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Interdecadal variability of the tropospheric biennial oscillation in the western North Pacific*

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The observed tropospheric biennial oscillation (TBO) in the western North Pacific (WNP) monsoon region has an interdecadal variability with a period of 40–50 yr. That suggests a weaker effect of the TBO on the East Asia followed by a stronger one. A simple analytic model was designed to investigate the mechanism of the interdecadal variability of the TBO. The results indicated that a local TBO air–sea system not only supports the TBO variability in the WNP monsoon region but also produces an interdecadal variability of the TBO.

Keywords: tropospheric biennial oscillation, western North Pacific, interdecadal variability, air–sea interaction

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1. Introduction

More and more facts and studies have confirmed that biennial variation is a fundamental feature in the tropospheric atmosphere. It is named as tropospheric biennial oscillation (TBO) to avoid confusion with the stratospheric quasi-biennial oscillation (QBO). Various observational studies have shown that the TBO in monsoon rainfall is manifested over various monsoon regions such as India,[1,2] Indonesia[3] and East Asia.[4−8] Moreover, the TBO itself is still changed on the interdecadal time-scale.[8,9] The interdecadal variability of the TBO makes it significant in several decades and neglected in several other decades. However, nearly all the recent theories and hypotheses[10−16] fail to explain this phenomenon. For the western North Pacific (WNP) monsoon, the latest study showed that the air–sea interaction in the Indo-Pacific warm ocean alone can support TBO variability that has many observed characters.[17] The warm ocean in this paper includes the WNP, the South China Sea (SCS) and the southeast Indian Ocean (SEIO). Based on the dynamics of TBO theory in the warm ocean, a simple analytic model is designed to investigate the interdecadal variability of the TBO in the WNP monsoon region.

2. Observed TBO and its interdecadal variability

The precipitation data used for this study are the precipitation reconstruction (PREC) data set—precipitation monthly anomalies Over Global Land & Oceans from 1948–2004.[18] The monthly averaged data have a horizontal resolution of 2.5° latitude by 2.5° longitude. According to the prominent TBO region in the WNP from Li *et al*,[17] the box area 5°N–15°N, 120°E–150°E is selected to compute the averaged WNP monsoon precipitation. Guangzhou (GZ), lying in the south of China (23.2°N, 113.3°E), is strongly affected by the SCS/WNP monsoon in weather and climate. In this paper, GZ surface station precipitation data spanning the period of 1908–2005 are also used due to the longer time series. Usually, many signals are mixed up,[19,20] so a bandpass filter[21] is applied to both of the rainfall data to obtain TBO signals. Figure 1 shows that the periods of 20–30 months, the main period band of TBO, are almost 100% passed through the bandpass filter. Figure 2 shows the TBO bandpass-filtered rainfalls in the WNP region and GZ. It can be seen from Fig.2 that the TBO of GZ rainfall has much larger amplitudes

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around 1920, 1958 and 2004 (solid line), and the pronouncedly larger amplitudes also appear in the TBO in the WNP monsoon rainfall around 1950 and 2000 (dashed line). Since the TBO in the WNP monsoon region behaves an interdecadal change even though the interdecadal variability has been filtered, it suggests that the interdecadal change is a natural variability of the TBO.

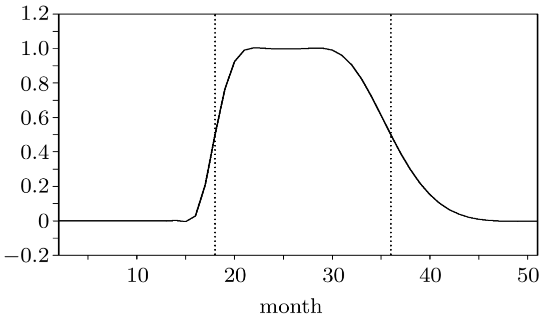

Fig.1. A response function for bandpass filter (half-response period chosen as 18 and 36 months).

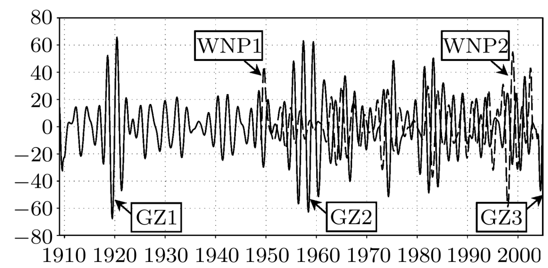

Fig.2. TBO bandpass-filtered rainfall (mm/mon) averaged for the WNP monsoon region (5°N–15°N, 120°E–150°E, dashed line) and the Guangzhou surface station (solid line). GZ1∼3 represent the various interdecadal phases of the TBO in GZ rainfall, and WNP1 and 2 the various interdecadal phases of the WNP monsoon TBO.

3. An analytic model and results

A good model can be greatly helpful for us to understand some physical processes.[22−24] In the warm ocean, evaporation due to anomalous wind is a main form of the air–sea interactions, which induces the TBO variability.[13] Furthermore, the air–sea interaction in the warm ocean alone can support TBO variability,[17] thus a TBO air–sea system in the WNP and maritime continent (MC) region can be designed as follows:

$$\frac{\partial T_{\mathrm{W}}}{\partial t} = -\lambda\Delta\bar{q}\frac{\bar{U}_{\mathrm{W}}}{V_0}U_{\mathrm{W}},$$
$$\frac{\partial T_{\mathrm{MC}}}{\partial t} = -\lambda\Delta\bar{q}\frac{\bar{V}_{\mathrm{MC}}}{V_0}V_{\mathrm{MC}}, \tag{1}$$

where the terms on the right side of Eq.(1) represent a linear form of surface wind–evaporation feedback due to the anomalous wind. In Eq.(1), T_{W} and T_{MC} denote the sea surface temperature anomalies (SSTA) in the WNP and MC (involving SCS and SEIO), respectively. U_{W} is the anomalous zonal wind and V_{MC} the anomalous cross-equatorial flows over the MC. The surface winds, U and V, are given by

$$V_{\mathrm{MC}} = c_1 T_{\mathrm{W}}, \tag{2a}$$
$$U_{\mathrm{W}} = -c_2 T_{\mathrm{MC}}. \tag{2b}$$

Here Eq.(2a) represents the anomalous cross-equatorial flows induced by the anomalous SSTA in the WNP, and Eq.(2b) reflects the anomalous zonal wind in the WNP due to anomalous SSTA in the SCS, MC and SEIO. For simplicity, the parameters in Eqs.(1) and (2) are assumed constants and specified in Table 1 according to Chang and Li[13] and Li *et al.*[14] Finally, by substituting Eq.(2) into Eq.(1) with the specified parameter values (listed in Table 1), we derived a pair of homogeneous differential equations that are piecewise in time

$$\frac{\partial T_{\mathrm{MC}}}{\partial t} = aT_{\mathrm{W}}, \quad \frac{\partial T_{\mathrm{W}}}{\partial t} = bT_{\mathrm{MC}}, \tag{3}$$

where $a = 0.064\bar{V}_{\mathrm{MC}}$ and $b = 0.254\bar{U}_{\mathrm{W}}$. We assume that precipitation over the monsoon region is primarily determined by boundary-layer moisture convergence. Following Chang and Li,[13] the rainfall rate in the WNP monsoon region can be written as

$$Pr_{\mathrm{W}} = \delta_{\mathrm{W}} c T_{\mathrm{W}}. \tag{4}$$

The solution to Eqs.(3) and (4) has a biennial period as shown in Fig.3. The results by using the simple analytic model confirm that the atmosphere–ocean interactions in the warm ocean can alone support the TBO variability. In Fig.3, the longer period is not highlighted because of the short time series. Figure 4 illustrates the 150-yr model results to make the interdecadal variability outstanding. It is noticeable that Fig.4 shows an interdecadal change with a period of 40 yr that is similar to that shown in Fig.2. The model results are just much more regular than the observations.

Table 1. The list of key parameters of the model.

parameter	symbol	value
wind-evaporation feedback coefficient	λ	2.1×10^{-5} K/m
interactive coefficient	c_1	$0.5\,\mathrm{mK^{-1}{\cdot}s^{-1}}$
interactive coefficient	c_2	$4\,\mathrm{mK^{-1}{\cdot}s^{-1}}$
precipitation due to change of SST in the WNP	c	$81.7\,\mathrm{mm \cdot mon^{-1}{\cdot}K^{-1}}$
air–sea humidity difference	$\Delta\bar{q}$	5.6×10^{-3}
seasonal switch coefficient for western North Pacific monsoon	δ_{W}	1 during the summer 0 rest of the year
mean constant surface wind speed	V_0	4.0 m/s over the WNP 2.5 m/s over the MC
maritime continent mean meridional wind speed	$\bar{V}_{\mathrm{MC}}$	2.0 m/s during JJA −2.0 m/s during DJF 0 rest of the year
western Pacific mean zonal wind speed	$\bar{U}_{\mathrm{W}}$	2.0 m/s during JJA −2.0 m/s during DJF 0 rest of the year

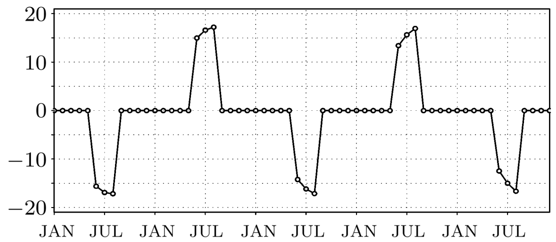

Fig.3. Model anomalous rainfall rate in the WNP monsoon region.

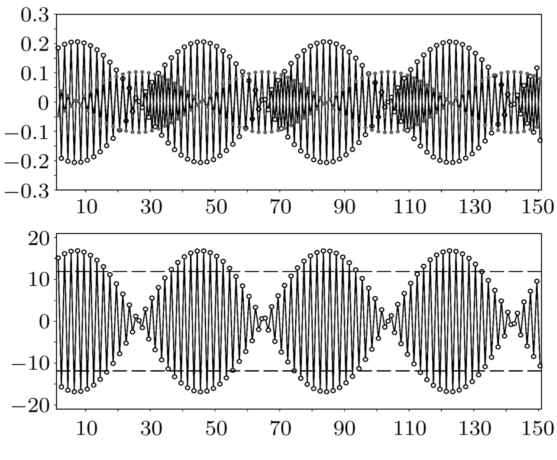

Fig.4. 150-yr June–August mean (a) model SSTA in the WNP (open circle) and MC (solid circle) and (b) model rainfall rate in the WNP monsoon region.

4. Conclusions and discussions

It is well known that the TBO plays an important role in the climate in the monsoon regions. On the other hand, the observational studies indicated that the TBO is not always significant or strong enough to influence the monsoon regions (as shown in Fig.2, see also Ref.[9]). It suggests that the TBO still changes on the larger time-scales. The air–sea interactions in the warm ocean (involving WNP, SCS, MC and SEIO) can support the TBO variability without other forcing.[17] Based the theory from Li *et al*,[17] a simple analytic model was designed to investigate the interdecadal variability of the TBO in the WNP. The results indicated that the TBO air–sea interactive system in the warm ocean can make the amplitude of TBO oscillate with an interdecadal period of ∼40 yr (Fig.4). Moreover, Fig.2 also shows a 7–8 yr period in the amplitude of TBO besides the interdecadal variability. That is not explained in this work and needs a further investigation.

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