Monsoon Circulation Related to ENSO Phase-Locking[①]

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ABSTRACT

The relation of interannual anomaly of East Asian monsoon to the ENSO cycle is investigated in terms of even and odd symmetry analysis over a tropical heating field based on the past 30-year data. Evidence suggests that odd and even symmetry components related to the monsoon and Walker heating, respectively, effectively describe the East Asian monsoon circulation and Pacific Walker analog, with the monsoon intensity index corresponding to its heating vigor and western Pacific Walker heating vigor to ENSO phase change, both types of heating marked by pronounced seasonal variation and phase-locking; the key region for linking monsoon-ENSO interaction is the western Pacific warm pool; the monsoon effect upon ENSO cycle is affected jointly by the seasonal evolution and interannual *anomaly of the heating components; the superimposition of an anti-Walker circulation phase produced by* interannual winter monsoon perturbation upon a weaker Walker phase on a seasonal basis leads to an El Nino happening in March-April and plays a significant role in maintaining a warm ENSO phase.

Key words: Monsoon heating, Walker heating, ENSO cycle, Phase locking

I. INTRODUCTION

It is well-known that Asian monsoon and ENSO cycle are crucial systems, having major influence on Eurasian-Pacific weather and climate and innegligible impact on climate on a global basis. For this reason, their interrelation has a been major concern in the context of atmospheric sciences (Huang and Wu, 1987; Wu et al., 1992; Sun et al., 1988; Ni et al., 1995; Qian, 1993; Webster and Yang, 1992; Yasunari, 1990). As far back as the early 1980s, Rasmusson and Carpenter (1982) showed in their classical contribution that an ENSO event occurs in close relation to its seasonal cycle, with the result that all the El Nino events but the *1963 / 64 one in the 1950-1979 period have a peak phase in March-May, a season just for a* winter-summer transition that is called seasonal phase locking. In the eastern Pacific, an ENSO onset coincides with a warm phase of the seasonal cycle, which is intensified at an initial El Nino phase, a phenomenon that is intimately associated with the interannual anomaly of Asian monsoon, as has demonstrated by numerous studies.

From the perspective of atmospheric circulations, East Asian monsoon differs from Indian counterpart (Tao et al., 1988; Huang et al., 1987; Chen, 1984; Zhu et al., 1986) in that it is affected mainly by land-sea pressure difference zonally as a form of the Hadley circulation on a local basis with the *monsoon strength strongly dependent on the Hadley vigor*; the variation of ENSO phases agrees with that of the Walker intensity in such a way that a strong (weak) Walker circulation relates to a cold (warm) ENSO phase, suggestive of a La Nina (El Nino) state. As a result, the Walker vigor is indicative, to some extent, of the ENSO cycle characteristics.

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Evidently, the diagnostic, if found for the vigor of Hadley and Walker circulations, will be of help to further study on the relation between East Asian monsoon and ENSO cycle. In fact, factors responsible for the variation in the two circulations are many, including tropical convective heating, among other things. Obviously, the convective heating effect on their intensity deserves much attention, Webster and Yang 1992) performed even / odd symmetry analysis of outgoing longwave radiation (OLR) as the tropical heating field, calling even symmetry components the near–equatorial or Walker heating indicative of the Walker cell vigor and the odd ones the monsoon heating indicative of variation in the Hadley cell vigor inside the monsoon region.

Following the consideration, odd / even symmetry analysis was applied to tropical OLR with focus on i) relation of interannual variation in East Asian monsoon vigor to the components of Walker and local Hadley heating; ii) effect of interannual anomaly of the monsoon upon ENSO seasonal phase–locking, thereby revealing a possible approach to the Asian monsoon–ENSO interactions.

II. OLR DECOMPOSITION ITS HORIZONTAL DISTRIBUTION AND SEASONAL VARIATION

Decomposition of the odd / even symmetry component is undertaken of tropical OLR in the period June 1974–December 1991 with missing data for March–December 1978.

In the light of calculations, winter / summer OLR and the horizontal patterns of the odd / even components show three vigorous centers in the total heating field located in South African, Asian–Australian and South American monsoon regions, separately and the one in the Asian–Australian sector in particular is strongest of all; that convective heating in Northern winter is in the Southern Hemisphere related to south–blowing winter monsoon with southward cross–equatorial flow at lower levels whilst convective heating in Northern summer is associated with north–blowing summer monsoon with northward cross–equatorial flow at lower levels; the heating intensity is a lot stronger in Northern winter than in summer.

The even component–revealed heating field exhibits three intense centers at equatorial latitudes in the total heating field with a pair of significantly high / low bands in the Asian–Australian Pacific; a low (high) valued strong convective area in the warm pool (eastern Pacific), suggestive of a rising (sinking) leg of the Walker circulation. The Walker heating is stronger in Northern winter with its E–W scale greater than in the summer, suggestive of higher vigor of the cell.

The odd component–related convective monsoon heating field fully displays features of its activities. In Northern winter positive (negative) anomaly of the three monsoon regions is centred in the Northern (Southern) Hemisphere. In Northern winter convective heating is quite weak in the Asian monsoon area and the heating is centred in North Australia whereas in Northern summer such heating is centred in the Northern Hemisphere, particularly intense being the heating over the Asian monsoon area. Obviously, Asian monsoon convective heating is much stronger in summer than in winter as revealed by the odd symmetry revealed monsoon heating component, contrary to the even symmetry Walker heating.

The foregoing analysis shows that there arises great difference in the patterns of the components in summer and winter, especially the difference of equatorial even–symmetry components and odd ones at 15°N and 15°S. To further illustrate seasonal conversion of the heating centers, analysis was undertaken of the equatorial and 15°N components.

Fig. 1 depicts the Walker heating in the warm pool peaks in December–February, weakens noticeably in March and reaches its minimum in May–June, starting to strengthen in September, but the monsoon heating center begins to intensify in March–April, maximizing in July–august, with two centers at its strongest phase, corresponding, separately, to the Indian

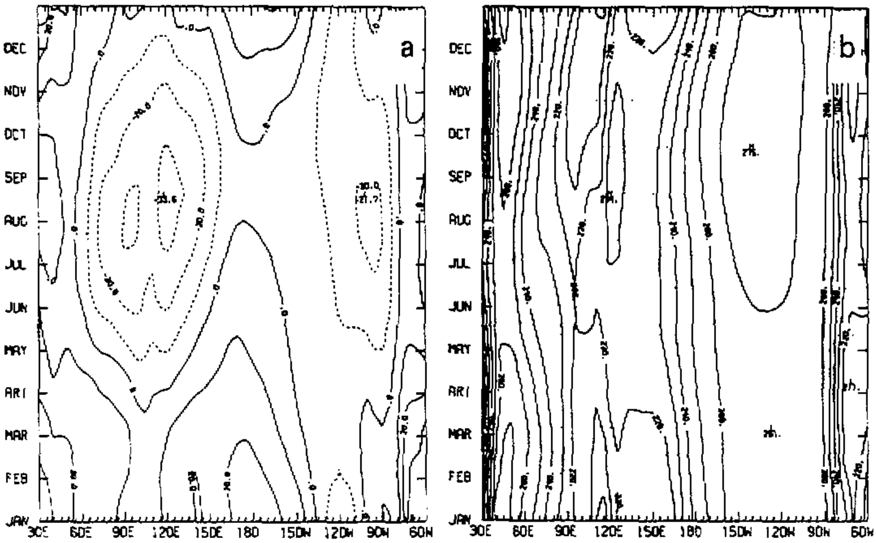

Fig. 1. Seasonal conversion of even (at the equator, a) and odd (15°N, b) symmetry heating components.

and East–Asian monsoon regions.

The monsoon and Walker heating are marked by seasonal variation. For vigorous monsoon heating the Walker heating is enfeebled except for their different phases. The weakest period of the even components (the WP–WH) is April–May, almost corresponding to the time interval of the conversion from weak to intense monsoon convection (odd component), which peaks in July–August. If the variation of the monsoon heating were in accord with East Asian monsoon varying on a seasonal basis, this would demonstrate that during winter monsoon changing into its summer counterpart the Walker circulation is weakest, so is air–sea interaction.

III. MONSOON INTENSITY INDEX IN RELATION TO ODD / EVEN SYMMETRY COMPONENT–REVEALED HEATINGS AND ENSO

On the basis of Xu et al. (1997a), the monsoon intensity index (MI) has ability to better describe the variation in East Asian monsoon vigor. Thus, the correspondence of the MI to the odd and even components, if it could be found, would provide an approach to the connection of East Asian monsoon and ENSO cycle.

In the seasonal cycle a positive MI changing to a negative one occurs in March–April and the reversal happens in September–October. Obviously, change from the winter monsoon into the summer counterpart denoted by MI takes place in March–April, which is in full agreement with the seasonal conversion of the monsoon heating center.

The interannual variation is illustrated by the winter monsoon. Years of stronger (weak) winter monsoon are 1976 / 77, 1980 / 81, 1983 / 84 and 1985 / 86 (1978 / 79, 1982 / 83 and 1987 / 88) in the study period. And composite analysis was done thereby of the heating fields (odd / even components) in winter months.

From Fig.2 we come to the following conclusions.

1. The Asian–Pacififc Walker heating (even component) experiences maximum variation at different vigor of the winter monsoon. For the intense (weaker) monsoon the heating in the warm pool (eastern Pacific) is more vigorous, related to a stronger (weak) Walker circulation.

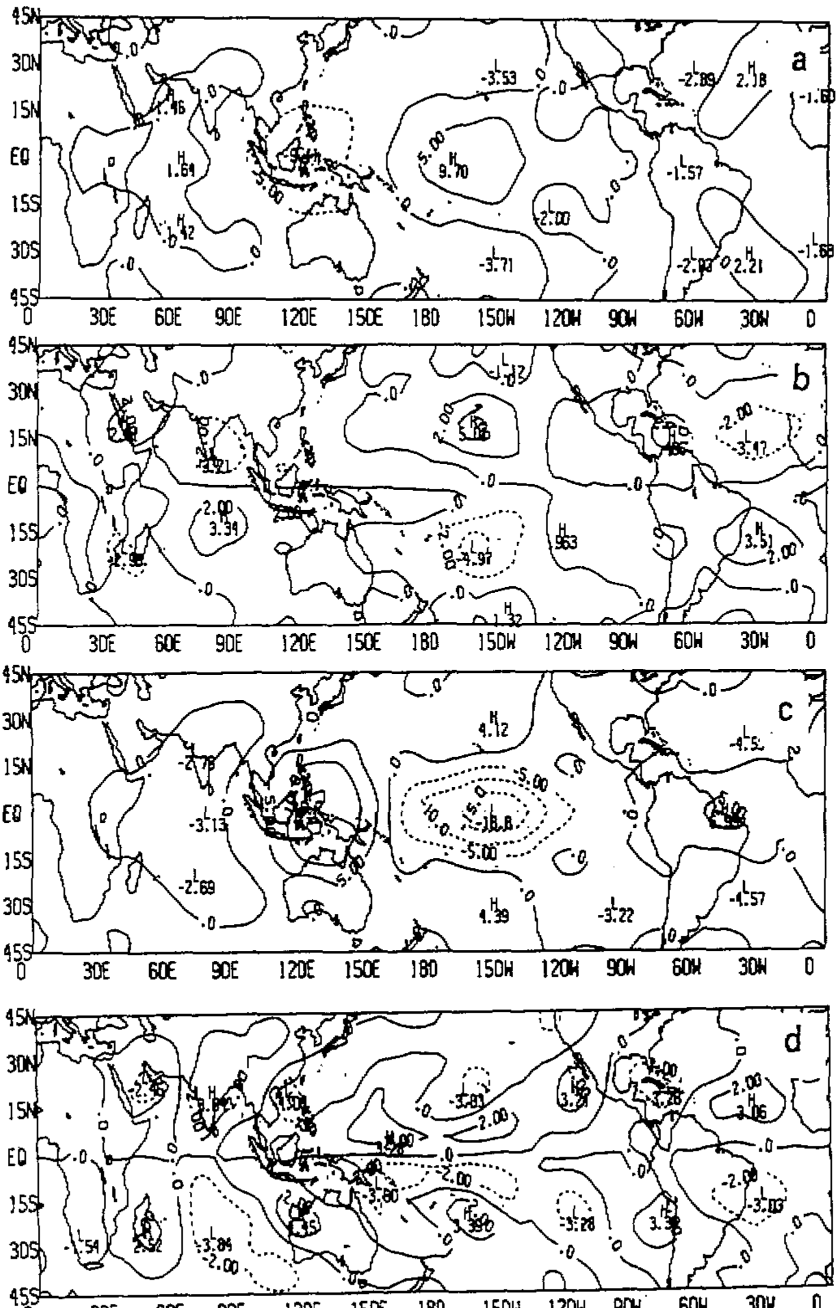

Fig. 2. Composited maps of symmetry components for East Asian winter monsoon, with even and odd components for strong monsoon shown in a) and b), and for weak monsoon given in c) and d), respectively.

2. The monsoon heating (odd component) shows greater difference on a local basis at different vigor of the winter monsoon. For the strong (weak) monsoon, a negative (positive) anomaly occurs in the Indian monsoon region (Southern Hemisphere), resulting in an anti-winter monsoon meridional circulation whilst the heating anomaly pattern in the East Asian monsoon area, though quite similar to that of the Indian region, produces a much weaker meridional circulation of such nature. For the feeble winter monsoon its meridional circulation is greatly enhanced over the Indian monsoon sector in contrast to the anti- winter monsoon circulation meridionally, greatly strengthened in the East Asian monsoon region.

From the above analysis the following are of note. 1) The seasonal and interannual variations of East Asian MI show so appreciable phase relation to the heatings revealed by odd / even symmetry analysis that the MI-given vigor agrees with odd component-denoted monsoon heating; 2) the monsoon heating differs significantly between the Indian and East Asian regions for high and lower MI, with the Asian monsoon heating enhanced more strongly for a feeble than for a vigorous winter monsoon, leading to a pronounced anti-winter meridional circulation as opposed to the condition of the Indian area; 3) the Walker heating vigor and ENSO phase associated with the monsoon strength is characterized by a noticeable phase locking relation. For an intense monsoon the Walker heating over the pool is enhanced, contributing to its intensified rising leg, corresponding to ENSO cycle for La Nina state; for a weaker monsoon the eastern Pacific Walker heating intensifies in association with ENSO cycle for El Nino state. This further demonstrates the conclusion (Xu et al., 1997b) that the intense (weak) winter monsoon of East Asian origin relates to a cold (warm) ENSO phase for La Nina (El Nino) breeding, according to the past 50-year data.

The following table was constructed based on the MI (Xu et al., 1997a) for the relation of the vigor of Eastern winter monsoon to El Nino events subsequent to the 1940s.

Table 1. Relation of East Asian Winter Monsoon Vigor to El Nino Episodes after the 1940s

year of monsoon vigor	(w / s for weak / strong)	El-Nino episode
1952 / 53s	1953 / 54w	1953 / 54
1956 / 57s	1957 / 58w	1957 / 58
1962 / 63s	1963 / 64w	1963 / 64
1964 / 65s	1965 / 66w	1965 / 66
1968 / 69w	1969 / 70e.w.*	1969 / 70
1971 / 72w	1972 / 73e.w.	1972 / 73
1975 / 76w	1976 / 77s	1976 / 77
1981 / 82s	1982 / 83w	1982 / 83
1985 / 86s	1986 / 87w	1986 / 87
1990 / 91w	1991 / 92e.w.	1991 / 92

* e.w. stands for even weaker.

It is seen therefrom that the exception of the ten events is the 1976 / 77 case. All the others occurred with relatively weaker winter monsoon in the same year and relatively stronger monsoon the year before the El Nino event. This demonstrates that the East Asian winter MI is a good indicator of an El Nino onset. The strong monsoon the year before and weak in the same year indicate that an ENSO event is to take place.

Evidently, the MI shows identical characteristics to those of the odd / even components in the year that ENSO happens.

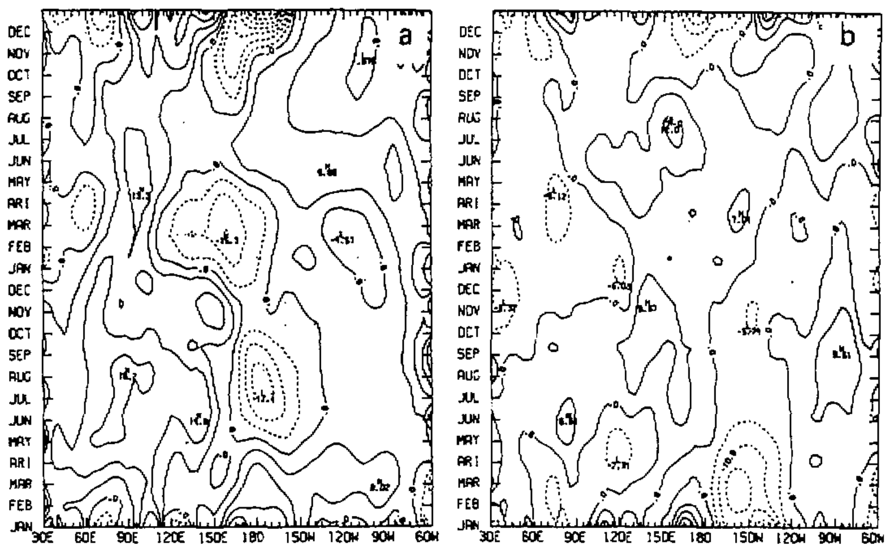

Fig. 3. Temporal variation of the even / odd symmetry heatings in the El Nino episode (January 1976 / December 1977). a. equatorial even symmetry component; b. 15°N odd symmetry component.

IV. TROPICAL EVEN / ODD SYMMETRY HEATING ANOMALY IN EL NINO YEARS

Under the effect of different factors, the anomaly of every El Nino event varies, suggestive of its multiplicity. We adopted an event (1976 / 77) with the background SST state of transitional character and another (1982 / 83) of warm for comparative study.

Fig. 3 is a plot of variation of the Walker heating field equatorially, showing that in the El Nino episode, the heating gives a positive anomaly over the Pacific in the winter and spring, indicative of its low intensity; a noticeable negative anomaly happens in May to the east of the dateline, implying, heating being enhanced in the equatorial eastern Pacific, entering gradually a warm ENSO phase; the eastern Pacific center is seen to begin to migrate westward; the heating reaches its peak in January 1977 in the eastern Pacific, corresponding to the mature phase of the event.

It is seen therefrom that in the 1982 / 83 period great difference arises; prior to the El Nino occurrence the Walker heating displays a negative anomaly centered to the west of the dateline, which moves progressively toward the east; in May the negative anomaly changes to its opposite, during which time the Walker heating is reduced greatly in vigor in contrast to the enhanced Walker heating in the eastern Pacific, reaching its peak in January 1983, all the variation features being quite similar to those of the 1986 / 87 El Nino episode (figure not shown).

Look at the 15°N monsoon heating. In the winter 1976 / 77 before the El Eino happening a positive anomaly is seen in the East Asian monsoon region, suggesting the convective heating centred in the Southern Hemisphere and the robust monsoon; in the midsummer a positive anomaly remains in the East Asian area with feeble monsoon; in the winter after the El Nino event under way, the monsoon region is negative–anomaly covered, implying the

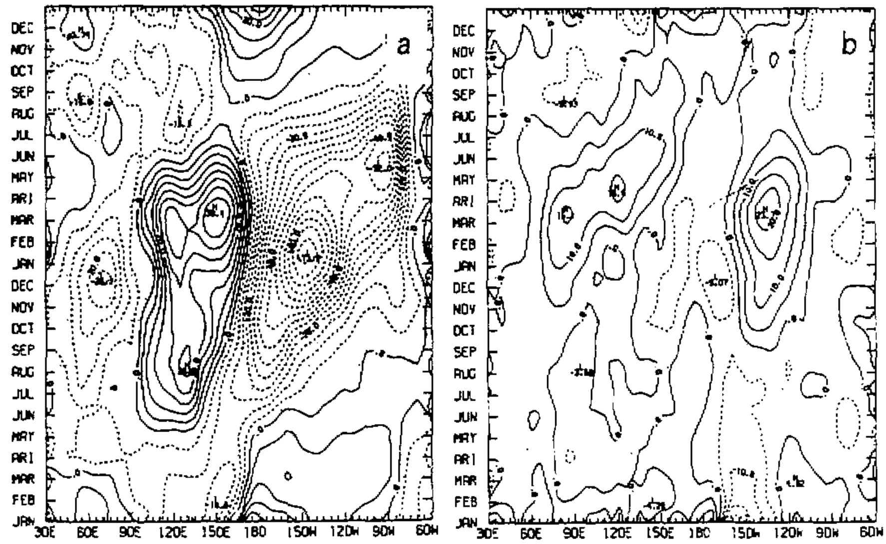

Fig. 4. Time variation of even / odd symmetry heating components in the 1982 / 83 El Nino year.
a. even component equatorially; b. odd component at 15°N.

intensified heating and the weakened winter monsoon; in the summer of 1977 a positive anomaly is shown in the East Asian region with weak monsoon blowing. In all the phases of the 1982 / 83 episode the odd-symmetry heating for the monsoon area bears quite close similarity to the 1976 / 77 counterpart except for greater magnitude of the anomaly. However, the heating in the Indian monsoon area differs greatly. This leads us to think that the relation of El Nino events to the region is exceptional. Therefore, to further explore the relation of the eastern Asian monsoon to ENSO cycle would help us to better understand eastern Asian weather anomaly in the ENSO year.

From the above we come to the following.

1) Noticeable anomaly arises in the Walker and monsoon heating under the influence of ENSO events. But greater difference is seen in the anomaly for different ENSO events. One of the causes is likely to be connected with the background SST state.

2) ENSO event is responsible for weakly convective heating in summer over East Asia and thus feeble monsoon, and for enhanced wintertime conective heating there, leading to an anti winter monsoon meridional circulation, thereby weakening the monsoon.

3) The odd-symmetry heating components for the Indian and eastern Asian monsoon regions differ considerable in the ENSO cycle. A possible cause is that the Asian monsoon-ENSO interaction is performed by the interplay between East Asian meridional circulation and the Walker circulation whilst the Indian monsoon-ENSO interaction is accomplished through the interplay between two zonal circulations equatorially (one being the Walker cell), the equatorial western Pacific warm pool, as being the key region.

V. INTERACTION BETWEEN MONSOON AND WALKER HEATING WITH POSSIBLE APPROACH TO ITS CONNECTION WITH ENSO

As shown earlier, East Asian MI corresponds well to the odd-symmetry monsoon heating and variation of the Walker heating vigor to the change of ENSO phase so that

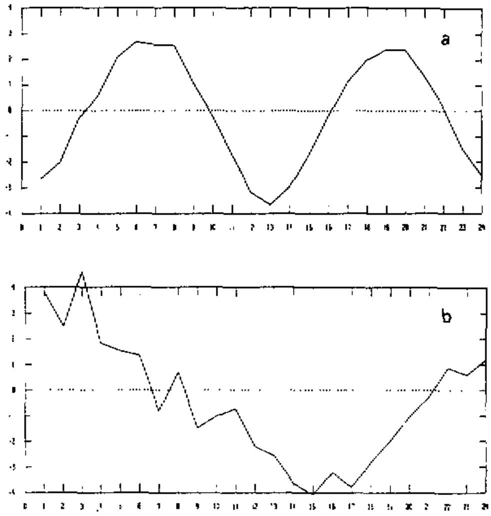

Fig. 5. Lagged correlation coefficients of the monsoon heating with the Walker heating. a. with annual variation retained; b. with annual variation removed.

interaction between the monsoon and Walker heating serves as an indirector of the monsoon–ENSO interplay. For this reason, correlation analysis was undertaken of year–to–year series of the Walker heating centre (5°N–5°S, 145–155°E) and the monsoon heating centre (10–20°N, 115–125°E). In the analysis, the timeseries was dealt with by removing and retaining the annual variation.

Fig. 5 illustrates that the patten of correlation coefficients with annual variation retained displays a salient feature of 1–year period, the synchronous and 1–year lagged correlations are negative maximum and the half–year lagged one in positive maximum, i.e., as the eastern Asian monsoon area exhibits negative anomaly, the monsoon heating is enhanced, and the Walker heating in the pool is of positive anomaly, indicative of a feeble circulation, in relation to a warm ENSO phase; the summer time Walker heating shows negative anomaly, thus indicating a more or less enhanced Walker circulation. Evidently, the correlation between the two types of heating is governed by the annual variation, which is responsible for their noticeable phase locking.

The correlativity from analysis of no–annual variation timeseries (Fig. 5b) shows that the negative–anomaly winter monsoon is indicative of its violence during which time the Walker heating over the pool is negatively anomalous, too, favorable for the maintenance of a cold ENSO phase. When spring (March–April) sets in, the negative–anomaly heating is greatly reduced and the pool is covered by a positive anomaly in June, thereby causing a weak Wakler heatint for the development of an El Nino event and thus a negative–anomaly Walker heating re–appears in July–August the following year.

Two aspects are of interest for the onset and development of an El NIno event at a warm ENSO phase. One is why the event normally begins in April–May and the other is why the equatorial eastern Pacific positive SSTA generally persists one year or so during an El Nino occurrence. Now we deal with them from the perspective of monsoon–ENSO interaction.

From the foregoing analysis we see that the East Asian monsoon heating is weaker in winter than in summer with its vigor conversion in March–April while the western Pacific Walker heating is stronger in summer than in winter with its greatly reduced vigor happening in March–April, too, the conversion that happens when the El Nino event is in a warm ENSO phase, suggesting that March–April is the period for generating a weak Walker circulation that promotes El Nino occurrence.

The seasonal variation in the heating takes place each year but not all years withess El Nino events, this leads us to assume that there must be some factors responsible for anomalous forcing that is imposed on the seasonal variation of the Walker circulation that is made to be exceptionally reduced, leading to an El Nino onset. The interrelation between monsoon–Walker heatings allows to presume that the monsoon meridional circulation is likely to be one of the essential factors of the anomaly in the seasonal Walker cell variation.

Our correlativity analysis shows that under the control of the seasonal phase–locking of the monsoon and Walker heating the stronger winter monsoon suggests its more intense heating in East Asia, which causes the Walker heating of the pool to be enhanced, a situation favoring energy accumulation in the westerm Pacific for El Nino onset. Once the situation is destroyed, an El Nino event is likely to happen. Besides, as far as the interannual relation (Fig. 5b) is concerned, since the winter monsoon experiences interannual perturbation, the Walker convective heating is very weak in March–April for stronger winter monsoon, suggesting a greatly enhanced anti–Walker circulation. Hence, when the interannual anomaly–related anti– Walker circulation is superimposed on the seasonally weakened Walker cell, an El Nino even tbegins in March–April and the anti–walker circulation changes to a normal Walker cell in July–august the following year, thus putting an end to the El Nino episode. Obviously, the interannual anomaly in East Asian winter monsoon plays an important role in maintaining a warm ENSO phase as well.

VI. CONCLUSIONS

From the study we arrive at the following conclusions.

1) The odd and even symmetry–given monsoon and Walker heatings are able to represent, to great extent, the variation in East Asian monsoon and western Pacific Walker circulations, respectively. The MI is an indicator of the heating vigor and the intensity of the western Pacific Walker heating relates to particular ENSO phase.

2) The monsoon and Walker heatings are marked by noticeable seasonal variation and phase locking. The monsoon is weaker in winter than in summer, as opposed to the condition of the western Pacific Walker heating. The conversion in their heating strength occurs in March–April, well corresponding to the phase of an El Nino onset.

3) Different from the Indian monsoon, stronger winter monsoon in East Asia means stronger heating there. In this season, the western Pacific Walker heating exhibits negative anomaly, suggestive of a weak Walker circulation, corresponding to a warm ENSO phase and v.v. for feeble winter monsoon in East Asia.

4) Influence of the winter monsoon on ENSO cycle is exerted jointly by seasonal evolution and interannual anomaly of the tropical heating components. As an anti– Walker circulation produced by the monsoon's interannual perturbation is superimposed on a weak phase of the Walker circulation in its seasonal variation, an El Nino event will begin in March–April and will contribute to the maintenance of a warm ENSO phase.

REFERENCES

Chen Longxun (1984). Structures of East–Asian monsoon system with medium–term variation, *Acta Oceanographica Sinica*, 6: 744–758.

Huang Shisong and Tang Mingmin (1987), On East–Asian monsoon system, *Scientia Meteorologica Sinica*, 7: 1–16.

Huang, R. H. and Wu, Y. F. (1987), The influence of the ENSO on the summer climate change in China and its mechanism, *Japan–U. S. workshop on the El Nino Southern Oscillation phenomenon, Tokyo, Japan,* November 3–7.

Ni Yunqi et al. (1995), Diagnosis of the effect of ENSO and western Pacific warm pool condition on climate of China, *Scientia Meteorologica Sinica,* **15(4):** 118–133.

Qian Yongfu (1993), Effects of different sea surface temperature over the western Pacific on summer monsoon properties, *Acta Oceanologica Sinica,* **12(4):** 535–547.

Rasmusson, E. M. and T. H. Carpenter (1982), Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation / El–Nino, *Mon. Wea. Rev.,* **110:** 354–384.

Sun Zhaobo et al. (1988), The correlations between SST and summer precipitation over eastern China and the effect of the SST anomaly in the South China Sea on the summer monsoon and precipitation, *Acta Meteor. Sinica,* **4(2):** 426–435.

Tao Shiyan, Zhu Wenmei and Zhao wei (1988), On interannual variability of Meiyu rainfall in China, *Scientia Atmospheric Sinica* (Spec. Issue), 13–21.

Webster, P. J. and S. Yang (1992), Monsoon and ENSO: Selectively interactive system, *Quart. J. R. Meteor. Soc.,* **118:** 877–926.

Wu Guoxiong and Ngar–Cheung Lau (1992), A GCM simulation of the relationship between tropical storm formation and ENSO, *Mon. Wea. Rev.,* **120:** 958–977.

Xu Jianjun, Zhu Qiangen and Shi Neng (1997a), Singular spectral analysis of dominant periods in 100–year variation of East Asian monsoon, *Acta Meteorologica Sinica,* **55(5):** 620–627.

Xu Jianjun, Zhu Qiangen and Shi Neng (1997b), The Interaction of East Asian Winter Monsoon with ENSO Cycle and Their Interdecadal Variation in Last Century *Scientia Atmospherica Sinica,* **21(6):** 641–648.

Yasunari, T. (1990), Impact of Indian monsoon on the coupled atmosphere / ocean system in the tropical pacific, *Meteor. & Atmos. Phys.,* **44:** 29–41.

Zhu Qiangen, He Jinhai, Wang Panxing (1986), A study of circulation differences between East–Asian and Indian summer monsoons with their interaction, *Advances in Atmospheric Sciences,* **3:** 446–477.