centres of the SH and the AL. One of composite parameters is the south–reaching latitude of 1030 hPa contour, defined as the south most latitude of the 1030 hPa contour. Another parameter is the difference of central strength between the SH and the AL divided by the central distance between them. At the years of missing data, we used the mean value of the past ten years and the next ten years to represent that of the lost year.

To indicate a long–term trend of the central strength for the SH and the AL, a corresponding climatic trend coefficient r_{xt} is calculated, which is defined as the correlation coefficient between certain climatic series with a time length n and natural number series 1,2, 3, ······ n (Zhu et al., 1997).

3. Interdecadal changes of SAT in China

In the past 100 years, the rapid change of SAT in the Northern Hemisphere in the 1920s was characterized by the sudden rise with a relatively large amplitude in mid–high latitudes (Fu et al., 1999; Jones et al., 1986). To investigate the SAT change in China in the past 100 years, we divide eastern China into four main basins. Based on the 100–year series in the ten regions constructed by Wang et al. (1998), the annual mean SAT series from 1880 to 1998 for those four basins of eastern China are reconstructed. These four basins are the Songhuajiang River (Northeast China), the Yellow River (North and Northwest China), the Yangtze River (Southwest, Central and East China), and the Xijiang River (South China). Figure 1 shows the averaged SATA series in the four basins. In this figure, SATA in Northeast China has experienced several different fluctuations. Around 1907 there was the coldest spell since observational data became available. In the 1920s, SAT rose about 1°C. From the 1920s to 1970s the changes were relatively small. Since the 1970s SAT has been rapidly rising with about 2°C increment during 30 years. Compared with the early twentieth century, SAT has risen about 3°C. The highest record of SAT for the past 100 years was observed in 1998. This long–term trend of SAT change in Northeast China is similar to that of the Northern Hemisphere (Jones et al., 1986).

SAT in the Yellow River basin has experienced two cold spells during this observed period: One was about the mid 1900s and another took place around the late 1960s. These two cold spells are also consistent with the cold periods in the series of spring and summer SAT of the Northern Hemisphere (Jones et al., 1986). From 1910 to 1940 the SAT of the Yellow River basin had increased about 1.3°C. There was an abrupt decrease in temperature from the 1940s to the early 1950s. Since the late 1980s, this region has experienced its second warming, with SAT increasing to the level of the 1940s. A distinguished feature with slower SAT increase and quicker SAT decrease has been observed in the Yellow River basin.

SAT in the Yangtze River basin has experienced similar changes to the Yellow River basin, but with a slightly weaker amplitude. In the first 40 years of the twentieth century, the SAT rose about 1°C. The period of 1960s– early 1980s is the second cold period for this region while for the Yellow River the second cold period appeared in the 1950s–1960s. The recent warming in the Yangtze River basin started from the middle 1980s, later than that of the Yellow River. The SAT in the late 1990s has reached the level of the 1940s.

In South China the SAT has the largest anomaly difference of around 0.8°C. Compared with the other three basins, the first cold spell of South China appeared in the 1880s while the first warm spell during the 1920s–1940s. The latest cold spell of this region in the last century as well as the recent warming is the same as that in the Yangtze River basin.

It is clearly found that Northeast China has experienced the most obvious warming in the past 100 years with the amplitude exceeding the level of the Northern Hemisphere's warming. Because the cooling and warming of this region is relatively consistent with those of the Northern Hemisphere and the globe, SAT variation along the Songhuajiang River basin would give a positive contribution to the Northern Hemisphere and the global SAT change. In this study four basins are mainly located at 46°N, 40°N, 30°N and 23°N from north to south, respectively. The dashed lines in Fig. 1 connect cold and warm spells between the four basins respectively. The primary warm spell during about 1920–1950 was dominated over all basins, but the first cold period in the south regions took place 20 years earlier than that in the north regions while the second cold period started almost at the same time in all basins. In recent 30 years the warming first started from north, then moved to south in China. A question arises whether or not there is a possibility of a rapid decrease of the SAT in the coming years as it has appeared in the Yellow River and the Yangtze River during the 1940s–1950s.

Another interesting feature is that there are relatively cold (shaded areas in Fig. 1) and warm spells between the 10th order polynomial fitting and the 7–point running average curves. In every basin, there are 6–7 relatively short cold periods and about 7 short warm periods, exhibiting a quasi–20–year oscillation (differences between the 10–order fitted curve and the 7–point running average curve) with a much smaller amplitude than in the long–term trend. These warm and cold periods appeared nearly at the same time in different basins, such as the cold spell around 1930, the warm spell around 1940, the cold spell around 1950 and the warm one around 1960. These spells are just like strong "cold surges" and "hot waves" which hit the whole China during a specific period. This kind of large scale, long term cold and warm waves should be directly linked with the activity of East Asian Acas in both strength and location.

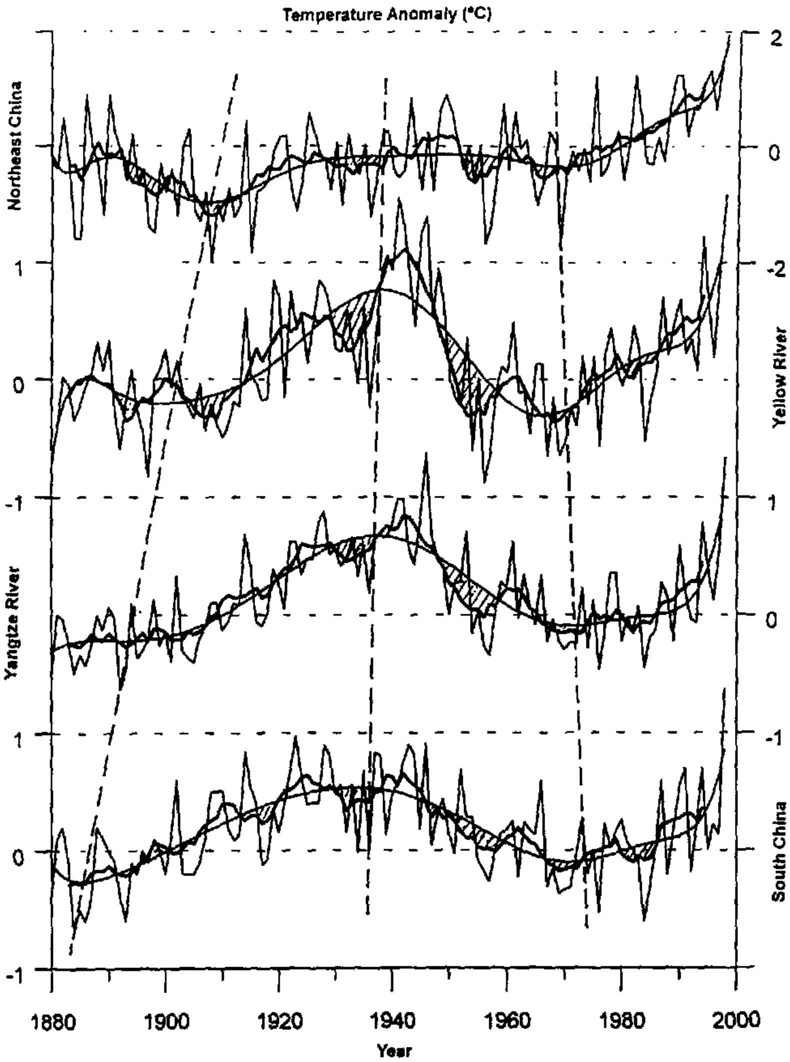

Fig. 1. Annual mean SATA (°C) series from 1880 to 1998 for the Songhuajiang River basin (Northeast China), the Yellow River basin (North and Northwest China), the Yangtze River basin (Southwest, Central and East China) and the Xijiang basin (South China). The thin solid lines represent SATA series, smoothed curves the 10th-order polynomial fitting to the original series and thick lines a 7-point running average.

4. Interdecadal variability of acas

4.1 *Central strength*

To examine the relationship between the evolution of general circulation and the

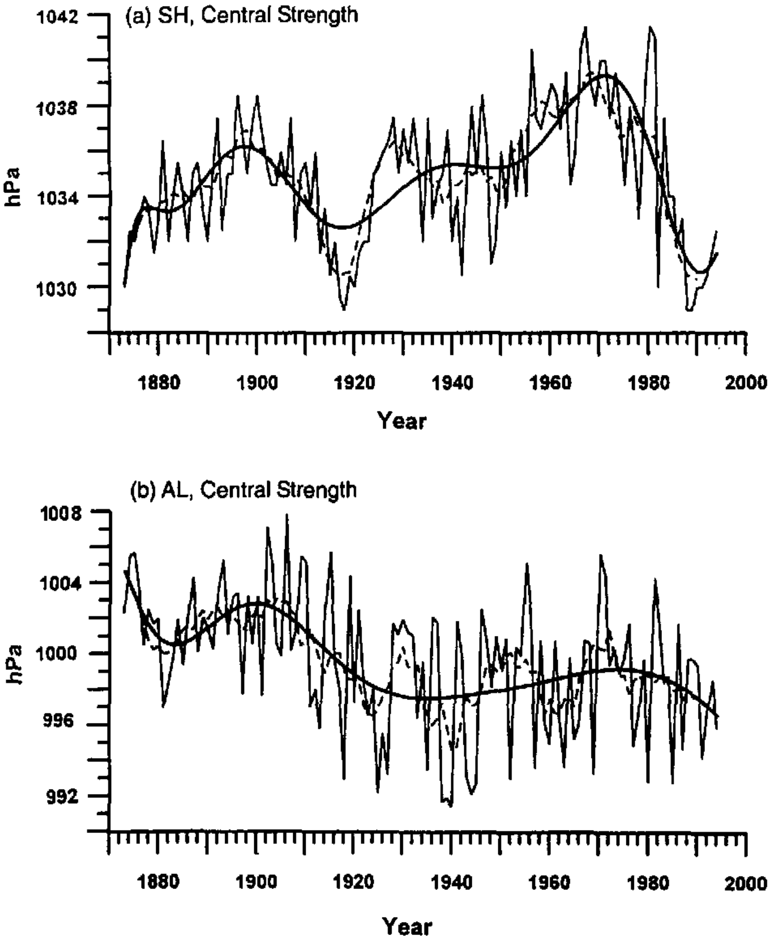

Fig. 2. The time series (light solid line: hPa) of (a) the winter SH central strength and (b) the winter AL central strength for 1873–1994. Heavy solid lines are for the 10th–order polynomial fitting to the original series while dashed lines the 7–point running average.

interdecadal variability of SAT over China, the central values of the sea level pressure at the SH and the AL systems for the past 100 years are displayed in Fig. 2. From Fig. 2a, the calculated climatic trend coefficient of the SH strength is 0.185 with the confidence level 0.05 of t–test passed for a positive trend. For the SH, there are two obvious interdecadal oscillations in the 10th order polynomial fitted curve of this series: two wave crests appearing in the late 1890s and about 1970, while two troughs in the late 1910s and about 1990, respectively. Comparing Fig. 1 and Fig. 2a, low SAT in the main four basins approximately corresponds to increased central strength of the SH, and vise versa. The strongest wave crests and troughs for the SH central strength took place in recent 20 years from 1970 to 1990 with a decrease of about 8 hPa. A positive trend from the 1870s to 1960s is more obvious than that from the whole period. However, a negative trend that is similar to the result of Zhu et al. (1997) could be noted from the 1890s to 1980s. It is identified that the long–term trend of the SH strength depends upon both of period and time length selected. For this series covering around 100 years, we particularly concern the different stages of the SH variation (Gong and Wang, 1999) and their relations with SAT changes. From this curve, a quasi–20–year oscillation also exists in the strength series. The quasi–20–year oscillation contained in the SH strength series is approximately consistent with the SAT changes over China.

Figure 2b exhibits the time series of the central strength of the AL. The central pressure value reached its highest point around 1900, then decreased gradually to a relatively low point in the late 1930s. During the late twentieth century, the central strength of the AL experienced another relatively weaker decadal variation. For the past 100 years, the overall trend of the AL central pressure is decreased (low–pressure system deepening) with a coefficient −0.108 with the confidence level 0.05 of t–test passed for a negative trend. Two interdecadal oscillations within both central strength of the SH and the AL have exhibited a certain similarity in phase, and the central pressure values have both increased and decreased during the same period. The only difference is that the SH was larger in the amplitude of variation and exerted more impacts on weather systems of East Asia.

4.2 *Longitudinal and latitudinal position*

As shown in Fig. 3a, latitudes of the SH centre have been confined in a region between 37°N and 60°N for the past 100 years. From the 1930s to 1940s, the SH centre maintained at higher latitudes with a mean value of 52°N while during the 1870s–1880s and 1910s it extended southward to lower latitudes with a mean value of 45°N. The relatively higher latitude of the winter SH centre during the 1930s–1940s is consistent with a warm spell in China and the Northern Hemisphere.

Figure 3b depicts the evolution of longitudes of the SH centre during the past 100 years. Before the 1960s, the variation was relatively smoothed with a mean position around 105°E. After the middle 1970s, the centre moved westward in the last 25 years which also fits well with warming for the same period in China.

Unlikly the SH, the location of AL has varied little during the past 100 years.

4.3 *Acas index*

It is well known that the central strength and position of the SH and the AL are closely linked with the winter SAT over China. To reflect the composite effects of those two Acas on Chinese SAT, two indexes mentioned in Section 2 are constructed. Figure 4a depicts the series of south–reaching latitude of the 1030 hPa contour of the SH and Fig. 4b the series of the gradient index between the SH and the AL. As mentioned above, these indexes have relations with both central pressure strength and their geographical locations. Before the 1920s (Fig. 4a) the 1030 hPa contour of the SH remained around 34°N, which is well consistent with a cold spell in China. From 1920 to 1940, this contour moved northward gradually corresponding to a higher SAT in China, then in the 1960s to 1970s, it retreated to 34°–35°N again corresponding to a colder period over China. The recent northward reaching 42°N is consistent with the latest warming in China. The prominent northward moving of the SH around 1990 has a direct relationship with consecutive warmer winters more than ten years experienced in China. From Fig. 4b, there are also interdecadal oscillations within the gradient index series with an obvious increasing trend before the 1970s. Basically this index reflects the central strength variation of the SH. The largest gradient value appeared in the late 1960s to early 1970s, which is the coldest period in the Yellow River basin. The rapid decrease of this

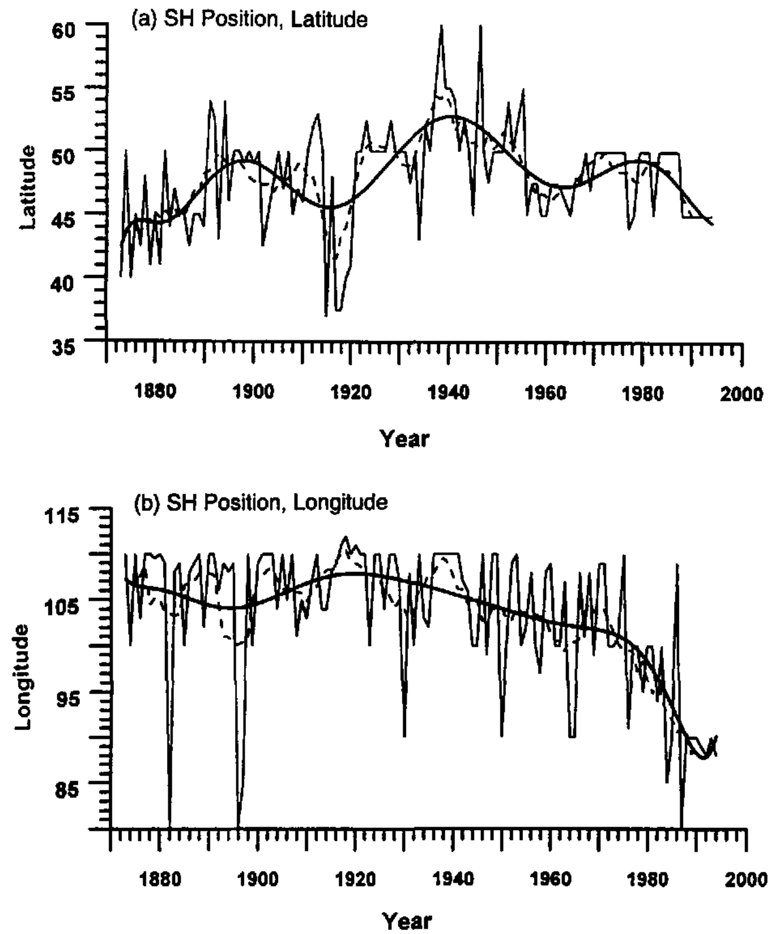

Fig. 3. Same as Fig. 2 but for the position of the SH centre at (a) latitudes (°N) and (b) longitude (°E) in winter season.

gradient value during the 1980s may be one reason leading to the SAT increase over the north part of China.

According to the interdecadal variability of the two Acas during the past 100 years, it should be noticed that there are two abrupt changes. One took place in the 1920s, with another more prominent one in the late 1970s to 1980s. For the former, Fu et al. (1999) has given an analysis example from general circulation and climate anomaly. For the latter, the remarkable changes in the Acas parameters in recent 20 years are coincided with that of the SAT over China. The extreme change of Acas parameters in recent years is rather fast and unstable. It implies that the reversed changes of those parameters may be possible in coming years. If so, the SAT in China, even in the globe may change to a cold or negative trend.

5. Correlation in the interdecadal timescale

In this section, we quantitatively examine the relationship between the central strength and position of the SH and the SAT over China. Table 1 shows the correlation coefficients between Acas parameters and the annual mean SAT over the 10 regions of China. The time period is 115 years from 1880 to 1994. The central strength of the SH is negatively correlated with the SAT in most regions of China except in the Taiwan and Xinjiang regions. The negative coefficient reached −0.21 for North China with the confidence level 0.05 of t−test passed. The coefficient for the Northwest region is −0.28 with the confidence level 0.01. These two regions are strongly affected by the SH.

Table 1. Correlation coefficient between Acas parameters and the annual mean SAT over the 10 regions of China. The second row lists the correlation coefficients of the SH central strength and the third row the south−reaching position of 1030 hPa contour of the SH

Correlation Coefficient	NE China	North China	East China	South China	Taiwan region	Central China	SW China	NW China	Xinjiang	Tibet region	China Total
Central Strength	−0.17	−0.21	−0.12	−0.011	0.11	−0.13	−0.03	−0.28	0.03	0.00	−0.20
South−reaching Latitude	0.36	0.26	0.31	0.22	0.20	0.18	0.21	0.34	0.21	0.27	0.32

The south−reaching latitude of the SH 1030 hPa contour exhibits positive correlation for all ten regions with the confidence level over 0.05, except for Central China. If the south−reaching latitude of the SH 1030 hPa contour is in the north of its normal position, the SAT would be higher than normal, and vise versa. The higher center value and lower latitude of the SH will result in large−scale cold outbreaks. For example, during the late 1960s the 1030 hPa contour had maintained at lower latitudes, causing the strong "cold surge" and severe snowy days in the northern Xinjiang region. So, monitoring the south−reaching latitude of the SH 1030 hPa contour may contribute to a forecast guide for severely low temperature and snow disasters.

6. Interannual variability

According to Fig. 4a and Fig. 4b, there is an abrupt change for the SH and the AL during the 1980s. For the past 100 years, Chinese observational data have been greatly increased since the 1950s. By analyzing the relation between Acas and observational winter SAT of recent 50 years, the interannual impacts of Acas on SAT can be clearly noted. Figure 5 shows the spatial distributions of correlation coefficients between parameter series of Acas and 160−station observational winter SAT over China from 1951 to 1994. The distribution of correlation coefficients between the winter SH strength and the observational winter SAT over China is displayed in Fig. 5a. Except for the southwest region, most parts were dominated with negative correlation values. The coefficients for Northwest and North China have reached −0.6. Moreover, there are also negative correlation centers appearing along the middle and low reaches of the Yangtze River basin, Xinjiang and the north part of Northeast China. This distribution indicates that the stronger SH would lead to the lower winter SAT

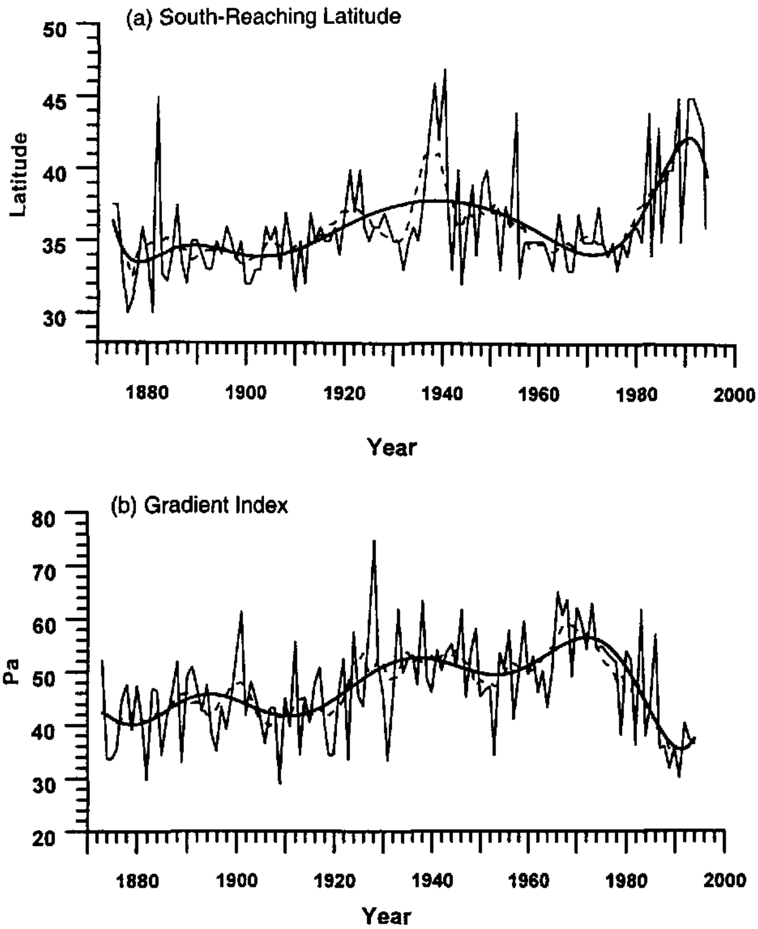

Fig. 4. Same as Fig. 2 but for (a) the south–reaching latitude (°N) of the SH 1030 hPa contour and (b) the gradient index (Pa / longitude) between the SH and the AL.

over the north and most east regions of China and vise versa. This result calculated by using winter SAT of the past 50 years is similar in sign to those calculated by using 100–year series but with relatively more evidence. In this distribution, a weaker positive correlation only exists in the southwest region of China. This implies that the effect of cold air rarely reaches Southwest China. According to the 850 hPa wind field, southerly wind prevails over Southwest China through the year, indicating that main factors affecting this region should come from the Tibetan Plateau and low latitudes.

Figure 5b shows the spatial distribution of correlation coefficients between the gradient index and observational winter SAT over China. Most regions exhibit negative correlation values except in the east part of the Tibetan Plateau and Southwest China. The maximum values also appears at the middle and lower parts of the Yellow River basin. This distribution indicates that the higher gradient index goes with the lower winter SAT. The similar pattern

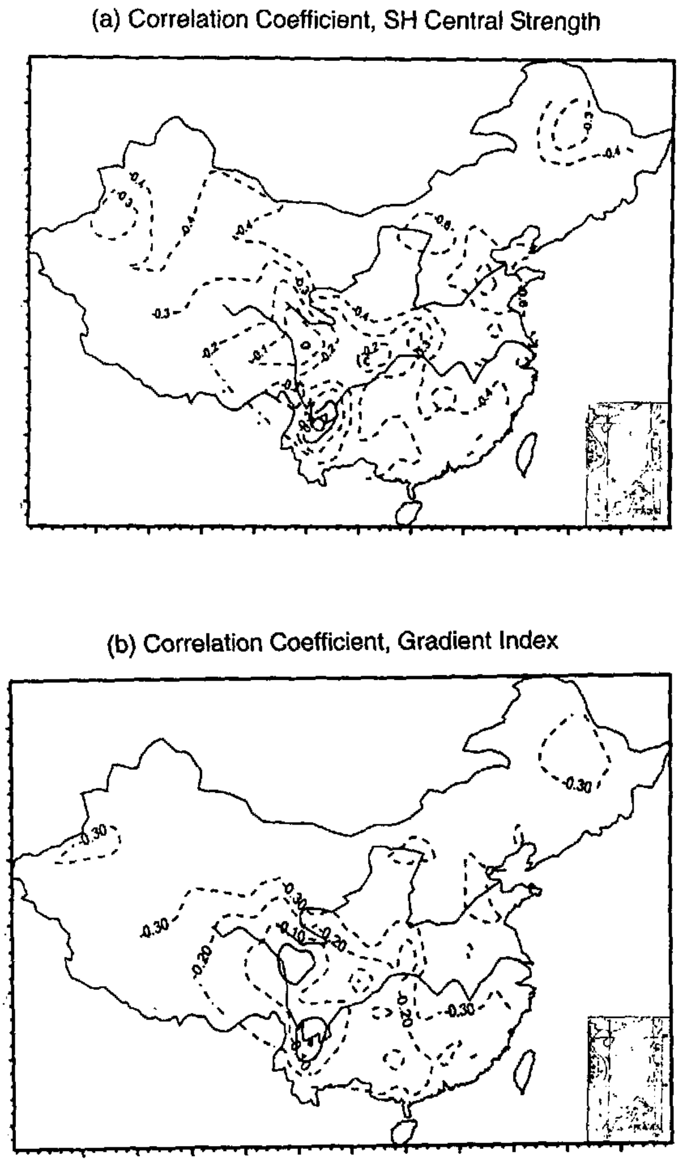

Fig. 5. The spatial distribution of correlation coefficients (a) between the winter SH central strength and 160–station observational winter SAT, and (b) between the gradient index and 160–station observational winter SAT in China for 1951–1994.

can also be found from the calculated correlation between other parameters and observation SAT.

From Fig. 5, it can be concluded that the impacts of the two Acas, especially by the SH strength and position, on the winter SAT of China are mainly in the north and east regions of China. This result is similar to that of the correlation coefficients using the 10–region annual mean SAT for the past 100 years.

7. Conclusions

In the past 100 and most recent 50 years, warming in China mainly took place in the 1980s. This process is more prominent in the winter season of the northern regions than in other parts of China. In this paper, we have better understood the interdecadal variability of the winter SH and AL as well as their relations with SAT over China. Several conclusions are listed as follows:

(1) Evident interdecadal variations exist in the annual mean SAT over the four basins in China. The 20th century's warming in China is mainly focused on Northeast China with a larger range more than that in the Northern Hemisphere. The warm spell from the 1920s to 1940s covers the four basins. The first cold period of the southern region was earlier than that of the northern for about 20 years, but the second cold period mostly took place in the whole China at the same time. The warming development beginning from north then moving to south during recent 30 years should be further studied.

(2) There are obvious stages in the variations of the winter SH central strength and location. From the 1890s to 1900s the SH was of stronger strength and in higher latitude while for the 1910s –1920s weaker strength and lower latitude. During the 1960s–1970s, the strength reached its highest value in the last century, then experienced an abrupt decrease in the 1980s. The central position also moved southwestward during this period. Two abrupt changes of the winter SH took place in the 1920s and 1980s, which are consistent with the changes of both Chinese and global SAT in the 1920s and 1980s.

(3) The composite indexes of the two Acas have experienced obvious interdecadal abrupt changes. The south–reaching latitude of the winter SH 1030 hPa contour and the gradient index between the SH and the AL are two important indices having close relationship with "cold surge" and cold disasters influencing China. These two indices exhibited completely different quantitative characteristics during the 1960s–1970s relative to the 1980s–1990s. Their abrupt changes commonly occurred in the 1980s. The long–term activity of Acas experiences the possibility of transition pattern in the variation trend, which may cause the decrease of SAT in China for the coming years.

(4) The interannual variability of Acas has direct impacts on the SAT of northern and eastern China. Based on analysis for observational SAT of recent 50 years, it is found that except for Southwest China and the Tibetan region the variations of the winter SH and AL have a strong effect on a broad area of China, especially on Northwest China and the eastern regions.

The first author wishes to thank the SEES at Seoul National University of South Korea through the BK 21 project for providing an opportunity on studying the paleoclimate and Asian monsoon, and the two anonymous reviewers for their helpful comments and suggestions, which led to improvements in the manuscript.

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近百年冬季东亚大气活动中心
年际—年代变率及其对中国气温的影响

钱维宏　　张鹤年　　朱亚芬

摘　要

利用历史海平面气压资料分析了近百年来冬季西伯利亚高压、阿留申低压强度和位置变化特征及与中国不同区域气温的关系. 分析发现中国气温, 西伯利亚高压和阿留申低压中心强度, 西伯利亚高压 1030 百帕等压线南伸纬度和两个大气活动中心之间的气压梯度在过去的 100 年中存在 1920 年代和 1980 年代的两次突变, 其中以后一次突变更为显著. 100 年的大气活动中心变化与中国 100 年的气温有着显著的年代际相关. 在过去的 50 年中, 冬季大气活动中心强度及其指数变化与中国北方和东部地区的冬季气温有显著的年际相关. 大气活动中心在 1980 年代的显著突变与中国乃至全球气温的突变一致. 大气活动中心的多种参数表明, 1980 年代后期以来大气环流正面临着重大调整. 这种调整可能预示着中国年代际气温的转变.

关键词: 西伯利亚高压, 阿留申低压, 气温, 气候突变