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Heavy Rainfall around the Suzuka Mountains (2)

——Synoptic Study——

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Abstract

Typical examples of the heavy rainfall around the Suzuka mountains being shown, the characteristics of precipitation distribution, the synoptic situation and the condition of upper air in these cases are analysed and the relations among them are investigated. Necessary conditions for the occurrence of this heavy rainfall are strong southeasterly or southwesterly wind and high humidity in the lower troposphere. The synoptic situation in the cases of heavy rainfall is that in which typhoon or cyclone generates such conditions. The typical orographic heavy rainfall with nearly neutral stability is supposed usually to have a characteristic wherein rain falls less intensely and continues longer, rather than in the case of convective rainfall. In the case of heavy rainfall with a convectively unstable state and low level strong southwesterly wind, such as the heavy rainfall in the last period of Baiu, it seems to be difficult to predict the area of heavy rainfall.

1. Introduction

In a previous paper (Gocho and Nakajima)[1], several cases of heavy rainfall around the Suzuka mountains during warm seasons of three years (1967–1969) were analysed, and some characteristics and problems of orographic rainfall were presented. Our observation with rain gauges has been continued. According to these observations including those by other government agencies for ten years (1967–1976), the number of days with daily precipitation of 100–200 nm and 200–300 mm were five and one a year, respectively; the number of days with more than 300 mm was one day every two years, on the average. In this paper, with typical examples of heavy rainfall from the observations for these ten years, the characteristics of precipitation distribution, the synoptic situation and the condition of upper air in these cases and the relations among them are investigated.

The observation points, the topographic situation around the mountains and their designation, etc. has been shown in a previous paper.[1] The examples described in this paper include five cases shown in previous papers.[1][2]

2. Typical examples of heavy rainfall

The distributions of daily precipitation (9h–9h JST) around the Suzuka mountains in eleven typical cases of heavy rainfall, the surface synoptic weather charts, the emagrams and the vertical distribution of winds, over Hamamatsu at a distance of about 120 km from the mountains to the southeast, at the nearest times when the rains fell most heavily respectively, are shown. The vertical distribution of wind for each case is indicated in the figure of precipitation distribution and the emagrams are indicated all together in Fig. 2. The courses of typhoons and cyclone over

24 hours for seven of the cases are shown in Fig. 4.

2.1. (a) Case of 25 Sep., 1968

This case of heavy rainfall has been analysed in detail (Gocho and Nakajima)[1] and the results are summarised as follows: As shown in Fig. 1, the heavy rainfall

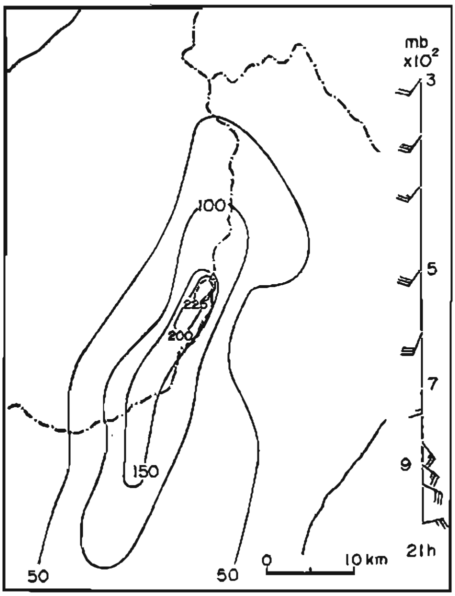

Fig. 1. Distribution of daily precipitation in mm (9^h–9^h JST) around the Suzuka mountains and the vertical distribution of wind (a long barb 10 knots) at 21^h over Hamamatsu, on 25 Sep., 1968.

area lay along the ridge of the mountains and the maximum precipitation of 225 mm was observed at a point just west of the ridge. Though a strong easterly wind was prevalent in the lower troposphere, a southwesterly wind was prevalent above the 600 mb level. The air was almost saturated and the stability was nearly convectively neutral, as a whole (Fig. 2(a)). The rainfall rate was considerably constant with the rate of about 5–20 mm/h and the time changes of the other meteorological factors at the surface were considerably small, for a period of more than 12 hours. Since typhoon 6816 in the west of Kyushu (Fig. 3) was travelling slowly southwardly (Fig. 4), the conditions of the upper air were considered to be steady. Evident convective echo was not found around the mountains by radar observation. Only weak and moderate echoes steadily dimmed the ground echoes of the mountains. Therefore this case of rainfall seems to have been brought about due to a stratiform cloud. Such a case is thought to be a typical orographic heavy rainfall.

2.2 (b) Case of 30 Aug., 1971

This case has been also analysed in detail (Gocho)[2] and the results are summarized as follows: The heavy rainfall area lay along the ridge similar to the case of (a) and the maximum precipitation of 626 mm, the largest one ever observed, was recorded at the same point as in the case of (a) (Fig. 5). An extremely strong easterly wind was prevalent below the 600 mb level with a strong southwesterly wind above that level (Fig. 5). Since the stability was remarkably convectively unstable

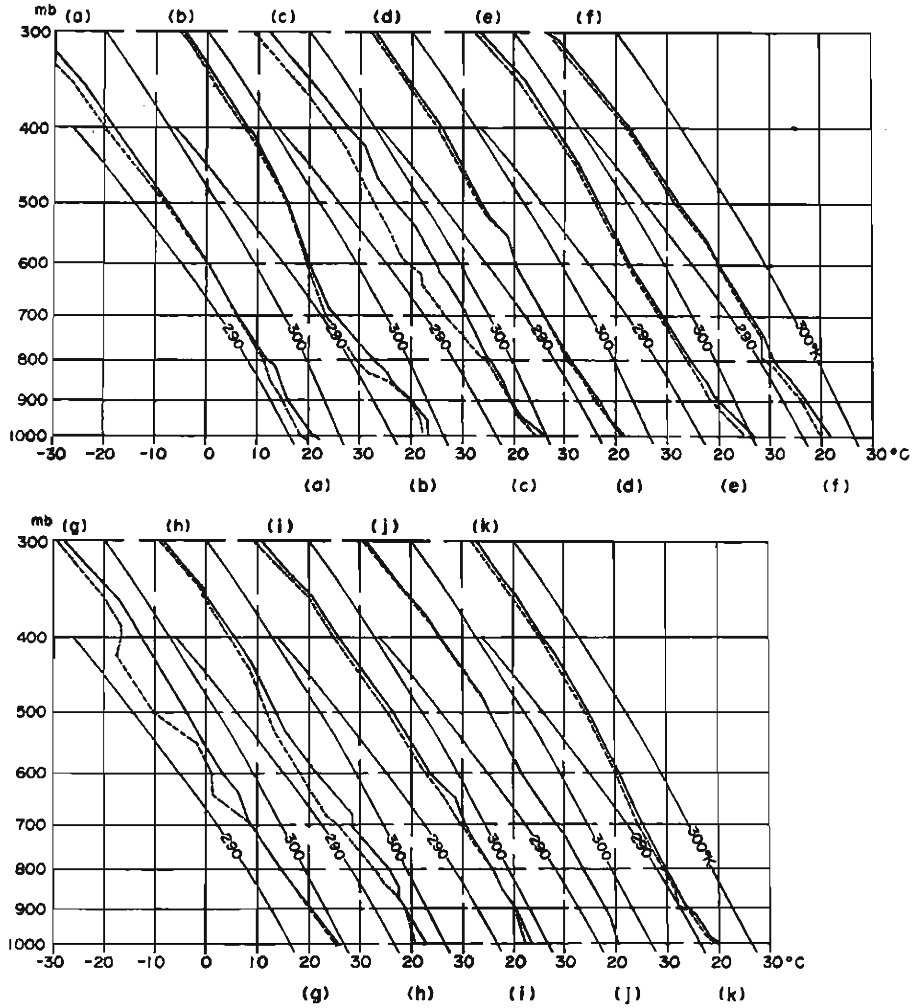

Fig. 2. Emagrams at Hamamatsu. Solid and dashed lines show temperature and pseudo-wet-bulb temperature respectively. Moist adiabats of 290° and 300°K are also shown.

(a) 21ʰ, 25 Sep., 1968.	(b) 21ʰ, 30 Aug., 1971.	(c) 9ʰ, 23 Jul., 1972.
(d) 9ʰ, 16 Sep., 1972.	(e) 21ʰ, 22 Aug., 1967.	(f) 9ʰ, 26 Sep., 1971.
(g) 9ʰ, 25 Jul., 1974.	(h) 21ʰ, 10 Jul., 1972.	(i) 9ʰ, 26 Aug., 1968.
(j) 21ʰ, 4 Jul., 1969.	(k) 21ʰ, 5 Jul., 1968.	

in the layer of 900–700 mb, active convection was expected (Fig. 2(b)). The maximum rainfall rate of 99 mm/h was observed at the same point of the maximum daily precipitation, while typhoon 7123 was over Shikoku at a distance of more than 200 km from the mountains to the southwest (Fig. 6 and Fig. 4). The intense rainfall resulted from the superposition of outer rainbands of the typhoon on the typical orographic rainfall such as the case of (a). The heavy rainfall around the mountains is thought to occur most frequently due to such superposition of the rainband of a typhoon on the orographic rainfall.

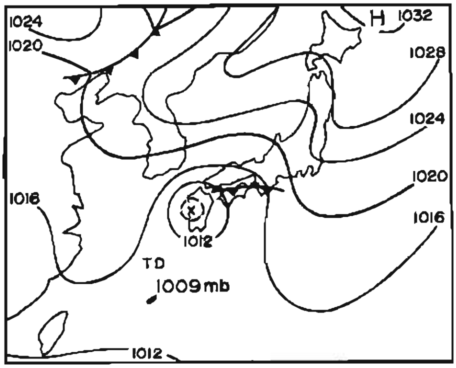

Fig. 3. Surface synoptic weather chart at 21^h on 25 Sep., 1968.

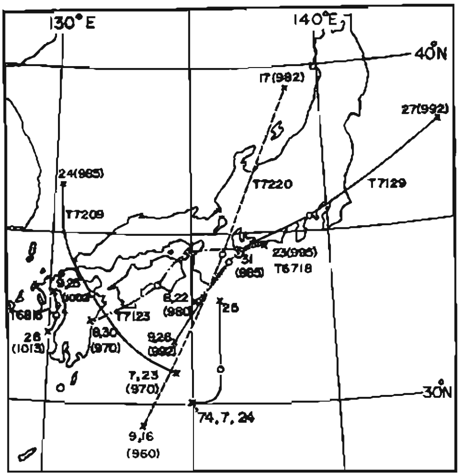

Fig. 4. Courses of typhoons and cyclone for 24 hours in seven cases. Numerals in the parentheses are surface pressures in mb at the center of typhoons and cyclon. × : position of the center at 9^h, ○ : position of the center at 21^h.

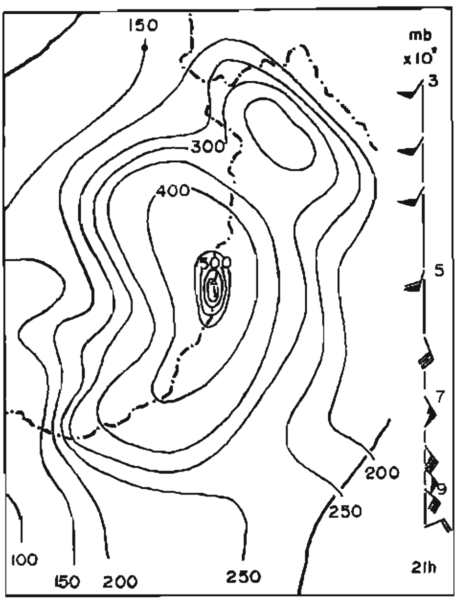

Fig. 5. Distribution of daily precipitation and the vertical distribution of wind at 21^h over Hamamatsu, on 30 Aug., 1971.

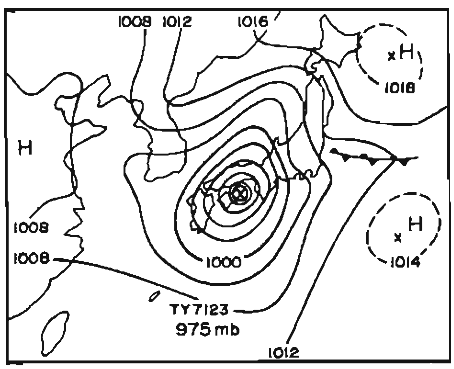

Fig. 6. Surface synoptic weather chart at 21^h on 30 Aug., 1971.

2.3 (c) Case of 23 Jul., 1972

The maximum precipitation of 167 mm was observed at the same point as in the previous cases just west of the ridge (Fig. 7). Although the heavy rainfall area also lay along the ridge, it shifted westward (toward the lee side of the mountains). A strong easterly wind was prevalent in the whole troposphere (Fig. 7). Generally, the heavy rainfall area along the ridge tends to shift westward according to the easterly component of wind in the upper troposphere, though wind usually veers according to altitude as in the previous cases. This case shows remarkable local concentration of rainfall, i.e. the heavy rainfall area was small and it rained only a little in the plain around the mountains. The state of the atmosphere was considerably convectively unstable in the deep layer below the 600 mb level, but it was relatively dry in the layer above 800 mb level (Fig. 2(c)). Typhoon 7209 travelled northwestwardly far off the south coast of Shikoku (Fig. 8 and Fig. 4). The strong southeasterly wind in the upper troposphere reflected the northwestward travel of the typhoon. The intense precipitation of about half of daily one falling within 2 hours was brought about by a large intense rainband generated in the south of Ise bay, which travelled slowly northwardly. For several hours after that time a stripe pattern of radar echoes, in which stripes inferred a kind of convective echoes were thin and in parallel with the wind direction, was seen over the mountainous region, but the rainfall rate was less than 1 mm/h.

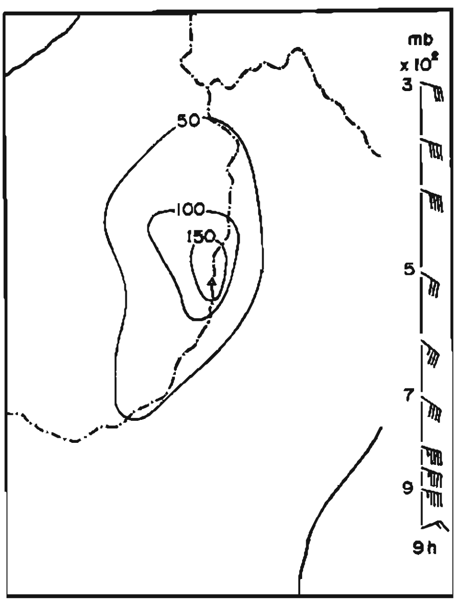

Fig. 7. Distribution of daily precipitation and the vertical distribution of wind at 9h over Hamamatsu, on 23 Jul., 1972.

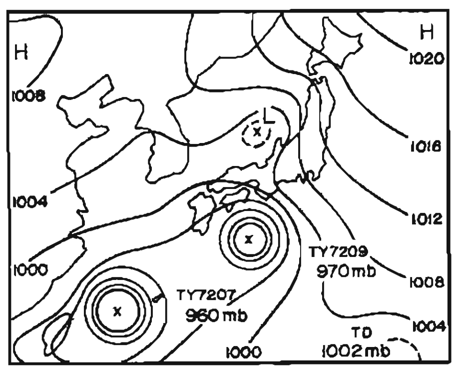

Fig. 8. Surface synoptic weather chart at 9h on 23 Jul., 1972.

2.4 (d) Case of 16 Sep., 1972

A heavy rainfall area with the second maximum precipitation of 476 mm lay along the ridge, but the area and the point of the maximum precipitation shifted somewhat northwestward compared with the previous cases (Fig. 9). As shown in Fig. 10 and Fig. 4, typhoon 7220 was travelling rapidly northwardly almost over and along the mountains. No observation at 21^h over Hamamatsu was made. It seems that much stronger winds than that shown in Fig. 9 had been prevalent during the period of the passage of the typhoon near the mountains. Although it was also problematic whether the emagrams for this case represented the state of the atmosphere during the whole period, the troposphere was almost saturated and the state was slightly unstable below the 800 mb level and slightly stable above that (Fig. 2(d)). This heavy rainfall could have been brought by the convective activity around the center of the typhoon. But it is interesting that the locality of rainfall similar to that in the previous case of (c) is evidently seen.

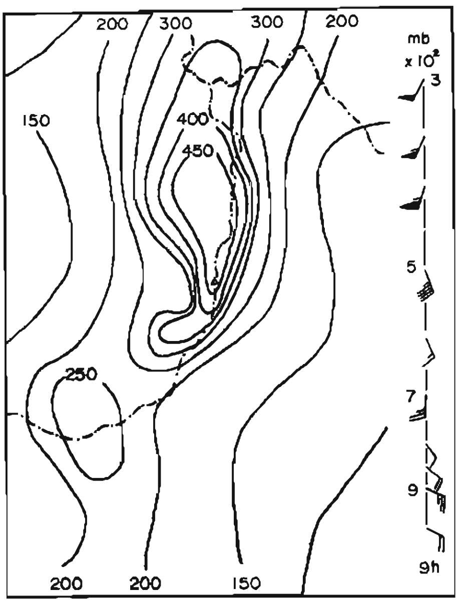

Fig. 9. Distribution of daily precipitation and the vertical distribution of wind at 9^h over Hamamatsu, on 16 Sep., 1972.

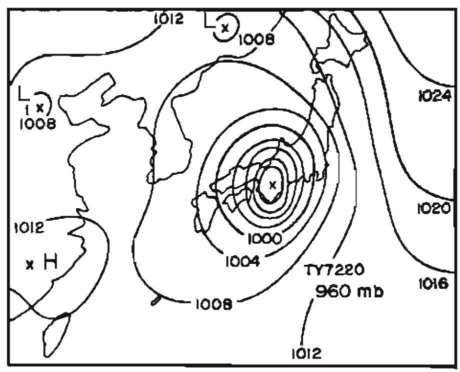

Fig. 10. Surface synoptic weather chart at 21^h on 16 Sep., 1972.

2.5 (e) Case of 22 Aug., 1967

In this case typhoon 6718 travelled along the east coast of the Kii peninsula, as seen in Fig. 11 and Fig. 4. Since in the next example a typhoon also travelled along the course similar to that of this case, this case is described for comparison. A heavy rainfall area lay along the ridge with the maximum precipitation of 240 mm at the same point just west of the ridge as in the case of (a) (Fig. 12). Though easterly winds were prevalent in the whole troposphere, it was considerably strong in the lower troposphere and weak in the upper (Fig. 12). The troposphere was almost saturated and the state was convectively unstable in the lowest thin layer and slightly stable or nearly neutral in the other layers (Fig. 2(e)).

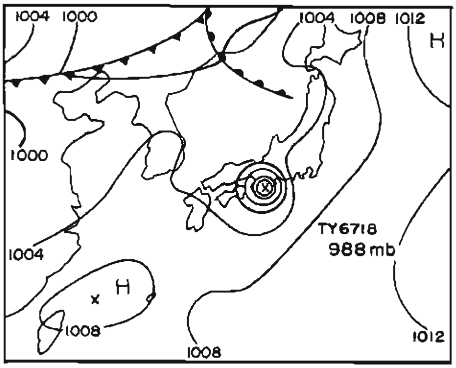

Fig. 11. Surface synoptic weather chart at 21h on 22 Aug., 1967.

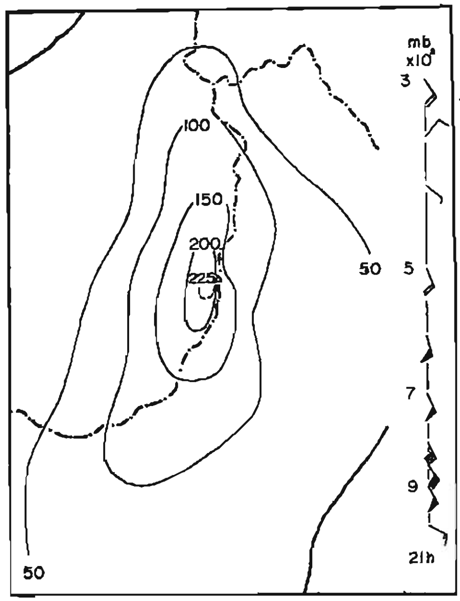

Fig. 12. Distribution of daily precipitation and the vertical distribution of wind at 21h over Hamamatsu, on 22 Aug., 1967.

2.6 (f) Case of 26 Sep., 1971

Although the small heavy rainfall area with the maximum of 200 mm lay around the ridge, the main long heavy rainfall area with 241 mm lay over the east plain or foot of the mountains in parallel with the ridge, different from the previous cases (Fig. 13). It was also problematic whether the results of upper air observation was representative, since the typhoon 7129 had travelled near the mountains (Fig. 14 and Fig. 4). A southeast wind with the maximum of about 20 knots was prevalent in the lowest troposphere and a southwest wind was in the layer above 800 mb level. The troposphere was almost saturated and the state was convectively unstable in the thin layer of lower troposphere and slightly stable or nearly neutral in the other layers, similar to the case of (e) (Fig. 2(f)). The typhoon travelled along the east coast of the Kii peninsula as in the previous case of (e), but the travelling speed in this case was much larger than that in the case of (e). The speed was about 50 km/h in this case compared with 10–15 km/h in the case of (e). It is inferred that the heavy rainfall in the case of (e) was brought about mainly by the contribution of typical orographic rainfall of long duration, while the cause in this case was rather by the contribution of active convection around the center of the typhoon than by the relatively short and weak contribution of orographic rainfall.

2.7 (g) Case of 24 Jul., 1974

The six above-mentioned cases were connected with typhoons. But following five cases are connected with cyclones and fronts.

Heavy rainfall occurred with a thunderstorm when an occluded cyclone travelled

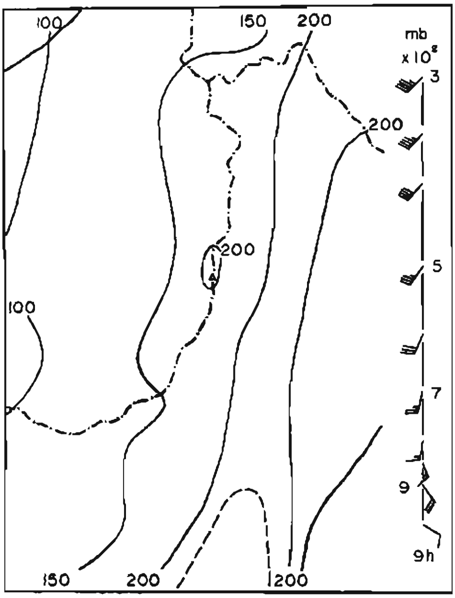

Fig. 13. Distribution of daily precipitation and the vertical distribution of wind at 9^h over Hamamatsu, on 26 Sep., 1971.

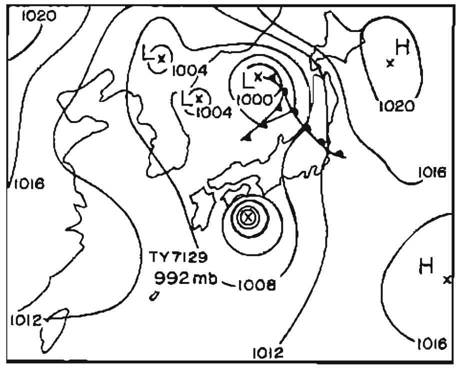

Fig. 14. Surface synoptic weather chart at 21^h on 26 Sep., 1971.

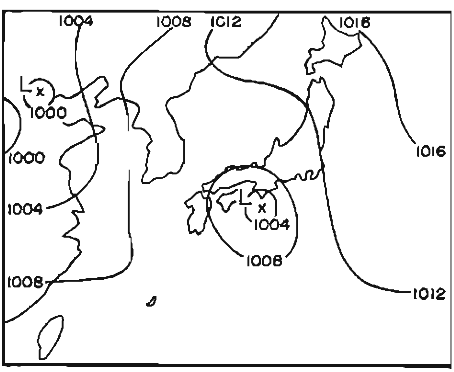

Fig. 15. Surface synoptic weather chart at 9^h on 25 Jul., 1974.

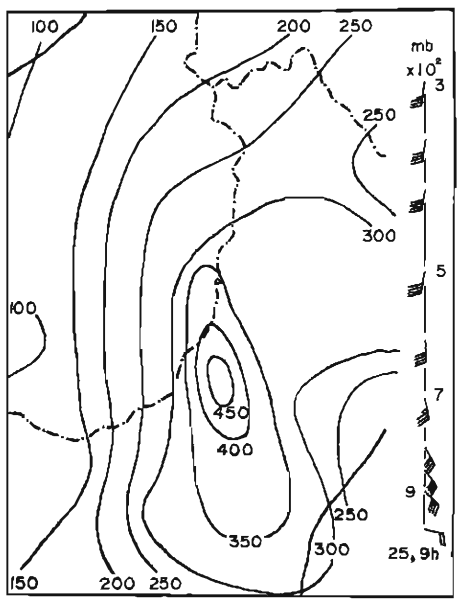

Fig. 16. Distribution of daily precipitation on 24 and the vertical distribution of wind at 9^h over Hamamatsu on 25, Jul., 1974.

northwardly far off the south coast of the Kii peninsula (Fig. 15 and Fig. 4). Different from most of the precipitation distributions in the previous cases, the heavy rainfall area lay on the windward side of the mountains, and the third maximum precipitation of 472 mm was observed on the windward slope (Fig. 16). A strong southeasterly wind was prevalent below the 700 mb level and a southerly wind above that level (Fig. 16). The state of the atmosphere was intensely convectively unstable in the layer below about the 650 mb level and it was saturated in the layer (Fig. 2(g)). The intense convective instability could also be inferred by the appearance of a thunderstorm. It was found by radar observation that irregular strong convective echo cells generated near the east coast of the Kii peninsula travelled repeatedly northwardly.

2.8 (h) Case of 10 Jul., 1972

This was typical example of heavy rainfall in the last period of Baiu. Baiu front extended on the whole from west to east over Western Japan and small cyclones were travelling eastwardly along the front (Fig. 17). A heavy rainfall area with the maximum precipitation of 215 mm, deviated considerably from the Suzuka mountains and lay on the other mountainous region with the tops of height of about 500 m, extending from west-southwest to east-northeast (Fig. 18). Strong west-southwest wind nearly in parallel with the direction of the axis of the heavy rainfall area was prevalent in the whole troposphere except for the lowest layer (Fig. 18). The state of the atmosphere was unstable in the layer of 900–700 mb and the air was not so moist (Fig. 2(h)). The reason for the relatively low humidity might be that Hamamatsu was situated in the lee side of the mountains. Orographic rainfall was expected on account of the large normal component of the wind to the ridge. But the Suzuka mountains appeared to have little effect on the distribution of rainfall, because the heavy rainfall area was not along the ridge. In such heavy rainfall with strong southwesterly wind and intense convective instability, convection seems to be rather active and rainfall by a meso-scale disturbance would be more dominant than the orographic one.

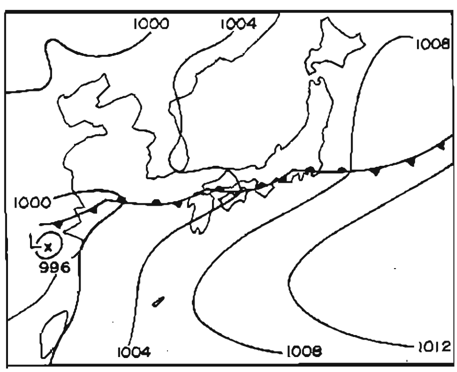

Fig. 17. Surface synoptic weather chart at 21^h on 10 Jul., 1972.

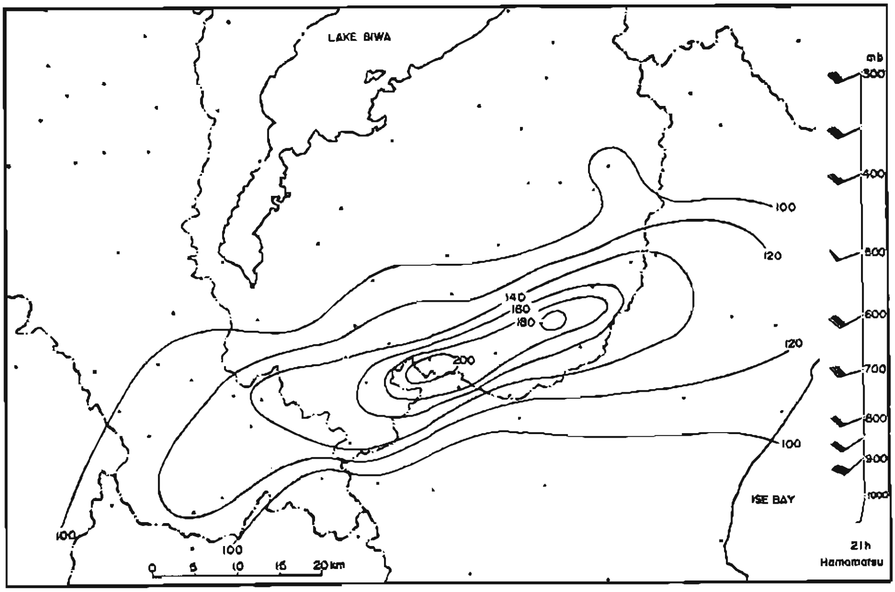

Fig. 18. Distribution of daily precipitation and the vertical distribution of wind at 21^h over Hamamatsu, on 10 Jul., 1972.

2.9 (i) Case of 25 Aug., 1968

This case is represented in comparison with the previous case of (h). A stationary front lay along the south coast of Western Japan and typhoon 6810 was stagnant far from Kyushu (Fig. 19). A west-southwesterly wind was prevalent in the whole troposphere as in the case of (h) (Fig. 20). The maximum precipitation of 134 mm, somewhat less than those of the previous cases, was observed at a distance of several km northwest from Mt. Gozaisho, a peak of the mountains (Fig. 20). The atmosphere was nearly saturated and stability was nearly convectively neutral as a whole

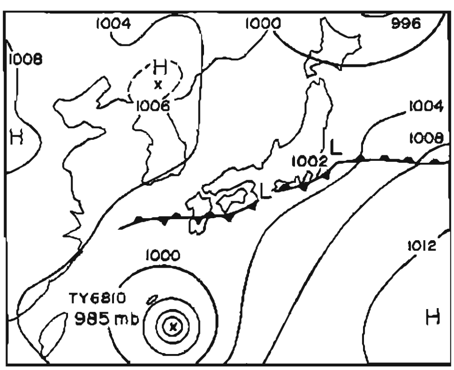

Fig. 19. Surface synoptic weather chart at 9^h on 26 Aug., 1968.

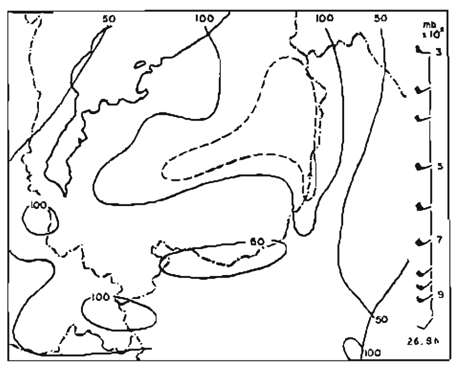

Fig. 20. Distribution of daily precipitation on 25 and the vertical distribution of wind at 9^h over Hamamatsu on 26, Aug., 1968.

(Fig. 2(i)). The distribution of rainfall appeared to be composed of the following two components; one was heavy rainfall area in Shiga prefecture nearly in parallel with the front, and the other one was along the ridge. It could be inferred that convective activity was somewhat less and the orographic component of rainfall appeared more obviously than those in the case of (h).

2.10 (j) Case of 4 Jul., 1969

In this case a westerly wind was also prevalent in the whole troposphere except the lowest layer (Fig. 21). The atmosphere was almost saturated and the stability was nearly neutral (Fig. 2(j)). A cyclone in the vicinity of the Strait of Korea was travelling east-northeastwardly and a warm front lay on the Kii peninsula (Fig. 22). The maximum precipitation of 108 mm was not so large and a considerably symmetric heavy rainfall area about the ridge lay along the mountains (Fig. 21). It may be said that this case is a typical orographic rainfall in the case of a westerly wind.

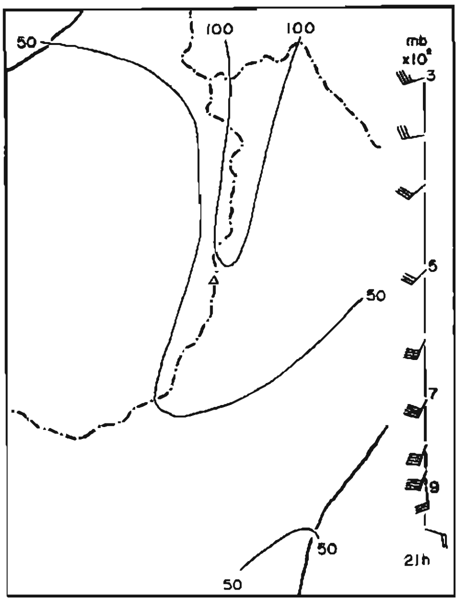

Fig. 21. Distribution of daily precipitation and the vertical distribution of wind at 21^h over Hamamatsu, on 4 Jul., 1969.

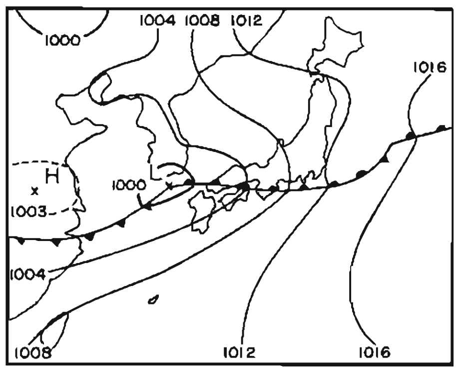

Fig. 22. Surface synoptic weather chart at 21^h on 4 Jul., 1969.

2.11 (k) Case of 5 Jul., 1968

Though the previous three examples were cases in which westerly winds were prevalent in the whole troposphere, in this case a westerly wind was prevalent above the 600 mb level and an easterly wind below that (Fig. 23). This case is similar to that of (a) with respect to the vertical distribution of wind. But, although the state of the atmosphere was slightly convectively unstable below 900 mb level, it was obviously stable above that, different from that in the case of (a) (Fig. 2(k)). The air was nearly saturated (Fig. 2(k)). This stable stratification and the vertical distribution of wind corresponded to the fact that this region was situated north of the warm front which extended from a cyclone located over Kyushu and was travelling northeastwardly (Fig. 24). On the other hand the fact that rain fell considerably steadily reflected the stable stratification. The maximum precipitation of 150 mm was certainly observed around the peak, but the heavy rainfall area was small. Furthermore large precipitation of more than 100 mm was observed widely over the plain in Mie prefecture (windward plain for the wind direction in the lower troposphere) (Fig. 23). The reason seems to be that the vertical speed of air flow over the mountains does not become so large on account of the stable stratification of the atmosphere and that rainfall is also less affected by the flow than in the case of the other stability. However it should be understood that rain falls considerably heavily even in the north of a warm front.

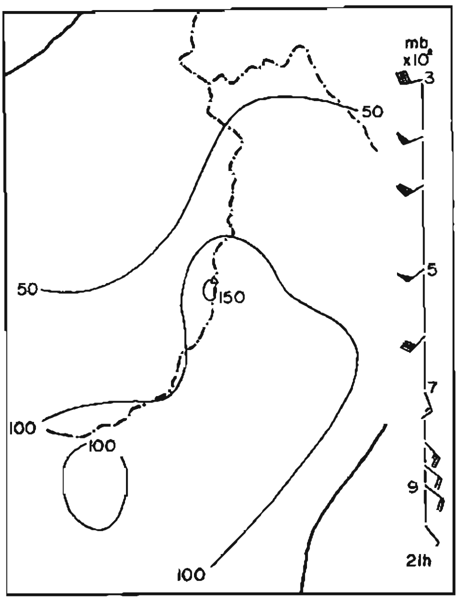

Fig. 23. Distribution of daily precipitation and the vertical distribution of wind at 21h over Hamamatsu, on 5 Jul., 1968.

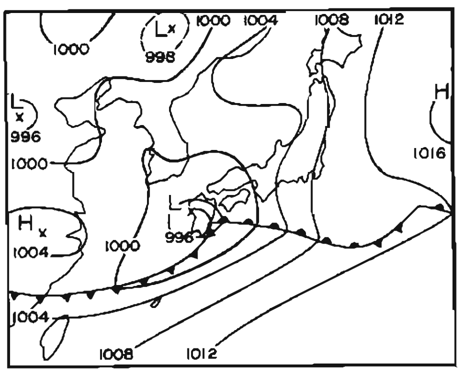

Fig. 24. Surface synoptic weather chart at 21h on 5 Jul., 1968.

3. Discussions

As the common necessary conditions for the occurrence of heavy rainfall around the Suzuka mountains, relatively strong southeasterly or southwesterly wind and relatively high humidity, in the lower troposphere, can be taken. As the synoptic situation, a typhoon or a cyclone is necessary in the cause of such strong wind at low altitude. On the whole, rainfall rate tends to increase according to wind speed at low level in the case of southeasterly wind, though it has not been described.

In the several cases mentioned above, fronts extended nearly from west to east in the region of Western Japan. But our objective area is small compared with the scale of the fronts and we are mainly interested in the precipitation distributions from west to east. Therefore the positions of the fronts were not our concern in the present study.

In any stability of the atmosphere heavy rainfall could occur, probably except in an intensely stable condition. Especially in the case of nearly neutral stability, of course satisfying the other condition, the feature of typical orographic rainfall seems to become obvious. It may be a characteristic of typical orographic heavy rainfall that rain usually falls less intensely and continues longer, rather than in the case of convective rainfall, as in the case of (a). In order to make a model of such typical orographic rainfall, a numerical experiment had been carried out on the assumption of a saturated and pseudo-adiabatic atmosphere (Gocho)[3]. It was found that in the case of mountains with a scale similar to that of the Suzuka mountains it was difficult to explain the observed distribution of rainfall only by the airflow over the mountains, but that it could be explained by the existence of a seeding light rain, falling from an upper cloud. In the case in which state is convectively unstable and southwesterly wind is prevalent at low level as in the case of (h), typical heavy rainfall in the last period of Baiu, it is difficult to predict where heavy rainfall might occur.

Even though wind is weak in the lower troposphere, heavy rainfall with a daily maximum precipitation of about 100 mm sometimes occurs anywhere, over mountains or plains. But in such a case, it is inferred that such intense rain falls in only a few hours and that the heavy rainfall area is relatively small. It is usually a heat thunderstorm.

Comparing the case (c) with that of (g), both of the states were considerably convectively unstable in the deep layers under about the 600 mb level, but a moist layer in the case of (c) was limited under 800 mb level. Though in the case of (c) a strong southeast wind was prevalent in the whole troposphere, in the case of (g) a strong southeast wind prevailed under the 700 mb level and a strong southerly wind above that. Synoptic scale disturbances were far from this region in both cases. An intense rainband formed in the case of (c), while irregular convective cells were observed in the case of (g). But those reasons are not yet clear. It is still a question where convective cell is generated on a given upper air condition.

As mentioned above, the locality of rainfall was a remarkable feature in the precipitation distribution of the case of (c). Such a feature appears more or less in the distribution of almost all cases of heavy rainfall in which a strong southeasterly wind is prevalent in the lower troposphere. It seems to be caused by the effect of Ise bay, through which the moist air was transported directly toward the Suzuka mountains.

These above mentioned characteristics must be also confirmed statistically.

4. Conclusions

Necessary conditions for the occurrence of heavy rainfall around the Suzuka mountains are strong southeasterly or southwesterly wind and high humidity in the lower troposphere. The synoptic situation in the case of heavy rainfall is that in which a typhoon or cyclone generates such necessary conditions.

The typical orographic heavy rainfall with nearly neutral stability is supposed usually to have a characteristic that rain falls less intensely and continues longer, rather than in the case of convective rainfall. This characteristic appeared in the difference of the precipitation distributions brought by the difference of travelling speeds of typhoons. In the case of heavy rainfall with the condition of convectively unstable state and low level strong southwesterly wind, such as the heavy rainfall in the last period of Baiu, it seemed to be difficult to predict the area of heavy rainfall.

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