

Automatic Long-Time Observation of the Volcanic Clouds at Satsuma-Iojima, Kyushu, Japan

MATSUI Tomoaki¹, KINOSHITA Kisei², MACHIDA Shoichi³, TAKAHARA Hiroyuki⁴,
YAMAMOTO Masashi⁵ and KANAGAKI Chikara^{1,6}

¹*Faculty of Education, Kagoshima University, Korimoto 1-20-6,
Kagoshima 890-0065, Japan*

²*Innovation Center, Kagoshima University, Korimoto 1-21-40,
Kagoshima 890-0065, Japan*

³*Nittetsu Mining Co., Ltd., Yusen Building, Marunouchi 2-3-2, Chiyoda-Ku,
Tokyo 100-8377, Japan*

⁴*Nittetsu Mining Consultants Co., Ltd., NOF Shiba Building, Shiba 4-2-3, Minato-Ku,
Tokyo 108-0014, Japan*

⁵*Asahi Primary School, Naze-Asahi 31-2, Amami, Kagoshima 894-0061, Japan*

⁶*Goshoura-Kita Junior High School, Goshoura-Yokoura 537, Amakusa,
Kumamoto 866-0302, Japan*

Abstract

Continuous recording of volcanic clouds at Io-dake taken with digital and video cameras has been carried out since 1998 in Satsuma-Iojima, and also with automated monitoring system using a web camera since 2003. The results of the photo observation with one-hour interval for three years during 2000 and 2002, supplemented with video records with ten-minute interval, were summarized concerning the behavior of the volcanic clouds, with special attention to their heights. Io-dake was almost always ejecting volcanic clouds with rather constant strength from the summit crater, while explosive eruptions were rarely seen. The cloud height seemed to be affected by wind velocity above the summit crater. That is, cloud height and wind velocity were roughly in reciprocal proportion to each other. In addition to this, an extra-rise in summer time was observed, compared with other seasons. The summit is often covered with a cap cloud in humid weather, especially in the summer.

Key words: volcanic plume, automated monitoring, cloud height, wind velocity

Introduction

Recently, Satsuma-Iojima has displayed a little activity in eruption throughout the year. As Satsuma-Iojima is an isolated island, it is expected that the behavior of volcanic clouds is strongly affected by wind, to say nothing of atmospheric pressure, tem-

perature of air and volcanic gases, inversion layer, internal pressure of magma, structure of vent, property of emissions and magnitude of eruptions. The characteristic features of the volcanic clouds influenced by wind make easy to connect and visualize both geological and meteorological phenomena. Therefore, they are considered to be good teaching materials for the people, including primary school and junior high school students who are interested in volcanic activity.

The purpose of this work is to write up the automatic observation of volcanic clouds at Satsuma-Iojima, with special attention to their heights in relation to wind velocity during January 2000 and December 2002. Since November 4th 2003, the volcanic activity level for main active volcanoes in Japan has been announced by Japan Meteorological Agency (YAMASATO *et al.*, 2004). At present, the volcanic activity for Satsuma-Iojima is defined as level 2, which means a little active. Japan Meteorological Agency started an automatic observation of the height of volcanic clouds by a camera with ultra-high sensitivity on November 16th 2002. UCHIDA and SAKAI (2002) reported seismic observations of volcanic earthquakes at Satsuma-Iojima since September 1997. SHINOHARA *et al.* (2002, 2003) reported degassing activity at Satsuma-Iojima in recent years. For the real time monitoring by the respective agency, studies of archived records of a long-time observation of volcanic clouds in this paper may serve as a basis for the understanding of the ejection activity of the volcano.

Geographical and Geological Aspects of Satsuma-Iojima

Satsuma-Iojima is a volcanic island located about 40 km SSW of the southern tip of Satsuma peninsula (Fig. 1). The island lies at the northwest edge of Kikai caldera, which measures 17×20 km², and is one of the large calderas in southern Kyushu (MATSUMOTO 1943). Most of the caldera except for three islands, Satsuma-Iojima, Take-shima and Shin-Iojima, lies below the sea level.

The landform of Satsuma-Iojima shows the history of volcanic activity of this region (ONO *et al.* 1982). Yahazu-yama volcano, which is a pre-caldera volcano with basalt and andesite lava flows, is cut by the caldera-bounding cliff where structure of stratovolcano is well exposed. Rhyolite and dacite lava flows which lie on Yahazu-yama volcano form the plateau west of the caldera rim.

About 7,300 years ago, a very big eruption occurred and an enormous amount of pyroclastic materials were erupted in this district (MACHIDA and ARAI, 2003). The large depression, resulting from the absence of underlying magma, formed the present Kikai caldera. Akahoya, a very fine, yellow to orange colored ash that is a good marker-tephra for the early Jomon age, is from this eruption (MACHIDA 1977).

Inside the caldera rim, Inamura-dake volcano is a central cone in the center of the island, 236 m high, comprising basaltic scoria, lava flows and a mafic andesite lava, which started up its activity after formation of Kikai caldera. The volcano ceased its activity before 3,000 y.B.P. Io-dake volcano located in the east of the island is another

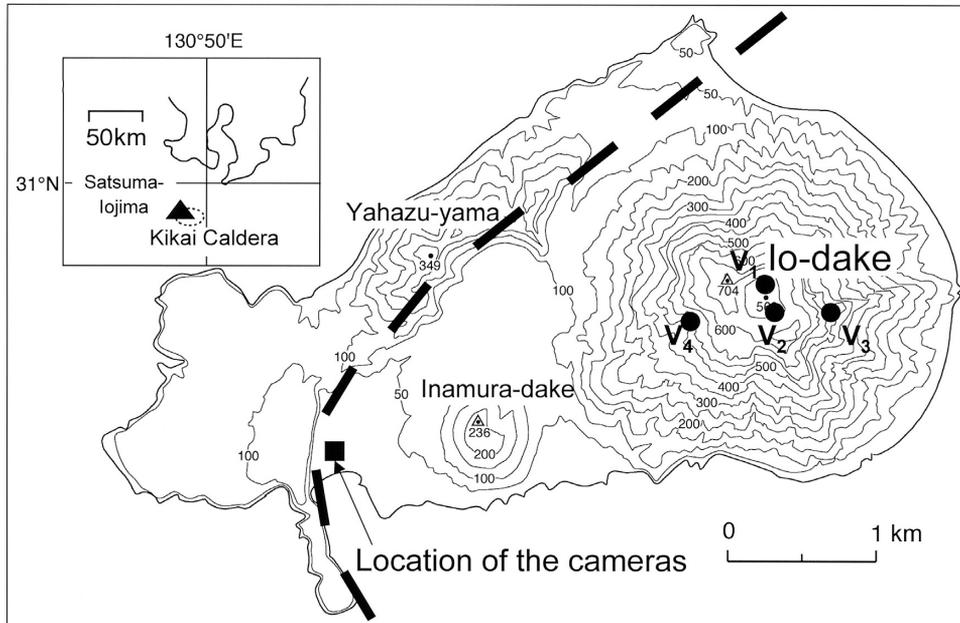


Fig. 1. Topographic map of Satsuma-Iojima modified after SHINOHARA *et al.* (2003). Filled square is the location of digital and video cameras. The location of the vents (V₁-V₄), estimated from photos and video pictures taken by these cameras, are shown in the map. Broken lines show the rim of Kikai Caldera.

cone, above the sea level, of Kikai caldera. It began to erupt after Inamura-dake volcano, and then has built itself up to a steep stratovolcano of rhyolite, 704 m high, and is now giving off strong sulfurous fumes and water vapor near the summit crater and the flank. Explosive eruptions with volcanic ash or bombs sometimes occur. Most ash clouds are thrown up to a height of less than 1 km and fall back on to the volcano or hang over the sea, depending on both the direction and velocity of the wind. The dissection by deep radial valleys is remarkable in contrast with Inamura-dake. Alluvium and fan deposits cover the crater floor between caldera wall and post-caldera cones.

Acidic hot spring waters are gushing copiously from the seashore of the island, which produce discolored seawater. Chemical composition of the mixtures of the precipitates and the coexistent solutions reflect that of the hot spring water (NOGAMI *et al.* 1993).

Automated Recording System

Investigations of volcanic clouds provide important information about volcanic activities. Since July 23rd 1998, recordings of volcanic plumes at Io-dake have been continuously taken with digital and video cameras installed at the Mishima-Mura gymnasium lying about 3 km WSW of the crater of Io-dake (Fig. 1). Moreover, in Febru-

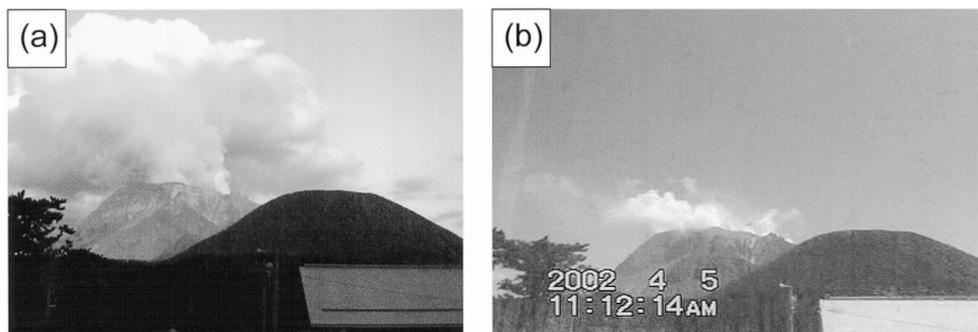


Fig. 2. Typical images by (a) digital camera, SHARP MD-PS1 and (b) digital video camera, SONY DCR-TRV900.

ary 2003, an automated monitoring system, composed of a web camera head and a computer connected to the Internet, has been constructed at the Mishima-Mura Development Center neighboring on the gymnasium. Each of these three cameras which faces the summit of Io-dake is inside the buildings, and taking images through the window glasses. Methods of continuous monitoring of volcanic clouds from the ground in general are discussed in KINOSHITA *et al.* (2004).

For the automatic long-time recording with one-hour interval, a digital camera SHARP MD-PS1 was used successfully during July 1998 and February 2003, by exchanging the MD media every three months. In order to supplement this, video cameras were used for the interval recording, which had been often exchanged for new apparatus because of the mechanical trouble at early stages. Since the end of September 1999, a video camera SONY DCR-TRV900 was working quite well until July 2003, with a half second recording at ten-minute interval, running about three months with one mini DV tape. Time-condensed records may reveal dynamical features of the atmospheric flow in quick motion. The discussion in this paper is based on the photos and video pictures, such as shown in Fig. 2 (a) and (b), taken by these cameras. We note that somewhat wider view is obtained by the video records, while the digital photo view is enough to observe daily activities of the volcano. The database of digital photos has been exhibited in an Internet homepage in Japanese, <http://arist.edu.kagoshima-u.ac.jp/volc/iwo/>.

Results and Discussion

Typical features of volcanic clouds

In Figs. 3-7, typical features of the volcanic clouds are shown from the records in 2002. Fig. 3 is a stationary cloud with a constant ejection strength, which was the dominant type of the clouds. Stagnation of the plume such as Fig. 4 was seen in weak wind, while downdraft along the mountain lee wave was seen under strong wind, such as shown in Fig. 5. Although the ejection of volcanic cloud was rather constant most



Fig. 3. Stationary cloud (02/11/19 17h).

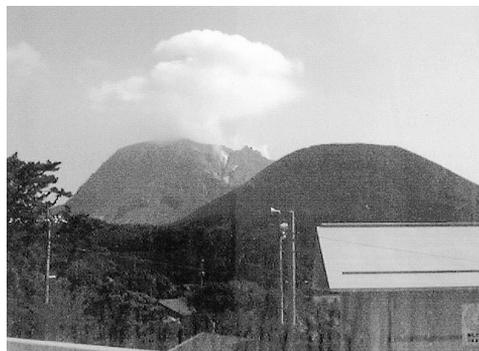


Fig. 4. Stagnation (02/3/13 11h).



Fig. 5. Downdraft (02/7/8 9h).



Fig. 6. Sequential eruption (02/6/1 19h).

of the time in this year, sequential and isolated eruption clouds were detected such as shown in Figs. 6 and 7. The summit was often covered with a cap cloud from June to the beginning of September.

Volcanic clouds used for the analysis were seen at center (V_1) and right (V_2) of the summit of Io-dake (Fig. 8). Except for V_1 and V_2 , the other vents on Io-dake volcano, which were detectable from the images taken with the automated monitoring system, were placed in east (V_3) and the flank faced west (V_4) (Figs. 9 and 10, respectively). Some examples of the cloud were mixing after lifted up independently from V_1 and V_2 , or waving vertically or horizontally.

Computer simulation of volcanic cloud

A computational program that provides the outline of volcanic plume by a wire-frame (KINOSHITA and YOSHIDA 1990) is used for the analysis of the Io-dake plume (Fig. 11 (a) and (b)). On the assumption that the plume flows display horizontal movements because of crosswind after getting the final heights, the wire frame of the plume envelope is constructed as follows. We define the x-axis along the horizontal direction of the plume at the stabilized height, and the y- and z-axes perpendicular to x in horizontal and vertical directions, respectively, with the origin above the vent. We describe the cross section of the plume at x by an ellipse with the horizontal and vertical radii



Fig. 7. Explosive eruption (02/5/28 10h).

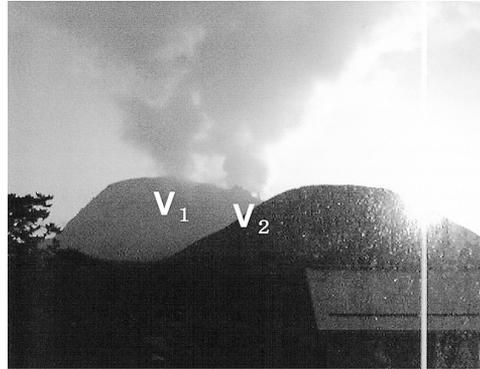


Fig. 8. Plumes from vents V₁ and V₂ (02/9/8 7h).

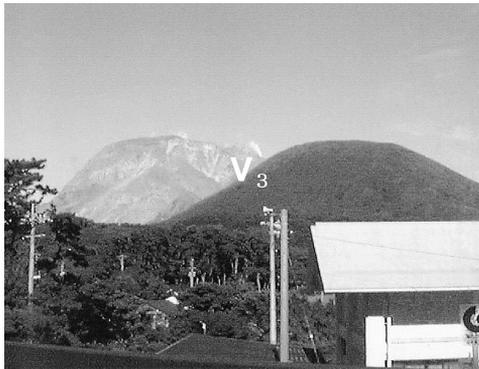


Fig. 9. Vent V₃ (02/3/30 16h).

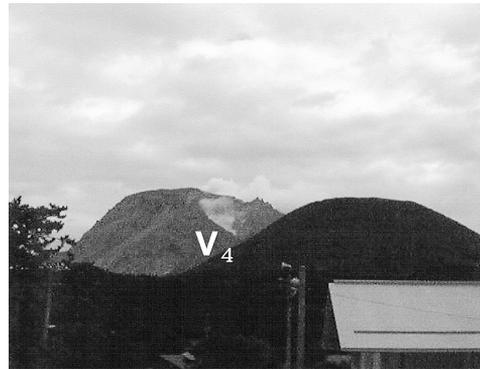


Fig. 10. Vent V₄ (02/12/8 12h).

given by $R_y(x) = ax^p + c$, $R_z(x) = bx^q + c$, where the constants a , b , c , p and q are obtained from the fits to the observed data. For the height estimate, horizontal levels with 100 m interval from 800 m above the sea surface are shown along the north-south direction, and at 1000 m along east-west direction. The levels to fit the wind direction are also shown with 100 m interval from 750 m. The centers of these levels are located on a vertical line above the bottom of the crater. Lines connecting the peak position, the bottom of the vent and other ground points are also shown. Values for height and outline of volcanic cloud and wind direction are determined by operating parameters of the program. Synthesis of a real image and a cloud drawn by computer simulation allows calculation of the height and flow direction of the cloud in question.

Io-dake plume heights and flow directions recorded between 2000 and 2002 were estimated by the simulations. Photos by digital camera were used for the simulation, which were supplemented by video pictures in case of absence of photo or eruption clouds extending beyond the scope of the camera. In this paper, plume height stands for the distance from the summit of Io-dake to the top of the plume.

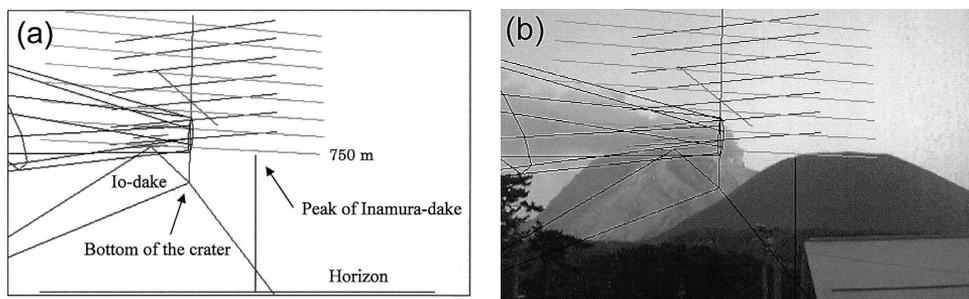


Fig. 11. (a) A sample of wire frame diagram and lines used for the computer simulation. (b) An example of a result by computer simulation superimposed on a real image (02/6/9 15h). To outline the shape of Io-dake, the summit peak, the bottom (566 m) of the crater, and the points on the seashore at 1800 m NNW and 1200 m SSW from the bottom of the crater are connected by lines. Vertical line to indicate the peak of Inamura-dake (240 m) and a horizontal line at the infinity are also shown. North-south and the wind directions are expressed by black and gray lines, respectively, which are drawn for each 100 meters staggered with 50 meters portions in height. The lowest gray line shows 750 meters above sea level. At the height of 1000 meters, east-west direction is indicated by a short gray line. Additional three short lines along the north-south direction are drawn for each 50 meters above the summit peak.

Seasonal dependence of Io-dake cloud heights from 2000 to 2002

Fig. 12 shows maximum, minimum and mean values for the month of cloud heights in 2000. The mean from February to June is lower than the other seasons, especially from July to September. These mean values of the cloud heights tend to be higher in summer and lower in winter also in 2001 and 2002 (Figs. 14 and 16).

Since the behavior of volcanic cloud is much affected by upper wind around the cloud height, it may be valuable to compare the plume flow with the radiosonde-derived wind data provided by Kagoshima Local Meteorological Observatory, 83 km NNE from Satsuma-Iojima. The use of nearest station data is reasonable as the upper winds are rather uniform with horizontal change less than 100 km.

Figs. 13, 15 and 19 show the mean for the month of the wind velocity at pressure levels of 900 hPa at 9:00 and 15:00 JST (Japanese Standard Time = UTC + 9 hours) at Kagoshima in 2000, 2001 and 2002, respectively. Among the standard pressure levels, 925, 900, 850 hPa and so on, the pressure of 900 hPa nearly corresponds to 1000 meters above sea level, and the mean for the year of cloud height of Io-dake is about 300 m (Figs. 17 and 18). Therefore, the wind data at 900 hPa may be suitable to discuss the transport and diffusion of volcanic cloud at Io-dake. The mean wind velocity at 15:00 for the month tend to be a little lower than at 9:00 (Figs. 13, 15 and 19). Both of the mean wind velocity at 9:00 and 15:00 in winter are higher than the other seasons.

The results which were obtained in the way described above are compiled in Fig. 20. Regardless of cloud height, wind velocity data at pressure level of 900 hPa is used here as a reference of the upper wind. Although the distribution of plots seems to be somewhat broad in each year, it appears to be that the maximum cloud height falls off inverse of the wind velocity as a whole.

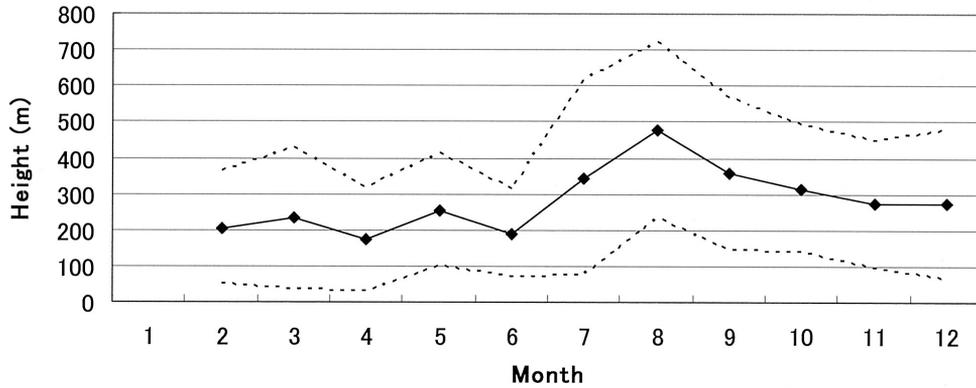


Fig. 12. Maximum, minimum and mean for the month of cloud height in 2000. Broken lines: maximum and minimum. Solid line: mean. Data in January is absent from this chart because of lacking sufficient record in the period.

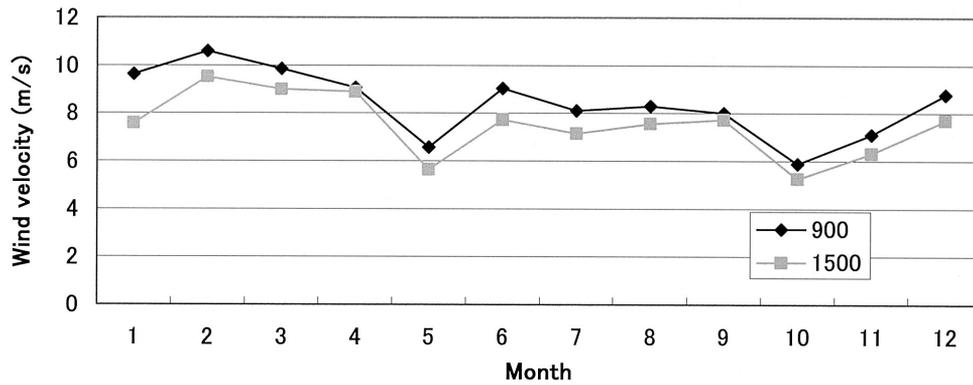


Fig. 13. The mean for the month of upper wind velocity at the pressure level of 900 hPa at 9:00 and 15:00 JST in 2000 at Kagoshima. The upper wind data were obtained by Kagoshima Local Meteorological Observatory.

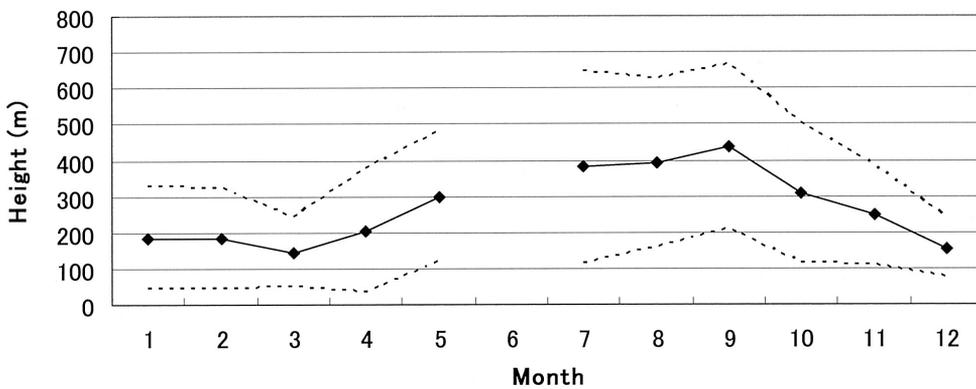


Fig. 14. Maximum, minimum and mean for the month of cloud height in 2001. Broken lines: maximum and minimum. Solid line: mean. Data in June is absent from this chart.

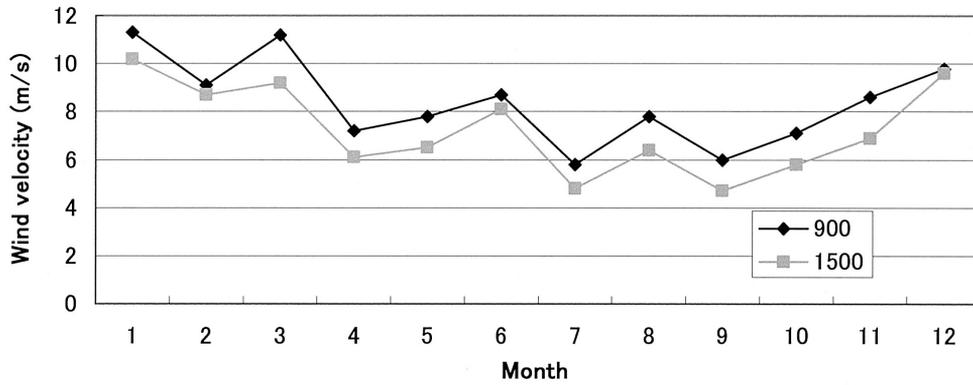


Fig. 15. The mean for the month of wind velocity at the pressure level of 900 hPa at 9:00 and 15:00 JST in 2001 at Kagoshima.

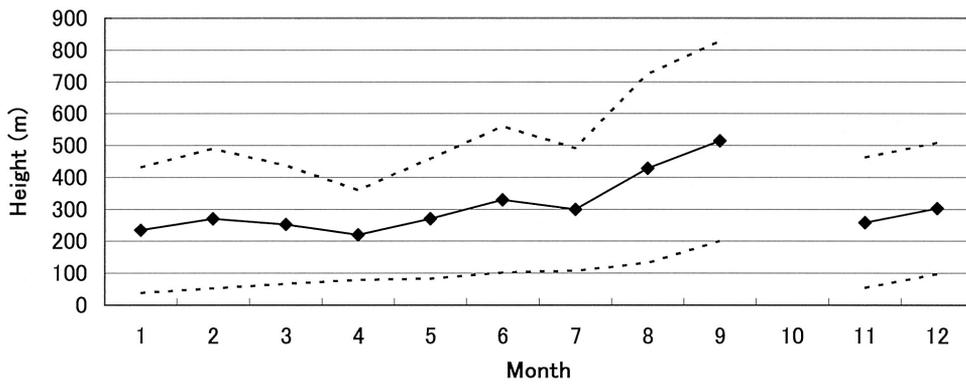


Fig. 16. Maximum, minimum and mean for the month of cloud height in 2002. Broken lines: maximum and minimum. Solid line: mean. Data in October is absent from this chart.

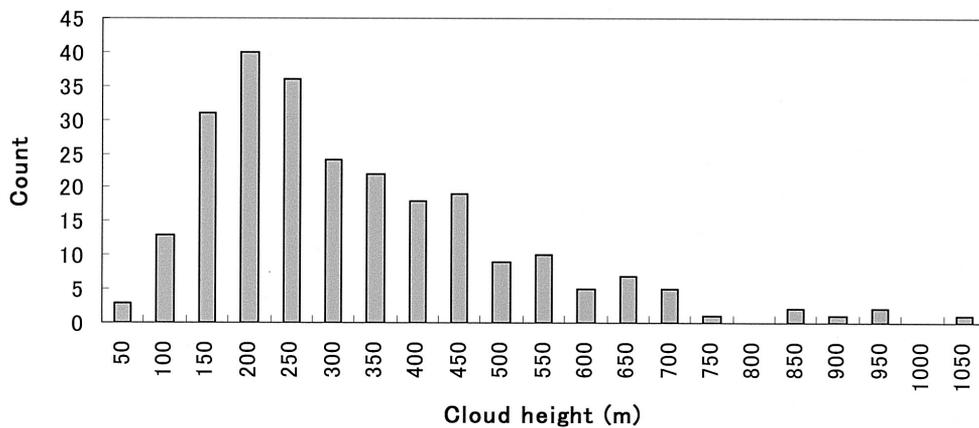


Fig. 17. Histogram of the mean for the day of cloud height in 2002.

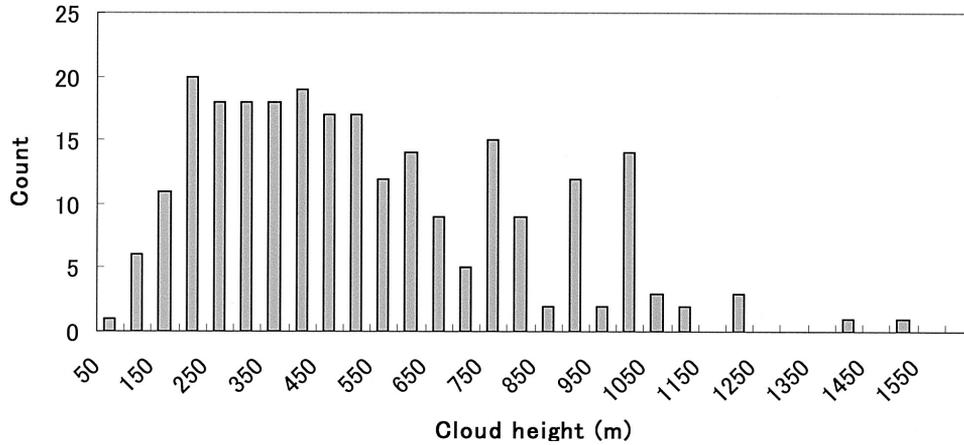


Fig. 18. Histogram of the maximum for the day of cloud height in 2002.

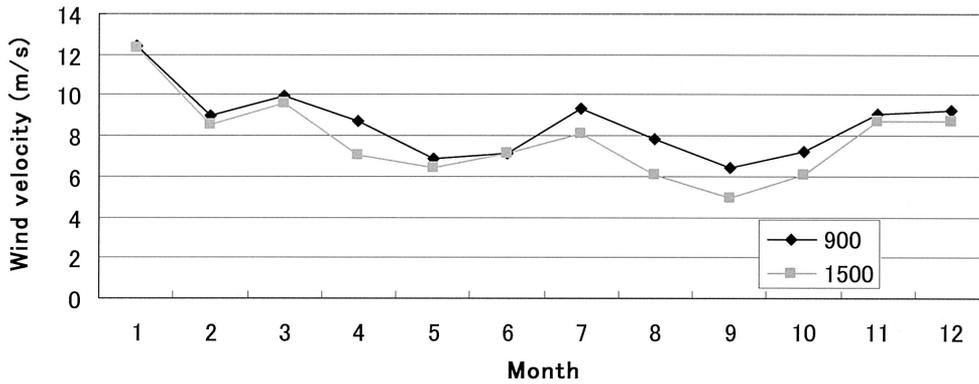


Fig. 19. The mean for the month of wind velocity at the pressure level of 900 hPa at 9:00 and 15:00 JST in 2002 at Kagoshima.

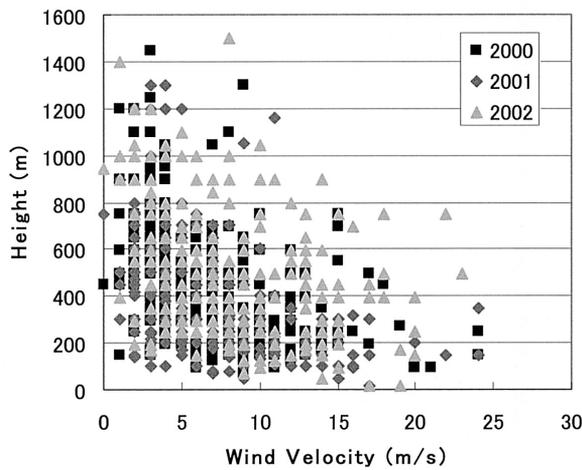


Fig. 20. Correlation between maximum value for the day of cloud height and wind velocity at pressure levels of 900 hPa when the cloud reached the highest altitude during the day.

Summary

From the analysis of the cloud heights from 2000 to 2002, it seems reasonable to conclude that the cloud height shows a tendency to increase in summer. Data from Kagoshima Local Meteorological Observatory represents an increase of mean of wind velocity in winter. We can see that the maximum cloud height varies in inverse proportion to the wind velocity at that time. These results lead to the conclusion that cloud height is strongly influenced by wind velocity. On the other hand, as seen in May and October 2000, the minimum of the wind velocity does not correspond the maximum of the height. Thus, the rising of volcanic cloud may be affected by seasonal atmospheric condition in addition to the wind velocity.

We started the search for hot spots at the crater wall by a near-infrared version of the video camera since 2003 (KINOSHITA *et al.* 2004). Further information about Iodake cloud can be expected by multiple-point observation and analysis. Outline of this paper in Japanese was reported in YAMAMOTO *et al.* (2004). Previous research up to this paper is summarized in KINOSHITA *et al.* (2003).

Acknowledgements

We are grateful to Nittetsu Mining Co. Ltd. for the financial support to this project, and previous students YOSHINO Makoto, HIGASHI Daisuke, KOMUTA Hisashi, TOMIYAMA Michitaka and HISABAYASHI Shohei in Faculty of Education, Kagoshima University, for the maintenance of the system and the analyses of the records. We are also thankful to Mishima-Mura Office and its Development Center, Mishima Junior High School for allowing the use of the observation place and various helps for the maintenance of the system.

References

- KINOSHITA, K. and YOSHIDA, K. 1990. Photo analysis of volcanic plumes from Mt. Sakurajima. Bull. Fac. Ed. Kagoshima Univ., Natural Sci. 42, 1-19 (in Japanese with English abstract).
- KINOSHITA, K., TOMIYAMA, M., MACHIDA, S. and TAKAHARA, H. 2003. Continual observation and analysis of Iodake plumes. Kagoshima Univ. Research Center for the Pacific Islands Occasional Papers, 37: 122-129 (in Japanese with English abstract).
- KINOSHITA, K., KANAGAKI, C., MINAKA, A., TSUCHIDA, S., MATSUI, T., TUPPER, A., YAKIWARA, H. and INO, N. 2004. Ground and Satellite Monitoring of Volcanic Aerosols in Visible and Infrared Bands. In: Proc. CEReS Int. Symp. Remote Sensing—Monitoring of Environmental Change in Asia—, Chiba, Japan, Dec. 2003., 187-

196.

- MACHIDA, H. 1977. What volcanic ash tells us—natural history of volcanoes and plains—. 324 pp., Soju Shobo, Tokyo (in Japanese).
- MACHIDA, H. and ARAI, F. 2003. Atlas of tephra in and around Japan (rev. ed.). University of Tokyo Press, 336pp. (in Japanese).
- MATSUMOTO, T. 1943. The four gigantic caldera volcanoes of Kyushu, Japan. *Jour. Geol. Geogr.*, 19: special no., 1-57.
- NOGAMI, K., YOSHIDA, M. and OSSAKA, J. 1993. Chemical composition of discolored seawater around Satsuma-Iwojima, Kagoshima, Japan. *Bull. Volcanol. Soc. Japan*, 38: 3, 71-77 (in Japanese).
- ONO, K., SOYA, T. and HOSONO, T. 1982. Geology of the Satsuma-Io-Jima District. Quadrangle Series, Scale 1 : 50,000, *Geol. Surv. Japan*, 80 pp. (in Japanese with English Abstract, 5 pp.).
- SHINOHARA, H., KAZAHAYA, K., SAITO, G., MATSUSHIMA, N., and KAWANABE, K. 2002. Degassing activity from Iwodake rhyolite cone, Satsuma-Iwojima volcano, Japan: Formation of a new degassing vent, 1990-1999. *Earth Planet Space*, 54, 175-185.
- SHINOHARA, H., KAZAHANA, K., SAITO, G., MATSUSHIMA, N. and KAWANABE, Y. 2003. Monitoring of volcanic gas emission from Satsuma-Iwojima volcano. In *Researching Eruption Clouds of Volcanic Island Chains*. Kagoshima Univ. Research Center for the Pacific Islands Occasional Papers. no. 37, 116-121 (in Japanese with English abstract).
- UCHIDA, N. and SAKAI, T. 2002. Analysis of peculiar volcanic earthquakes at Satsuma-Iojima volcano. *Earth Planets Space*, 54, 197-209.
- YAMAMOTO, M., TOMIYAMA, M., KINOSHITA, K., KANAGAKI, C. and MACHIDA, S. 2004. Automatic observation and analysis of meteorological conditions of Io-dake plumes. In: *Abstracts of Annual Meeting of Kyushu Branch, Meteorological Society of Japan*, 7-8 (in Japanese).
- YAMASATO, H., OGA, S., DAIKU, Y., FUNASAKI, J, MATSUSHIMA, M, NAITO, H., and KANNO, T. 2004. Announcement of volcanic activity level by Japan Meteorological Agency. *Bull. Volcanol. Soc. Japan*, 49, 217-222 (in Japanese).