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ADVANCE IN STUDIES OF TROPOSPHERIC BIENNIAL OSCILLATION

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ABSTRACT: There are obvious biennial phenomena of circulation, meteorological and climatic elements in the troposphere, named as Tropospheric (Quasi-) Biennial Oscillation (TBO). Many phenomena of TBO are discovered, such as variations of TBO in tropospheric temperature, pressure, winds field, monsoon and subtropical high etc. The mechanism of TBO is explored and the results demonstrate that tropical ocean (the Indian Ocean and the Pacific Ocean, mainly) and Stratospheric QBO play important roles in the TBO. In addition, Eurasian snow cover and solar activity of 11yr period can affect TBO very possibly.

Key words: tropospheric biennial oscillation (TBO); tropical ocean; quasi-biennial oscillation (QBO)

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1 INTRODUCTION

Great abundant information is hidden in the atmosphere, and quasi-periodic signals are important compositions of them. On the interannual timescale, the steadiest signals is tropical zonal wind Quasi-Biennial Oscillation (QBO) in the lower stratosphere (ENSO cycle has a wide frequency band in spite of its strongest energy). The QBO signal had already revealed since early 1960s when Reed et al.[1] found zonal wind with different signs in the lower tropical stratosphere in every other year. Seven years after then, Belmont and Dartt[2] introduced the word QBO to denote the quasi-periodic variation. Many theories and hypothesizes had been proposed to explain the QBO, and the well accepted one is the driving force by vertical transfer of momentum from the troposphere to stratosphere by Kelvin and Rossby-Gravity waves[3,4]. Matsuno[5] also played an important role for the theory by finding stratospheric Kelvin and Rossby-Gravity waves. Many elements other than zonal wind behave as QBO variation (e.g. stratospheric temperature, tropopause height and total ozone amount[6,7]). More than that, stratospheric tracers such as O_3, NO, NO_2 and HCl also vary by QBO period[8-15]. In contrast to studies on stratospheric QBO, those on tropospheric QBO (TBO) just became a focus from the 1980's, though several pioneering work had been done in late 1960's and early 1970's[16,17]. Especially, on the QBO timescale, people highlight on the Atmospheric elements and activities associating with the Asian monsoon. The TBO phenomena and mechanisms are summarized as the following.

2 ADVANCES IN STUDIES ON TBO

There are all kinds of synoptic processes and interactions with other climatic sub-systems in the troposphere, which make the TBO processes more complex. From then on, there are TBO phenomena not only in atmospheric circulation, but also in climatic elements, even in

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synoptic processes.

2.1 *TBO variability about monsoon intensity*

Monsoon activities greatly affect industry, agriculture and people's living, so studies about them are emphasized throughout the world. People now have more understanding of monsoon but are still not able to explain many phenomena (e.g. monsoon interannual variability). Meehl[18] defined TBO as the tendency for a relatively strong monsoon to be followed by a relatively weak one, and vice versa. Therefore the TBO is not so much an oscillation, but a tendency for the system to flip-flop back and forth from year to year. Yasunari[19] emphasized the relationship of Asian monsoon with ENSO and united them in a joint system——Monsoon-Atmosphere-Ocean System (MAOS). His further study showed the QBO variability in the MAOS[20]. There are also clear QBO signals in the East Asia Monsoon, which induce strong convections over the tropical Pacific to affects on the ENSO cycle[21].

The mechanisms of monsoon TBO transitions agree well with the land-air-sea interactions, while the air-sea system (Pacific and Indian Ocean) seems to be a dominant one, comparing with the land-sea interactions (South Asia), through analyzing the observations and the results of sensible experiments[22,23]. Yasunari[24] deduced a TBO cycle in which summer monsoon plays an active role. Weaker (stronger) summer monsoon promotes the development of El Niño (La Niña) in the tropical pacific from summer to winter, then evolution of high (low) index at the middle latitude of the eastern hemisphere is led by waves' propagation, with weaker (stronger) winter monsoon and reduced (enlarged) Eurasia snowcover area in winter and spring, which result in stronger (weaker) summer monsoon and a completive TBO cycle. Chang and Li's theory[25] points out that TBO is an inherent result of the interactions between northern summer and winter monsoon and the tropical Indian and Pacific Oceans. Thus, it is an important component of the tropical ocean-atmosphere interaction system, separate from the El Niño/Southern Oscillation. Recently, Yu et al.[26] use a series of coupled atmosphere–ocean general circulation model (CGCM) experiments to examine the roles of the Indian and Pacific Oceans in the transition phases of the tropospheric biennial oscillation (TBO) in the Indian–Australian monsoon system. The results show that the in-phase TBO transition from a strong (weak) Indian summer monsoon to a strong (weak) Australian summer monsoon occurs more often in the CGCM experiments that include an interactive Pacific Ocean. The out-of-phase TBO transition from a strong (weak) Australian summer monsoon to a weak (strong) Indian summer monsoon occurs more often in the CGCM experiments that include an interactive Indian Ocean. The interaction of the Indian Ocean dynamics and the tropospheric biennial oscillation (TBO) is analyzed in the 300-yr control run of the National Center for Atmospheric Research (NCAR) Climate System Model (CSM) by Loschnigg et al.[27], and the results indicate that the coupled ocean–atmosphere dynamics and cross-equatorial heat transport contribute to the interannual variability and biennial nature of the ENSO–monsoon system, by affecting the heat content of the Indian Ocean and resulting SST anomalies over multiple seasons, which is a key factor in the TBO. As well as Indian monsoon TBO, that of East Asia monsoon is also explored by its mechanism. Li et al.[28] consider the interaction between anomalous East Asia winter monsoon and ENSO cycle origin of the TBO (as seen in Fig.1). The continuous strong (weak) East Asian winter monsoon can excite El Niño (La Niña) through the air-sea interaction; the El Niño (La Niña) event can lead the East Asian winter monsoon to be weak (strong) through the teleconnections or remote responses.

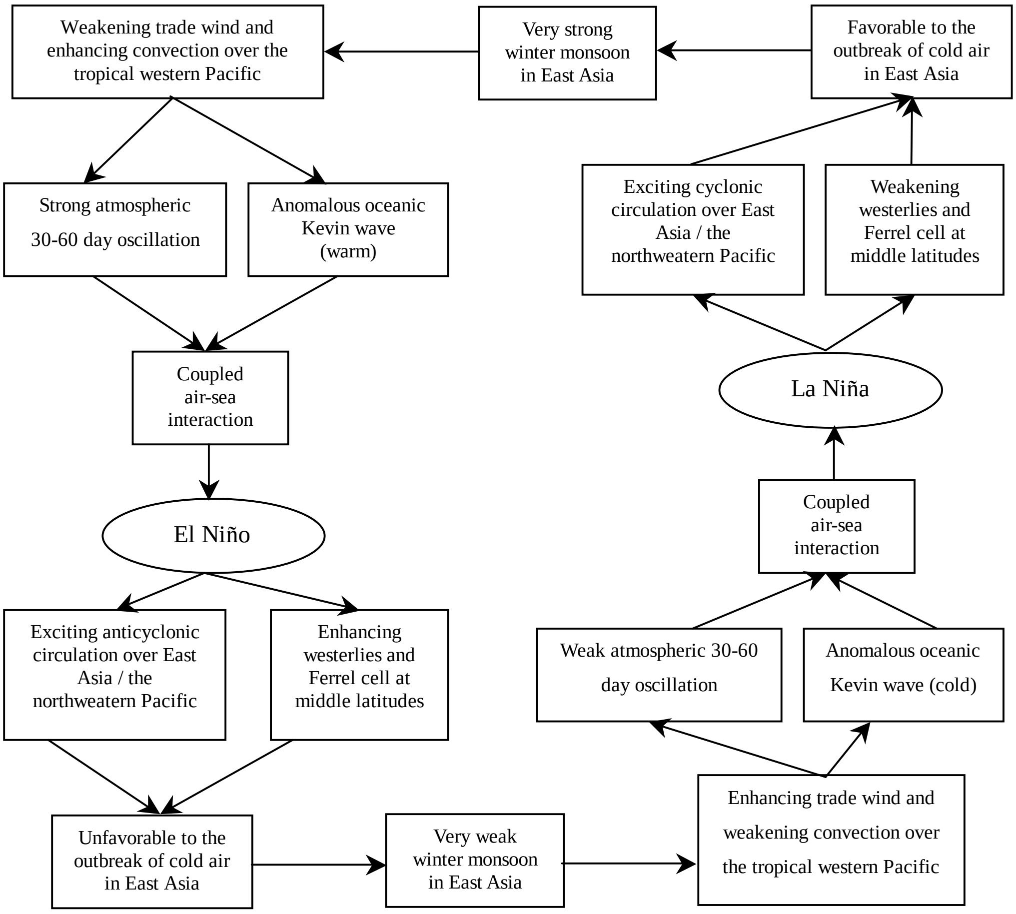

Fig 1 Schematic diagram of the interaction between anomalous winter monsoon in East Asia and ENSO cycle. (From [28], Li et al., 2001)

2.2 *TBO on Precipitation*

Early studies on precipitation biennial variation mostly encompassed India summer monsoon (ISM) rainfall[29,30]. Mukherjee et al. (1985) also studied the relationship between the TBO in rainfall from ISM and stratospheric QBO. The results indicate abundant precipitation of ISM when QBO is on the westerly phase, and vice verse. A number of studies on the rainfall QBO variability in East Asia, especially in China mainland, are along with exploring East Asia monsoon further[31-34]. Other than that, rainfall in some locations, such as in Yangtze River basin[35,36], in Zhejiang[37], also behave as QBO variability. In great degree, interannual variability in China monsoon rainfall behave as shift of rainband, that is the most different from the QBO in ISM rainfall. Liao and Wang[38] had analyzed the relationship between QBO of mean zonal wind at 30 hPa — 50 hPa and the rainfall belt of July in China, and their results show that the position of rainfall belt in July would be to the north when it is in the west phase, and to the south when it is in the east phase.

Several theories had been suggested to explain the TBO of precipitation. Firstly, some works attribute it to the stratospheric QBO[30,38,39]. The opinion is supported by the phenomenon that tropical tropopause height has quasi-biennial variability[7,40]. Further study confirms that through vertical zonal wind shear, stratospheric QBO can affect tropopause, even troposphere[41,42], as showed in Fig.2. Fig.2 indicates that easterly (westerly) shear corresponds to stronger (weaker) subtropical high and the ridge locating to north (south) side. The ascending (sinking) motion in the upper troposphere over the equator caused by the easterly (westerly) shear in lower stratosphere will strengthen (weaken) the Hadley cell. In countries affected by the monsoon, precipitation strongly relies on monsoon activities. From then on, precipitation TBO naturally relates to monsoon interannual variability[43,44]. Another mechanism refers to the impact of Eurasia snowcover. The results from Yang[45] show that QBO variability is very obvious for Eurasia snowcover, which causes the cold source anomalies on underlying surface. Directly, the anomalies excite the atmospheric flow pattern on low-frequency or affect the energy balance and hydrological cycle that eventually result in internal intensity variation of atmospheric heat source (sink).

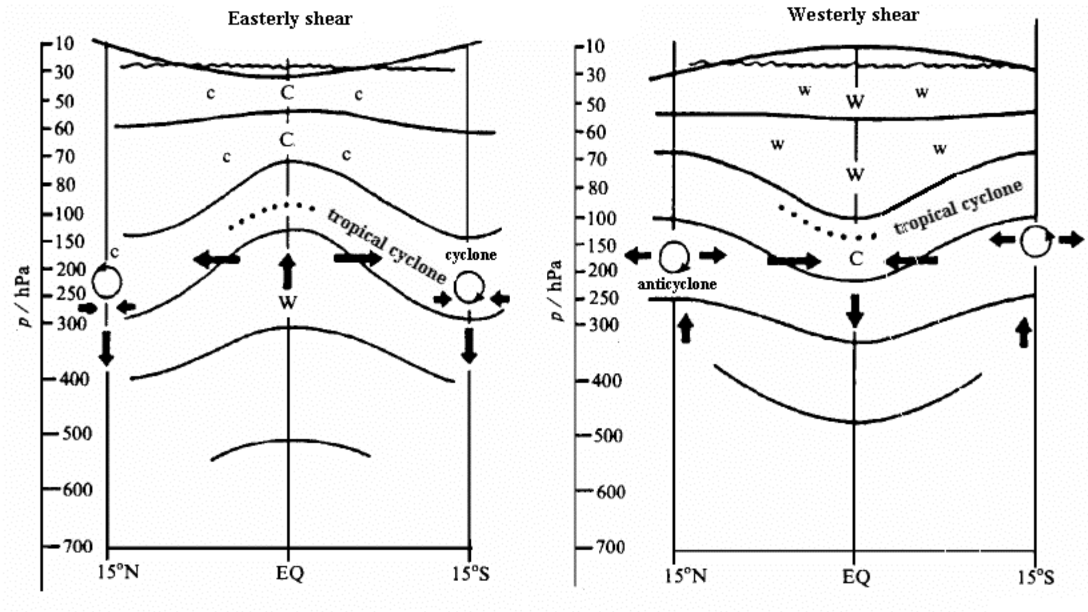

Fig.2 Schematic of stratospheric vertical zonal wind shear and its impact. (from Li and Long, 1997)

2.3 *Other TBO phenomena*

Besides in precipitation and monsoon, TBO also exists in other meteorological and climatic elements and synoptic systems. For example, the quasi-biennial period had been found by James[46] in the power spectrum of northern sea level pressure. Thereafter, through analysis of meteorological anomaly patterns over the United States, Walsh and Mosterk[47] reveal the TBO not only in precipitation, but also in surface pressure and temperature. In fact, northern sea level pressure[48], global mean temperature, northern and southern mean temperature[49,50], tropical zonal wind and sea surface temperature[51], and so on, actively behave as quasi-biennial oscillation. As a synoptic system, subtropical high oscillates its relative intensity, ridge latitude location[42,52] in quasi-biennial period. Occurrence has higher and lower frequency at Atlantic seasonal hurricane[53] and Western Pacific typhoon[54], respectively, when the QBO is in the westerly phase.

Some theories were used to explain their mechanisms in recent years. Sathiyamoorthy and Mohanakumar[55] associated the 20-32 months period in the temperature over Thumba (8º23'N，76º52'E) with the India monsoon rainfall and stratospheric QBO. Li et al.[56] found that the model TBO is sensitive to both internal air–sea coupling coefficients and external basic-state parameters. With slight change of these parameters, the model may undergo a bifurcation from a TBO regime to a chaotic regime or an annual oscillation regime. After analysis of the stratospheric QBO and TBO of tropopause height, height of 500hPa and sea surface temperature, Kwan and Samah[57] deduced that The QBO and TBO seem to be interrelated to each other thermodynamically. An entirely different opinion considers that the fundamental cause of the QBO in the climate system is a nonlinear resonance to the seasonal forcing that is modulated by the 11-yr solar cycle[58].

3 SEVERAL TOPICS OF THE TBO STUDY

As stated above, studies on TBO are very hot not only from observations, but also from numerical simulations. And the revealed phenomena and proposed theories help us understand TBO better. Nevertheless, some scientific problems on TBO need to be paid more attention to.

3.1 *What is the principal part on TBO?*

So many tropospheric elements, even including SST, have been featured as quasi-biennial variability, that it is difficult to estimate which one is the principal part or which ones. It is a different case in stratospheric QBO, although many elements behave as QBO, that tropical zonal wind QBO is the most important QBO phenomenon in the stratosphere, not only for the earliest findings, but also for the dynamical origin of the tracers concentration and temperature QBO in the stratosphere[14][59]-[61]. Since then, Lindzen and Holton are lucky for deducing the famous theory. But, what is the principal part of TBO? If the question is not well answered, we'll be misled in exploring TBO mechanism. Due to that, no one of the present theories of TBO is popular for the most.

3.2 *Interactions between TBO and climatic systems*

In the symposium organized by WMO and ICSU in 1974, the concept of climatic system, including atmosphere, hydrosphere, cryosphere, lithosphere and biosphere, comes to being. Deeper atmospheric science is studied; more attention interaction between atmosphere and other climatic spheres is paid to. Monsoon climate affects more than 60% of the population on Earth. As an important member, Asian-Australian Monsoon System (AAMS), whose variability largely results from interactions between atmosphere and hydrosphere and biosphere, is the most important topic at present. So, The US CLIVAR Asian-Australian Monsoon Working Group takes as science goals predicting AAMS variability and their interaction with other climatic system on timescales from day to decades[62]. TBO in AAMS and its member have been referred to interact strongly with tropical India and Pacific Oceans. As to its interaction with cryosphere, lithosphere and biosphere, our understanding is far behind due to relatively less studies. In addition, internal interactions in the atmosphere need to be taken into account. Stratosphere is very close to troposphere, and they can strongly be affected by each other. Thereby, WCRP began to carry on SPARC (Stratospheric Processes And their Role in Climate) to explore the effects of stratospheric processes on nature climatic variability and change in 1992. SPARC report showed that both observations and numerical simulations confirm the stratospheric effects, that cannot be neglected, on studying tropospheric variance and long term change[63]. On the other hand, the close relationship between TBO and stratospheric QBO would be destroyed in El Niño year[37][38]. Further study is needed to reveal in what degrees every interaction contributes.

3.3 *In what degrees can TBO improve our understanding and predicting on global climatic change TBO?*

CLIVAR program, formed in 1995, aims at studying climatic variability on all kinds of timescales and their predictability. TBO signals are so significant that it is important to understand them in undergoing CLIVAR. Still, it would take a period of time to develop TBO theory, especially to understanding the former two scientific topics.

4 CONCLUDING REMARKS

It is a half century from 1961 when stratospheric QBO was found. During the period, stratospheric QBO theories develop rapidly, and QBO in tropospheric circulation and weather and climate elements are revealed and called as TBO. The mechanism of TBO is explored and the results demonstrate that tropical ocean (the Indian Ocean and the Pacific Ocean, mainly) and Stratospheric QBO play important roles in the TBO. In addition, Eurasian snow cover and solar activity of 11yr period can affect TBO very possibly.

Valuable results of TBO have been presented, but some questions are still not answered. First is the principal part of TBO that we need to concentrate on; secondly, how does TBO interact with climatic systems; subsequently, the former two would help us understand TBO contributions on global climate change and its prediction. To address the questions, endeavor from atmospheric and associated scientists are needed.

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