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OBSERVATION AND ANALYSIS OF PLUMES AND GAS FROM VOLCANIC ISLANDS IN JAPAN

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ABSTRACT

The development and dispersion of volcanic clouds are large-scale phenomena that provide information about the transport and diffusion of air pollutants from fixed sources. We discuss volcanic clouds from Japanese islands using satellite imagery, observations from the ground, and continuous monitoring of sulfur dioxide at the surface.

INTRODUCTION

In recent years, a number of volcanoes in Japan have been ejecting plumes almost continuously, with plume lengths often reaching to tens or hundreds of km, and with occasional eruptions. Most of them are island volcanoes: Miyakejima in the Izu Islands south of Tokyo, and Satsuma-Iojima and Suwanosejima in the Nansei Islands south of Kyushu. The other, Sakurajima in southern Kyushu, is a half-island almost surrounded by the sea.

The horizontal dispersion of volcanic clouds can be studied using remote sensing data from satellites, while the vertical structure is observed with still-photo, video and web cameras from the ground. Furthermore, there are continuous monitoring data of air quality, such as of the sulfur dioxide (SO_2) concentrations at the foot of volcanoes at Sakurajima and Miyakejima. With the improvement of digital technology, it is now possible to construct an image database of these results. This presentation is a status report toward this goal.

METHODS OF OBSERVATION AND RELATED DATA

Satellite imagery

From the perspectives of spatial resolution and frequency of observation, the capabilities of satellites and their sensors are complementary, with geostationary satellites such as GMS-5 and orbiters with high-resolution sensors such as LANDSAT/TM at opposite extremes.

In the western Pacific, GMS-5 has been in operation since 1995, and will be temporarily replaced by GOES-9 until the launch of MTSAT-R at the end of 2003. The high temporal resolution, an image every one or half-hour, of GMS-5 makes it feasible to study the time variation of large eruption clouds. However, the horizontal resolution, which is 1.25 and 5 km at the equatorial nadir for visible and infrared bands respectively, is not enough for studying smaller-scale daily activities.

In order to observe detailed features of volcanoes and the clouds, polar-orbiters with high-resolution sensors, around 10-30 m, are useful, such as LANDSAT/(E)TM, SPOT/HRV and Terra/ASTER series. A serious shortcoming of such orbital satellites is the scarcity of the observations. For example, LANDSAT has a sixteen-day cycle, and the images may be obscured by cloud. Another limitation of the high-resolution observations is the swath width, for example 60 km for SPOT/HRV and 185 km for LANDSAT/TM, which is sometimes not enough to see the horizontal extension of large-scale volcanic clouds.

In between the two extremes stand the orbital NOAA meteorological satellites with the AVHRR sensor, which has a swath 3000 km and nadir resolution 1.1 km. Two or three of NOAA satellites provide four or six scenes for a point every day. Recently, the new satellites/sensors SeaSTAR/SeaWiFS, Terra/MODIS and Aqua/MODIS are providing images during the daytime approximately once a day for each satellite, with improved spatial and spectral resolutions and limited swaths of about 1000 km.

Ground observation

As the broad scale features of the volcanic clouds change over periods of minutes to hours, video recordings are very appropriate to investigate their properties [1]. The ejection of the clouds is rather stationary most of the time, so interval recording is suited to cover a long duration without excess data storage problems. Furthermore, time-condensed records may reveal dynamical features of the atmospheric flow in quick motion. With a sufficiently short interval, we may also record the rapid evolution of eruption clouds.

Random access to video recordings is now possible by converting a cassette record into mpeg files. An overview of long-time activities of a volcano at a glance can be seen in an album of scenes by digital still-camera with the function of interval recording, or by a web-camera system with archived records. The latter is also useful for the real-time monitoring and remote control by using Internet facilities.

Air quality data

The continuous SO_2 monitoring and other surface air data, originally designed to detect anthropogenic air pollution, are very useful to investigate the behavior of volcanic gas at short and long distances. Such data are available at various stations in Japan with a temporal resolution of one hour.

Meteorological data

Radiosonde-derived upper wind data are obtained 4 times a day at 0300, 0900, 1500 and 2100 JST (Japanese Standard Time = UTC + 9 hours) at eighteen stations. Data from nearby stations are useful and are given at standard pressure levels, (925, 900, 850 hPa and so on) up to heights of 20 km or more. The temperature and relative humidity for standard levels, obtained at 0900 and 2100 JST, are useful to study air stability, which also affects the rise and vertical dispersion of volcanic clouds.

MIYAKEJIMA

Since July 8, 2000, Miyakejima volcano, about 160 km south of Tokyo (Fig. 1), has been very active, with occasional big eruptions in August 2000, and continuous ejection of a great amount of poisonous gas since mid-August 2000, which compelled all of the inhabitants to evacuate since September 2000. The SO_2 flux in the ejected gas monitored by airborne COSPEC (Correlation Spectrometer) was a few 10000s of tons per day in late-2000, and decreased gradually: it is still exceeding 5000 ton/day in March 2003 [2]. Since 28 August, high concentration events of SO_2 occurred at many ground stations 100-400 km leeward in mainland Japan, under strong winds, or under medium winds with convective mixing in sunny conditions helping to bring gases aloft down to the surface. These mechanisms have been confirmed by satellite images and simulation studies, as discussed in a recent forum “Researching Eruption Clouds of Volcanic Island Chains”[3].

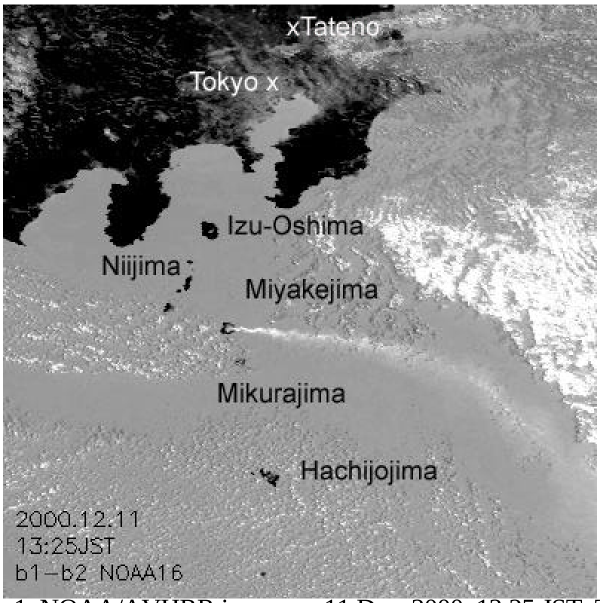

Fig. 1. NOAA/AVHRR image on 11 Dec. 2000, 13:25 JST. The locations of the web camera, Mikurajima, and the upper air observatories, Hachijojima and Tateno, are indicated as well as the volcanic islands Miyakejima and Izu-Oshima. Niijima is seen also in Fig. 2a.

Plumes observed from space (Fig. 1) and commercial flights (Fig. 2) indicate that, when the plume disperses in a high wind without rising, it is blown in a narrow area downstream from the crater. As the advection of volcanic gases can generally be inferred from the visible plumes, high-density gas may be experienced at a great distance in the narrow area leeward of the volcano. In understanding and predicting the plume behavior, the upper air data is very important. The nearest observatory is located in Hachijyojima (Fig. 1), while Tateno and the others are on the mainland.

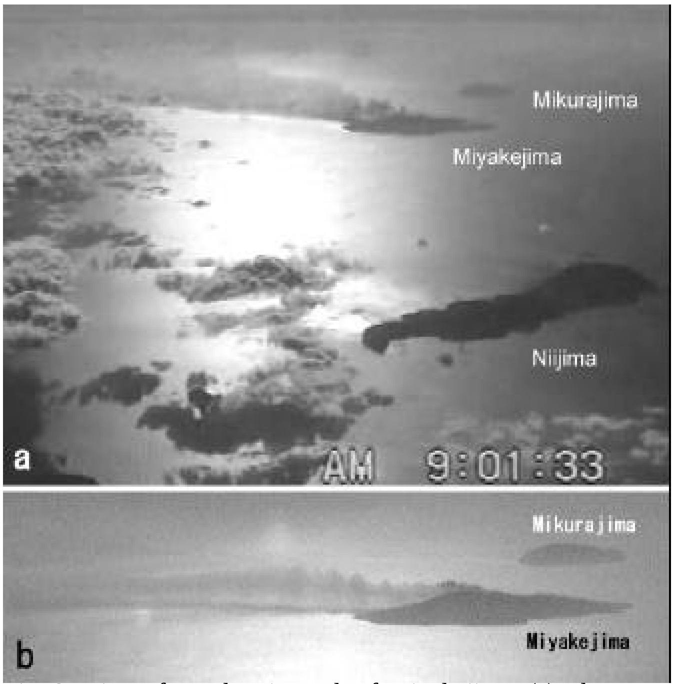

Fig. 2. Views from the air north of Miyakejima. (a) The same day as Fig. 1 at 9:01 JST. (b) Dec. 3, 2001, 9:35 JST.

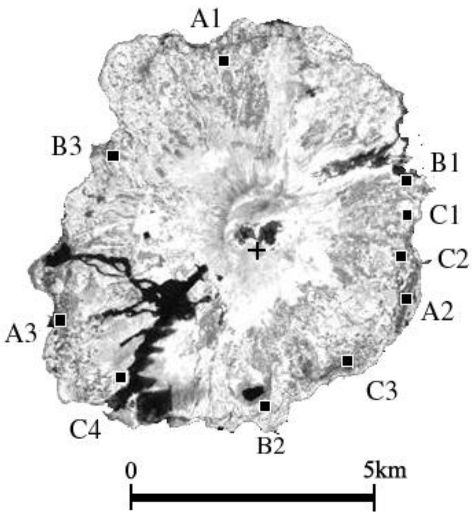

Fig. 3. The gas monitoring stations in Miyakejima denoted by black square, and the crater of the volcano by a cross. The points denoted by A, B and C were installed in Nov. 2000, mid-Sept. 2001, and Mar. 2002 respectively.

Three gas-monitoring stations have been installed at the foot of volcano since December 2000, and ten stations are presently operating (Fig. 3). They provide continuous measurement data of SO_2 and H_2S, and show high concentration events when lee waves formed over Miyakejima bring down dense gas from the summit crater (the wall height is about 800 m above sea level). Ground observation of the plume flow and other related data also shows these events. Simulation studies are being done, taking into account the detailed topography and meteorological conditions to understand the surface gas densities [4].

From August 2000 to May 2002, the Earthquake Research Institute set up a web camera system to observe the volcanic clouds from Mikurajima, about 20km SSE of Miyakejima (Fig. 1), as described in [5]. A portion of the images is released on the web site (in Japanese): http://www.eri.u-tokyo.ac.jp/topics/MIYAKE/kansi/. The Japan Meteorological Agency is now operating web-camera systems with close-up view at three points in Miyakejima, and also in Mikurajima.

SAKURAJIMA

Sakurajima Volcano in southern Kyushu has been continuously active since 1972, ejecting ash plumes almost daily from the summit crater Minamidake at 1040 m above sea level, mixed with occasional large eruptions. Fig.4 is a NOAA/AVHRR image of volcanic cloud at Sakurajima 25 minutes after an eruption. Though Sakurajima is now technically not an island following an eruption in 1914 that formed a narrow isthmus to the mainland, it is almost surrounded by the sea. Fig. 5 shows the topography of Sakurajima and the surroundings.

Time-lapse video recordings started in September 1987 at the station near Kamoike port, 9.8 km WSW from the crater. Between December 1998 and February 2003, automatic recordings by digital camera with an hourly interval were done near Tarumizu, 11 km SSE from the crater, so as to enable stereographic analysis of the cloud dispersion. The properties of volcanic clouds were investigated based on the ground observation and satellite images [7], and the various morphologies shown in satellite images were reproduced well by a simple model based on the upper wind [8].

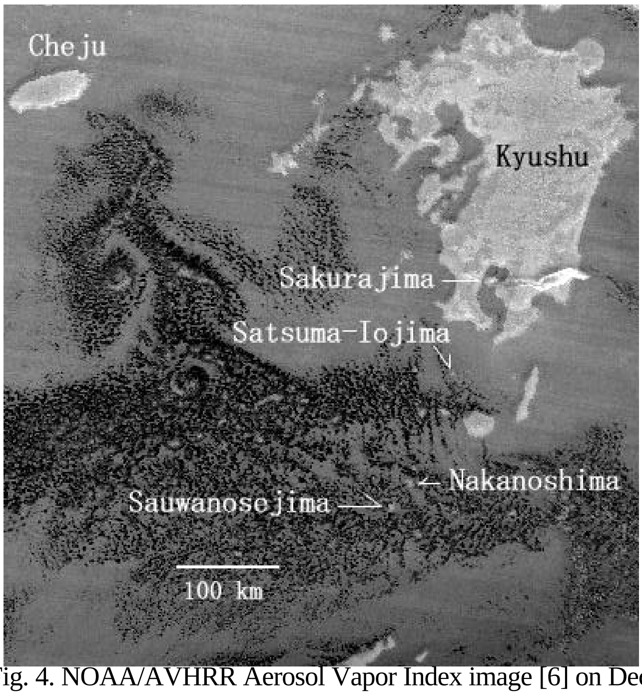

Fig. 4. NOAA/AVHRR Aerosol Vapor Index image [6] on Dec. 10, 1999 at 6:17 JST.

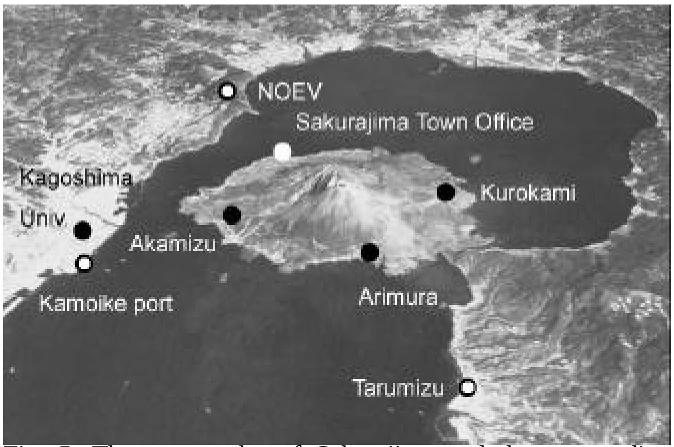

Fig. 5. The topography of Sakurajima and the surrounding Kagoshima Bay observed from southern sky (SiPSE 3D graphics). The gas monitoring stations in Sakurajima and continual camera observation points outside Sakurajima are also indicated by full circles.

A web camera system was installed at the main campus of Kagoshima University 10 km west from the crater in December 2000, and also at the Tarumizu city office 10.5 km SSE from the crater, and at Nansei-Toko Observatory for Earthquakes and Volcanoes (NOEV) 10 km NW from the crater in March 2003. There are many other web sites watching Sakurajima as listed in [9], with or without image archives.

There are four stations monitoring surface air pollutants such as SO_2 and suspended particulate matter (SPM), as shown in Fig. 4. There are many other air quality stations around Sakurajima along the bay and farther field. Most of them have been in operation from the 1980s, providing continuous measurement data with one-hour resolution.

It was found that SO_2 concentrations at the foot of the volcano are high only when the winds around the summit are strong enough to blow the volcanic plumes and gases down to a measuring station downstream. As an illustration, Fig. 6 shows the SO_2 concentration at Arimura station in November 1994. Very high concentration of SO_2, exceeding 100 ppb, the tolerable limit for public health in Japan, occurred when a low-pressure system was passing just to the east, resulting in strong northerly winds. This situation may be clearly seen in Fig. 7(a) in the early morning on November 23 1994, exhibiting a mountain lee wave with a Froude number of close to one. In the case of Fig. 7(b) with a Froude number of less than one, the increase of the SO_2 density was unremarkable. Fig. 7(c) shows a lee wave toward the west, owing to an eastery wind caused by a typhoon approaching from the south. The SO_2 concentration data at Arimura and Kurokami since 1992 are displayed, together with highlight scenes, at http://www-sci.edu.kagoshima-u.ac.jp/volc/gas/ (in Japanese).

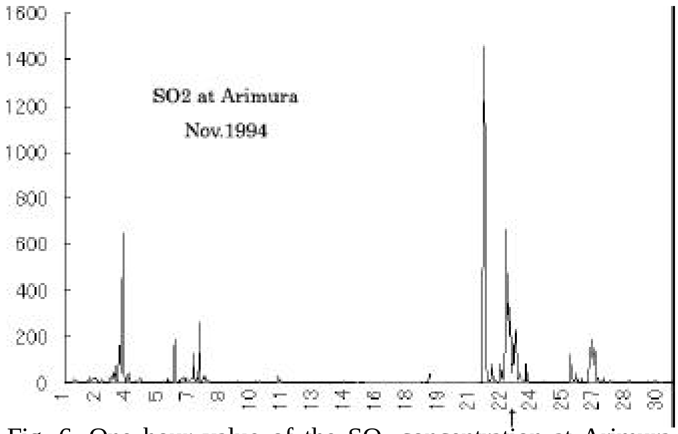

Fig. 6. One-hour value of the SO_2 concentration at Arimura station in November 1994. The horizontal axis is marked by the dates, and the arrow on the axis indicates the time corresponding to Fig. 6(a).

Fig. 7. Sakurajima plumes exhibiting mountain lee waves, observed from the point near Kamoike port. (a) Nov. 23, 1994, 6:31 JST. (b) Jan. 12, 1995, 8:03 JST. (c) Aug. 19, 1990, 14:49 JST.

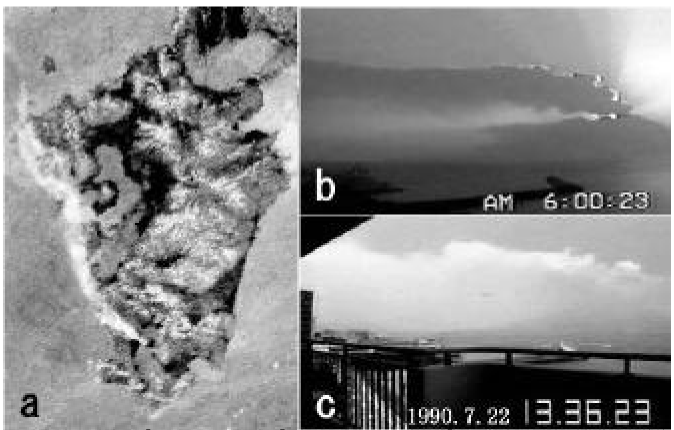

Fig. 8. Sakurajima plumes on July 22, 1990. (a) NOAA/AVHRR image at 13:24 JST. (b) and (c) Ground observations from the station near Kamoike port.

At the downtown stations in Kagoshima city separated from Sakurajima by the sea at the locations 10-15 km from the crater, strong winds are an important cause of the high concentration events of SO_2. The other mechanism is convective mixing in sunny conditions with mild or weak winds. The SPM data exhibit strong correlations with the increase of the SO_2 concentrations.

Gas from Sakurajima was occasionally detected at stations 100-200km away in Kyushu. While the convective mixing in sunny conditions is important at lowland stations, mountain site measurement has more chances of the detection of high density events [10], as the gas and plumes flow with little vertical dispersion. Fig. 8a illustrates a NOAA/AVHRR image and Figs. 8b and 8c the corresponding ground observations.

SATSUMA-IOJIMA

At the remote islands Satsuma-Iojima and Suwanosejima to the south of Kyushu, shown in Fig. 4, continual camera observations of volcanic clouds have been done [11], in addition to satellite monitoring of eruption activities.

Io-dake(703 m) at Satsuma-Iojima has continued active emission of volcanic clouds for more than several hundreds of years, accompanied with SO2 emissions estimated to be 300-500 t/day. Detailed geo-chemical studies have recently been done every year by Shinohara et al. [12]. Fig. 9a shows a top view of Satsma-Iojima, where the locations of Io-dake, Inamuradake (236 m) and observation point, 3 km WSW from the crater, are indicated. Fig. 9b illustrates the topography observed from southern sky.

Since the end of July 1998, records of volcanic plumes at Io-dake have been taken with digital and video cameras installed at the observation point [13]. In addition, automated monitoring system using a web camera has been constructed in February 2003. The results are shown in http://arist.edu.kagoshima-u.ac.jp/volc/iwo/ (in Japanese).

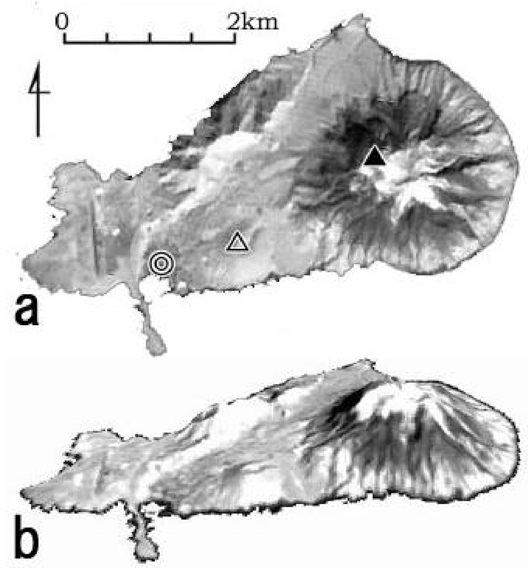

Fig. 9. Satsuma-Iojima. (a) The top view, where the locations of Io-dake, Inamura-dake and the observation point are indicated by filled and open triangles, and a circle respectively.
(b) The topography observed from the southern sky.

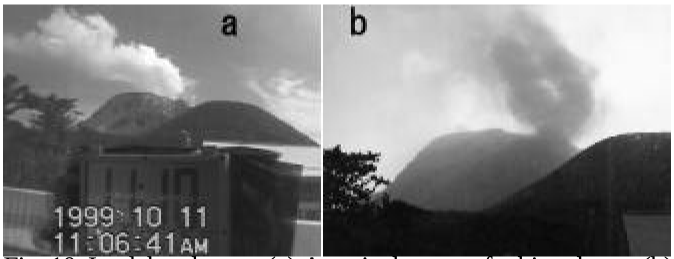

Fig. 10. Io-dake plumes. (a) A typical scene of white plume. (b) Bifurcated plume.

Fig. 10a is a typical scene of a white plume, and Fig. 10b a rare bifurcated one. The height of the plume is about 100-650m above the summit, depending on the winds around the summit height. The highest height, recorded in 2001, was 1300m. There is a seasonal tendency of the plume to be relatively higher in summer compared with other seasons. Explosive eruptions are rarely seen at Io-dake in recent years. The summit is often covered with a cap cloud in humid weather, especially in the summer.

SUWANOSEJIMA

Suwanosejima Volcano, located 220km south of Kagoshima, is the most active volcano in the Nansei Islands. It has a U-shaped summit crater as shown in Fig. 11, with Strombolian type activities such as shown in Fig. 12a, mixed with Vulcanian type eruptions occasionally such as shown in Fig. 12b, sometimes exceeding the activity of Sakurajima Volcano.

The Kagoshima University Group operated a time-lapse video camera system from August 2001 until March 2002 at a southern point inside Suwanosejima, where a wide view could not be obtained. Since August 6, 2002, a web camera system at Nakanoshima, 25 km NE of Suwanosejima is operating successfully, providing a live view and archived results [14]. Since then, eruption clouds with heights reaching 3500m above mean sea level have been observed on many days such as shown in Fig. 12b, and relatively big eruptions have been observed once a month. The plumes were also seen in satellite images of NOAA, MODIS and GMS. Results of the web camera system are shown at http://arist.edu.kagoshima-u.ac.jp/volc/suwa/ in Japanese, and highlighted results are at the more general page of the Satellite Image Network Group in Kagoshima (SING-Kagoshima) page at http://arist.edu.kagoshima-u.ac.jp/sing/topics/ in Japanese.

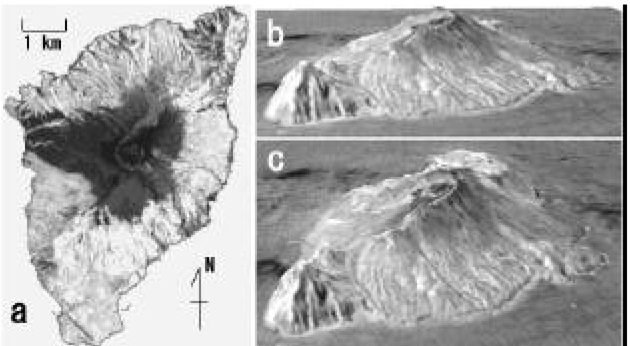

Fig. 11. LANDSAT/TM near-infrared images of volcanic island Suwanosejima. (a) Top view, (b) and (c), topography observed from northern air.

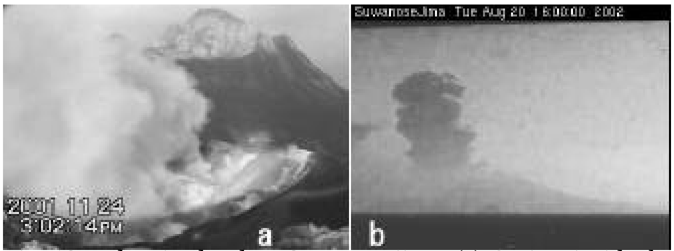

Fig. 12. Volcanic clouds at Suwanosejima. (a) A view inside the crater observed from a southern crater wall on Nov. 24, 2001. (b) An eruption cloud on Aug. 20, 2002, 16:00 JST observed by the web camera located in Nakanoshima.

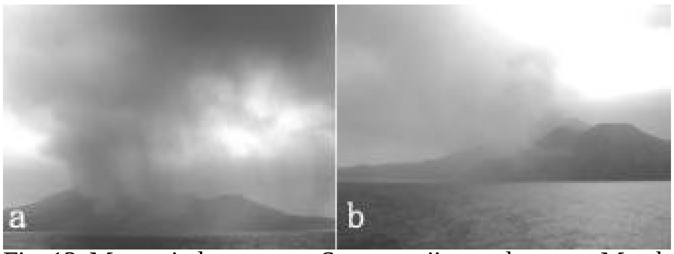

Fig. 13. Mountain lee wave at Suwanosejima volcano on March 3, 2002. (a) From a vessel east of the volcano. (b) From the northeast.

Strong activity of Suwanosejima Volcano indicates a large amount volcanic gas may be ejected from the crater. In fact, smells of sulfuric matter are often reported by inhabitants at the southern foot of the volcano. In the case of the mountain lee wave toward a vessel, shown in Fig. 13, a strong smell of gas was felt on the vessel. Detailed studies of the gas are highly desirable.

CONCLUDING REMARKS

Ejected clouds and gas from volcanic islands in the sea provide precious data of atmospheric dispersion of air pollutants from fixed sources. The local dispersions are sensitive to the interplay of topography of an isolated volcanic mountain, wind speed and atmospheric stability, and may be compared with computer simulations and wind tunnel experiments. The plumes from the four volcanoes we have discussed may be regarded as tracer experiments from isolated mountains with various shapes. Long-range transport can be seen in satellite images, and air quality monitored at remote stations downstream.

At Miyakejima and Sakurajima, various data have been accumulated, which are now under investigation. An important step of the goal is to construct an image database of volcanic clouds observed from the ground and the space, together with other digital data. Digital images in still and movie forms can be displayed on web sites. The limitation of low Internet bandwidths can be avoided by off-line exchanges of CD-R`s and DVD`s.

Early publications are summarized in a booklet [15], and typical results are displayed in the following web sites:
Volc: photo and video pictures of volcanic clouds and related phenomena,
http://www-sci.edu.kagoshima-u.ac.jp/volc/index-e.html
Satellite Image Network Group in Kagoshima,
http://arist.edu.kagoshima-u.ac.jp/sing/index-e.htm

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REFERENCES

[1] K. Kinoshita, Video Monitoring of Ejection and Dispersion of Volcanic Ash Clouds from Mt. Sakurajima, Proc. 3rd Asian Symp. on Visualization, Chiba, Japan (1994), 416-421.
[2] K. Kazahaya et al., Extremely large amount of volcanic gas emission from Miyakejima volcano, Japan, in [3], 24-31. http://staff.aist.go.jp/kazahaya-k/miyakegas/COSPEC.html.
[3] K. Kinoshita (ed.), Forum "Researching Eruption Clouds of Volcanic Island Chains", Occasional Papers of Kagoshima Univ. Res. Center for the Pacific Islands, **37** (2003) (in Japanese with English abstracts).
[4] H. Sasaki, N. Seino, J. Sato and M. Chiba, Development of a Dispersion Model for Volcanic Gas over Miyake Island, J. Met. Soc. Japan, **80** (2002), 1279-1288.
T. Uchida and Y. Ohya, Numerical Investigation of the Behavior of Volcanic Smokes from Miyake-jima in Stably Stratified Fluids, 8th Int. Conf. Atmospheric Sci. and Applications to Air Quality, Tsukuba, Japan (2003), 280.
[5] K. Kinoshita, C. Kanagaki, N. Iino, M. Koyamada, A. Terada and A.C. Tupper, Volcanic plumes at Miyakejima observed from satellites and from the ground, Proc. SPIE **4891** (2003), Optical Remote Sensing of the Atmosphere and Clouds III, part of SPIE's 3rd Int. Asia-Pacific Environmental Remote Sensing Symp., October 2002, Hangzhou, China, 227-236.
[6] M. Koyamada, K. Kinoshita, N. Iino and C. Kanagaki, Satellite detection of volcanic aerosol at Miyakejima and Sakurajima, Nagasaki Workshop on Aerosol-Cloud Radiation Interaction and Asian Lidar Network, Nagasaki, Japan (2001), 96-101.
[7] K. Kinoshita, Observation of flow and dispersion of volcanic clouds from Mt. Sakurajima, Atmospheric Environment **30** (1996), 2831-2837.
K. Kinoshita and H. Togoshi, Rise and flow of volcanic clouds observed from the ground and from satellites, J. Visualization **3** (2000), 71-78.
[8] N. Iino, K. Kinoshita, T. Yano and S. Torii, Detection and morphology of volcanic ash clouds from Mt. Sakurajima in satellite images, Proc. 3rd Pacific Symp. Flow Visualization and Image Processing, F3023, Maui, USA (2001), 1-8.
N. Iino, K. Kinoshita, S. Torii and T. Yano, Satellite monitoring of advection of volcanic clouds, Progress in Transport Phenomena, The 13th Int. Symp. Transport Phenomena, Victoria, Canada (2002), 779-784.
[9] A. Tupper and K. Kinoshita, Satellite, Air and Ground Observations of Volcanic Clouds over Islands of the Southwest Pacific. South Pacific Study, **23** (2003), 21-46.
[10] K. Kinoshita, N. Iino, I. Uno, A. Mori and J. Kohno, Day and night detection of volcanic clouds and aerosol by NOAA/AVHRR data, CEReS Int. Symp. on the Atmospheric Correction of Satellite Data and its Application to Global Environment, Chiba, Japan (1998), 37-44.
K Kinoshita, N. Iino, I. Uno, A. Mori, S. Ikebe and J. Kohno, Satellite analysis of volcanic clouds and transport of acidic substances from Mt. Aso and Mt. Sakurajima, Water, Air & Soil Pollution, **130** (2001), 385-390.
[11] K. Kinoshita, C. Kanagaki, M. Tomiyama, A. Tupper, T. Matsui, H. Yakiwara, N. Iino, S. Machida, H. Takahara and T. Fukuzumi, Observation of volcanic clouds at the Nansei Islands of Japan with automated camera systems and satellite images, Japan Earth and Planetary Science 2003 Joint Meeting, Chiba, Japan, V055-P024.
[12] H. Shinohara, K. Kazahaya, G. Saito, N. Matsushima and K. Kawanabe, Degassing activity from Iwodake rhyolitic cone, Satsuma-Iwojima volcano, Japan: Formation of a new degassing vent, 1990-1999, Earth, Planet and Space, **54** (2002), 175-185.
[13] K. Kinoshita, M. Tomiyama, S. Machida and H. Takahara, Continual observation and analysis of Io-dake plumes, in [3], 122-129.
[14] C. Kanagaki, K. Kinoshita, A. Minaka, S. Tsuchida, H. Yakiwara, and T. Fukuzumi, Ground observation and satellite images of Suwanosejima plumes, in [3], 136-143.
C. Kanagaki, K. Kinoshita, A. Tupper, H. Yakiwara, and T. Fukuzumi, Ground and Satellite Observations of Eruptions and Plumes at Suwanosejima Volcano, 23rd IUGG General Assembly, Sapporo, Japan, 30 June - 11 July, 2003.
[15] K. Kinoshita (ed.), Flow and Dispersion of Volcanic Clouds, Kagoshima University (2001).