Discussion of Meridional Propagation Mechanism of Quasi-40-Day Oscillation

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ABSTRACT

Based on researches made by the author in recent years, discussion is made of the quasi-40-day oscillation (QDO) nature and its characteristic propagation, with emphasis on the Southern Hemisphere mid-latitude quasi-periodic cold air forcing on the tropical atmosphere quasi-40-day oscillation along with its effect upon the Northern Hemisphere summer monsoon. It is proposed that the interaction between, or lateral coupling of, meridional circulation systems may serve as the mechanism of the oscillation propagation in a meridional direction.

I. INTRODUCTION

The QDO is one of the strongest low-frequency signals ever discovered in the tropical atmosphere thus far. The study of the oscillation has made much progress of consequence since the pioneering contribution done by Madden and Julian (1971; 1972). Apart from the zonal propagation the meridional travel of QDO has attracted general attention with its relation to the summer monsoon of the Northern Hemisphere. Yasunari (1980) first indicated that the QDO northward propagation is associated with the phase change in Indian summer monsoon; Krishnamurti et al. (1982) showed that the northward propagation of meridional trough (ridge) of the quasi-40-day period corresponds well to the active monsoon (monsoon break) over India; Murakami et al. (1983) discussed, by means of composite analysis, the QDO meridional propagation in East Asia and associated circulation evolution, moisture transport and energy balance, together with the relation to the Asian monsoon variation. Chen et al. (1982) indicated that QDO is the behavior of the Southern Hemisphere cold air in its northward propagation to the Northern Hemisphere ITCZ; Tao et al. (1983) emphasized the important role of the baroclinity development in the Southern Hemisphere mid-latitudes over 40°-160°E in the establishment, intensification and northward advance of Asian summer monsoon. It seems that some inherent relationship exists among the mid-latitude cold air activity, meridional propagation of QDO and change in Asian summer monsoon. It concerns a problem regarding the QDO origin and meridional propagation mechanism. This paper is based on the researches made by the author in recent years to investigate with special attention the interaction between QDO and Southern- and Northern- Hemisphere circulations, with the emphasis on the forcing of the quasi-periodic cold air activity upon the tropical atmosphere and QDO, and finally a mechanism is proposed of the propagation probably caused by the interaction between meridional circulation systems or their lateral coupling.

II. QDO'S NATURE AND EASTWARD PROPAGATION

Chang (1977) first proposed that the eastward propagation of QDO is the manifestation of Kelvin waves driven convectively and trapped equatorially, indicating that the time and
vertical scales agree well with the theory of equatorial waves under conditions of cumulus friction and Newtonian cooling. Many other researchers, e.g., Webster (1983), Anderson (1984) and Lau et al. (1987) made studies of the problems relating to the properties and origin of low-frequency oscillation. Particularly successful is the work of Lau et al. for the interpretation regarding the QDO eastward propagation.

Lau et al. employed a σ-coordinate five-layer primitive equation model for the intensive exploration of the mechanism of QDO eastward propagation with the result that the QDO is a flow pattern with an intrinsic oscillation period and the eastward movement as its character produced by the interaction between convection and dynamics due to the mobile wave – CISK mechanism, whereby equatorial waves on both sides of a heat source have remarkably asymmetric response to the disturbance, with Kelvin waves in the east amplified selectively because of their faster phase velocity responsible for their quicker response to the instantaneous forcing and higher divergence than Rossby waves in the west. Therefore, for a given initial disturbance, the low-level convergence is much more vigorous in relation to Kelvin waves than to Rossby ones, and such effect would be even more marked should the disturbance be in the neighborhood of the equator. Hence the heat source will travel towards the east along with the Kelvin waves convergence, thus exciting the generation of Kelvin analogs to the east. (For the west part Rossby waves, although producing excitation without break, have no sufficiently long response time before the heat source moves along). This creates a new balance between the mobile source and wind field, leading to the continuous eastward propagation of the resulting circulation pattern.

In view of the fact that when discovered, the QDO was believed to be the oscillation of a wavenumber 1 or 2 zonal wind associated with tropical convection, it was naturally regarded as some form of Kelvin waves, especially after Lau, et al. accounted quite satisfactorily for their eastward propagative character in terms of Kelvin waves based on the introduced mobile wave – CISK. This theory cannot, however, interpret the significant meridional wind component in the flow pattern with the QDO nor its meridional propagation, still less the westward travel in some cases. Clearly, the dynamics differs to a great extent between the QDO and Kelvin waves.

The structure of the circulation at various phases of the quasi-40-day periodic disturbance is shown in Fig. 1 (He, 1988a) where the disturbed east (west) wind region between heavy solid lines moves eastward and upward with the phase. Also, in the Indian Ocean region the strong updraft (downdraft) combined with negative (positive) temperature disturbance leads to the conversion of disturbance kinetic into disturbance potential energy, with the westerly momentum transported downward. As we know, however, for Kelvin waves the phase movement is downward and eastward and the westerly momentum upward. This shows a remarkable difference in dynamics between the quasi-40-day periodic disturbance and Kelvin waves.

In his study of the effect of cumulus heating on trapped equatorial waves in terms of both linear and nonlinear vertical models, Hendon (1988) showed that for the linear model the steady cumulus heating (i.e., adiabatic cooling compensates for the heating) makes the eastward propagation Kelvin waves fall off rapidly free phase velocity to the QDO one (< 10 m s⁻¹). However, these moist waves weaken very fast and do not account for the meridional wind disturbance observed; for the nonlinear model, under the condition of unsteady heating, the circulation pattern with increasing CISK stabilizes the atmosphere with rapidity. The growth of the stability reaches a maximum in the west where the CISK heating works, thus resulting in the eastward propagation of the flow pattern, which, when balance is attained,