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Seasonal evolution of atmospheric and land surface conditions around the Huaihe River Basin in China in the pre-Meiyu stage of 1998

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Seasonal evolution of atmospheric and land surface conditions around the Huaihe River Basin in China in the pre-Meiyu stage of 1998 were examined, mainly based on the GAME re-analysis data.

Around the Huaihe River Basin in China (just to the north of the Changjiang River Basin), although the air temperature increased rapidly already in early June (the Meuyu front was located to the south of that region), the specific humidity did not increas so much at that time. In addition, the latent heat supplied from the ground there decreased from late May to early June, compared to that before early May.

The time mean southerly wind component across the low-level baroclinic zone (although not so strong as in the mature stage of the Meiyu) invaded into Central China during late April to early May. On the other hand, the relatively strong wind region once retreated southward in the middle of May associated with the onset of the Southeast Asian monsoon, and the calm wind region with frequent appearance of the surface high was seen around the Huaihe River Basin from late May to early June. Thus the present study shows that the Huaihe River Basin once experiences the rather drier stage just before the onset stage of the mature Meiyu there.

Keyword: arid region in China and the Meiyu front, seasonal evolution in East Asia, land surface condition around the Meiyu front

1. Introduction

It is well known that the air mass is extremely humid in the subtropical region just to the south of the Meiyu/Baiu front (a significant subtropical front) in China and the western part of Japan (e.g., Ninomiya 1984). On the other hand, although the extremely dry and hot region is located just to the north or northwest of the Meiyu front in China, the moisture content in North China also increased to some extent, at the onset of the Meiyu in Central China, according to a case study for 1979 (Kato et al., 1995).

Preliminary studies by Ikeda et al. (2004) and Ikeda and Kato (2005) examined the maintenance processes of moisture content in both regions to the north and the south of the Meiyu front in China in the 1998 Meiyu. However, behaviors of the subtropical front in East Asia present considerable seasonal and intraseasonal variations, as well as the regional variety (Kato 1985, 1987, 1989; Ninomiya 1989; Ninomiya and Muraki 1989; Kawamura and Murakami 1998; Ueda et al. 1995). Thus it would be also necessary to examine seasonal evolution of the atmospheric conditions associated with the moistening process to the north of the frontal zone, as well as the maintenance of the huge moisture content to the south of it.

Ikeda and Kato (2005) pointed out that once the Meiyu rainfall belt stagnated around the Huaihe River Basin at the beginning of July 1998, the moisture content there was sustained rather high value, even when the Meiyu rainfall belt moved southward to the Chanjiang River Basin in late July. They suggested the important role of the relatively large sensible and latent heat fluxes there, which might be due to the moistening of the soil by the persistent Meiyu frontal rainfall belt there. Behaviors of the meso-scale rainfall systems are controlled not only by the low-level inflow of warn and humid air but also by that of the dry air in the middle troposphere. Thus the behavior of the dry air to the north of the Meiyu frontal zone would be also an interesting factor for the rainfall characteristics there. In this reason, the present study will examine the evolution of atmospheric and land surface conditions before the Meiyu season in Central China, mainly based on the GAME (GEWEX (Global Energy and Water cycle Experiment) Asian Monsoon Experiment) re-analysis data for 1998 (at every $1.25° \times 1.25°$ latitude/longitude grid). The details of this data set is referred to Yamazaki et al. (2000). The operational Global Analysis Data (the same horizontal resolution as in GAME re-analysis data) provided by the Japan Meteorological Agency (JMA) are also used (the latter data set is referred to as GANAL, hereafter).

2. Evolution of the large-scale Meiyu (Baiu) rainfall belt in early summer in 1998

Figure 1 shows the time-latitude section of 6-hourly rainfall amount averaged for 112.5 - 120 E (longitude belt around the eastern part of China), based on the GAME re-analysis data. The values are presented in a unit of mm day^{-1}. The zone with relatively large rainfall amount at ~ 29N around 25 June corresponds to the Meiyu frontal zone in China. As preliminarily reported by Kato et al. (1999), the Meiyu cloud zone began to stagnate around the coastal region of South China on ~17 May in this year, associated with the onset of the Southeast Asian Monsoon. This cloud zone extended from South China to the south of the Japan Islands. However, its western part was once moved southward to the central part of South China Sea area, as an intraseasonal variation (around 21 to 30 May). The Meiyu rainfall had persisted around the southern part of the Changjiang River Basin since ~

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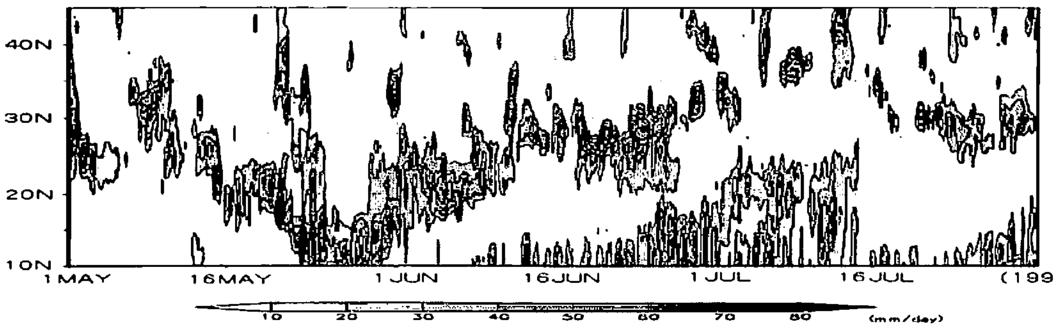

Fig. 1. Time-latitude section of 6-hourly rainfall amount, PR, averaged for 112.5 - 120 E, based on the GAME re-analysis data (mm day^{-1}). The labels of the data are shown at 03 UTC. The contours are drawn at every 10 mm/day interval.

10 June, but the first event of the extreme heavy rainfall in the basin of this main branch occurred after 20 June with slight northward shift of the Meiyu front (e.g. Ding et al. 2001;National Climate Center of CMA 1998). However, little rainfall was brought around the Huaihe River Basin at that time. On ~28 June, Meiyu front shifted to the Huaihe River Basin to bring a considerable rainfall amount there till ~3 July.

3. Large-scale thermodynamic and land surface conditions around the Huaihe River Basin in the pre-Meiyu season of 1998

Figure 2 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 in 1998 (roughly corresponding to the Huaihe River Basin), based on the GANAL. As pointed out by Kato (1985a and 1987), the low-level air temperature there (to the north of the Meiyu rainfall belt) rose abruptly around 10 June also 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.

The Meiyu front once shifted further northward from the basin and the subtropical high covered that area in the middle of July in 1998. It is interesting that the specific humidity showed also the large value in late July where the Meiyu rainfall belt is located to the south of this basin again. However, the present paper will not make further examination on that phenomena (see preliminary results by Ikeda and Kato (2005)).

Figures 3 (a), (b) and (c) show the time series of daily mean latent heat flux at the ground (LH) and daily precipitation (PR) based on the 6-hourly GAME re-analysis data for 35-40N/ 110-120E (roughly corresponding to the Huanghe River Basin), 31.25-35N/110-120E (the Huaihe River Basen) and 27.5-31.25N/110-120E (the Changjiang River Basin), respectively. The series of their 5-day running mean values are also presented.

As preliminarily pointed out by Ikeda and Kato (2005), the latent heat supplied from the ground to the

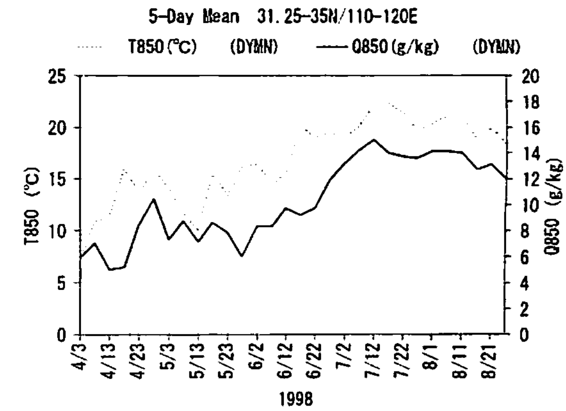

Fig. 2 Time series of pentad mean T850 (℃, solid line) and Q850 (g kg-1,dotted line) at 850 hPa level for 31.25-35N/110-120E in 1998, based on the GANAL.

atmosphere in the Huaihe River Basin (Fig. 3(b)) has increased in early July, just after the persistent rainfall event by the Meiyu (see also Fig.1). The similar relatively great increase in LH was found for the Huanghe River Basin (Fig. 3(b)) around the middle of July after the Meiyu frontal precipitation zone once stagnated there. It is also interesting that, although the rainfall events sometimes appeared there intermittently also in April and May, the latent heat flux once decreased gradually from late May to early June when the precipitation was rather small.

As for the Changjiang River Basin, the persistent precipitation event by the Meiyu front (the two heavy rainfall periods; in late June and late July) brought much more total precipitation there than in the Huaihe River Basin. Maybe reflecting that, the latent heat flux increased greatly in the middle of July. It is noted that the latent heat flux decreases again rather rapidly, after the relatively dry period persists for 2 or 3weeks.

These might reflect some different processes on the recycling of the moisture among these regions and stages, including those in the Changjiang River Basin. However, we will focus our attention to the large-scale atmospheric fields associated with the processes around the Huaihe River Basin.

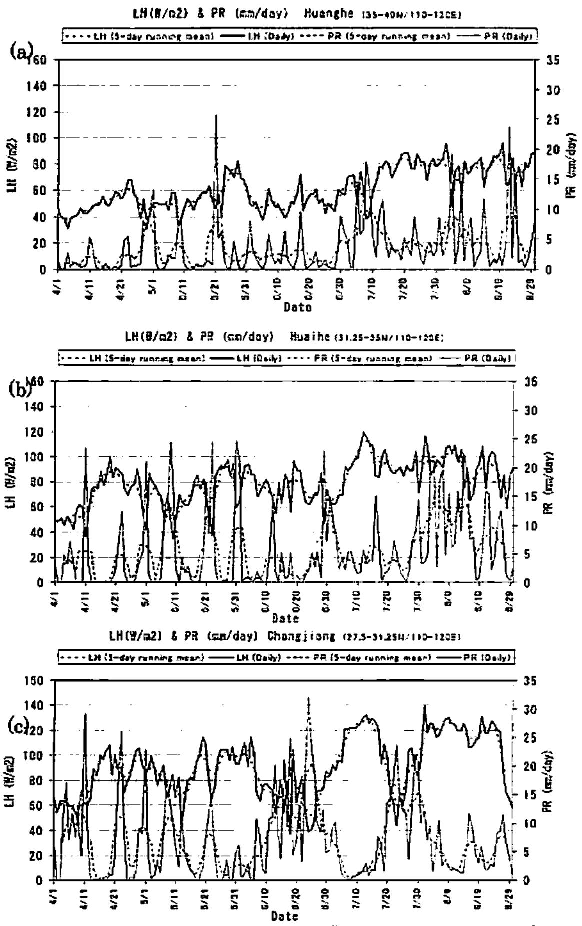

Fig. 3 Time series of LH (W m^{-2}) and PR (mm day^{-1}) in 1998, based on the 6-hourly GAME re-analysis data. The series of the daily values and their 5-day running mean ones are presented for 35-40N/ 110-120E (the Huanghe River Basin), 31.25-35N/110-120E (the Huaihe River Basin) and 27.5-31.25N/110-120E (the Changjiang River Basin) in (a), (b) and (c), respectively. Solid lines indicate the daily values and broken ones the 5-day running mean values. Thick and thin lines show LH and PR, respectively.

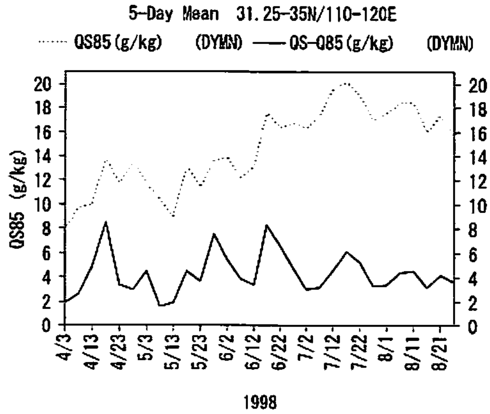

Fig. 4 Time series of the pentad mean saturation specific humidity (QS85) (g kg^{-1} , dotted line) and its difference from the actual specific humidity (QS-Q85) (g kg^{-1} , solid line) at 850 hPa level averaged for 31.25-35N/110-120E in 1998 (the Huaihe River Basin), based on the GANAL.

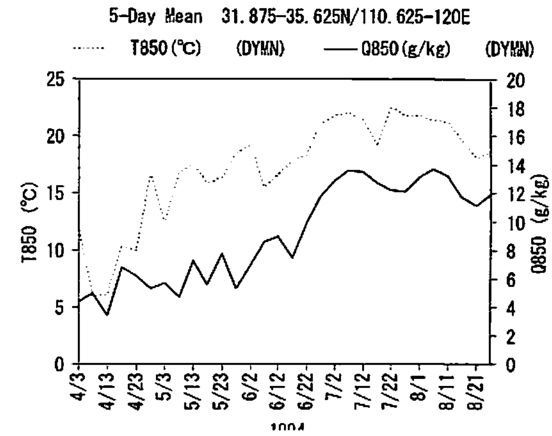

Fig. 5 Same as in Fig. 2, except for 1994.

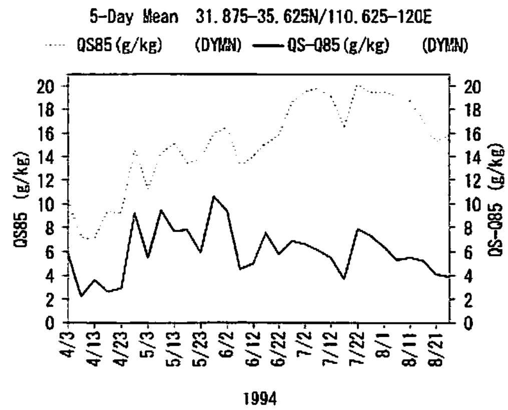

Fig. 6 Same as in Fig. 4, except for 1994.

Figure 4 shows the time series of the pentad mean saturation specific humidity (QS85) and its difference from the actual specific humidity (QS-Q85) at 850 hPa level averaged for 31.25-35N/110-120E in 1998 (the Huaihe River Basin), based on the GANAL. (QS-Q85) is an indicator for the degree of unsatuartion. From late May to early July, QS85 increased due to the temperature rise when this area is located to the north of the Meiyu rainfall belt. Also reflecting that, (QS-Q85) showed relatively large value then. Thus it would be anticipated that the latent heat supplied from the ground increase then if the ground is wet enough. However, if the ground does not contain enough moisture, LH would also decrease after a while. The present study can point out that both the atmosphere and the ground become drier around the Huaihe River Basin in the stage just before the onset of the Meiyu there.

Figures 5 and 6 present the same as in Figures 2 and 4, respectively, except for 1994 based on the GANAL. In this year, we experienced the extremely hot and dry summer around the Japan Islands (e.g., Ysunari (Ed.) 1997). Large positive anomaly of air temperature at the surface level persisted already from April of this year in the Japan Islands. In the Huaihe River Basin (Fig. 4), air temperature at 850 hPa level increased

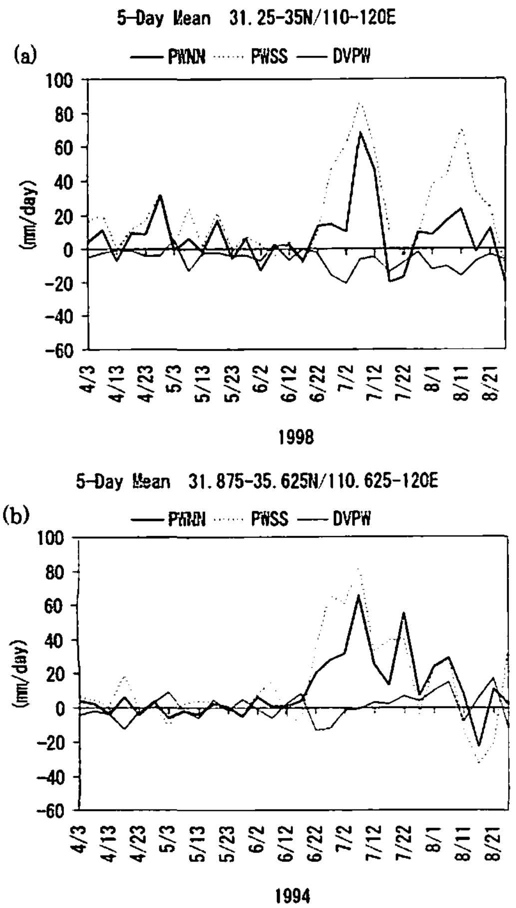

Fig. 7 Series of pentad mean values of vertically integrated northward moisture flux components at the northern and the southern boundaries (PWNN (thick solid line) and PWSS (dotted line), respectively), and the total divergence of vertically integrated moisture flux (DVPW, thick solid line) averaged for the region 31.25-35N/110-120E (Huaihe River Basin) in 1998 (in (a)) and 1994 (in (b)), respectively. Integration was performed from 300 to 1000 hPa levels. Values of PWNN and PWSS are also presented in the same unit of DVPW (mm day^{-1}), with dividing by the area of this region.

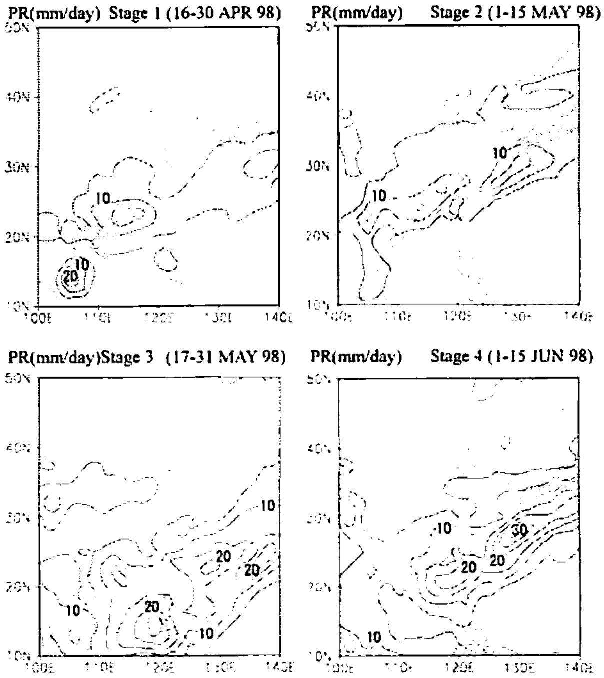

Fig. 8 Distribution of mean precipitation (mm/day) for the periods of 16 to 30 April (Stage 1), 1 to 15 May (Stage 2), 17 to 31 May (Stage 3) and 1 to 15 June 1998 (Stage 4) based on the GAME re-analysis data.

considerably in late April, but the specific humidity did not followed it until late June. Thus (QS-Q85) showed rather large value during late April through early June in 1994 (Fig. 6). The dry condition around the Huaihe River Basin appeared just before the onset of the Meiyu there in 1994 more remarkably than in 1998, although we do not have the data on LH for 1994.

Figures 7 (a) and (b) indicate the series of pentad mean values of vertically integrated northward moisture flux components at the northern and the southern boundaries (referred as PWNN and PWSS, respectively), and the total divergence of vertically integrated moisture flux (DVPW) averaged for the region 31.25-35N/110-120E (Huaihe River Basin) in 1998 and 1994, respectively. Integration was performed from 300 to 1000 hPa levels, based on the GANAL at the standard pressure levels. Values of PWNN and PWSS are also presented in the same unit as in DVPW, with dividing by the area of this region.

As well known, the huge northward moisture flux from the southern boundary (PWSS) and the convergence of the flux (the negative DVPW) are observed in the mature stage of the Meiyu season in this region (from late June to the beginning of July in both years). It is also interesting that the influx from the south is relatively larger before early May than in the period from late May to early June in 1998. In 1994, magnitude of PWSS showed nearly zero already from late April or early May. Although we can not make conclusive judgment due to the accuracy of the moisture budget estimation, the moisture inflow from the south also tends to be once reduced in the stage just before the mature Meiyu around the Huaihe River Basin, resulting in the drier ground surface condition there.

4. Role of the seasonal transition of large-scale atmospheric fields

Figure 8 shows the distribution of precipitation for the periods of 16 to 30 April (referred as Stage 1, hereafter), 1 to 15 May (Stage 2), 17 to 31 May (Stage 3) and 1 to 15 June 1998 (Stage 4) based on the GAME re-analysis data. During Stages 1 to 2, rainfall area was found in the coastal region of South China (20~25N/110~120E). However, the area with precipitation of more than 5 mm day^{-1} extends to the more northern area up to ~35N in Stage 2, although the peek of the precipitation was found around the South

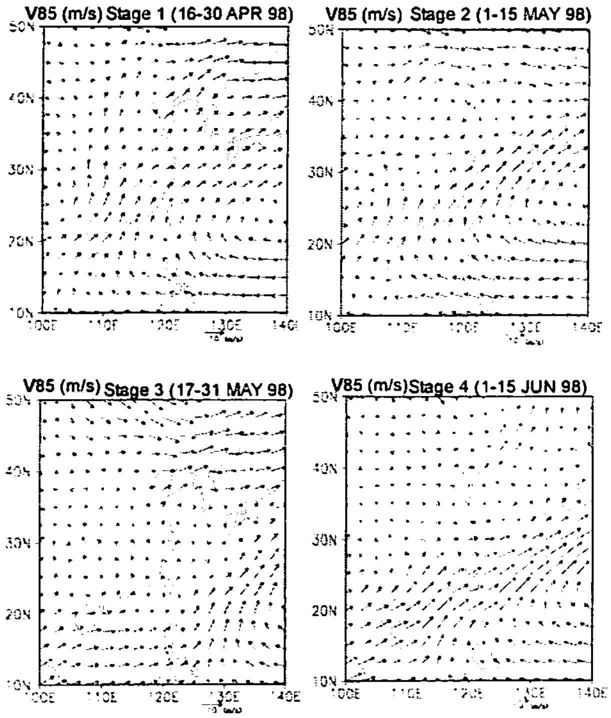

Fig. 9 Same as in Fig. 8, expect for the mean wind vector at 850 hPa level.

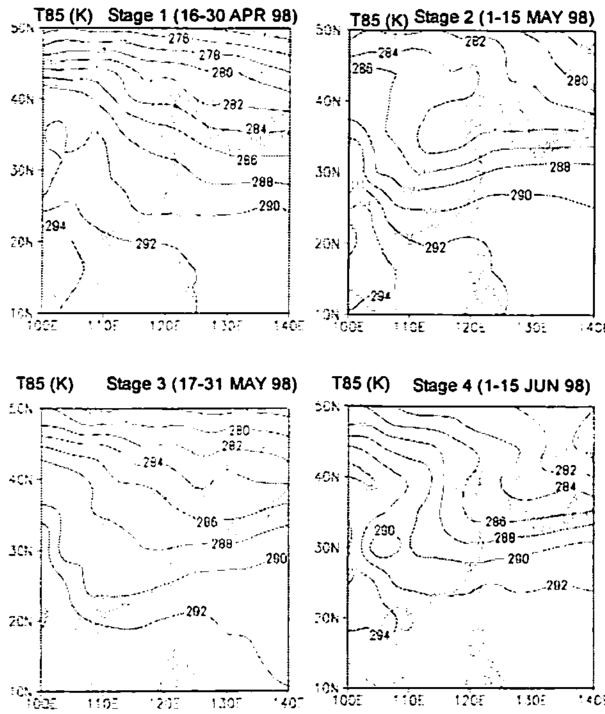

Fig. 10 Same as in Fig. 8, expect for air temperature at 850 hPa level (K).

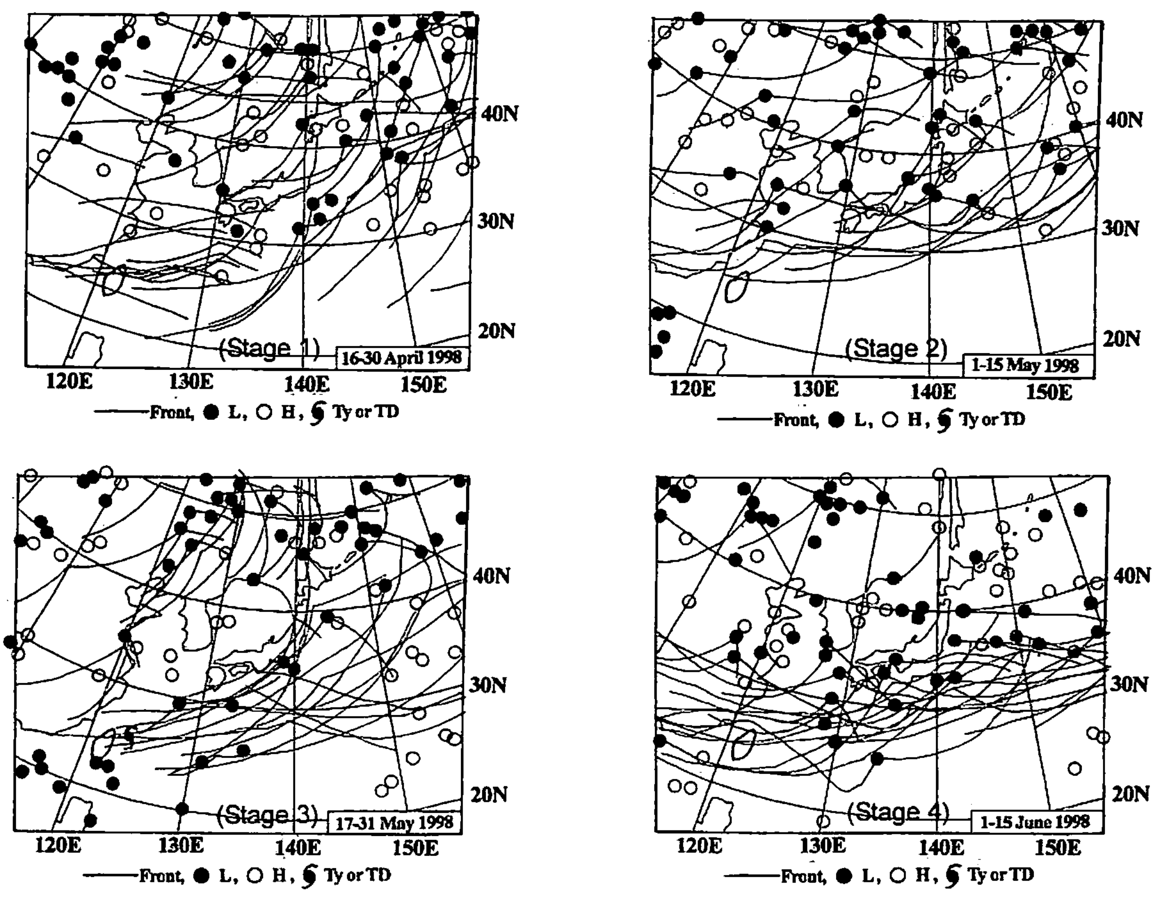

Fig. 11 Composite map of the positions of fronts. high and low pressure centers and the tropical disturbances on the daily surface weather maps at 00 UTC (by JMA) for each stage. The weather maps in this analysis are referred to in "Kisho" (issued by the Japan weather association (JWA)).

China coastal area. Just after the onset of the Southeast Asian Monsoon (Stage 3), the precipitation area once shifted southward and the area with precipitation of 5~10 mm day^{-1} decreased around Central China. Reflecting this, the northern edge of the rainfall belt got sharper in Stages 3 and 4 than before.

Figures 9 and 10 show the time mean fields of wind vector and air temperature at 850 hPa level, respectively, in each stage. The southerly or southwesterly wind prevailed at 850 hPa level in Stages 1 and 2 from the northern part of the South China Sea to Central China (15-30N/110-120E), where the meridional temperature gradient was not so small, especially in Stage 2. Thus the time mean fields in Stages 1 and 2 seems to correspond to those in "Spring Rainfall" season (called "Lian-Yin-Yu" in China) (Kawai and Kato 2001; Tian and Yasunari 1998).

Figure 11 shows the composite map of the positions of fronts, high and low pressure centers and the tropical disturbances on the daily surface weather maps for each stage. The surface front tended to appear in South China through these stages frequently. However, the region with relatively high frequency of surface front spreads from South China to Central China in Stages 1 and 2. Thus the mean southerly wind component across the baroclinic zone in lower layer together with the appearance of extratropical disturbances and fronts seems to contribute to the rainfall around the Huaihe River Basin in Stages 1 and 2 (through it is not so intense).

On the other hand, once the Southeast Asian Monsoon started on ~17 May, the northern boundary of the low-level southwesterly region retreated southward to the southern coast of South China, and the calm wind area in the time mean field covered Central China including the Huaihe River Basin in Stages 3 and 4. In those stages, another baroclinic zone corresponding to the polar frontal zone was located to the north of ~40N. Although the surface front appeared rather frequently also in the southern half of the Changjiang River Basin (27~30N), the surface high center was often seen around the Huaihe River Basin to North China Plain (32~40N), especially in Stage 4. Thus the formation of the weak wind region in the lower layer with the surface high around the Huaihe River Basin, corresponding to the onset of the Southeast Asian monsoon, would influence on bringing the drier stage there in Stages 3 and 4.

Figure 12 shows the distribution of the specific humidity at 850 hPa level for each stage. Although the specific humidity increases gradually during these stages in the Huaihe River Basin to North China Plain (32~40N), the meridional gradient of specific humidity became sharper around 25~30N (just to the south of the Huaihe River Basin), due to the relatively large increase in the southern region. It should be noted that the air temperature also increased considerably in Stages 3 and 4 compared to that in Stages 1 and 2 in the Huaihe River Basin but the specific humidity increased only a little there.

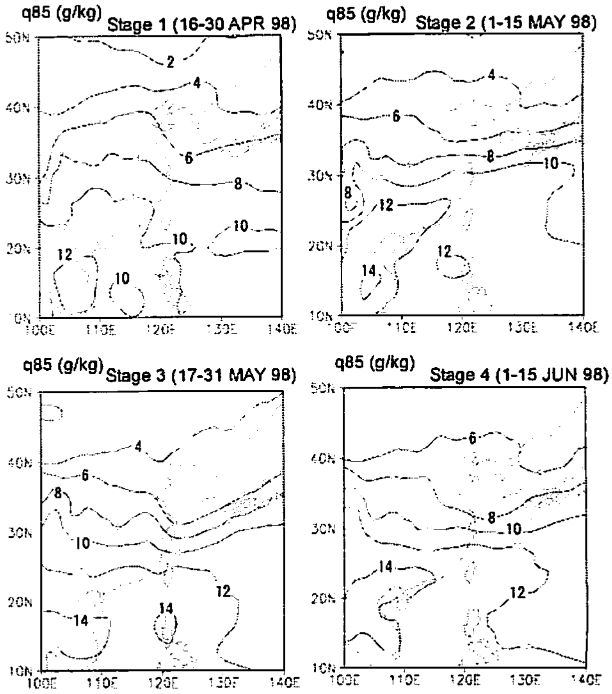

Fig. 12 Same as in Fig. 8, expect for specific humidity at 850 hPa level (g/kg).

Hirasawa et al. (1995) revealed that the convective clouds tend to be activated rapidly in the Meiyu/Baiu frontal zone from South China to the Southwest Islands area (20~25N/110~130E), nearly simultaneously with the onset of the Southeast Asian monsoon in the middle of May. The present study suggests that the region to the north of the Meiyu frontal zone (~Huaihe River Basin) would experience such drier atmospheric and ground surface conditions just before the stage of the Meiyu there.

5. Concluding remarks

Seasonal evolution of atmospheric and land surface conditions around the Huaihe River Basin in China in the pre-Meiyu stage of 1998 were examined, mainly based on the GAME re-analysis data.

Around the Huaihe River Basin in China (just to the north of the Changjiang River Basin), although the air temperature increased rapidly already in early June (the Meuyu front was located to the south of that region), the specific humidity did not increas so much at that time, as pointed out by Kato (1985) for the case of 1979. In addition, the latent heat supplied from the ground there decreased from late May to early June, compared to that before early May.

The time mean southerly wind component across the low-level baroclinic zone (although not so strong as in the mature stage of the Meiyu) invaded into Central China during late April to early May, together with the appearance of surface fronts or disturbances there. On the other hand, the relatively strong wind region once retreated southward in the middle of May associated with the onset of the Southeast Asian monsoon, and the calm wind region with frequent appearance of the surface high was seen around the Huaihe River Basin from late May to early June. Thus the present study showed that the Huaihe River Basin (just to the north of the Changjiang River Basin) once experiences the rather drier stage just before the onset of the mature Meiyu there.

By the way, the low-level southerly wind in the subtropical high area, affected greatly by the global-scale Asian monsoon, primarily controls the moisture supply into the Meiyu/Baiu frontal zone. However, the property of the air mass to the north of the front, the middle and the higher latitude westerly systems, and so on, can also contribute to characterizing the rainfall features or activity in the frontal zone. For example, the inflow of middle-level dry air into the convective systems sometimes enhances the persistent heavy rainfall there.

Since the mature stage of the Meiyu in Central China is characterized by the rapid northward invasion of the extremely warm air toward the northern dry region as the seasonal cycle, how the air in the northern region is dry might affect considerably the characteristics of the heavy rainfall systems there. Although the present study have not examined possible effects on these problems yet, roles of the drier stage in the northern region of the front in the Meiyu heavy rainfall activity are interesting remaining problems in the future.

Acknowledgements

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