

## Estimation of Miyakejima volcanic gas hazards using vegetation index images

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### Abstract

The eruptive activity of Miyakejima volcano started on 8 July 2000, and the ejection of enormous amounts of sulphur dioxide (SO<sub>2</sub>) has been continued since August 2000. The Tokyo Metropolitan Government started monitoring volcanic gas concentrations at the foot of the volcano from the end of 2000. We studied the seasonal and regional characteristics of high concentrations of SO<sub>2</sub> using the data. In order to estimate the volcanic gas hazards for the whole Miyakejima, a hazard mapping method using the Normalized Difference Vegetation Index (NDVI) images is proposed.

### 1. Introduction

Volcanic gases and aerosols released into the atmosphere have adverse impact on air quality, vegetation, animals, and human health. Miyakejima volcano, about 170 km south of Tokyo (Fig. 1), has been ejecting enormous amounts of sulphur dioxide (SO<sub>2</sub>) from the summit (775 m a.s.l.) since mid-August 2000.

The Tokyo Metropolitan Government stated the monitoring of volcanic gas concentrations from the end of 2000 at three gas-monitoring stations at the foot of the volcano, and expanded into fourteen stations as of April 2004 (Fig. 2 and Table 1). We have been analyzing the SO<sub>2</sub> concentrations to investigate the mechanism of high concentration occurring at the volcano. The following results were obtained from our previous studies (Iino et al., 2003, 2004a, b). (i) High SO<sub>2</sub> concentrations at the ground surface on Miyakejima are mainly caused by downdraft owing to strong wind. (ii) The seasonal and regional characteristics of high SO<sub>2</sub> concentrations correspond well to the 925 hPa wind observed at Hachijyojima, the nearest upper air observatory from Miyakejima (Fig. 1). (iii) There is notable difference of environment of SO<sub>2</sub> concentrations owing to a slight directional difference from the crater. This should be considered in making a volcanic gas hazard map at the volcano. (iv) The frequency distribution of high SO<sub>2</sub> concentration events corresponds well to the distribution of vegetation shown in an image of Terra/ASTER.

In this study, we propose a method to estimate the volcanic gas hazards for the whole Miyakejima using satellite imagery which shows the distribution of vegetation before and after the 2000 Miyakejima eruption. The resultant hazard map is examined by comparing with the occurrence frequency of high SO<sub>2</sub> concentrations at each gas-monitoring station and with the ground observations by visible (VIS) or near-infrared (NIR) cameras. Here, the NIR photographs are obtained based on our previous studies (e. g., Kinoshita et al, 2003).

In addition, we briefly discuss the long-term trend and the seasonal and regional characteristics of the occurrence frequency of high SO<sub>2</sub> concentrations, defined above 0.1 ppm and 1.0 ppm, using SO<sub>2</sub> concentration data during January 2001 - September 2005

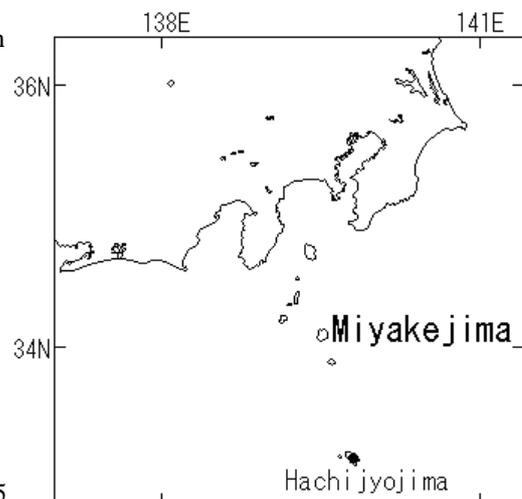


Fig. 1 Location of Miyakejima volcano.

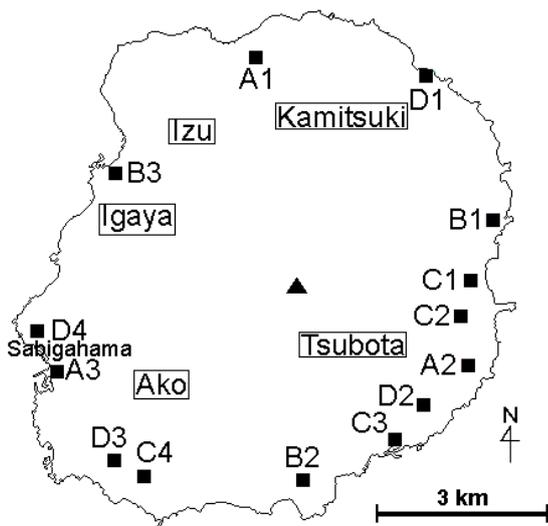


Fig. 2 Locations of volcanic gas-monitoring stations on Miyakejima as of April 2004 (■), the summit vent (▲), and the district names.

Table 1 Gas-monitoring stations

Symbol	Station name	Abbreviation	Observation start (month/year)
A1	Branch Office	BO	12/2000
D1	Mimoi	MM	04/2004
B1	Ainohama	AH	09/2001
C1	Miike	MI	03/2002
C2	Yakuba	YK	05/2002
A2	Airport	AP	12/2000
D2	Mitake-Jinjya	MJ	04/2004
C3	Tsubota	TS	03/2002
B2	Akacocco	AC	09/2001
C4	Usugi-Namakon	UN	03/2002
D3	Usugi-Bus Stop	UB	04/2004
A3	Ako	AK	12/2000
D4	Furusato	FU	04/2004
B3	Igaya	IG	09/2001

## 2. Sulphur dioxide concentrations at Miyakejima

Figure 3 shows occurrence frequency of high SO<sub>2</sub> concentrations of all gas-monitoring stations since January 2001. The environmental standard of SO<sub>2</sub> concentration, which was prescribed by the Ministry of Environment in Japan, is less than 0.1 ppm for one-hour averaged value. However, much higher concentrations, several ppm, were often recorded at Miyakejima. Thus, we defined here the two standards of high concentration levels of SO<sub>2</sub> as 0.1 and 1 ppm. In each figure, solid and dotted lines indicate the high concentrations frequencies of 0.1 and 1 ppm, respectively.

The occurrence frequency of high SO<sub>2</sub> concentrations is not in the obvious decreasing trend though five years have passed since the Miyakejima 2000 eruption. The seasonal and regional characteristics of high concentrations derived from a ten stations analysis (Iino et al., 2004b) are essentially the same as the results including four stations, which were added from April 2004. These are summarized as follows. (i) The stations located between east and east-southeast directions from the vent, C1, C2 and A2, observe very high rate in winter. (ii) At east-northeast station, B1, the rate of high concentrations is high not only in winter but also in summer. (iii) At southwest stations, C4 and D3, the rates of high concentrations are relatively high throughout a year. (iv) At north and southeast stations, A1 and C3, respectively, the high concentrations rates are not high.

Here, we focus on the four stations added in April 2004, D1-D4. The Mimoi station, D1, located at northeast is interesting, because there had been no continual gas-monitoring station though southwesterly wind is dominant in spring and summer. As expected from the wind, the rate of high concentrations defined as 0.1 ppm at the station is high in spring and summer, while low in autumn and winter (Fig. 3b). Whereas the rate of high concentrations defined as 1 ppm, the rate of high concentrations is low though in spring and summer. It may depend on the characteristics of wind of which the rate of strong wind in summer is lower than that in winter. For the Mitake-Jinjya station, D2 (Fig.3g), located at southeast, the characteristics of high concentrations is similar to the Airport station, A2 (Fig. 3f), but the rate is obviously lower, about one third. The characteristics of the Usugi-Bus Stop station, D3 (Fig.3k), located at southwest and near the Usugi-Namakon station, C4 (Fig. 3j) is similar to the tendency and frequency levels of the C4 station. For the Furusato station, D4 (Fig. 3m), located at west-southwest near the Ako station, A3 (Fig. 3l), the tendency of high concentrations is similar to the A3 station but the levels are about one half.

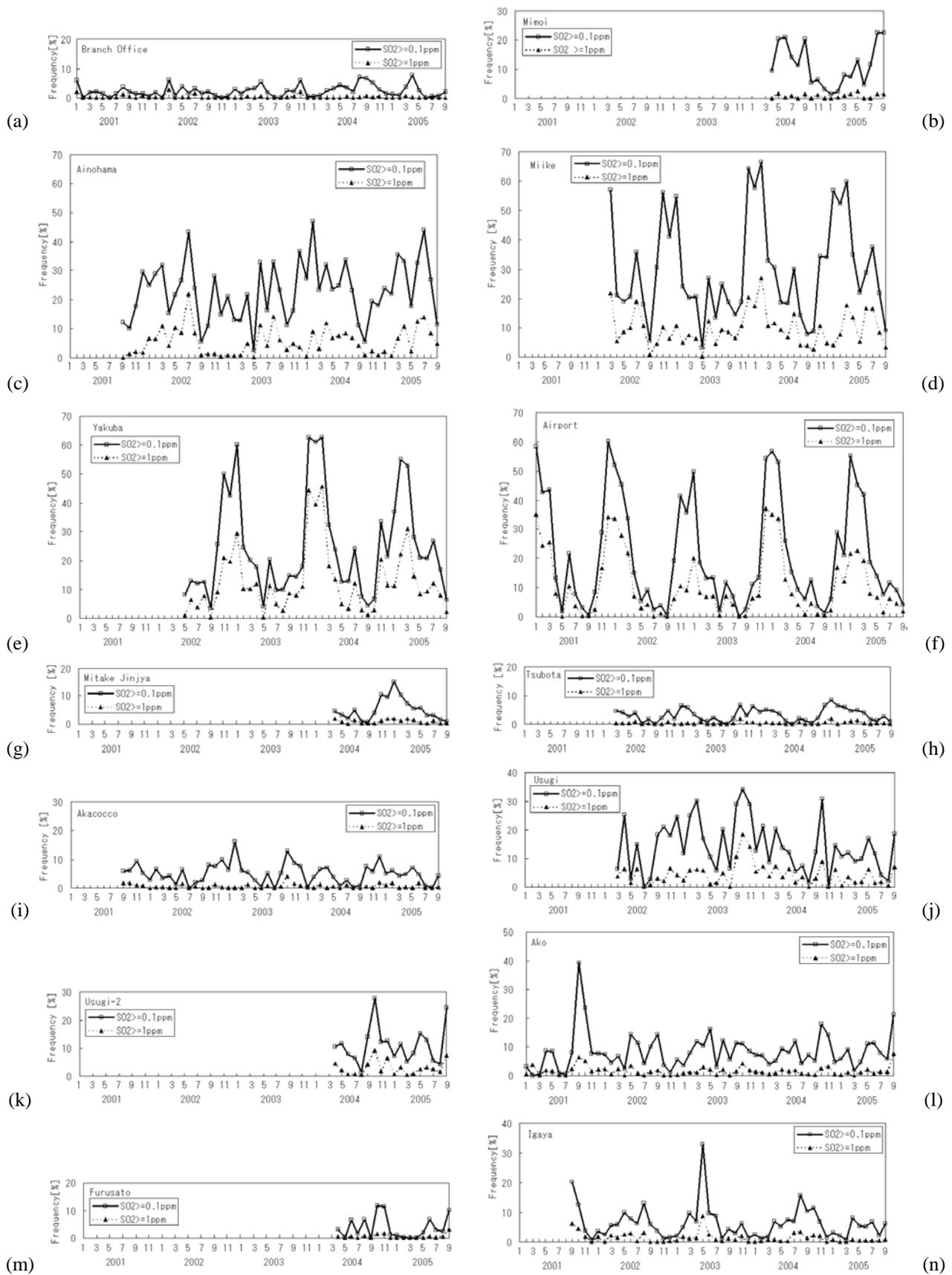


Fig. 3 The occurrence frequency of high SO<sub>2</sub> concentrations during January 2001 - September 2005.

### 3. Hazard mapping for high sulphur dioxide concentrations

In order to estimate the volcanic gas hazards for the whole Miyakejima, we propose a new hazard mapping method using the Normalized Difference Vegetation Index (NDVI) images. This method is based on a hypothesis that the distribution of vegetation at Miyakejima volcano well reflects the influence of volcanic gases. The satellite data used are as follows. Before the 2000 Miyakejima eruption is JERS-1/OPS on 3 April 1994, while after the eruption is Terra/ASTER on 7 April 2003. We selected the same season data to eliminate the effect of seasonal change in vegetation.

First, the JERS-1/OPS was corrected geometrically to fit to Terra/ASTER data, by taking eight GCP-points. Second, the NDVI is calculated as the difference between the near-infrared and visible reflectances divided by the sum of the two. The NDVI images of JERS-1/OPS (OPS-NDVI) and Terra/ASTER (ASTER-NDVI) are shown in Figs. 4a and b, respectively. As shown in Fig. 4a, Miyakejima had been covered with vegetation except for the lava or artificial areas. After the 2000 Miyakejima eruption shown in Fig. 4b, the east and southwest regions are shown as dark-colour areas, that is the area with low NDVI values. Therefore, it can be considered that vegetation there was damaged by volcanic gases. The difference between OPS-NDVI and ASTER-NDVI was calculated to visualize the relative change in vegetation, and classified into four steps of hazards by referring with one-year averaged value of SO<sub>2</sub> concentrations at each station (Table 2), during May 2002 - April 2003. Finally, originally less vegetation areas, such as open water, the lava, artificial areas, were masked by using near-infrared image of JERS-1/OPS though the mask is not enough, e.g., for the areas of airport or crater. The resultant volcanic gas hazard map is shown in Fig. 4c. The color image of Fig. 4c is shown at our web site (in Japanese). <http://ese.mech.kagoshima-u.ac.jp/miyake/>.

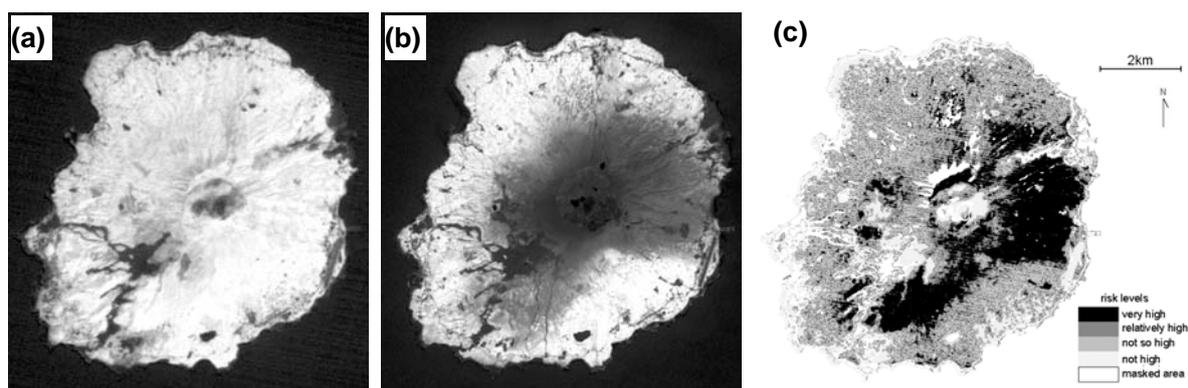


Fig. 4 NDVI images. (a) JERS-1/OPS on 3 Apr. 1994, (b) Terra/ASTER on 7 Apr. 2003. (c) Volcanic gas hazard map.

Table 2 The one-year averaged SO<sub>2</sub> concentrations during May 2002- April 2003.

Gas-monitoring station	SO <sub>2</sub> concentrations [ppb/year]
Branch Office	11
Ainohama	143
Miike	279
Yakuba	280
Airport	166
Tsubota	17
Akacocco	29
Usugi-Namakon	120
Ako	46
Igaya	40

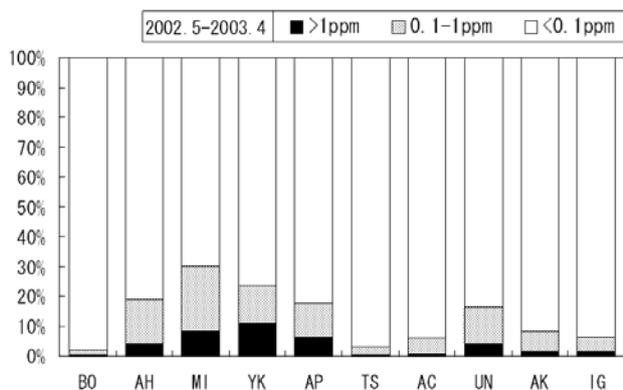


Fig.5 The rate of SO<sub>2</sub> concentration levels during May 2002 - April 2003.

In Fig. 4c, the difference of NDVI values becomes large with the decrease of the vegetation, that is, the gas hazard level is evaluated to be high. Figure 5 shows the rate of SO<sub>2</sub> concentration levels at each station during May 2002 - April 2003. At the foot of the volcano, the gas hazard levels, e.g., the highest level is seen in east and followings is in southwest, correspond well to the environment of SO<sub>2</sub> concentrations shown in Fig. 5. It is also found that the hazard level becomes higher at the mountainside near the crater.

#### 4. Ground observations

Figure 6 shows ground observations in May 2005 from the coastal loop-line road around Miyakejima and from a ship with visible (VIS) and near-infrared (NIR) cameras. Vegetation is shown as dark in VIS images (Figs. 6a-c), and as white in NIR images (Figs. 6d-f). In the high volcanic gas concentration districts, Tsubota in the east (Fig. 6a) and Ako in the southwest (Fig. 6b), many wilted trees were observed at the foot of the volcano. In contrast, vegetation in other districts (e.g., Figs. 6d-f) was almost normal at the foot of the volcano, except for some wilted Japanese cedar. We confirmed that the volcanic gas hazard map (Fig. 4c) is consistent with ground observations of Miyakejima island. The observation results containing animation files are displayed at our web site mentioned above.



(a) Tsubota high concentration district (VIS)



(b) Ako high concentration district (VIS)



(c) Izu-Kamitsuki (VIS)



(d) The Tsubota station, C3 (NIR)



(e) Ako-Sabigahama (NIR)



(f) Igaya-Izu (NIR)

Fig.6 Ground observations from the coastal loop-line road around Miyakejima, (a)-(d) and from a ship, (e)-(f).

Figs 6(a)-(c) are visible photographs. Figs. 6(d)-(f) are near-infrared photographs by SONY DCR-TRV30 with night-shot mode and Fujifilm IR84 and Kenko ND400. The district names are shown in Fig.2.

## 5. Concluding remarks

In order to estimate the volcanic gas hazards for the Miyakejima island as a whole, a hazard mapping method using the Normalized Difference Vegetation Index (NDVI) images was proposed. The resultant hazard map was consistent with the occurrence frequency of high SO<sub>2</sub> concentrations at ten gas-monitoring stations as of 2003, and with the ground observations by visible or near-infrared cameras.

However, it should be noted that volcanic gas behaviour depends on the wind around the crater and that the high concentrations have the seasonal characteristics as shown in Fig. 3. Therefore, the volcanic gas hazard map should be used together with the meteorological information. In order to improve and complete the Miyakejima volcanic gas hazard map, further studies will be done in near future.

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