Influence of Interannual Variability of Antarctic Sea-Ice on Summer Rainfall in Eastern China

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ABSTRACT

Based on the Antarctic sea-ice coverage reanalysis data from the Hadley Center and other observational data during the 30-year period from 1969 to 1998, it is shown that Antarctic sea-ice coverage exhibits considerable interannual variability with a complex relation to El Niño and the South Oscillation (ENSO). Besides this, the ice maintains the seasonal persistence of the atmospheric circulation in high latitudes of the Southern Hemisphere. Thus it can be used as a predictor in short-term climate prediction. Both correlation and time series analyses demonstrate that summer rainfall in eastern China is closely related to Antarctic sea-ice coverage. When it is extended during boreal spring through summer, there is more rainfall in the lower reaches of the Yellow River of North China, and in contrast, less rainfall is found in the Zhujiang River basin of South China and Northeast China. A further analysis indicates that this rainfall pattern is related to the intensity of the East Asian summer monsoon caused by interannual variability of Antarctic sea-ice coverage.

Key words: Antarctic sea-ice, interannual variability, summer rainfall

1. Introduction

The great Antarctic ice sheets and the surrounding southern ocean environs are large heat sinks in the global heat budget. Satellite observations have shown that the Antarctic sea-ice undergoes a pronounced interannual variability superimposed on the annual cycle. Such variations result in strong surface heat budget changes over the southern ocean, and the redistribution of local heat sinks may alter the large-scale circulation thus affecting weather and climate in regions far away from the Antarctic (Bromwich and Parish, 1998; Yuan and Martinson, 2000). In particular, the role of the Antarctic sea-ice changes on the East Asian summer monsoon and summer rainfall in China has been increasingly recognized. Fu (1981) noted the possible linkage between Meiyu in the Yangtze River valley and the Antarctic sea-ice coverage during the end of the proceeding year. Based on more reliable Antarctic sea-ice data, the relationships between Antarctic sea-ice coverage and the number of tropical cyclones landing in China and the western Pacific subtropical high were further validated. (Zhao and Ji, 1989; Peng and Wang, 1989). More recently, our study on the seasonal division of the general circulation of the atmosphere showed that in the lower troposphere, the southern winter circulation is first established over the Antarctica and its surrounding areas by the end of March, resulting in the establishment of the Asian summer monsoon circulation through cross-equatorial currents (Xue et al., 2002). In addition to the observational study, the influence of Antarctic sea-ice on the general circulation of the atmosphere and global climate is also substantiated in numerical experiments (Yang and Huang, 1992; Yang and Xie, 1993; Chen et al., 1996).

While the earlier studies provide us some suggestive clues, uncertainties exit due to sparse and relatively short observations in the Antarctic region. It is therefore necessary to validate or modify the aforementioned conclusions using the most up-to-date observational data. In particular, the mechanism of how the Antarctic sea-ice influences the East Asian summer monsoon and summer rainfall in China is not fully understood. For this purpose, the Antarctic sea-ice data

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and China precipitation data from 1969 to 1998 are used to investigate the influence of Antarctic sea-ice on summer rainfall in China, in order to better understand the physical mechanism responsible for interannual variability of summer rainfall in China.

2. Data description

The analyses in this study are based on several datasets. The Antarctic sea-ice data consists of the reanalysis products from the Hadley Center for Climate Prediction and Research, with a resolution $1^\circ \times 1^\circ$, for the 30-year period from 1969 to 1998. The ice coverage is represented with index values of 0, 1, 2, ..., 10, and the total coverage is thus obtained using an equal-area mean within high latitudes of the Southern Hemisphere (Parker et al., 1995; Rayner et al., 1996). The monthly mean sea level pressure data are taken from the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) on a resolution of $2.5^\circ \times 2.5^\circ$ during the same period (Kalnay et al., 1996).

Monthly mean rainfall data of 160 stations in China during June, July, and August (JJA) from 1969 to 1998 were compiled by the China Meteorological Administration. The geographical distribution of the 160 stations is generally uniform, especially in the eastern part of China. As a complementary dataset, the monthly rainfall index γ in 15 regions reorganized by the National Climate Center of China is also used in the analysis (Chen and Zhao, 2000). The index γ is defined as

$$\gamma = \left(\frac{1}{n} \sum_{i=1}^{n} \frac{R_i}{\overline{\overline{R_i}}} + \frac{n^+}{n} \right) \times 100\%, \quad (1)$$

where R_i is monthly mean rainfall, $\overline{R_i}$ the multi-year mean of R_i, n the total number of stations in one region, i the station index, n^+ the total number of stations for which the monthly mean rainfall anomaly is greater than or equal to zero (i.e., $\Delta R_i \geq 0$). Obviously, the first term on the right side represents the mean rainfall intensity in the region, and the second term represents the range of positive rainfall anomaly. Therefore, rainfall in one region can be evaluated well using the rainfall index.

3. Interannual variability of Antarctic sea-ice and persistence of general circulation of the atmosphere

Figure 1 shows the normalized total Antarctic sea-ice coverage (ASI) in JJA during the period 1969 to 1998, together with their corresponding counterparts in March-April-May (MAM) and December-January-February (DJF) for comparison. ASI exhibits considerable interannual variability in all three seasons. It is also noted that ASI tends to be extended in some La Niña years while it tends to retreat in some El Niño years during the concerned period (Wang and Gong, 1999). On the other hand, no significant change in ASI is found in the strong El Niño event around 1982 and 1983 while the negative anomaly in 1980 has nothing to do with El Niño or La Niña, so that ASI seems to be unstably correlated with the ENSO cycle on an interannual timescale, and more importantly, it is not entirely a "slave" to ENSO. On a seasonal timescale, ASI in MAM is in good agreement with that in JJA with a correlation coefficient as high as 0.84. ASI in DJF is also positively correlated with that in JJA except for the significant differences around 1975 and the early 1990s, with a relatively lower coefficient of 0.45. This fact indicates that ASI can be used as a good predictor for seasonal or even extra-seasonal forecasts.

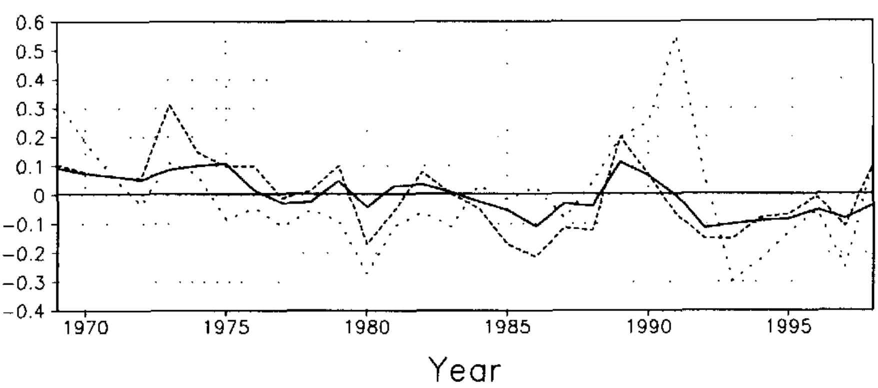

Fig. 1. Time series of the normalized total Antarctic sea-ice (ASI) from 1969 to 1998, the solid, dashed, and dotted lines represent the June-July-August (JJA), March-April-May (MAM), and December-January-February (DJF) seasonal means, respectively. The ordinate represents the magnitude of ASI.

As shown in Fig. 2, the correlation coefficient of sea level pressure between JJA and MAM can be used to evaluate the seasonal persistence of general circulation of the atmosphere. There exists a significant persistence in the tropics due to the thermal inertia of the tropical oceans. Besides, the large-scale seasonal persistence in high latitudes of the Southern Hemisphere and the Antarctic obviously indicates the lag effect of ASI on the atmospheric circulation similar to the tropical oceans. In fact, the similar phenomenon was already noted in a numerical experiment of atmospheric general circulation model (Wang, 1999). Over the East Asian summer monsoon region, however, seasonal correlation is very weak due to the significant seasonal changes there. It should be noted that the strong correlation in western China is probably caused by errors due to the topographic effect in the reanalysis data. In high latitudes of the Northern Hemisphere, the influence of snow and ice near the Arctic can be detected from the negative correlation with less significant values confined to small regions. As a result, the Arctic sea-ice is less valuable compared with its Antarctic counterpart for short-term climate prediction.

4. Interannual variability of Antarctic sea-ice and summer rainfall in eastern China

Figure 3 displays the correlation coefficient between summer rainfall in eastern China and ASI in JJA, MAM, and DJF from 1969 to 1998. Except over some regions in South China, the distributions of Fig. 3a and Fig. 3b are found to be generally similar because of the very high correlation between JJA and MAM for ASI as stated in the previous section. The positive correlation extends over most of North China with significant correlations in the Huaihe River valley and lower reaches of the Yellow River, and the negative correlations are located in South China and Northeast China. These correlation patterns seem to be connected, to some degree, with the second category of summer rainfall pattern in China as reviewed by Chen and Zhao (2000). On the other hand, the correlation patterns in Fig. 3c are somewhat different from those in the above two figures, namely, the positive correlations are situated in Northeast China and the middle and lower reaches of the Yangtze River. In particular, it is worth noting that the positive and negative correlations are maintained respectively in lower reaches of the Yellow River of North China and in the Zhujiang River basin of South China during DJF through JJA, though they are not so significant in some seasons. This result indicates that ASI is especially valuable for summer rainfall prediction in the two regions.

In order to further explore the relationship between summer rainfall in China and ASI, Fig. 4 shows the normalized rainfall index in South China (Huanan) in June and North China (Huabei) in July, when the major flood period occurs, together with the corresponding ASI in MAM. Clearly, the tendency of rainfall in South China is generally opposite to ASI especially after the 1980s, with a correlation coefficient of 0.41. In contrast, the consistent tendency between rainfall in North China and ASI is evident in Fig. 4b, with a correlation coefficient of 0.45. The result agrees well with the one revealed from the correlation patterns.

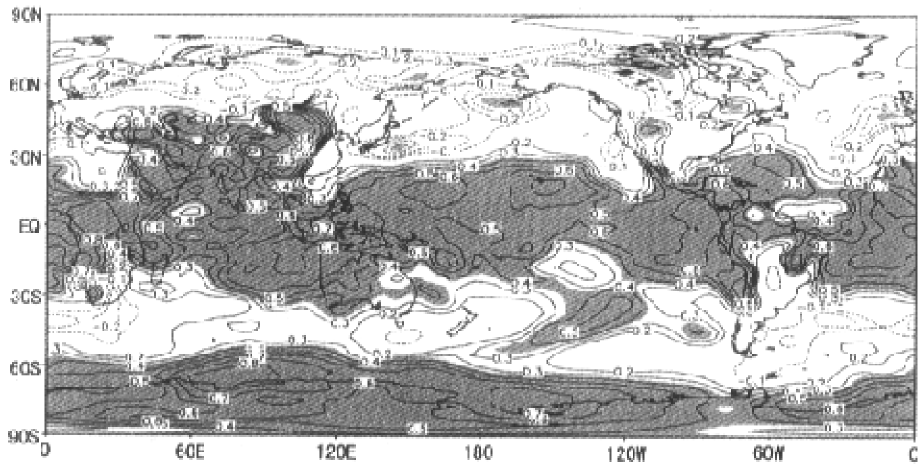

Fig. 2. Correlation coefficient of sea level pressure between JJA and MAM from 1969 to 1998. Regions above the 95% significance level are shaded.

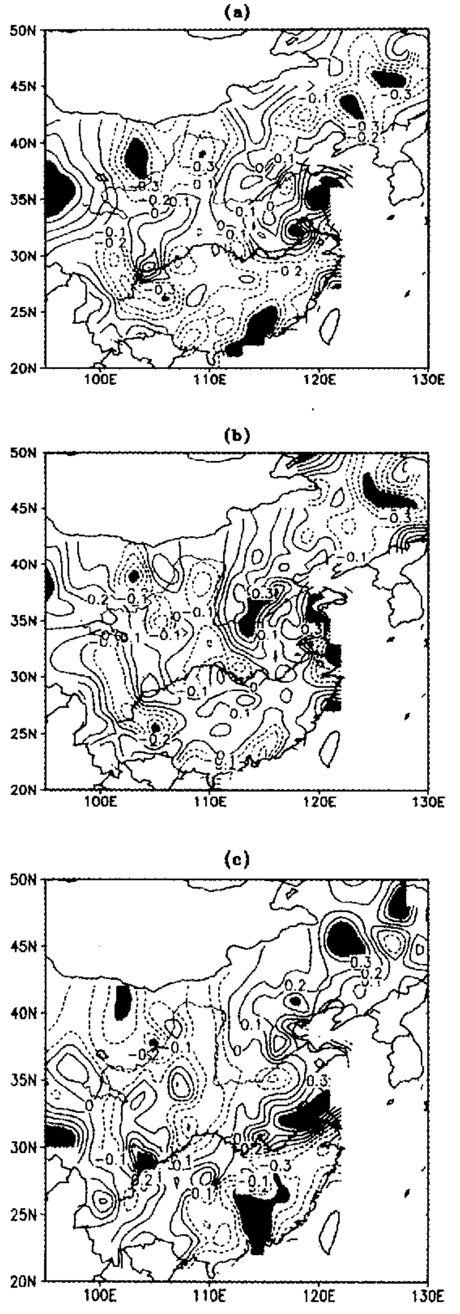

Fig. 3. Correlation coefficient between JJA rainfall in eastern China and Antarctic sea-ice in (a) JJA, (b) MAM, and (c) DJF. Regions above the 95% significance level are shaded.

The influence of Antarctic sea-ice on summer rainfall in China can be explained with the following inter-hemispheric teleconnection. As shown in Fig. 5, ASI is positively correlated with sea level pressure in high latitudes of the Southern Hemisphere and most regions of the Pacific except in the southeastern Pacific. Negative correlations extend over the Asian-Australian-African monsoon region especially in East Asia and tropical Africa, although the correlation in the Tibetan Plateau and its neighboring regions is not fully reliable. The above correlation pattern indicates that when Antarctic sea-ice is extended, surface pressure will be reduced in East Asia while being enhanced in the North Pacific especially for the North Pacific subtropical high. As such, the East Asian summer monsoon circulation will be intensified. Since North China is located on the northern border of the East Asian summer monsoon region, summer rainfall in North China will increase with the extension of Antarctic sea-ice.

5. Summary

We have provided a basic description of variability of Antarctic sea-ice and its influence on summer rainfall in eastern China. It is shown that due to the influence of Antarctic sea-ice, the atmospheric circulation in high latitudes of the Southern Hemisphere possesses significant seasonal persistence during the seasonal transition from DJF to JJA, and especially from MAM to JJA. Therefore, ASI can be used as an efficient predictor in short-term climate prediction.

Correlation analysis reveals the relationships between ASI and summer rainfall in Eastern China. When ASI is extended during MAM though JJA, there is more rainfall in the lower reaches of the Yellow River of North China while there is less rainfall in the Zhujiang River basin of South China and northeastern China. This is further demonstrated by a time series analysis for South China in June and North China in July. Although correlation pattern in DJF is somewhat different from the one in JJA, positive or negative correlations are still maintained in the above two regions. ASI is therefore useful for summer rainfall prediction. A further analysis indicates that when ASI is extended, the East Asian summer monsoon circulation will be intensified with a sea level pressure reduction in East Asia and sea level pressure enhancement in the North Pacific.

Although a controversy exits whether the extent of Antarctic sea-ice is compatible with the increase of surface air temperature during the last decades, the retreat of Antarctic sea-ice seems to be inevitable with the global warming (Chapman and Walsh, 2000; Zhao et al., 2001). With this understanding, the East Asian summer monsoon will be weakened, thus the serious

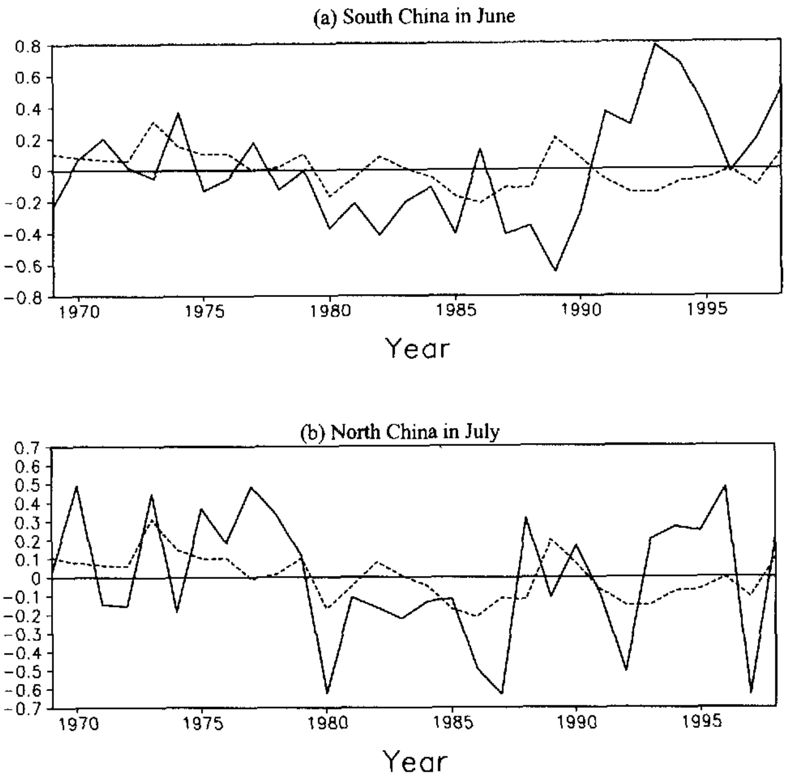

Fig. 4. Time series of the normalized rainfall index in South China (a) and North China (b), respectively (solid line), compared to the corresponding Antarctic sea-ice in MAM (dashed line).

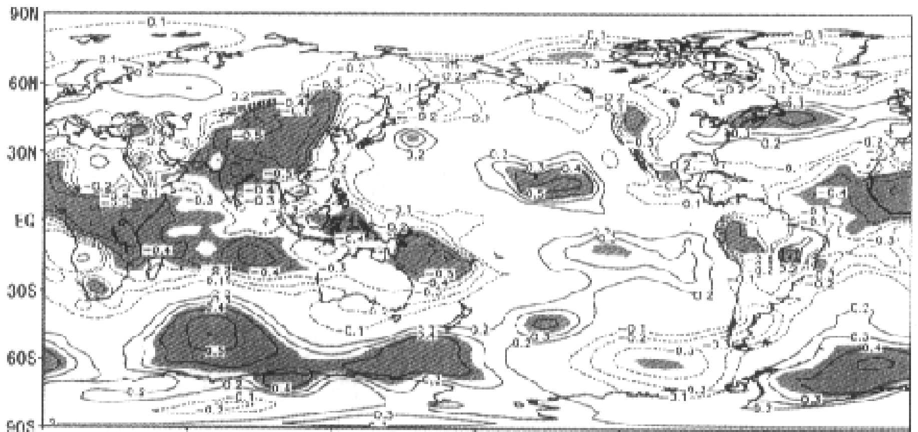

Fig. 5. Correlation coefficient between sea level pressure and Antarctic sea-ice in JJA from 1969 to 1998. Regions above the 95% significance level are shaded.

drought in North China will be further aggravated. It is therefore suggested that the interactions of the atmosphere-ocean-ice system in high latitudes of the Southern Hemisphere deserve to be explored further for a better understanding of the long-term trend of summer rainfall in eastern China.

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南极海冰的年际变化对中国东部夏季降水的影响

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摘 要

根据Hadley中心提供的1969-1998年的南极海冰再分析资料和其它多种观测资料，分析了南极海冰的年际和季节变化，指出南极海冰具有显著的年际变化，但与ENSO的关系则较为复杂。南极海冰维持了南半球高纬地区大气环流的季节持续性，因而对短期气候预测有较大帮助。相关分析和时间序列分析均证实中国东部夏季降水与南极海冰的年际变化有关，当北半球春夏季南极海冰增多时，华北降水增多而华南和东北降水减少。研究还表明，此种雨型分布与南极海冰变化引起的东亚夏季风环流变化有关。

关键词：南极海冰，年际变化，夏季降水