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Volcanic Activity around Showa Crater of Sakurajima Volcano Monitored with Infrared and Video Cameras

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Synopsis

The 2006 eruptions around Showa crater which located at the eastern flank of Minamidake, Sakurajima volcano, started on June 4, 2006, after 58 years dormancy. It continued about half a month. This eruption was characterized by the numerous emissions of volcanic slugs with time intervals of 5-30 min. Small scaled pyroclastic surges were observed after June 9 till the end of the eruption. As results of infrared thermal observations during 2006, geothermal activities of eastern to southeastern flank of Minamidake have increased prior to the 2006 eruptions. Still March 2007, no significant changes of thermal activities have been recognized after the eruption.

Keywords: Sakurajima volcano, Showa crater, the 2006 eruption, infrared thermal observation

1. Introduction

In October 1939, eruptions started at eastern flank of Minamidake, Sakurajima volcano (Fig. 1), with opening a new crater at an altitude of 800 m (Showa crater). Eruptive activities of these eruptions were high at the first three days and then decreased. They ceased about half a month later (Kagoshima Meteorological Observatory, 1940). After the 1939 eruptions, several eruptions have occurred every year until 1948. At the Showa eruption in 1946, huge amount of lava flow was issued out from this crater (~0.2 km^3; Ishihara et al., 1982) and this lava flow buried the local village of Kurokami. There had been no eruptions occurred at Showa crater after July 1948.

From 1974 to 1992, ground based and/or airborne infrared thermal observations were conducted repeatedly as a part of the Joint Observations for Sakurajima Volcano (e.g., Kamo and Nishi, 1975). As results of these observations, we found that several thermal anomaly areas were existed at the flank of Minamidake including the area around Showa crater. Thermal activity at there had been higher than the other thermal anomaly areas in early 1980s (Kamo et al., 1980; 1986). Temporal change of the maximum ground temperature different

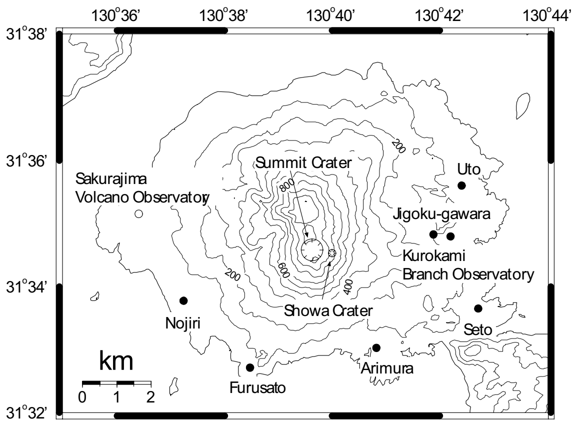

Fig. 1 Map of Sakurajima volcano with the locations of 2006 infrared thermal observations. The 2006 eruptions around Showa crater was observed from Jigoku-gawara and Kurokami branch observatory with the video cameras.

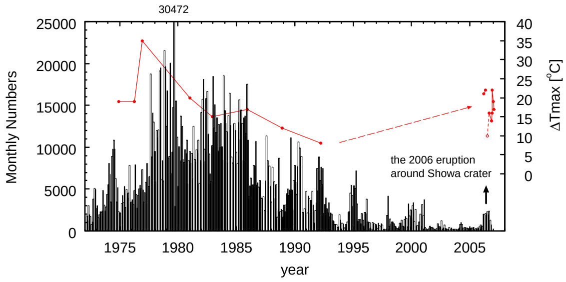

Fig. 2 Monthly Number of B-type earthquakes occurred at Sakurajima volcano from 1972 to 2006. Red line with points is ΔT_{max} at the thermal anomaly area around Showa crater.

from that of normal area, ΔT_{max}, at the area around Showa crater seemed to be correlated with temporal change of the numbers of B-type earthquakes (Fig. 2). B-type earthquakes were investigated to be closely related with a magma intrusion to magma conduit and/or the degassing of magma extruded up to the crater bottom (Ishihara and Iguchi, 1989). This meant that monitoring for thermal activity is one of the important monitoring methods to understand change of volcanic activity.

In January 2006, we recognized that fumaloric activities have increased around Showa crater. Increasing of B-type earthquakes were also observed from February, compared with the numbers of recent a few years (Fig. 2). We therefore have restarted to monitor geothermal activity of the flank of Minamidake repeatedly (Yokoo et al., 2007). And then, at the morning of June 4, 2006, eruptions started after the 58 years dormancy from a new craterlet around Showa crater, at an altitude of 850 m of eastern flank of Minamidake. Eruptions continued about half a month until the early morning of June 20.

In this report, the sequence and characters of the 2006 eruptions around Showa crater determined based on the analysis of monitoring movie images are summarized. Then, geothermal activity at the flank of Minamidake in the year of 2006 is also reported. This is from the results of infrared thermal observations.

2. The 2006 Eruptions around Showa Crater

2.1 Monitoring with Video Cameras

From June 4 to 13, we observed the eruptions occurred around Showa crater using handy video cameras, SONY HDR-HC3 and TRV-900, from Jigoku-gawara and Kurokami branch observatory about

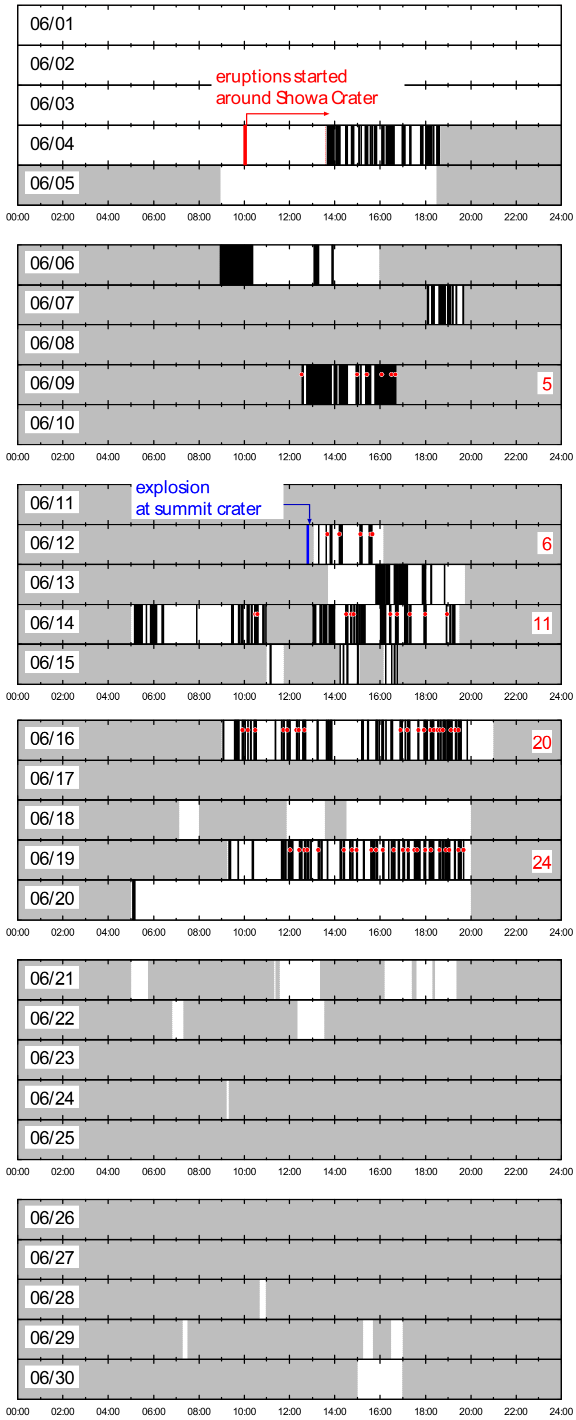

Fig. 3 Time table of the 2006 eruption determined by recorded movie images. Black and white colored areas means the occurrences of eruptions and no eruptions, respectively. Gray colored areas were the time we cannot determine whether the eruptions occurred or not due to bad weather conditions, the night time or no record of movie images. Red numbers on the day of June 9, 12, 14, 16 and 19 were the numbers of small scaled pyroclastic surges: each was occurred at the time of red circle.

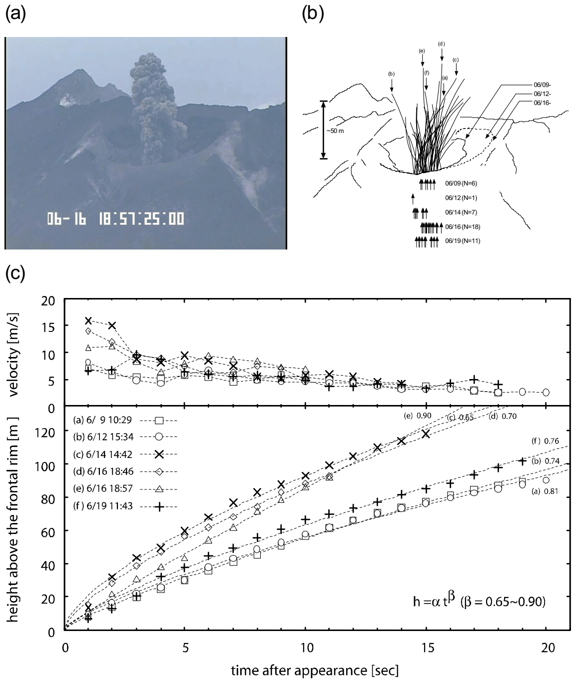

Fig. 4 (a) Snapshot of the typical rising volcanic slug. This was 10 sec after the start of the eruption at 18:57 on June 16. (b) Little change of vent position (arrows at the lower part) was observed based on the tracking of the heads of volcanic slugs during the first 10 sec of eruptions. (c) Time change of uprising velocity and height for selected 6 vigorous volcanic slugs (see figure b).

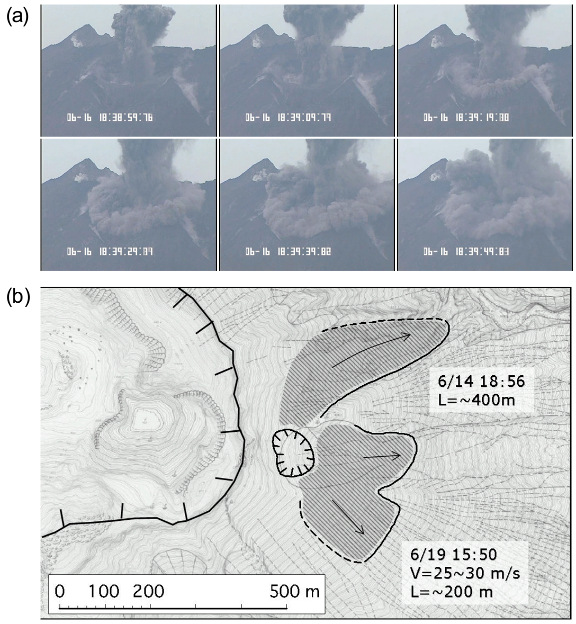

Fig. 5 (a) Snapshots with 10 sec intervals of typical small scaled pyroclastic surges occurred at the 2006 eruptions. Almost all surges were made by the collapse of volcanic cloud. (b) Two largest surges run out 200~400 m from the crater rim.

4 km east from the crater (Fig. 1). A GPS clock (DATAMARK LS-20K) was used for time correction of recorded images. On the other hand, a high-sensitive TV camera was installed on the roof of Kurokami branch observatory on June 12 and captured movie images were recorded to a DVD recorder at Kurokami. For these movies, GPS satellite time-code was inserted on the movie images by combining several devices of a GPS sensor (THALES A12), a function generator (Agilent Technology 33220A) and a time-code generator (IKEGAMI TSUSHINKI VTG-33).

2.2 Sequence and Characters of the 2006 Eruption

Based on the monitoring movie images, more than 235 events of eruptions were identified during these 16 days, June 4 to 20, although this period was in the rainy season (Fig. 3). These eruptions were occurred everyday except for two days of June 5 and 18. Each eruption was typically started with the ejection of a cauliflower shaped volcanic slug (Fig. 4a) and the emission of pyroclastic materials continued about a few minutes. The volcanic slug was started to uprise at the velocity of 5-15 m/s, but it suddenly decreased to about 5-10 m/s within a few second. Then, it went up with almost constant velocity of a few m/s (Fig. 4c). The height of volcanic cloud reached about a few 100 m to 1000 m which made us difficult to observe the eruptions directly from Sakurajima volcano observatory located at the west-side of Sakurajima (Fig. 1). Intervals of these eruptions were about 5-30 minutes at the time of intermittent eruptions (e.g., June 4 and 19). In contrast, the continuous but weak emissions of volcanic ashes, for instance the eruption of June 6, were sometimes observed. They lasted more than 1 hour.

These all eruptions were occurred at the one new craterlet. Diameter of this craterlet increased as time; 70 m on June 7 to 120 m on June 16 (Fig. 4b). A shape of it was a distorted rounded-heart. After June 16, no significant enlargement and change in shape were observed. Vent position within the craterlet did not change in the range of 25-30 m width in NS direction during the 2006 eruptions.

After June 9, 65 small scaled pyroclastic surges were observed (Figs. 3 and 5). They flowed down inside and outside of Showa crater, typically less than 100 m long, with a few m/s. The longest distances were recorded to

Fig. 6 An explosive eruption at summit crater occurred on June 12, 2006. This photo was taken from Kurokami branch observatory.

be 400 m by the surges occurred at 18:56, June 16 which flowed down along with the northern valley of Showa crater (Fig. 5b). The pyroclastic surge of June 19, 15:50, flowed down about 200 m long toward both directions of east and south from the craterlet. Almost all surges were made by the collapse of volcanic cloud (Fig. 5a) but a few surges were made by the overflow from the craterlet directly. Numbers of the surges were increased with time (Fig. 3), which might mean that buoyancy force of volcanic cloud tended to become small. That was, the vapor content degassed from magma associated the 2006 eruptions decreased with time.

Beside, the eruptive activity of summit crater of Minamidake during these periods did not turn to a new one. At the noon of June 12, an explosive eruption with an air shock was occurred (Figs. 3and 6). Rising speed of the volcanic cloud was estimated about 11 m/s in average of 28 sec duration. Height of the cloud was reached to ~2000 m. Amplitude of the air shock was 70 Pa recorded at Sakurajima volcano observatory.

3. Thermal Activities around Showa Crater during the year of 2006

3.1 Monitoring with Infrared Thermal Camera

From March 2006, three months before the 2006 eruptions, we have restarted to observe thermal activity on the flank of Minamidake after 14 years' interval (Table 1; Yokoo et al., 2007). We continued the observations after the 2006 eruptions and it have counted 9 times until the present, March 2007. For these observations, we used an infrared imaging camera (NEC San-ei TH7102MV). The specification of this camera is almost same (e.g., FOV is H29º and V22º, IFOV is 2 mrad) as those of cameras used in previous observations except for the 1992 observation.

Table 1 Infrared thermal observations conducted in 2006

Date	Locations of the observations*1
2006/03/29	ARI, FUR, JIG*2, NOJ, SET
2006/05/22	ARI, JIG*2, SET
2006/07/12	ARI, KUR
2006/09/21	ARI, KUR
2006/11/02	ARI, KUR, SET, UTO
2006/12/06	ARI, FUR, KUR, NOJ, SET, UTO
2006/12/18	ARI, KUR, SET, UTO
2007/01/22	ARI, FUR, KUR, SET, UTO
2007/02/13	ARI, KUR, SET, UTO

*1 ARI: Arimura, FUR: Furusato, JIG: Jigoku-gawara, KUR: Kurokami branch observatory, NOJ: Nojiri, SET: Seto and UTO: Uto (see Fig. 1).

*2 We can not observed at Jigoku-gawara after the 2006 eruption.

At each location of the observations (Fig. 1 and Table 1), we measured local air temperature and humidity by Asman ventilation type wet and dry bulb thermometer. These data with the aerological weather conditions above Kagoshima city were used to correct the absorption of an infrared spectrum by the air (weather condition was observed by Kagoshima Meteorological Station, JMA). For the correction, we used some empirical equations A3.7~A3.31 of Kondo (2000) with following parameters λ=11μm, P_0=1.013×10^5 Pa, ρ_{d0}=1.193 kg/m^3 and V=25 km. Then ground temperature of the flank of Minamidake was estimated from observed one using the Stephan- Boltsman equation with ε=0.97 (Ehara, 1972). These processes enabled us to compare the temperature in different time and discuss the time change of thermal activity (Fig. 7).

3.2 Change of Thermal activities before and after the 2006 Eruptions

Five thermal anomaly areas at the flank of Minamidake were identified from the 2006 observation as follows (Fig. 8):

A: area around Showa crater,

B: eroded area at southeastern flank of Minamidake,

C: area just between the B and Nabeyama,

D: area at the upper part of An-ei crater, and

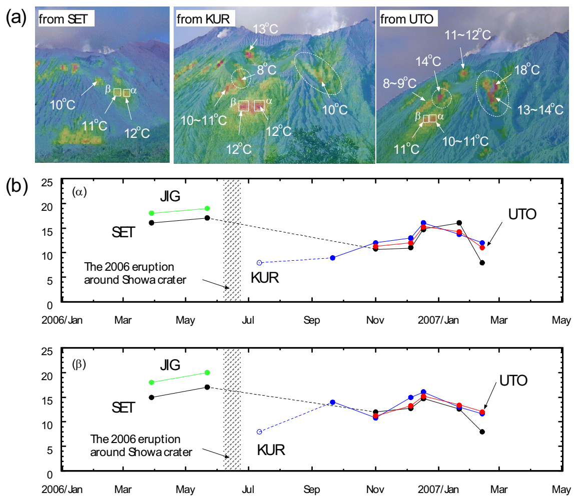

Fig. 7 (a) Infrared thermal images around Showa crater overlapping on visible images taken from three different locations. There is no large difference in the corrected difference of ground temperatures, ΔT, except for two circled areas where we can not see same point from each location. (b) Change of ΔT at two points, α and β in the (a), during the 2006 observations.

E: area ~500 m south from the C.

Here, areas of A and B were divided by the ridge drawn by broken lines in Fig. 8. Areas of A~D have been already reported in 1970s-1990s, but the area of E has not (e.g., Kamo et al., 1986; 1995). Westside anomaly point located inside a large eroded valley was not able to see from any locations on the ground particularly (Fig. 8b).

Maximum ground temperature different from that of normal area, ΔT_{max}, was estimated for each anomaly area (Fig. 9). Comparing with the 1990s data, thermal activities on eastern to southeastern flank of Minamidake (areas of A~C) have already increased about 5~20°C prior to the 2006 eruptions. In contrast, ΔT_{max} of the E (southern part of Minamidake) have slightly decreased from the last data. After the 2006 eruptions, no significant change of ΔT_{max} was observed for all the anomaly areas.

Heat discharge rate from each anomaly area, Q, was also estimated by the equation of Kagiyama and Hagiwara (1980). Parameters of k_1 and k_2 in the equation were used as 2 and 35, here. From the results shown in Fig. 10, we found that thermal activities of eastern to southeastern flank (A~C) have been still higher than the southern flank (D). Heat discharge rates of eastern to

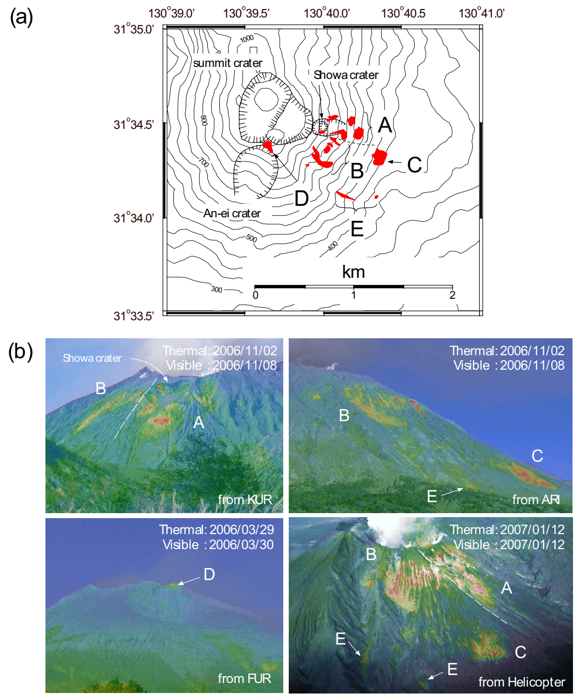

Fig. 8 (a) Five thermal anomaly areas were determined based on the results of the 2006 thermal observation. (b) Infrared thermal images overlapping on visible images taken from Kurokami branch observatory, Arimura, Furusato (see Fig. 1) and the helicopter flew over the Sakurajima volcano. Observed raw temperatures are displayed in the rainbow color scale with the constant range of 12°C.

southeastern flank (A and B) were almost same order but that of B was sometimes higher than the area of A (around Showa crater) in 2006 although these relations between them was in reverse in 1970s. Summing of Q of the areas A and B on March 2006 was estimated to 35MW. This was 2.5 times larger than the 1970s value of 14MW. Considering that the highest volcanic activity of Sakurajima volcano was observed at the late of 1970s and the beginning of 1980s (Fig. 2), this also might indicate that increasing thermal activity was observed as the precursor of the 2006 eruptions.

On the other hands, the duration of the 2006 eruptions, about half a month, was almost same as that of the 1939 eruption which had an opening event of Showa crater. Considering that no significant change of thermal activity was observed at the areas of eastern to southeastern of Minamidake including the area around Showa crater, these areas may still have a potential to erupt with similar styles of 1930s-1940s; sporadic eruptions.

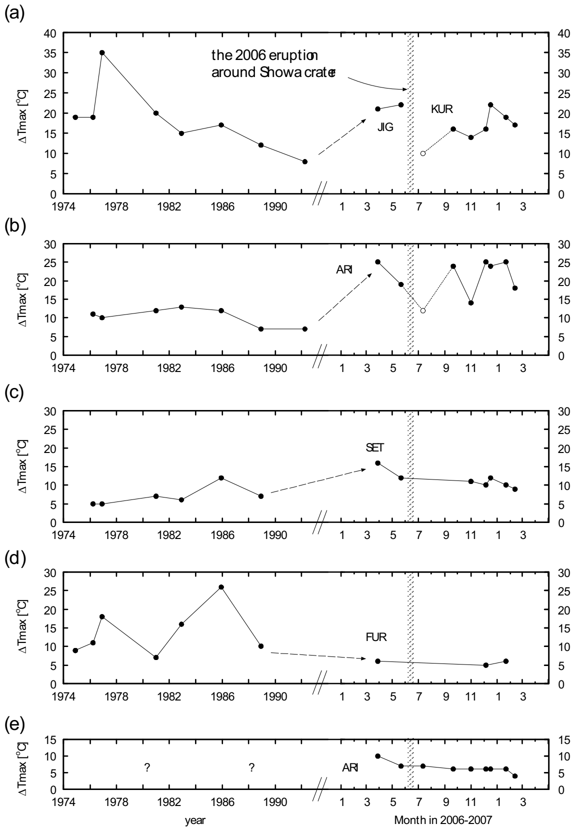

Fig. 9 Temporal change of ΔT_{max} at each thermal anomaly area. Data before 1990s were from Kamo and Nishi (1975) and Kamo et al. (1980; 1982; 1986; 1988; 1989; 1995).

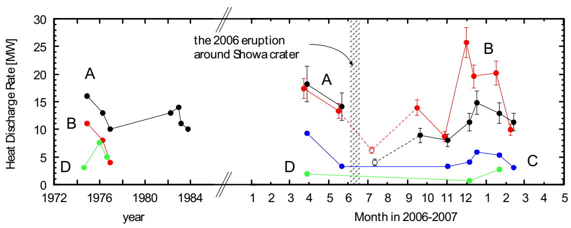

Fig. 10 Time change of estimated Q from thermal anomaly areas. Data of 1970s-1980s are from Kamo et al. (1980; 1986).

4. Concluding Remarks

On June 4, 2006, eruptions around Showa crater on southeastern flank of Minamidake, Sakurajima volcano started after 58 years silence and it continued about half a month. We observed volcanic activity around Showa crater using infrared and video cameras. As the results, the 2006 eruptions was characterized by the numerous emissions of volcanic slugs with time intervals of 5-30 min. Small scaled pyroclastic surges were observed after the day of June 9 till the end of the eruption. Geothermal activities on the eastern to southeastern flank of Minamidake have increased prior to the 2006 eruptions. It has passed about half a year after the 2006 eruptions however no significant changes of thermal activities have been recognized still March 2007.

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Appendix

Estimated maximum ground temperature different from the normal temperature ΔT_{max} and the heat discharge rate Q for each thermal anomaly areas during the 2006 observations are summarized (Table A1 and A2).

Table A1 Estimated ΔT_{max} for each thermal anomaly areas during the 2006 observations

Date	ΔT_{max} [°C][*1]				
	A	B	C	D	E
2006/03/29	21	25	16	6	10
2006/05/22	22	19	12		7
2006/07/12	(10)	(12)			(7)
2006/09/21	16	24			6
2006/11/02	14	14	11		6
2006/12/06	16	25	10	5	6
2006/12/18	22	24	12		6
2007/01/22	19	26	10	6	6
2007/02/13	17	18	9		4

[*1] A: estimated from the data observed from Jigoku-gawara (March and May, 2006) and Kurokami branch observatory (from July 2006), B: from Arimura, C: from Seto, D: from Furusato and E: from Arimura. Small values of July 2006 were caused by misty condition.

Table A2 Estimated heat discharge rate Q for each thermal anomaly areas during the 2006 observations

Date	Q [MW]			
	A	B	C	D
2006/03/29	18±3	17±2	9.3	1.9
2006/05/22	14±3	13±1	3.3	
2006/07/12	(4.0±0.6)	(6.2±0.6)		
2006/09/21	8.9±1.3	14±1		
2006/11/02	8.0±1.1	8.7±0.9	3.3	
2006/12/06	11±2	26±3	4.1	0.7
2006/12/18	15±2	20±2	5.9	
2007/01/22	13±2	20±2	5.3	2.7
2007/02/13	11±2	9.9±1.0	3.1	

熱赤外カメラとビデオカメラによる2006年桜島昭和火口周辺の火山活動モニタリング

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要　旨

2006年6月4日に，桜島東斜面の昭和火口周辺部から噴火活動が始まり，6月20日までのおよそ半月間継続した。今回の噴火活動は間欠的な小規模噴煙放出で特徴付けられ，6月9日以降はごく小規模な火砕サージも発生した。昭和火口周辺を含む桜島南岳の東～南東斜面の熱異常域は，2006年3月にはすでに活発化しており，これは2006年噴火の前兆現象のひとつであった。

キーワード:　桜島、昭和火口、2006年噴火、熱赤外映像観測