Northward Development and Propagation of Tropical and Subtropical 30-60 day Oscillation over the Western Pacific

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摘要

熱帶地區 30-60 天季內對流振盪的北移伴隨之大尺度上升運動與台灣地區深對流的建立密切相關，台灣地區 5-7 月強降水在南海地區 30-60 天對流達最強並開始北移後明顯增多。本文利用三維流線函數趨勢方程演算出的三維渦度趨勢分析渦度平流、溫度平流、非絕熱加熱作用及靜力穩定度其高低層結構與 30-60 天對流北移及發展的關係。

研究結果顯示，影響 30-60 天對流波列自赤道太平洋向西北/北發展及移行至東亞地區之主要機制來自渦度平流及非絕熱加熱效應，渦度平流在對流的西北側產生正渦度趨勢，有利降水中心西北側正渦度的發展，因此對流西北側前緣形成一有利對流發展的環境，降水帶持續向西北方發展與移行。非絕熱加熱效應則主要在支持對流本身的發展，由非絕熱加熱效應產生的正渦度趨勢與對流區相當吻合。對流一旦發展後，強烈上升運動將伴隨靜力穩定度增大、雲輻射效應導致 SST 的下降；此外，對流向西北移至東亞陸地後，陸地-大氣間的交互作用亦抑制 30-60 天對流發展，使之無法無限制地一直發展。

關鍵詞：季內振盪、三維渦度趨勢

1. Introduction

ISO (Intraseasonal Oscillation) has been suggested to play an important role in the abrupt change of the Indian and Asian Summer Monsoon (e.g., Krishnamurti and Subrahmanyam 1982; Lau and Chan 1986; Chen and Chen 1995). To improve the seasonal forecast of heavy precipitation associated with monsoon, one may need to understand the characteristics and mechanisms responsible for the development and propagation of ISO.

Webster (1983a) found that the northward propagation of ISO in the Indian Monsoon region can exist in a zonal symmetric non-linear two layer model only when a full hydrology cycle is considered. The enhancement of sensible heat flux ahead of the rising motion would destabilize the atmosphere ahead of the ascending zone and cause the moist convective heating to move northward. Contrary to Webster's numerical experiments, Ferranti et al. (1999) suggested that the northward propagation is primarily related to internal atmospheric dynamics.

Wang and Xie (1997) emphasized the role of moist static energy on the emanation and development of westward propagating Rossby waves over the Western Pacific. Recently (Hsu and Wang; 2001; Lawrence and Webster, 2002), surface moisture convergence to the north of convection has been proposed as an important factor to the northward movement of ISO. Lawrence and Webster (2002) suggested that the northward movement of Summer ISO is induced by surface frictional convergence into the low pressure center to the north of deep convection. Jiang et al. (2004) proposed that the generation of barotropic vorticity in the free atmosphere causes the moisture convergence in the planetary boundary layer.

While several studies have

attempted to explain the northward and/or northwestward propagation in the Indian Monsoon and Western Pacific regions, the physical mechanism responsible for the propagation of 30-60 day oscillation are still in debate. Most studies emphasize the propagation of 30-60 day oscillation located south of 20°N, whereas less attempts have been made to explain the propagation of 30-60 day oscillation in the western Pacific north of 20°N. This study attempts to investigate and explain the development and propagation of ISO as they approach East Asia in the mid-latitude.

2. Data and vorticity tendency

NCEP/NCAR reanalysis data (Kalnay et al. 1996) and daily OLR analyzed from the Climate Diagnostic Center (Libmann and Smith 1996) from 1979 to 1998 are used in this study to analyze the circulation and convection, respectively. Other data sets adopted in this study are weekly SST (Sea Surface Temperature) from 1982 to 1998 produced by the NCEP/NCAR (Reynolds and Smith 1994). To isolate the signal of ISO, an orthonormal wavelet transform developed by Daubechies (1988) is adopted to extract the ISO from the original data.

To understand the mechanism responsible for the northward propagation and development of 30-60 day oscillation, 30-60 day vorticity tendency was further diagnosed by a 3-D streamfunction tendency equation (1). The vorticity tendencies were obtained through the relationship $\nabla^2\psi = \zeta$.

Following the scale analysis by Charney (1963) and Webster (1983b), a three-dimensional streamfuction for the planetary-scale waves over the entire globe can be derived as:

$$\underbrace{\left[\nabla^2 + \frac{f^2}{\sigma}\frac{\partial^2}{\partial P^2}\right]}_{(A)}\frac{\partial\psi}{\partial t} = \qquad (1)$$

$$\underbrace{-\bar{V}\cdot\nabla\left(\nabla^2\psi + f\right)}_{(B)} - \underbrace{\frac{fR}{\sigma}\frac{\partial}{\partial P}\left(\frac{-\vec{V}\cdot\nabla T}{P}\right)}_{(C)} - \underbrace{\frac{f\omega}{\sigma}\frac{\partial\sigma}{\partial P}}_{(D)} - \underbrace{\frac{f}{\sigma}\frac{R}{C_p}\frac{\partial}{\partial P}\left(\frac{\dot{q}}{P}\right)}_{(E)}$$

Term (A) of (5) is the Laplacian of streamfunction tendency. The forcing terms (B), (C), (D), and (E) on the right side are vorticity advection, differential thermal advection, differential heating, and vertical advection of static stability, respectively.

3. Results

Fig. 1 shows the lag regression between 30-60 day OLR over the South China Sea and the 30-60 day OLR over the globe (shaded), superimposed on the lag regression between 30-60 day OLR over the South China Sea and the 30-60 day vorticity tendencies due to vorticity advection, diabatic heating and the effect of static stability for active events (contoured). In the present study, the effect of temperature advection appeared small (not shown). For simplicity, it was neglected in the following discussion.

At lag 0 day, as the 30-60 day convection over the South China Sea reached maximum intensity (Fig. 1a), the vorticity advection induced cyclonic (anticyclonic) vorticity to the northwest of the convection (dry belt) of a wave train in the region from the Equatorial Western Pacific to South China Sea at 850 hPa. Its main effect was to lead this wave train to propagate northwestward. The development of the 30-60 day convection was primarily maintained by diabatic heating. It contributed cyclonic (anticyclonic) vorticity on the center of the convection (dry) belt (Fig. 1e). By lag 5 day, the cyclonic circulation and convection propagated northwestward but weakened as they reached maximum intensity (Fig. 1b). The weaking of 30-60 day convection was contributed by the effect of vertical advection of static stability (Fig. 1i). By lag 10 day, the original cyclonic circulation and convection dissipated as they reached Asian landmass (Fig. 1c). In addition to the cloud-radiation effect (Lau and Sui 1997) and land surface depletion of moisture supply, the static stability effect associated with the adiabatic cooling, prevented the unlimited growth of 30-60 day oscillation.

Investigating the vorticity tendency fields, we found that prior to the occurrence of convection over the region east of Japan (140 160蚩) on lag 5 day, positive vorticity tendency was generated in this region by vorticity advection at lag 0 lag +5 day (Fig. 1a and 1b). The diabatic heating induced negative vorticty tendency to the north of the convection where the warm SST occurred (Fig. 1e). The ocean may play a passive role on the development of 30-60 day oscillation over the Northwestern Pacific. The northwestward propagation of 30-60 day in North Pacific was also contributed by the vorticity advection. The effect of the diabatic heating play a dominate role on the development and maintenance of the low-level cyclonic vorticity. The static stability effect associated with adiabatic cooling (upward motion) or warming (downward motion) would inhibit the northwestward propagation or development of cyclonic (anticyclonic) circulation in tropics and subtropics.

According to the previous analysis, the northwestward propagation of 30-60 day oscillation was mainly contributed by the vorticity advection. To investigate the relative importance of vorticity advection by rotational winds and divergent winds, we divided the wind fields into rotational and divergent winds. Fig. 2 depicted the horizontal distribution of these two components of winds superimposed on the vorticity fields and their relative contribution to the vorticity advection. Apparently, at phase 0, the vorticity advection advected by these two components of winds were comparable at 1000 hPa (Fig. 2b and 2e). Since the rotational winds was generally pararell to the vorticity fields (Fig. 2a), the rotational winds advected the positive (negative) planetary-scale vorticity to the west (east) of cyclonic vorticity center over the SCS (Fig. 2b).

At 850 hPa, vorticity advection by the rotational winds was larger than that by the divergent winds (Figs. 2c and 2f). The importance of divergent winds was confined to the surface. 30-60 day divergent wind converged toward the center of cyclonic vorticity to the northwest of deep convection (Fig. 2d). Such feature implied that the surface frictional effect associated with the cyclonic vorticity induced surface convergence to the northwest of 30-60 day convection over the SCS (Lawrence and Webster, 2002). In the mean time, the divergent and rotational winds advected cyclonic vorticity to the northwest of the cyclonic circulation (Figs. 2b and 2e). The surface convergent and vorticity advection was favorable for the 30-60 day cyclonic circulation to develop and move northwestward.

The role of each forcing mechanisms on the northwestward propagation of 30-60 day oscillation is illustrated in Fig. 3. In the beginning of northwestward propagation, the vorticity advection contributed cyclonic vorticity ahead (northwestward) of the 30-60 day cyclonic circulation (C1), while anticylonic vorticity ahead (northwestward) of the 30-60 day subsidence and anticyclonic circulation at low-level (Fig. 3a). Its main effect was to lead this wave train to propagate northwestward. The development of the 30-60 day convection was primarily maintained by diabatic heating. It contributed cyclonic (anticyclonic) vorticity on the center of the convection (dry) belt. The surface friction associated with the enhancement of cyclonic circulation to the northwest of the convection would in turn induce the low-level convergence and 30-60 day convection to develop and propagate northwestward.

As the precipitation reached maximum intensity over the South

China Sea/Western Pacific, the static stability effect associated with the adiabatic cooling (Tsou et al. 1987) and cooling of SST associated with the cloud-radiation effect (Lau and Sui 1997) would inhibit the development of the cyclonic circulation (C1) (Compare Fig. 3a and Fig. 3b). The original cyclonic circulation disappeared as it reached the Asian landmass (Fig. 3b). The land-atmosphere interaction further decreases the intensity of diabatic heating by cutting off the moisture supply from the ocean.

While the original convection belt weakened and dissipated, the 30-60 day vorticity and convection redeveloped over the Northwest Pacific (C2). The establishment of this low-level vorticity over the Northwest Pacific Ocean was mainly contributed by vorticity advection at lag 0 lag +5 day (Fig. 3b). The diabatic heating induced negative vorticty tendency to the north of the convection where the warm SST occurred (Fig. 3b). Once the low-level cyclonic circulation enhanced and precipitation started, SST changed to negative anomaly immediately (Fig. 3c). The ocean may play a more passive role on the development of 30-60 day oscillation over the Northwestern Pacific. The northwestward propagation of 30-60 day in North Pacific was also contributed by the vorticity advection (Fig. 3c). The effect of the diabatic heating play a dominate role on the development and maintenance of the low-level cyclonic vorticity. The combined effect of vorticity advection and diabatic heating would lead the convection to propagate and develop northwestward.

Reference

Charney, J. G., 1963: A note on the large-scale motions in the tropics. *J. Atmos. Sci.*, 20, 607-609.

Chen, T.-C. and J.-M. Chen,1995: An observational study of the South China Sea monsoon during the 1979 summer: Onset and life cycle. *Mon. Wea. Rev.*, 123, 2295-2318.

Daubechies, I., 1988: Orthonormal bases of compactly supported wavelets. *Commun. Pure Appl. Math.*, 41,909-996.

Ferranti, L., J. M. Slingo, T. N. Palmer and B. J. Hoskins, 1999: The effect of land-surface feedbacks on the monsoon circulation. *Q. J. R. Meteorol. Soc.*, 125, 1527-1550.

Hsu, H. H. and C. H. Weng, 2001: Northwestward propagation of the intraseasonal oscillation in the western north Pacific during the boreal summer: Structure and Mechanism. *J. Climate,* 14, 3834 850.

Jiang, X., Li, Tim, Wang, Bin. 2004: Structures and Mechanisms of the Northward Propagating Boreal Summer Intraseasonal Oscillation. *Journal of Climate,* 17, 1022 039.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, A. Leetmaa, B. Reynolds, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. C. Mo, C. Ropelewski, and J. Wang 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.*, 77, 437-471.

Krishnamurti, T. N. and D. Subrahmanyam, 1982: The 30-50 day mode at 850 mb during MONEX. *J. Atmos. Sci.*, 39, 2088-2095.

Lau, K. -M. and P. H. Chan, 1986: Aspects of the 40-50 day oscillation during the northern summer as inferred from outgoing longwave radiation. *Mon. Wea. Rev.*, 114, 1354-1367.

_____ and C. H. Sui, 1997: Mechanisms of short-term sea surface temperature regulation:Observations during TOGA COARE. *J. Climate*, 10, 465-472.

Lawrence, D. M., Webster, P. J. 2002: The Boreal Summer Intraseasonal Oscillation: Relationship between Northward and Eastward Movement of Convection. *Journal of the Atmospheric Sciences*, 9, 1593 606.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, A. Leetmaa, B. Reynolds, M. Chelliah, W. Ebisuzaki, W. Higgins, J.

Janowiak, K. C. Mo, C. Ropelewski, and J. Wang 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.*, 77, 437-471.

Reynolds, R. W. and T. M. Smith, 1994: Improved global sea surface temperature analyses using optimum interpolation. *J. Climate*, 7, 929-948.

Tsou, C. H., P. J. Smith, and P. P. Pauley, 1987: A comparison of adiabatic and diabatic forcing in an intense extratropical cyclone system. *Mon. Wea. Rev.*, 115, 763-786.

Wang, B. and X. Xie, 1997: A model for the boreal summer intraseasonal oscillation. *J. Atmos. Sci.*, 54, 72-86.

Webster, P. J., 1983a: Mechanism of monsoon low frequency variability: Surface hydrological effects. *J. Atmos. Sci.*, 40, 2110-2124.

_____, 1983b: The large-scale structure of the tropical atmosphere. In B. J. Hoskin and R. Pearce (eds.), *Large-scale Dynamical Processes in the Atmosphere*, Academic Press, New York, 235-276.

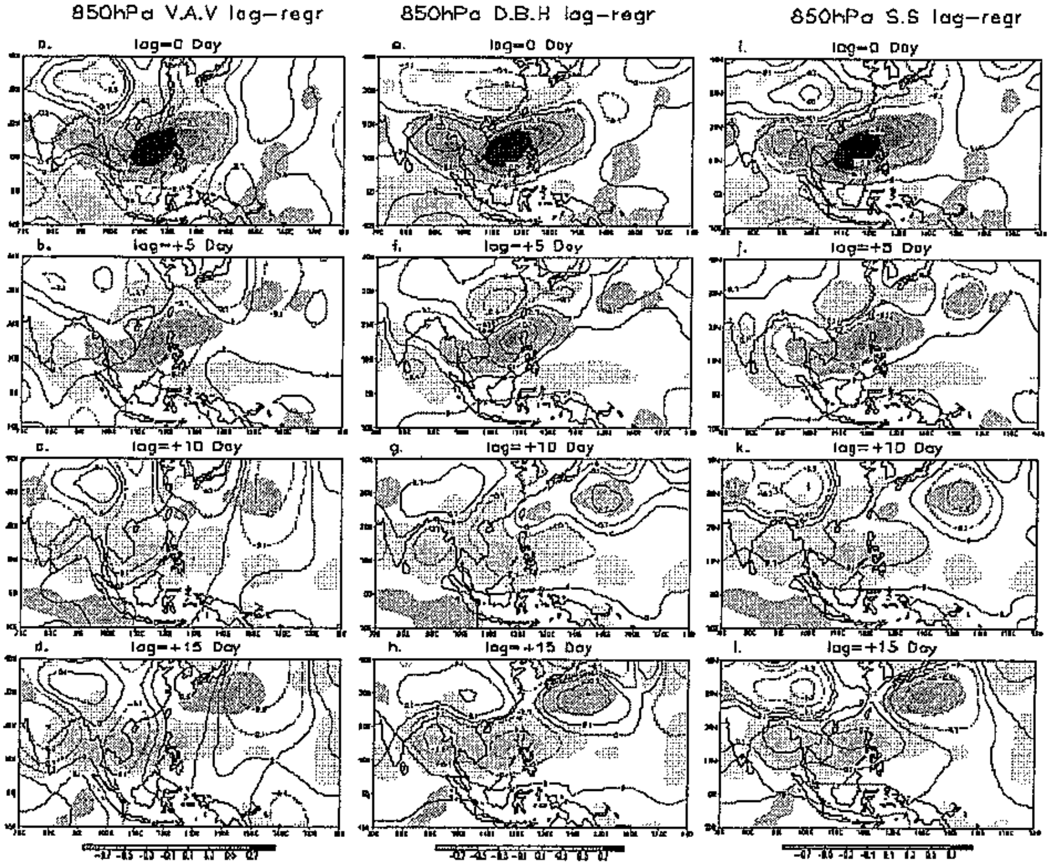

Fig1. Lag correlation coefficient between 30-60 day OLR at (110-120E,7.5-17.5N) and 30-60day OLR over the global for active events (shaded), superposed lag correlationcoefficient between 30-60 day OLR at SCS and 30-60 day vorticity tendency due to (a)-(d)vorticity advection, (e)-(h) diabatic heating and (i)-(l) static stability over the global for active events.

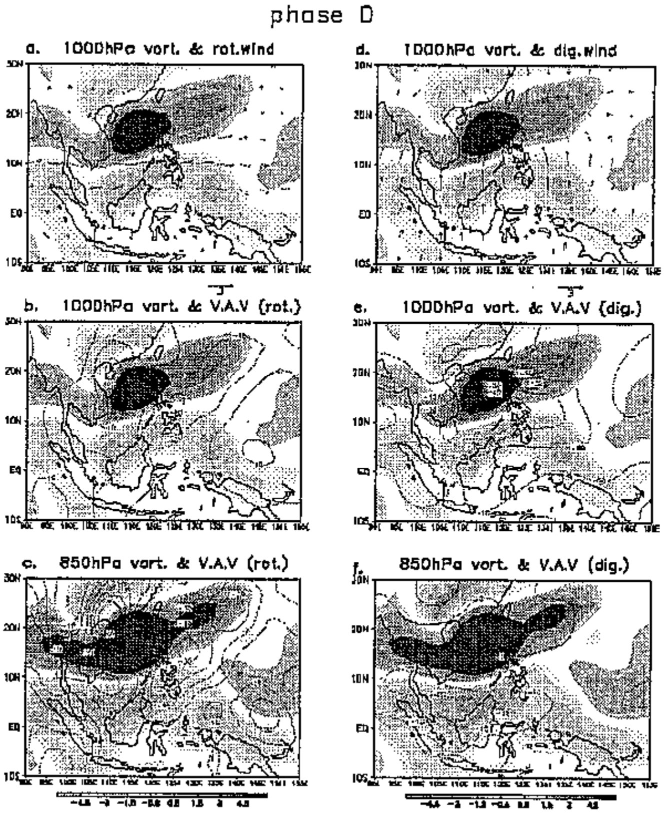

Fig 2 1000hPaVorticity (shaded) and (a)1000hPa wind vector of rotational component, (b) vorticity tendency due to 1000hPa rotational wind, the shaded part in (c) is 850hPa vorticity and superimposed by vorticity tendency due to 850hPa rotational wind. shaded in (d)-(f) are same as (a)-(c) but vectors and contour are associated with divergent wind.

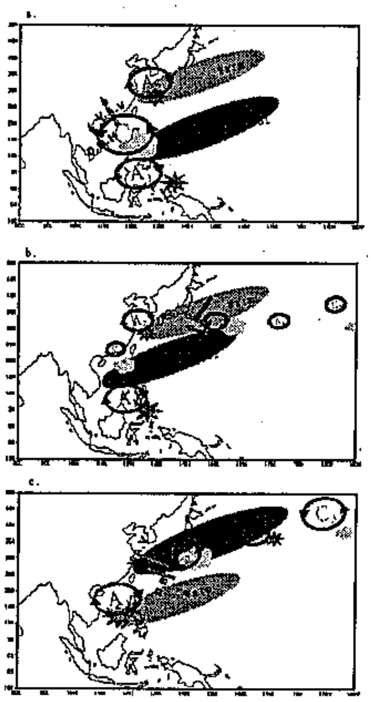

Fig3. Schematic diagram illustrate the northward/westward develop and propagation of 30-60 day oscillation from (a) South China Sea to (c) Northwestern Pacific. The bold streamline with character A and C indicate anticyclonic and cyclonic circulation at low levels (850 hPa) and high levels (200hPa), respectively. Red (blue) strips indicate positive (negative) vorticity advection due to V.A.V(vorticity advection)· D.B.H(diabatic heating). The cloud indicates the convection/precipitation.