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FEATURES AND COMPARISONS OF THE QUASI-BIENNIAL VARIATIONS IN THE ASIA-PACIFIC MONSOON SUBSYSTEMS

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Abstract: The National Centers for Environmental Prediction (NCEP) reanalysis data, Climate Diagnostics Center Merged Analysis of Precipitation (CMAP) results, and NOAA Extended Reconstructed Sea Surface Temperature (SST), have been utilized in this paper to study the quasi-biennial variations in Asia-Pacific monsoon subsystems and associated SST anomalies (SSTA) and wind anomalies. Four monsoon indices are computed from NCEP/ National Center for Atmospheric Research (NCAR) reanalysis to represent the South Asian monsoon (SAM), South China Sea summer monsoon (SCSSM), Western North Pacific monsoon (WNPM) and East Asian monsoon (EAM), respectively. The quasi-biennial periods are very significant in Asia-Pacific monsoons (as discovered by power spectrum analysis), and for SAM and EAM---with moderate effects by El Niño-Southern Oscillation (ENSO)---the quasi-biennial periods are the most important factor. For SCSSM and WNPM (once again due to the effects of ENSO), the quasi-biennial periods are of secondary durations. There are obvious interdecadal variations in the quasi-biennial modes of the Asia-Pacific monsoon, so in the negative phase the biennial modes will not be significant or outstanding. The wind anomalies and SSTA associated with the biennial modes are very different in the SAM, WNPM and EAM regions. Since the WNPM and SCSSM are very similar in the biennial modes, they can be combined into one subsystem, called SCS/WNPM.

Key words: Asia-Pacific monsoon; power spectrum; wave filtering; monsoon indices; quasi-biennial variation

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1 INTRODUCTION

Many studies have suggested that biennial variation is a fundamental and significant feature in atmospheric circulations and interannual climate variability. In the 1960s, by studying the lower tropical stratospheric zonal winds, Reed et al. [1] revealed quasi-biennial variability, which they call quasi-biennial oscillation (QBO). Theories on QBO developed quickly, and recent studies have been concerned with the tracers of QBO and its numerical simulations [2-4]. In contrast, tropospheric biennial oscillation (TBO) had been neglected for quite some time, although the biennial variability for certain elements of the troposphere was investigated in the late 1960s and early 1970s [5, 6]; TBO was not a focus until the 1980s. Many variables, such as surface pressure over the Northern Hemisphere (NH) [7], NH averaged surface temperature [8] and tropical zonal winds [9], had been revealed by the biennial variability. Furthermore, Asia-Pacific monsoon rainfall also exhibits pronounced biennial features (e.g., India summer rainfall [10,11] and East Asia rainfall [12, 13]). To a great extent, interannual monsoon rainfall in China behaves in the manner of rainfall bands, with respect to shift and distribution, which differs from the Indian monsoon rainfall. In 1997, Chen et al. [14] found distinct characteristics (1989-1995) in the quasi-biennial period of rainfall over the east of China. In general, a pattern of above-normal rainfall exists in the Changjiang-Huaihe area, and below-normal rainfall over the South and North China in odd-numbered years; in the opposite pattern, more rainfall in South and North China and less in the Changjiang-Huaihe area often occurs in an even year. Liao et al. [15] pointed out that the

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rain-band locations of China in July should be linked to the QBO in the equatorial stratosphere of 30-50 hPa. In the westerly phase, the July rain-bands in China move more northward, and shift more southward in the easterly phase. Kuang et al. [16] analyzed monthly precipitation of 160 China surface stations from 1951 to 1996: The results indicate that QBO variations in rainfall are evident and steady. The first eigenvector of the QBO variations is characterized as alternating countrywide above- and below-normal rainfall; the second shows a pattern out of phase between the north and south areas of China. The positive values centered in the lower reach of the Yellow River, and the negatives—covering the Pearl River drainage area (including the Yunnan-Guizhou Plateau, centered in the lower reach of the Pearl River), are distinguished by the middle and lower reaches of the Yangtze River. Recently, many researchers outside China conducted power spectrum analysis on sea surface temperature (SST) and precipitation. These results show that TBO is a strong, large scale quasi-periodic phenomenon of the troposphere, only weaker than the El Niño–Southern Oscillation (ENSO). Together with ENSO, the TBO affects atmospheric circulation and leads to weather and climate anomalies. Using Singular Value Decomposition (SVD), Lau and Weng [17] found the second coherent mode of summertime rainfall variability over China. Global SST for the period from 1955 to 1998 is comprised of a quasi-biennial variability manifested in alternate wet and dry years over the Yangtze River valley. The severe flooding of the Yangtze River valley in 1998 is associated with the biennial tendency of basin-scale SST anomalies (SSTAs) during the transition from El Niño to La Niña from 1997 to 1998. Subsequently, Lau and Wu [18] investigated the covariability of the Asian summer monsoon and ENSO using global rainfall and SST data for the past two decades (1979-1998) and found that the first mode is characterized by a pronounced biennial variability. Hence, the TBO plays a large role in weather and climate in China: Studies on the TBO are helpful for developing the skill of short-term climate prediction.

Comparison of the biennial characteristics in the Asia-Pacific monsoon subsystems (APMSs) composed of the South Asian monsoon (SAM), South China Sea summer monsoon (SCSSM), Western North Pacific monsoon (WNPM) and East Asian monsoon (EAM) has not been made, although much research has been conducted on them. It is well known that there are both links and differences among the APMSs, however their biennial connections should be studied further. In this paper, the features of APMSs and their differences and links are explored on the biennial scale. The studies on the mechanism of the Asia-Pacific monsoon TBO and its effects on the weather and climate over the Asia-Pacific area completely depend on the understanding of the key processes of the quasi-biennial variations in the APMSs.

2 DATA AND METHODS

As well as the monthly NCEP and NCAR reanalysis data, the Climate Diagnostics Center (CPC), Merged Analysis of Precipitation (CMAP) monthly values, and the monthly SST of Version 2 are also applied in this paper. Also included are the power spectrum, filtering and correlation analyses. Four circulation indices of monsoons are selected and computed to represent the SAM, SCSSM, WNPM and EAM, respectively (See Table 1). Fig.1 shows the correlations between the indices and global precipitation in boreal summer (June-August). It also indicates that the four circulation indices specify the corresponding precipitation distributions in the subsystems.

Table 1 Asia-Pacific Summer Monsoon Indices.

Indexes	Definition	Regions represented
SAM (RM1)[19]	V850-V200（10º-30ºN，70º-110ºE）	South Asia
SCSSM[20]	（U850+V850）/ $\sqrt{2}$ （5º-20ºN，105º-120ºE）	South China Sea
WNPM (DU2)[21]	U850（5º-15ºN，90º-130ºE）-U850（22.5º-32.5ºN，110º-140ºE）	Northwest Pacific
EAM (RM2)[22]	U200（25º-35ºN，110º-150ºE）-U200（40º-50ºN，110º-150ºE）	East Asia

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Quasi-biennial periods from the power-spectrum analysis displayed in Fig.2 are all significant; main periods are given in Table 2.

Fig.3 shows the time series of the amplitudes of the biennial modes in the APMSs that behave with evident interdecadal variations. This does not reflect a common interdecadal variation [23, 24] but an intrinsic feature of the biennial mode.

The positive SSTA of the Maritime Continent and the equatorial Indian Ocean associated with a strong SAM can persist from the previous winter through the onset of SAM (figure omitted). For a strong SCSSM or WNPM, the corresponding SSTA in the western Pacific and east of the South China Sea would be sustained from the previous winter to the spring prior to the monsoon onset. Then, the SSTA in the equatorial

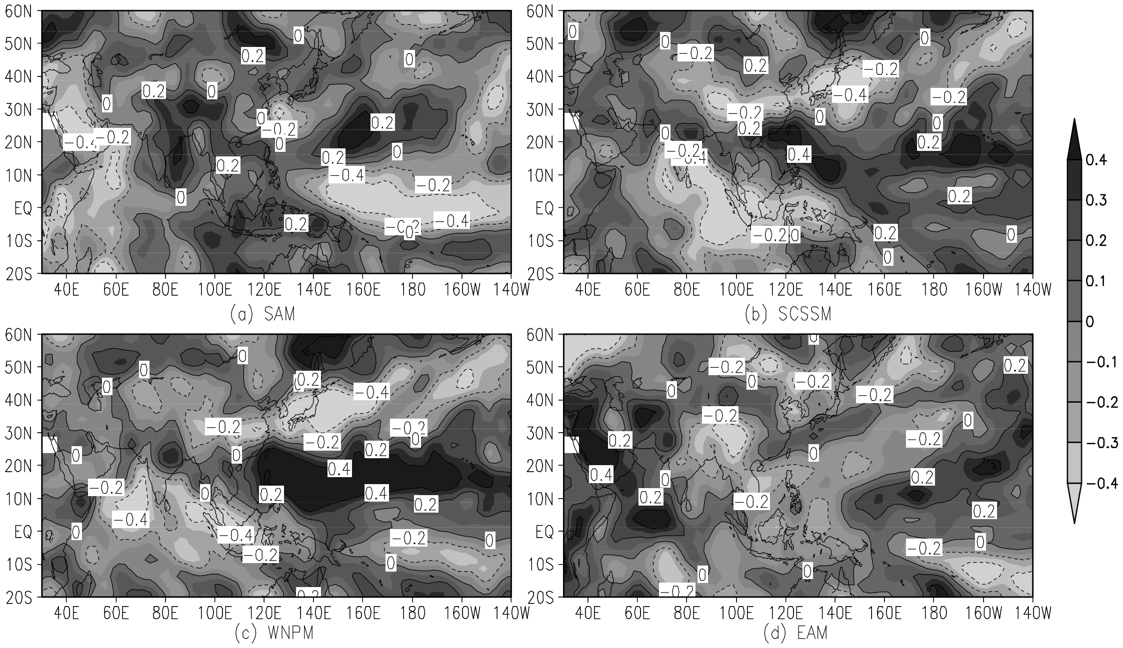

Fig.1 Correlations of the Asia-Pacific monsoon indices and CMAP precipitation, (a) South Asian monsoon (b) South China Sea summer monsoon (c) Western North Pacific monsoon (d) East Asian monsoon.

western Pacific and entire Maritime Continent involving the South China Sea and Bay of Bengal changes into negative sign after the onset of SCSSM and WNPM (figure omitted). In a strong EAM year, the positive SSTA first appears in the western North Pacific in the previous winter and is then enhanced in spring. After the onset of EAM, the positive SSTA is weakened in the western North Pacific, while a negative SSTA appears in the eastern region of Japan. The circulation pattern necessary for a strong SAM is opposite to those of SCSSM and WNPM (figure omitted). The former excites wave trains of easterly (anomaly)-westerly-easterly in the NH, while the latter exhibits westerly-easterly-westerly wave train patterns. The zonal wind anomaly associated with the EAM mainly behaves as a cyclonic/anticyclonic anomaly over the western North Pacific. The SCSSM and WNPM biennial modes are rather similar to each other—both in SSTA and wind anomalies—and thereby can be combined into a subsystem, namely SCS/WNPM, at least on the biennial scale.

Table 2 Primary and secondary periods of the Asia-Pacific monsoon indices from 1958-2002.

Regional monsoon	South Asia	South China Sea	Northwest Pacific	East Asia
Primary period / month.	28.6	40, 15.4	40, 15.4	28.6, 16.7
Secondary period / month	15.4	25	28.6	/

4 SUMMARIES AND DISCUSSIONS

Four monsoon circulation indices are selected and computed to represent the APMSs of SAM, SCSSM, WNPM and EAM, respectively. Relationships of the four indices and the precipitation field are also examined. The results indicate that the indices can soundly reflect the precipitation characteristics in the APMSs. Significant biennial modes are found in the APMSs by means of power spectrum analysis. Using wavelet analysis, interdecadal variations of the Asia-Pacific monsoon biennial modes are explored. Then, the evolutions of SSTs and winds associated with the APMSs biennial modes are analyzed.

(1) The SAM and EAM favor the quasi-biennial period over the ENSO period; the quasi-biennial period is their prime phase, while the SCSSM and WNPM experience a significant ENSO period with a secondary period of quasi-biennial variation.

(2) There are evident interdecadal variations in the Asia-Pacific monsoon biennial modes. The impacts of the Asia-Pacific monsoon biennial modes on the monsoon regions would be more effective in positive phases than in negative phases.

(3) The key processes of SST and wind associated with the SAM biennial mode occur in the tropical Indian Ocean and Maritime Continent regions; the SSTs and winds related with the SCSM and WNPM biennial modes mainly evolve in the

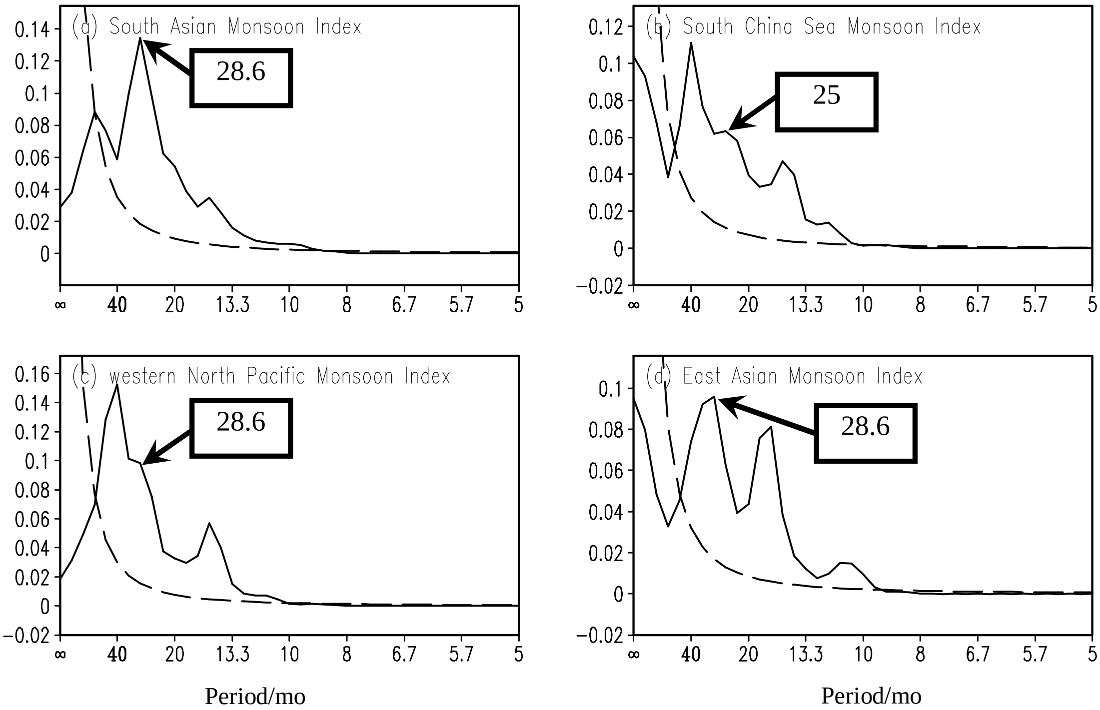

Fig.2 Power spectrum analyses of the Asia-Pacific monsoon indices (seasonal cycles are removed; dash-lines represent red noise at a 95% level): (a) South Asian monsoon (b) South China Sea summer monsoon (c) Western North Pacific monsoon (d) East Asian monsoon.

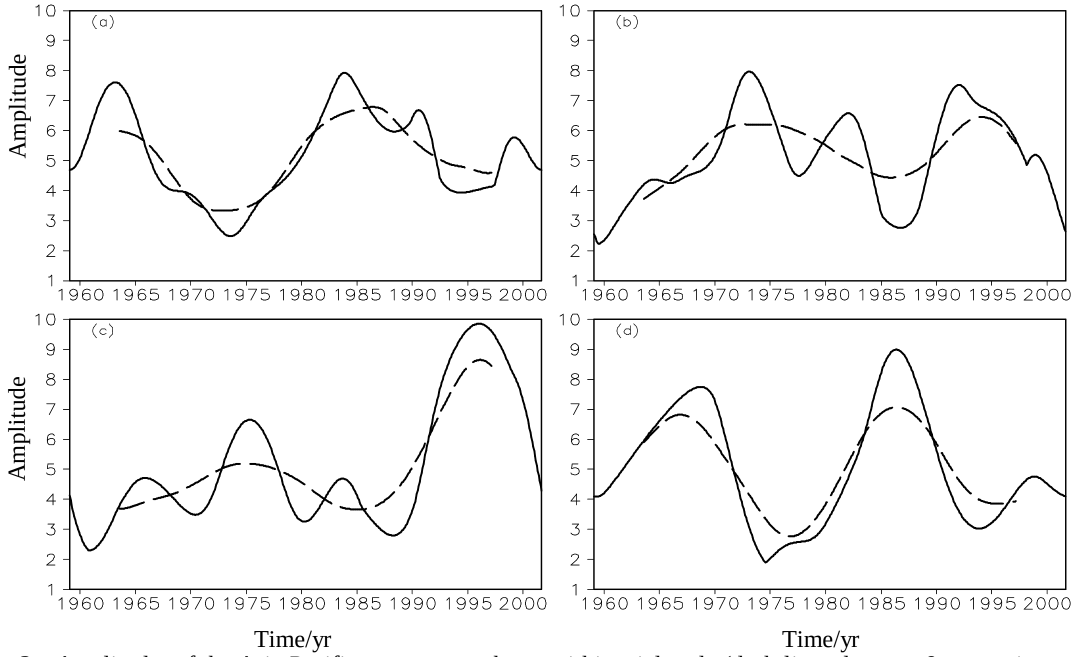

Fig.3 Amplitudes of the Asia-Pacific monsoon on the quasi-biennial scale (dash-lines denote a 9-yr running mean): (a) South Asian monsoon (b) South China Sea summer monsoon (c) Western North Pacific monsoon (d) East Asian monsoon.

tropical western Pacific and Maritime Continent areas; the EAM biennial mode-induced SST and wind anomalies appear in the subtropics and mid-latitude of the area northwest of the Pacific.

(4) The zonal wind anomalies in the lower troposphere associated with the biennial modes of SAM, SCSSM and WNPM have wave train structures in a strong or weak year. In a strong year, the corresponding wave train of the SAM biennial mode is easterly (anomaly)-westerly-easterly. On the contrary, the SCSSM and WNPM excite a wave train of westerly-easterly-westerly in a strong year, while the zonal wind anomaly related with the EAM biennial mode exhibits a western North Pacific

cyclonic anomaly (weak year) or anticyclonic anomaly (strong year) instead of a wave train.

The biennial modes of the APMSs have been analyzed in this paper. However, the modes do not reflect a pure Tropospheric Biennial Oscillation (TBO) since the biennial mode of ENSO is still mixed up and not excluded; this renders them simply biennial coupled modes. It is difficult to distinguish the biennial mode of ENSO from the TBO through analysis of observations. The best way would be to use a coupled numerical model to study the TBO. This will be the focus of our next work.

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