Some Analyses and Numerical Simulations of Meiyu in East Asia in 1983

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ABSTRACT

In this paper the differences between Meiyu and Baiu front in 1983 have firstly been analysed, the trajectories of air on and to the north side of Meiyu and Baiu fronts during the Meiyu period have then been traced, and the forecasting and simulating of 4 sets of Meiyu onset of the year have finally been run utilizing the global model at UK Meteorological Office. The results show: 1) Meiyu fronts are different from Baiu ones in temperature, humidity and stratification fields in lower atmosphere; and the possibly reasons for it are explained. 2) The Bay of Bengal is the main moisture source for Meiyu front, the South China Sea and the Pacific, for Baiu ones; and some existed arguments on it are also discussed. 3) The onset of Meiyu and its rainfall and rain belts are sensitive to the Tibetan Plateau, and the water vapour conditions over the Bay of Bengal and the South China Sea, but not sensitive to the SST over the equatorial area or to the East of Japan.

I. INTRODUCTION

Meiyu in China or Baiu in Japan, a well–documented phenomenon in literature and notes, mainly occurs over the mid–and lower–reaches of the Yangtze River in China and central and south parts of Japan in the period of 15 June to 10 July on the average.

The wide range of work on Meiyu observations and forecasts studied by Chinese and Japanese meteorologists has been done by now (Zhang, 1987; Zhang et al., 1988). The onset of East Asia Meiyu is not a local phenomenon and is the result of seasonal adjustment of general circulation over Eurasian continent and the whole Northern Hemisphere from late spring to early summer (Tao et al., 1957). It is the northward extention of Indian monsoon (Gao et al., 1962; Kato, 1985). Forecasters in China and Japan laid stress on the large scale situation forming East Asia Meiyu as well (Xiang et al., 1986; Zhu, 1963).

In spite of above common points of East Asia Meiyu, some differences between temperature fields along the Meiyu front in China and Japan in 1979 have already been showed (Kato, 1985). We need to check the rest of Meiyu years and to discuss the reasons.

During the Meiyu season it rains a lot, often heavy rain. So scientists often argue where the main water vapour source of the Meiyu comes from. Isit from South China Sea (Tao et al., 1958) or the Bay of Bengal (Zhang et al., 1988) or the both? We need trajectory analyses to confirm it. The mechanism forming East Asia Meiyu is another challenge. Some different viewpoints about it, from thermal viewpoint of the diabatic cooling effect of blocking high over Okhotsk Sea to dynamical one of cold air advection from Bering Sea to Okhotsk Sea again to the influence of Tibet Plateau (Nakamura et al., 1985), have been existing. Only very few of numerical experiments, however, concern it (Nakamura et al., 1985; Chen et al., 1986).

In this paper an effort will be directed toward answering partly above questions. A typical Meiyu year 1983 was firstly chosen, some analyses of it were then made, after that its numerical prediction and simulations were run, the remarks and conclusions were finally given.

II. SOME ANALYSES OF EAST ASIA MEIYU IN 1983

1. *Typical Meiyu Year*

The Meiyu in 1983 commenced with 19 June and ended with 18 July. During the Meiyu period of one month the typical blocking system in higher latitudes had been locating between Lakes Balkhash and Baikal, the ridge of western Pacific subtropical high had been laying between 20–24 ° N, and the Meiyu rain belts had been oscillating north and south between 28 and 33 ° N in the mainland of China(not shown).

The rainfall throughout the Meiyu period in China was as much as 240–420 mm. It was wetter than normal Meiyu year. We can guess that 1983 should also be a good Baiu year judging from above typical characteristics of the Meiyu systems and good Meiyu rainfall in China.

2. *Differences between Meiyu and Baiu Fronts*

The Meiyu fronts are characterized by weak temperature contrast, but quite large humidity one (Ninomina et al.,1986; Xiang et al., 1986). While the Baiu front is something different. Fig.1 shows the temperature and humidity fields along Meiyu or Baiu front for a typical active Meiyu day. The temperature field between AB and A′B′ in China was nearly homogeneous, but the contrast between CD and C′D′ in Japan was much larger than that in China (Fig.1a). The relative humidity (RH) field was something opposite (Fig.1b). By taking a spatial and temporal average of temperature and humidity differences at 850 hPa across the Meiyu front and Baiu front during the active Meiyu period from 21 June to 10 July of 1983, the averaged temperature difference $\overline{\triangle T}$, was only 1.8 °C in China; but 3.3 °C in Japan (Table 1), For the averaged RH difference, $\overline{\triangle RH}$, it was somewhat smaller in Japan than in China. The averaged lapse rate of wet bulb potential temperature, $\overline{\partial Qwe / \partial P}$, between 850–and 700–hPa was also calculated for the same period. The both negative values indicating the

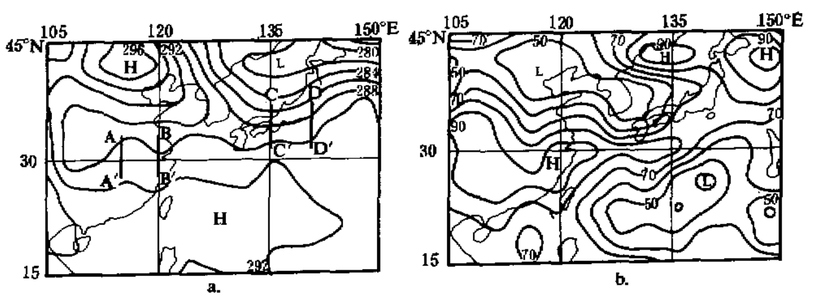

Fig.1. Temperature (a) and RH (b) at 850 hPa for 12 Z 21 June of 1983. Letters (used in Table 1) A, B, C and D show the north side points of Meiyu and Baiu fronts, respectively; A′, B′, C′ and D′, the south side ones.

lower layer frontal atmosphere on both sides were unstable, especially in China (Table 1).

Table 1. Comparisons of Spatial and Temporal Average of the Lower Level Atmosphere along Meiyu and Baiu Fronts

Regions	$\overline{\triangle T}$	$\overline{\triangle RH}$	$\overline{\partial \theta we / \partial P}$
Meiyu fronts	1.8 °C	16%	−1 °C
Baiu fronts	3.3 °C	−2.5%	−0.3 °C

3. *Trajectory Analyses*

To trace the source of moisture a 2−D time−backwards trajectory method was utilized(Barwell,1984). We have tracked backwards for six days for some chosen locations on and to the north side of Meiyu or Baiu fronts at 850−and 700−hPa from 21 June to 5 July of 1983.

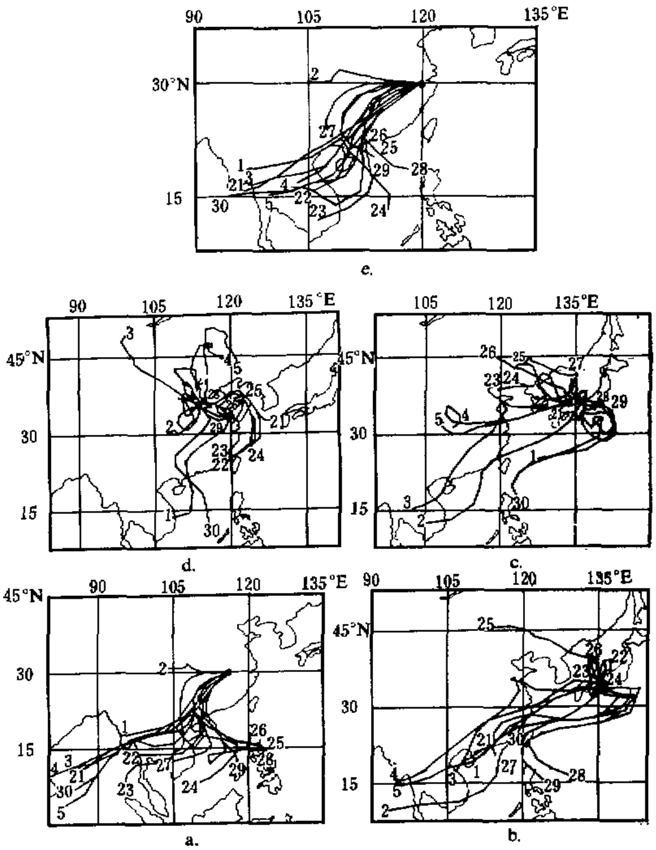

Fig.2. Trajectory paths tracked backwards for 6 days at 850 hPa for active Meiyu period of from 00 Z 21 June to 00 Z 5 July for points 30 °N, 114 °E (a), 34 °N ,136 °E (b), 36 °N, 136 °E (c), 36 °N, 116 °E (d), and 30 °N, 120 °E tracked backwards only for 4 days(e). The number at the starting point of each path shows the date on which the air particle gets its ending point.

The trajectories show that for points west of (30 °N, 114 °E) on Meiyu front at 850–hPa, most of air parcels come from the Bay of Bengal, only a few of them come directly from the South China Sea or the western Pacific (Fig.2a). At the point (30 °N, 120 °E), the air particles at 850–and 700–hPa still follow the similar path, only with more striking influence of the western Pacific subtropical high (not shown). However at the point (34 °N, 136 °E) west of Japan, the majority of air mass at 850 hPa come from the South China Sea or the western Pacific instead of the Bay of Bengal, a few of them come from the northern seas, even from Asia continent (Fig.2b). At the point (36 °N,136 °E) to the north side of Baiu front, dramatic changes happen: most of the air flows come from the north (Fig.2c), especially at 700–hPa (not shown).

But in China at the location(36 °N,116 °E) to the north side of the Meiyu fronts, although the dominant paths at 850 hPa are, in fact, from the north, some of them, in the period of 29th–2nd, trend to be purely from the south; and some, in the period of 21st–23rd and 26th–28th, are firstly from south–east, then go further north, and again then return from north–east or east, suggesting strong convergence along the Meiyu front, not like Baiu ones; only from the 3rd to 5th all show from the north or Northwest (Fig.2d). What is need to mention is that to the north side of Meiyu front the shear converged path is so weak and their directions changed so often that some paths come round and take circular ones.

Therefore there are different moisture sources during Meiyu period. The main source in China is from the Bay of Bengal; but in Japan (especially at 700 hPa), from the South China Sea and the western Pacific.

III. A SIMPLE DESCRIPTION OF THE MODEL AND EXPERIMENTS

1. *Simple Description of the Model*

The model used is the operational forecasting model in UK Meteorological Office. The 15–level model covers the global area and has the B–type horizontal staggered grids with the resolution of 1.875 × 1.5 °Lon. / Lat.. A full of model physics processes, of course, is covered. They are vertical and horizontal diffusions, dynamic precipitation, shallow–and deep–cumulus convections, radiations, and gravity wave drag (Bell and Dickinson, 1987). The model has a high reputation for its good performance in the world.

2. *Control Experiment*

To show the model performance for Meiyu onset forecast of 1983 and to compare the rest sensitive experiments with it, the exactly same run as the operational one was performed.

3. *The SST Experiments*

During the period of pre–and well post–onset of the Meiyu period, the observed sea surface temperature(SST) shows that it is warmer over the equatorial pacific and colder to the East of Japan(Fig.3) than the normal, especially the latter was as low as −2.5 °C anomaly. Kershaw (1986) revealed that the SST anomaly over the Arabian Sea has had an important role in the onset of Indian monsoon of 1979. In the control run the climatic SST values were still used. To show the impact of the SST at the aforementioned areas on Meiyu, two runs were carried out in which only nearly real time–averaged SST over the above areas from 15 to 29 June (with somewhat smoothing) was respectively replaced. The rest were the same as the control run.

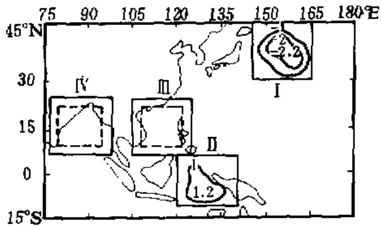

Fig.3. Schematic diagram showing the boxes for the SST and halfing moisture experiments. Boxes I, II, III and IV are the areas to the East of Japan, the equatoial pacific, the South China Sea and the Bay of Bengal, respectively. The isopleths in Boxes I and II show the abnormality of the SST used. In Boxes III and IV, the RH inside and outside of the dashed line areas are reduced by half and one third, respectively.

4. *Half Humidity Experiments*

Since the Bay of Bengal and the South China Sea are the moisture sources for the East Asia Meiyu. A question to be put forward is what will happen to the behaviour of the event if the moisture at the source region is reduced. Hence additional two runs were made: one halfing humidity values on all levels over only the Bay of Bengal; the other, over both the Bay of Bengal and the South China Sea (Fig.3).

5. *No Tibetan Plateau Experiment*

The fact that Meiyu exists only over East Asia, but not over eastern America may suggest that there are some relationships between the Meiyu and Tibetan Plateau. So in the last run both Tibetan Plateau and Tianshan Mountains higher than 1.5 km were taken away to see the influence of the Plateau on the event.

In doing so, to avoid the abrupt topography gradient changes after removing mountains, especially on the north side of the Plateau, we let the terrain elevation reduce gradually from the north highland about 1.5 km to South Ganga Plain near 0.2 km rather than simply set them all as zero km. Meanwhile to warm up the model and get better internal consistent initial fields, a 24–h assimilation cycle was firstly run beginning with 12 Z 16 June and during the period the mountain height over above regions was gradually decreased with time.

For all of the above 4 sets of experiments 12 Z 17 June were chosen as initial fields, the forecast and simulations for 6 days ahead were computed.

IV. RESULTS OF THE EXPERIMENTS

1. *Forecasting of Meiyu Onset of the Year*

It has been a challenge for us to forecast Meiyu onset, but the model had a quite good performance. On the onset date, 19 June, the 48–h forecast height and flow fields at 850 hPa were very similar to the observed (Fig.4a–b). It forecast correctly the members of Meiyu systems: the blocking high over Lake Balkhash, the westward extending of the western Pacific subtropical high, the frontogenesis of Meiyu front. As seen from Fig.4b the forecast shear line, F′F′, corresponds well to the observed Meiyu front, FF.

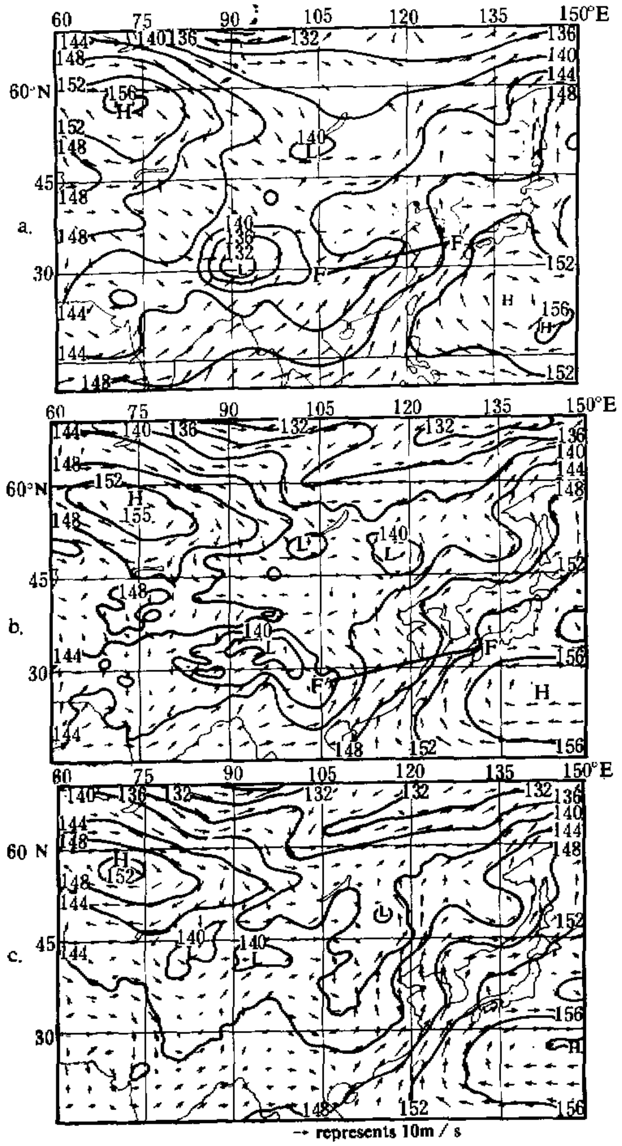

Fig.4. Wind and potential fields at 850 hPa for 12 Z 19 June, 1983 of the observed (a), 48-h forecast (b) by the control run and simulated (c) by no Plateau run. FF and F'F' are the observed and forecast shear lines, respectively.

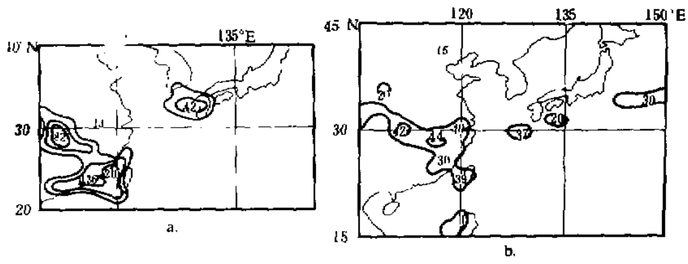

Fig.5. 24–h rainfall of the observed (a) and the forecast (b) ending at 12 Z 19 June, 1983. The contours are drown every 20 mm.

The dramatic shifting of rain belt was also well–forecast. Initially the rain belt stayed at the SE coast of China on 17 and 18 June, a forecast split rain belt jumped to the Yangtze River Basin up to 19 June, being the same as the observed (Fig. 5). From then on the forecast rain belts have been oscillating south and north over the Yangtze River. The coast rain band disappeared (not shown). The forecast rainfall was encouraging as well. These results show that the model has good ability to simulate the rainfall of Meiyu.

2. *Influence of the SST*

Changing the SST over the equatorial area only, from Day 3 onwards the simulated convective rainfall over Chinese side shows either an increase or a decrease of some 5–10 mm / day and is more realistic than the control run. Say on Day 3, although there were almost the same large scale circulation, rain band positions and even the rainfall over Japanese side in both runs, in Chinese side it was 7 mm / day at west end of the rain band and 10 mm / day over the coast heavier in the run (Fig.6c) than the control one (Fig.6b; A′, B′). The former was obviously closer to the observed rain cores A and B, respectively (Fig.6a).

Changing the SST to the East of Japan alone, the SST anomaly more than −2.2 °C caused the differences of about 5 mm / day rainfall from the control run from Day 4 on, again the run was closer to the reality (not shown).

Therefore after being replaced by real SST over aforementioned areas the simulated three–day rainfall is more reasonable to some extent than the control run, in addition, the both runs show that Meiyu more sensitive to the SST over the equalarial area than to the East of Japan. The reasons for it are partly that because the South China Sea is one of the origins of Meiyu air–mass, so the SST over the source will directly affect the rainfall; at Meiyu front; partly because some kind of mechanisms now are indirectly functioned by either the Hadley cell circulation or teleconnection. From the SST viewpoint perhaps the diabatic cooling effect over Okhotsk Sea is less important in forming East Asia Meiyu.

3. *Influence of Moisture over the Source Areas*

In halfing moisture run over only the Bay of Bengal, firstly a dry region less than 40% of the RH was gradually advected northeastward from the origin and led to the reduction of upstream rainfall, secondly from Day 4 on the rainfall in China was reduced by 20 mm / day

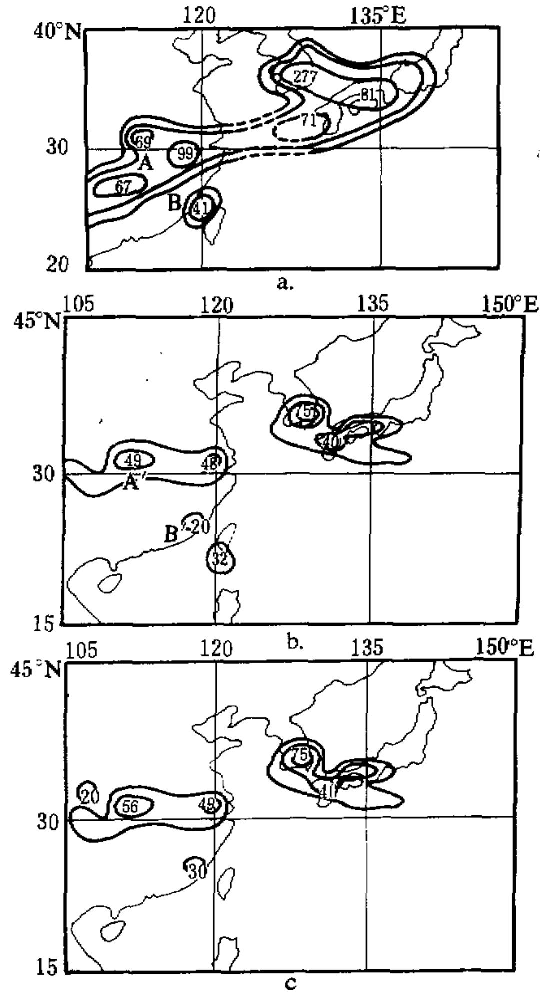

Fig.6. 24-h rainfall of the observed (a) and the forecast (b) in control run and simulated in halfing SST run over the Equatorial pacific only (c) ending at 12 Z 20 June 1983. The rests are the same as Fig.5.

(Fig.7b), then on Day 5 the rainfall drop of same magnitude appeared in Japan as well(not shown). There was still no essential change in rain belt positions of Meiyu in the run.

When halfing the humidity further over the both source areas, one day afterwards the rain belt located originally in the SE coast of China was obviously shifted northward and the onset of Meiyu was advanced from 18 to 19 June, and the rainfall was cut by more than40 mm / day(not shown). In the following three days the Meiyu rain bands moved 2 ° Lat. north further and sometimes even had heavier rain than the control run. For example, on Day 4 the

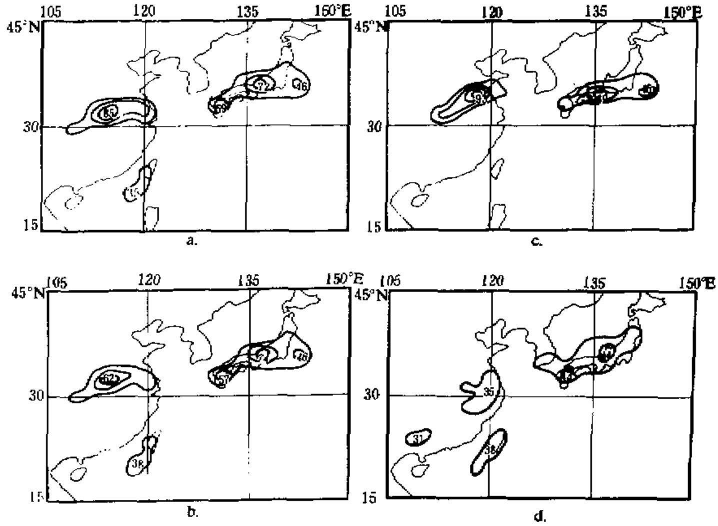

Fig.7. 24–h rainfall of the forecast in control run (a), and simulated in halfing moisture run over the Bay of Bengal only (b) or both the Bay of Bengal and the South China Sea (c), and in no Plateau run (d) ending at 12 Z 21 June 1983. The rests are the same as Fig.5.

Meiyu rain belt ever moved to the north of 34 °N and caused the short break of Meiyu as the well as the increase in rainfall in China, but the decrease in Japan (Fig.7c).

Therefore once the moisture is cut down over the both source areas, the run not only changesthe Meiyu rainfall immediately but also shifts its rain belts north furtherand causes the advancing of onset date and the breaking of Meiyu.

4. *Influence of Tibetan Plateau*

As expected no Plateau run was far different from the control run in either large scale circulation or rain band positions or their rainfall. The simulated blocking ridges on the north side of the Plateau were about 3–4 DAM weaker than those in control run on the same day. For example, on Day 2 the blocking ridge in Fig.4c was weaker than that in Fig.4a. There was no low pressure over Tibetan Plateau, the result is similar to Nakamura et al. (1985). So no trough over the Yangtze River formed, in which the Meiyu frontogenesis occurred. As a result both the cold air from the north and warm air from the south mixed up over the SE coast of China, not over the Yangtze River. Hence up to 21 June main rain bands in China still stayed at the coast only with the rain cores of about 35 mm / day (Fig.7d), it was far less than that in control run (Fig.7a). It was not until on Day 5 that the main rain band shifted to the Yangtze River and began the onset of the Meiyu only after the Meiyu blocking ridges moved further east and the cold air from the north became unclear.

Of particular interest is that in the control run the rain areas along the Meiyu fronts were almost heavier in China than those along Baiu ones, but vice versa in no Plateau run (Table 2).

These differences may make us infer that the influence of the Plateau on Meiyu is to intensify the blocking ridge and block the cold air moving southward, to delay the onset date of

Meiyu, and to increase the Meiyu rainfall in China but to decrease it in Japan.

Table 2. Comparisons of 24–h Rainfall Centers (in mm) between the Control and no Plateau Runs along Meiyu Fronts (MFs) and Baiu Fronts (BFs).

Forecasted days	Control run		no Plateau run	
	MFs	BFs	MFs	BFs
Day 1	67	43	65	41
2	44	37	32	55
3	49	60	47	68
4	85	72	65	44
5	80	41	34	60
6	69	41	54	78

V. DISCUSSIONS AND CONCLUSIONS

1. It is well–recognized that the stationary fornt in South China in spring have, sharp contrast of temperature acress the front. Why does the thermal contrast disappears when the stationery front (Meiyu front) moves to the Yangtze River in early summer? Some papers explained that it was mainly caused by rapidly temperature rise over North China Plain(35–41 ° N, 113–120 ° E) in May due to sensible heat transfer from the ground to the atmosphere(Kato,1985). For the Meiyu of 1983, the fact that there is often an isolate dry area less than 40% of the RH in the lower troposphere over the North China Plain during pre–and post–Meiyu onset suggests that there exists dominant subsidence motion over the area in late spring and early summer. Hu (1986) also inferred this point. Therefore the warming due to subsidence and drying over the area to the north of the Meiyu front in pre–and post–Meiyu onset would reduce the thermal contrast, and increase the moisture contrast along the Meiyu front.

2. As shown from foregoing trajectory analyses the main vapour source is the Bay of Bengal for Meiyu. Since our analysis is chosen from a typical Meiyu year, we hope that our results could be representative for the normal Meiyu years.

As to the discrepancies of the moisture sources of Meiyu in papers of different authors in the past the rearons are threefold : firstly, earlier studies may infer intuitively that moisture of the Meiyu comes from the South China Sea based just on the instantaneous flow parttern on west flank of the western Pacific subtropical high; secondly, many analyses on water vapour flux and budget for Meiyu have been done based on instantaneous flow fields and led to ambiguously conclusions (Xu, 1958; Zhu, 1982). The instantaneous flow fields and their vapour flux fields are not able to replace the trajectory analyses, thirdly, even the trajectory analyses are made, but just tracked backwards for somewhat shorter time (say 4 days), the main source area still tracked to the South China Sea (Fig.2e). Only when tracking backward further, the main source over the Bay of Bengal will be clearly found. He et al. (1983) showed the distribution of averaged vertical–integrated water vapour flux over 11 Meiyu days in 1979, and fount that the strong and stable water vapour transport belt was extended from the Bay of Bengal to China.

From the trajectories at other points (near Chengdu and Changsha etc.) for 21 June– 5

July of 1983 (not shown) and from the flow pattern of the west extending of the western Pacific subtropical high in summer, it is likely that the Bay of Bengal is also the main moisture source of heavy rain for areas south of the Yangtze Rivev in summer, not just over the Yangtze River and in the Meiyu period.

From above analyses, wa have the following conclusions:

1. During the Meiyu period in East Asia there exists marked difference of the Meiyu front both in Chinese and in Japanese sides in temperature and moisture fields in the lower troposphere: on the main land there is weak temperature contrast, but quite large moisture contrast, and vice versa on Japanese side . The differences of the air–mass sources, the influences of the Plateau, and the diabatic heating of the cold air to the north of the front on the land may be the possible reasons.

2. During the Meiyu period of East Asia, there are different moisture sources. For Meiyu in mainland the Bay of Bengal is the main moisture source; for Baiu in Japan the moisture source is from the South China Sea and the western Pacific.

3. *It seems that the Tibetan Plateau has an prominent role in determining the rain band* position and the onset date of Meiyu: if there is the Plateau, the simulated rain band position and onset date are the same as the observed; if without the Plateau, the far less heavy rain bands stay longer in the SE coast of China, the onset date would postpone three days.

4. The moisture conditions over the source regions have some influences on Meiyu rainfall and rain band positions. If halfing the moisture only over the Bay of Bengal, from Days 4 and 5 on, the Meiyu and Baiu rainfall will cut by about 20 mm / day, respectively, but the position of the rain band does not change. If halfing the moisture over both the Bay of Bengal and the South China Sea, the Meiyu onset date in China will be one day earlier, and the Meiyu rain bands will shift northwards. It causes the Meiyu to break shortly and Meiyu rainfall to reduce dramatically. So for Meiyu rainfall forecast, the forecasters should pay much attention to the water vapour conditions over the both source regions.

5. Also the SST anomaly (especially over the equatorial area) during the period of pre–or post–Meiyu onset has some influences on the Meiyu rainfall in China 4 days later.

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