Satellite imagery of ash clouds of the 2000 eruption of Miyake-jima Volcano

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Abstract

We analyze GMS/VISSR images for big eruptions in August 2000 and the NOAA/AVHRR images in August and September to detect the volcanic clouds from Miyake-jima. Furthermore, we discuss the dispersion of volcanic clouds corresponding to the SO_2 high concentration episodes in Main Island of Japan by comparing the satellite images with simulation results of a vertical shear model.

Keywords: GMS/VISSR, NOAA/AVHRR, vertical shear, plume, volcanic gas

1. Introduction

Miyake-jima volcano, about 160 km south from Tokyo, started eruptive activities at the summit Oyama (814 m) on 8 July 2000. Big eruptions were recorded on 10, 18 and 29 August with the altitudes of volcanic clouds about 8, 15 and 8 km, respectively. Since 28 August, volcanic clouds and gas toward Main Island of Japan caused high concentration events of SO_2 at many ground stations 100-400 km leeward from Miyake-jima. Although big eruptions were not recorded since September, and plume heights were less than 3000 m above the sea level, the estimated emission of SO_2 increased to 20-30 kt/day since the middle of September. Southern and south-westerly winds brought the volcanic gas to the Main Island of Japan, where the smells of sulfur and/or H_2S were reported in various places. Since October, gray ash clouds are hardly seen, and the plumes turned out to be white with the heights less than 1500 m above the sea level after the middle of that month. However, very high level of gas emission has continued.

In this study, we analyze GMS/VISSR images for three big eruptions in August, and 29 scenes of NOAA/AVHRR images during August 28 – September 27 to detect the volcanic clouds from Miyake-jima, and also compare with other satellite images found in the Internet. Furthermore, we discuss the satellite images of volcanic clouds corresponding to the SO_2 high concentration episodes recorded in central part of Japan, August 28 in Kanto area and September 13-15 in Chubu district, by comparing the dispersion of volcanic clouds in the satellite images and gas informations at the surface with the simulation result of a vertical shear model based on the upper wind data.

2. Informations on volcanic ejecta and methods of analyses

Many detailed informations on the activities of Miyake-jima volcano are publicized in various web-sites in the Internet with almost real-time and mostly in Japanese. Some of them are well archived. These informations are very helpful in our analysis of the dispersion of volcanic ejecta in addition to the satellite images and meteorological data.

2-1. Satellite data and their analysis

GMS-5/VISSR data with visible (VIS) and thermal infrared (IR1 and IR2) bands provided by Japan Weather Association (JWA) are analyzed concerning three big eruptions in August. GMS images at one-hour intervals are suited to see the time developments of big eruptions.

NOAA/AVHRR and other satellite data of the volcanic clouds at Miyake-jima are listed in Table 1, together with observation results of volcanic clouds from helicopters in Geological Survey of Japan (GSJ) home page: http://www.gsj.go.jp/~yagi/miyake/heliobs.html. Volcanic clouds from Miyake-jima were recognized as bright objects in visible and near infrared images. Although it is difficult to discriminate between the volcanic clouds and meteorological ones by these grayscale images, their advection shapes from the crater may be taken as clues for our understanding. Satellite imagery characteristics of volcanic clouds for various bands are described in detail in the references [1, 2]. As for the daytime NOAA/AVHRR data, the false color composite images by assigning n(4), n(2) and n(1) to blue, green and red colors are useful to detect the volcanic clouds and discriminate them from meteorological ones.

In our previous studies, the split-window method taking the difference of AVHRR-4 and 5 (dT = T(4) – T(5)) was very useful for the discrimination of volcanic clouds of Mt. Sakurajima and Mt. Aso from meteorological ones [1-3]. This is due to the ash components with emissivity at 12 μm higher than at 11 μm, and similar response to dT is expected from the sulfuric acid aerosol in the downstream [4]. This method can be applied in monitoring large volcanic eruption by GMS-5/VISSR [5].

NOAA/AVHRR images received at Kagoshima University (K-N) are provided as a 10-bit data. The original data are converted into 16-bit data where the value n(i) of thermal infrared band i corresponds to the brightness temperature T(i) in degrees centigrade as $T(i) = -50 + 0.1 \times n(i)$, i = 4, 5. On the other hand, the data provided by Hokkaido University (H-N) is an 8-bit format, thus $T(i) = - X + Y \times n(i)$, i = 4, 5, where X = 10 and Y=0.2, except for the * marked data, where X = 30 and Y = 0.3.

In this study, as an expression of the brightness temperature difference, we define the Aerosol Vapor Index (AVI) as

AVI = n(5) - n(4) + Z, for NOAA/AVHRR with Z = 200 (K-N) or 100 (H-N)

AVI = IR2 – IR1 + 100, for GMS/VISSR

Table 1 Satellite data of volcanic clouds from Miyake-jima. Dir. and L denote the direction and length of a volcanic cloud, respectively. The data sources are denoted as K, H and I for Kagoshima University, Hokkaido University and Internet web-sites, respectively. The mark + denotes the case that plume flow exceeded the image scene. The mark – denotes the cases without signal and no comment. The observation results of volcanic clouds from helicopters are also listed from GSJ home page.

2000	JST	Sat.	Dir.	L(km)	Source	Observation of volcanic clouds from a helicopter			
						height (m) above sea level	color	advection dir.	comment
8/28	4:39	NOAA-14	-	-	H				
	5:51	NOAA-12	NW	49	K				
	9:54	Landsat-5	NW-N	188	I				
	12:00	SeaWiFS	NNW-NE	312	I				
	17:07	NOAA-12	N-NE	179	K				
8/29	4:27	NOAA-14	Erupt.	-	H				
	5:28	NOAA-12	NE	18	H*				
	7:59	NOAA-15	NE	46	K				
	10:42	ASTER	N-NE	54	I				
	12:00	SeaWiFS	N-NE	300+	I				
	15:51	NOAA-14	N-E	280	H*				
	16:46	NOAA-12	N-E	218	K				
9/3	11:01	ASTER	W	38+	I				
9/6	17:03	NOAA-12	NE	58	K				
9/7	16:40	NOAA-12	NNE	19	K				
9/9	3:59	NOAA-14	N	62	H	2200	dark gray	N	-
	15:23	NOAA-14	N-NNE	215	H				
	15:56	NOAA-12	NNE	115+	K				
9/10	15:11	NOAA-14	N-NNE	152	H				
	17:12	NOAA-12	NNE	77	K	2200	dark gray	N	-
9/12	5:09	NOAA-12	NNE	31	H	1700	white	N-NNE	Ash
	16:27	NOAA-12	NE	58	K				
9/13	4:53	NOAA-14	NNW	32	H	1900	white	-	-
	9:54	Landsat-5	W-NW	88	I				
9/14	4:42	NOAA-14	NW	25	H				
	6:05	NOAA-12	NW	62	K				
	16:05	NOAA-14	NW	165	H				
9/15	4:30	NOAA-14	-	-	H	2500	white	W-WNW	-
	5:42	NOAA-12	WNW	11	K				
	15:53	NOAA-14	N-W	239	H				
9/18	6:35	NOAA-12	NNE	77+	K	1500	white - white gray	E	Ash
	10:28	SPOT-1	NE	17+	I				
9/21	16:51	NOAA-12	SSW	192	K	2000	white	SE	-
9/22	10:20	SPOT-2	W	10+	I				
9/24	16:53	NOAA-12	ESS	19	K				
9/25	5:14	NOAA-12	E	65	K	1800	white	E-ESE	-
9/26	16:08	NOAA-12	SE	115	K				
9/27	10:24	SPOT-2	E	10+	I	2500	white - white gray	upper layer: SW lower layer:SE	Ash

LANDSAT and SPOT images on Miyake-jima are found in NASDA-EOC home page: http://www.eoc.nasda.go.jp/guide/topics/news/miyake/miyake_iland_j.html. ASTER images are displayed in ERSDAC home page at http://www.gds.aster.ersdac.or.jp/gds_www2000/gallery_e/image_miyake_e/set_image_miyake_e.html. SeaWiFS images can be seen in NASA home page at http://visibleearth.nasa.gov/Sensors/OrbView-2/SeaWiFS.html.

2-2. Meteorological data and vertical shear model

Upper air data by means of radio-sonde measurements are obtained at observation points illustrated in Fig.1. In addition, surface weather charts are also considered.

To investigate the advection and dispersion of volcanic clouds and gas corresponding to SO_2 high concentration episodes in Kanto area and Chubu district in conjunction with satellite images, we simulate the dispersion of volcanic clouds based on a simple vertical shear model (VSM) using upper wind data [2]. In this study, we assume that the volcanic gas behaves almost together with volcanic clouds, on the bases of previous analysis of Sakurajima volcano [1].

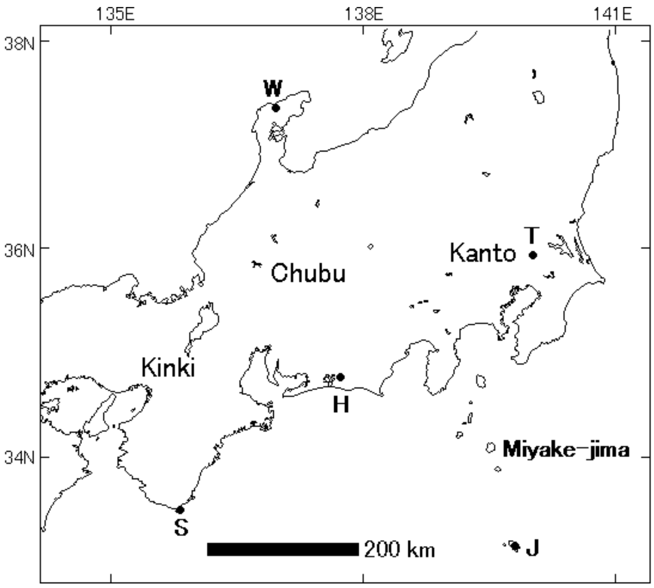

Fig. 1 Observation points of upper air in central part of Japan, denoted as H: Hamamatsu, J: Hachijojima, S: Sionomisaki, T: Tateno and W: Wajima.

As shown in Fig. 1, the nearest station of upper air observation is Hachijojima. We confirmed that the wind field around Miyake-jima is well approximated by the Hachijojima-winds in most cases, based on the advection of volcanic clouds seen in the satellite images and ground-observation informations. For simplicity, we assume that the wind field is uniform at certain height and time, and we use only the wind data of Hachijojima observed at six-hour intervals at standard pressure levels, 925, 900, 850, 800 and 700 hPa which correspond to the altitudes about 790, 1000, 1500, 2000 and 3100 m, respectively. We first get the upper-wind data set in height and time at intervals of 10 hPa and one hour, respectively by the linear interpolation for wind speeds and directions. In the interpolation, we choose the wind directions so that the variations never exceed 180 degrees.

We calculate the locations of dimensionless, weightless particles at 1-hour increments after they are released into the atmosphere at specified pressure-altitudes above the volcano. The model's ideal particles remain at the initial pressure-altitudes which are released. Emission rate of particles is assumed to be constant for a certain time interval, and the positions of them at a certain time are displayed corresponding to the satellite images of volcanic clouds.

2-3. SO_2 concentration and other informations

The estimates of total SO_2 emission by the correlation spectrometer (COSPEC) data are shown in the home pages of GSJ and Japan Meteorological Agency: http://www.gsj.go.jp/~imiyagi/Works/Event/Miyake2000/geol/000916cospec/ and http://www.kishou.go.jp/miyake/jyoukyo/1116.pdf, respectively.

The one-hour values of SO2 concentration in Tokyo were provided by Tokyo Metropolitan Government, as analyzed in details in [6].

Other informations, such as volcanic activities and plume photos are collected from Internet news and related home pages. Especially, the reports of habitants about the smells of H_2S and/or SO_2 are obtained via Internet BBS: http://www.jah.ne.jp/%7Echili/camp/nagaya.cgi?room=005.

3. Results and discussions

3-1. Satellite imagery of volcanic clouds

GMS/VISSR images for three big eruptions in August were analyzed. Although spatial distributions of them are rather limited, they can be seen in AVI images. We will discuss the observation time of each scene based on the filename time according to JWA. As for the eruption at 6:30 on August 10, the eruption clouds are seen as small but bright clear objects with linear shape in 9 and 10 JST images. The dispersion of time-series of the eruption cloud after the eruption at 17:02 on August 18 can be seen during 18-24 JST image, though the volcanic clouds were merged with meteorological ones. In these images, two directional flows toward NW and SE are recognized, and this behavior is explained well by the PUFF Model simulation result in http://www.geo.tsukuba.ac.jp/~tanaka/tanaka/m0818b.html. After the eruption at 4:35 on August 29, the ejected clouds were detected with both AVI images of the GMS/VISSR and NOAA/AVHRR. In the GMS images, it can be seen during 6-10 JST with wide spread form.

In Table 1, analyzed results of the length and direction of volcanic plumes are also listed. A part of the images are reported in [7] in details. AVI images can detect the eruption clouds and the plumes containing gray-colored ash significantly. On the other hand, white-colored volcanic clouds, for instance on September 14-15, were difficult to be seen in AVI images, though it can be detected easily by single band images of AVHRR-1 and 2. In the daytime images, the false color composite image by assigning n(4), n(2) and n(1) to blue, green and red colors is useful. In such images, meteorological clouds at high altitudes are displayed in yellow color, while volcanic clouds tend to become magenta colored. We may attribute the difficulty of the detection of volcanic clouds by AVI images to the following reasons: (i) Plumes ejected from Miyake-jima volcano since the middle of September were containing less silicates than from Sakurajima and Aso volcanoes. (ii) The large amounts of water vapor in summer above the volcanic clouds cancel the AVI signal of the ejecta.

3-2. High concentration episodes of SO_2 in long distances

3-2-1. August 28

Fig.2 (a) shows a composite image of NOAA-12 at 17:07 on 28 August 2000, and Fig.2 (b) illustrates a corresponding VSM simulation. This simulation result reproduces well the upstream of the plume, while the downstream over the land are not well reproduced since the advection near the surface by the sea breeze and the topographical effect are not implemented in model. On this day, the SO_2 high concentration values at the surface were reported all over Kanto area such as Tokyo, Kanagawa, Shizuoka, Saitama and Gunma in the daytime, as shown in Atmospheric Environmental Regional Observation System (AEROS). The maximum values were recorded during 12:00-14:00. This may be due to the convection mixing developed in the daytime to pull down the gas in the plume in the upper air to the surface. The distribution of these high concentration points corresponds well to the dispersion of volcanic clouds demonstrated in the satellite images and to the detailed simulation of the convection mixing by the SPEEDI of Japan Atomic Energy Research Institute: http://www.jaeri.go.jp/genken/press/000907kan/index.html.

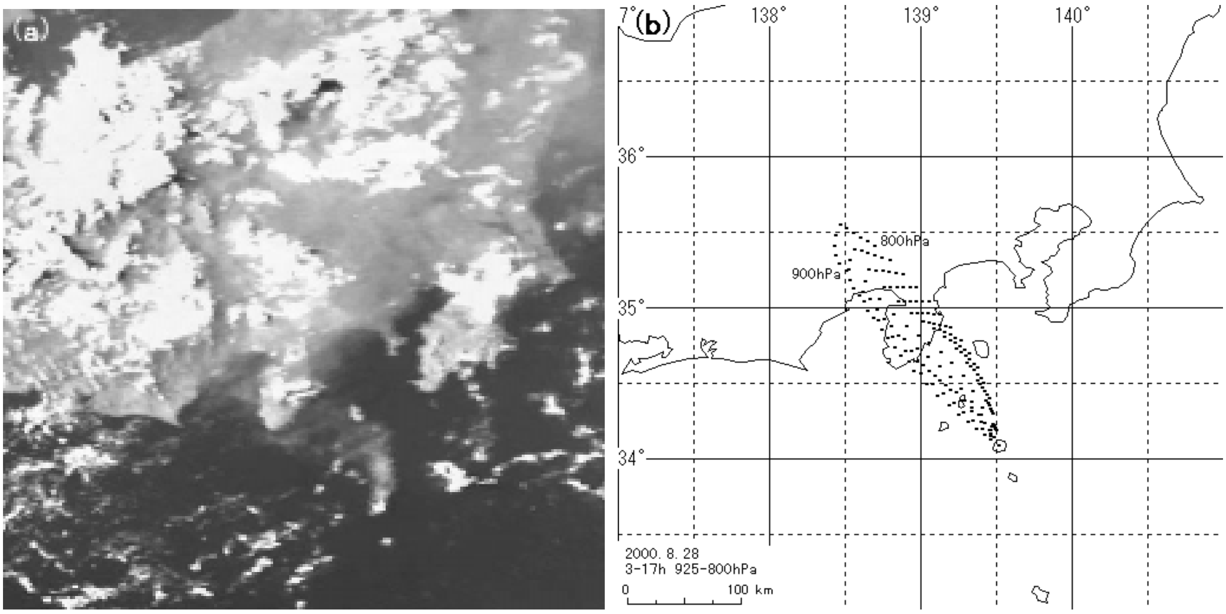

Fig.2 A composite image of NOAA-12 at 17:07 on 28 August 2000 (a), and the VSM simulation result at 925-800 hPa for the ejection during 3-17 JST (b).

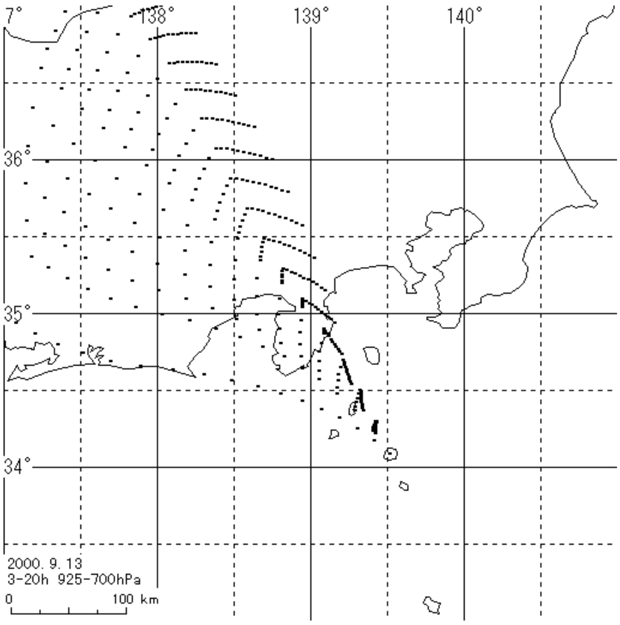

Fig. 3 Simulation result at 925-700 hPa for the ejection during 3-20 JST on 13 September 2000

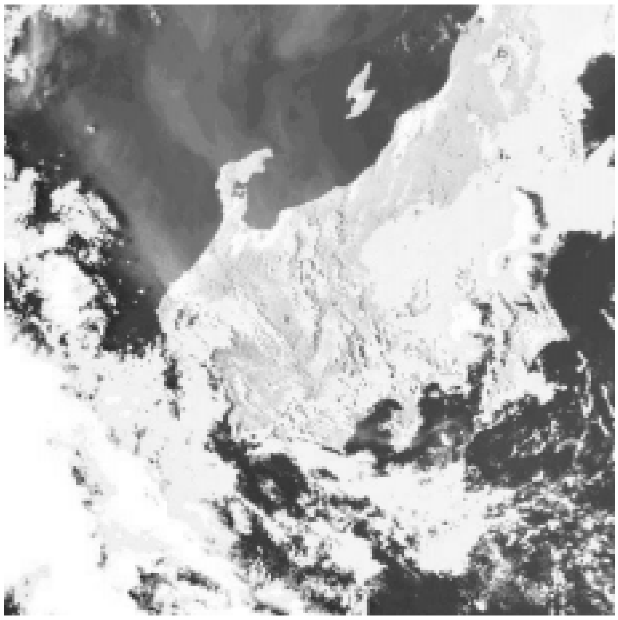

Fig. 4 A composite image of NOAA-14 at 15:53 on 15 September 2000

3-2-2. September 13-15

In these days, SO_2 high concentration records from various stations were reported in Chubu district. Volcanic clouds flowing toward NW due to the wind around typhoon stagnating in south-western direction are seen in satellite images. Fig. 3 illustrates the simulation result at 925-700 hPa for the ejection during 3-20 h, on September 13 which is similar to the PUFF Model simulation at the University of Tsukuba: http://www.geo.tsukuba.ac.jp/~tanaka/tanaka/m0913a.html. We may infer that the high concentration events at Nagano caused by the plume flowed at the altitude of 2000-3000 m with collimated winds, and it is understood that the smells of sulfur and/or H_2S in the northern-part of Kinki and the high concentration values observed at night in Kyoto were due to the dispersion owing to the large vertical wind shear at the altitudes less than 2000 m. Similar results of the simulation and satellite images are obtained the next day.

On the other hand, a composite AVHRR image at 15:53 on September 15 shown in Fig.4 indicates the long-range advection of volcanic cloud reached to the Sea of Japan, which is in accord with the high concentration values observed at the both sides of central mountains in Main Island, i. e., Gifu and Fukui, and also with the simulation result.

4. Concluding remarks

We have analyzed GMS/VISSR images for three big eruptions in August and 29 scenes of NOAA/AVHRR images during August 28 - September 27 to detect the volcanic clouds from Miyake-jima. Furthermore, we have discussed the satellite images of volcanic clouds corresponding to the SO_2 high concentration events recorded in central parts of Japan, August 28 in Kanto area and September 13-15 in Chubu district, and these VSM simulations to describe the dispersion of them. The results are summarized as follows:

(1) The eruption clouds and ash plumes from Miyake-jima volcano were detected in AVI images.

(2) As for the white plumes, the false color composite image by assigning n(4), n(2) and n(1) to blue, green and red colors is very useful. It is possible to discriminate between the volcanic clouds and the meteorological ones by color tones.

(3) The dispersion of volcanic clouds corresponding to the distribution of the SO_2 high concentration points are understood by means of a simple vertical shear model based on the upper wind data of Hachijojima.

Here let us make a few remarks on remaining problems.

(a) Instead of the uniformity of upper wind field, spatial interpolation of winds in a VSM should be considered. In our previous study [2], the simulation results of volcanic clouds from Sakurajima with a long-range advection toward north shown in NOAA images were reproduced well by means of an extended VSM that performed spatial interpolation of the upper wind data between Kagoshima and Fukuoka.

(b) In this study, we assumed that the volcanic gas behaves almost together with plumes. This assumption will be clarified by the direct detection of SO_2 using ASTER sensor [8].

(c) Highlight scenes of satellite images of this study are displayed in our home page: http://www.mech.kagoshima-u.ac.jp/lab/netu/miyake008/miyake-e.htm.

Acknowledgments

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