# Heavy Rainfalls and Disasters

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## Abstrat

There are various kinds of heavy rainfall. Some of them concentrate in a small area and others spread over considerably large areas. Primarily we will discuss about the scale of the meteorological phenomena. Possibility of the heavy rainfall can be found by the analysis of the global circulation system of the atmosphere. There must be amplification of the planetary wave near Japan to explain the heavy rainfall there, both in winter and summer seasons. In such cases, a potential energy increase is immediately converted into kinetic energy. In winter, warm moist current can be introduced into Japan by such amplified westerly waves.

However, the position and the intensity of heavy rainfall is decided by atmospheric phenomena of smaller scale and complicated orographic conditions. To explain these mechanisms, we have shown many examples in various districts. Moving periodic rainfall of relatively strong intensity can be explained by the so-called meso-scale meteorological disturbances or meso-scale spiral rain bands in typhoons. But, extraordinary strong and concentrated heavy rainfall may occur by the special conditions relating to the orography.

By these analyses, we can understand the relation between the intensity and the area of heavy rainfall for each meteorological and orographic conditions. However, for the prevention of hydrological disasters, we must consider the relation between the scale of heavy rainfall and the scale of rivers and the other objects which can cause disasters. We have discussed the direct and the background cause of such disasters relating them with the scale of heavy rainfall.

## 1. Introduction—Scale of Meteorological Phenomena—

South East Asia is located in the humid subtropical and tropical region. In this region, monsoon phenomena are predominant and westerly currents in the middle latitudes have climatic troughs near Japan. In this paper, we want to discuss the heavy rainfalls in Japan while relating to the disasters made by them. Then, we want to compare the behaviors of rainfall in subtropical and tropical regions in South East Asia.

In Japan, maximum daily amount of precipitation is about 1000 mm, the hourly amount of that is about 150 mm, and the maximum amount in 10 min. is about 40 mm. On the other hand, the largest area with rainfall over 100 mm/day is about 20,000 km$^2$ and in the smallest case it is about 100 km$^2$. Heavy rainfalls in larger areas are caused mainly by typhoons, and the heavy rain concentrating in smaller areas occur by convective thunderstorms during the rainy season ("Baiu").

Thus, precipitation has locality in its distribution and much variation in its intensity. However, from the climatic point of view, the location and intensity of rainfall area has some regulality. The planetary wave pattern in the westerly jet stream and the position and intensity of the Pacific anticyclone has intimate relation to the climatic distribution of the rainy areas in Japan.

Intensity of rainfall has a large correlation with the vertical stability of the air mass, and also has an intimate relation with the orographic condition. In general, the mean amount of precipitation increases with height. For example, this rate is 200 mm/100 m for the case of western Japan. Of course, on mountains higher than about 3000 m, the amount of precipitation begins to decrease again because of the lack of the amount of vapour in the atmosphere.

To understand the behavior of rainfall, it is convenient to classify the meteorological phenomena into several types according to their horizontal scales. In the case of thunderstorms in summer season, the horizontal scale of the individual heavy rain area is only 1 km or smaller, and the vertical scale of a cloud system is 10–20 km. The main energy source of such convective motion is potential energy. When a cold current comes from the north to Japan in the upper troposphere and moist warm current come from south, the potential energy increase in the atmosphere over Japan and upward transport of vapour by vertical current also intensify the unstableness of the air coloumn. In the severer thunderstorm, the intensity of precipitation can reach more than 20 mm/10 min.

We can find frequently during the Baiu season, disturbances of small scale with a wave length of about 100 km and period of 1–3 hours which are called meso-scale disturbances. These disturbances have a most intimate relation to the occurrence of concentrated heavy rainfall. The main energy source of these disturbances is potential energy, which is the same as the case of convection described above, but kinetic energy due to the vertical shear in the general horizontal current is also very important. So, it is a kind of gravitational wave, but occurs only in wet areas, and the release of latent heat is important for the supply of potential energy.

Disturbances of the scale of about 1000 km is the so-called frontal wave, and the main energy source is the difference of the potential and kinetic energy in two air masses divided by the front. Waves of this type are active mainly in the lower troposphere, and the forecasting of the movement and the intensification using the numerical analysis of upper atmmosphere is very difficult. However, it is also important for understanding the distribution of heavy rainfall.

Disturbances of the scale of 3000–4000 km is known as synoptic or baroclinic waves. The main energy source of this wave is potential energy due to the temperature gradient from south to north in the middle latitudes. Waves of this type are not limited to the lower troposphere but also extend to the deep tropospheric layer. This wave can travel along the jet stream around the whole earth from west to east. This kind of wave corresponds to the general weather condition, and has no direct relation with the intensity of rainfall.

The disturbance with the largest scale on the earth is known as planetary or barotropic wave. This wave is nearly horizontal and the main energy source of this wave is not potential energy but the kinetic energy of general current rotating with earth.

This kind of wave can be seen not only on the earth but also on the other planets and the sun. This wave movse slowly westward or eastward and in some cases it becomes stationary. This wave is very important for climatic conditions in the world.

We have classified the meteorological disturbances into 5 types according to those horizontal scales, and described the main energy sources of these waves. But the orographic effect is also very important for all kind of waves with various scales. Smaller orographic conditions can be combined with smaller scale waves, and larger orographic one can be combined with larger waves. In the following sections we want to discuss every scale of disturbance relating to the disasters produced by that wave.

## 2. Large Scale Phenomena

Orographic conditions in the Japanese islands is much complicated and the distribution of rainfall amount is also variable. However, there is some regularity in the rainfall pattern when we pay attention to the intensity and position of the Pacific anticyclone. Fig. 1 shows the relation between the position of heavy rainfall area and the Pacific anticyclone in the 500 mb weather chart for the warm season. When an upper trough line located at the eastern side of the Japanese Islands, type A or B appears and the Pacific anticyclone is divided into two portions and the western part of the anticyclone is isolated over the East China Sea. When these types prevail for 1-2 months, the northern part of Japan suffers from cold summer damage, and south-

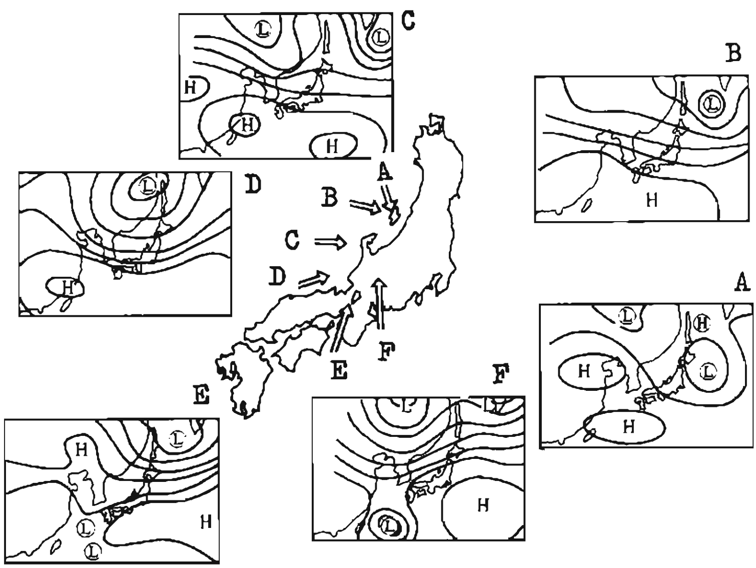


Fig. 1. Relation between the distribution of heavy rainfall and the type of 500 mb chart.

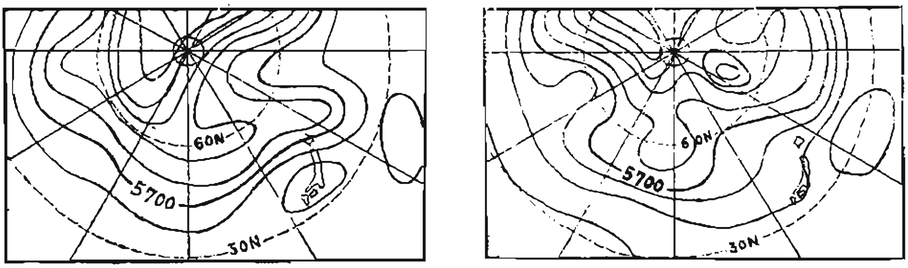


Fig. 2. A) Mid summer type-8 days mean 500 mb chart (29 July to 4 August 1960), B) Cool summer type-(9 to 16 August 1960)

western Japan suffers from hot dry summer damage. In these cases, the Japan Sea side of middle Japan have frequent heavy rainfalls, while the whole of middle Japan has frequent thunderstorms due to the instability of air columns. When the anticyclone with its center over the East China Sea extends eastward to the south sea of Japan, types of C or D appear. In these cases, the Japan Sea side of middle Japan also has heavy rainfall, but the center of heavy rainfall shift to westward. In extreme cases, the center of heavy rainfall comes to north Kyushu. When the Pacific anticyclones located over the south-east sea of Japan and the upper trough with a cyclone or typhoon exit over the East China Sea, types E or F appear. In these cases, the Pacific side of Japan has heavy rainfall. Thus warm moist currents approach Japan along the edge of the anticyclone, so the mean location of heavy rainfall is decided by the position of the Pacific anticyclone. The direction of warm moist current is indicated by arrows in Fig. 1. The various types of Pacific anticyclone mentioned above is not local phenomena near Japan but also has relation to the character of the general circulation of the atmosphere. Fig. 2 A shows an example of mid summer type in western Japan corresponding to types A and B in Fig. 1 using an 8-days mean 500 mb chart (29 July to 4 August 1960). Fig. 2 B shows an example of cool summer type in the western Japan corresponding to types E and F in Fig. 1 (8 days mean 500 mb chart from 9 to 16, August 1960). In the case of Fig. 2 B, the trough line over the East China Sea does not extend to Siberia, but it becomes ridge in the northern part. In the other cases, this trough extends to the north and a broad deep trough appears to the west of Japan.

In winter season in middle latitudes, the amount of precipitation is small because of low temperature and small content of vapour in the atmosphere.

But when a warm, southerly air current flows up to the middle latitudes in some portion, the rainfall amount may increase there. So, a warm winter corresponds to a rainy winter and a cold winter to a dry winter. In the case of summer, a hot summer corresponds to a dry summer and a cold summer to a rainy summer. The reason is that the cold air from north meets with warm air and potential energy increases along the frontal region between the two air masses and becomes unstable. On the other

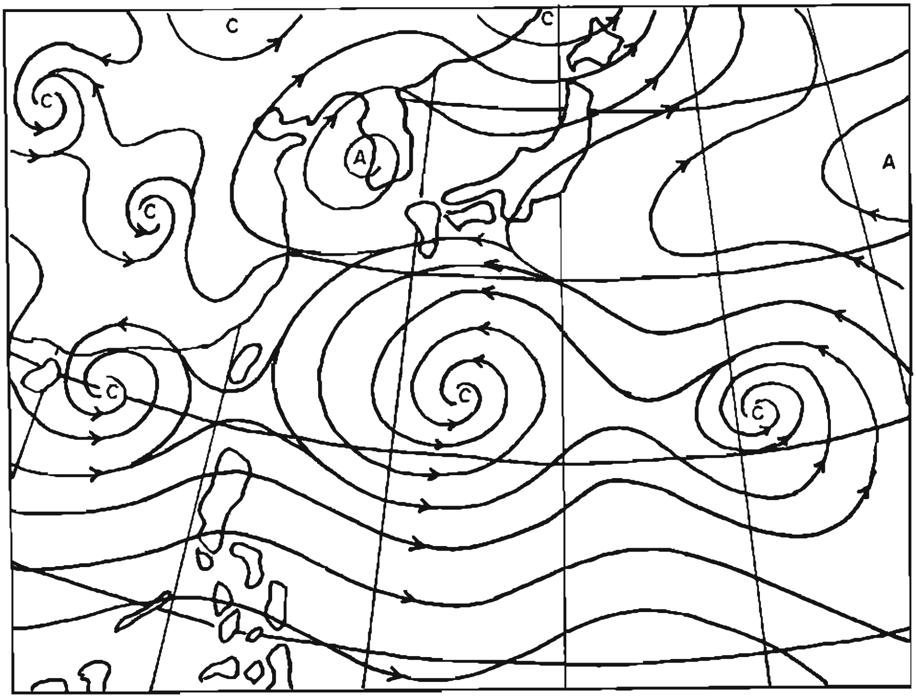


Fig. 3. Stream lines in 850 mb surface at 21 LST 17 July 1972.

hand, it is difficult to become unstable within one uniform air mass without cold air.

Thus, for the rainfall pattern in the South East Asia, the direction and the intensity of monsoon current is very important. Between the planetary wave in middle latitudes and the monsoon, there are intimate relations. Then, we must analyse the general circulation both in middle latitudes and in low latitudes to understand the broad pattern of rainfall in South East Asia. Fig. 3 shows a example of 850 mb streamlines when heavy rainfall occurs both in Japan and Philippines. On 18 July 1971, two typhoons appeared in East Asia as can be seen in Fig. 3. The Philippines were located in the ridge between these two typhoons, and this ridge line stayed there for several days. Then, the monsoon current over the South China Sea maintained a SW direction for a long time and the western coast of Luzon Island had heavy rainfall for 4 days, the total amount reaching 1000 mm/4 days (Fig. 4). The Baiu front remained along the southern coast of Japan until 14 July and the combined effect of this front and the typhoon caused heavy rainfall in western Japan. But after that, the Baiu front went to the northern part of Japan, and the heavy rainfall area in Japan also moved to the northern part. Thus, a typhoon in the middle region between the Philippines and Japan is affected by the direction and intensity of the monsoon in this area. And

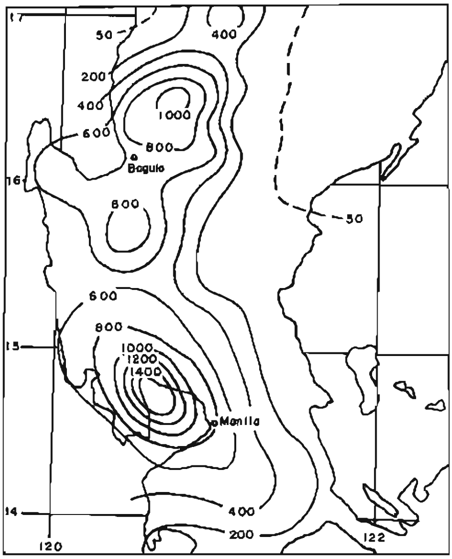


Fig. 4. Distribution of the amount of the rainfall in the last 10 days of July 1972 in Luzon Island. (unit mm)

these typhoons also appear and move according to the condition of the general circulation pattern in both middle and low latitudes.

## 3. Mutual relationship between larger and smaller scale phenomena

As mentioned in the previous section, a large scale pattern of general circulation can explain the distribution of rainfall, but the intensity and the detailed locality of rainfall is determined by smaller scale meteorological phenomena. In respect to this, we would like to show some examples.

The first example is for the winter season. Fig. 5 shows the 500 mb chart at 21 LST, 16 March, 1965. A developed cut-off cold vortex is seen to be surrounded by a strong jet stream. The wind velocities along the jet stream axis are 30–50 m/sec, and in the southern part of the jet stream the wind is especially strong. This cut-off cold vortex was created initially in a deep trough at 120 E on 14 March, and moved southward to the East China Sea increasing its intensity. From 16 March, this vortex turned eastward to the sea east of Japan weakening its intensity.

It is seldom that such a developed cold vortex comes down as far as western Japan. Therefore, there were many kinds of extraordinary disasters in western Japan. However, a number of disasters were not directly caused by the upper cold vortex but by

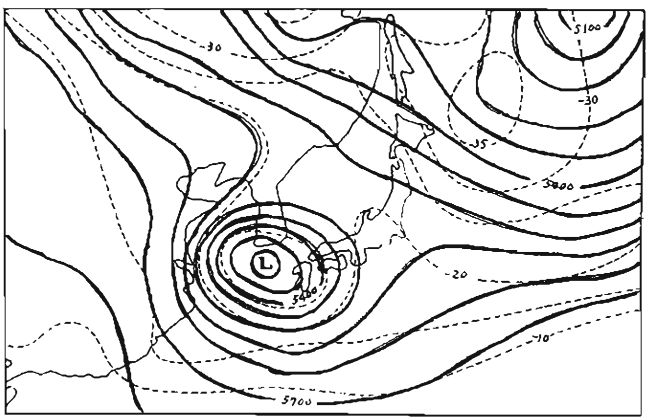


Fig. 5. 500 mb chart at 21 LST 16 March 1965. (black lines: isoheights, dotted lines: isotherms)

the meterological phenomena of smaller scale in the lower troposphere. Fig. 6 shows the 850 mb chart of 21 LST 16 March. There are two kinds of surface lows in this chart. One of them is located in almost the same place as the center of the upper cold vortex, but the other occluded one over the Kinki District was located at the eastern boundary of the upper cold vortex. As can be seen from the isotherms (broken lines) in this figure, a warm air current flowed in the lower troposphere along the boundary of the upper cold vortex. Then, a secondary low appeared in this portion, and this secondary cyclone was the main cause of the various disasters.

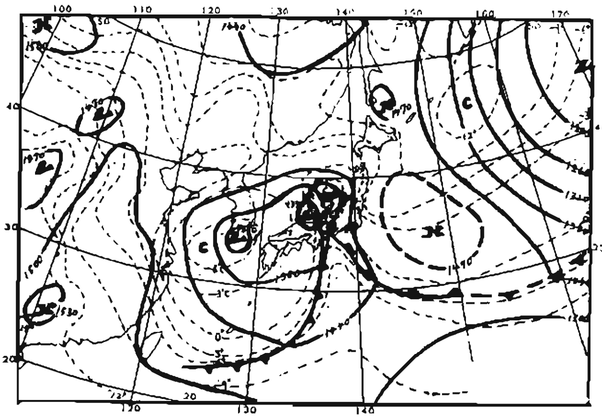

Fig. 6. Same as Fig. 5 but for 850 mb.

Fig. 7 shows the local surface weather map on 15 LST (6GMT) 16 March. Low level warm currents could easily flow into the inner part of Japan through such straits as Bungo, Kii and Ise Straits. On 15 LST, a warm surface current with a temperature of 14°C flowed into Kii Straits, and the difference of temperatures between this current and cold air 200 km north-west of this current was 14°C. Also in the middle part of Kii Penninsula, there was cold air of 6°C. As can be seen from isobars in this figure, a small surface low presusre appeared over the Kii Strait because of this warm surface current.

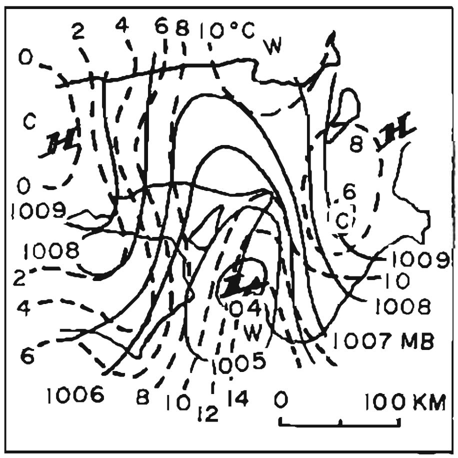


Fig. 7. Same as Fig. 5 but for the surface at 15 LST 16 March.

Fig. 8 shows the distribution of the greatest depth of the snow accumulation on 16, 17 March. In an ordinary winter, snowfall occurs mainly over the Japan Sea side of Japan by the northwesterly monsoon. However, in this case, heavy rainfall concentrated in the Pacific coast of the western Japan, and in some places the total amount of rainfall reached 100 mm, while on the Japan Sea side, rainfall was very slight. This rainfall became snowfall in areas with temperatures lower than 4°C, as shown in Fig. 7. Thus the snowfall concentrated in the middle part of the Kinki district as can be seen in Fig. 8. There was no snow or rain in the northern part and it was

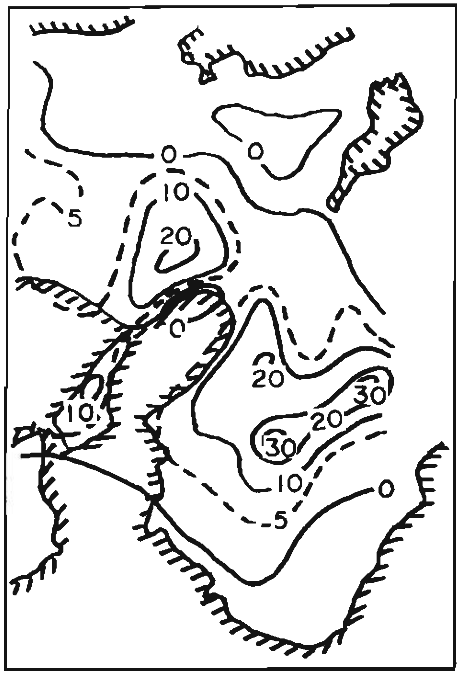


Fig. 8. Distribution of the greatest depth of the snow accumulation of 16-17 March. (unit cm)

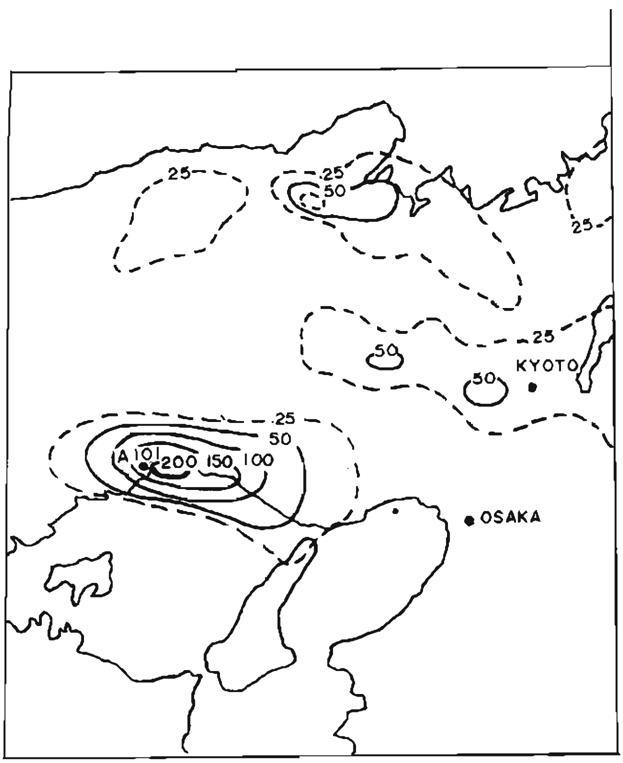


Fig. 9. Distribution of the daily amount of rainfall for 18 July 1971. (unit mm)

too warm in the southern part. Because of this abnormal snowfall, there were various kinds of damage in the forest and also in the urban area. The specific weight of such a warm snow is very large, 0.4, but it is only about 0.1 in colder regions.

As described above, this disastrous heavy snowfall was caused by the combined effect of the large scale upper cold vortex, meso-scale disturbance in the lower troposphere, orographic conditions of the Kinki district and the delicate difference of the temperature over this area producing the change from snow to rain. In this case, not only the disastrus snowfall but also the various kinds of meteorological disasters such as the damage of ships by strong wind and dense fog, damage of electric power by thunderstorm, avalanche in the mountainous areas all occurred simultaneously in western Japan.

The second example is for the summer season. We want to explain this example according to the analysis by H. Edagawa. On 18 July, 1971, there was a typical case of concentrated heavy rainfall in the western Japan. Fig. 9 shows the daily amount of precipitation in this case. This figure shows that the area with the rainfall of more than 25 mm/day is 90×40 km and the area of 200 mm/day is only 10×5 km. Also, in this case, a cut off cold low in the upper troposphere came down from the eastern Siberia to the Japan Sea. Fig. 10 shows the 500 mb chart on 21 LST 18 July.

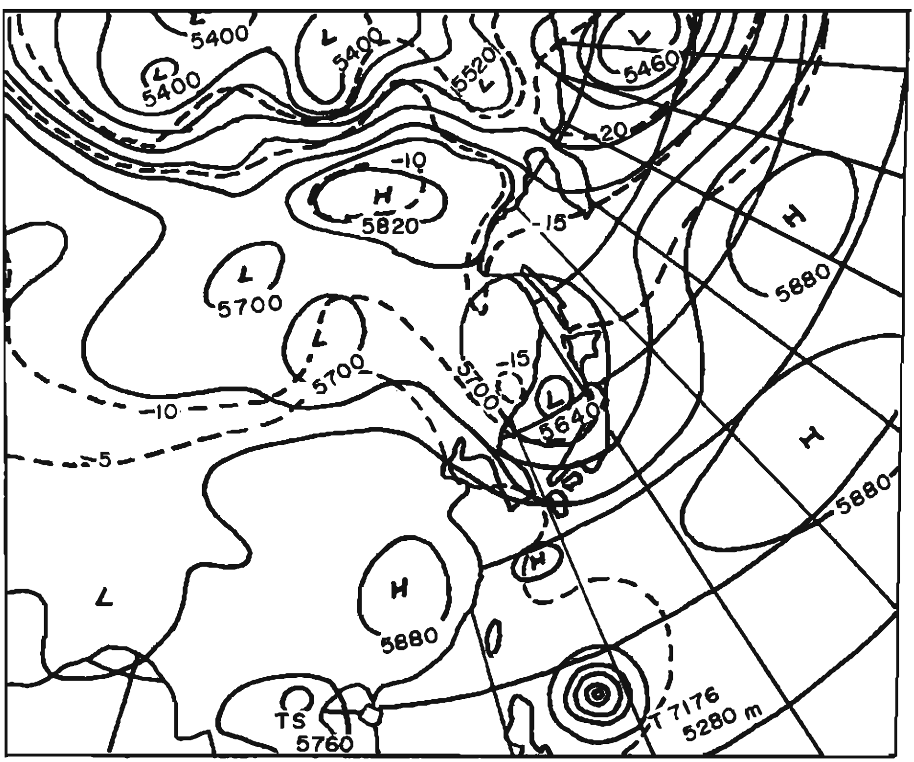


Fig. 10. 500 mb chart at 21 LST 18 July 1971.

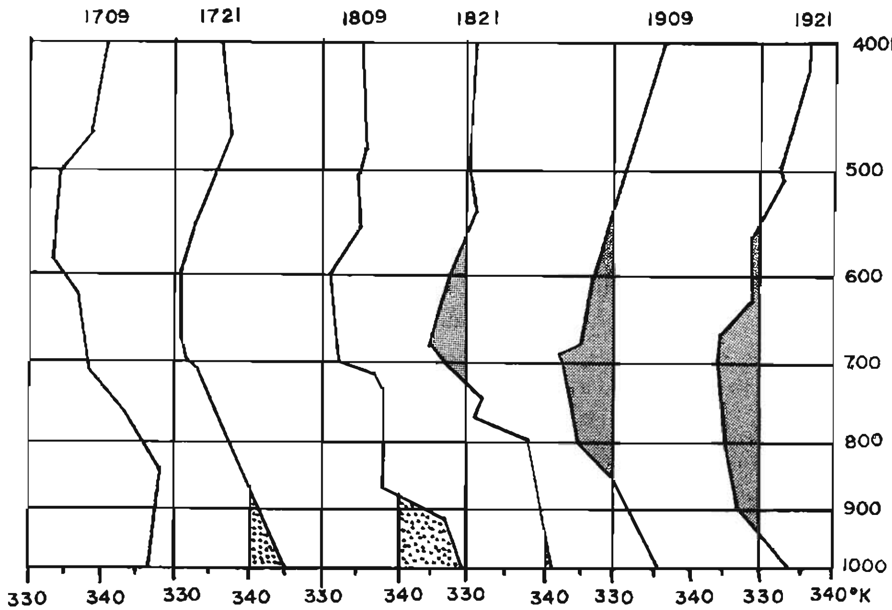


Fig. 11. Sequence of the vertical distribution of the equivalent potential temperature at Yonago for every 12 hours from 09 LST, 17 to 21 LST 19 March 1971.

Along the southern boundary of this cold vortex, a weak, low level jet stream flowed from northern Kyushu to the Seto Inland Sea. In Fig. 11, the vertical distribution of the equivalent potential temperature at Yonago is shown for every 12 hours from 09 LST, 17 to 21 LST 19 March. At 09 LST, 17, the lowest equivalent potential temperature appeared in the layer between 500–600 mb, but it subsided gradually to the approach of the cold vortex to Japan, and at 21 LST 19, this appeared in the layer between 650–750 mb. The portion with that temperature lower than 330°K is shaded in this figure. On the other hand, in the lower level, heating by the introduction of the warm low level jet stream appears also in this figure. The dotted area in this figure shows the portion with temperatures warmer than 340°K. Thus, strong instability occurred in the lower part of the troposphere because of the effects of both upper cold air current and lower warm current. These analyses can explain that heavy rainfall may occur in some places in the western Japan, but can not explain the concentration of the heavy rainfall in such a narrow area.

Fig. 12 shows the sequence of the amounts of the rainfall occurring every 10 minutes at Aioi near the center of the heavy rainfall. These figures show that the occurrence of heavy rainfall concentrated only in 3 hours, with a variation of the intensity of rainfall within the period of about 1 hour. When we analyse the barographs in the stations in the western Japan, we can find waves moving eastward with the amplitude of 0.2–0.6 mb the period of 1–2 hours and a wave velocity of 80–160 km/hour. At Himeji near Aioi, we can find 7 wave crests from 12 to 19 LST. With the propagation of this barometrie wave, the areas of rainfall also moved eastward. The oscillation of the intensity of rainfall can be explained by these waves, but the concentration into such a small area can not be explained by these waves. The explanation of the cause of the concentration is very difficult. However, we can suggest two reasons. One is the existence of land and sea breezes. Aioi is at the western part of the Himeji Plain and at the coast of the Seto Inland Sea, so it is easy for both land and sea breezes to prevail. A relatively strong sea breeze there may start the release of vertical instability. Another factor is in the character of convection itself. If for some reason, a convection cell develops which exceeds some limitation, the flow pattern and the thermal pattern around this area changes considerably. The energy of the propagation of energy transforms to the amplification of the wave, and this wave with severe convection may become stationary there.

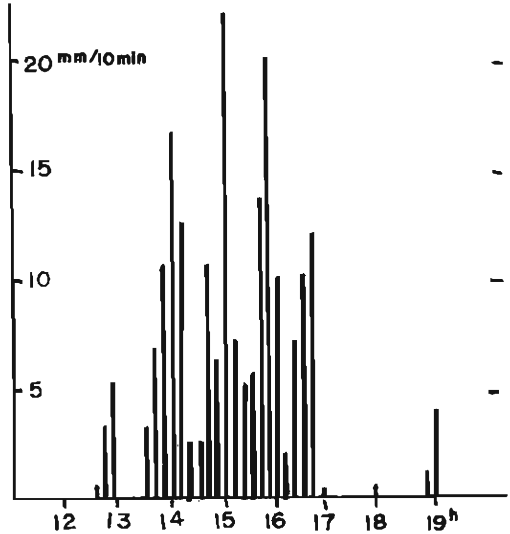

Fig. 12. Sequence of the amounts of the rainfall for every 10 minutes on 19 March 1971 at Aioi.

We can understand from these examples both in winter and summer seasons that the cause of the heavy rainfall is not so simple, but complicated, multiple effects of the atmospheric disturbances of various scales.

## 4. Meso-scale Analysis

As mentioned above, the general cause of rainfall is in the character of the general circulation, but to determine the detailed location and the intensity of heavy rainfall, consideration of the meso-scale atmospheric character is necessary. So-called meso-scale atmospheric disturbances have wave lengths of about 100 km and periods of 1–2 hours. However, these pure meteorological phenomena are much influenced also by orographic conditions. So, in this chapter, we want to discuss the various kinds of heavy rainfall of smaller scale in relation to the meso-scale disturbances and the orographic conditions.

At first, we want to show examples of heavy rainfall caused by typhoons and thunderstorms. Fig. 13 a is the time sequence of the amount of rainfall every 10 minutes when a thunderstorm occurred over Nago in the northern part of Naha Island on 11 August 1972. The total amount of the rainfall in 4 hours from 13 to 17 LST was about 200 mm, and the maximum amount of the rainfall in 10 minutes was over

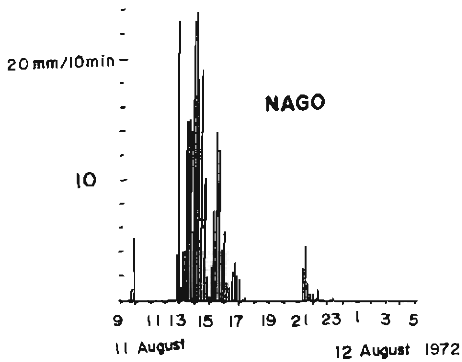


Fig. 13 a. Same as Fig. 12 but for 11–12 August 1972 at NAGO in OKINAWA.

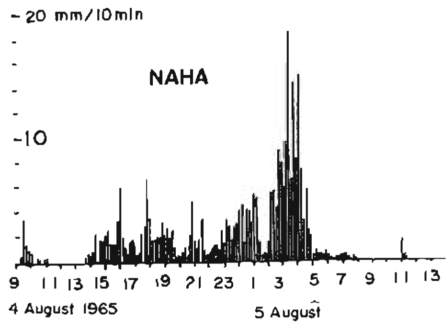


Fig. 13 b. Same as Fig. 12 but for 4 – 5 August 1972 at NAHA.

20 mm. By this heavy rainfall, many mountain slopes along the roads were destroyed. However, the diameter of the heavy rainfall area was only 50 km or smaller. In some places in the southern part of the Naha Island, there was no rainfall. In this case the heavy rainfall can be explained by the results of the thunderstorms which occurred in the cold front system with the additional effect of the mountains in this island.

Fig. 13 b shows the same, but for a Typhoon 6515 on 4 August 1965. In this case, the total amount of the rainfall was about 400 mm, but this rainfall continued for about 15 hours. So, this rainfall can be considered as a relatively large scale rainfall. However, even in this case, we can see the variation of the intensity of rainfall within the period of 1–2 hours. Unique intense rainfall with a short period corresponds to the meso-scale features of the typhoon.

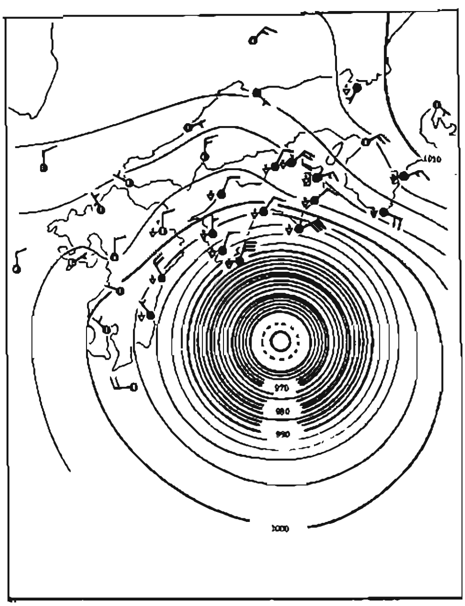

Fig. 14. Surface map at 03 LST 21, August 1970 (Typhoon 7010, pressure of the center: 960 mb)

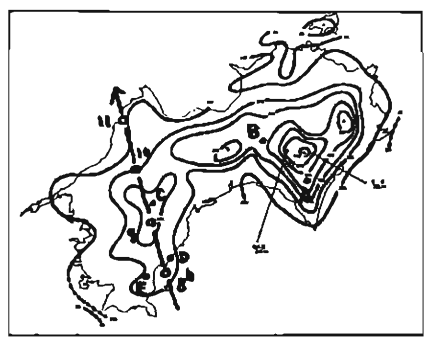

Fig. 15. Total amount of precipitation and the path of Typhoon 7010. Locations of (A) Kamiyanase, (B) Nishihoe, (C) Funado, (D) Saga, (E) Nakamura

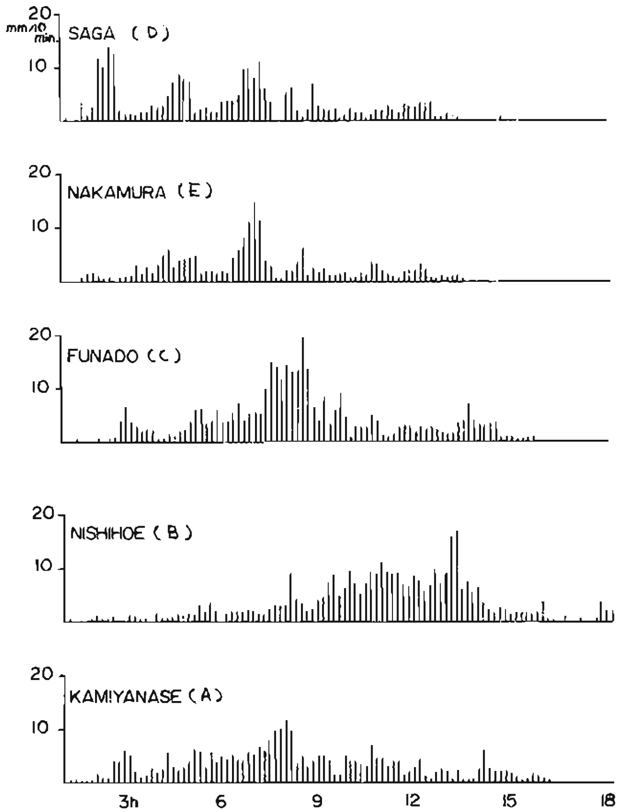


Fig. 16. Sequence of the amounts of the rainfall for every 10 minutes at 6 stations for Typhoon 7010 on 21 August 1970.

In the following, we want to show that various types of precipiration can appear within a single typhoon. Fig. 14 shows the weather map at 03 LST, 21 August 1970 when typhoon 7010 was approaching the Shikoku District. Fig. 15 shows the path of this typhoon, the total amount of the precipitation and the location of the obsevring stations. The total amount of the precipitation was about 700 mm in the eastern mountainous region and about 300 mm in the western mountainous region near the path of the center of this typhoon. Fig. 16 shows the time sequences of 10 minute intervals of precipitation by this typhoon at 6 stations in the Shikoku District. In the case of Saga (D) located on the Pacific Coast and near the path of the center of this typhoon, there are 7 peaks of intense rainfall with the intervals of about 2 hours. Nakamura (near Saga) shows nearly the same condition as Saga but the periodic character is not so distinct. These peaks of rainfall intensity correspond to the strong rainbands in this typhoon. The distance between these rainbands and the center of typhoon are 40, 120, 200 km respectively. Thus, at the stations near the landing point of the typhoon, meso-scale features of the typhoon are not destroyed by the orographic effects and were conserved very well.

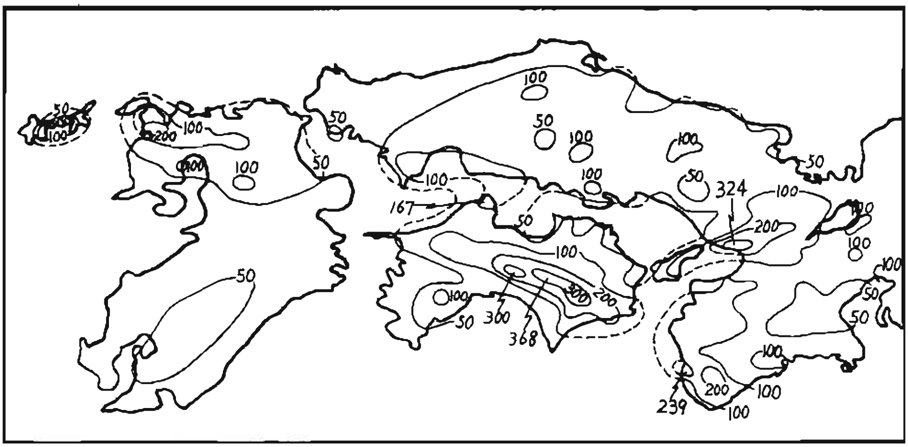

Fig. 17. Distribution of the daily amount of the rainfall over Western Japan from 09 LST 9 to 09 LST 10 July 1967. (unit mm)

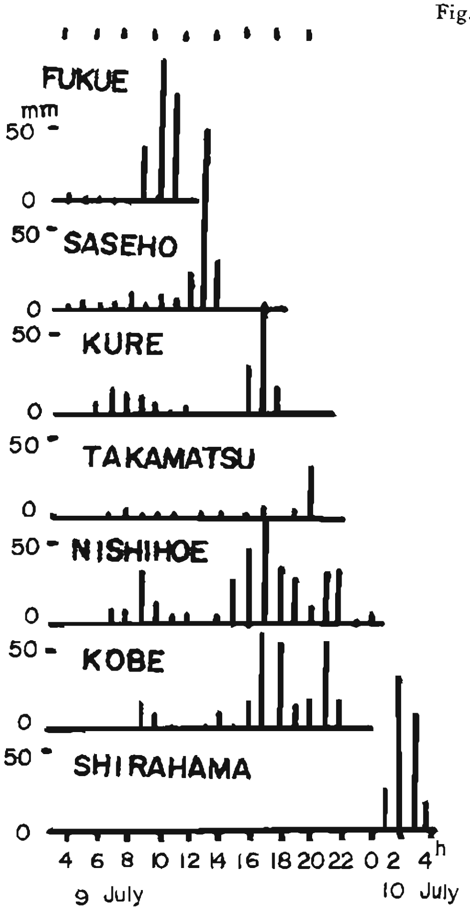


Fig. 18. Sequence of the hourly rainfall amount at 7 stations from 04 LST 9 to 04 LST 10 July 1967.

However, at Funado (C), Nishihoe (B) and Kamiyanase (A), the periodical variation of the intensity of rainfall can not be found distinctly. In these stations, a peak of intensity appeared only one time and then not so sharply. This peak corresponds to the strong wind by typhoon. So, it is easily explained as orographic rain.

There are two kinds of orographic effects. The first one is the upward motion on the windward slope as mentioned in the example of Typhoon 7010. However, in the case of stable flow, there is the atmospheric current flow through the lower part among mountains. Fig. 17 shows the distribution of the total amount of rainfall over the Western Japan from 09 LST 9 to 09 LST 10 July 1967. In this case, SW-ly current prevailed and flowed through the Bungo Strait and Kii Strait. This current horizontally converged and made an upward motion and a heavy rainfall area appeared near Hiroshima and along the Yodo River. The heavy rainfall area over the north-western part of the Kyushu was also made by the converging current along the western coast of Kyushu. These three areas have heavy rainfall frequently for the same reason as in this case. There are two other heavy rainfall areas in the mountains in the eastern portion of Shikoku and the southern part of the Kinki District. These two heavy rainfall areas have quite heavy rainfalls frequently by the orographic upward motion as mentioned in the case of Typhoon 7010. From this, it seems that the heavy rainfall area is fixed according to orographic conditions.

However, also in this case, a meso-scale travelling wave existed. In Fig. 18, the sequences of the hourly rainfall amount is shown for the stations located from western Kyushu to the western Kinki District. We can see at least three peaks of heavy rainfall travelling from west to east.

## 5. Heavy rainfalls and disasters

As mentioned above, the locally concentrated heavy rainfall refer to the meso-scale meteorological disturbance and the relatively heavy rainfall in broad area refer to the large scale disturbance. So, we can estimate the maximum intensity of rainfall for the meteorological disturbances with various scales and various locations.

We want to make some statistical analyses about the time concentration of rainfall. Fig. 19 shows the relation between the daily amounts and the 3 hourly amounts of rainfalls for 77 examples of heavy rainfall from 1922 to 1970 at Kyoto. In 27 cases, 80% of the daily amount concentrated in only 3 hours, and in almost all cases, 60% of the daily amount concentrated in 3 hours. Kyoto is located in the inner part of Honshu Island. So, almost all the heavy rainfall was caused by thunderstorms, as shown in this figure. Fig. 20 shows the same but for Naha in Okinawa District. We used 184 examples in 10 years (1961–1970) for the heavy rainfall with the daily

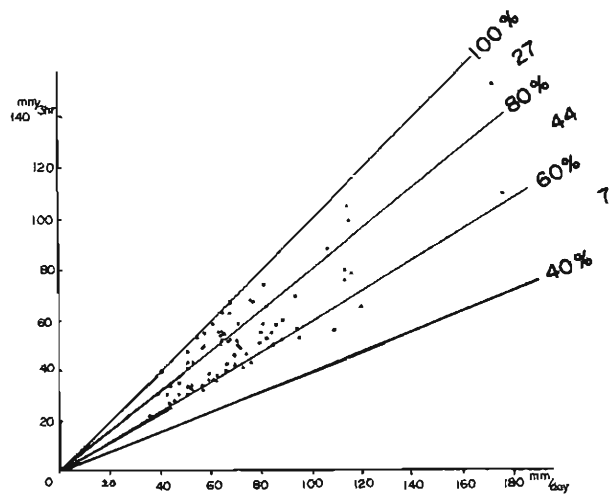


Fig. 19. Ratio (%) of 3 hours to 24 hours rainfall amounts for 77 examples of heavy rainfall at Kyoto from 1922 to 1970.

amount more than 30 mm. In this case, the correlation between 24 hours and 3 hours amount of rainfall is not as high as in the case of Kyoto. Naha is located on a island in the sub-tropical sea. So heavy rainfall is caused by the various meteorological disturbances such as typhoons, cyclones, fronts and thunderstorms. From Fig. 19 and Fig. 20, we can see that there are more rainy days with the 24 hours rainfall over 30 mm in Naha than in Kyoto and maximum value of the daily amount of rainfall is larger in Naha. But, for the 3 hours or one hour amount of rainfall, Kyoto has more heavy rainfall than Naha.

Such a behaviour of rainfall is very important when considering the method of

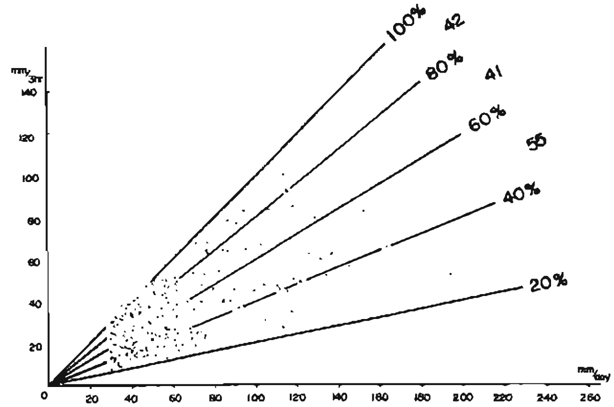


Fig. 20. Same as Fig. 19 but for 184 examples in 10 years (1961-1970) at Naha.

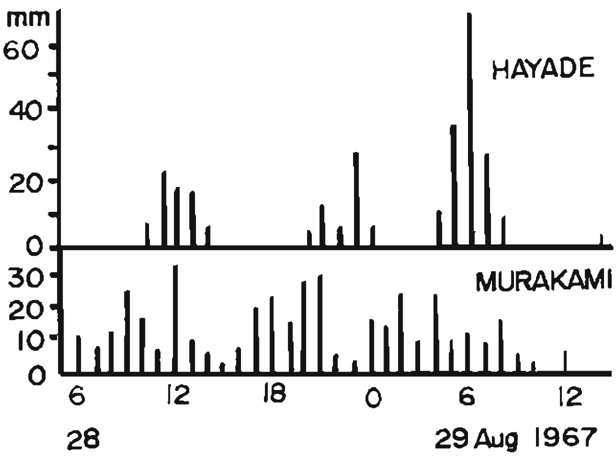


Fig. 21. Sequence of the hourly amount of the rainfall at Hayada and Murakami in Niigata Prefecture from 06 LST 28 to 12 LST 29 August 1967.

the prevention of hydrological disasters. For floods in small rivers and for the rocky mud flows along the mountain slopes, thunderstorms are the important cause. However, for the large scale floods, large scale meteorological disturbances such as typhoons are important. Fig. 21 is a example showing the difference of two kinds of disasters. On 28 and 29 August, we had heavy rainfall with a total amount over 600 mm along the Japan Sea coast of the Niigata Prefecture. As shown in Fig. 21, the total amount of the rainfall at Hayade was only 273 mm but the maximum amount of the hourly rainfall exceeded 60 mm/1 hour. On the other hand, the total amount at Murakami was 345 mm, but the maximum hourly amount was about 30 mm/1 hour. The distance between Murakami and Hayade is only 30 km, but the characters of the disasters in these two locations was much different according to the difference of the characters of rainfall. Arakawa near Murakami had large scale flooding while severe rocky-mud flows occurred near Hayade.

The next example is the disaster at Asuwada-mura on the north-western slope of Mt. Fuji by Typhoon 6626. Fig. 22 shows the sequence of the amount of rainfall for every 10 minutes from 21 LST 24 to 3 LST 25 September 1966. Maximum value of 10 min. rainfall was 25 mm/10 min. at 0130 LST 25. The occurrence time of the rocky-mud flow was reported at 0110 or 0120 LST, and well coincided with the peak

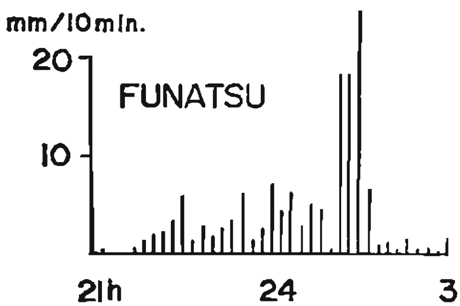


Fig. 22. Sequence of the amount of the rainfall for every 10 minutes at Funatsu in Yamanashi Prefecture from 21 LST 24 to 03 LST 25 September 1966 by Typhoon 6626.

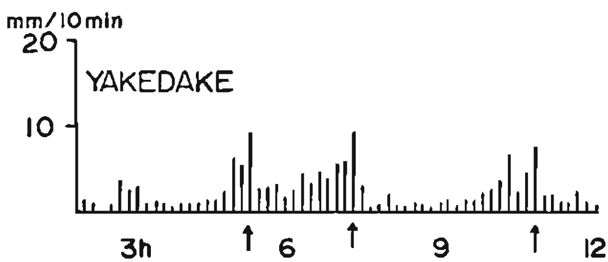


Fig. 23. Same as Fig. 22 but for Yakedake in Nagano Prefecture from 02 LST to 12 LST 6 September 1971 in the case of the occurrence of rocky-mud flow in Kamihorizawa at the foot of Yake-dake. Arrows indicate the time of the occurrence.

time of the heavy rainfall. Thus, the peak of the 10 min. rainfall intensity may be a trigger for the start of a disastrous rocky-mud flow. Of course, continuous rainfall is important for the back ground of the disaster. Therefore, the combination of the primary continuous rainfall and the secondary sharp peak of rainfall intensity may be important for the initiation of the rocky-mud flow.

The accurate records of the time of the occurrence of severe rocky-mud flows or land slides are very few. S. Okuda and his collaborators made a special observation system for the measurement of the rocky-mud flow in the rainy seasons of 1971 and 1972 at the eastern foot of Yake-dake. Fig. 23 shows a record obtained by their group. Arrows in this figure indicate the occurrence time of the rocky-mud flow accurately observed by this group. We can see that the occurrence time of these disasters and the peak times of the 10 min. rainfall intensity coincided very well.

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