Article ID: 1006-8775(1999) 02-0123-10

ESTABLISHMENT OF SUMMER MONSOON IN SOUTH CHINA SEA AND INTENSITY VARIATION*

LIANG Jian-yin (梁建茵), WU Shang-sen (吴尚森) and YOU Ji-ping (游积平)

(*Guangzhou Institute of Tropical and Oceanic Meteorology, Guangzhou* 510080 *China*)

ABSTRACT: The 850 hPa wind field data from NCEP and OLR data are used to study the variation behavior of the southwesterly wind and OLR in the South China Sea and their mutual relationship. A monsoon index is put forward that reflects the variation of the southwest monsoon in the region. In the preliminary study of intensity variation and establishment time of the monsoon, it is found that it is of dual peaks on the seasonal scale and the interannual variation of the monsoon intensity and the establishment time are related with sea surface temperature. The summer monsoon is established earlier and with higher intensity in the El Niño year and vice versa.

Key words: summer monsoon; establishment; intensity; South China Sea

CLC number: P425.42 **Document code:** A

Ⅰ. INTRODUCTION

In research on East Asia monsoon over the past few years (Ding and Ma, 1996), it is pointed out that it is in the South China Sea that the monsoon breaks out the earliest (averaging in the middle of May) of all branches in Asia. The monsoon then transports westward to India and northward to eastern China, Japan, and the Korean Peninsula. It is one of the problems engaging the meteorological community that the timing and intensity of the outbreak of South China Sea monsoon as the earliest branch in Asia monsoon system.

Using the OLR and T_{BB} data, Chen, Song and Kumi (1996) study the variation of convective cells during the outbreak of the South China Sea monsoon. It is found that the cells make a sudden northward jump from the equator to 10 ~ 15°N when the west Pacific high occupying the lower levels of the South China Sea suddenly shifts eastward to withdraw from the sea. The southwesterly wind takes over and the monsoon breaks out in the South China Sea. He and Luo (1996) used T_{BB} data to conclude that summer monsoon starts in the 4th pentad of May in the region. According to Liu, Xie, Yie et al.(1998), the onset time of the monsoon is defined at the time when pentad-mean OLR averaged over the region drops to 235 W/m^2 in association with zonal shifts from the easterly to westerly wind. By this definition, the average time is the fourth pentad of May for the outbreak of summer monsoon in the South China Sea over a 16-year period (1979 ~ 1974). Lau and Song (1997) study global precipitation, wind and geopotential height averaged over pentad and month for 9 years (1986 ~1994) and indicate that the monsoon in southeast Asia breaks out around the middle decade of May, which is the earliest phase of the whole Asian summer monsoon. With information from island, coastal stations and highly reflec-

---

* **Received date:** 1998-05-21; **revised date:** 1998-10-06

Foundation item: Scaling project A in "Research of South China Sea Monsoon Experiment" of the Science and Technology Ministry; Science Foundation of Guangdong Meteorological Bureau.

Biography: LIANG Jian-yin (1964 –), male, native from Shunde City Guangdong Province, senior engineer at Guangzhou Institute of Tropical and Oceanic Meteorology, studying monsoon and climatology.

tive clouds (HRC) that have been measured for over 10 years, Yan (1997) studies how the southwest monsoon breaks out in the South China Sea and its climatological features and suggests that the monsoon begins in the middle of May on average, with an earlier onset in the northern part of the sea than in the southern. By studying pentad-mean ECMWF wind field and OLR data from 1980 to 1986, Wang and Ding (1997) find that in the area of the South China Sea, the zonal wind speed at 850 hPa performs the first jump in 2nd to 3rd pentad in May while there are easterly and northerly wind bursts in the upper troposphere to form a meridional circulation cell in East Asia. It tends to be stable, signaling the establishment of the South China Sea monsoon. In their analysis with 30-year conventional surface observations (1959 ~ 1988) 9-year rawinsondes (1980 ~ 1988), Wu and Liang (1998) reveal that the outbreak of southwest monsoon in mid-May on the surface of the Xisha Islands in northern South China Sea is followed by sudden strengthening of convection. They also define two indexes for the monsoon so that three stages are categorized by the season, namely the southeast (early April ~ early May), southwest (mid-May ~ early September) and end of summer monsoon (mid-September ~ early October), for the Xisha Islands area.

Considerable consistence is with the outbreak date of the South China Sea summer monsoon from the viewpoint of multi-year mean, as found in the work above, but it varies much in each particular year, sometimes as much as a month and more. It is mainly caused by relevant definitions used. There has not been a single definition for the South China Sea monsoon that is both exact and consistent. It is just for this reason that more discussion is needed to address the issue. Our work presents analysis of the variation of long time series (15 years) of wind field (NCEP) for the South China Sea region and OLR data, formulation of definition of monsoon index for the region and discussions of multi-year and interannual variation.

II. DATA AND TREATMENT

The basic data used in the work include reanalyzed 850 hPa wind field and OLR data from NCEP (the magnitude of OLR values indicates activity of the subtropical high or convection in the tropics). The resolution is 2.5°×2.5° with the domain of 40–160°E and 40°S ~ 40°N and the duration between April and October from 1979 to 1993. We process the daily data into pentad-to-pentad data. In view of the prevalence of southwesterly wind at lower levels of the South China Sea region during the monsoon, the low-level wind is projected on the southwest-northeast direction, i.e. $V_{sw} = (U + V)/1.414$. The area of interest is bounded by 5 ~ 20°N and 105 ~ 120°E.

III. MULTI-YEAR MEAN OF SOUTHWEST MONSOON IN SOUTH CHINA SEA

It is known that the variation of the southwest monsoon in the South China Sea is reflected in the evolution of southwesterly wind and convection.

1. *Southwesterly component at 850 hPa*

The line in Fig.1 that joins together the open circles denote the evolution of pentad-to-pentad southwest-northeast component U_{sw} (simplified as NE wind) at 850 hPa for the region. The component indicates the SW wind when it is positive and NE wind when it is negative. On average, U_{sw} is negative before the fourth pentad of May, or the NE wind prevails, in the South China Sea. It weakens slowly. U_{sw} is positive from the fourth pentad of May to the third pentad of September when the SW wind is dominant, during which June is the month with rapid increase of SW wind. It decreases in the end of June through mid-July but strengthens once more in late July through mid-August. The SW wind weakens again starting from late August. It is then obvious that the speed of SW wind in the South China Sea is distributed as a dual-peak pattern with peaks appearing in the last decade of June and middle decade of August. It is replaced by the NE wind from the fourth pentad of September with increasing speed.

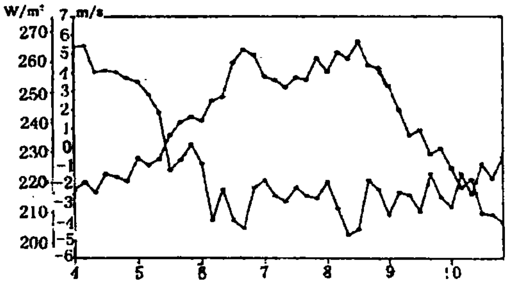

Fig.1 Five-day evolution curves of SW wind component at 850 hPa (dotted line with open circle. m/s) and OLR (dotted line with close circle, W/m^2) averaged for 1979–1993 over the South China Sea

Fig.2 is the time-latitude profile of 850-hPa SW-NE wind profile on a pentad basis that is averaged over 105°E ~ 120°E from 1979 to 1993. On the longitudinal sphere that crosses through the South China Sea, a sustained NE wind prevails from April to October across the 10°N ~ 20°N section in Southern Hemisphere. The SW wind appears in continental China as early as in April, whose maximum being over South China. In fact, rather than the tropical southwest monsoon, it is a joint result by the southern branch of the westerly trough and the southwesterly to the northwest of the subtropical high (NE wind is the dominant feature before mid-May south of 16°N). The SW wind appears and gets strong on the 0°N ~ 20°N latitudinal zone with relevant peaks in June and August. The northward advancement of SW wind is shown to have some corresponding relation to the movement of rain belts in China.. By the last decade of May, the SW wind has been mild in southern South China Sea while it remains strong in the northern part and South China. The maximum region (SW wind$\geq$2 m/s) extends to areas south of the Changjiang River in the first decade of June, which corresponds to the beginning of the Mei-yu (long sustained rain) season in the middle and lower valleys of the river. In the meanwhile, the first peak of SW wind appears in the middle and last decades of June as the SW wind increases. The Mei-yu enters its phase of maturing in the valleys while the rainy season for the Huanghe and Huihe River Basins begins. By August, the maximum SW wind has rapidly moved back to areas south of 20°N and the second SW wind peak appears in the region of South China Sea. It is also the period when the amount of precipitation in South China reaches its second peak. As the NE wind spreads from the north to affect South China and northern South China Sea in September, the SW wind begins to weaken and move southward in the South China Sea. When it comes to the month of October, the NE wind strengthens in South China and the sea.

Fig.3 is the temporal cross-section of 850-hPa SW wind pentad-averaged at 5°N ~ 20°N from 1979 to 1993. The figure reveals the longitudinal variation of the southwest-northeast component in April ~ October that is averaged over years. Around 100°E (or the region of the Indochina Peninsula) and 40°E, the SW wind first appears, which in the middle decade of April spreads to 80°E from the peninsula and further westward. From the mid-May onwards, the SW wind exerts influence rapidly from west to east to the South China Sea and the western side of west Pacific. In the last decade of July, it extends westward once again, coming around 155°E. In late September, it has changed to the NE wind in the South China Sea region while the SW wind shrinks towards the Indochina Peninsula, which is dominated by NE wind in late October. Two centers of strong westerly wind are respectively at 50°E ~ 70°E and 85°E ~ 95°E, corresponding to the southwest monsoon in South Asia and tropical southwest monsoon in East Asia, respectively. Two peaks of strong SW wind at 85°E ~ 95°E, appearing in June and August, respectively, are in temporal agreement with the peaks of SW wind in the region of South China Sea. There is only one peak at 50°E ~ 70°E for strong SW wind (in the end of July). It is shown in the multi-year average that the SW wind first appears in early April in the Indochina Peninsula and extends westward in mid-April through early May to the region of the Bay of Bengal and further to the South China Sea in mid-May. It is then obvious that the southwest monsoon in the sea is mainly subject to the SW wind over the peninsula.

2. *Variation of OLR*

The solid circles in Fig.1 present the evolution of pentad-averaged OLR in April ~ October averaged over 5°N ~ 20°N and 105°E ~ 120°E from 1979 to 1993. The value of OLR in the fourth pentad of May substantially drops to 230 W/m^2 and below, which is followed by mild rise in the subsequent two pentads and another fall in the early decade of June. The OLR remains below 230 W/m^2 afterwards, followed by a slow rise again in October. Being consistent with the variation of SW wind in the South China Sea, the large fall of OLR value is taking place simultaneously with shifts to the SW wind over the sea such that the appearance of SW wind peaks is accompanied by two low valleys of OLR in June and August. It is seen from the multi-year mean that OLR is closely linked with the southwest monsoon in the South China Sea. After the middle decade of September, the SW wind changes to NE wind there, but the former does not rise significantly with the increase of the latter, suggesting the presence of convection over the sea even when the southwest monsoon comes to a close.

Examining the pentad-averaged OLR time cross-section at 105°E ~120°E for years (Fig.4), we find that the period from April to the middle decade of May witnesses cores of strong convection south of the equator and the fourth pentad of May is the time when convection develops explosively in the South China Sea, especially over the central part. Starting from the month of June, strong convection centers move to the South China Sea and remain there until September as they migrate southward. Examining the pentad-averaged OLR time cross-section at 105°E ~120°E for years (Fig.5), we know that convection appears the earliest near the Indochina Peninsula at 100–105°E and expands to both east and west. Convection strengthens in mid-May there, causing much faster expansion and the growth of convection over the South China Sea. The convection is so vigorous east of 70°E in June ~ September that the coverage even expands to 155°E

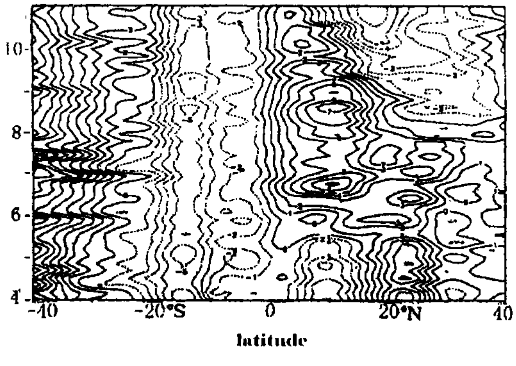

Fig.2 Latitude-time section of SW wind component At 850 hPa averaged for 1979~1993 over 105°E ~120°E

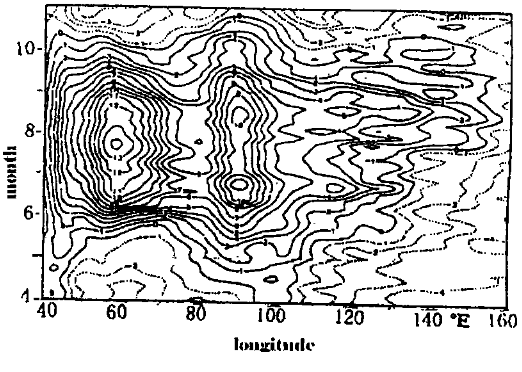

Fig.3 Longitude-time section of SW wind component at 850 hPa averaged for 1979–1993 over 5°N ~20°N

in August. The centers of strong convection are in the eastern Bay of Bengal at 90°E ~100°E while relatively smaller value areas are near 110°E (western South China Sea), separating convection areas in the eastern Bay of Bengal from those in the central and western South China Sea. It may closely relates to the topographic effects of the Indochina Peninsula. Comparisons made with Fig.3 have indicated that the SW wind has a good correspondence with OLR in areas east of 80°E — the SW wind extends westward with much the same pace as the convection and the strong cores of the former corresponds well with the growing areas of strong convection, etc. In a word, OLR has almost the same mode of distribution as the SW wind does.

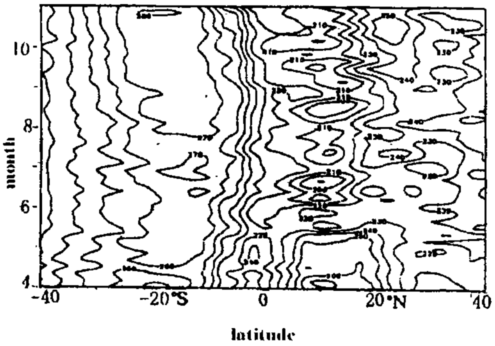

Fig.4 The same as Fig.2 but for OLR

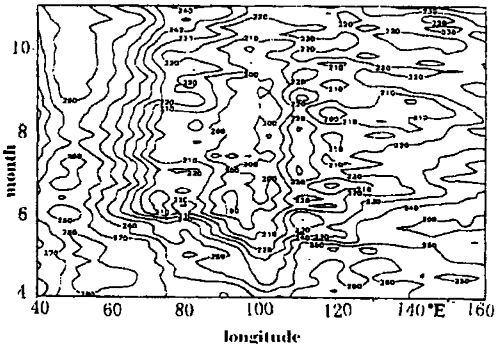

Fig.5 The same as Fig.3 but for OLR

Points as presented below can be drawn based on observational study of variation of the southwest monsoon averaged over years in the South China Sea:(1)Viewing from a multi-year point, there is much resemblance between the SW wind and OLR in the region and they both reflect the variation of the southwest monsoon there from different angles. For instance, they both point to the average date of its onset (the fourth pentad of May) and indicate a dual-peak pattern of distribution, etc.;(2)the variation of the SW wind and convection over the Indochina Peninsula is a direct cause for variations in the southwest monsoon in the sea. The mechanism works like this: the SW wind and convection at the low levels first appear in the peninsula before advancing eastward to the region of South China Sea; when the SW wind separately reaches the peak in June and August over the peninsula, both the wind and convection experience an eastward progression, accompanied by corresponding peaks in their counterparts in the South China Sea.

Ⅳ. INTERANNUAL VARIATION OF SOUTHWEST MONSOON IN SOUTH CHINA SEA

The SW wind in the South China Sea closely corresponds to OLR, but they differ to some extent when judged from each individual year. For example, the wave spectral analysis shows that during the southwest monsoon, the OLR varies with a cycle of 4 ~ 6 pentads and the SW wind of 6 ~ 12 pentads. The oscillatory frequency is relatively higher in the former and sometimes leads to difference in phase. Therefore, they must be comprehensively analyzed in the issue of the variation of the southwest monsoon over the South China Sea.

1. *Variation of intensity of southwest monsoon in South China Sea*

There are quite a number of indexes that can be used to indicate the intensity of monsoon.

For instance, the difference of pressure between land and sea denotes the intensity of subtropical monsoon in East Asia (Guo, 1983), the precipitation amount expresses the intensity of Indian monsoon (Krisnamurti and Bhalme,1976), and the shear in wind speed between upper and lower levels describes the intensity of monsoon (Webster and Yang, 1992). The concept of monsoon intensity is on the whole vaguely defined. It is desirable that the southwesterly component and OLR are used to give a combined reflection of the intensity of monsoon in the South China Sea.

Here, an index for the monsoon in the sea is designed in the form of

$$I_{ms} = (V_{sw} - 1.0)/a + (235 - V_{\mathrm{OLR}})/b \qquad (1)$$

where I_{ms} is the index of southwest monsoon, V_{sw} is the speed of southwesterly component (in unit of m/s), V_{OLR} is the value of OLR (in unit of W/m^2), V_{sw} and V_{OLR} are both pentad-mean values for the region of South China Sea (5°N ~ 20°N, 105°E ~ 120°E). a and b are constants, a=1 m/s and b=10 W/m^2.

In Eq.(1) computing for monsoon index, a and b are constants that make the dimension and order of magnitude of the SW wind consistent with those of the OLR value. The numeric "1.0" and "235" are determined in view of the feature found on the establishment of southwest monsoon in the South China Sea: on average, the SW wind is larger than 1 m/s and the OLR is smaller than 235 W/m^2. The index takes account of the variation of both the southwesterly component and OLR (i.e. convection). It is statistically obtained that I_{ms} is correlated with V_{sw} at a coefficient of 0.91 and with V_{OLR} at a coefficient of 0.81. It is suggested that the greater the I_{ms}, the larger the southwesterly component or the smaller the OLR value in the region will be, i.e. the stronger the convection, the stronger the southwest monsoon will be there; vice versa. Fig.6 gives the variation of I_{ms} on a pentad basis in April–October averaged over 1979–1993. $I_{ms} > 0$ from the 4th pentad of May to the 4th of September, that corresponds to the period of southwest monsoon, which intensifies to the utmost in May and June but weakens from mid-August to mid-September. On the other hand, the southwest monsoon becomes the strongest in the last decade of June and middle decade of August but it is relatively weak in July. Consistence is found in the variation of monsoon index and southwesterly component as given in Fig.1 but opposite trend exists between the former and OLR, in which a much larger resemblance with the variation of the wind speed. It is then understood that the SW wind speed takes up a little larger percentage than the OLR does. The intraseasonal variation is also characteristic of dual peaks in the southwest monsoon in the South China Sea.

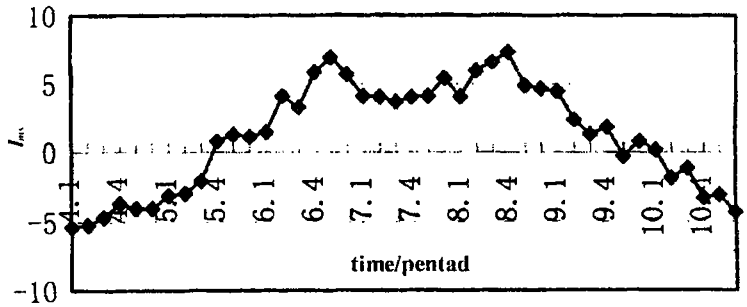

Fig.6 Five-day evaluation curve of I_{ms} averaged for 1979-1993

In our work, the sum of I_{ms} for every pentad from April to October is used to depict the intensity of the southwest monsoon in a given year in the region of South China Sea. In Tab.1 presenting the value of monsoon intensity in each year between 1979 and 1993, one significant point is that the monsoon is generally light in the El Niño years, such as 1982, 1987, 1993 and 1991 and it is generally large in the La Niña years, such as 1984 and 1985. It is indicative of significant effects of abnormal variation of SST in the eastern Pacific on the southwest monsoon in the South China Sea.

Tab.1 Intensity of SCS summer monsoon in 1979 ~ 1993

Year	1979	1980	1981	1982	1983	1984	1985	1986
Intensity	53	45	66	46	26	101	90	63
Year	1987	1988	1989	1990	1991	1992	1993	mean
Intensity	7	63	58	47	36	52	28	52

Next, we shall discuss the relation between monsoon intensity and 850-hPa wind field. Coefficients are computed of the correlation between I_{ms} and U and V wind components at 850 hPa on a pentad basis (the time series being 450 pentads in the length) in May–September from 1979 to 1993 (Fig.7). It is known from the distribution of isolines in the figure that there are three significant areas of positive correlation, locating at 40°E ~ 60°E, 90°E and 110°E, respectively. They are just the areas where there are strong cross-equatorial airflow, suggesting strong (weak) southwesterly monsoon is associated with strong (weak) airflow crossing the equator from south to north, with the largest correlation coefficient near 110°E (above 0.60). It is an indication that the cross-equatorial airflow plays an more important role than the other two air currents.

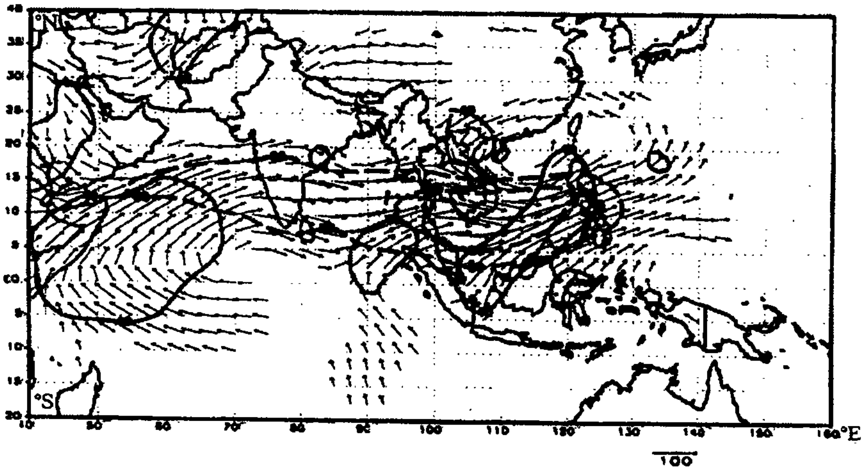

Fig.7 The correlation coefficient distribution between I_{ms} and U components or V components at 850 hPa of 1979–1993 in May–September. Solid line for correlation coefficients with V components, dashed lines for correlation for correlation coefficients with U components. The horizontal and vertical direction of vectors stand for the correlation coefficients with U and V components respectively

It is known from the dashed isolines in the figure that the significant areas of positive correlation are distributed from the west Pacific to the Arabian Sea at the 0° ~ 15°N latitude zone. It shows to some extent that the variation of southwest monsoon in the South China Sea is subjected to the SW wind from the Indian Ocean, with the maximum positive correlation appearing over the Indochina Peninsula and the Bay of Bengal (except for the South China Sea). It is the SW wind that has direct effect on the southwest monsoon in the South China Sea.

The vector arrows as shown in the figure give a clearer illustration of the relation between the intensity changes of the southwest monsoon in the sea and southwest monsoon over the Bay of Bengal and India, the southeast trade in the tropical south Indian Ocean and three air currents crossing the equator. It is clear that the southwest monsoon in South Asia plays an essential part in the variation of the southwest monsoon in the South China Sea. It is our argument that the southwest monsoon over the tropics in southern Asia is an integral body consisting of three components, which correspond to three important cross-equatorial air currents of Indian southwest monsoon, Bay of Bengal southwest monsoon and South China Sea southwest monsoon. They have a close interrelation, e.g. the SW wind is distributed in a dual-peak pattern for both the regions of Bay of Bengal and South China Sea, linking the southwest monsoon of the two. Due to the influence from different cross-equatorial airflow, some variations with individual features are also expected.

2.*Interannual variation of establishment of southwest monsoon in South China Sea*

The date on which the southwest monsoon is established is determined through indexes of OLR (Chen et al., 1996; Liu et al., 1998 and Lau et al., 1997), precipitation, and wind (Yan, 1997). From the point of multi-year mean, they all point to a consistent date of establishment in the fourth panted of May. Large difference occurs when it comes the determination for a given year. The main cause may be as follows: Though with a close link with convection (precipitation), the SW wind component is correlated with OLR by –0.51 in May–September, which is significantly negative and with going forward or lagging behind at times. It may be possible that one factor is considered at the expense of the other in the determination of concrete date of monsoon establishment

The same index for southwest monsoon as designed above is used here. When I_{ms} is greater than or equals zero, the southwest monsoon is defined to be on for the South China Sea. The monsoon index is computed pentad after pentad, year after year, so that the establishment date can be settled on any period that start with $I_{ms} > 0$ the first time of the year and lasts for at least 2 pentads. Tab.2 gives the onset time of the southwest monsoon in 1979–1993.

The multi-year mean is the fourth pentad of May according to the determination by monsoon index, which is consistent with that concluded in the previous section. It somehow justify that it would be reasonable to determine the onset date of monsoon.

For the period 1979 ~ 1993, the earliest onset is in the fifth pentad of April and latest one in first pentad of June. The earliest establishment is in end of April in two years (1984 and 1985) with breaks ($I_{ms} < 0$ for no less than 2 pentads) in May without exception and they are both La Niña years. The latest establishment (1987 and 1991) is in El Niño years. On average, following the El Niño event in the first six months of the year, the southwest monsoon is established in the sixth pentad of May in the South China Sea. The mean date is the third pentad of May for other years. From the difference of mean SST in April between the earliest 5 years and latest 5 years (Fig.8), we also know that there is positive difference in the eastern equatorial Pacific. It may imply that the monsoon is established on a later date in the El Niño years than in the other years.

Tab.2 Onset date of SCS summer monsoon in 1979 ~ 1993 (month • pentad)

Year	1979	1980	1981	1982	1983	1984	1985	1986
Onset date	May • 3	May • 4	May • 3	May • 6	May • 5	Apr. • 6	Apr. • 5	May • 2
Year	1987	1988	1989	1990	1991	1992	1993	Mean
Onset date	Jun. • 1	May • 5	May • 4	May • 4	Jun. • 1	May • 6	May • 6	May • 4

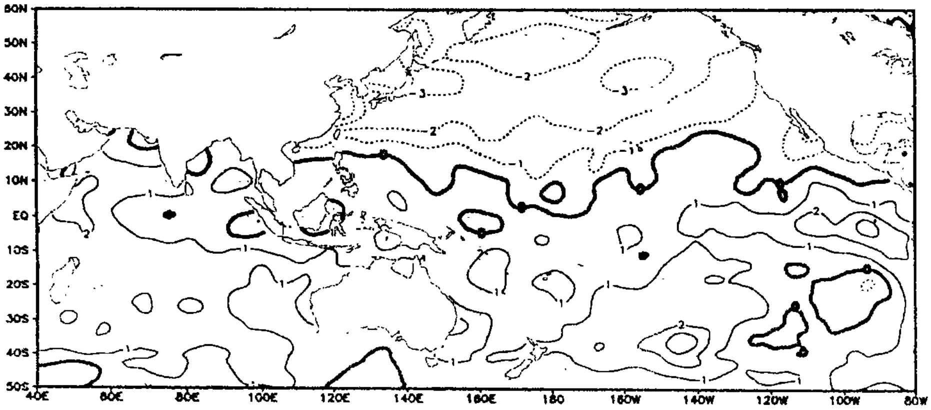

Fig.8 Correlation coefficient distribution between I_m and height at 850 hPa for 1979 ~ 1993 of May ~ September

V. CONCLUDING REMARKS

a. There is significant negative correlation between the SW wind component and OLR variation in the South China Sea. The stronger the former is, the lower the latter will be and the stronger the convection will be and vice versa. We have presented a high correlation between the southwest monsoon index, SW wind speed and the value of OLR, which can be used to reflect variation of the SW wind and convection in the southwest monsoon system in the South China Sea.

b. During the southwest monsoon in the South China Sea, the monsoon intensity is of a dual-peak pattern, appearing in June and August, respectively. The intensity is subjected to substantial influence by El Niño events such that the monsoon is strong in the El Niño years but weak in the La Niña years. It is also directly affected by the SW wind in tropical Bay of Bengal. In the meantime, the cross-equatorial airflow is posing a significant effect on the monsoon system in the South China Sea in addition to the southwest monsoon system in India (including the Somali jet and trade wind from Southern Hemisphere) and the cross-equatorial air current near 90°E.

c. From the viewpoint of multi-year mean, the southwest monsoon in the South China Sea is established in the fourth pentad of May. The analysis for 1979 ~ 1993 has shown that the earliest date is the fifth pentad of April and the latest one the first pentad of June. On an earlier date than in the region of South China Sea, the SW wind and convection appear over the Indochina Peninsula and eastern Bay of Bengal and spread their influence over the South China Sea region. A preliminary study has indicated that the date of monsoon onset is related to the El Niño event. If there is an El Niño event in the first six months of the year, the southwest monsoon will be established on a later date and vise versa.

Acknowledgements: We are grateful to Mr. CAO Chao-xiong, who works at the Guangzhou Institute of Tropical and Oceanic Meteorology, for his translation of our paper into English

REFERENCES:

CHEN Long-xun, SONG Yi, MURAKAMI T, 1996. The characteristics of convective system change during the onset period of summer monsoon (in Chinese) [A]. In: HE Jing-hai, DING Yi-hui and CHEN Long-xun. eds. *Latest Progress in the Research of Asian Monsoon* [M]. Beijing: China Meteorological Press. 54-65.

DING Yi-hui, MA He-nian, 1996. The present status and future of research of the East Asian monsoon (in Chinese) [A]. In: HE Jing-hai, DING Yi-hui and CHEN Long-xun. eds. *Latest Progress in the Research of Asian Monsoon* [M]. Beijing: China Meteorological Press. 1-13.

GUO Qi-yun, 1983. Analyses of intensity index of east Asian summer monsoon and variation (in Chinese) [J]. *J. Geography.* **38**: 207-217.

HE Jin-hai, LUO Jing-jia, 1996. Features of South China Sea monsoon Onset and Asian summer monsoon establishment sequence along with its individual mechanism (in Chinese) [A]. In: HE Jing-hai, DING Yi-hui and CHEN Long-xun. eds. *Latest Progress in the Research of Asian Monsoon* [M]. Beijing: China Meteorological Press. 74-81.

KRISHNAMURTI T N, BHALME H N, 1976. Oscillations of a monsoon system. Part I: Observational aspects [J]. *J. Atmos. Sci.*, **33**: 1937-1953.

LIU Xia, XIE An, YIE Qian et al., 1998. The climatic characterisitcs of summer monsoon onset over South China Sea (in Chinese) [J]. *J. Trop. Meteor.*(Chinese edition), **14**: 28-37.

LAU K-M, SONG Yang, 1997. Climatology and interannual variability of the southeast Asian summer monsoon (in Chinese) [J]. *Advances in Atmos. Sci.*, **14**: 141-162.

WANG Qi-wei, DING Yi-hui. 1997. Climatological features of summer monsoon evolution in South China Sea [J]. *Acta Meteor.Sin.*, **55**: 466-483.

WU Shang-sen, LIANG Jian-yin, 1998. Climatological features of intraannual evolution of monsoon of South China Sea in Xisha Islands (in Chinese) [J]. *Sci. Atmos. Sin.*, **22**: 771-778.

WEBSTER P J, YANG S, 1992. Monsoon and ENSO selectively interactive systems [J]. *Quart. J. R. Met. Soc.*, **118**: 877-926.

YAN Jun-yue, 1997. Climatological features of southwest monsoon evolution in South China Sea (in Chinese) [J]. *Acta Meteo.Sin.*, **55**: 174-186.