5D.4 THE FIRST TRANSITION OF THE ASIAN SUMMER MONSOON, INTRASEASONAL OSCILLATION, AND TAIWAN MEIYU

Chih-wen Hung and Huang-Hsiung Hsu
Dept. of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan

1. INTRODUCTION

Among the various monsoons in the world, the widely studied Asian summer monsoon (ASM) is considered the most distinct (e.g., Webster et al. 1998), due to its complex interannual and sub-seasonal variability and onset. Since the ASM covers the southern coastal areas of the Asian continent, its onset in the summer is usually characterized by the reversal in the circulation from anti-cyclonic to cyclonic in the lower troposphere. Moreover, the occurrence of the wind reversal also usually marks the onset of the rainy season. Many definitions of ASM onset and the monsoon indices for different purposes and areas are introduced by previous studies (see summary in Wang and Fan 1999).

Despite the complex terrain and land-sea contrast of the different regions, the full development of the low-level cyclonic circulation signals the circulation reversal from the northeasterly to the southwesterly in the lower troposphere, which occurs in a large region covering the Arabian Sea and all the way to the SCS. Hsu et al. (1999) named this development as “the first transition of the ASM”, following previous studies (e.g, He et al. 1987; Nakazawa 1992; Yanai et al. 1992; Li and Yanai 1996), since this onset marks the initiation of the ASM relative to other latter steps in other regions. They found that the first transition of the ASM is closely associated with the onset of the SCS summer monsoon, and suggested that the latter is merely a part of the abrupt change in the large-scale circulation and convection in South and Southeast Asia.

The rainy season in Taiwan and South China during this period is a distinguishing point between the spring and summer season. It usually starts in mid-May and ends in mid-June during the first transition of the ASM. Although the timing of the first transition of the ASM and the onset of the Taiwan Meiyu are very close, few researches have focused on the relationship between the large-scale monsoon system and the regional Taiwan Meiyu rainfall during this period. In this study, the European Centre for Medium-Range Weather Forecast Re-Analysis 40 (ERA40) data (1958-2002) is used to delineate the relationship between the first transition of the large-scale ASM and the onset of the Taiwan Meiyu. This study adopts the definition of the first transition of the ASM by Hsu et al. (1999) to identify the abrupt changes in the large-scale circulation and convection, and also to investigate the relationship between the large-scale Asian monsoon system and the Taiwan Meiyu.

* *Corresponding author address*: Chih-wen Hung, Dept. of Atmospheric Sciences, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd., Taipei, 106, Taiwan. e-mail: cwhung@webmail.as.ntu.edu.tw

2. DATA AND METHODOLOGY

The daily rainfall data was provided from 21 weather stations (18 of them are evenly distributed around the main island of Taiwan, and the remaining stations are situated on the small islands surrounding Taiwan) operated by the Central Weather Bureau (CWB). They are used to represent the overall rainfall variations over Taiwan during the Meiyu season (May and June). These weather stations were chosen because they provide the most comprehensive data starting from 1950s. In addition, several variables from the ERA40 were also analyzed as well. The ERA40 data were available from 1958 to 2002 with a 2.5°x 2.5° spatial resolution.

In order to identify the timing of the first transition of the ASM, the onset is defined by an empirical orthogonal function (EOF) method described in Hsu et al. (1999). The main purpose of this method is to pinpoint the reversal of the wind directions (from northeasterly to southwesterly) in the large-scale flow over the southern edge of the Asian continent. The first EOF (hereafter referred to as EOF1) explains 52% of the total variance. This spatial pattern, which is the same as the pattern obtained by Hsu et al. (1999), is a zonally elongated dipole covering the Indian Ocean, South/Southeast Asia, and the western Pacific. The positive (negative) phase corresponds to the anticyclonic (cyclonic) circulation anomaly in southern Asia, the cyclonic (anticyclonic) circulation anomaly in the Indian Ocean, and the easterly (westerly) anomaly that encompass the regions between the Arabian Sea and the SCS. Hsu et al. (1999) used the temporal variation of EOF1 amplitudes (hereafter referred to as “principal component 1” or “PC1”) to define the onset of the first transition of the ASM. This approach was also incorporated in the present study.

3. ONSET OF THE ASM AND TAIWAN MEIYU

A detailed examination demonstrates that among the 45 year time period (1958-2002), a total of 24 years can be classified as a specific temporal pattern, “the sharp onset”, where the PC1 falls sharply only once changing from a positive value to a negative one in a 60-day period (30 days before and 30 days after the onset in April-June). However, within these 24 years, five cases (1973, 1987, 1991, 1992, and 1996) are excluded in the subsequent analysis, because their onset dates are in June, which is too close to the ending date (June 30th) that is applied in the EOF method. In addition to this major type of onset, the remaining years reveals the PC1 changing from a positive to a negative value several times in April-June. It is difficult to conclude a regular temporal pattern during the first transition for these particular cases. Therefore, no further classification is done.

To get a clear view of the mechanisms behind the sharp onset of the ASM and its relationship with the Taiwan Meiyu, the composites of several variables are made relative to the onset dates. 'Day 0' denotes the onset day, and negative (positive) values of the dates represent days before (after) the onset. Figure 1 is the composites of the PC1 (shown in a thick black line) and Taiwan rainfalls (shown in a thin black line with gray shading) relative to the sharp onset. It is evidently seen that the PC1 values drops sharply from positive to negative during the period around day 0. At the same time, the Taiwan rainfall increases dramatically from less than 5 mm day^{-1} to about 15 mm day^{-1} in a few days. The rainfall remains above 10 mm day^{-1} for almost 30 days after the initial onset. The contrast between the periods before and after the onset is easily seen. This result suggests that during the sharp onset years, the changes in the large-scale circulation and convection during the first transition might have a strong effect on the regional circulation and convection near Taiwan, which in turn induces the heavy and persistent rainfalls in Taiwan.

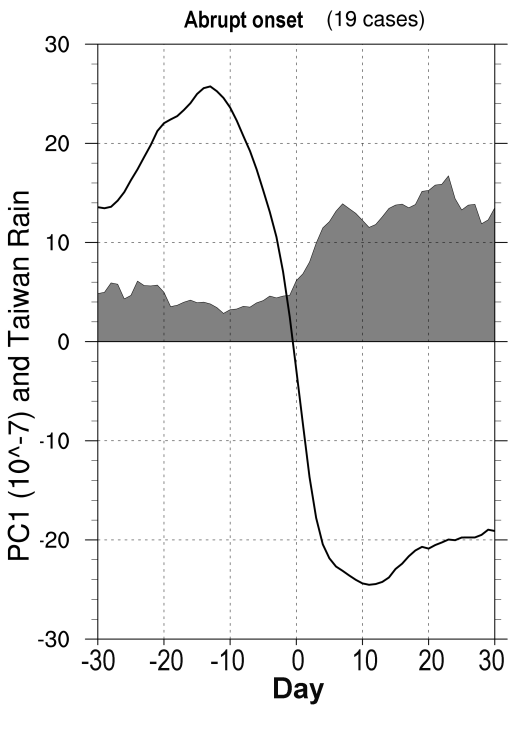

Figure 1: The rainfalls in Taiwan (with gray shading; mm day^{-1}) and the PC1 (gray line; 10^{-7} is multiplied in order to be shown in conjunction with the rainfalls). Only April 1 to June 30 are displayed for each year.

4. ONSET OF THE ASM AND ISO

The result shown above demonstrates the strong relationship between the Taiwan Meiyu rainfalls and the first transition. It is therefore important to understand how the changes in the large-scale circulation lead to the occurrence of the heavy and persistent rainfall in Taiwan after the onset.

Several studies pointed out that the onset of the ASM is highly related to the movement of the intraseasonal oscillation (ISO) (e.g., Krishnamurti and Ardanuy 1980; Zhang et al. 2002.). The eastward propagating features seen from 850-hPa *u* resembles closely to the tropical intraseasonal oscillation (TISO or Madden and Julian oscillation; terminology is used according to the definition suggested by Lau and Waliser 2004). The negative and positive 200-hPa velocity potential anomalies represent the upper-level divergence and convergence, where they are often accompanied by the low-level convergence and divergence in the deep convection region, respectively. It is interesting to note that the region of maximum absolute value of the negative velocity potential reaches 120°E around the onset date. This result suggests that the arrival of the eastward- propagating, large-scale convective system in Southeast Asia and the SCS, may play an important role in inducing the onset of the rainy season in Taiwan and the surrounding region of the SCS.

5. ROLE OF MOISTURE TRANSPORT IN THE INITIATION AND MAINTENANCE OF TAIWAN MEIYU

To fully see the contribution from the moisture transport to the Taiwan Meiyu in the first transition period, the divergence component of *uq* and *vq* at 850 hPa is calculated. This divergence component is then shown in the form of streamlines and potentials in Figure 2 with the time means between day -30 to 30 removed. The convergence of the moist transport appears first at day -30 to -20 near eastern Africa, and gradually moves eastward along the equator at day -20 to -10 to the western Indian Ocean. Roughly 10 days before the onset, the moisture convergent center moves to the region near the Sumatra peninsula. During day 0 to 10, the moisture convergent center jumps northeastward to the western North Pacific and becomes a zonally elongated, stationary zone near 120-160°E along the latitudes between 20-30°N.

This feature is consistent with the significant increase in the moisture transport to the SCS, and the arrival of the TISO at the Maritime Continent. The zonally elongated moisture convergent zone located between 120°E and 160°E remains stationary for at least 30 days after the onset occurred. This long-standing system exists without much change, because the large-scale monsoon circulation does not switch back and forth between the westerly and easterly winds in these sharp onset cases. Therefore, the moisture can be transported continuously, leading to a persistent rainy Meiyu season in Taiwan. When the PC1 of the pattern fluctuates back and forth between the positive and negative values (such as those non-type 1 cases), the moisture supply channel is likely to be connected and disconnected intermittently. Therefore, there is a lower probability for a continuous rainy season to occur, causing less accumulated rainfall over Taiwan during this period.

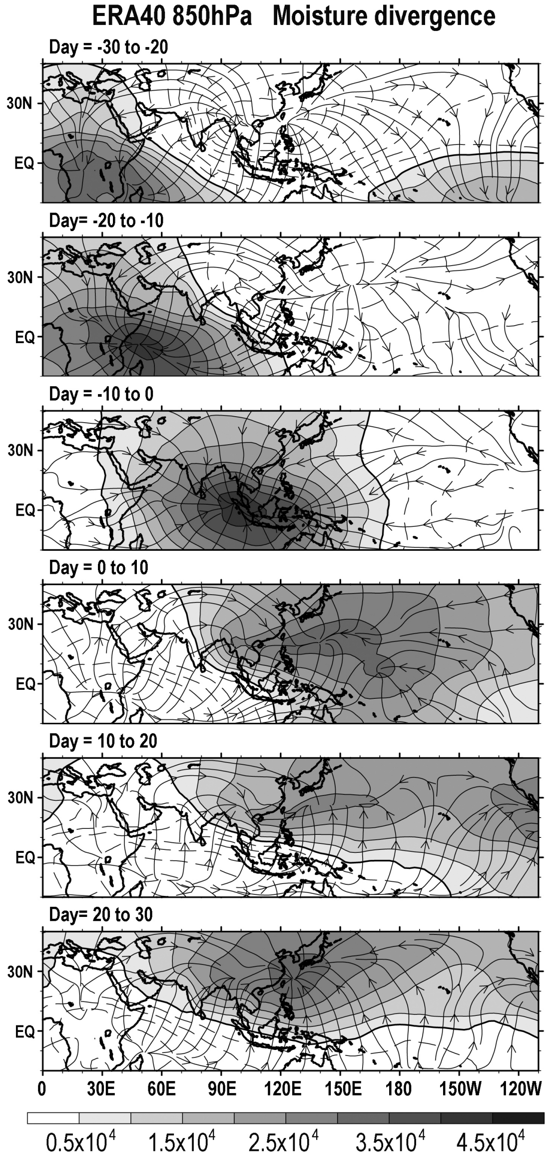

Figure 2: 11-day mean of the divergence component of moist transport composites at 850hPa for 19 abrupt onset cases. The divergence component of the moist transport is shown in streamlines of the moisture flux and potential (in gray shading for positive values). The contour interval is 0.5 x 10^4 m^2 s^{-1}.

6. CONCLUSIONS

This study reveals the close relationship between the first transition of the Asian summer monsoon, intraseasonal oscillation and the Meiyu in Taiwan, which occurs climatologically between mid-May and mid-June. The major findings are highlighted as follows:

(1) For about half of the years in 1958-2002, the first transition of the ASM can be classified as sharp onset. This type of onset is associated with an abrupt reversal of the monsoon flow from northeasterly to southwesterly. For the remaining years that are not sharp onset cases, the wind directions of the monsoon flow swings back and forth more than once in April-June, and it is apparently seen that there is no abrupt change in the large-scale circulation.

(2) The evolution of the large-scale circulation and convection in the sharp onset years is characterized by an eastward-propagating TISO from eastern Africa and the western Indian Ocean south of the equator to the Maritime Continent and the western North Pacific. Upon the arrival of the TISO in the Maritime Continent, the sharp onset occurs. After the onset, a moisture supply channel in the lower troposphere is well established across the Indian Ocean. This channel consists of the Somali jet transporting the water vapor from the Southern Hemisphere to the Northern Hemisphere, and the southwesterly monsoon transporting the moisture across the Indian Ocean to the SCS and the western North Pacific.

(3) A new moisture convergent zone develops in the SCS and the western North Pacific upon the arrival of the TISO at the Maritime Continent. It is presumable due to the Rossby wave response to the convection in the Maritime Continent. This response would enhance the cyclonic circulation and result in the southwesterly surge and moisture convergent zone in the SCS and the western North Pacific. This zonally elongated convergent zone becomes stationary in the region for the next 30-day period, which corresponds to the Taiwan Meiyu.

(4) The heavy Meiyu rainfalls in Taiwan occur after the sharp onset of the ASM. When the moisture supply channel is established, the conduit of the moist air is abruptly enhanced from the Indian Ocean all the way to the South China Sea. The moisture can then be efficiently and persistently transported to the SCS and surrounding areas to provide a favorable condition for the maintenance of the quasi-stationary Meiyu front, and the embedded MCCs. This marks the onset of the Taiwan Meiyu season.

(5) Most wet (active) Taiwan Meiyu years are sharp onset cases, but only few dry (inactive) Taiwan Meiyu years are considered as sharp onset cases. As the sharp onset of the ASM implies a clear sudden change in the large-scale monsoon circulation along with a continuous monsoon flow after the onset, the moisture in the sharp onset cases can be transported more efficiently via the monsoon flow to the SCS and Taiwan areas in contrast to the non-sharp onset cases.

REFERENCES

He, H., J. W. McGinnis, Z. Song, and M. Yanai, 1987: Onset of the Asian summer monsoon in 1979 and the effect of the Tibetan Plateau. Mon. Wea. Rev.,

115, 1966-1995.
Hsu, H.-H., C.-T. Terng and C.-T. Chen. 1999: Evolution of large-scale circulation and heating during the first transition of Asian summer monsoon**.** *J. Climate*: **12**, 793–810
Krishnamurti, T. N., and P. Ardanuy, 1980: The 10-to-20-day westward propagating mode and “breaks in the monsoon”. *Tellus.,* **32**, 15–26.
Lau, K.-M., and D. Waliser, 2004: *Intraseasonal Variability in the Atmosphere - Ocean Climate System*, Praxis.
Li, C., and M. Yanai, 1996: The onset and interannual variability of the Asian summer monsoon in relation to land–sea thermal contrast. *J. Climate.,* **9**, 358–375.
Nakazawa, T., 1992: Seasonal phase lock of intraseasonal variation during the Asian summer monsoon. *J. Meteor. Soc. Japan.,* **70**, 597–611.
Wang, B. and Z. Fan, 1999: Choice of South Asian summer monsoon indices. Bull. Amer. Meteor. Soc., **80**, 629–638.
Webster, P. J.,1987: The elementary monsoon. *Monsoons*, edited by J. S. Fein and P. L. Stephens, 3-32, John Wiley, New York, N.Y.
Webster, P. J., V. O. Magana, T. N. Palmer, J. Shukla, R. A. Tomas, M. Yanai, and T. Yasunari, 1998: Monsoons: Processes, predictability, and the prospects for prediction. *J. Geophys. Res.,* **103**, 14451–14510.
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. Meteor. Soc. Japan.,* **70**, 319–351.
Zhang, Y., T. Li, B. Wang, and G. Wu, 2002: Onset of the summer monsoon over the Indochina Peninsula: Climatology and interannual variations. *J. Climate.,* **15**, 3206–3221.