Chapter 1 Introduction

1.1 Purpose of this study

Explosive eruptions are accompanied by ejections of eruption clouds and it is possible to catch occurrences of volcanic eruptions by detection of eruption clouds. In cases of active volcanoes without observation facilities or in inconvenient geographical situations, it is often difficult to know even occurrences of volcanic eruptions and to monitor volcanic eruption sequences. Eruption clouds containing volcanic ejecta inside disperse over a broad region, drop them and sometimes cause severe accidents to flying aircraft which encounter eruption clouds. In general, it is very difficult to observe the whole configurations of eruption clouds which spread over a broad region only by ground observation. From this viewpoint, however, images returned from artificial satellites such as geostationary or orbital satellites are effective for monitoring eruption clouds dispersed over wide regions and may be useful techniques for global monitoring of volcanic eruptions with detections and observations of eruption clouds. Furthermore, we can use satellite image data to estimate and warn the areas in danger of ejecta-fall and to provide information for the safe navigation of aircraft. Observations of eruption clouds by satellite image data can also provide useful data for investigations on energy-releases by volcanic eruptions and on the dynamic behavior of rising and dispersing eruption clouds in the atmosphere.

Orbital satellites such as LANDSAT and NOAA have a high IFOV (instantaneous field of view) effective in detecting small-scale eruption clouds, but intervals of their image taking are too long to monitor the time variations of the behavior of dispersing eruption clouds. On the other hand, the Geostationary Meteorological Satellite (GMS) does not have such a high resolution of IFOV as orbital satellites, but the short time intervals of image taking, ranging from 30 minutes to 4 hours and mostly 3 hours, make it possible to monitor dispersing eruption clouds. GMS's detector, the Visible and Infrared Spin and Scan Radiometer (VISSR) can get both infrared and visible images, and it is possible to observe the earths's surface not only in the daytime but also in the nighttime. The image data are provided in photographs and computer compatible tapes (CCT) for the period from the first launch of GMS in late 1977 till now. The author carefully inspected those image data, mainly on photograph data, to find out eruption clouds by volcanic eruptions which occurred in the field of view of GMS and thoroughly examined the capability of GMS images to detect eruption clouds and the possibility of monitoring dispersing eruption clouds and sequences of volcanic eruptions and of estimating thermal energy release based on analyses of CCT eruption cloud data.

1.2 General characteristics of GMS

The general characteristics of GMS are shown in Table 1-1 (after the Meteorological Satellite Center, 1980). GMS is located at 140°E longitude over the equator. The images are routinely obtained at intervals of mostly 3 hours and partly 30 minutes and 4 hours ; 00, 03, 06, 09, 10, 10:30, 11, 12, 16, 18, 21, 22, 22:30 and 23 GMT. The image-scanning begins about 25 minutes before the above-mentioned image taking times and the whole globe images are completed by the times. IFOV subsatellite of visible and infrared images are 1.25 km and 5 km, respectively. The field of view of GMS is shown in Fig. 1-1, together with the locations of more than 300 active volcanoes in it. Considering that IFOV decreases at the edge of the globe, inspections of eruption clouds are conducted about volcanic eruptions in the area encircled by bold lines as shown in Fig. 1-1. We can get two kinds of image data of albedo and surface temperature (T_{BB}) values with visible and infrared detectors of VISSR, respectively. Albedo data mean brightness distribution on the earth's surface received by the visible band radiometer and the data are assigned to a range of 0 — 95 %, and T_{BB} data correspond to surface temperature distribution on the earth's surface received by the infrared band radiometer in a range of + 30°C— −80°C. These temperatures in °C are obtained from the relations between infrared radiance and black body radiation temperature. GMS's image data are provided in black and white pictures and with digital data on albedo values in % and surface temperature in °C registered in CCT.

1.3 Data

This study uses two kinds of GMS image data, picture and CCT data obtained during the period from late 1977 to 1985. For inspection of eruption clouds in GMS images, volcanic eruptions reported in the SEAN Bulletin during 1977 - 1985 (Scientific Event Alert Network, 1977 - 1985) and the Bulletin of Volcanic Eruptions during 1979 - 1986 (Volcanological Society of Japan, 1979 - 1986) are consulted. The results of analysis of time variations of drifting directions and velocities of dispersing eruption clouds are compared with wind velocities and wind directions at various altitudes obtained by radio sounding data at nearby stations around the respective volcanoes.

1.4 Method

To find out eruption clouds in GMS images, the occurrence times of volcanic eruptions reported in the bulletins and reports mentioned in the preceding section were the most useful information, because it is usually difficult to distinguish eruption clouds from atmospheric clouds in GMS images. Therefore, the occurrence times of volcanic eruptions were first obtained from those bulletins, and then judgements on the existence of eruption clouds from respective volcanos were formed mainly on infrared photograph images. The extnet, drifting directions, the maximum width and the horizontal lengths of the eruption clouds detected were also measured on them.

These data were used for analyses of the time variations of dispersions of eruption clouds. It is considered that the brightness of eruption clouds in images reflects their thickness and thick eruption clouds are generated by occurrences of active eruptions. And eruption clouds normally move away from the volcanoes after the decay or ending of eruption. Therefore, the data measured on GMS images were used for judgements of occurrences or decays of volcanic eruptions.

Numerical values of the albedo and temperature of the eruption clouds detected were processed from CCT data by using the computer system at the Meteorological Satellite Center, Japan Meteorological Agency. The digital data were printed out mostly at every 0.05° grid point, partly at 0.1° grid point in latitude and longitude over and around the volcanoes for which eruption clouds were detected in GMS images. Temperature data were used to estimate the altitudes of eruption clouds based on air-temperature profiles. The maximum altitudes estimated were tracked to indicate the time sequences of volcanic eruptions. The estimated altitudes of eruption clouds were also used for calculations of thermal energy release of volcanic eruptions for evaluations of the intensity or strength of the activities. The distribution of surface temperature of eruption clouds were also utilized to obtain the profiles of some eruption clouds and to analyze the time variations of areal scale of isothermal domains of eruption cloud surfaces. The moving velocities of eruption clouds in several examples were obtained as movement distances between two images taken at different times in order to get fundamental information on the behavior of dispersing eruption clouds.

The altitude of an eruption cloud was estimated under the assumption that it rises high by the buoyancy force generated during its adiabatic expansion and gained with heat discharged during the mixing of ambient atmospheric air inside it, and that the surface temperature of an eruption cloud which has risen high is cooled to almost the same temperature as the ambient air. Therefore, the altitude of the surface of an eruption cloud can be estimated either from the air-temperature profile obtained by radio sounding data or from an appropriate model of atmospheric temperature profile in substitution.

Thermal energy release by eruption cloud data was estimated from the thermal energy release rate (Q in mega watts) by the following equation proposed by Briggs (1969) under the assumption that an eruption cloud at high altitude behaves as plume rise, and from the duration time of a volcanic eruption based on analyses of eruption cloud data or ground observational data :

$$Q = 0.0264 \cdot \Delta h^3 \cdot u^3 \cdot x^{-2} \qquad (1,1)$$

where Δh, u and x denote the height of the surface of an eruption cloud in m above the crater, the mean wind velocity in m/ sec at the altitude of the eruption cloud and horizontal distance from the crater in m, respectively. The limiting condition for applying this formula is $x \leqq 10$ hc, where hc means the elevation of the plume source. However, IFOV of GMS's IR image data exceeds several km at a position far from the subsatellite point, and the elevations of all the craters analyzed were under 3 km a. s. l.. Besides, the upper portions of most of eruption clouds are not located within an area of 10 hc, because they were drifted away from the sites of the craters by the prevailing winds. Therefore, in this paper, Q was calculated using Δh data under the extended condition of $x \leqq 50$ hc. This extended condition may result in a relatively lower estimation of Q, but Δh data on the upper portions of eruption clouds that moved from volcanoes could be used for the calculations of Q.

Thermal energy (E_{th} in erg) released by juvenile ejected materials was also calculated with the method proposed by Yokoyama (1957) and using abbreviated values for the parameters in the formula proposed by Nakamura (1965) as follows :

$$E_{th} = M \cdot (T \cdot C + H) \cdot 4.18 \cdot 10^7 \qquad (1,2)$$

where M, T, C and H mean the total mass of ejected materials in g, difference of temperature as 600°C between ejected materials and surrounding air temperature, specific heat as 0.25 cal/ g • °C and latent heat of melting as 10 cal/ g, respectively. Here, the volume of juvenile ejecta to obtain M was based on reported data or roughly estimated values from the descriptions of respective volcanic eruptions, except for cases where reported values of M are available. The bulk density of ejected materials was tentatively assumed as 1.8 g/cm^3 in cases of ejected materials composed of not only fallen ejecta, but also pyroclastic flows and/ or lava flows. The bulk density of ejecta composed of only fallen ones was assumed to be 1.2

g/cm^3.

For information on energy released by eruption, kinetic energy (K_e in erg) was also calculated by the following formula :

$$K_e = 0.5 \cdot M \cdot v^2 \qquad (1,3)$$

where M and v denote the total mass of ejected materials in g and the initial velocity of ejection in cm/ sec, respectively.

Horizontal diffusivity (K_y in cm^2/ sec) of eruption clouds was also estimated by the following formula proposed by Gifford (1959) :

$$K_y = u \cdot Y_m{}^2 \cdot e^{1/3} \cdot (2X_t)^{-1} \qquad (1,4)$$

where u, Y_m and X_t denote mean wind velocity in cm/ sec, width of eruption cloud in cm and horizontal length of eruption cloud in cm from the crater, respectively.