The relationship between the summer precipitation in the Yangtze River valley and the boreal spring Southern Hemisphere annular mode

Sulan Nan

Department of Atmospheric Science, College of Resources and Environment, Lanzhou University, Lanzhou, China

LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

Jianping Li

National Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

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[1] The relationship between the boreal spring (April–May) Southern Hemisphere annular mode (SAM) and the following summer (June–August) precipitation in China for the period of 1951–2001 is examined statistically in this study. There is a significantly positive correlation between the boreal spring SAM index (SAMI) and the following summer rainfall in the middle and lower reaches of the Yangtze River. The summer large-scale atmospheric circulation anomalies over East Asia are also related to the boreal spring SAMI events. A strong SAM in boreal spring is followed by a weakened East Asian summer monsoon, a strengthened and westward expanded western Pacific subtropical high (WPSH), as well as increased ascending vertical velocity, specific humidity and water vapor flux convergence. These situations provide necessary circulation and water vapor conditions for increasing the summer precipitation in the middle and lower reaches of the Yangtze River valley, and *vice versa*. The boreal spring SAM variation provides a potential valuable signal for predicting the summertime precipitation in the middle and lower reaches of the Yangtze River valley. *INDEX TERMS:* 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3349 Meteorology and Atmospheric Dynamics: Polar meteorology; 3354 Meteorology and Atmospheric Dynamics: Precipitation (1854). **Citation:** Nan, S., and J. Li, The relationship between the summer precipitation in the Yangtze River valley and the boreal spring Southern Hemisphere annular mode, *Geophys. Res. Lett.*, *30*(24), 2266, doi:10.1029/2003GL018381, 2003.

1. Introduction

[2] As early as in the late 1920s, *Walker* [1928] pointed out that there is a seesaw between the sea-level high-pressure belt across Chile and the Argentine and the low pressure area of Weddell Sea and the Bellingshausen Sea. Since then, many studies [*Kidson*, 1975; *Rogers and van Loon*, 1982; *Gong and Wang*, 1999; *Thompson and Wallace*, 2000] have been carried out to provide clear evidences that the leading empirical orthogonal function (EOF) mode of variability of the extratropical Southern Hemisphere (SH) sea level pressure (SLP) anomalies is characterized by annular structure, which is referred to as the SH annular mode (SAM). It involves a zonally symmetric seesaw in SLP between the south-polar region and middle latitudes, thus SAM is also called the Antarctic Oscillation (AAO) [*Gong and Wang*, 1999; *Thompson and Wallace*, 2000]. At present, the more attention has been paid to the structure and signature of SAM and the influence of SAM on the climate in SH middle and high latitudes [*Thompson and Wallace*, 2000; *Mo*, 2000; *Clare et al.*, 2002; *Hall and Visbeck*, 2002], and less to the connection between SAM and Northern Hemisphere (NH) atmospheric circulation and to the influence of SAM on NH climate. In this paper we will investigate possible relationships among three variables: the spring SAM, the summer precipitation in the Yangtze River valley and the East Asian summer monsoon.

[3] The main datasets employed in this study include National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data [*Kalnay et al.*, 1996] (1958–2000), the China's 160-station monthly precipitation data (1951–2001), the East Asian summer monsoon index [*Li and Zeng*, 2002] (1948–2000), and the SAM index (SAMI) (1948–2001) which is defined as the difference in the normalized monthly zonal-mean SLP between 40°S and 70°S. This SAMI is a modification of the AAO index defined by *Gong and Wang* [1999], which is the difference in the normalized zonal-mean SLP between 40°S and 65°S. The modified SAMI is used here because the negative correlation in the zonal-mean SLP anomalies between 40°S and 70°S is stronger than that between 40°S and 65°S. The spring and summer in this paper, defined as April–May and June–August respectively, refer to the boreal spring and summer.

2. Results

[4] Figure 1a shows the lag correlation map between the spring (April–May) SAMI and the summer (June–August) precipitation in China. There is an area with significantly positive correlation in the middle and lower reaches of the Yangtze River valley, implying that the above- (below-) normal summer rainfall over the valley is associated with a strong (weak) spring SAM. If the mean precipitation of the ten stations enclosed in the significant correlation area in Figure 1a is used to represent a rainfall index (hereafter

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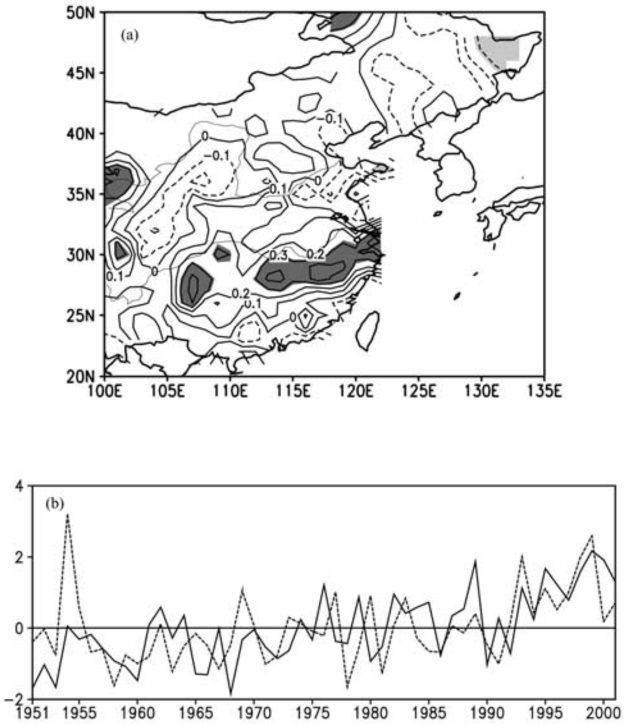

Figure 1. (a) Correlation between the spring (April–May) SAMI and summer (June–August) precipitation in China for the period 1951–2001. The positive (negative) correlation coefficients that are significant at the 95% confidence level are shaded dark (light). The contour interval is 0.1. (b) Normalized time series of the spring SAMI (solid line) and the summer rainfall index YRRI (dashed line) in the middle and lower reaches of the Yangtze River valley.

YRRI) of this region, the variation of the summer YRRI is consistent with that of the spring SAMI, as shown in Figure 1b. The correlation coefficient between them is 0.49, which is significant at the 99.9% confidence level. In Figure 1b, there are also some signals of the long-term changes. After their linear trends being removed, there is still a good relationship between the two indexes with a correlation coefficient of 0.34, which is significant at the 98% confidence level. Besides, from 1951 to 2001, in the nine strong spring SAM years with the SAMI values being greater than one standard deviation of the index, there is eight years with positively anomalous summer YRRI, while in the nine weak spring SAM years with the SAMI values being less than one negative standard deviation of the index, there is nine years with negatively anomalous summer YRRI. These results indicate that the following summer precipitation in the middle and lower reaches of the Yangtze River tends to be above-normal when the preceding boreal spring SAM is in its positive phase, and *vice versa*.

[5] To elaborate the relationship between the spring SAM and the following summer precipitation in the Yangtze River valley, a singular value decomposition (SVD) analysis [*Overland and Preisendorfer*, 1982; *Wallace et al.*, 1992] is applied to the spring SH SLP over the domain south-pole ward of 10°S and the following summer precipitation in China. The first SVD mode is shown in Figure 2, which accounts for 51% (above the noise level) of the total squared covariance. The spring SH SLP pattern of the leading SVD mode is characterized by the signature of the SAM with significantly negative correlation over the south-polar cap and significantly positive correlation over SH middle latitudes (Figure 2, left panels). The summer precipitation pattern in China for the leading SVD mode shows an appearance with strong correlation in the middle and lower reaches of the Yangtze River valley (Figure 2, right panels). These patterns imply that a strong spring SAM will be followed by an increased summer precipitation over the middle and lower reaches of the Yangtze River valley, and *vice versa*. The result is in conformity with the conclusion from Figure 1 and confirms further the strongly positive correlation relationship between the spring SAM and the summer precipitation in the middle and lower reaches of the Yangtze River valley. Therefore, the intensity of the spring SAM may be regarded as a predictor for the following summer precipitation in the middle and lower reaches of the Yangtze River valley.

3. Further Analysis

[6] Figure 3 shows the summer 850 hPa wind composite difference over Asia between the strong and weak spring SAM years, which were defined earlier. In East Asia, there is a strong anomalous anticyclone with the center over the Mongolia plateau and a weak anomalous cyclone over the Yellow Sea, and the strongly anomalous

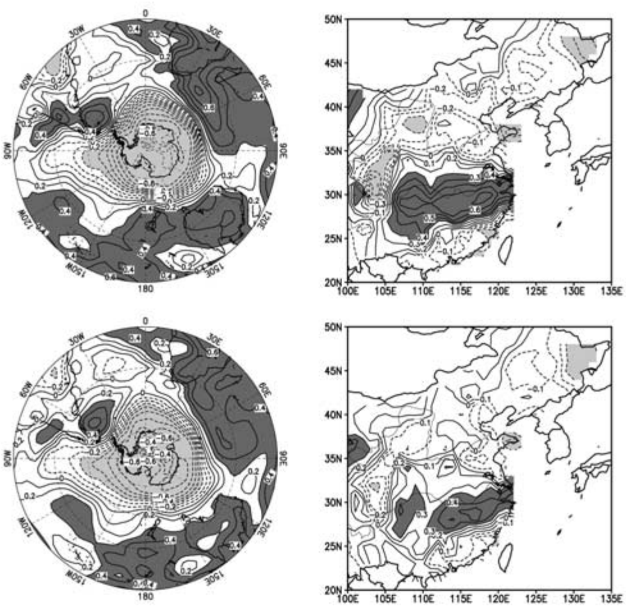

Figure 2. The leading SVD mode for the spring SH SLP anomalies to the south of 10°S and the summer precipitation in China. The upper panels are the homogeneous correlation patterns, and the lower ones the heterogeneous correlation patterns. The areas with positive (negative) correlation coefficients being significant at the 95% confidence level are shaded dark (light). The latitude lines in the left panels are at a 20-degree interval starting from 10°S at the edges. The temporal correlation coefficient between the corresponding expansion coefficients is 0.81, which is significant above 95% confidence level. The contour interval is 0.1.

northeasterlies in the eastern China. These indicate that a high (low) spring SAMI situation tends to be followed by a weakened (strengthened) East Asian summer monsoon, which provides a basic circulation background for the increased (decreased) summer rainfall in the Yangtze River valley [*Zhao and Zhang*, 1996; *Shi et al.*, 1996]. Moreover, over the tropics, the broad anomalous easterlies prevail in the belt between 10°–20°N from 180°E through South Asia and turn to anomalous northeasterlies over Somali (Figure 3). In addition, the South China Sea summer monsoon index [*Li and Zeng*, 2002, 2003] is negatively correlated with the spring SAMI (the correlation coefficient between them is −0.32, above the 95% confidence level). These results suggest that corresponding to a strong spring SAM event, the following summer tropical southwest monsoon tends to be weaker, which is also one of the circulation conditions leading to the increase of the summer precipitation in the middle and lower reaches of the Yangtze River valley [*Zhang and Tao*, 1998], and *vice versa*.

[7] The composite summer 500hPa geopotential height over East Asia (not shown) corresponding to the strong spring SAM situation exhibits a stronger-than-normal western Pacific subtropical high (WPSH), the western edge of which is located about 10 degrees to the west of its climatic position. These conditions help increasing of the precipitation in the middle and lower reaches of the Yangtze River valley [*Chen and Wu*, 1998; *Wu et al.*, 2002]. The weak spring SAM phase brings the opposite conditions to those mentioned above.

[8] The vertical sections of composite difference of the summer vertical velocity (Figures 4a–4b), and specific humidity (Figures 4c–4d) between high SAMI and low SAMI in the preceding spring show that for the strong spring SAM years, both the summer ascending vertical velocity and the specific humidity are significantly enhanced in the middle and lower troposphere over the middle and lower reaches of the Yangtze River valley, conducing to increase the precipitation in the valley. Besides, it can be found from the composite charts of the summer water vapor flux divergence (not shown)

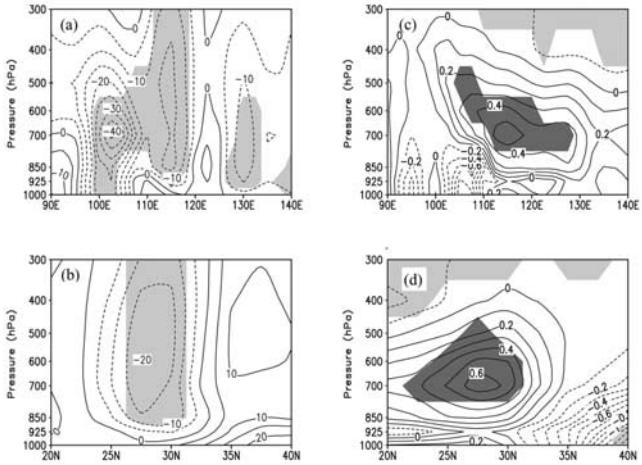

Figure 4. Composite difference of the summer vertical velocity (a) and (b) (in 10^{-3} Pa s^{-1}) and the specific humidity (c) and (d) (in g kg^{-1}) between the spring high and low SAMI years. The upper panels (a, c) are longitude-pressure cross sections between 25°–32.5°N. The lower panels (b, d) are latitude-pressure cross sections between 110°–120°E. The values in the shaded areas are significant at the 95% t-test confidence level.

corresponding to strong and weak spring SAM years that the high spring SAMI composite is characterized by strong summer water vapor flux convergence over the middle and lower reaches of the Yangtze River valley, and *vice versa*. Therefore, the summer situations over East Asia corresponding to strong spring SAM tend to be of stronger vertical velocity, specific humidity and water vapor flux convergence over the Yangtze River valley, providing the elementary vapor conditions for precipitation augment in the area, and *vice versa*.

4. Discussion

[9] The result in this paper shows clear evidence that there is a significantly positive correlation between the spring SAM and the following summer rainfall in the middle and lower reaches of the Yangtze River. When the spring SAM is stronger than normal, the East Asian summer monsoon weakens, the WPSH strengthens and expands westward. Moreover, if the SAM is stronger in a spring, then the ascending vertical velocity, the specific humidity, and the water vapor flux convergence tend to reinforce in the following summer over the middle and lower reaches of the Yangtze River. These situations offer significant large-scale circulation backgrounds and vapor conditions for the increased precipitation in the middle and lower reaches of the Yangtze River. The opposite situations are corresponding to the weak spring SAM. Therefore, the spring SAM intensity is expected to provide a potential valuable signal for predicting summer precipitation in the middle and lower reaches of the Yangtze River valley. However, the mechanisms responsible for the relation between them are still open questions and need further exploration in the future.

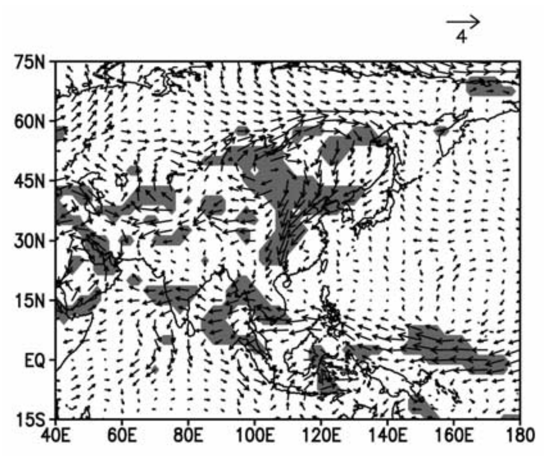

Figure 3. Composite difference of the summer 850 hPa horizontal wind field (in m s^{-1}) between the spring high and low SAMI years, which are defined in the text.

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S. L. Nan, Department of Atmospheric Science, College of Resources and Environment, Lanzhou University, Lanzhou 73000, China. (nsl@mail.iap.ac.cn)

J. P. Li, LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China. (ljp@lasg.iap.ac.cn)