On the onset of the Asian summer monsoon

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Extended Abstract

The onset of the Asian summer monsoon is a key indicator characterzing the abrupt transition from the dry season to the rainy season and subsequent seasonal march. Numerous investigators have studied this problem from the regional perspectives. It is to some extent difficult to obtain a unified and consistent picture of the climatological onset dates of the Asian summer monsoon in different regions due to differences in data, monsoon indices and definitions of monsoon onset used in these investigations. Recently, Wang and Lin (2002) have identified two phases in the evolution process of the Asian summer monsoon. The first phase or the onset phase begins with the rainfall surges over the South China Sea in mid-May, which establishes a planetary-scale monsoon rainband extending from the South Asian marginal seas (the Arabian Sea, the Bay of Bengal, and the SCS) to the subtropical western North Pacific (WNP). The second phase of the Asian monsoon onset is characterized by the synchronized initiation of the Indian rainy season and the Meyu/Baiu in early to mid-June. The peak rainy seasons tend to occur primarily in three stepwise phases, in late June over the Meiyu/Baiu regions, the northern Bay of Bengal and the vicinity of the Philippines; in late July over India and northern China; and in mid-August over the tropical WNP (10°-22°N, 120°-160°E). The rainy season retreats southward in East Asia during late August and early September while the Indian summer monsoon and the WNPSM withdraws southward after mid-September. Ding (2004) has summarised the climatological dates of the onset of the Asian summer monsoon in different tropical regions based on various sources, with dividing the whole onset process into four stages: (1) Stage 1 (late in April or early in May): the earliest onset is often observed in the central Indochina Peninsula late in April and early in May, but in some cases, the onset may first begin in the southern part or the western part of the Indochina Peninsula. (2) Stage 2 (from mid to late May): this stage is characterized by the areal extending of the summer monsoon, advancing northward up to the Bay of Bengal and eastward down to the SCS. (3) Stage 3 (from the first dekad to second dekad of June): this stage is well known for the onset of the Indian summer monsoon and the arrival of the East Asian rainy season such as the Meiyu over the Yangtze River Basin and the Baiu season in Japan. (4) Stage 4 (the first or second dekad of July): the summer monsoon at this stage can advance up to North China, the Korean Peninsula (so-called Changma rainy season) and even North Japan.

During the first pentad of May, the summer monsoon is established only over Sumatra. In the next two pentads, the tropical monsoon advances up to the land bridge, first establishing itself over the southwestern Indochina Peninsula and then expanding to the entire southern peninsula. During the pentad of May 16-20, the build-up of the summer monsoon is observed over the central Indochina Peninsula. At the same time, the onset location extends into the central and southern SCS, accompanied by a rainfall rate of ＞5 mm day^{-1} over the entire SCS. In the next pentad, onset expands

quickly and almost covers the entire SCS. On the other hand, the Asian summer monsoon also advances northwestward to the Indian monsoon region from the near-equatorial East Indian Ocean and the Indochina Peninsula starting from mid-May. Earliest onset of the Asian summer monsoon in this region may be observed over the southern tip of the Indian subcontinent. In early June, the Asian summer monsoon rapidly advances northwestward, arriving in the central Indian subcontinent. Meanwhile, the onset over the Arabian Sea and the western coast of the Indian subcontinents is observed, due mainly to the enhancement of the cross-equatorial airflow off the Somali coast and the development of the onset vortex in the central and northern Arabian Sea (Krishnmaurti *et al*., 1981; Ding, 1981). This date is generally believed to be normal onset dates for the Indian summer monsoon. So, the onset of the East-and Southeast Asian summer monsoon and the South Asian summer monsoon is closely interrelated in the context of the Asian summer monsoon. However, the earliest onset of the Asian summer monsoon occurs over the Indochina Peninsula and the SCS.

Similar to the onset vortex over the Arabian Sea, a twin cyclone is often observed to develop in the near-equatorial East Indian Ocean (near Sri Lanka) prior to the onset of the summer monsoon over Indochina Peninsula and the South China Sea. The equatorial westerlies are acceclerated and extend northeastward into the Indo-China Peninsula and the northern SCS, thus greatly enhancing the low-level westerlies there. Therefore, a pre-condition of the first onset of the Indochina Peninsula and SCS summer~~s~~ monsoon is the development of a twin cyclone over equatorial East Indian Ocean. The climatological and case study both have shown that this pre-condition generally exists (Lau *et al*., 1998, 2000; Zhang *et al.*, 2001). For 13 cases of the first monsoon onset of the northern SCS out of 47 years from 1953 to 1999, the twin cyclones over the equatorial East Indian Ocean were always observed, although their developmental processes may have some differences.

Another pre-condition for the first summer onset of Indochina Peninsula and the South China Sea (especially northern SCS) is the southward intrusion of strong cold air accompanied by Chang and Chen (1995) an obvious cold front. As pointed out by Chang *et al.* (2000), and Ding and Liu (2001) ,this process from mid-latitudes may be a triggering mechanism for the monsoon onset in the northern SCS, especially for rapid amplification of regional precipitation and convection in these regions. This condition is different from that of the Indian summer monsoon whose onset is basically forced by tropical impacts. Recently, Liu et al. (2002) suggest that the southward intrusion of midlatitide frontal systems is related to the downstream propagation of the Rossby wave excited by convective activity in Bay of Bengal.

One important indicator characterizing the onset of the Indochina Peninsula and the SCS is the of precipitation and convection. Based on observations made by the dual-Dpppler radars deployed in the northern SCS by SCSMEX, the organized convections in the monsoon trough were very vigorous after the onset, which often organized into meso-scale rainbands or meso-scale convective systems (MCSs). These MCSs are closely related to the synoptic processes and systems (Ding, Li and Liu, 2004). In particular, the establishment of the low level monsoon trough and associated wind shear line during the monsoon onset provides the favorable synoptic and dynamic condition for formation and maintenance of MCSs. The latter will in turn create a significant feedback effect on large-scale circulation and synoptic system in which are embedded the MCSs, through vertical heat and moisture transport and release of latent heat. Johnson and Ciesielski (2001) have recently studied the characteristics of the onset of the summer monsoon over the northern SCS utilizing observation from the May – June 1998 SCSMEX. They have shown that the onset occurred in the northern SCS in mid-May with a rapid increase in deep convection over a week to ten-day period, thus producing the significant vertical transports of heat and moisture. During the undisturbed pre-onset period (May 6-12), there is upper-level convergence, low-level divergence and deep subsidence, consistent with the mostly clear skies and high values of OLR. Q_1 (the apparent heat source) is negative at all levels with values in excess of -2.5K day^{-1} in the upper troposphere. The profiles of divergence and vertical motion during the onset (May 16-22) and post-onset periods (June 3-9) are dramatically different from the pre-onset period. Low-level convergence, upper-level divergence and strong upward motion occur during both periods. Deep convergence extends to 300-500 hPa, Q_1 and Q_2 (the apparent moisture sink) profiles are characteristic of deep convection during these periods, with a peak heating rate of 5 K day^{-1} located at about 400 hPa and a considerable separation of the two curves, suggesting more vigorous deep convection at that time. Thus, the intense heating can led to the surface pressure in the monsoon trough further to fall down and tropical low-level southwesterlies to monsoon trough was enhanced. This positive feedback process is also favorable for eastward retreat of the subtropical high out of the SCS region.

The onset of the monsoon is the most anxiously awaited weather singularity in the sub-continent as it heralds the rainy season and marks the end of the hot summer (Ding and Sikka, 2004). Over continental India, the drama of the onset of the South Asian summer begins first across Kerala coast, normally by 31 May (Ananthakrishnan and Soman,1988) when heavy rains lash the coastal state after the cross equatorial low level jet (LLJ) is established across the Somali coast into near-equatorial Arabian Sea. This phenomenon is usually accompanied by the formation of a mid-troposphere shear zone across central Bay of Bengal to SE Arabian Sea in which may be embedded a cyclonic vortex. The vortex may even intensify into a cyclonic storm either in the Bay of Bengal or SE Arabian Sea. The cyclonic storm forming in the SE Arabian Sea is known as the Monsoon Onset Vortex (Krishnamurti et al., 1981) after the event which occurred on 11 June 1979 during the Summer MONEX year. The vortex is formed to the north of the LLJ, in the zone of maximum cyclonic shear in the lower tropospheric zonal winds. In association with the northward movement of the vortex, the large scale monsoon current also advances northward along the West Coast of India. On the average, the onset vortex forms in nearly 50 percent of the years and in other years the onset is accompanied by either mid-tropospheric shear line or formation of an off-shore trough along 10 to 15^{0}N off the Kerala coast of India with an embedded weak low pressure area. Prior to the onset the cross-equatorial flow increases in strength, the moisture fields builds upto the mid-tropospheric level 7 to10 days in advance (Pearce and Mohanty, 1984), the near-equatorial cloud band in the Arabian sea expands eastward and the upward motion field in the troposphere near the equator enhances which eventually moves northward with the advance of the monsoon.

Yin (1949) was the first to link the process of monsoon onset to the displacement of westerly troughs in the circumpolar westerlies and shift of STJ to the north of the Himalayan periphery. Pearcl (1983) examined the monsoon onset over India during 1979 from the perspective of planetary scale circulation features and noted their gradual setting up prior to the formation of a transient disturbance off the Kerala coast. Murakami and Ding (1982) have opined that the onset is related to the warming of the Eurasian region by diabatic heating. Yanai et al. (1992) have linked the onset to the effect of the Tibetan Plateau. Thus the onset of monsoon over India is linked to a combination of regional and planetary scale changes over the entire Indian Ocean region. There exists a variety in the linkages of the onset process with the seasonal developments or transitions in the regional and planetary scales features. Lack of uniqueness among them points to the initiation of chaotic dynamics with the formation of the weather system at Kerala coast which heralds the onset process.

Reference

Ananthakrishnan, R. and M.K. Soman, 1988: The onset of SW monsoon over Kerala, Int. J. Climatol. 8, 283-296.

Chang, C.-P., and G.T.-J. Chen, 1995: Tropical circulation associated with southwest monsoon onset and westerly surge over the South China Sea. Mon. Wea. Rev., 123, 3221-3267.

Chang, C.-P., Y. Lan, and G.T.J. Chen, 2000: A numerical simulation of vortex development during the 1992 East Asian summer monsoon onset using the Navys Regional Model. Mon. Wea. Rev., 1604-1631.

Ding, Y.H., 1981: A case study of formation and structure of a depression over the Arabian Sea. Chinese J.Atmos.Sci., 5, 267-280 (in Chinese).

Ding, Y.H., and Y.J. Liu, 2001: Onset and the evolution of the summer monsoon over the South China Sea during SCSMEX field experiment in 1998. J. Meteor. Soe., Japan, 79, 255-276.

Ding, Y.H., C.Y. Li, and Y.J. Liu, 2004: Overview of the South China Sea Monsoon Experiment. Adv. Atmos. Sci., 21, 343-360.

Ding, Y.H., 2004, Seasonal march of the East Asian summer monsoon in The East Asian Monsoon, ed. by C.P. Chang, World Scientific Publisher, Singapore. (In print)

Ding, Y.H. and D.R. Sikka, 2004: Synoptic Systems and Weather in the Asian Monsoon, Ed. By Bin Wang. To be published.

Johnson, R.H., and P.E. Ciesielski, 2002: Characteristics of the 1998 summer monsoon onset over the northern South China Sea, J. Meteor. Soc. Japan, 80, 561-578.

Krishnamurti, T.N., P. Ardanuy, Y. Ramanathan, and R. Pasch, 1981: The onset-vortex of the summer monsoon. Mon. Wea. Rev., 109, 344-363.

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

Lau, K.-M., Y.H. Ding, J.T. Wang, R. Johnson, R. Cifelli, J.G.erlach, O. Thjiely, T.Rikenbach, S.C. Tsay and P.H. Lin, 2000: A report of the field operation and early results of the South China Sea Monsoon Experiment (SCSMEX). Bull. Amer. Meteor. Soc., 81, 1261-1270.

Liu, Y.M., J.C.L. Chan, J.Y. Mao and G.X. Wu, 2002: The role of Bay of Bengal convection in the onset of the 1998 South China Sea summer monsoon. Mon. Wea. Rev., 130, 2731-2744.

Murakami, T., and Y.H. Ding, 1982: Wind and temperature changes over Erasia during the early summer of 1979, J. Meteor. Soc., Japan, 60, 183-196.

Pearcl, R.P., and O.C. Mohanty, 1984: Onset of the Asian summer monsoon 1979-82. J. Atmos. Sci., 41, 1620-1639.

Wang, B., and H. Lin, 2002, Rainy season of the Asian-Pacific summer monsoon, J. Climate, 15, 386-396.

Yanai, M., C. Li and Z. Song, 1992: Seasonal heating of the Tibetan Plateau and its effects on the evolution of the Asian summer monsoon, J. Meteoro. Soc., Japan, 70, 319-351.

Yin, M.T., 1949: A Sysmatic aerological study of onset of the summer monsoon over India and Burma, J. Meteor. 6, 393-400.

Zhang, X.Z., J.L. Li, Y.H. Ding and J.Y. Yan, 2001: Research of circulation charachteristics and index of South China Sea summer monsoon, Acta Meteorologica Sinica, 15, 450-464.