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Significant relationship between spring AO and the summer rainfall along the Yangtze River

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Abstract **The influence of spring AO on the summer rainfall along the Yangtze River is investigated. The long-term rainfall observations are filtered to remove the low-frequency variations longer than 10 years. The inter-annual components show a high correlation to AO in the last hundred years. The strongest correlation appears for May AO and summer rainfall with a value of –0.39, significant above the 99% confidence level. Associated with one standard deviation stronger May AO index, the rainfall over the Yangtze River to the southern Japan decreases by about 3%—9%, while, at the same time increases by about 3%—6% in the northern China and far-eastern Russia. The coherent changes in rainfall are significantly related to the East Asian summer jet stream in the upper troposphere. When there is stronger AO in spring, the jet stream tends to move polarward in summer, and leads the rainfall-belt to move northward too. That gives rise to a drier condition in the Yangtze River valley, wetter anomalies in northern China. This signal would be helpful for the summer rainfall prediction in China.**

Keywords: Yangtze River, precipitation, Arctic Oscillation (AO).

There are a lot of factors exerting influence on summer rainfall over the Yangtze River, including the tropical eastern Pacific sea surface temperature, western Pacific Subtropical High, ground snow over Tibetan Plateau or/and mid-high Eurasian latitudes in winter to spring, solar activity, etc.[1,2]. However, many studies suggest that the state of the atmospheric circulation and lower boundary condition anomalies in the mid- high latitudes in winter to spring are also important for the summer climate. The leading mode of the extratropical Northern Hemisphere circulation is Arctic Oscillation (AO). Fluctuations in the AO create a seesaw pattern in which atmospheric pressure at northern polar and middle latitudes alternates between positive and negative phases. Numerous evidence indicates that the AO has wide-ranging effects over the Northern Hemisphere in winter and spring, involving surface air temperature[3,4], precipitation[3,5], sea-ice[6], atmospheric center of action[7,8], extreme weather/climate events[9], and so on. However, by now most of those researches primarily focus on the simultaneous relationship, i.e. AO's effect in the cold seasons when the AO is much active. An arisen question is whether there is a lag influence, or in other words, whether AO can impact the summer climate. The answer is yes. Here we present evidence for the significant connection between spring AO and summer rainfall along the Yangtze River on the interannual time scale.

1 Data and method

Precipitation data used include (i) 32 stations' monthly observations. These stations are located along the Yangtze River valley. Data are taken from the 160-station data set of the Chinese mainland for the period of 1951—2000, provided by the National Climate Center, China Meteorological Administration. (ii) Seasonal long-term precipitation records of six stations, namely Shanghai (121.4° E, 31° N, 4.5 m), Nanjing (118.5° E, 32° N, 8.9 m), Jiujiang (116° E, 29.7° N, 32.2 m), Wuhan (114.1° E, 30.6° N, 23.3 m), Yichang (111.3° E, 30.4° N, 133.1 m) and Changsha (113.1° E, 28.2° N, 44.9 m), are available since 1880[10]. (iii) Hulme's global land-area monthly rainfall data set are available for the period of 1900—1998 with a 5° by 5° spatial resolution[11]. Atmospheric circulation data (horizontal and vertical wind velocities) are obtained from the National Centers for Environmental Prediction/the National Center for Atmospheric Research (NCEP/NCAR) reanalysis, for the period of 1958—1999. AO index is taken from Thompson and Wallace[12].

A lot of studies show that there is strong inter-decadal variability in summer monsoon and rainfall which is, as some researches suggested, due to the tropical sea surface temperature anomalies, in order to remove the possible influence of this low-frequent changes and get a robust signal at inter-annual time scale a high-pass filter is necessary. Thus, a 9-point Gaussian digital filter with the weights of 0.01, 0.05, 0.12, 0.20, 0.24, 0.20, 0.12, 0.05 and 0.01 is applied to all time series. This filter removes the variations longer than 10 years and retains the inter-annual changes. In the present study all time series are filtered and shown as the departures of the 9-point-weighted moving means. The first and last 4 years are discarded after filtering to avoid the edge effect.

2 Results

The 32 stations, located in the region 105° E eastward and 27° N—33° N with evenly geographical distribution, depict the regional rainfall satisfactorily. Time series of the 32-station mean correlate to the spring AO evidently, with a negative correlation coefficient of -0.30. Among the three spring months, the strongest signal appears in May. AO index of May is correlated with summer rainfall significantly, $r = -0.37$ (above 95% confidence level). Since the data period for 32 stations is short, the robustness and significance of the correlations found here should be checked using a longer rainfall time series. The rainfall records of six stations are also averaged to get a regional mean time series for the period of 1880—2000. Time series from these two data sets (i.e. the means of 32 and 6 stations) agree very well, with a high correlation coefficient of 0.92 for the shared period of 1951—1999. That is due to the high consistent variations of summer rainfall over this region as some previous empirical orthogonal function analysis revealed. This means that the 6-station-mean rainfall time series also represent the regional condition very well. This long-term summer rainfall time series shows a very strong correlation with the May AO, $r = -0.39$ (significant at 99% confidence level). See table 1 for details. Fig. 1 displays the May AO as compared with the changes in the summer rainfall. Obviously there is an out-of-phase relationship between the two curves. This implies that there usually is less summer rainfall over the Yangtze River valley during the years when AO is strong in spring (especially the late spring), more rainfall when AO is weak in spring.

Table 1 Correlation statistics for AO and summer rainfall

Summer rainfall	AO in spring	AO in May	Period
32 stations mean	-0.30^{*}	-0.37^{**}	1951—1999
6 stations mean	-0.24^{**}	$-0.39^{\#}$	1899—1999

* Significant at 90% confidence level, ** at 95% and # at 99.9% respectively.

The summer rainfall in the Yangtze River valley is known as Meiyu. Meiyu is not a local phenomenon but a large-scale one, spanning a broad region from China to western Pacific in the east-west direction. Besides the Meiyu, the East Asian summer monsoon rainfall includes Baiu in southern Japan, and Changma in southern Korea. The AO's impact on monsoon rainfall should appear not only over the Yangtze River, but also over the Baiu and Changma regions. Here we check this using Hulme's global land-area rainfall data. Given the data availability, we only analyze the period of 1922—1998. Only grids with missing data less than 5% are analyzed. These grids are also shown as gray squares in fig. 2. The AO index in May is regressed upon the summer rainfall at each grid, the results are shown in fig. 2. The regression coefficients measure both the sign and the strength of the relationship between the two parameters. Before the regression analysis the AO index is normalized. Obviously, there are well-defined spatial features. The highly consistent variations in eastern Asia are remarkable. The precipitation anomalies spanning from about 100°E along the Yangtze River valley to southern Japan are of particular interest. Associated with a one standard stronger AO in May, the summer rainfall over the monsoon-rainfall-belt usually decreases by about 3%—12%. This kind of zonal-direction feature in summer rainfall anomaly is also evident in northern China and far-eastern Russia, displaying an in-phase relationship to AO. Statistic tests indicate that

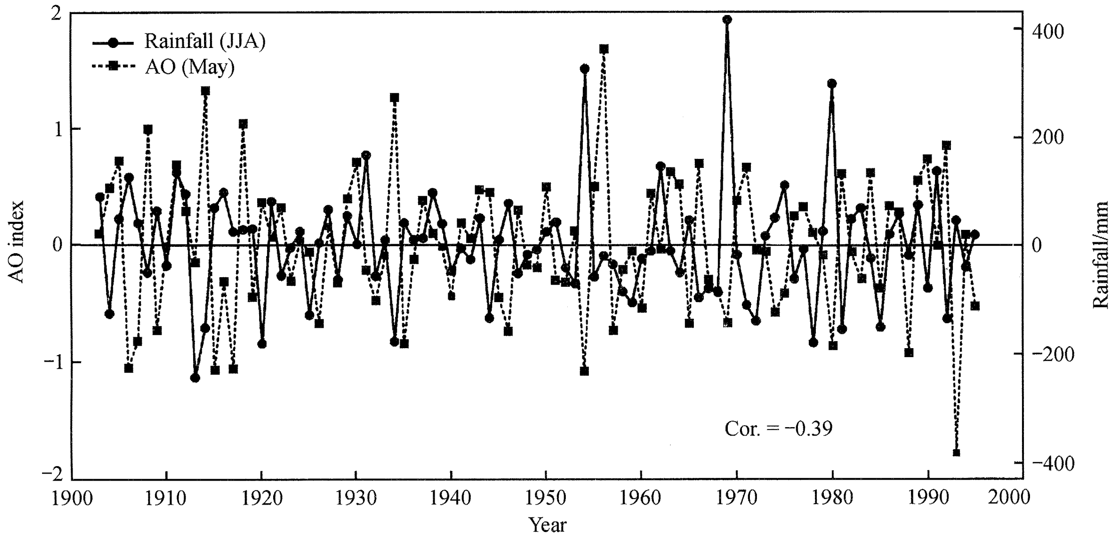

Fig. 1. Interannual variations in May AO index and summer rainfall over the Yangtze River valley.

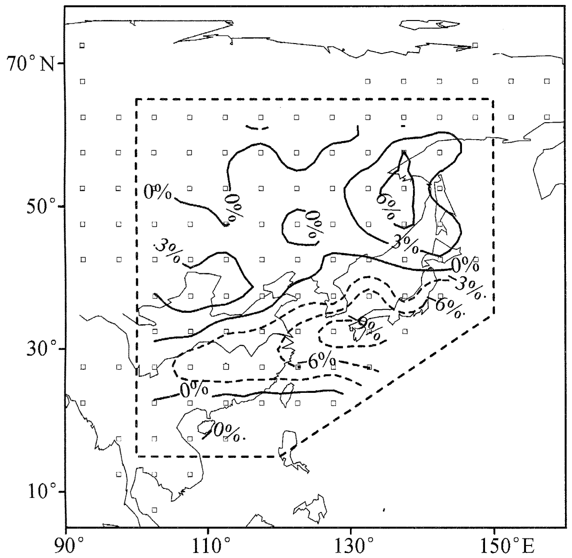

Fig. 2. Changes in summer precipitation (in %) corresponding to a one standard deviation of the May AO index. Computed over the period of 1922—1998. Gray squares indicate the grids with data availability above 95% in the entire period. Regions above 95% confidence level are shaded.

these relationships are significant at 95% confidence level from the Yangtze River valley toward southern Japan. All of these results suggest that the AO exerts significant influence on the large-scale East Asian summer monsoon rainfall.

3 Changes in East Asian jet stream

Two planetary-scale atmospheric circulation systems predominate the East Asian summer monsoon precipitation. One is the western Pacific subtropical high, which is related to the Hadley cell, and the other is the East Asian jet in the upper troposphere. A lot of previous studies investigated the connection of monsoon rainfall to the subtropical high. Recently some authors state that East Asian jet also plays a very strong dynamical role in the summer monsoon variability[13—15]. The location of the jet stream is identified with the fronts that produce extensive summer monsoon rainfall, usually this main rainfall belt extends from the Yangtze River valley to southern Japan. When the jet stream moves to the north, the rainfall band also moves poleward. This leads to a drier condition over the Yangtze River valley and a wetter condition in northern China. When the jet stream is located in the south of normal position, the conditions reverse. The covariance between rainfall and zonal wind at 200 hPa in summer, as shown in fig. 3, confirms that. Clearly, associated with the heavy summer rainfall in the Yangtze River valley, there are stronger westerlies over the Yangtze River to southern Korea and southern Japan, and weaker westerly anomalies in about 40°N—50°N.

It is of interest to note that the covariance between the AO in May and summer zonal wind at 200 hPa shows almost the same pattern as for rainfall and zonal wind. As fig. 3(a) reveals, with the positive phase of AO, stronger westerly wind appears in regions of 40°—50°N and 15°—25°N. Latitudes between these two westerly zones are dominated by strong easterlies. This implies that the anomalous East Asian jet associated with the AO undergo meridional displacement. The climatological location of East Asian jet core is around 40°N in summer. During the high positive phase AO years the jet is displaced poleward and an anomalous westerly center appears at about 45°N, 5°latitudes north of the mean position. There are very high similarities between fig. 3(a) and (b). The anomalous zonal wind, meridional and vertical wind in the boreal summer averaged over the domain of 110° E—150° E are regressed onto the May AO index.

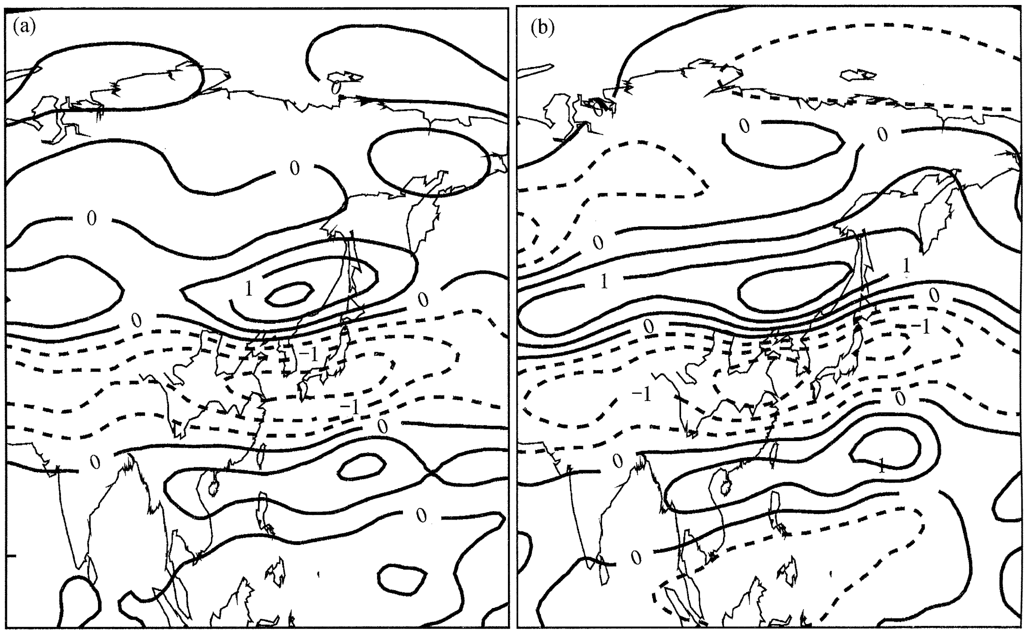

Fig. 3. Changes in summer zonal wind (ms^{-1}) at 200 hPa associated with a one standard deviation anomaly in the May AO index (a) and in the simultaneous six-stations mean rainfall (JJA) (b). Computed over the period 1958—1999. To facilitate comparison rainfall records are multiplied by −1. The contour interval is 0.5 ms^{-1} per standard deviation of May AO and JJA rainfall, respectively. NCEP/NCAR reanalysis data.

Results also display the well-defined features. Three cells are clearly described. Anomalous easterly with the concurrently strong descending motion are predominant around 30° N. The strong westerly to the north and the relatively weak one to the south are also significant in the upper level. The wind anomaly structure generally shows an equivalent barotropic vacillation with the largest covariance at ~200 hPa. Evidently, the north-south displacement of the zonal wind jet appears at almost all pressure levels throughout the troposphere.

4 Conclusion and discussion

Our analysis reveals that a stronger May AO is associated with a northward movement of the summer jet stream, and a strong easterly as well as significant descending motion around 30°N. That gives rise to a drier condition in the Yangtze River valley and a wetter anomaly over northern China and far-eastern Russia.

It is not well understood how AO in spring impacts the summer monsoon circulation. Some possible mechanisms are suggested, including the jet-tropical sea surface temperature interaction[15], AO signal's downward propagation from the stratosphere, wave-mean flow interaction, land surface process-atmosphere interaction. However, the responsible mechanisms should be further exploited using both detailed observations and climate models.

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