Chapter 3 Analyses of eruption cloud data from individual volcanoes

In this chapter, photograph image data of eruption clouds detected at 23 volcanoes are compiled with a summary of the volcanic eruptions and some features of the eruption clouds. The locations of the 23 volcanoes are shown in Fig. 2-2. Time variations of the maximum horizontal width, length and the maximum altitude of the eruption clouds were analyzed at several volcanoes. In many cases, the altitudes of eruption clouds were estimated by using the air-temperature profiles obtained by radio-sounding data at nearby meteorological stations around the volcanoes. When radio-sounding data are not available, the air temperature profiles at different latitudes as shown in Fig. 3-1, proposed by McClatchey et al. (1972), are tentatively used. The results of measurements of width, length, drift direction, the coldest surface temperature of eruption clouds and the estimated highest altitude for all the eruption clouds are compiled in Table 2-2.

3.1 Sheveluch (Kamchatka, U.S.S.R.. 56.783° N, 161.583° E, 3,395 m)

This volcano is located on the eastern side of the Kamchatka Peninsula and showed volcanic eruptions in 1980 and 1984. In 1980, volcanic eruptions took place in March, and lava extrusion caused the growth of a lava dome continuing through December. The strength of eruptions during the activity was not great, but the lava dome extruded reached a volume of 2×10^8 m^3. Another small eruption was observed in May, 1984.

The eruption clouds during these eruptions were not detected in GMS images owing to the presence of thick atmospheric clouds around this volcano. However, image data which are very similar to volcanic eruption clouds from this volcano could be found during 18 GMT on June 17, 1981 - 00 GMT on June 18, 1981, as shown in Photo 3-1. During this period, no eruptions were reported, but cloud-like eruption plumes were recognized at almost the exact location of this volcano, and showed dispersion like actual volcanic clouds.

Those plumes drift in the NE or ENE direction from the volcano in GMS images, and especially, clear image data having a maximum width of 100 km and a maximum horizontal length of 420 km drifting to ESE are obtained at 21 GMT on June 17, 1981 (see the middle photograph in Photo 3-1). It is impossible to determine whether these plume images are volcanic clouds or not, because we have no reports of volcanic eruption at the same hour from this volcano. There still remains a strong possibility that the plume-like images were

generated by meteorological events over this volcano.

3.2 Kleuchevskoi (Kamchatka, U.S.S.R.. 56.18° N, 160.78° E, 4,850 m)

This volcano is located on the eastern side of the middle of the Kamchatka Peninsula. During late-1977 - 1985, this volcano frequently showed strombolian eruptions accompanied by occasional pourings of lava as follows :

1977	Aug.---Dec.	strombolian.
1978	Jan.--- Mar. and July	eruption. lava flow.
1980	Jan.	strombolian. lava flow.
	Mar.	eruption. lava flow ($2 \times 10^6 m^3$).
1981	Dec.	eruption.
1982	Mar.---May, Oct. and Dec.	eruption.
1983	Mar.---June	strombolian. lava flow ($1.5 \times 10^8 m^3$).
		scoria cone ($3 \times 10^5 m^3$).
1984	Mar.---Dec.	strombolian. cone. lava flow.
1985	Jan.	eruption.
	Aug.---Dec.	strombolian with lava fountains and partly vulcanian eruptions. lava flow.

These eruption clouds were mostly low in altitude, but sometimes went higher than 3 - 6 km during the 1984 and 1985 Eruptions. Outflows of lava were active during the 1980 and 1983 Eruptions.

Eruption clouds from Kleuchevskoi volcano were found on March 4, 5, 7- 9, 1980 and January 14, 1985 in GMS images as shown in Photo 3-2 (a) - (d). They are pointed out in the photographs by white arrows and their approximate extent by black arrows in the sketches shown below the photographs. It is rather difficult to judge whether the plume at 12 GMT on March 14, 1980 was an actual volcanic cloud, because of the surrounding atmospheric clouds.

After March 5, 1980, eruption clouds were well detected as narrow and long plumes. During 09 - 12 GMT on March 5, narrow and long plumes, 50 - 60 km in width and 660 km in the maximum length, were recognized to come continuously out of the presumed location of Kleuchevskoi volcano. It is considered that eruptions continued at this volcano during this period. During 16 - 18 GMT, however, narrow volcanic plumes about 800 km long were seen in GMS images ; they had already detached from the location of the volcano, suggesting

that the volcanic eruptions had decayed or ended.

Short and narrow eruption clouds were found in GMS images during 22 : 30 GMT on March 7 - 22 : 30 GMT on March 8, 1980, which were not detached from the location of this volcano, showing that successive or frequent volcanic eruptions continue. However, it is considered that the intensity of eruption activities were not strong, compared to the activities on March 5, because the horizontal lengths of their plumes were not long. The erpution clouds during 12 - 21 GMT on Marh 8 were disturbed by the surrounding atmospheric clouds.

Eruption clouds at 00 - 03 GMT on March 9 are narrow but long and coming from the location of the volcano, showing that the intensity of the eruptions had become stronger. The eruption clouds during 06 - 09 GMT were merged into atmospheric clouds at the edges, forming apparently long plumes.

In only one image returned at 03 GMT on January 14, 1985, is seen a volcanic plume of 220 km in length coming out of the volcano and drifting to W. The volcanic cloud on the visible image showed a slightly dark tone in its brightness compared to the surrounding atmospheric clouds, as shown in the VIS photograph of (d) in Photo 3-2. Digital data processing was not conducted, but judging from the rather low tone of brightness of all eruption clouds in IR images, it is considered that their altitudes are not so great, probably at altitudes of about several km above sea level. This rough estimation roughly coincides with the observed height of 1 km in the reports above the crater at an elevation of about 4.9 km.

All images of these eruption clouds are returned during the periods of reported eruptions, and are seem to come from the location of this volcano in the images showing occurrences of successive or frequent volcanic eruptions. Comparing the horizontal lengths of these eruption clouds, it is concluded that the activities on March 5 were stronger than those of other eruptions.

3.3 Bezymianny (Kamchatka, U.S.S.R.. 56.07° N, 160.72° E, 2,800 m)

This volcano is located on the eastern side of the middle of Kamchatka Peninsula, near Kleuchevskoi volcano. Its volcanic eruptions with explosions and lava flows continued almost annually as follows :

1977 March	5 - 10 km high eruption clouds. lava flow (1×10^7 m^3). pyroclastic flow.
1979 February	small eruptions. pyroclastic flow. lava flow (2×10^8 m^3).

1980	April	5 - 6 km high eruption clouds. lava flow (7×10^7 m^3).
	August	small eruptions.
1981	June	8 km high eruption clouds. lava flow.
1982	June	1.5 km high eruption clouds. lava flow. pyroclastic flow.
1983	May	5 - 6 km high eruption clouds. lava flow. extrusion of a lava dome.
1984	February	small eruption.
	September - October	5 km high eruption clouds. pyroclastic flow. The dome was partly destroyed by these eruptions.
1985	June - July	strong eruptions.

Frequent volcanic eruptions took place, but the eruption clouds were not well detected mainly owing to the presence of atmospheric clouds around this volcano. The eruption clouds detected in GMS images by volcanic eruptions in 1980 and 1984 are shown in Photo 3-3 (a) - (b) with white arrows in photograph images and black arrows in sketches.

Eruption clouds during 18 - 19 April, 1980 were 20 - 60 km in width and about 400 km in maximum horizontal length, but their outer extent was rather unclear in photograph images. Those on October 14 were severely hampered by surrounding atmospheric clouds, but their approximate outer extent could be seen in photograph images to have a broad width of 110 - 130 km and a long elongation of 1300 km in maximum size. These eruption cloud images in 1980 and 1984 at the location of Bezymianny volcano, suggesting continuous volcanic eruptions, except the one returned at 03 GMT on April 19, 1980.

The widths and lengths of eruption clouds in October, 1984, are larger than those in April, 1980. Brightness of eruption clouds in the 1984 activity is higher than that in 1980, too. So the intensity of volcanic eruption in October, 1984, should be stronger than that in April, 1980. The processing of digital data for temperature distribution was not conducted, but it is considered that the eruption clouds in October, 1984, went up to high altitudes, probably higher than several km above the crater.

3.4 Gorely-Khrebet (Kamchatka, U.S.S.R.. 52.45° N, 158.12° E, 1,829 m)

Gorely-Khrebet is located on the southern side of the Kamchatka Peninsula. The eruptions during 1977 - 1985 were as follows :

1980	June---September	mostly phreatic eruptions, but strong magmatic eruptions in July. total ejecta of $3.5 \times 10^7 m^3$.
1984	December	mostly phreatic eruptions. 3.5 km high eruption cloud.
1985	January	eruption.

Of these eruptions, eruption clouds were detected in GMS images at 09 and 10 GMT on December 21, 1984. Both eruption clouds are hampered by surrounding atmospheric clouds and show a slightly indistinct extent, but they could be detected by their manner of dispersion to be from the volcano. The image obtained at 09 GMT is shown in Photo 3-4, where its length extends 150 km in horizontal distance from the location of this volcano.

The coldest temperature of 09 GMT eruption cloud was -41°C, and the estimated altitude 6.6 km representing about 4.8 km above the crater. This is rather higher than the reported observation value. The estimated altitude of 10 GMT eruption cloud was 7.3 km and about 5.5 km above the crater (see Table 2-2). There was no subsequent eruption cloud detected in GMS images, and therefore the volcanic eruption at this volcano was not a continuous one.

The domain of eruption cloud at 09 GMT lower than -20°C which corresponds to about 3 km a.s.l. is shown in Fig. 3-2. There are two domains lower than -30°C located on the NE and E - ESE sides of the location of this volcano. By comparing the eruption cloud image in the upper enlarged photograph data in Photo 3-4 and the temperature distribution in Fig. 3-2, it is considered that the NE domain may not be a volcanic cloud.

3.5 Alaid (Kurile Islands, U.S.S.R.. 50.80° N, 155.50° E, 2,339 m)

Alaid volcano is a volcano on an island located at the northernmost end of the Kurile Islands as shown in Fig. 3-3. This volcano began to erupt in the daytime on April 27, 1981, and the eruptive activity increased its intensity the next day and showed the peak on April 30, but decreased its intensity during May 2-4. Eruptions intermittently occurred on May 8-10, 15-27 and June 1, but the activities were limited to smaller- medium ones compared to those during April 28 - May 1.

In the activity on April 28 - May 1, a 1900 km long eruption cloud is detected in NOAA satellite image, and ash-falls were observed at distances even 1000 km away from this volcano. According to reports during April 28 - 30, the maximum height of eruption clouds

was 15 km and the ash falls covered a wide area of 1.5×10^5 km^2 in total, and the total mass of ejected materials was estimated at more than 5.5×10^8 m^3. After June, 1981, there was no report on Alaid activity, but ejection of small-scale volcanic plume was deteced on March 29, 1982 in GMS image.

Eruption clouds by the Alaid Eruption are well detected in GMS images in spite of cloudy conditions around this volcano caused by the clear dispersing extent of volcanic clouds. Eruption clouds were found in GMS images intermittently on April 27 - May 3, May 7 - 9, May 15 - 25, 1981 and March 29, 1982, as shown in Table 2- 2.

The first image data of the eruption cloud are obtained in GMS images at 11 GMT on April 27, 1981, but the extent is greatly blurred by atmospheric clouds. According to surface temperature data, the altitude of the detected eruption cloud was estimated 6.8 km representing about 4.5 km above the crater (see Table 2-2).

Rather distinct eruption clouds were detected after 12 GMT on the same day and many eruption clouds could be found in May and early June, 1981 and one image in March, 1982. Their infrared photograph images (expressed as IR in the photographs) are shown in Photo 3-5 (a) - (P), the visible ones in Photo 3-5 (A) - (L) and the 1982 image data in Photo 3-5 (M). Especially, eruption clouds were continuously found in all GMS images routinely returned during the period of more than 4 days from 11 GMT on April 27 through 06 GMT on May 1, 1981, and during the following periods : 09 GMT on May 8 - 12 GMT on May 9, 22 : 30 GMT on May 15 - 12 GMT on May 19 and 00 GMT on May 23 - 09 GMT on May 25, 1981.

The IR images of eruption clouds during April 27 - 30, 1981 are clear and distinct in photograph images as shown in Photo 3-5 (a) -(g), and show pale or rather indistinct extent through May 3 (see Photo 3-5 (h) - upper pictures of (i)). Relatively clear extent of eruption clouds were recognized on May 8 - 9 as shown in the lower pictures (i) - (j) in Photo 3-5. After that, they show a small, relatively pale and narrow extent in Photo 3-5 (k) - (p).

The approximate areas of detected eruption clouds in GMS images are shown in Fig. 3 -4 (a) - (b) with solid lines in cases of clear outlines and dotted lines in cases of indistinct ones due to the surrounding atmospheric clouds. The patched area shows the Kamchatka Peninsula. As seen in Photo 3-5 (a) - (p) and Fig. 3-4 (a) - (b), the eruption clouds were distinct and clear during April 27 and 30. The drifting directions were ENE -NE during April 27 - early April 28, then turn to the E - SE directions during April 28 and April 29 as seen in Photo 3-5 (a) - (d). These time variations of drifting directions of eruption clouds well correspond to the observed wind directions obtained at three radiosounding stations as shown

in Fig. 3-5, especially to the observation results for altitudes of 8 - 10 km obtained at Mys Vasil Eva station, which is located nearer than any other to Alaid volcano.

From IR images of detected eruption clouds in Photo 3-5 (a) - (p), we see they were ejected on April 27 - early April 30 from the location of Alaid volcano, which made active volcanic eruptions then. During this period, the longest eruption cloud extended as far as 2800 km in horizontal distance from the volcano (see Table 2-2).

The eruption cloud obtained at 12 GMT on April 27 is not clear in GMS's IR image, but thereafter the images of eruption clouds are clear and distinct. Then the eruption clouds become relatively small ones through April 30. These phenomena show that the intensity of volcanic eruptions increased from 16 GMT on April 27 through 18 GMT on April 28, and somewhat decreased thereafter. The maximum length of eruption clouds reached about 3000 km SE from this volcano at 10 : 30 GMT on April 30, but at that time, the eruption cloud was thin and indistinct at the location of the volcano, for the brightness is low in GMS images, indicating that the eruptions had already decayed (see Photo 3-5 (f)). The eruption cloud that had drifted more than 3000 km from Alaid volcano become thin and indistinct in GMS images, and there were only small eruption clouds over the volcano at the latter part of April 30, 1981 (see Photo 3-5 (g) and Fig. 3-4 (a)).

Small and rather indistinct eruption clouds continue to be detected on May 1 - 2 as shown in Photo 3-5 (h) and Fig. 3-4 (b). Relatively bright eruption clouds were found in GMS images during the period from 16 GMT on May 8 to 03 GMT on May 9 as seen in Photo 3-5 (i) - (j). The eruption cloud did no leave the location of the volcano, which continued to make relatively active and successive volcanic eruptions. Another increase in activity is seen during the period from 10 : 30 GMT on May 15 to 09 GMT on May 16, sending narrow but elongated eruption clouds from the location of the volcano as shown in Photo 3-5 (k) - (l). The eruption clouds become very thin or showed low brightness in GMS images, but still continued to come from the location of Alaid volcano through May 19 (see Photo 3-5 (m) - (o)). Small and low-brightness eruption clouds were intermittently found on May 20 - 22 (see Table 2-2). Eruption clouds probably generated by successive eruptions continue to be detected on May 23 - 25, and relatively clear and distinct extents of eruption clouds were seen during the period from 18 GMT on May 23 to 06 GMT on May 24 as seen in Photo 3-5 (o) - (p), showing an increase in eruption.

The visible (VIS) images of detected eruption clouds during the 1981 Alaid Eruption showed a dark-toned extent in most of the image data as shown in Photo 3-5 (A) - (L).

Especially, the eruption clouds during the strong activities on April 27 - 28 were almost black in color as obtained in GMS images (see Photo 3-5 (A) - (B)), and very dark in the images taken on April 29 (see Photo 3-5 (C)), in contrast to the white tones of surrounding atmospheric clouds. Eruption clouds obtained on May 1 - 3, and May 16 - 24 were also very dark in spite of their small size (see Photo 3-5 (E) - (L)). When a large quantity of fine-grained ejected materials are borne in eruption clouds, it may be expected that the surface of the eruption cloud will be dark-colored compared to the surface of eruption clouds which do not contain a large volume of fine-grained ejected materials inside. Therefore, it is possible to consider that these dark colored eruption clouds in VIS images were generated by the large much quantity of fine ejected materials contained in dispersing eruption clouds.

No further activity of Alaid volcano was reported after July, 1981, but one small eruption cloud was observed in IR and VIS images on March 29, 1982 as shown in Photo 3 -5 (M). A sketch of its extent is also shown in Fig. 3-4 (b). The eruption cloud extent in IR image was not so clear and the color of the eruption cloud detected in VIS image showed only slightly dark tones compared to the surrounding atmospheric clouds. There is no eruption cloud in other GMS images returned either before or after this time.

The lowest surface temperature of the eruption cloud obtained by IR digital data processing is compiled in Table 2-2. Examples of surface temperature distributions of eruption clouds are shown in Fig.3-6. Areas of the coldest temperatures of these eruption clouds are shown with solid portions in those figures. Their values were -49°C at 06 GMT on April 28, -48°C at 00 GMT and -52°C at 06 GMT on April 29, and -61°C at 00 GMT on April 30, 1981. Domains colder than -10 — -20°C, which correspond to altitudes of about 4 - 7 km of these eruption clouds, are shown in this figure, and it was possible to get sharp out-lines of these eruption clouds which clearly changed their drift directions with the time variations of the surrounding wind directions.

For estimation of the maximum altitude of the respective eruption clouds, air-temperature profiles obtained at three radio-sounding stations are used, and some of the results are shown in Fig. 3-7. Capital T with a dotted line in this figure denotes the altitude of the tropopause. The maximum altitudes estimated are also compiled in Table 2-2. Judging from the surface temperature distribution of eruption clouds shown in Fig. 3-6, we can not see the suface temperature distributions which represent that the eruption cloud did penetrate the tropopause. The altitude of the tropopause was rather low, at around 8 - 9 km on April 28 - 29, then rose to 10 - 11 km, sometimes to 12 km (especially, see the results at

Mys Vasil Eva station at the lowest figure in Fig. 3-7). The estimated altitudes of eruption clouds in Fig. 3-6 were 8.3 km at 06 GMT on April 28, 8.9 km at 00 GMT and 9.5 km at 06 GMT on April 29, and 11.4 km at 00 GMT on April 30, 1981. These results are very near the altitudes of the tropopause observed at Mys Vasil Eva station on the respective day as shown in Fig. 3-7, but it is not clear whether these eruption clouds actually penetrated the tropopause or not, since we have only the estimated values of maximum altitude and use the air temperature profiles obtained at radio-sounding stations which are located around but not near enough to Alaid volcano.

The coldest temperature of processed eruption cloud image data is -62°C at 06 GMT on April 30, 1981, and its estimated altitude 11.7 km. This altitude shows that the top of this eruption cloud reached a height of about 9.4 km above the eruption crater of this volcano.

The time variations of the horizontal lengths along the long axes of eruption clouds and the estimated maximum altitudes are shown in Fig. 3-8 with solid circles and smaller open circles, respectively, Black arrows mean that the eruption cloud is detached from the location of Alaid volcano in GMS images at the respective image-returning time. From these results, it is considered that there were 6 peaks of eruption during April 27 - 28, April 29 - 30, May 8 - 9, May 16, May 17 - 18 and May 24 - 25, 1981, judging from the length of the eruption clouds. If we assume that the image-returning time when the eruption clouds leave the location of this volcano represents the decay or temporary end of volcanic activity, we may obtain the occurrence frequencies of 30 eruption events. However, the duration times of continuous ejection of eruption clouds during April 27 - 28 and April 29 - 30 were clearly longer than those of other eruption clouds, showing occurrences of strong and frequent or successive volcanic eruptions. In some cases, we notice the length of eruption clouds to gradually decrease before the image-returning time when eruption clouds detach themselves from the location of the volcano, showing that observations of horizontal lengths of eruption clouds in GMS images shoud be effective in following the sequence of successive eruptions.

3.6 Gareloi (Aleutian Island. 51.80° N, 178.80°W, 1,573m)

This volcano is an insular volcano located in the W of the Aleutian Islands and is situated near the edge of the field of view of GMS as seen in Fig. 2-2. There were strong eruptions in August and September, 1980 and mild ones in 1982 as follows:

1980	August	big magmatic eruption after phreatic eruptions.
		10.5 km high eruption cloud.

	September 19	eruption. 6 km high eruption cloud.
1982	January	small eruption with ash cloud.

The eruption cloud 10.5 km high in August and one 6 km high on September 19, 1980, and those in January, 1982, were not detected in GMS images owing to thick atmospheric clouds around this volcano. Only relatively indistinct eruption cloud images were found in GMS images on the occasion of intermittent eruptions during September 16 - 17, 1980, as shown in Photo 3 - 6. Eruption clouds detected on September 16 are already detached from the location of Gareloi volcano, but the horizontal length is rather long, i.e. about 500 km. The eruption cloud at 10 : 30 GMT on September 17 was from the volcano, but its extent was small and indistinct (see Photo 3 - 6 and Table 2 - 2). There were no reports on the height of these eruption clouds for September 16 - 17, and no IR digital data processing, but their altitudes should be under several km judging from the rather low-toned brightness of the eruption cloud areas in GMS images.

3.7 Asama (Honshu, Japan. 36.40° N, 138.53° E, 2,550 m)

Asama is located in the central part of Honshu Island, Japan. In recent years, eruptions have been infrequent at this volcano, but moderate ones took place in 1982 and 1983 as follows :

1982	April 25 (17 : 25 GMT)	4.5 km high eruption cloud. ash fall of 8×10^7 m² to 240 km SE. total ejecta 7.9×10^4tons (Aramaki and Hayakawa, 1982).
	October 2 (00 : 58 GMT)	ash fall to 8 km SE.
1983	April 7 (16 : 59 GMT)	5 km high eruption cloud. ash fall 240 km to NE. total ejecta $1.2 - 1.5 \times 10^5$ tons (Aramaki et al., 1983).

By examining the enlarged photograph images in and around Japan, the eruption clouds could be detected on April 25, 1982 and April 7, 1983 as shown in Table 2 - 2 and Photo 3 - 7, but not in the October 2, 1982, images. The eruption cloud detected at 18 GMT on April 25, 1982, was clear and distinct in GMS image and came from the location of Asama volcano. However, other eruption clouds detected on April 25, 1982, were indistinct owing to their being thin and detached from the location of the volcano in images taken after 21 GMT.

The eruption clouds of the 1983 Asama Eruption taken at 18 GMT on April 7, 1983, were

not clearly distinguishable from the surrounding atmospheric clouds as seen in Photo 3 - 7, but their approximate extent can be seen as a white domain extending in the NE direction from the location of Asama volcano among relatively low-toned atmospheric clouds. No further eruption clouds could be seen in other images. The approximate extent of the detected eruption clouds is also shown in Fig. 3 - 9.

The surface temperature distribution of the eruption cloud detected at 18 GMT on April 25, 1982, was shown in Fig. 3 - 10. The domain colder than 0°C which corresponds to an altitude of about 3 km of about 0.4 km above the crater was from the location of Asama volcano. The eruption cloud is drifting in the SE - ESE direction from the volcano and the lowest temperature is -28°C as shown by the hatched portion in Fig. 3 - 10.

The altitude of the eruption cloud was estimated by using radio-sounding observation data obtained at Tateno station, about 150 km ESE of Asama volcano. According to the radio -sounding observations on April 25 - 26, 1982, as shown in Fig. 3 - 11, the coldest temperature of -28°C of the April 25, 1982 cloud corresponds to an altitude of about 7.2 km and about 4.7 km above the eruption crater. The estimated altitude of the April 7, 1983 cloud was about 7.5 km and about 5.0 km above the crater.

The time variations of the maximum altitude and the maximum horizontal length of the April 25, 1982, eruption clouds were shown in Fig. 3 - 12. After the first eruption cloud taken at 18 GMT on April 25, the detected clouds quickly decrease their maximum altitude from 7.2 km to 1.7 km and they left the location of this volcano becoming very thin and indistinct in its extent. But its horizontal length increases in the 21 GMT image, and then it almost disappears in GMS images. The wind direction at altitudes of 1 - 3 km, however, does not well coincide with the drifting directions of eruption clouds in GMS images, which had estimated altitudes of about 1 - 3 km (see Photo 3 - 7 and Fig. 3 - 11). These phenomena possibly suggest that the estimated altitude of a thin eruption cloud having low-toned brightness in GMS images might be smaller than the actual altitude. These will again be shown with other examples in Chapter 5.

3.8 Sakurajima (Kyushu, Japan. 31.583° N, 130.667° E, 1,118 m)

This volcano is located in the southern part of kyushu Island, Japan, and has continued its frequent vulcanian type eruptions at the summit crater, Minamidake, for about 30 years since the outbreak in 1955. During 1977 - 1985, there were frequent eruptions every month, except the period from May through July in 1979. The usual heights of eruption clouds above

the crater were 2 - 3 km and the maximum height did not exceed 5 km during 1977 - 1985. Ashes and lapilli accompanying eruptions were ejected and fell around this volcano, and caused great damage of breaking the windshields of automobiles and the roofs of houses at the foot of this volcano. In recent several years, ash-ejections have increased with the increase of frequency of eruptions.

There is a regular route at altitudes of 3 - 5 km near Sakurajima volcano for jetliners which land and take off at the air port located about 24 km N of this volcano. There were several accidents to aircraft, in which the windshields were rubbed and sometimes cracked by ejected materials when the planes encountered eruption clouds from this volcano.

The eruption clouds were not wide and high enough to be detected in GMS photograph images of the whole globe. However, by careful inspections of enlarged photograph images in and around Japan in 1984 and 1985, small eruption clouds could be found out in them. The eruption clouds detected had very low-toned brightness and were very small ones. Some of them are shown in Photo 3-8 (a) - (c) with white arrows in photographs and black ones in sketches. There may be other eruption clouds to be detected in enlarged GMS photograph images taken in other periods, too, but they are not examined here. In Photo 3-8 (a) - (c), VIS means visible image and others IR ones.

All the eruption clouds detected were small and low-toned in brightness in GMS images, but relatively clear in VIS images compared to those in IR ones, because the IFOV (instantaneous field of view) of VIS images has better resolution than that of IR ones. The width and length of the eruption clouds detected were usually under 20 km and 40 km, respectively. The altitudes of the eruption clouds were estimated by using radio-sounding data at Kagoshima station, located about 11 km W of the crater. The estimated altitudes of the eruption clouds ranged from 0.3 km to 5.6 km, mostly around 1 - 2 km, as shown in Table 2-2. We can see that these small eruption clouds can disperse over a wide area and to distances of several ten km or farther (see Table 2-2 and Photo 3-8 (a) - (c)).

However, there are still problems regarding estimated altitudes, such as, especially, whether estimated low altitudes of eruption clouds are actual or not, because of the possibly same reasons as the noticed phenomena in cases of Asama eruption clouds expressed in the former section.

In Fig. 3-13, are shown the surface temperature contour below +5 °C (upper) and albedo value contour higher than 18 % (lower) of the eruption cloud taken at 03 GMT on February 24, 1985. In this figure, the temperature of +5 °C corresponds to an altitude of about 1.1 km,

almost the same as the elevation of the summit crater of Sakurajima volcano. It is possible to say that the eruption cloud has almost same the extent in both temperature and albedo distributions. Areas of the coldest temperature and the highest albedo value are located at a site of about 30 km SE of the crater. This means that the thickest portion of this eruption cloud was driven to the site by winds. At the time when this GMS image was returned, there was a little atmospheric cloud around this volcano. So the domain of this eruption cloud could be well detected on both IR and VIS image data. The albedo value of the eruption cloud showed a higher value than those of land and sea surfaces, but the atmospheric cloud has also the same characteristics as this eruption cloud. This means that it is not easy to separate eruption clouds from surrounding atmospheric clouds only with the albedo values of GMS image data.

3.9 Pagan (Mariana Islands, Central Pacific. 18.13° N, 145.80° E, 570 m)

This volcano is located in the Mariana Islands as shown in Fig. 3-14. Big eruptions took place on May 15, 1981, followed by 16 - 20 km high eruption clouds and lava flows, according to the reports. Thereafter, intermittent eruptions continued through late May. After the occurrence of the big eruptions, moderate - small eruptions took place intermittently through 1985. A summary of the activities is as follows:

1981	May 15	big eruption. 16 - 20 km high eruption clouds. lava flows and pyroclastic flows. activity continuing intermittently through late May. total mass: fallen ejecta about $3.6 \times 10^7 m^3$, lava flow $4.3 \times 10^7 m^3$, cone $3.6 \times 10^7 m^3$, their total about $2 \times 10^8 m^3$, (Banks et al., 1984).
	June 11	moderate eruption
	November	small eruptions.
1982	January, February and September - December	small eruptions.
1983	March, July and September	small - moderate eruptions.
1984	March 29	eruption.
	April and May	eruptions. 2 - 4 km high eruption cloud.
1985	April and May	eruptions. 2.5 km high eruption cloud.

Of these erutions, only the eruption clouds by the 1981 May Pagan Eruption were well detected in GMS images as shown in Photo 3-9 (a) - (c). Other eruption clouds that include moderate events were not detected mainly owing to disturbances due to atmospheric clouds around this volcano. The eruption clouds of the 1981 May Eruption, however, give the best GMS image data compared to those of other cases, because the eruption took place under good weather conditions that were almost completely free from disturbances due to atmospheric clouds. Besides, the eruption cloud image data are available in GMS images from the initial stage of ascent just after the occurrence of the eruption, through the whole of expanding process to the last dispersion after the end of the eruptive activities.

The first and very small eruption cloud was found in the GMS image returned at 23 GMT on May 14, 1981 and the almost circular extent which reached near the highest altitude was obtained at 00 GMT on May 15. The eruptive activity almost ceased at around 09 : 30 GMT on May 15, according to the reports, and the further spread and dispersal of the eruption clouds after the decay of the activity were well monitored in GMS images till 22 : 30 GMT on the day.

The extent of detected eruption clouds is shown in Photo 3-9 (a) - (c) with white arrows and black ones. They are also outlined by solid and dotted lines in Fig. 3-15. In photograph images, their IR and VIS images show almost the same extent as in Photo 3-9 (a) - upper (b). And the brightness of eruption clouds in VIS photograph images showed almost the same tone as the surrounding atmospheric clouds, showing very different features in cases of the Alaid eruption clouds noticed in section 3.5 (see Photo 3-9 (a) - (c)). The eruption clouds quickly expanded and spread to a distance of about 700 km at 09 GMT on May 15 without detach themselves from the location of this volcano, and reached a farthest distance of about 1000 km at 21 GMT, after the subsidence of eruptive activity (see Fig. 3-15).

The surface temperature distribution of the first eruption cloud detected at 23 GMT on May 14 is shown in Fig. 3-16. The domain colder than +15 °C which corresponds to an altitude of about 2.2 km and a height of about 1.6 km above this volcano is considered to be volcanic cloud, while the domain colder than 0 °C which corresponds to an altitude of about 4.8 km and a height of about 4.2 km above this volcano must be an eruption cloud. According to the reports on the volcanic eruptions, there were heavy ash falls on the W side of this volcano at the initial stage of the eruption. This event is well explained by the wind direction from ENE at an altitude of about 3 km based on the observation results obtained at Guam radio-sounding station, located about 450 km SSW of this volcano, as shown in Fig. 3-18.

The eruption cloud at 23 GMT on May 14 is located at the N - NE side of the location of Pagan volcano, and this is also well explained by the wind from SE at an altitude of about 1.2 km (see Fig. 3-18). It is considered that the heavy ash falls on the W side of this volcano were generated by winds at about an altitude of 2 km, and the location of the eruption cloud detected in GMS image at 23 GMT on May 14 was due to the wind direction at lower altitude.

Surface temperature contours of eruption clouds taken at 00, 03 and 06 GMT on May 15, 1981 are shown in Fig. 3-17. The eruption cloud returned at 00 GMT shows an almost circular extent, but the whole domain is slightly shifted to the southern side of the location of Pagan volcano and the main axis of the eruption clouds taken after 03 GMT extended in the SE direction. This direction well coincides with the wind direction from NW at an altitude higher than 5 km (see Fig. 3-18). The coldest temperature of -79 °C was obtained in the eruption clouds taken at 00 and 03 GMT on May 15, after which time the coldest temperature in eruption clouds decreased as shown in Table 2-2. The highest altitude of the eruption cloud estimated with the radio-sounding data obtained at Guam station shown in Fig. 3-18 was about 16.5 km, the height being about 15.9 km above this volcano, at 03 GMT. The altitude of the tropopause over Guam station was about 16.5 km and the top of the highest eruption cloud of the Pagan Eruption reached to this height at least, and may slightly have penetrated the tropopause (see Figs. 18 and 19).

The time variations of the estimated highest altitude and the maximum horizontal length of detected eruption clouds are shown in Fig. 3-19. The first eruption cloud at 23 GMT on May 14 quickly increased its highest altitude from 6.9 km to 16.2 km at the initial stage after the occurrence of the eruption, and kept almost the same altitude of 16.2 - 16.5 km till 06 GMT, decreasing its altitude to 14.1 - 12.4 km after 09 GMT. According to the reports, the eruptive activity stopped at around 09 : 30 GMT, and by that time, the highest altitude of the eruption cloud had decreased to 14.1 km and the eruption cloud had left the location of Pagan volcano (see the data at 09 GMT in Table 2-2 and Fig. 3-19). These phenomena indicate that observations of time variations of the highest altitude of eruption clouds and image-returning time when the eruption cloud detachs itself from the volcano in GMS image are effective information by which to judge or monitor the decay or end of eruption activity.

3.10 Mayon (Luzon, Philippines, 13.26° N, 123.68° E, 2,462 m)

Mayon volcano is situated at the southern tip of Luzon Island, the Philippines, as shown

in Fig. 3-20. The occurrences of its eruption have not been so frequent, but the big - moderate eruptions at the summit crater were usually accompanied by lava flows, pyroclastic flows and lahars. During 1977 - 1985, there were two big events in 1978 and 1984 with lava flows and pyroclastic flows, respectively, and there were small events in 1977 and 1980. The activities are summarized as follows :

1977	November	small phreatic eruption.
1978	May	eruption. lava flow of 1.5×10^7 m³.
	July	eruption.
1980	December	small phreatic eruption.
1984	September 10 - 14 and 23 - 25 and October	at first, vulcanian eruption, then strombolian activity. 15 km high eruption clouds. lava flow. pyroclastic flows.

During these eruptions, eruption clouds of the 1984 September - October Eruption were detected in GMS images returned on September 10 - 16, 23 - 26 and 28 - 29, and October 1 - 2, 1984. The photograph images are shown in Photo 3-10 (a) - (h). Especially, clear and bright-toned eruption cloud images were obtained on September 23 - 25. They were from the location of Mayon volcano, indicating the occurrence of active and successive eruptions. The extent of some of the eruption clouds during this period is shown in Fig. 3-21.

Around Mayon volcano, we can get better IFOV of GMS images, because the resolution of IR image is about 6 km and that of VIS about 1.7 km. However, scanning troubles of GMS occurred in the summer of 1984 and the daily image-taking frequency was limited to the 4 times of 00, 06, 12 and 18 GMT. After the launch of the next GMS, we could again receive GMS images routinely for 14 times a day after late September, 1984.

As seen in Photo 3-10 (a) - upper (d), the eruption clouds detected on September 10 - 16 showed very low-toned, indistinct and small extent in GMS images. Of the eruption clouds detected in middle September, the eruption clouds on September 13 were comparatively clear ones, as shown in Photo 3-10 lower (b) - upper (c).

Clear eruption cloud images were obtained on Setember 23 - 24 as shown in Fig. 3-21. In GMS images returned at 00 GMT on September 23, there was a clear, bright-toned and long eruption cloud image, which grew into a big and expanded eruption cloud at 06 GMT. The size of the eruption cloud temporarily decreased at 12 GMT, but again increased at 18 GMT on the same day, and showed the largest extent at 00 GMT on September 24. Thereafter, the eruption cloud decreased its domain till 00 GMT on September 25, as shown

in Photo 3-10 lower (d) - lower (g). During this period, the detected eruption clouds did not detach itself from the location of Mayon volcano. These phenomena indicate that a strong volcanic eruption commenced about 00 GMT on September 23, intensified its magnitude at 06 GMT, and then temporarily decreased its activity till 12 GMT. It resumed its strength at 18 GMT, with its peak at 00 GMT on September 24. Thereafter, the activity decresed and decayed by 00 GMT on September 25. After then, there were small and indistinct eruption clouds detected on late September 28 - 29 and early October, 1984. They are shown in Photo 3-10 lower (g) - (h).

The widest domain of eruption clouds detected was obtained on September 23 - 24, but the length was limited to 200 - 300 km from the volcano, and in the case of most other eruption clouds, the length was within 100 km as shown in Table 2-2. Examples of surface temperature contours of the eruption clouds detected are shown in Fig. 3-22 (a)- (b). In this figure, the domain under -10 °C, which corresponds to an altitude of about 6 km, was shown to distinguish eruption clouds from nearby atmospheric clouds. The lowest temperature of these eruption clouds was -81 °C of the one taken at 00 GMT on September 24, 1984 (see the upper figure in Fig. 3-22 (b)).

According to radio-sounding observation data obtained at CAB station (No. 98327, located at 15.17° N and 120.57° E at 196 m a.s.l.. see Fig. 3-23 (a) - (c)), the lowest temperature of -81 °C corresponds to an altitude of about 16.0 km (see Fig. 3-23 (b) and Table 2-2).

According to the reports, the maximum height of the eruption clouds on September 23 - 24 was about 15 km above the crater, which corresponds to an altitude of about 17.5 km. So we can say that the estimated altitude, 16 km, of the eruption clouds well coincides with the ground observation height. The maximum altitudes, the maximum horizontal lengths and the maximum widths of the eruption clouds detected are compiled in Table 2-2, and the time variation is shown in Fig. 3-24. The altitudes of eruption clouds on September 10 - 16 were under 10 km, mostly several km (see the upper figure in Fig. 3-24). The eruption cloud during September 23 - 25 exceeded an altitude of 10 km as shown in Table 2-2 and the lower figure in Fig. 3-24. The eruption cloud at 00 GMT on September 24 went up nearly as high as the tropopause, but did not penetrate it as shown in Fig. 3-24.

According to the time variation of altitude, length and width of eruption clouds in Fig. 3-24, the eruption cloud on September 23 - 24 showed the maximum value. On the basis of these phenomena, the eruption on September 23 - 24 is supposed to be the most intense one

during the 1984 September - October Eruption. The decrease of horizontal length of eruption cloud taken at 12 GMT on September 23 well coincided with its decrease in altitude. Then the maximum altitude sharply decreased on September 25. Therefore, we can say that the analyses of the time variation of length and altitude of eruption clouds detected in GMS image are useful in judging the resumption, the decay and the cessation of eruption activity.

By the way, the maximum altitude of the eruption cloud taken at 00 GMT on September 12 was 2 km, which is less than the elevation the summit of Mayon volcano. There are no observational data on actual altitude at this time, but it is considered that this result was due to thin and low-toned eruption clouds which are subject to radiations from the ground and sea surface, so their surface temperature was responsible for the underestimation of their altitude. This problem will be treated with other examples in Chapter 5, again.

3.11 Bulusan (Luzon, the Philippines. 12.77° N, 124.05° E, 1,559 m)

This volcano is located in the southern part of Luzon Island, the Philippines (see Fig. 2-2), and showed intermittent eruptions, especially relatively strong ones in 1980 and 1981. All its activities were phreatic eruptions, and an outline of them is as follows:

1978	July - August	moderate eruptions. 3 km high eruption cloud. total mass of fallen ejecta 1.5×10^5 m³.
1979	December	small - moderate eruptions.
1980	January---April and June---September	eruptions.
		February 9; strong eruption. 5 km high eruption ash cloud.
		July 19 and 30; strong eruptons. 6 km high eruption cloud.
1981	April	strong eruption. 8 km high eruption ash column.
1983	June	small eruption.

In spite of a careful inspection of GMS images, no eruption cloud was found in IR images, and very thin, small and low-toned eruption clouds were detected only in VIS images taken in February, 1980. They are shown in Photo 3-11 with white arrows and black ones. Eruption clouds of high altitude, especially expected in April 1981, were not detected owing to the surrounding atmospheric clouds.

The eruption clouds detected in VIS images were disturbed by atmospheric clouds and indistinct in GMS images, but the approximate extent could be traced as shown in Photo 3-11 with black arrows. The size of the eruption cloud was 60 km in the maximum horizontal

length (see Table 2-2). The eruption clouds detected have a rather bright tone in GMS images compared to the surrounding atmospheric clouds. The IR digital data were not processed, but it is supposed that the altitudes of the eruption clouds were several km, judging from their brightness and from the fact the surrounding atmospheric clouds were 4 - 9 km in altitude.

3.12 Dukono (Halmahera, Indonesia. 1.70° N, 127.87° E, 1,087 m)

This volcano is located in the Halmahera Islands, about 200 km W of Sulawesi, Indonesia (see Fig. 2-2). Big eruptions of this volcano were reported in 1978 and a moderate one in 1979 :

1978	July 15---25	intermittent eruptions. big eruption with 10 km high eruption column.
1979	August	small - moderate eruptions.

Eruption clouds were found in GMS images returned on July 24, 1978 as shown in Photo 3-12. The image at 09 GMT on July 24, 1978, has a relatively clear extent, but the one taken at 10 : 30 GMT is obscured by the surrounding atmospheric clouds. The brightness of eruption clouds in GMS images was low-toned at 09 GMT, but they were from the location of Gamalama volcano, having a horizontal length of 240 km (see Table 2-2). The image returned at 10 : 30 GMT was marred by atmospheric clouds, but had a bright tone. The processing of the IR digital image data was not conducted, but it is considered that the altitude of this eruption cloud went up higher than several km judging from the brightness in GMS images.

3.13 Gamalama (Halmahera, Indonesia. 0.80° N, 127.33° E, 1,715 m)

Gamalama volcano is located about 170 km SSE of Dukono volcano (see Fig. 2-2). This volcano showed the following moderate - major eruptions in 1980 and 1983 :

1980	September	moderate eruption. 2 km high eruption cloud. total mass of ejecta 2 - 3 $\times$ $10^6 m^3$.
1983	August 9 - 10	moderate - major eruption. 6.5 km high eruption cloud.

No eruption clouds were found for the 1980 Eruption in GMS images because a large quantity of atmospheric clouds obscured the area around this volcano. The eruption clouds of the 1983 August Eruption were found in GMS images as shown in Photo 3-13, showing a relatively bright-toned extent in spite of the presence of atmospheric clouds around them.

The eruption cloud taken at 21 GMT on August 8, 1983, was from the location of the volcano showing a bright-toned extent in its image ; then the eruption cloud detached itself from Gamalama volcano. However, a small and relatively low-toned eruption cloud was seen in GMS image taken at 21 GMT on August 10, but the brightness of its extent was somewhat lower than the clouds existing before as shown in Poto 3-13. These phenomena indicate that the explosive eruption occurred in isolation.

The size of the eruption cloud deteced during its first stage of ejection out of the volcano was 80 km in maximum length, and during the spreading process about 350km (see Table 2-2). According to IR digital data processing, the lowest temperature of the eruption cloud at 21 GMT on August 8 was -75 °C and this temperature corresponds to an altitude of about 15.8 km, very near the altitude of the tropopause on this day. For estimation of altitude of the eruption cloud, the materials of the radio-sounding data used for the estimation in the case of Una Una eruption clouds were substituted (see section of 3.15). The estimated altitude of 15.8 km thus obtained is more than double the reported height of 6.5 km, and this result poses one of the problems concerning the estimation of the altitude of an eruption cloud on the basis of its surface temperature and profiles of air-temperature by radio-sounding data. The same results in other cases as well as this one will be dealt with again in Chapter 5.

3.14 Soputan (Sulawesi, Indonesia. 1.11° N, 124.73° E, 1,784 m)

Soputan volcano is located in the E of Sulawesi as shown with a solid triangle in Fig. 3-25. Between 1977 and 1985, this volcano erupted in 1982, 1984 and 1985, and all of these eruptions were modrate - big ones accompanied by ejections of high eruption clouds as follows :

1982	August 26 - 28	moderate - big eruptions. 15 km high eruption clouds. much ash fall.
	September 16-18	moderate - big eruptions. 14 km high eruption clouds.
	November 9 - 10	moderate eruptions. 5 km high eruption clouds. total mass of fallen ejecta 3.5×10^6 m^3.
1984	May 24 - 26	moderate eruptions. 4 km high eruption clouds.
	August 25 - 31	moderate eruptions. 6 km high eruption clouds.
1985	May 19 - 20	eruptions. 4 km high eruption clouds.

The eruption clouds by the above-mentioned eruptions were well detected in GMS images on August 26 - 27, September 17 - 18 and November 9 - 10, 1982, May 25 - 26 and

August 31, 1984 and May 19, 1985, as shown in Table 2-2 and Photo 3-14 (a) - (m). Eruption clouds are pointed out with white arrows in photograph images and the approximate extent is outlined by solid or dotted lines in attached sketches. When the remains of eruption clouds that had spread could still be seen in GMS images and the next new eruption cloud was detected in the same GMS image, both of them are indicated with two arrows in the image as seen in Photo 3-14 (e) - (f) and (h).

The eruption clouds from this volcano were seen in GMS images for 2 - several days, but individual eruption clouds were separately detected in the images, indicating that the individual eruptions were not successive ones but took place at some intervals. The extent of eruption clouds detected in GMS images on August 26 - 27 and September 17 - 18, 1982, is outlined by solid and dotted lines, which mean distinct and relatively indistinct extent respectively, as shown in Fig. 3-26. We can see that some of eruption clouds drifted on prevailing winds to the eastern part of Borneo Island, about 500 km W of this volcano.

In the case of the eruption on August 26, 1982, a very small eruption cloud was detected at the initial stage of the eruption and its spreading and dispersal were well traced in GMS images (see Photo 3-14 (a) - (b) and Fig. 3-26). In the upper photograph of Photo 3-14 (a) are the remains of the outspread Galunggung eruption cloud at the lower left, indicated with white arrow outlined in black. The first eruption cloud having the size of 90 km × 120 km and drifting to W of the volcano was found at 06 GMT on August 26, 1982. Then it rapidly expanded and spread to distance of about 600 km by 12 GMT and 16 GMT showing two separated drifting axes to NW and WSW, but did not leave the location of the volcano. Then the eruption cloud dispersed and left the volcano just after 18 GMT indicating the cessation of activity (see Photo 3-14 (a) - (b) and Table 2-2). Another eruption cloud, which was detected at 00 GMT on August 27, 1982, was also a very small one, having a domain of 30 km × 50 km and spreading to WNW of the volcano by 03 GMT ,but after 06 GMT it dispersed and left the location of Soputan volcano. The thin dispersed cloud drifted to WNW and reached Borneo Island by 12 GMT (see Photo 3-14 (c)).

Eruption clouds were also well detected on September 17 - 18, 1982. A small eruption cloud 50 km × 150 km in size elongating to WSW of the volcano was found in GMS image taken at 06 GMT on September 17 and then dispersed to WSW by 16 GMT without detaching itself from the location of this volcano, showing the greatest length of about 660 km. Thin dispersed eruption clouds were continuously seen in GMS image till 12 GMT on September 18. And during the dispersion, another eruption cloud having a domain of 30 km × 90 km was

detected at 03 GMT on September 18. This cloud drifted to WSW and left the volcano at 09 GMT in GMS image. A thin dispersed eruption cloud of a length of about 620 km could be seen by 12 GMT on September 18 (see Photo 3-14 (d) - upper (f)).

The eruption clouds detected on Nobember 9 - 10, 1982, showed relatively complicated spreading patterns owing to different wind directions at lower and at upper altitudes over this volcano and occurrences of successive eruptions. The first eruption cloud detected at 10 : 30 GMT on November 9 was 70 km × 170 km in size and could be tracked till 06 GMT on November 10 without detachment from the volcano. During this spreading, the bright-toned domain of the eruption cloud drifted to W and the relatively low-toned domain dispersed to NW - N of this volcano. This phenomenon suggests that the domain of the eruption cloud at high altitudes was driven by the wind from E and the lower portion was moved by the wind from S - SE. The bright-toned domain of the eruption cloud decreased its brightness in the image taken at 12 GMT, but there was no clear variation of domain of the dispersed eruption cloud in the N - NW direction of this volcano. However, the bright-toned domain increased in the image taken at 22 : 30 GMT on November 9 and became clearer, then reached its peak of brightness and its widest size of 320 km × 680 km in the image taken at 06 GMT on November 10, drifting to WSW - SW of Soputan volcano. The eruption cloud detached itself from the volcano in GMS image at 09 GMT on November 10, and became lower toned in brightness, but showed a very wide domain of 700 - 800 km. Dispersed eruption clouds could be seen around 18 GMT showing the widest domain of 640 km × 1140 km and reached Borneo Island (see Photo 3-14 middle of (f) - (h)). Judging from the spreading out of these eruption clouds, it s considered that the successive active eruptions which commenced on November 9 continued for more than one day and intensified its strength around 22 : 30 GMT after a temporal decay in activity, and that complicated profiles of wind directions and wind velocities at various altitudes dispersed the eruption clouds very wide.

Eruption clouds by GMS VIS images taken at 03 and 06 GMT on August 27, September 18 and November 10, 1982, are shown in Photo 3-14 (i). The extent is almost the same as in IR images and the brightness was relatively dark-toned compared with the surrounding atmospheric cloud.

An almost round-shaped eruption cloud of 60 km × 60 km was seen in GMS image returned at 15 GMT on May 25, 1984, during the 1984 May Soputan Eruption and then spread to W. The extent was not clear, possibly due to different wind directions at various altitudes. The eruption cloud left the location of this volcano at 03 GMT on August 26 and

could be traced till 09 GMT (see Photo 3-14 (j) - upper left of (k)). An almost round-shaped eruption cloud of 40 km × 50 km was also detected at 00 GMT on August 31, 1984, and quickly dispersed over a domain of 310 km × 410 km showing a fan-shaped extent by 06 GMT without detachment from the location of Soputan volcano. The cloud could be traced till 18 GMT, but the extent was already thin and indistinct (see Photo 3-14 (k)). During the 1984 May and August Eruptions, unfortunately, we could not routinely get 14 GMS images a day owing to GMS's scanning trouble ; especially the frequency of GMS image taking in August, 1984, was limited to 4 times a day, that is, every 6 hours. According to an examination of eruption clouds taken by GMS images, it is considered that the type of activity of the Soputan Eruption in 1984 was a single isolated eruption, and not a continuous one.

There is a report that a jetliner navigating at an altitude of about 11 km encountered volcanic clouds to the south of Soputan volcano on May 19, 1985. After careful examinations of GMS images, an eruption cloud-like extent could be detected during the period from 06 GMT to 22 : 30 GMT on May 19, 1985 (see Photo 3-14 (l) - (m)). There is a report that a volcanic eruption took place on May 19 - 20, but its intensity was not so strong. During this period, a large mass of atmospheric cloud obscured the region around this volcano and obstructed the detection of the eruption cloud in GMS images. The eruption cloud-like extent was from the volcano till 18 GMT spreading over the widest domain of 180 km × 260 km and could be traced till 22 : 30 GMT.

Examples of isothermal contours of the eruption cloud surface at 06, 09 and 11 GMT on August 26, 1982, are shown in Fig. 3-27 (a) - (c). The lowest temperatures were - 70 °C, - 72 °C and -69 °C, respectively. By substitution of air-temperature profiles based on radio-sounding observations at the stations, mainly No. 98836, shown in Figs. 3-28 and 3-29, the highest altitudes of these eruption clouds were estimated as 14.6 km, 15.0 km and 14.4 km, respectively. The extent of these eruption clouds could be well traced by detecting domains colder than 0 °C or - 10 °C, which correspond to altitudes of about 4.8 km or 7.2 km. The lowest temperature and the estimated highest altitude of the detected eruption cloud are compiled in Table 2-2 with measurement results of its width, length and drifting direction. The altitude of the eruption cloud-like image detected during the 1985 May Eruption was estimated partly by using of air-temperature profiles based on model atmospheres shown in Fig. 3-1.

The eruption cloud detected on August 26, 1982, was divided into two major drifting axes by 11 GMT (see Fig. 3-27 (c)). The portion extending in the direction of WNW has a

domain showing lower temperatures ranging from - 50 °C to - 69 °C, which correspond to altitudes of about 12.5 km - 14 km, though another domain is seen to drift to WSW showing temperatures ranging from - 40 °C to - 50 °C for altitudes of about 10.8 - 12 km. According to profiles of wind directions by the radio-sounding observations at No. 98836 as shown in Fig. 3-30, the wind directions at altitudes of about 12.6 km - 15.7 km were approximately from E - ESE and those at altitudes of about 7 - 11 km from NE - ENE. So it is considered that the higher or colder portion of the eruption cloud drifted to WNW and the lower one drifted to WSW by the prevailing winds at respective altitudes.

As compiled in Table 2-2, the lowest temperature of the detected eruption clouds during the eruptions in 1982, 1984 and 1985 was - 77 °C, - 82 °C and - 83 °C, corresponding to the highest altitudes of about 15.2 km, 15.9 km and 16.8 km, respectively. The clouds detected in GMS images in May, 1985, may not be volcanic ones, but it is considered that the top of the cloud reached near or penetrated the tropopause over this volcano.

The time variations of the estimated highest altitude is shown by cross mark with H axis in Fig. 3-31, and the longest horizontal length is shown by solid circles and by open ones with L axis in the figure, for eruption clouds detected. The solid circle means that the eruption cloud is coming from the location of Soputan volcano and the open one that it is detached from the volcano. T means the altitude of the tropopause. The hatched portion and the rectangle in this figure denote the highest altitude of the eruption cloud and the duration period of eruptive activity based on the ground observations, respectively. Individual eruptions were well monitored by the detection of eruption clouds in GMS images mainly isolated occurrences of relatively strong eruptions having time intervals. We notice that the eruption cloud decreased its altitude after the end of eruption activity in many cases. However, it is also noticed that decrease of horizontal length and the time when the eruption cloud left the location of volcano did not well coincide with the end of eruptive activity. In the case of the eruption cloud from this volcano, there was seen problem regarding the differene in the highest altitude between the observed values and the estimated ones, the latter showing higher values than the former in many cases. This problem will be treated with other examples in Chapter 5.

3.15 Una Una (Sulawesi, Indonesia. 0.17° S, 121.61° E, 508 m)

This is an insular volcano at Sulawesi, Indonesia, and its location can be seen in Fig. 3-28. Major eruptions accompanied by pyroclastic flows took place in 1983 as follows :

1983	July 18-31	big eruptions after phreatic eruptions. 14 km high eruption cloud. pyroclastic flows.
	August 1-30	big eruptions. 12 km high eruption cloud. pyroclastic flows over an area of 6.3 × 10 km².
	September 3 - 4	moderate eruptions. 2 km high eruption cloud.
	October 2 - 10	small eruptions. 0.7 km high eruption cloud.

Examinations of GMS images revealed eruption clouds during the July and August Eruptions, but not the September and October Eruptions, owing to presence of clouds over this volcano and the relatively small intensity of eruptive activities. The eruptive activities of this volcano were mostly successive events. Some of the eruption clouds having an almost circular extent generated at the initial stages of eruptions were well traced in GMS images. Several eruption clouds in late August were reported to have penetrated the tropopause, and the estimated highest altitudes of eruption clouds during this period also showed that they may have reached or penetrated the tropopause. The GMS photograph images of the eruption clouds are shown in Photo 3-15 (a) - (n).

The first eruption cloud from this volcano was found in GMS image taken at 09 GMT on July 23, 1983, having a domain of 90 km × 100 km and an almost round-shaped extent (see Photo 3-15 upper of (a)). This eruption cloud was bright-toned in IR image and rapidly expanded till 09 GMT and was seen to spread widely over this volcano at 12 GMT, but it was not distinguishable after then owing to the presence of a large quantity of atmospheric clouds. The next eruption cloud was also a circular spot of the size of 30 km × 30 km in GMS image at 16 GMT on July 25, 1983. It had dispersed till 21 GMT (see Photo 3-15 (a)).

The eruption cloud detected at 12 GMT on July 27 could be traced in GMS images till 16 GMT on July 28, as shown in Photo 3-15 (b) - middle of (c), indicating occurrences of succesive eruptions. The eruption cloud at 12 GMT on July 27 had the size of 30 km × 70 km and relatively low-toned brightness. However, the brightness and the size of the eruption cloud increased and reached the size of 60 km × 180 km at 21 GMT, then showed the peak size of 120 km × 650 km at 06 GMT on July 28 without detachment from the location of Una Una volcano. The eruption cloud on July 28 was well detected by NOAA satellite, too (Malingreau and Kaswanda, 1986). Thereafter, the size and the brightness of the extent of this eruption cloud decreased with time till 12 GMT, but without detachment from the volcano. The tip of the eruption cloud reached a distance of about 800 km WSW of Una Una volcano, and reached the E area of Borneo Island at 06 GMT - 12 GMT on July 28 (see Photo

3-15 upper - middle of (c)). At 16 GMT, the eruption cloud detached the volcano and became very low-toned in GMS image.

The eruption cloud detected at 09 GMT on July 30, 1983, showed the size of 60 km × 80 km and also a bright-toned domain in GMS image, and its dispersed extent was traced till 22 GMT (see Photo 3-15 lower of (c) - middle of (d)). Before the dispersion, the eruption cloud expanded from 10 : 30 GMT to 12 GMT over this volcano showing a bright-toned extent and its widest domain of 180 km × 390 km, then decreased its domain from 16 GMT to 18 GMT, but without decreasing its brightness or detaching itself from the volcano.

The next eruption cloud was detected at 21 GMT on August 1, 1983, having a bright-toned extent, and could be traced till 16 GMT on August 2, including a new eruption cloud which was detected at 06 GMT (see Photo 3-15 lower of (d) - upper of (f)). The eruption cloud detected at 21 GMT on August 1 continued to spread till 03 GMT on August 2, still having its bright-toned extent and the size of 180 km × 440 km. The cloud left the location of Una Una volcano in GMS image at 06 GMT, but at that time, another eruption cloud of the size of 20 km × 50 km was found at 09 GMT, as indicated with white and smaller arrows in Photo 3-15 middle of (e). Then, it dispersed and joined the remainder of the former eruption cloud at 10 : 30 GMT, which could be traced till 16 GMT.

At 16 GMT on August 2, there was a newly detected eruption cloud having a bright-toned extent, but it soon dispersed and its thin remnant was seen till 21 GMT. Another small and low-toned eruption cloud was detected at 22 : 30 GMT, but was not found in GMS image taken after that (see Photo 3-15 (f)).

The new eruption cloud of the size of 70 km × 90 km was detected at 03 GMT on August 4, 1983, and spread to N of this volcano showing its widest size of 170 km × 190 km at 09 GMT (Photo 3-15 (g)). An almost circular eruption cloud having the size of 90 km × 110 km was found at 09 GMT on August 6 and spread over this volcano by 10 : 30 GMT and then, left the location of this volcano about 12 GMT. The eruption cloud had a bright-toned domain (Photo 3-15 (k)).

The newly detected eruption cloud at 06 GMT on August 7, 1983, had a bright-toned extent and spread till 12 GMT showing the widest domain of 320 km × 410 km at that time and the dispersed domain could be traced till 16 GMT. However, at that time, 16 GMT, the bright-toned extent of another new eruption cloud of 90 km × 160 km was found over this volcano (see Photo 3-15 (i)). This cloud had detached itself from the location of this volcano in GMS image taken at 18 GMT, but kept its bright-toned domain. A small and relatively

low-toned spot of the new eruption cloud could be detected in GMS image returned at 21 GMT on August 7, while the former cloud was dispersing (see Photo 3-15 upper left of (j)).

A new eruption cloud was obtained at 06 GMT on August 11, 1983, having the size of 110 km × 290 km, and could be traced till 10 : 30 GMT showing an expanded domain of 170 km × 650 km. The cloud left the volcano at 09 GMT, then became pale and low-toned in GMS image. At 18 GMT, another bright-toned eruption cloud was detected, but it left the location of the volcano and spread after 21 GMT (Photo 3-15 (j)).

A spot of 20 km × 20 km could be noticed in GMS image taken at 06 GMT on August 22, 1983, and quickly spread to the size of 120 km × 160 km in the GMS image at 09 GMT. Then the cloud left the volcano at 10 : 30 GMT showing the widest size of 130 km × 240 km and drifted to W. The dispersed extent could be traced at 12 GMT (see Photo 3-15 (k)). A new clear eruption cloud was detected at 03 GMT on August 26 and it spread by 06 GMT into a relatively bright-toned domain of 120 km × 340 km. However this cloud left the location of Una Una volcano and dispersed after 09 GMT (see Photo 3-15 (l)).

The VIS photograph images of eruption clouds are shown in Photo 3-15 (m) - (n). The eruption clouds in VIS images taken at 03 GMT and 06 GMT on July 28, 1983, have a bright -toned extent compared with those taken at 09 GMT, but this phenomenon should be due to the fact that at the image-taking time, 09 GMT, the region including Sulawesi was already in the evening. The poor sunlight may have been responsible for the dark-toned surface of the eruption cloud in GMS VIS image at 09 GMT (see Photo 3-15 (m)). However, the brightness of the eruption clouds in VIS images taken not only at 09 GMT but also at 03 GMT and 06 GMT on August 2, 7 and 11 showed a low-toned extent compared with that of the surrounding atmospheric clouds in spite of its being the day time (see Photo 3-15 (n)). These phenomena indicate the possibility that spreading eruption clouds show low-toned extent. Some examples of low-toned brightness of eruption clouds in VIS images including the cases of Una Una eruption clouds will be treated in Chapter 5 with regard to the distinction of eruption clouds from atmospheric clouds.

An example of surface temperature distribution of the eruption cloud returned at 03 GMT on August 2, 1983, is shown in Fig. 3-32. The lowest temperature was - 79 °C. The cold temperature domain lower than - 70 °C was from Una Una volcano and drifted to WSW - SW. The long axis of this eruption cloud having higher temperatures ranging from - 70 °C to - 30 °C also drifted to SW. According to the profiles of air-temperature in Fig. 3-33 and the profiles of wind speed and wind direction shown in Fig. 3-34, the lowest temperature of

the eruption cloud corresponds to the highest altitude of about 15.9 km, and the surface temperatures ranging from - 70 °C to - 30 °C correspond to altitudes of about 14.9 km - 9.4 km. The wind directions at around altitudes 14 - 10 km were from NE - ENE, so the direction of the long axis of this eruption cloud can be well explained by the prevailing winds at the estimated altitude of the surface of the eruption cloud. The radio-sounding data for Figs. 3 -33 and 3-34 were based on observations at the stations shown in Fig. 3-28 in section 3.14 above.

The lowest temperatures and the estimated highest altitudes of eruption clouds detected in GMS images are compiled in Table 2-2. The lowest temperature during the 1983 July - August Una Una Eruptions was - 80 °C obtained at 10 GMT on July 30, but this value has a problem because it is near the uppermost value in the reliable temperature range for IR digital data. The highest altitudes of individual eruption clouds, estimated here, range from 11.2 km to 16.7 km, and it is supposed that several of the eruption clouds penetrated the tropopause. However, the distributions of their surface temperatures do not clearly show the features which are expected when they penetrated the tropopause. So, in those cases, two kinds of highest altitudes of the eruption clouds, under and over the tropopause, are shown in Tabl 2-2.

The time variation of the estimated highest altitude (a cross mark with H axis) and the longest horizontal length (a solid circle and an open one with L axis) of detected eruption clouds are shown in Fig. 3-35. A solid circle and an open one denote, respectively, that the eruption cloud comes continuously from the location of Una Una volcano and is detached from it. T means the altitude of the tropopause with H axis. The hatched portion and rectangle denote, respectively, the highest altitude of the eruption cloud and the duration time of eruptive activity based on visual observation from the ground.

Decreases of the altitudes of spread eruption clouds after the decay or end of eruptions were noticed with the eruption clouds detected on August 1, 4, 6 and 26, but the tendency was not always recognized. The longest horizontal length of a detected eruption cloud did not clearly decrease after the end of the eruption. On the contrary, the spreading of eruption cloud even after the end of eruptive activity was observed in GMS image as shown in cases of eruption clouds obtained on July 23 and 27 - 28, August 1, 4 and 26. Eruption clouds were continuously detected in GMS images during the eruptions on July 27 - 28 and August 1 - 2, although there were not continuous eruptive activities. It is possible to consider that the above-mentioned phenomena were due to the long-term presence of ejected eruption clouds

over the volcano owing to complicated effects of different wind directions at various altitudes, or to the large quantities of ejected eruption clouds which could be present over the volcano for long hours even after the end of the eruptions owing to their high potentials for rising and spreading forces by heat sources expected in the eruption clouds bearing high concentrations of ejected materials inside.

3.16 Galunggung (Java, Indonesia. 7.25° S, 108.05° E, 2,168 m)

This volcano is located on the western side near the center of Java Island, Indonesia, as shown in Fig. 3-36. Big eruptions occurred in April, 1982, following by frequent pyroclastic flows, and intermittently continued through January, 1983. More than 20 people were killed during the activity. Occurences of weak phreatic eruptions were reported in January, 1984. A brief outline of the activity is as follows :

1982 April 5 - 9, 20 - 22 and 25 - end of the month
big eruptions. ultra-vulcanian and vulcanian type eruptions. 16.5 km high eruption clouds. pyroclastic flows. 10 people killed and 3 missing on April 8.

May 6 and 17-19 big vulcanian type eruptions. 16.5 km high eruption cloud. pyroclastic flows. lahars.

June 3 - 5 and 24 - 27
big vulcanian type eruptions. 13.5 km high eruption clouds. pyroclastic flows.

July 13 - 16 and 28 - end of the month
strong vulcanian type eruptions. 10.5 km high eruption cloud. pyroclastic flows. more than 10 persons killed.

August 1-31 (continued during a whole month)
big vulcanian type eruptions. 16 km high eruption cloud.

September 2---27 big vulcanian type eruptions intermittently continued. strombolian type eruptions, too.

October 14 - 28 moderate eruptions. strombolian type eruptions preceded 8 km high eruption cloud.

November - December strombolian type eruptions.

1983 January small strombolian type eruptions.

1984 January 9 and 31 small phreatic eruptions.

After the outbreak in April 1982, strong vulcanian type eruptions with intermittent occurrences of pyroclastic flows continued till September, when the nature of the activity changed to mostly strombolian type eruptions. During the vulcanian type eruptions in April - September, the 1918 dome was partly destroyed and heavy ashes and lapilli fell widely around this volcano, including Jakarta and Bandung. Eruption clouds which went up above 10 km generated severe navigation crises for two air craft on June 24 and July 13 when they encountered the eruption clouds from Galunggung volcano. One aircraft was flying at an altitude of 11.4 km at a distance of about 210 km SE of the volcano and the other at an altitude of 11.1 km about 160 km SW. According to an estimation of the volume of ejected materials during the 1983 Galunggung Eruption, the total volume of deposited materials in land area was about 1.3×10^8 m^3 and that of pyroclastic flows was about 1.4×10^7 m^3. During the strombolian type eruptions, the ejected materials formed a cone inside the main crater.

The eruption clouds out of Galunggung volcano during the period when this volcano manifested frequent vulcanian type eruptions in April - September and partly October were well detected in GMS images as shown in Photo 3-16 (1) - (33) for IR images and (a) - (d) for VIS ones. They are indicated with white arrows in photograph images and their approximate extent with black arrows in sketches beside the photographs. During the period of vulcanian type eruptions, not only small but also low-toned and dispersed eruption clouds could be detected. This is due to the relatively strong activities of many of those eruptions, the period when they took place, that is, the dry season in this region, and the location of this volcano which is near the equator, where GMS image has a high quality of ground-resolution. After the change of eruption type from vulcanian to strombolian in October 1982, the frequency of detection of eruption clouds sharply decreased because of the small extent of eruption clouds of strombolian type eruptions and because it was a rainy season in this region. The approximate extents of detected eruption clouds during April - October 1982 are outlined by solid lines for distinct domains and dotted lines for indistinct cases in Fig. 3-37 (a) - (d).

The first eruption cloud during the 1982, Galunggung Eruption was found in GMS image returned at 00 GMT on April 5, 1982 as a small bright-toned domain of 50 km × 70 km (upper of (1) in Photo 3-16) and could be traced till 06 GMT. An almost round-shaped and a bright-toned eruption cloud having a domain of 60 km × 60 km was seen at 22 : 30 GMT on April 24 and could be seen till 00 GMT on April 25, in spite of the presence of thick atmospheric clouds over this volcano (middle of (1) in Photo 3-16). The eruption cloud detected at 21 GMT on May 5 had already expanded over this volcano in the GMS image having an extent

of 140 km × 160 km and its extended domain could be traced till 10 GMT on May 6. The extent enlarged both to WSW and NE of this volcano as indicated by two white arrows in the upper and the middle part of (2) in Photo 3-16.

During May 17 - 19, isolated eruption clouds generated by the five eruptions could be detected. The 1st eruption cloud of 80 km × 90 km in size was detected at 16 GMT on May 17 and left the location of this volcano by 18 GMT (see the lower part of (2) in Photo 3-16), but could be traced till 06 GMT on May 18 as a low-toned domain showing a maximum size of 160 km × 400 km at 03 GMT on May 18 (see the extent shown by dotted arrows in the photograph images). The 2nd eruption cloud was seen at 00 GMT on May 18 and left the volcano by 03 GMT, but after spreading it was seen as a bright-toned domain having the widest domain of 430 km × 440 km till 12 GMT. And its dispersed and low-toned extent of 520 km × 880 km could be traced till 00 GMT on May 19 and reached the NW region of Australia (see the extent pointed out by solid arrow in (3) - the upper part of (5) in Photo 3-16). The 3rd eruption cloud was found at 09 GMT on May 18 having a domain of 130 km × 210 km (in the lower right of (3) in Photo 3-16) and detached itself from the location of this volcano by 10 : 30 GMT. Its dispersed extent could be seen till 03 GMT on May 19, showing a relatively bright-toned extent of 200 km × 600 km till 16 GMT on May 18, and the low-toned dispersed extent could be seen till 03 GMT on May 19 (see the eruption clouds indicated by white arrows in (4) - the upper part of (5) in Photo 3-16). The 4th eruption cloud was detected at 16 GMT on May 18 having a bright-toned domain of 70 km × 90 km slightly detached from the volcano till 18 GMT. The dispersed and low-toned extent could be traced till 09 GMT on May 19 showing the widest extent of 430 km × 870 km at 06 GMT on May 19 (see the eruption cloud pointed out by dotted arrows in the middle of (4) - the middle of (5) in Photo 3-16). The 5th eruption cloud was very small showing a low-toned domain of 30 km × 40 km and already detached from the location of this volcano at that time (see the small extent pointed out by a white arrow in the middle right of (5) in Photo 3-16). Its indistinct extent could be traced till 12 GMT on May 19. After examining the sequences of the above-mentioned eruption clouds, we consider that the individual eruptions during this period were isolated and relatively strong ones which did not last so long, because their eruption clouds could be individually detected in the series of GMS images.

At 16 GMT on June 24, an eruption cloud having a distinct, bright-toned and fan-shaped extent of 240 km × 250 km was detected as pointed out by a white arrow in the lower part of (5) in Photo 3-16. During the dispersion of this eruption cloud, another eruption cloud, having

a domain of 120 km × 180 km, was detected at 03 GMT on June 25 as pointed out by a solid arrow in the middle of (6) in Photo 3-16. The eruption clouds by both eruptions spread and joined together by 12 GMT as shown by a white arrow in the upper right of (7) in Photo 3-16 and could be monitored till 03 GMT on June 26 (see lower of (5) - (7) in Photo 3-16). The 1st eruption cloud spread over this volcano without detachment from the location of the volcano till 00 GMT on June 25, but its brightness sharply decreased after then. The 2nd eruption cloud also showed a bright-toned extent but detached itself from this volcano by 06 GMT on June 25, keeping its relatively bright-toned extent till 10 : 30 GMT. The joined eruption cloud at 12 GMT showed a low-toned and indistinct extent having its widest domain of 400 km × 930 km at 12 GMT on the same day.

There was a bright-toned and distinct eruption cloud of 180 km × 230 km in size in GMS image taken at 16 GMT on July 13 and spread to S of this volcano showing its bright-toned extent, but detached itself from the location of this volcano by 22 : 30 GMT. Another eruption cloud having a round-shaped domain of 40 km × 50 km was detected at 00 GMT on July 14 and it left the volcano by 03 GMT. A 3rd eruption cloud having a round-shaped domain of 40 km × 60 km was detected at 06 GMT on July 14 and quickly spread over a domain of 250 km × 350 km in the next image taken at 09 GMT, leaving the volcano later. The eruption cloud at 16 GMT on July 13 spread to S - SE of the volcano, and could be monitored till 12 GMT on July 14 showing the widest domain of 180 km × 400 km at 06 GMT as shown with a white arrow in (8) - the middle of (9) in Photo 3-16 and Table 2-2. The eruption clouds taken at 00 GMT (pointed out by a solid arrow in the lower left of (8) in Photo 3-16) and 06 GMT (pointed out with a dotted arrow in the upper left of (9) in Photo 3-16) on July 14 soon spread, and their joined eruption cloud at 09 GMT is shown by a dotted arrow in the upper right of (9) of Photo 3-16. All of the dispersed eruption clouds taken at 16 GMT on July 13 and 00 GMT and 06 GMT on July 14 finally joined together by 16 GMT on July 14 as shown with a white arrow in the lower part of (9) in Photo 3-16. The extent of the joined eruption cloud was indistinct in shape and low-toned in brightness, but showed the widest domain of 200 km × 990 km at 06 GMT on July 15, and the tip seemed to reach the NW coast of Austraria at that time.

A new eruption cloud having a bright-toned extent of 60 km × 140 km was detected at 12 GMT on July 15 and detached itself from the volcano by 16 GMT, but another small eruption cloud having a low-toned extent of 40 km × 60 km was found at that time (see the lower of (10) of Photo 3-16) and disappeared before 21 GMT. The dispersed eruption cloud was traced

till 09 GMT on July 16 showing the widest domain of 270 km × 480 km at 00 GMT on July 16 (see the middle of (11) in Photo 3-16).

A bright-toned eruption cloud of 80 km × 230 km in size was detected at 16 GMT on July 28 and showed an elongated extent of 130 km × 480 km to SW of this volcano without detachment from the volcano till 18 GMT as shown in the lower part of (11) in Photo 3-16. This eruption cloud was detached from the volcano by 21 GMT and its dispersing extent could be tracked till 12 GMT on July 29, showing its widest domain of 200 km × 750 km at 22 : 30 GMT on July 28. The eruption cloud at 16 GMT on July 29 shown in the lower right of Photo 3-16 (12) is a new eruption cloud, but already detached from the location of this volcano at that time. Its low-toned extent could be seen in GMS image by 00 GMT on July 30 (see the lower right of (12) - the middle of (13) in Photo 3-16 and Table 2-2).

A spot of eruption cloud of 20 km × 30 km in size could be seen at 18 GMT on July 30, detached itself from the volcano, and then quickly expanded to a domain of 210 km × 290 km by 21 GMT as shown in the lower part of (13) of Photo 3-16. This dispersed eruption cloud was separated into two portions, one drifting to NW and the other to SW at 00 GMT on July 31, and the former was traced till 03 GMT on July 31 and the latter could be traced till 10 : 30 GMT. A new eruption cloud having a bright-toned domain of 190 km × 250 km was also detected at 16 GMT on the day. After its detachment from the volcano at 18 GMT, the eruption cloud was separated into two portions, one drifting to WNW and the other to SW - S. Both of them could be traced in GMS images till 22 : 30 GMT (see the middle right-the lower part of (14) in Photo 3-16). It is considered that these two examples of separation of one eruption cloud were generated by different wind directions at different altitudes over this volcano.

A small eruption cloud of 50 km × 60 km in size was detected at 12 GMT on August 1 and dispersed after 16 GMT. The indistinct extent of the dispersed eruption cloud was traced till 22 : 30 GMT showing the widest domain of 420 km × 610 km as shown in the upper - the middle part of (15) of Photo 3-16. The eruption cloud newly detected at 16 GMT on August 7 dispersed to SW of this volcano after 18 GMT, too. The eruption cloud could be seen till 06 GMT on August 8 in GMS image (see the lower part of (15) - the upper part of (16) in Photo 3-16 and Table 2-2). The cloud newly detected at 06 GMT on August 9 had a domain of 60 km × 110 km at that time and was from the location of this volcano till 10 : 30 GMT, then detached itself from the volcano at 11 GMT. This eruption cloud was divided into two portions drifting, one to NW and SW the other to, at the time of the detection in GMS image, and

its dispersed extent of low-toned brightness was seen till 18 GMT (see the middle - the lower part of (16) in Photo 3-16). A low-toned and indistinct eruption cloud having an extent of 70 km × 140 km was detected in GMS image at 09 GMT on August 10, and was detached from the location of the volcano soon after 10 GMT. Its dispersed domain could be seen till 12 GMT (the upper part of (17) in Photo 3-16 and Table 2-2).

A small but bright-toned eruption cloud having an extent of 60 km × 70 km was detected at 18 GMT on August 11, and spread to SW of this volcano to a length of about 260 km at 21 GMT. It left the location of Galunggung volcano after 23 GMT but the dispersed extent could be seen in GMS image till 18 GMT on August 12 showing the widest domain of 360 km × 460 km at 09 GMT on that day (the middle of (17) - the upper part of (18) in Photo 3-16 and Table 2-2). A small and bright-toned eruption cloud having an extent of 40 km × 60 km was detected at 06 GMT on August 13. It expanded to the size of 130 km × 290 km at 09 GMT extending to SW, and detached itself from this volcano after 10 : 30 GMT. The dispersed domain could be traced till 00 GMT on August 14 showing a maximum domain of 180 km × 490 km at 12 GMT on August 13 (the middle of (18) - the middle of (19) in Photo 3-16 and Table 2-2). These eruption clouds were not big ones at first, but their extent was clear in GMS images and spread widely soon after their detection in GMS images. It is considered that these eruption clouds were produced by relatively strong and isolated eruptions because they spread widely within a short time keeping their bright-toned extent and could be traced for more than one day in GMS images. These phenomena may suggest that large quantities of ejected materials were borne inside the eruption clouds, and therefore the dense eruption clouds could keep its bright-toned extent and expand for long hours in the atmosphere.

The eruption cloud of 60 km × 140 km in size, detected at 16 GMT on August 14, was separated and drifted in two directions of SES and NW after 18 GMT. Both clouds left the volcano after 21 GMT, but could be traced separately in GMS images till 03 GMT on August 15. The portion of the eruption cloud that drifted to NW showed a bright-toned extent compared with that of the portion that drifted to SES - S. These phenomena will also indicate that the eruption cloud was ejected by a relatively strong eruption bearing large quantities of ejected materials inside, because they could be traced for long hours in GMS images in spite of its relatively small extent at first. One bright spot of 40 km × 40 km in size was detected at 10 : 30 GMT on August 15, but there were no traces of it in GMS image later (the lower part of (19) - (20) in Photo 3-16).

A very small spot of eruption cloud of 20 km × 30 km in size was detected at 00 GMT on

August 16. It quickly expanded to a domain of 110 km × 340 km at 03 GMT, indicating the ejection of a dense eruption cloud. The cloud left the volcano after 06 GMT but its domain spread widely showing the widest domain of 310 km × 790 km at 10 : 30 GMT and kept its bright-toned extent during the dispersion. The dispersed cloud was seen by 16 GMT . We suppose that this eruption cloud was generated by a strong and isolated eruption because of the long duration of its bright-toned extent in spite of its brief presence over the volcano (the middle of (21) - the upper left of (22) in Photo 3-16).

A small and narrow eruption cloud of 20 km × 110 km in size was detected at 03 GMT on August 24 and detached itself from the volcano by 06 GMT, and could be seen till 10 GMT showing a domain of 20 km × 100 km (the upper right - the middle of (22) in Photo 3-16). A relatively bright-toned eruption cloud of a domain of about 30 km × 60 km was detected at 22 GMT on August 25 and continued to come out of the volcano till 00 GMT on August 26 showing the widest domain of 110 km × 150 km, but decreasing its brightness. This eruption cloud left the location of this volcano after 03 GMT and could be traced till 16 GMT showing the widest domain of 270 km × 280 km (the lower of (22) - the upper of (23) in Photo 3-16). During the dispersion of this cloud, there was seen an eruption cloud spreading out of Soputan volcano, which erupted at this period as pointed out with a black arrow in the upper right of (23) in Photo 3-16. A small eruption cloud having a domain of 20 km × 30 km was detected in GMS image returned at 16 GMT on August 27 and detached itself from the volcano after 21 GMT. The low-toned and rather indistinct extent of the dispersed eruption cloud could be found till 10 : 30 GMT on August 28 showing the widest domain of 340 km × 810 km at 09 GMT (the middle of (23) - the upper part of (24) in Photo 3-16). These eruption clouds did not show a bright-toned extent and detached itself from the location of the volcano within a relatively short time. After dispersion, those clouds did not show any bright-toned domains and could not be traced for more than one day. So, we can conclude that the above-mentioned eruption clouds were generated by not so strong eruptions and the type of the eruptions should be single ones, at least not successive eruptions.

A bright-toned eruption cloud was detected at 06 GMT on August 29 and the dispersed extent could be traced till 12 GMT on August 30 showing the widest domain of 230 km × 640 km at 09 GMT, after detachment from the location of the volcano at 10 : 30 GMT on August 29. This eruption cloud was approximately divided into two domains — a bright-toned portion drifting to S and a low-toned one drifting to NNW of this volcano, and the both moved to SW in the whole (see the middle - the lower part of (24) in Photo 3-16). The domain

having a low-toned brightness in IR image should represent the lower altitudes and the portion having a bright-toned extent represents the higher altitudes. The eruption cloud is supposed to have separately drifted by the prevailing winds at the lower and the upper altitudes. The low-toned portion that drifted to NNW was traced till 16 GMT on August 29, but the bright-toned domain that drifted to SW retained its brightness longer and could be traced till after that time, we can consider that a dense eruption cloud was ejected to high altitudes by a relatively strong eruption, so the dispersed eruption cloud could be traced for more than one day in GMS images (the middle of (24) - the middle of (26) in Photo 3-16 and Table 2-2). The eruption cloud which was detected at 22 : 30 GMT on August 30 having a small domain of 20 km × 30 km and dispersed to SW showed similar sequences. Namely, the cloud was divided into two portions - a bright-toned domain drifting to SW and another having a low-toned domain drifting to N - NW of the volcano in GMS images taken at 00 GMT - 03 GMT on August 31. The dispersed eruption cloud drifted to SW as a whole and kept all its brightness till 12 GMT on August 31 showing the widest domain of 390 km × 460 km. It is considered that the intensity of the eruption which produced this eruption cloud was relatively small compared with that of the former eruption because the extent of the eruption cloud was smaller and the duraton time of the dispersed extent in GMS images was shorter (see the lower of (26) - (27) in Photo 3-16 and Table 2-2).

A clear and bright-toned extent of the eruption cloud was taken in GMS image on September 2 and the dispersed domain was well traced after then. The first small and low -toned eruption cloud having an extent of 30 km × 70 km was detected at 00 GMT on the day. At 03 GMT there was a bright extent which elongated to S was from the location of Galunggung volcano showing a domain of 90 km × 240 km. At that time, we can notice that a rather low-toned eruption cloud was over this volcano. The eruption cloud left the location of this volcano at 06 GMT, and the rather bright-toned portion drifted to S and the low-toned portion which was present over the volcano at 03 GMT drifted to W of this volcano. The bright-toned extent of the dispersed eruption cloud was traced till 16 GMT on September 2. The event on September 2 should be one of the strong and isolated eruptions of this volcano (see Photo 3-16 (28) - the uppermost part of (29)).

After then, small eruption clouds were intermittently detected in GMS images at 16 GMT on September 16, 18 GMT on September 18, 16 GMT on September 20, 12 GMT on September 22 and 10 : 30 GMT on September 24. The sizes of the eruption clouds in the respective first GMS images were 50 km × 110 km, 50 km × 60 km, 90 km × 240 km, 60 km ×

80 km and 20 km × 30 km, respectively (Table 2-2), and they were detached from the location of Galunggung volcano in the images taken about 2 - 4 hours later. The domain of individual eruption clouds during their expansion did not appear so bright-toned and distinct-shaped except those taken at 18 GMT on September 18, 12 GMT on September 22 and 10 : 30 GMT and 12 GMT on September 24. Besides, the extent of their dispersal was not so wide and the duration time of dispersing was less than 12 hours, even less than 6 hours in the case of the eruption clouds on September 20, 22 and 24. On the basis of these observational results, we can estimate that the eruptions which generated the eruption clouds on 16, 18, 20, 22 and 24 September were not so strong, while the events on 22 and 24 September were relatively larger ones (see the middle of (29) - (31) in Photo 3-16 and Table 2-2).

A bright-toned and distinct-shaped eruption cloud was detected at 09 GMT on October 8 having a domain of 110 km × 190 km. It was already divided into two portions elongated to N and SW at that time and drifting to SW as a whole domain by 16 GMT. The eruption cloud left the volcano about 10 : 30 GMT, but kept its brightness till 12 GMT after its from the volcano showing a domain of 160 km × 280 km (Photo 3-16 (32)). The eruption cloud detected at 09 GMT on October 11 had a small and indistinct but relatively bright-toned extent of 30 km × 60 km. It detached itself from the volcano about 12 GMT (Table 2-2 and the upper - the middle left of (33) in Photo 3-16). The eruption cloud detected at 06 GMT on October 14 was the last one which was found in GMS image during the 1982 Galunggung Eruption. The cloud had a bright-toned and distinct domain of 70 km × 90 km and was detached from the location of this volcano in GMS image returned three hours later, but kept its brightness till 10 : 30 GMT during its dispersion. In October, the frequency of detection of eruption clouds sharply decreased owing to the infrequent occurrence of eruptions, but the eruption cloud detected on October 14 should be one of the strongest eruptions in this month judging from its bright-toned extent (see the middle right - the lower part of (33) in Photo 3-16).

In Photo 3-16 (a) - (d), there are examples of eruption clouds taken by GMS VIS images. They are indicated with white arrows in photograph images and their approximate extent is outlined by solid or dotted lines in sketches beside them. Three dispersing eruption clouds generated by three eruptions at some time intervals during 03 GMT - 09 GMT on May 18 are shown by solid, dotted and white arrows in Photo 3-16 (a). Two kinds of dispersing eruption clouds detected on May 19 and June 25 are shown in (b) of Photo 3-16 and the eruption clouds detected on 13, 16, 26, and 31 August and 2 September are shown in the lower right of (b) - (d) of Photo 3-16.

All the eruption clouds taken in VIS images showed relatively low brightness in their extent compared with the surrounding atmospheric clouds in the VIS images taken not only at 09 GMT in the evening, but also at 03 GMT and 06 GMT in the daytime. These results of relatively low-toned eruption clouds in VIS images may be one of the important differences from atmospheric clouds when we are to distinguish the extent of eruption clouds from that of atmospheric clouds in GMS images. This problem will be discussed again in Chapter 5 with other examples.

Examples of surface temperature contours in °C of the eruption clouds are shown in Fig. 3-38 (a) - (b). These isothermal contours of the eruption clouds are based on the image data at 22 GMT, 22 : 30 GMT (upper right in (a)), 23 GMT on April 24, 00 GMT on April 25 and 16 GMT on May 17, 1982. Hatched portions in the figures mean the coldest portions of - 77 °C, - 81 °C, - 81 °C, - 81 °C and - 77 °C. These lowest temperatures are estimated to correspond to altitudes of about 16.2 km, 17.8 km, 17.8 km, 17.8 km, and 16.2 km, respectively. The estimation of altitudes is conducted mostly by using radio-sounding data at the stations shown in Fig. 3-28 and partly by using the air-temperature profiles based on model atmospheres shown in Fig. 3-1.

Looking at the temperature contours in Fig. 3-38 (a), it is noticed that the coldest or highest portions of these eruption clouds were over the volcano (solid triangle) at 22 GMT on April 24, then drifted toward SE and the whole domain also spread to SE. And it will be correct to judge that the major portion of the eruption cloud taken at 22 GMT on April 24 did not leave the location of Galunggung volcano by 00 GMT on April 25, but the major portion of the spread eruption cloud in GMS image taken at 16 GMT on May 17 had already been detached from the volcano.

The measurement results of the longest horizontal length, the widest width and the drifting direction of the eruption clouds detected in GMS image and their lowest temperature and estimated highest altitude are listed in Table 2-2. When spread eruption clouds generated by different eruptions were separately found in one GMS image, their features are shown in parentheses in this table. The time variation of the measurement result and the estimated highest altitude are shown in Fig. 3-39.

The estimated highest altitude of the eruption cloud is shown by a larger solid circle with H axis at the upper side in the respective figure, and the horizontal length by a smaller solid circle or open one with D axis at the lower side in the figures of Fig. 3-39. Solid circles and open ones for widths of eruption clouds respectively mean that the clouds were coming from

the volcano and that they were detached from the volcano in GMS images. Black arrows downwards in this figure denote the times of the cessation of eruption on the basis of the judgements whether the eruption clouds were continuous to detached from the location of this volcano in GMS images. According to the results of these judgements, 52 isolated eruptions in total were counted. In individual eruptions of Galunggung volcano, decrease of the horizontal length of eruption clouds in GMS image was relatively useful in judging the end and an isolated eruption. And it was possible to observe by analyses of eruption clouds detected in GMS images that the frequency of isolated eruptions was rather high during May - July compared with other periods. The data processing on the highest altitude of eruption clouds was not thoroughly carried out in this study, but there is a tendency that the altitude of the top of eruption clouds decreases at the end of an individual eruption.

3.17 Sangeang Api (Sunda Islands, Indonesia. 8.183° S, 119.067° E, 1,949 m)

This volcano is located in the Sunda Islands, E of Java Island, Indonesia, as shown in Fig. 2-2, and erupted in July, 1985, sending forth 6.5 km high eruption clouds. After that, lava pouring activity accompanying small - moderate strombolian type eruptions took place intermittently through the end of the year. An outline of the activity is as follows :

1985	July 30	vulcanian type eruption after small eruptions. 6.5 km high eruption cloud. much ash falls and pyroclastic flow.
	August	eruptions. lava flow.
	September	progressively changed to strombolian type eruptions. 1 km high eruption clouds. lava flow.
	October - November	small strombolian type eruptions.
	December	strombolian type eruptions. lava flow.

Of these eruptions, the eruption clouds generated by the activity on July 30 were detected in GMS images. No eruption clouds from activities after August could be detected in GMS images. The cloud taken at 06 GMT on July 30 was the first one having a bright-toned domain of 100 km × 130 km, and this eruption cloud had detached itself from the location of this volcano in the next image taken at 09 GMT. Its dispersed extent could be traced in GMS images till 18 GMT, showing a maximum domain of 210 km × 440 km at 16 GMT. The detected eruption clouds are shown in Photo 3-17, as pointed out with white arrows ; the approximate extent is shown with black arrows in the sketches beside the photograph.

The eruption cloud taken at 06 GMT on July 30 was coming from the volcano, but it had

already drifted to SW of the volcano, and the extent taken in VIS image showed a low-toned domain in spite of the bright-toned extent in IR image (see the upper part of Photo 3-17). The detached eruption cloud at 09 GMT still showed a bright-toned domain in IR image, but the brightness decreased and the extent quickly dispersed after 10 : 30 GMT (the middle - the lower part of Photo 3-17). This phenomenon suggests that the eruption on July 30 was a relatively strong one and therefore the eruption cloud could rise to high altitudes showing a bright-toned domain in IR image. The low-toned surface of this eruption cloud in VIS image will possibly represent great concentrations of ejected materials inside. The eruption cloud left the volcano within three hours and this indicates that the activity was an isolated type eruption.

The time variations of the domains of eruption clouds detected on July 30, colder than + 10 °C which coincides with an altitude of about 3.1 km, are shown in Fig. 3-40. It is observed that the eruption cloud quickly spread at about 09 GMT, and there was no extraordinary expansion of domain during the dispersion.

The surface temperature contours of the eruption clouds taken at 06 GMT and 09 GMT on July 30 are shown in Fig. 3-41. The coldest portions of the clouds were - 71 °C and - 51 °C, which correspond to altitudes of 14.1 km and 11.8 km, respectively. According to these results, we can observe that the coldest or highest portion of the eruption cloud at 06 GMT was not just over the volcano, but had already drifted to SW, indicating that this eruption took place at least about one hour before this image was taken. It is also observed in the image taken at 09 GMT, that the highest portion in the image at 06 GMT had drifted to S from the location, but the major portion of this eruption cloud showing higher temperatures was widely dispersed.

Radio-sounding data used for the estimation of altitude of the Galunggung eruption clouds at the stations shown in Fig. 3-28 were substituted for the altitude estimations of these Sangeang Api eruption clouds. The results on the highest altitude of the eruption cloud is shown in Table 2-2 with the measurement results of the width, length and drifting direction. The highest altitude of the eruption cloud was 14.1 km at 06 GMT, and it is considered that this eruption cloud did not penetrate the tropopause, and the altitude progressively decreased with time.

3.18 Karkar (New Guinea, Papua New Guinea. 4.65° S, 145.96° E, 1,840 m)

The location of this volcano is shown in Fig. 2-2. This volcano showed active fumings

in August, 1978, and small phreatic eruptions commenced in January in 1979 and strong eruptions accompanied by blast that killed two volcanologists took place in March. Small phreatic eruptions intermittently occurred through August of this year and also in 1980. An outline of the activities is as follows :

1979	January - February	small phreatic eruptions. ashfalls.
	March 8	strong eruption with blast. 2 volcanologists killed. total of ejecta through March 23 : 8×10^6 m^3.
	April - August	small phreatic eruptions.
1980	January - December	small phreatic eruptions.

One eruption cloud-like extent was found in GMS image returned at 00 GMT on March 11, 1979, as shown in Photo 3-18. There was much atmospheric cloud during the March Eruption, and the eruption cloud which was expected to be seen in GMS image could not be detected. The cloud taken at 00 GMT had a domain of 90 km × 210 km drifting to W. The brightness of the extent was rather low in brightness compared with the surrounding atmospheric clouds. The measurement results of the width, length and drifting direction of this detected volcanic cloud-like extent are shown in Table 2-2 with the mark of ? because of uncertainties in judgement.

3.19 Langila (New Britain, SW Pacific. 5.53° S, 148.42° E, 1,189 m)

The location of this volcano is shown in Fig. 2-2. Langila volcano showed frequent vulcanian type eruptions during the period from 1977 through 1985, and is still continuing its activities. The intensities of the eruptions were generally small - moderate but some of them were strong eruptions accompanied by 5 - 9 km high eruption clouds. During the activities, the growth of a lava dome, the flowing out of lava and pyroclastic flows took place. An outline of its activities is as follows :

1977	January and April - December	small eruptions. growth of lava dome.
1978	January - December	small - moderate eruptions.
1979	January - April	small eruptions
	May - September	moderate eruptions. growth of lava dome.
	late-September - December	small eruptions.
1980	January	moderate vulcanian type eruptions. lava flow.
	October	only lava flow.
	November - December	eruptions. growth of lava dome.

1981 January, April, June - July and October - December
vulcanian type eruptions.
November : pyroclastic flows of 10^4 - 10^5 m^3 in total and rock avalanche.
December : lava flow of 2×10^5 m^3 in total.

1982 January - May, June and August - December
moderate eruptions. strong eruptions in August, September, November and December.
December 1 - 26 : strong eruptions. 9 - 10 km high eruption clouds. lava flow of 2×10^6 m^3 in total.

1983 January — moderate eruptions.
February 11 - 16 — moderate vulcanian type eruptions. 3 - 4 km high eruption clouds.
April - June — small - moderate eruptions.
December — small - moderate vulcanian type eruptions. lava flow of $1 - 2 \times 10^5 m^3$ in total.

1984 January - November — small - moderate vulcanian type eruptions. 5 km high eruption clouds in April - May.

1985 February — strong vulcanian type eruptions. 4 km high eruption clouds.
March — small eruptions.
June - November — small - moderate eruptions. ashfalls.

There was no GMS image data of a clear eruption cloud out of this volcano despite careful inspections of the images. However, two spots which might be volcanic clouds out of Langila volcano were noticed in GMS images taken at 18 GMT on December 23, 1982, and at 16 GMT on February 11, 1983, as shown in Photo 3-19 and the measurement results of width, length and drifting direction are given in Table 2-2 with ? marks. Both spots have a low-toned domain of 20 km × 20 km. There was no eruption cloud-like extent in the GMS images taken after the above images, nor is it certain whether they were actually volcanic clouds or not.

3.20 Ulawun (New Britain, SW Pacific. 5.04° S, 151.34° E, 2,300 m)

This volcano is located on New Britain Island as shown in Fig. 2-2 and frequently

showed strombolian type eruptions during 1977 - 1985, and is still continuing its activities. Generally the eruptions were not big ones, but in October 1980 this volcano vigorously erupted with about 20 km-high eruption clouds and pyroclastic flows, according to the reports. Lava flows and the growth of a small lava dome were also reported in 1978 and 1985. An outline of its activities is as follows :

1978	May	strombolian type eruptions. moderate volume of lava flow. pyroclastic flow.
1980	October 6 - 7	big eruptions with 7 - 20 km high eruptions clouds. total volume of ejecta 10^7 - 10^8 m^3. pyroclastic flows.
1982	December	strong vapour rising.
1983	March - May and November - December	strong vapour rising.
1984	January and March	eruptions. 2 km high eruption cloud.
	August, September and December	small eruptions.
1985	January	small strombolian type eruptions. growth of small lava dome.
	November 17	small strombolian type eruptions. lava flow.
	December	eruptions.

Distinct and bright-toned domains over this volcano were seen in GMS images returned at 22 : 30 GMT on October 6 and at 00 GMT on October 7, 1980, during the occurrence of the big eruptions at this volcano as shown in Photo 3-20. They had domains of 120 km ×140 km and 170 km × 270 km, respectively, and drifted to WNW of the volcano. These eruption cloud-like domains showed bright-toned surfaces and the brightness almost coincides with the altitude near or above the tropopause over this volcano. However, it is not certain whether they were actually volcanic clouds or not, because they were detected in GMS images during periods when there were active and growing atmospheric clouds in this region. Therefore, the measurement results of width, length and drifting direction of erution cloud were shown in Table 2-2 with marks of ?. No eruption clouds by other eruptions could be found in GMS images, due mainly to the low intensity of the eruptions.

3.21 Lopevi (New Hebrides, SW Pacific. 16.51° S, 168.35° E, 1,447 m)

The location of this volcano is shown in Fig. 2-2. This volcano frequently erupted during 1977 - 1982. The intensity of the eruption was generally at low level, but the it was

sometimes followed by lava pourings. There were relatively strong eruptions with 5 - 6 km high eruption clouds in 1980 and 1982. An outline of the activities is as follows :

1977	February	small phreatic eruptions.
1978	November	small magmatic eruptions. lava flow.
1979	February - March	eruptions. lava flow.
	July and September	small eruptions.
1980	April and July	small eruptions.
	August	moderate eruptions. 5 km high eruption cloud. lava flow.
1982	October 24 - 25	eruptions. 6 km high eruption cloud. much ash.

The eruption clouds accompanying explosive activities could not be found out in GMS images before the 1980 Eruptions. However, a bright-toned and distinct shaped eruption cloud having a domain of 80 km × 190 km and drifting to SSE of this volcano was detected in GMS image at 21 GMT on October 24, 1982, as shown in Photo 3-21. The cloud was coming out of the volcano, but detached itself from the location of this volcano after 22 GMT, almost one hour after the first detection and decreased its brightness with time. So it is considered that the eruption cloud was generated by an isolated eruption which did not last for a long time. The dispersed eruption cloud could be traced till 00 GMT on October 25, showing the widest domain of 130 km × 310 km at this time.

The temperature contour in °C of the surface of the eruption cloud colder than + 15 °C, taken at 21 GMT on October 24, is shown in Fig. 3-42. The lowest temperature was - 57 °C, which corresponds to an altitude of about 13.2 km. The radio-sounding data at the stations in Fig. 3-28 are substituted for the estimation of altitude of the Lopevi eruption cloud. The estimated altitude of the eruption clouds was higher than the reported value (about 6.5 km), and showed an almost double value. This disagreement between the estimated altitude based on GMS image data using air-temperature profiles and the reported data based on eyewitness observations will be treated in Chapter 5 with other exmaples.

In Fig. 3-43, the time variations of the highest altitude (upper) and the longest horizontal length (lower) of the detected eruption clouds of this volcano are shown. Dotted lines among solid circles denote that the Lopevi eruption cloud left the location of this volcano after 22 GMT on October 24. The horizontal length of the eruption cloud increased with time, but the highest altitude quickly decreased after the detachment from the location of this volcano. In the case of the eruption of this volcano, monitoring of decrease of the

highest altitude of the eruption cloud and judgement of its detachment from the volcano were effective for the observation of the end of eruptive activity.

3.22 Ambrym (New Hebrides, SW Pacific. 16.25° S, 168.08° E, 1,334 m)

The location of this volcano is shown in Fig. 2-2. This volcano intermittently erupted during 1977 - 1981 with small - moderate intensities, while big eruptions took place in July - August in 1980. An outline of its activities is as follows :

1977	January	eruptions. 2 km high eruption cloud.
	September	eruption.
1979	February	eruption.
	June	moderate eruption.
	November	eruption.
1980	May	small - moderate eruptions.
	July 16 - 17	small eruptions.
	July 23 - August	big eruptions. 15 km high eruption cloud.
1981	February and March	eruptions.
	May	strong eruptions.
	September	moderate eruptions. lava flow.

The eruption clouds accompanying these activities were not well detected in GMS images, mainly due to the rather low intensity of the eruption. However, one eruption cloud was detected in GMS image taken at 00 GMT on July 23, 1980, as shown in Photo 3-22. The eruption cloud showed a bright-toned extent having a domain of 30 km × 50 km, but already detached from the location of this volcano at the detection time. The dispersed eruption cloud could not be traced in the next GMS image, and it is considered that this eruption did not continue for a long time.

3.23 Home Reef (Tonga, SW Pacific. 18.99° S, 174.78° W, submarine)

The location of this submarine volcano is shown in Fig. 2-2. This submarine volcano manifested strong submarine eruptions in May 1984 and formed a new island. The eruption cloud reached a height of 7.5 - 12 km, according to the reports, and generated widely floating pumice rafts. An outline of its activities is as follows :

1984	May 2 - 5	7.5 - 12 km high eruption clouds. a new island formed. pumice rafts produced, widely floating.

According to the reports, the biggest eruption took place on May 2 at this submarine volcano. However, thick atmospheric clouds obscured the visibility in GMS image around this region. A relatively bright-toned but indistinct eruption cloud-like extent extending from the location of the volcano was detected at 09 GMT on March 2, showing an approximate domain of 90 km × 100 km and drifted to W among atmospheric clouds as shown in Photo 3-23. The cloud domain left the volcano about 10 : 30 GMT and could be traced till 12 GMT showing widest domain of 100 km × 200 km.

The detection-time of this eruption cloud-like image well coincides with the period of the reported occurrence time of the big eruption at this volcano. However, the estimated highest altitude of the eruption cloud-like image increased with time from 12.5 km to 15.2 km (see Table 2-2). This phenomenon suggests that the cloud may not be volcanic events, but may be the growing atmospheric clouds that usually develop around this region. Therefore, the measurement data in Table 2-2 are given marks of ?. Radio-sounding data at the stations in Fig. 3-28 were substituted for estimations of the highest altitudes of the eruption cloud-like domain.