Regional and Synoptic–scale Features Associated with Inactive Periods of the Summer Monsoon over South China①

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ABSTRACT

This paper presents an observational study of the physical processes responsible for the inactive period (break) of the summer monsoon over South China (SC). The break of the monsoon is defined by using the rainfall data over Hong Kong Meteorological parameters provided by the European Centre for Medium–Range Weather Forecasts (ECMWF) for the period 1985–1990 are examined. Daily values of each parameter for the six years are then composited each day for the period of 5 days before to 1 day after the break.

It is found that several days before the break, changes opposite to those occurred during the onset and active periods begin to take place. This suggests that a feedback mechanism is present which tends to restore the atmosphere to a more stable state. This mechanism may be initiated by the formation of convective clouds during the onset and active periods. These clouds then reduce the solar radiation to the ground, leading to a gradual drop in the temperature. This drop, together with the cooling of the atmosphere due to the large amounts of rainfall, causes the pressure over the SC region to become higher, which in turn induces a westward extension of the subtropical ridge. The decrease in temperature over SC may also shift the location of the heat source to the west, which leads to a concomitant westward shift of the convergence of the southerlies and results in less moisture–laden air reaching the SC region. The atmosphere then becomes unfavourable for heavy convection and therefore a break starts.

Key words: Inactive period, Summer monsoon, South China subtropical high

I. INTRODUCTION

Asian summer mosoon, in general, consists of four stages by considering the changes in the amount of rainfall. These four stages are the onset, alternate active and inactive (break) periods, and retreat. On the average, heavy rainfall over South China (SC) brought by the Asian summer monsoon begins around the middle of May. Chinese meteorologists (e. g., Tao and Chen, 1987; Ding, 1992) usually calls this period the "presummer rainy season". This is also the onset and the first active phases of the entire summer monsoon period. Previous studies on the onset of the summer monsoon over SC (e. g. Chang and Chen 1995; So and Chan 1996) showed several components related to the onset phenomenon: (1) development of three main branches of southwesterly flows: the Somali jet, the cross–equatorial flow along 105°E, and the southwesterly wind from the southern flank of the subtropical high over the Pacific Ocean, (2) formation of the monsoon trough over the South China Sea (SCS) and western Pacific, (3) the northward advance of the subtropical high over the Pacific Ocean, (4) the

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enhancement of the upper-level northeasterlies and the anticyclone above the Asian region, and (5) the development of a surface low (or cyclogenesis) over Beibu Wan or the Andaman Sea.

The onset and active periods generally last for one to several weeks and a break in the monsoon rainfall then occurs. During a break, the amount of precipitation decreases dramatically. The duration of the breaks exhibits considerable variability. Some of them last for only several days while some can last for periods as long as one month. After a break, another active period begins. Therefore, more than one break can occur during each summer monsoon season. In years of near-normal rainfall, the active and break spells alternate with an approximate period of one week each. Recent studies on the breaks in the summer monsoon focus mainly on the propagation of low-frequency modes and middle-latitude interactions (Tao and Chen, 1987). Krishnamurti (1985) found that the arrival of ridges over the region of a climatological monsoon trough coincides with the occurrence of breaks in the summer monsoon. Also, Tao and Chen (1987) pointed out that in the middle of June, the ridge line of the subtropical high advances from 20 to 25°N, which causes the quasi-stationary front in SC to move northward. At the same time, stable easterlies at 200 hPa exist over Hong Kong. This is the time corresponding to the cessation of heavy rainfall over SC.

In order to understand the life cycle of the summer monsoon, it is necessary to examine each phase of it. Since the whole atmospheric circulation should favour the active phase of the summer monsoon once it has started, it is interesting that breaks can occur. In this study, it is suggested that apart from the propagation of low-frequency modes, negative feedback effects of the onset may participate in the causes of breaks in the summer monsoon. That is, changes in the components or phenomena during the onset and active periods might lead to breaks. The main scope of the present study is therefore to examine the changes in the dynamic and thermodynamic features in the atmospheric circulation before and during these inactive periods.

All the data used in defining the breaks and the composite studies are described in Section 2 together with method employed in identifying the breaks. The results of the composite study on the onset characteristics are presented in Section 3 and 4. Here, the regional variations of surface pressure, moisture content and lower tropospheric flow around the inactive period are first studied. These regional changes are then related to the circulation on the synoptic-scale. A summary of the results is made in Section 5. Based on these results, the possibility / importance of the feedback mechanisms on the formation of breaks in the Asian summer monsoon over South China is presented.

II. DATA AND METHODOLOGY

1. *Data Sources*

Two sets of data are used in this study:

(1) 1985 to 1990 daily rainfall from the Monthly Weather Summary published by the Royal Observatory Hong Kong (ROHK);

(2) European Centre for Medium-Range Weather Forecasts (ECMWF) 00 UTC gridded analyses with a horizontal resolution of 2.5° latitude square for surface data and 5° latitude square for upper-level (850, 500 and 200 hPa) data from 1985 to 1990 (the Tropical-Ocean-Global-Atmosphere (TOGA) data set);

The first set of data provides daily rainfall data over Hong Kong and daily weather charts to help define the break. The composite study (see Section 3 and 4) makes use of the ECMWF data which consist of the mean-sea-level pressure (MSLP), meridional winds at 850 hPa, temperature and dewpoint temperature at 2 m, and the geopotential heights at 500 hPa.

2. *Methodology*

The breaks of the summer monsoon over SC from 1985 to 1990 are defined by using the 5–day weighted running total (WRT) rainfall of the ROHK from April to June. It is found that 80% of the WRT rainfall is smaller than 36 mm (see Fig.1), which is therefore chosen as a reference to define the breaks in the monsoon. That is, a break in the monsoon must satisfy

$$\left\{\frac{1}{4}R_i - 2 + \frac{1}{2}R_{i-1} + R_i + \frac{1}{2}R_{i+1} + \frac{1}{4}R_{i+2}\right\} \leqslant 36 \text{ mm} ,$$

where R_i is the daily rainfall on i–th day. The i–th day is then the beginning of the break and assigned as Day(0). It is found that within the six years from 1985 to 1990, the mean active period (time between the onset and the first break) is 11.8 days, the mean duration of the breaks is 9.2 days, and the mean number of breaks is 3.8 in each year (Table 1).

Table 1. Statistics of the Breaks in the Summer Monsoon over South China from 1985 to 1990

Year	Number of days between onset and the first break	Average duration of break	Number of breaks
1985	11	12.2	5
1986	4	8.3	4
1987	23	10	3
1988	9	7.5	2
1989	5	9.7	6
1990	19	7.3	3
Mean	11.8	9.2	3.8

After the breaks for each year have been defined, the daily (00 UTC) dynamic and thermodynamic parameters from the ECMWF data set for the 23 breaks in six years are composited relative to the day of break in the area of 80°–180°E and 10°S–50°N. A time–span of 7 days (from 5 days before to 1 day after the break) is used in the composite study. These 7 days are denoted as Day(−5), Day(−4), ..., Day(−1), Day(0), and Day(1).

III. REGIONAL VARIATIONS

The results presented in this section are composites of the six years from 1985–1990 using the ECMWF data set. The averaging is done by aligning the 23 cases of breaks at Day(0).

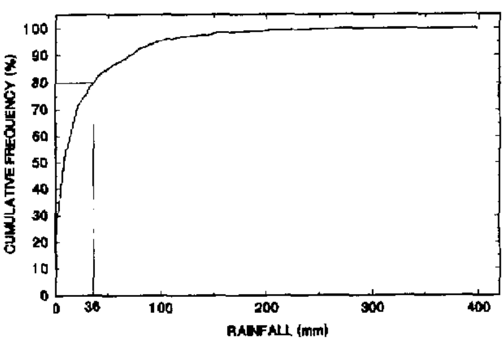

Fig. 1. Culmulative feequency of 5–day weighted running total rainfall distribution from 1985 to 1990 (April to June).

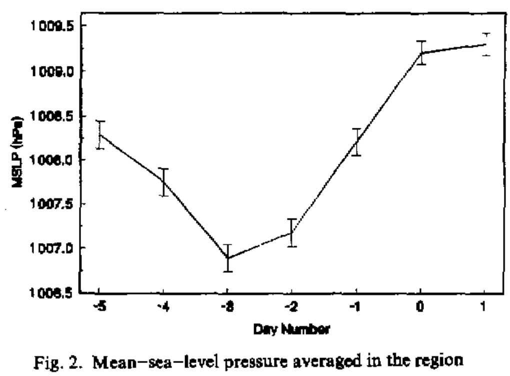

Fig. 2. Mean–sea–level pressure averaged in the region 110–120°E, 20–25°N. the error bars represent the standard errors.

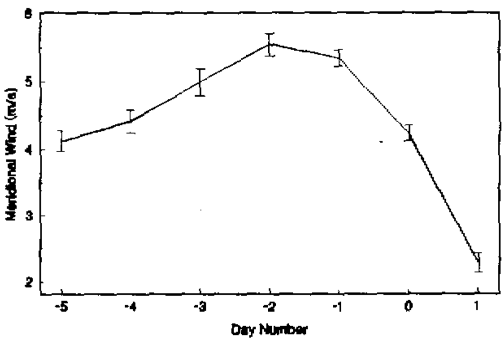

Fig. 3. Meridional wind averaged in the region 20–25°N, 110–120°E. The error bars represent the standard errors.

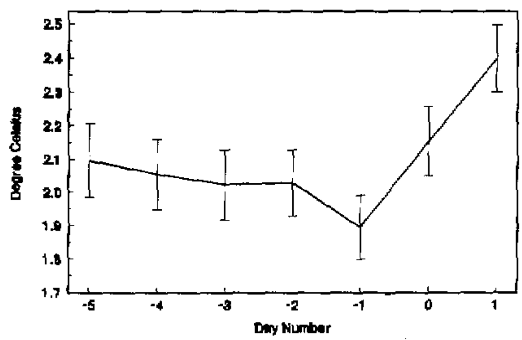

Fig. 4. Dewpoint depression averaged in the region 20–25°, 110–120°E. The error bars represent the standard errors.

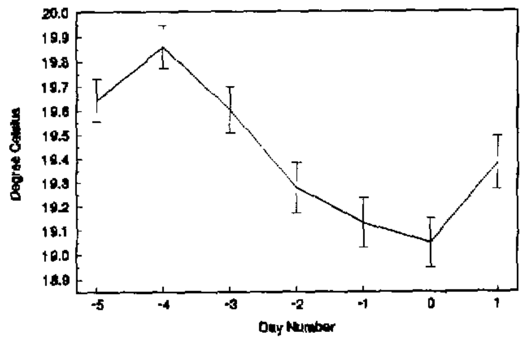

Fig. 5. 850 hPa temperature averaged in the region 20–25°N, 110–120°E. The error bars represent the standard errors.

Prior to the summer monsoon over SC, a general feature of the atmospheric circulation is the development of a trough at around 20°N (Chang and Chen, 1995, So and Chan, 1996). This trough results in an increase in convective activity over SC and brings about aboundant rainfall. So, it is natural to examine the pressure distribution during the inactive period. The MSLP variations averaged over 20–25°N and 110–125°E show a switch from a decreasing trend in pressure to an increasing one on Day(−3) (Fig.2). Before this time, SC is under the influence of a low pressure system. Although the difference is only 2 hPa, error bars suggest that the low pressure system has indeed been replaced by a high pressure system (or the intrusion of a ridge). One of the factors favouring monsoonal rainfall is therefore removed. This is consistent with the findings of Krishnamurti (1985).

During the onset and active periods, three branches of southerly flows prevail over the SC regions: the Somali Jet, the cross–equatorial flow at around 105°E, and the southerly coming from the western flank of the subtropical high. These three flows merge over the SC region to bring moisture–laden air from the adjacent ocean. This also increases the low–level convergence and hence the convective activity in the region. However, the meridional wind over SC obviously weakens prior to a break. The 850 hPa winds starts to decrease on Day(−1), reaching a minimum of 2 m s^{-1} by Day(1) (Fig.3). This weakening of the southerlies is probably in response to the increase in pressure over the region. Concomitant with this decrease in the southerlies is a reduction of the moisture content of the air coming from the

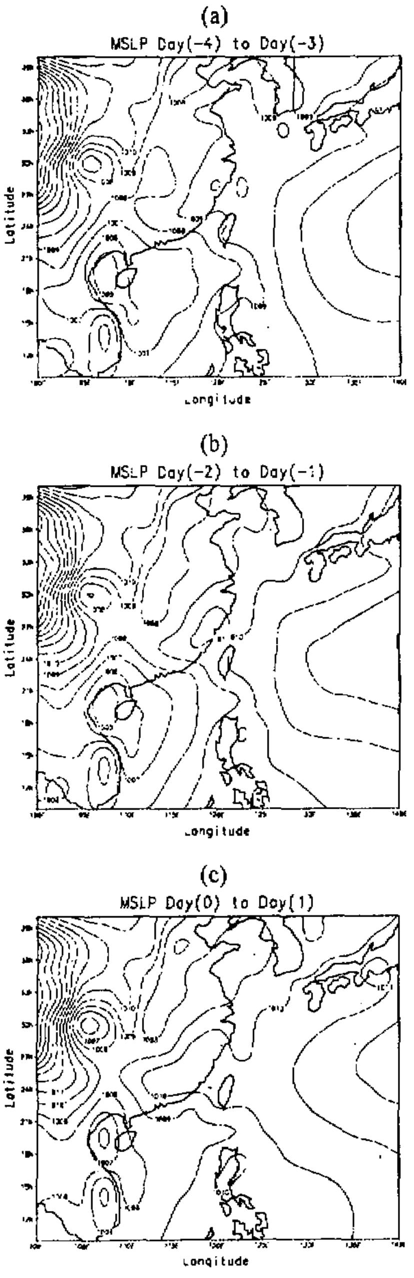

Fig. 6. MSLP averaged from: (a) Day(−4) to Day(−3), (b) Day(−2) to Day(−1), (c) Day(0) to Day(1). (unit: hPa).

adjacent ocean. Before Day(−1), the moisture content in the air is rather constant with a surface dewpoint depression (DD) value of about 2.0°C (Fig.4). The DD value then begins to increase afterward. Similar to changes in DD, the 850 hPa temperature also shows a decrease of about 1°C from Day(−4) to Day(0) (Fig.5). This drop in the temperature may be due to the blocking of solar radiation by the convective clouds formed during the onset and active periods.

To summarize, the regional variations show that prior to an inactive period, surface pressure increases over the SC region. The meridional wind, moisture content and the 850 hPa temperature also decrease. In the next section, the synoptic–scale features are examined to determine the causes of these regional changes.

IV. SYNOPTIC–SCALE FEATURES

The increase in surface pressure over the SC region prior to an inactive period appears to be related to the formation and intensification of a ridge over SC (Figs.6a–c). This is consistent with the results found by Krishnamurti (1985) about the arrival of ridge over the region of a climatological monsoon trough during a break. In this study, a westward extension of the subtropical ridge occurs. It is also worthwhile to note that the surface low over Beibu Wan still exists even during the inactive period. This implies that the general atmospheric conditions still favour the monsoon. A similar westward extension of the subtropical ridge can also be seen from the 500 hPa heights (Figs.7a–c).

The 850 hPa flow shows that during the inactive period, the two branches of cross–equatorial flow and the southerly wind from the western flank of the subtropical high still exist (Fig.8). However, only the southerly coming from the 105°E crossequatorial flow dominates in the SC region. To study these change more closely, the latitudinal cross–section of meridional wind averaged over 20–25°N is examined. During the active period (Fig.9a), two maxima of low–level meridional wind can be found between 100 and 135°E, centred at 110°E and 120°E respectively. The two branches of southerly combine together, giving strong southerly flows over SC in the lower troposphere. When approaching the inactive period, only one maximum is observed (Fig.9b). This maximum is situated along 110°E and the magnitude increases from about 4 to 6 m s^{-1} at this time. This suggests that the two branches of southerlies merge near 110°E in the low–levels. In other words, a westward shift of the southerly flow occurs when approaching the inactive period. This is further confirmed from the wind field during the break (Fig.9c). The maximum 850–hPa southerly wind has now moved to 105°E. A westward tilt in the vertical of the axis of maximum southerly wind is also observed. Further, an intensification of the upper–level northerly above the centre of low–level southerly can be seen. This westward shift of the southerlies apparently plays an important role in the break of the summer monsoon since one of the important conditions in leading to heavy rainfall over SC, especially over the coastal regions of Guangdong, is the convergence of southerlies (Ding, 1994).

One characteristic during the onset and active phases of the Asian summer monsoon is the upper–level diffluent flow (Tao and Chen, 1987; So and Chan, 1996). However, this diffluent flow is replaced by a confluent flow when a break occurs. During the active period (Fig.10a),

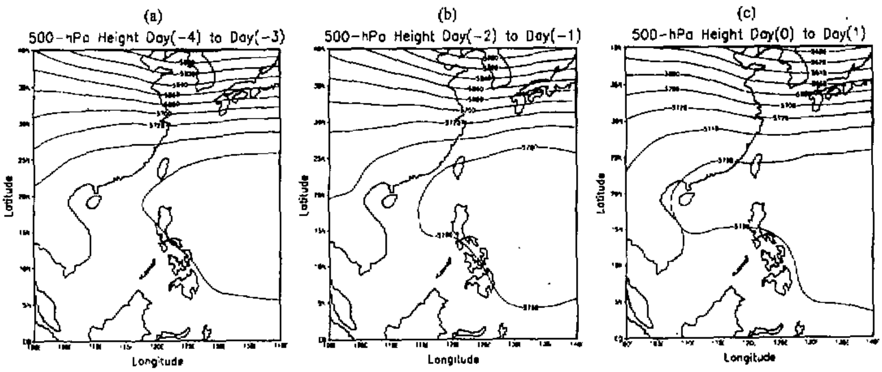

Fig. 7. 500 hPa heights averaged from: (a) Day(−4) to Day(−3), (b) Day(−2) to Day(−1), (c) Day(0) to Day(1). (unit: m).

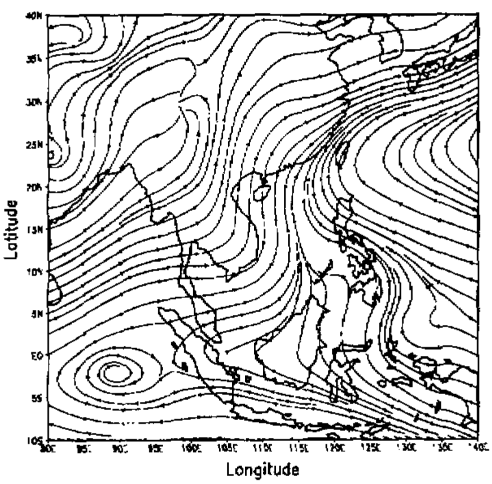

Fig. 8. 850 hPa streamlines averaged from Day(0) to Day(1).

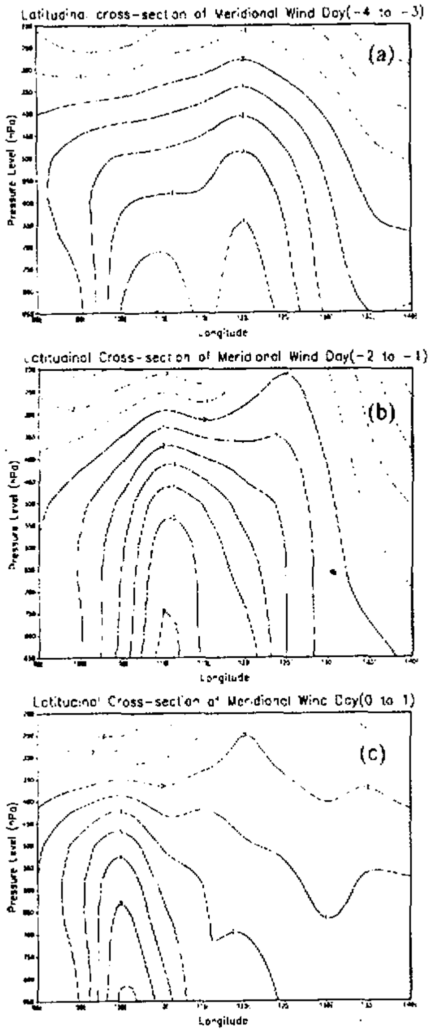

Fig. 9. Latitudinal cross-section (20–25°N) of meridional wind averaged from: (a) Day(−4) to Day(−3), (b) Day(−2) to Day(−1), (c) Day(0) to Day(1). (unit: ms^{-1}).

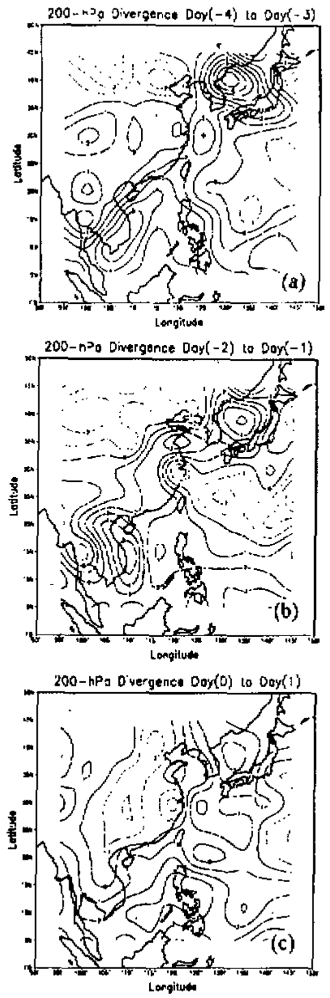

Fig. 10. 200 hPa horizontal divergence averaged from: (a) Day(−4) to Day(−3), (b) Day(−2) to Day(−1), (c) Day(0) to Day(1). (unit: $10^{-6}s^{-1}$).

the entire SC, South China Sea (SCS) and even the central part of mainland China are under the influence of a divergent flow. As the break approaches, the convergent flow originally over the northern China and western Pacific moves southward and westward respectively while the SC region is still under the influence of a divergent flow (Fig.10b). A large upper−level convergence then covers the entire East China during the break (Fig.10c). This kind of upper−level convergence implies that the convective activity during the break is very weak.

The results presented in this section illustrate the relationship between the regional changes prior to and during the inactive period of summer monsoon over SC, and the synoptic–scale changes. Apparently, the latter are responsible for bringing about the occurrence of the former, which then leads to the breaks of summer monsoon over SC. Such cause–and–effect relationships togther with some hypothesized mechanisms for these causalities will be discussed in the next section.

V. CONCLUSIONS

In this study, the physical processes that may lead to the breaks of summer monsoon over SC are examined. The break is defined by using the ROHK rainfall data, which can be used to represent the rainfall over the SC regions (Lam, 1993). The ECMWF data for 23 cases of the six summers from 1985 to 1990 are then composited relative to the first day of break. The characteristic features occurring around the inactive period can be summarized as follows:

. (1) westward extension of the subtropical ridge, (2) air temperature over the SC regions decreases; (3) westward shift of the convergence of southerlies over SC, (4) moisture–content of air decreases, (5) upper–level divergence switches to convergence.

It is noted that these features are just the opposite of those occurring during the onset and active periods. This suggests that a feedback mechanism is present which tends to restore the atmosphere to a more stable state. The feedback mechanism may work as follows.

During the onset and active periods, convective clouds are formed and they reduce the solar radiation reaching the ground, leading to a gradual drop in the temperature. When this happens, together with the cooling of the atmosphere due to large amounts of rainfall, the pressure over the SC region becomes higher which in turn induces the intrusion of the subtropical ridge. The other possible cause may be due to some modes of oscillations in the pressure field (Krishnamurti, 1985). Also, the decrease in temperature over SC may shift the average position of the heat sources to the west, which leads to a westward shift of the convergence of the southerlies and results in lesser moisture–laden air reaching the SC region. The atmosphere then becomes less favourable for heavy convection and therefore a break starts.

However, since the general conditions between mid–April to July should favour the occurrence of heavy rainfall, breaks generally last only for several days to two weeks. That is, one of the reasons for breaks to occur may be an self–adjustment of nature in the atmospheric circulation (a feedback process).

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REFERENCES

Chang, C. P., and G. T. J. Chen (1995), Tropical circulations associated with southwest monsoon onset and westerly surges over the South China Sea, *Mon. Wea. Rev.*, **123**: 3254–3267.

Ding, Y. H. (1994), *Monsoons over China*, Kluwer Academic Publishers, 419 pp.

Ding, Y. H. (1992), Summer monsoon rainfalls in China, *J. Meteor. Soc. Japan*, **70**: 397–421.

Krishnamurti, T. N. (1985), Summer monsoon experiment–a review, *Mon. Wea. Rev.*, **113**: 1590–1626.

Lam, S. –H (1993), Interannual variability and prediction of wet–season and annual rainfall over southern Guangdong, M. Phil Thesis, City Polytechnic of Hong Kong, 162 pp.

So, C. H. and J. C. L. Chan (1996), An observational study on the onset of the summer monsoon over South China, *J. Meteor. Soc. Japan*, (conditionally accepted)

Tao, S. and L. Chen (1987), A review of recent research on the East Asian summer monsoon in China, *Monsoon Meteorologly*, C. P. Chang and T. N. Krishnamurti (Eds.), Oxford Univ. Press, 60–92.