Synoptic- and Meso-α Scale Processes around the Meiyu Front in China at the Sharp Boundary of very Wet and Dry Regions

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Abstract

The present report firstly summarizes the results of the synoptic and meso-α-scale analeses on the GAME/HUBEX, including the case around the Japan Islands, in relation to the seasonal background of the continental-scale heat low as pointed out by Kawamura and Murakami (1998). Then, a preliminary results of the analysis on the moisture import process toward the northern area of the Meiyu front in China.

Keyword:GAME/HUBEX, LAPS/CREST, Meiyu/Baiu, meso-α-low and Baiu front.

1. Introduction

The rainfall activity around the Meiyu/Baiu front is sustained by the huge northward transport of moisture from the subtropical high region. It is noteworthy that the air mass is extremely humid in the subtropical region just to the south of the Meiyu/Baiu front in China and the western Japan, influenced by the Indian monsoon airflow and the especially warm western Pacific so-called the 〝warm water pool〟. On the other hand, the extremely dry and hot region is located just to the north or northwest of the Meiyu front in China, while the relatively cool air mass (called the "Okhotsk air mass") affects the Baiu frontal system as a northern system.

The mean position, the intensity and the rainfall characteristics of the Meiyu/Baiu front show considerable seasonal transition affected both by the Asian monsoon systems and westerly systems in the higher latitude. The variety of the higher latitude systems results in the significant different features of the Meiyu/Baiu front between the continental part of China and the Japan Islands side. Especially, the heating from the ground over the arid and the semiarid region in China plays an essential role in the seasonal evolution of the large-scale circulation and the rainfall characteristics around the Meiyu front (Kato, 1985, 1987). Furthermore, the authors have pointed out that the heating from the ground around the arid region in China contributes to the maintenance of the continental-scale heat low in the lower layer surrounding the Tibetan Plateau, combined with the condensation heating on and to the south of the plateau. Such process also seems to affect the rainfall activity around the Meiyu/Baiu front through the temporal variation of moisture transport to the northern region of mean position of the Meiyu front.

It is also noticed that the roles and the variety of the formation processes of meso-α-lows are interesting features of the Meiyu/Baiu frontal heavy rainfalls. In some types of the large-scale situation, the activation of the frontal-scale rainfall results in the initiation of a meso-α-scale low. An important connection of the continental-scale heat low with such evolution is also pointed out. Thus the present lecture will discuss on the frontal activity in the seasonal background of the heat low surrounding the Tibetan Plateau, referring to some studies by the present authors.

It is also interesting that the moisture content in North China (which is located to the north of the mean Meiyu frontal zone) increased at the onset of the Meiyu in Central China, according to a case study for 1979 (Kato et al., 1995). While the moisture inflow into the Meiyu frontal zone in Central China is brought mainly by the low-level southerly wind of the time mean fields, the coupling with the temporal southerly transport would be important for the further northward moisture transport to the northern area. On the other hand, once the soil became somewhat wet due to the rainfall associated with the eventual southerly transport of moisture, re-evaporation from the ground might partly contribute to the rainfall there. That is, a role of the re-cycling of water vapor would not be negligible. Furthermore, the change in the ground surface condition such as the soil moisture content would modify the sensible heating from the ground, as well as the latent heating. Thus the recycling process of the water vapor there in relation to the transient southerly transport of moisture should be quantitatively examined.

The Huaihe River Basin (LAPS (Lower Atmosphere and Precipitation Study) special observation area), where the GAME/HUBEX intensive observations were also carried out, is located just around the boundary of the very humid and the dry regions. For example, although the Meiyu frontal rainfall persists in this area from late June to early July as in the Changjiang River Basin, rather dry situation is sustained there until the Meiyu onset. The present report also introduces the preliminary results of the large-scale study on the LAPS..

2 Continental-scale heat low around the Tibetan Plateau in the mature stage of the Meiyu/Baiu season

Climatologically speaking, a continental-scale heat low around the Tibetan Plateau is formed associated with the slowly varying seasonal transition, according to Kawamura and Murakami (1998) (Fig. 1. They call it the L-mode). This would mainly due to the condensation heating by the monsoon rainfall in South Asia or heating over the Tibetan Plateau. Simultaneously, the heating from the ground around the arid region in China would give rise of the lower atmosphere there, and nearly the highest temperature in a year is sustained in the lower layer from early June to early August. While the synoptic-scale cyclcones and

anticyclones pass there alternatively around May, the quasi-stationary surface low covers there after June with deepening in the evening (the low would be sustained due to the heating from the ground). Thus the continental-scale heat low mentioned by Kawamura and Murakami (1998) would be a result of combination of these heating processes

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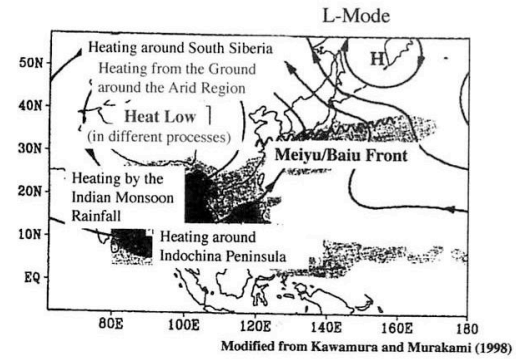

Fig. 1 Schematic figure of the L-mode circulation in relation to the East Asian large-scale systems (modified from Kawamura and Murakami (1998))

Although Kawamura and Murakami (1998) also suggests the seasonally rapid varying mode (S-mode) also contributes to the enhancement of low-level southerly wind toward the Baiu/Meiyu, further northward penetration of the southerly wind component through the mean position of the Meiyu frontal zone in China could be realized combined with the L-mode. In addition, the dominancy of the L-mode in the mature Meiyu/Baiu season implies the large-scale eastward pressure gradient in the seasonal mean field in East Asia, not only for the subtropical high area but also in its northern area. In the following sections, examples of analysis results on such processes by our groups will be briefly introduced (Kato, et al., 2001a, 2001b,Kato and Hisayasu, 2002).

3. Large-scale Features associated with the Heavy Rainfall in Central China in the Meiyu of 1998

The Meiyu rainfall belt sifted slightly northward to bring the heavy rainfall around the Changjiang River Basin (Fig. 2). The Meiyu rainfall belt shifted northward to the Huaihe River Basin (～33N) around 29 June, and further northward with being weakened around 4 July. The Meiyu rainfall zone shifted southward to the Changjiang River Basin and was enhanced again around 20 July.

Especially in the first heavy rainfall event around the Changjiang River Basin (22-27 June), huge rainfall zone (e.g., the zone with rainfall amount of more than 20 mm/day for the average from 110 E to 120 E) persisted everyday without changing its latitude very much. It is noted that the huge amount of northward moisture flux persisted almost everyday, which contributed largely to that of the heavy rainfall there during this period.

The eastward pressure gradient just to the south of the Meiyu front in China, associated with the strong southerly wind toward the frontal zone, was enhanced from 20 to 24 June due to the deepening of the low-pressure area around 23N/100-110 E. As known by the previous studies, so-called the southwest vortex (SW vortex) propagating eastward from the eastern foot of the Tibetan Plateau sometimes enhances the Meiyu frontal activity (e.g., Murakami and Huang, 1984). The propagation of such disturbance is also affected by the mid-latitude westerly, although it is initiated over the plateau in association with the diurnal variation of convective activity there. However, the low-pressure area found for this case seems to be the different kind of system from the SW vortex, and so on. The deepening of the low-pressure area mentioned above corresponded to the eastward extension of the continental-scale heat low mentioned in Section 2.

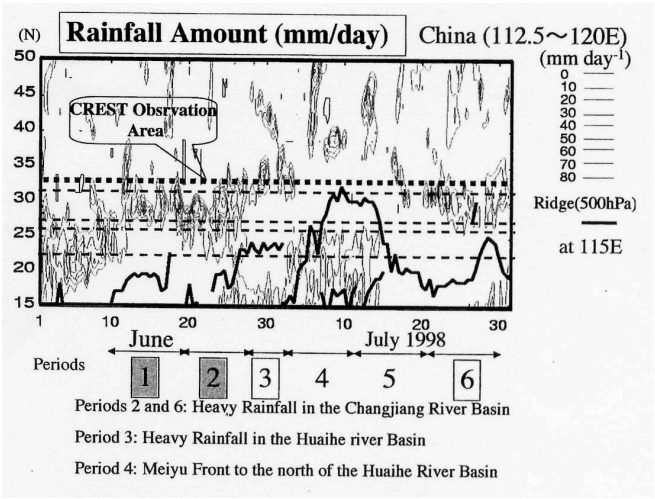

Fig. 3 Time-latitude section of 6-hourly rainfall amount averaged for 112.5-120 E (over the eastern China) based on the GAME re-analysis data (value is transformed into the unit of mm/day). The thick solid lines indicate the latitude of the ridgeline of the subtropical high at 500 hPa level on the daily Weather Maps, JMA. The Huaihe River Basin is located around the latitude indicated as "CREST Observation Area". The main branch of the Changjiang River is around 30 N. The first heavy rainfall event around the Changjiang River Basin inn 1998 corresponds to Period 2 in this figure.

4. A role of the arid region in China in the initiation of meso-α-lows on the Meiyu front in China

As for the meso-α-scale systems on the Meiyu front in China, it is known that the Tibetan Plateau plays an important role in initiating the meso-α-scale lows originated around the eastern foot of the Plateau and move eastward on the Meiyu front (so-called the southwest vortices (SW vortices)). However, we often find another situations in which the rainfall is firstly enhanced in the Meiyu frontal scale to organize the convective clouds into

a meso-α-scale cloud cluster. In such cases, meso-α-scale low is also initiated after the organization of the clouds. Results of the case study for ～29 June 1998 and ～2 July 1991 will be briefly introduced in this section.

As for the 1998 case, a cloud system associated with the SW vortex propagated from Sichuan basin on 28 June. The low-level shear line extended eastward from there after 12 UTC 28 June. New cloud clusters were generated on that shear line (around 33 N/116 E, just near the Japanese Doppler Radar sites), and the Meiyu cloud zone shifted northward to the Huaihe River Basin. After that, heavy rainfall area persisted from the morning of 29 to the morning of 30 June there, accompanied by the successive generation and eastward propagation of meso-β-scale echo systems as observed by the Fuyang Radar. Just during that period, geopotential height at ~33 N/ 115.5 E decreased rapidly and a meso-α-scale low was initiated there. It should be also noted that the center of a synoptic-scale surface low was located around 38 N/107 E (the eastern edge of the arid/semiarid region in China). Similarly, a meso-α-low was initiated after the activation of the frontal-scale rainfall with organization into the meso-α-scale clouds also for the case in 1991.

In both cases, the enhancement of the rainfall activity in the frontal zone was accompanied by the further northward intrusion of strong low-level southerly wind across the time mean position of the Meiyu front. It is noted that such intrusion of the southerly wind component would result in the increase in moisture transport and the generation of convective activity there, in addition to the nearly stationary low-level southerly wind in the subtropical high area toward the front. The intrusion of the relatively strong southerly wind around Fuyang, where the meso-α-low was initiated, was due to the enhancement of eastward or southeastward pressure gradient associated with the eastward extension of a synoptic-scale surface low along ～40N, in both cases.

Climatologically speaking, the low-level southerly wind component in the subtropical high area toward the Meiyu front is enhanced in late June, and the mean position of the frontal zone shifts to Central China then. The subtropical high area with strong southerly wind, and the area with the surface-level heat low in the northwestern China are located rather adjacent to each other, in the mature stage of the Meiyu in Central China. Thus the present processes could be seen in the limited stage in the seasonal march.

It is well known that the inflow of the dry air in the middle troposphere is one of the important processes for enhancement of the severe rainfall systems. The arid or semiarid region in China could provide such dry air into the rainfall systems on the Meiyu front. In addition, the result introduced here implies that the arid region in China might play another interesting role in the evolution of a meso-α-scale low on the Meiyu front.

5. A possible effect on the time evolution of active rainfall area on the Baiu front around the Japan Islands area

Meso-α-scale lows are also sometimes initiated due to the active convections on the Baiu front and are deepened in the Baiu frontal zone with relatively strong baroclinicity to the east of the Kyushu District (～130E, the western edge of the Japan Islands). In such cases, meso-β-scale rainfall systems often stagnate around Kyushu, corresponding to its trailing portion of the low passed eastward (Ninomiya et al., 1988a, b).

Around 29 June 1999, the heavy rainfall area around the northern Kyushu (～131E) expanded rapidly eastward to the Chugoku District (132-135E, also in the western part of the Japan Islands). That heavy rainfall area in Kyushu was located in the eastern part of a meso-α-scale low which propagated from the west. The eastward propagation of the heavy rainfall area was faster than that of the low. This eastward expansion occurred when the heavy rainfall area was still stagnated around Kyushu (～00 UTC 29 June) with the slight deepening of the low just to the west of that area. The area with the strong low-level southerly wind component just to the south of the Baiu frontal zone rapidly expanded eastward then.

It should be also remarked that both of the Pacific high (to the south of the Baiu front) and the Okhotsk high were stagnated to the east of Japan during the period from 28 to 30 July. The zone with a concentrated meridional temperature gradient was found around 30 to 40 N to the east of the Japan Islands (to the east of ～140 E). Nevertheless, the synoptic-scale eastward pressure gradient was sustained even around that latitude (corresponding to the mean position of the Baiu front there). Thus the results of this case also imply an interesting role of meso-α-scale lows on the behaviors of the heavy rainfall area in Japan under the basic field with the continental-scale heat low mentioned in Section3.

6. Large-scale thermodynamic conditions around the Huaihe River Basin (seasonal and temporal variations)

6.1 Pre-Meiyu period in the Huaihe River Basin

Figure 3 shows the time series of the pentad mean air temperature (T850) and specific humidity (Q850) at 850 hPa level averaged for 31.25-35N/110-120E for 1998 (roughly corresponding to the Huaihe River Basin). In this year, although the Meiyu rainfall had persisted around the southern part of the Changjiang River Basin since ～ 10 June, the first heavy rainfall event in this basin occurred during the last decade of June with slight northward shift of the Meiyu front after 20 June.

As pointed out by Kato (1985 and 1987), low-level air temperature rose abruptly around 10 June in this year but the specific humidity remained a small value in the Huaihe River Basin, in coincidence with the temperature rise around the arid region in China (not shown here). This indicates the relative humidity decrease there, just before the Meiyu stage in the Huaihe River Basin. In 1998, the Meiyu front once shifted further northward from the basin and the subtropical high covered that area in the middle of

July. The specific humidity showed also the large value then.

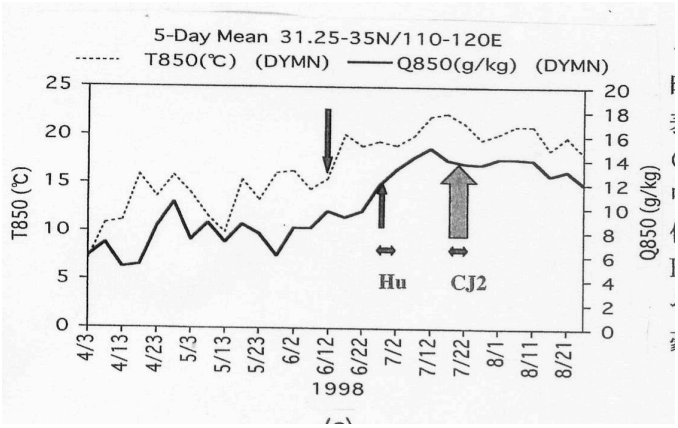

Fig. 3 Time series of pentad mean T850 (℃, solid line) and Q850 (g kg-1,dotted line) at 850 hPa level for 31.25-35N/110-120E for 1998, based on the GANAL. The letters Hu and CJ2 indicate the Periods 3 (heavy rainfall around the Huaihe River Basin) and 6 (that in the Changjiang River Basin) in Fig. 2, respectively.

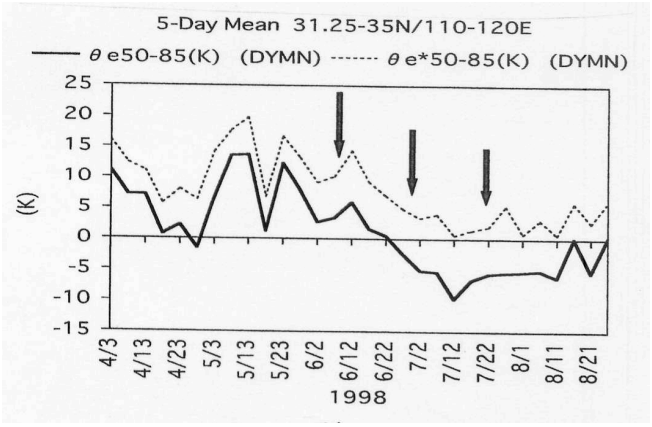

Fig. 4 Time series of the pentad mean (θ e500－ θ e850) (solid line) and (θ e500*－ θ e850) (dotted line) averaged for 31.25-35N/110-120E in 1998 (K).

In the pre-Meiyu stage in the Huaihe River Basin in June, the stability for moist convection seen from the potential temperature difference between 500 and 850 hPa levels (θ e500－ θ e850) decreased, due to the temperature increase in the lower layer (Fig. 4). However, the moisture content was not so large there and the stability for the dry convection (θ 700－ θ 850) was not so small even at 12 UTC (20 BST, where the mixed layer shows still the daytime character) (figure is not shown here). This implies the potentially stable condition for moist convection, as shown by the positive value of (θ e500*－ θ e850), where θ e* denotes the saturation equivalent potential temperature (Fig. 4).

6.2 After the onset of the Meiyu in the Huaihe River Basin

The Meiyu front shifted southward again and stagnated around the Changjiang River Basin in the last decade of July 1998 to bring the second heavy rainfall event there. It is interesting that the specific humidity at 850 hPa level was not decreased so much in the Huaihe River Basin even when the Meiyu front is located to the south of this region (Fig. 3). In that situation, (θ e500－ θ e850) shows the large negative value (convective unstable), and the value of (θ e500*－ θ e850) is nearly zero.

Relatively large amount of rainfall could moisten the ground so that enough amount of latent heat together with sensible heat is supplied from the ground to the lower atmosphere. In fact, although the latent heat flux to the north of the Meiyu frontal over China is rather small before the beginning of July, it shows a considerable amount (about 100 Wm^{-2}) after the middle of July (based on the GAME reanalysis data) (not shown here).

In 1991, when the severe flood occurred around the Huaihe River Basin in early July, the Meiyu season once started in late May, rather earlier than in the normal year. However, the intraseasonal variation of the location and the activity of the Meiyu front were also very large, and the four peak rainfall periods appeared around the Huaihe River Basin during May through the early August 1991. In this year, the Meiyu front shifted rather southward to merge the tropical convetive systems around the end of June. The specific humidity in the lower layer did not decrease so much after it increased in late May.

Thus the present study suggests that the memory of the Meiyu frontal rainfall might play an interesting role in the water cycle just to the north of the mean position of the Meiyu frontal zone. However, what kind of roles the land surface processes and the temporal variation of the large-scale atmospheric disturbances play on the water cycle there, including their interaction processes, effects on the rainfall characteristics there, is a remaining problem.