Climate Change in China Congruent with the Linear Trends of the Annular Modes

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Abstract The authors exploit the remarkable connection between the Chinese climate trends and the annular modes by partitioning the trends into components linearly congruent with and linearly independent of the annular modes. Results show that the winter hemisphere annular mode has closer connection to Chinese climate than the summer one, e.g., the wetting JJA (June-July-August) rainfall trend along the Yangtze River valley and the associated temperature trends are significantly linearly congruent with the trend of the southern annular mode, while the JFM (January-February-March) climate trends are closely linked to the northern annular mode. The seasonal differences of a meridional wave-train-like chain associated with the equatorial Pacific associated with the annular modes are responsible for the seasonal-dependent connections to Chinese climate.

Keywords: Chinese climate, trend, annular modes

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1 Introduction

China experiences a typical monsoonal climate in the world. Precipitation and temperature anomalies, especially the seasonal floods and droughts in China, are intimately related to the country’s economy and people’s lives. To reveal the mechanisms responsible for the anomalous climate has been the research focus during the past decades. Substantial effort has been devoted to the decadal and interannual scale climate variation in China (e.g., Hu, 1997; Yu and Zhou, 2004, 2007), and the potentia
governing factors such as ENSO (Wang et al., 1999; Chang et al., 2000; Wu et al., 2003). Recently, the northern and the southern annular modes (or namely the Arctic Oscillation “AO” and the Antarctic Oscillation “AAO”) (Gong and Wang, 1999; Thompson and Wallace, 2000) are suggested as new factors linked to the interannual variability of Chinese climate (Gong et al., 2001; Gong and Ho, 2003; Xue et al., 2003; Nan and Li, 2003; Gao et al., 2003; Yu and Zhou, 2004; Fan and Wang, 2004; Li et al., 2005, 2008; Xin et al., 2006).

Besides the periodic or semi-periodical climate variation, long term trend is another research focus of Chinese climate. In the above noted research, this trend used to be removed prior to their analyses. Observational analyses of climate changes in East Asia showed a pronounced warming trend in northern China and a minor cooling trend in central China, and this trend can be found throughout the year although with seasonally dependent features (Hu et al., 2003; Li et al., 2005; Xin et al., 2006; Yu and Zhou, 2007). The observed trend does not necessarily equal the global warming signal, and the mechanism responsible for the trend remains an open problem. Given the close relationship between the annular modes and climate over China at interannual scale, and the substantial trend observed in the annular modes (Gong and Wang, 1999; Thompson et al., 2000; Thompson and Solomon, 2002), potential connections or contributions of the AAO (AO) to the linear trends of climate over China should be discussed, which is the brief motivation of this study. Our results indicate that the winter hemisphere annular mode has closer connections to Chinese climate than the summer one, and the seasonal differences of a meridional wave-train-like chain associated with the annular modes are responsible for the seasonal-dependent relations.

The outline of this paper is as follows. Section 2 introduces the data and methods used in the analyses. Main results are addressed in section 3. Section 4 presents a summary.

2 Data and analysis techniques

The main surface climate data sets for this study include the monthly mean air temperature and precipitation data of 160 stations in China compiled by the China Meteorological Administration. Monthly mean sea level pressure (SLP) data taken from National Center for Environmental Prediction/National Center for Atmospheric Research Reanalysis data set (hereinafter NCEP) is used (Kalnay et al., 1996). The SLP data in the European Center for Medium range Weather Forecasting (ECMWF) reanalysis data set (hereinafter ERA-40) is also used for comparison. Although the station and the NCEP data are available over a longer time period, we only use those of 1958–2000 to facilitate the comparison with the ERA-40 data, which are available from mid-1957 to 2001.

The definition of the AO (AAO) follows that of Climatic Prediction Center/National Centers for Environmental Prediction (CPC/NCEP) except using SLP instead of height anomalies. Empirical Orthogonal Function

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¹ http://www.ecmwf.int/research/era/Project/Plan/Project_plan_TOC.html
² http://www.cpc.ncep.noaa.gov/products/precip/cwlink/daily_ao_index/history/method.shtml
(EOF) is applied to the monthly mean SLP poleward of 20° latitude for the Northern (Southern) Hemisphere. The seasonal cycle is removed from the monthly mean SLP. To ensure equal area weighting for the covariance matrix, the gridded anomaly data is weighted by the square root of the cosine of latitude. The loading pattern of AO (AAO) is defined as the first leading mode from the EOF analysis of SLP covering 1979–2000. Note that year-round monthly mean anomaly data is used to obtain the loading patterns. Monthly AO (AAO) indices for the period 1958–2000 are constructed by projecting the monthly mean SLP anomalies onto the loading EOF mode. Both time series are normalized by the standard deviation of the monthly index.

The observed trends are partitioned into linearly congruent and linearly independent components with respect to the AAO (AO) index in the following manner.

1) Total linear trends are estimated as the slope of a straight line fitted (in a least squares sense) to the observed data at each grid point based on the reference periods defined.

2) The component of the trends that is linearly congruent with the AAO (AO) index is estimated at each grid point by (a) regressing values of that grid point’s time series onto the AAO (AO) index, and then (b) multiplying the resulting regression coefficients by the linear trend in the AAO (AO) index.

Since our interest here is the AAO (AO) congruent component, the linearly independent component obtained by subtracting 2) from 1) will not be shown.

3 Results

3.1 AAO/AO congruent components of JJA climate trends

The long-term trends of Chinese climate are highly seasonally dependent (Hu et al., 2003). Our analyses will focus mainly on the JJA mean and the JFM mean condition. The linear trend of JJA precipitation over 1958–2000 is depicted in Fig. 1a. A “southern flood and northern drought” pattern is evident. A wetting trend controls the central China, especially along the middle and lower reaches of the Yangtze River valley. Parts of North China are dominated by a drying trend. Of particular interest is the AAO congruent component (Fig. 1b). The structural similarity between the total trends in precipitation and the corresponding signatures of the AAO is striking. The wetting along the Yangtze River valley is linearly congruent with the AAO. The signal of the AO is not significant and weaker than that of the AAO (Fig. 1c). Hence it is the trend of the AAO that contributes greatly to the total trend of JJA precipitation.

There are obvious cooling trends in central China and warming trends elsewhere in particular North China (Fig. 1d). The amplitude of the cooling is larger than 0.5°C (43 yr)^{−1} in the middle and lower reaches of the Yangtze River valley. A close pattern resemblance is found between the AAO congruent component (Fig. 1e) and the total trend. The amplitude of the cooling in central China (32.5°N, 110°E) of Fig. 1e is approximately one-third of that shown in Fig. 1d. The AO congruent component is weak and not significant (Fig. 1f).

3.2 AAO/AO congruent components of JFM climate trends

The long-term trend of JFM precipitation is depicted in Fig. 2a. An increase in precipitation is seen in the southern part of the mainland. The AO congruent component is strong (Fig. 2c). The linear trend of the AO is closely related to the intensified JFM precipitation of South China. According to Fig. 2e, Thompson et al. (2000)'s selection of central China (25–40°N, 105–110°E) as the target region is not the best choice and a better selection is restricted to south of 30°N. In addition, no significant signals can be found in the AAO congruent component (Fig. 2b).

The corresponding signals of JFM surface temperature are clearer than those of precipitation. As shown in Fig. 2d, a remarkable warming trend dominates the Northeast China. The AO congruent component (Fig. 2f) closely resembles the total trend in general pattern. The AO congruent component is also significant in northeastern China (Fig. 2e), it is however apparently weaker than the AO congruent component in intensity, which accounts for more than half of the total trend.

3.3 The results revealed by the ERA-40 data

The quality of the NCEP data at the Southern Hemisphere high-latitudes is poor (Hines et al., 2000). The new ERA-40 data provides an improved representation of SH high-latitude atmospheric circulation and can be used with higher confidence than the NCEP data right back to 1958 (Marshall, 2003). To check whether the AAO (AO) congruent components of climate trends over China are data-dependent signals, we recompute relevant results by using the ERA-40 data. Comparison of the newly derived AAO congruent component of JJA rainfall trend with that using NCEP data reveals a pattern coincidence (Figs. 3a and 3b). The intensity of the new estimation is however obviously weaker, and the central value of the wetting belt along the Yangtze River valley is approximately half of that using NCEP data. The difference between two datasets in the AAO congruent temperature is similar as that of precipitation. The AO-related signal is still not significant. The intensity of the cooling in central China for the AAO congruent component (Fig. 3c) is less than half of that using NCEP data.

The ERA-40-based AO congruent components of JFM rainfall closely resemble the NCEP-based estimation and the AAO-related signal is not significant (Figs 4a and 4b). The difference in magnitude of rainfall signals between these two datasets in JFM is smaller than that in JJA. A close coincidence in terms of both pattern and amplitude is found for JFM temperature (Figs. 4c and 4d). The reproducibility of nearly similar significant AAO (AO)
congruent components of Chinese climate trends by using two different reanalysis datasets adds confidence to the fidelity of the results presented here.

3.4 The related atmospheric circulation change

The physical mechanisms responsible for the connection between Chinese climate and the annular modes are attractive but challenging subjects. Both the precipitation and the temperature change are essentially resulted from the atmospheric circulation change. Associated with a positive phase of the AAO in JJA, there exists a clear meridional wave-train-like chain across the equatorial Pacific over the Asian-Australian monsoon region at the 200 hPa zonal wind (U200) (Fig. 5a). This pattern initiates from the Antarctic and extends meridionally northward, and a significant positive correlation is observed over the East Asia between 30°N and 40°N. Relative to the normal position of the 200 hPa jet stream along 40°N (Zhou and Li, 2002; Zhang et al., 2006), this anomaly pattern indicates a southward shift of the jet stream, which is usually associated with flooding summer climate in central China (Zhou and Yu, 2005). The condition of middle troposphere is revealed by analyzing the 500 hPa geopotential heights (Z500) change (Fig. 5b). Associated with a positive phase of the AAO in JJA, Z500 tends to be above normal at tropical and extratropical regions of both hemispheres. The climate mean position of the ridgeline of the western Pacific subtropical high (WPSH) at 500 hPa locates south to 25.0°N from 110°–140°E, the height anomalies over East Asia in Fig. 5b indicate a southwestward intensify-
cation of the WPSH. This anomaly pattern corresponds to a heavier rainfall along the Yangtze River valley (Zhou and Yu, 2005). In contrast to the AAO-related circulation-change, the AO-related signals are not as robust as those of AAO (figures omitted). Situations are changed however in JFM. As seen from Fig. 5c, correlation patterns of U200 against AO exhibit a wave train-like pattern. Besides the branch initiates from Greenland and extends southeastward to the Arabian Sea, another branch initiates from the Ochotsk and extends southward along the eastern Asian coast. Northern China is dominated by negative anomalies. At the middle troposphere (Fig. 5d), anomalies of Z500 appear as a North Atlantic Oscillation pattern over the North Atlantic basin. The northeastern China-Japan is dominated by a blocking signal, and the opposite sign controls Urals. This indicates a shallower East Asian trough and a weaker anticyclone over Urals, which would bring less cold surges blowing over the East China and cause a warmer air over there. In addition, Thompson and Wallace (2000) noted that the AAO is still prominent in JFM; current analysis finds that the AAO-related meridional wave train of U200 is no longer so robust as that in JJA, and no significant change can be found in Z500 over East Asia (figures omitted). The circulation change discussed here explains why mainly the winter hemisphere annular mode, viz. JJA AAO or JFM AO, exerts a significant influence on Chinese precipitation and temperature.

4 Conclusions

The climate of China in terms of the precipitation and the surface air temperature has exhibited a significant trend over the past decades. This trend is consistent with
Figure 3  The AAO (a) and AO (b) congruent components of JJA rainfall linear trends in unit of mm (43 yr)$^{-1}$ with contour interval 50. The AAO (c) and AO (d) congruent components of JJA surface air temperature linear trends in unit of°C (43 yr)$^{-1}$ with contour interval 0.3. The AAO (AO) indices are derived from the ERA-40 reanalysis. Areas with confidence limit of 0.05 using F-test are shaded.

Figure 4  Same as Fig. 3 except for the JFM.
the trend toward the positive polarity of the annular modes in both hemispheres. Analyses reveal that although the trend of Chinese climate is highly seasonally dependent, it is briefly related to the linear trend of the winter hemisphere annular mode. The winter hemisphere annular mode has a closer connection to Chinese climate than the summer one. The JJA wetting trend along the Yangtze River valley and the associated temperature trend are linearly congruent with the trend of the AAO, while the JFM wetting trend in South China and the warming trend in North China are more intimately linked to the AO. The relationship between the Chinese climate and the annular modes including their seasonal-dependent influences is explained in terms of a meridional wave-train-like chain spanning East Asia associated with the annular modes.

Examinations of relevant results using two different reanalysis datasets found similar AO-related signals. For the AAO-related results, the NCEP data produces stronger AAO congruent trends in JJA, and this can be explained in terms of the data quality of the NCEP, which has a stronger austral winter AAO trend in comparison with the observation (Marshall, 2003).

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References
Chang, C., Y. Zhang, and T. Li, 2000: Interannual and interdecadal variations of the East Asian summer monsoon and tropical Pacific SSTs, part 1: Roles of the subtropical ridge, J. Climate, 13, 4310–4325.


