Satellite Observation of Volcanic Phenomena in Kyushu, Japan

Kisei KINOSHITA*, Shin-ichiro IKEBE** and Ko-ichi ISOGAI***

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Abstract

Remote sensing data from earth observation satellites concerning active volcanoes in Kyushu and Ryukyu Islands, Japan are reviewed. The themes are volcanic topography, land cover, volcanic clouds and thermal aspects. The data on volcanic clouds detected by the NOAA meteorological satellites are also mentioned.

Key words : Sattellite image, volcano, Aso, Unzen, Suwanosejima, Kyushu

§ 1. Introduction

Monitoring Volcanic activity is one of the important uses of the earth observation satellites such us LANDSAT, MOS, SPOT, JERS-1 and newly launched satellite ADEOS. The regular surveillance of volcanoes serves to find anomalous changes and eruptions, understand their behavior, and predict their activities to avoid or minimize volcanic hazards [1, 2]. For analysis of the remote sensing data of volcanoes, it is important to compare with ground truth data. For this purpose, the well-observed volcanoes such us Aso, Unzen and Sakurajima in Kyushu, Japan provide precious testing grounds.

In this paper, we try to present the archives of satellite data detecting volcanic activities in Kyushu, one of four main islands in Japan. We also consider Ryukyu Islands, where many small volcanic islands are less well monitored on the ground. We discuss the topography and land cover characteristic of volcanoes, and try to give a short review of preceding works on remote sensing of the volcanoes in Kyushu. The general background of setellite imagery of volcanoes and ash clouds are discussed in a review book [2].

* Faculty of Education, Kagoshima University, Kagoshima 890, Japan
** Aso Volcano Museum, Kusasenri, Aso, Kumamoto 869−22, Japan
***Earth Remote Sensing Data Analysis Center, Tokyo 104, Japan

In §2, We explain the geography of Kyushu and Ryukyu islands in relation to satellite scenes, and give introductory remarks on the satellite imagery of volcanoes. We discuss the topography and land cover of volcanic zones and islands in §3. Then volcanic clouds are discussed in §4, where lists of daytime satellite data are given. Thermal data from LANDSAT-5 are briefly discussed in §5. Concluding remarks are given in the last section.

§2. Geography and satellite scenes

2－1. Distribution of volcanoes in south-west Japan

Among the ring of volcanoes in the circum-Pacific area, there are many active volcanoes in the west-Japanese volcanic belt, as shown in Fig. 1. Numbers of them are ejecting ash clouds actively, while some others are dormant or quite quiescent. Among them, listed in a recent year report of world active volcanoes are Aso, Unzen, Kirishima, Sakurajima and Suwanosejima [3]. The seismicity of Kuchinoerabujima is also mentioned.

At Aso Volcano, one of the authors (S.I.) has been performing continuous monitoring of the vent by robot video-cameras located at the crater wall, and occasional video recording of ash clouds from 3 km west of the crater [4]. This is in addition to the seismic monitoring and other techniques used by Aso Volcanic Observatory of Disaster Prevention Institute, Kyoto University and Aso Station of Kumamoto Local Meteorological Observatory [5].

Unzen Volcano has been a subject of intensive studies of many volcanologists all over Japan since its eruption on 17 Nov. 1990 [6]. Volcano Sakurajima is one of the most well-monitored volcanoes in the world with the exception of the inside of the crater [7], and analyses of the satellite data in conjunction with the ground observation have been previously discussed [8].

In contrast to the above volcanoes on the mainland Kyushu, small volcanic islands in the southern sea belonging to Ryukyu Islands are not well monitored from the ground excect for the continuous recording of seismicity [9] and special intensive observation during limited periods [10]. Therefore, a general survey of satellite data for these volcanoes may also be worthwhile.

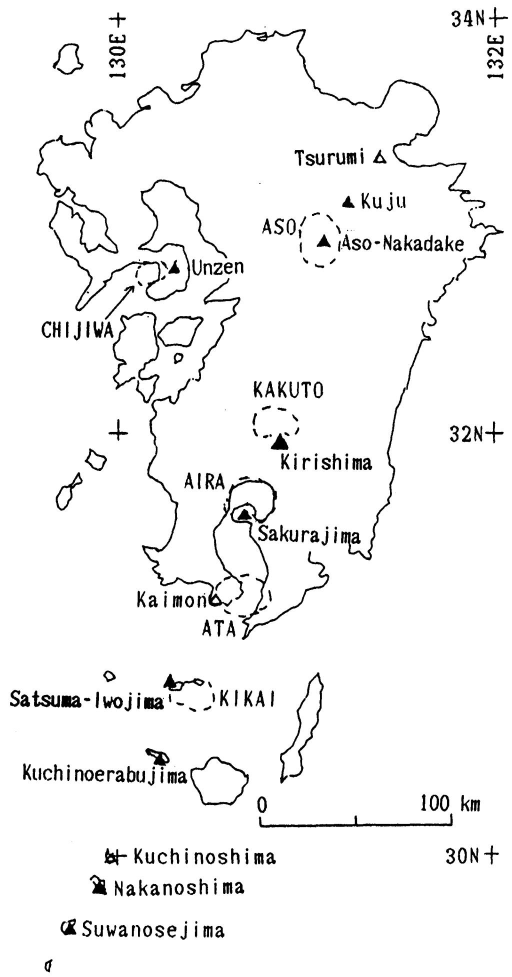

Fig. 1. The distribution of volcanoes in south-west Japan. Those with volcanic activities within these 100 years are indicated by solid triangles, while dormant ones by open triangles. Calderas are described by loops of broken lines.

2 — 2. Satellite scenes of volcanoes

Nowadays there are many earth observation satellites (EOS) with high resolution sensors. With the spatial resolution of 10 - 80 m in visible and near-infrared bands, they are able to detect faint fumalolic plumes and ash falls on the ground. Furthermore, thermal activities can be monitored by means of the TM-6 sensor of LANDSAT-5 with a resolution of 120 m. This is in contrast to the 1.1 km at best of the AVHRR sensor on the NOAA weather satellite, which is able to detect volcanic clouds with large scale. The shortcomings of earth observation satellites are their limited perspectives and infrequent observation, subject to weather condition. However, the combined use of various satellites in a long term may enable us to accumulate considerable amounts of data for investigetion.

In Table 1, we list the path-row of EOS for each volcano, where a path number is specific to the sun-synchronized orbit of each satellite observing a volcano, and a row number is specific to the scene in one data set on computer compatible magnetic tapes. In the case of a volcano being located near the boundary of a scene with a specific path, it has a chance to be observed from the neighboring path, due to the overlapping of two scenes. The boundary of a row is flexible in the data processing. The EOS data are received and processed at Earth Observation Center (EOC), Hatoyama near Tokyo, of National Space Development Agency of Japan (NASDA). For easy handling, magnetic tapes are converted into magneto-optical disks, and further into floppy disks for sub-scenes.

Table 1. Path-rows of earth observation satellites vs. volcanoes.

Satellite	LANDSAT			MOS	SPOT		JERS	
No.	2〜3	4	5	1〜1B	1〜3		1	
Duration	79〜83	82〜87	84〜	87〜96	86〜		92.2〜	
Period (day)	16	16	16	each 34	each 26		44	
Sensor	MSS	MSS	TM	MESSR	XS	Panchro	OPS	SAR
Resolution (m)	80	80	30	50	20	10	18*24	18
Scene width (km)	185	185	185	60	60	60	75	75
Aso	121-37	112-37 [A211-207]		25W(26E)-74	315-284		79-245	
Unzen	121-37	113-37 [A211-207]		26E-74	313-284		80-246	
Sakurajima	121-38	112-38 [A211-206]		25W(26E)-76	315(314)-287		79(78)-248	
Satsuma-Iwojima	121-39	112(113)-39 [A212-205]		25W(26E)-77	315-288		79-249	
Suwanosejima	121-39	112／113-39／40 [A212-205]		25W(26E)-78／79			79／80-251	

These are descending paths in daytime, except for ascending path-row [A**-***] of LANDSAT-5 in nighttime.
In addition to the above, there are a few LANDSAT-1 data in 1972 received in U.S.A.

In addition to the above volcanoes, the followings belong to the same LANDSAT scenes as the near-by ones indicated:

Kuju to Aso,

Kirishima and Kaimondake to Sakurajima,

Kuchinoerabujima and Nakanoshima to Satsuma-Iwojima.

As for other satellites, the scenes may be the same or neighboring ones as above listed.

2 − 3 . Properties of satellite images

In this report, we limit ourselves to present monochromatic images which are composed of single band or a combination of two or three bands. A merit of monochromatic superposition of different bands is to indicate a signal image on a background indicating geographic situation. Another use of combination is the vegetation index — a combination of visible and near-infra-red bands. However, the properties of single bands are basically important. We summarize them concerning volcanic phenomena in Table 2, where NIR, SIR and TIR denote near, short-wave and thermal infra-red bands respectively, while Vis. stands for bands of light visible to the naked eye. We leave datailed specifications of satellite sensors to the literature.

Table 2. Properties of monochromatic images.

Type	Sensor	Band	Properties
Vis.	TM MSS MESSR XS OPS	1 - 3 4, 5 1, 2 1, 2 1, 2	Sensitive to faint plumes especially for shorter wave length, and so for ash cover. Bare lands without vegetation are bright, while forest and water areas are dark.
NIR	TM MSS MESSR XS OPS	4 6, 7 3, 4 3 3	Water areas are black , and bare lands are dark. Forest areas are bright, and the topography of mountainous regions can be seen owing to the shadow of the sunlight.
SIR	OPS TM	5~8 5, 7	Distinction of rock types by combinations. Very high temperature.
TIR	TM	6	Surface temperature even in daytime, but with upper limit around 70 degree.
Micro wave	SAR	1	Roughness and direction of the surface by an active rader.

For color images, we are constructing a compilation of volcanic phenomena in Kyushu on the home page of Satellite Image Network Group in Kagoshima (SING-Kagoshima) :

http://www-rk.kagoshima-u.ac.jp/sing/index_e.htm .

Recent images of volcanic activities received by EOC may also be found on their home page,

http:/www.eoc.nasda.go.jp .

For convenience, we list the basic properties of typical patterns of simple color images in Table 3. For satellite sensors, we list the cases of LANDSAT/TM and MOS/MESSR only, as the other cases are essentially similar to them with corresponding bands. An exception is true color, where the blue band is unique to TM-1. False color images of type B are also limited to TM and JERS-1/OPS, since SIR sensors are specific to them. All types of images produced by assigning three bands to different colors are generally called "false color" in the literature.

Table 3.　Properties of color images.

Image type	Sensor	Band			Properties
		Blue	Green	Red	
True color	TM	1	2	3	Similar to naked eyes image and color photo. Forests depressed.
Natural color	TM MESSR	1 (2) 1	4 4 (3)	2 (3) 2	Vegetation areas are green. Bare lands tend to be pinky／reddish. Land-water separation is clear.
False color A	TM MESSR	2 1	3 2	4 3 (4)	Vegetation areas are brown or reddish.
False color B	TM	3	5	7	Vegetation areas are light green. Rivers tend to be blue.
Pseudo-color	Any single band				Differentiation of spectral emissivity by level slicing.

Instead of asigning a single band to one color, one may assign a numerical combination of different bands to a color for specific purposes. There are other methods of classification expressed by different color, such as the multi-level-slice and mininum-distance methods, not listed in Table 3.

In the original data around Kyushu provided by NASDA, the north direction is slightly shifted to the amounts 9.0, 10.4, 10.5 and 8.3 degrees for LANDSAT-5 in daytime, MOS, SPOT and JERS-1 images, respectivery. In this paper, we show the images with the original orientation with the indication of the north direction, or the altered ones to make the north direction exactly upward by cutting printer outputs or by the rotation of digital data sets using the cubic convolution.

§ 3. Volcanic topography and land cover

In this section, we review the characteristic features of topography and land cover of typical volcanic zones in the mainland Kyushu, and volcanic islands in the southern sea. There is an extensive compiration of aerial photographs of volcanoes in Japan [11]. The satellite data may add new points of view with wide perspectives and observation bands beyond the domain of visible lights. Understanding the capability of satellite imagery with limited space resolution compared with the aerial photographs is also a problem.

3－1. Aso Volcano

Aso Volcano in central Kyushu is characterized by a large caldera, 18 km from east to west and 25 km from north to south, and is shown on a map (Fig. 2) and MOS／MESSR images

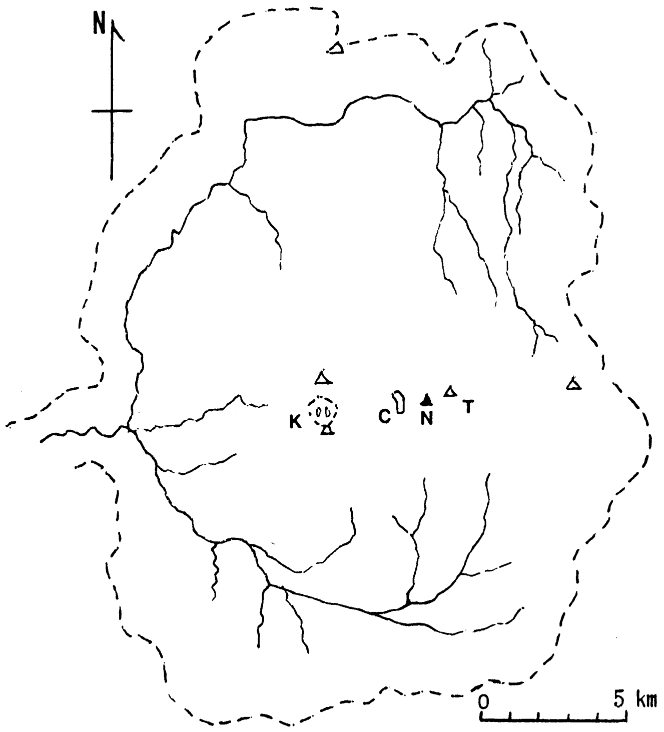

Fig.2. A map of Aso Caldera. The caldera walls are described by broken lines, while the rivers and streams by solid lines. C: the Nakadake crater, K: Kusasenri, N: Nakadake, T: Takadake.

(Fig. 3). The topography may be inferred from the NIR image (Fig. 3A) and gross features of land cover by visible image (Fig. 3B). At the center of Aso Caldera stand central cones such as the highest peak Takadake (1592 m) and the peakNakadake (1520 m) with an active crater on its flank (1300 m). The crater is constantly emitting high-temperature volcanic gas and sometimes ejecting ash clouds, as shown in close up images of LANDSAT-5／TM-3 in Fig. 4. On the ground, one can look inside the crater when it is relatively dormant. The basin of Aso Caldera is separated into north and south valleys by the central cones. There extend agricultural fields, villages and towns in both valleys, with about fifty thousand residents. Rivers in each valley join near the only exit in the west side break of the caldera. This break, clealy seen at lower west in Fig. 3A, is the Kitamukiyama Fault.

Forests are mainly located at the foot of the central cones and caldera walls seen as black belts in Fig. 3B. Outside the caldera wall (altitude about 900-1100m), there extend mild slopes of grasslands (bright in Fig. 3A and B) and forests (grey in Fig. 3A and dark in Fig. 3B).

At the mountain summit region, bare lands with heavy ash fall and volcanic gas are seen in the NIR image of Fig. 3A as a dark area not attributable to the shadow effect, while in visible red image as a somewhat bright area (Fig. 3B). In the close-up images of LANDSAT-5／TM-3 shown in Fig. 4, we may see the Nakadake crater where an open vent with white volcanic clouds is observed, For both images, heavy rains on preceding days had filled the vent with a pond of hot water, and strong steaming was observed by the robot video-camera. The grass covered old crater named Kusasenri is also seen with two small lakes inside. The relative brightness of the bare lands in these images is different compared to the grasslands on the slopes of central cones, as the growth of grass changes with seasons. We note here that, in order to see the crater structure, the visible band such as TM-3 (0.63～0.69 μm) is appropriate, while the images of NIR are too dark.

3－2. Unzen Volcano

Unzen Volcano is located at the center of Shimabara peninsula. This area is densely covered with forests except for coastal zones and the paths of the pyroclastic flows and mud avalanche at the eastern slope, starting from the dome on the central peak, Fugendake (see Fig. 5B). In the NIR image shown in Fig. 5A, we can easily see the topographic structure of the peninsula due to the shadow of the sunlight. The Chijiwa fault is especially clear, and other faults can be seen nearly parallel to it in Fig. 5A. These are characteristic to Unzen Graben as indicated in the map (Fig. 7). On the other hand, these faults are not so easy to detect in the SAR image shown in Fig. 6, since the direction of the micro-wave beam from JERS-1 at east-side orbit was almost parallel to these faults. In general, the beam direction is very important revealing topographic structure oriented perpendicular to it best.

The multi-pass data sets of JERS-1／SAR are utilized by Fujii et al. [13] to evaluate the 2-dimensional ground deformation of the lava dome, however the accuracy is not sufficient for this due to the steep topographic gradients and the smallness of the horizontal deformation.

The activity of Mt.Unzen, ejecting volcanic plumes from Fugendake peak, started on 17 Nov. 1990 after 198 years of dormancy. At the peak, a lava dome with complicated lobe structure started to develope in May 1991, and pyroclastic flows from the dome occurred during May 1991 - Feb. 1995. The most hazardous flow on 3 June 1991 resulted in 43 casualties. The initial flows went toward the east, but later flows also went towards SE and NE. At the downstream of the pyroclastic flows, another type of flow called "dosekiryu" occurred, i.e., the avalanche flow of mud and rocks caused by intensive rain. These flows have had severe impacts on the lives of residents in this region during these years. The danger of a disaster from the dosekiryu is still persistent and construction works to prevent this are ongoing. The paths of pyroclastic and dosekiryu flows appear as lines of bare land, where the debris of the flows is deposited. In single band images, these flow paths are most evident in visible