

## DISPERSION OF VOLCANIC CLOUDS AND SULFUR DIOXIDE CONCENTRATIONS AT MIYAKEJIMA

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### Abstract

To clarify the high concentration events of volcanic gas at Miyakejima, Japan, we focus on the seasonal wind characteristics around Miyakejima volcano, which has been ejecting enormous amount of sulfur dioxide (SO<sub>2</sub>) since summer 2000. The following results were obtained. The wind around the summit of the volcano is relatively strong throughout the year, and the fresh wind brings the volcanic gas to a leeward gas-measuring station. The seasonal rate of high concentration events at each station corresponds very well to the seasonal characteristics of the wind rose.

### Introduction

Volcanic gases and aerosols released into the atmosphere have adverse effect on air quality, vegetation, animals, and human health. Miyakejima volcano, about 160 km south of Tokyo (Fig. 1), has been ejecting enormous amounts of sulfur dioxide (SO<sub>2</sub>) from the summit (814 m a. s. l.) since mid-August 2000. All of the inhabitants have been evacuated from Miyakejima since 1 September 2000. The SO<sub>2</sub> flux monitored by airborne COSPEC (Correlation Spectrometer) is still exceeding 5000 ton/day in September 2003. The SO<sub>2</sub> flux measurements are described at <http://staff.aist.go.jp/kazahaya-k/miyakegas/COSPEC.html>.

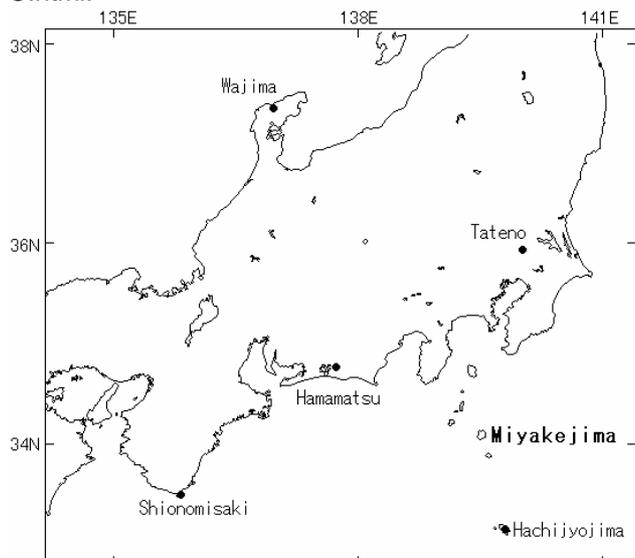


Fig.1. Location map of volcanic island Miyakejima and the upper air observatories in the central part of Japan, Hachijyojima, Hamamatsu, Tateno, Shionomisaki and Wajima.

The Tokyo Metropolitan Government started the monitoring of SO<sub>2</sub> and hydrogen sulfide (H<sub>2</sub>S) concentrations from the end of 2000 at three gas-measuring stations around the foot of the volcano, and ten stations have been operating since March 2002 (Fig. 2). Here, we analyzed SO<sub>2</sub> concentrations only since the H<sub>2</sub>S concentrations have not been so high in most of the time and limited the analyzing period to 2002 as an object of this study.

We have been analyzing the behaviour of volcanic plumes and gases in meso [1, 2] and local scales [2, 3]. It has been elucidated that high SO<sub>2</sub> concentrations at the ground surface are caused by downdraft owing to strong wind and by the convection mixing in sunny daytime. In this study, we investigate the relationship between high SO<sub>2</sub> concentration events and seasonal wind characteristics at the volcanic island Miyakejima.

### VOLCANIC GASES RELEASED INTO ATMOSPHERE

The chemical composition of volcanic gases emitted from a volcano depends on the pressure and temperature during magma ascent and crystallization. The most abundant gas typically released into the

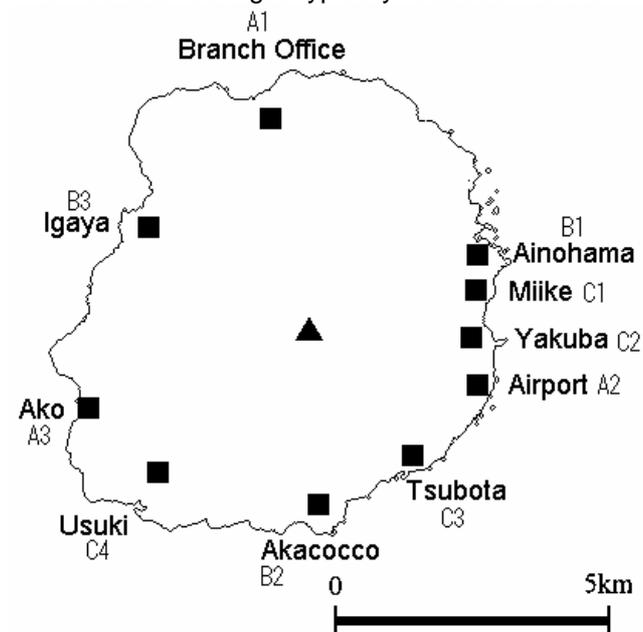


Fig.2. Map of the gas-measuring stations in Miyakejima. Square: observation points. Triangle: the vent of Miyakejima volcano.

atmosphere is water vapor (H<sub>2</sub>O), and the rate is exceeding 90 % in Japanese volcanoes [4]. Volcanoes also release other gases, including carbon dioxide (CO<sub>2</sub>), SO<sub>2</sub>, H<sub>2</sub>S, hydrogen (H<sub>2</sub>), hydrogen chloride (HCl), hydrogen fluoride (HF), helium (He) and so on.

For sulfuric composition, the following reaction takes place:  $\text{H}_2\text{S} + 2 \text{H}_2\text{O} \rightleftharpoons \text{SO}_2 + 3 \text{H}_2$ . The equilibrium depends on the ambient environment. The mole fraction of H<sub>2</sub>S increases under the condition of low-temperature and atmospheric pressure, while it is not dominant in high-temperature. Active volcanoes, such as Miyakejima and Sakurajima in Japan, emit the high-temperature type gas, whose principal composition is SO<sub>2</sub>.

Both H<sub>2</sub>S and SO<sub>2</sub> are dense gases, which have a larger molecular weight than that of the air. For low-temperature type gas, which is cooled down to the air temperature before releasing, the H<sub>2</sub>O is condensed from gas to liquid. Thus, H<sub>2</sub>O is eliminated from the volcanic gas, and inevitably H<sub>2</sub>S becomes high concentration. The air containing concentrated H<sub>2</sub>S flows to lower places and is pooled at depressed grounds if there is no wind, and it may cause toxicological accident if one goes into such a place.

However, it should be noted that the density of emitted gas from a volcano is strongly affected by its temperature. For high-temperature type gas, the temperature is significantly higher than that of ambient air, and the SO<sub>2</sub> mixing ratio is relatively small. Therefore, the volcanic gas rises entraining the surrounding air up to a temperature-balanced height, if wind is not so strong. Under this circumstance, turbulent diffusion in various scales is predominant than molecular diffusion. Therefore, SO<sub>2</sub> is not inclined to be collected at depressed ground. The behaviour of volcanic gas in the atmosphere can be inferred from the observable clouds composed of volcanic ash and condensed vapour [2].

### **WIND CHARACTERISTICS AROUND MIYAKEJIMA VOLCANO**

Upper wind data are observed 4 times a day at 03:00, 09:00, 15:00 and 21:00 JST (Japanese Standard Time = UTC + 9) by radiosonde measurement. As shown in Fig. 1, the nearest observatory from Miyakejima is Hachijyojima, which is also an isolated island. The upper wind around the summit height of Miyakejima dominantly affects the SO<sub>2</sub> concentration at the ground surface [3]. Thus, we used Hachijyojima wind data at 925 hPa corresponding to the altitude about 830 m a. s. l., which is close to the Miyakejima summit height.

We classified each month into four seasons according to the wind properties as follows: winter: January, February, November and December; spring: March, April and May; summer: June, July and August; autumn: September and October. We assigned the wind directions to the notation of 16 cardinal points, as shown in legend in Fig. 3. Wind

velocities were classified into four types as follows: light wind: 0-3 m/s; moderate wind: 4-6 m/s; fresh wind: 7-9 m/s; strong wind: exceeding 10 m/s.

Fig. 3 shows the wind rose for each month classified into four seasons. Occurrence frequency of wind velocity in 4 types for each month is shown in Fig. 4. The seasonal characteristics of wind direction are as follows. In winter, westerly monsoon is dominant because the typical winter weather pattern is maintained well. In summer, southerly wind owing to the Pacific high pressure system is dominant. In spring and autumn, northerly wind composition is added to the tendency of summer, and wind direction is changeable due to the periodical high/low pressure system change. The wind is relatively strong throughout the year because Miyakejima is a sea-isolated island. In particular, the advent rate of fresh and strong winds is over 80 % in winter and spring. In summer and autumn, the wind below 7 m/s increases.

### **RELATIONSHIP BETWEEN HIGH SO<sub>2</sub> CONCENTRATION EVENT AND WIND**

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 cases of high concentration levels of SO<sub>2</sub> as 0.1 and 1 ppm. We used SO<sub>2</sub> concentration data obtained in 2002, in which the observation periods of 4 stations were different from the others, because they were installed in March 2002. The data at Miike, Tsubota and Usuki have been provided since March 2002, and at Yakuba since May 2002.

#### **High SO<sub>2</sub> concentration events in 2002**

In order to investigate the relationship between SO<sub>2</sub> high concentration events and wind characteristics, we first picked up the events, for which the upper air data were available at the same day and time, and then calculated the mean value and standard deviation of the wind direction and velocity for each station. The result of each station is shown in Table 1 and Fig. 5. Here, the directions in Table 1 are based on the idiomatic expression for meteorology, i. e., 0, 90, 180 and 270 degrees correspond to north, east, south and west, respectively. The difference of installed date is indicated as alphabetical order in station number. The defined high concentration levels are respectively 1 ppm and 0.1 ppm corresponding to Fig. 5a and b. The area of each sector is proportional to the observation rate, and the direction and angle indicate mean value and standard deviation of wind direction, respectively. The center of the sectors indicates the vent of the volcano, and the direction and relative distance of each station from the vent is shown as squared symbol.

The results show that the basic characteristics of

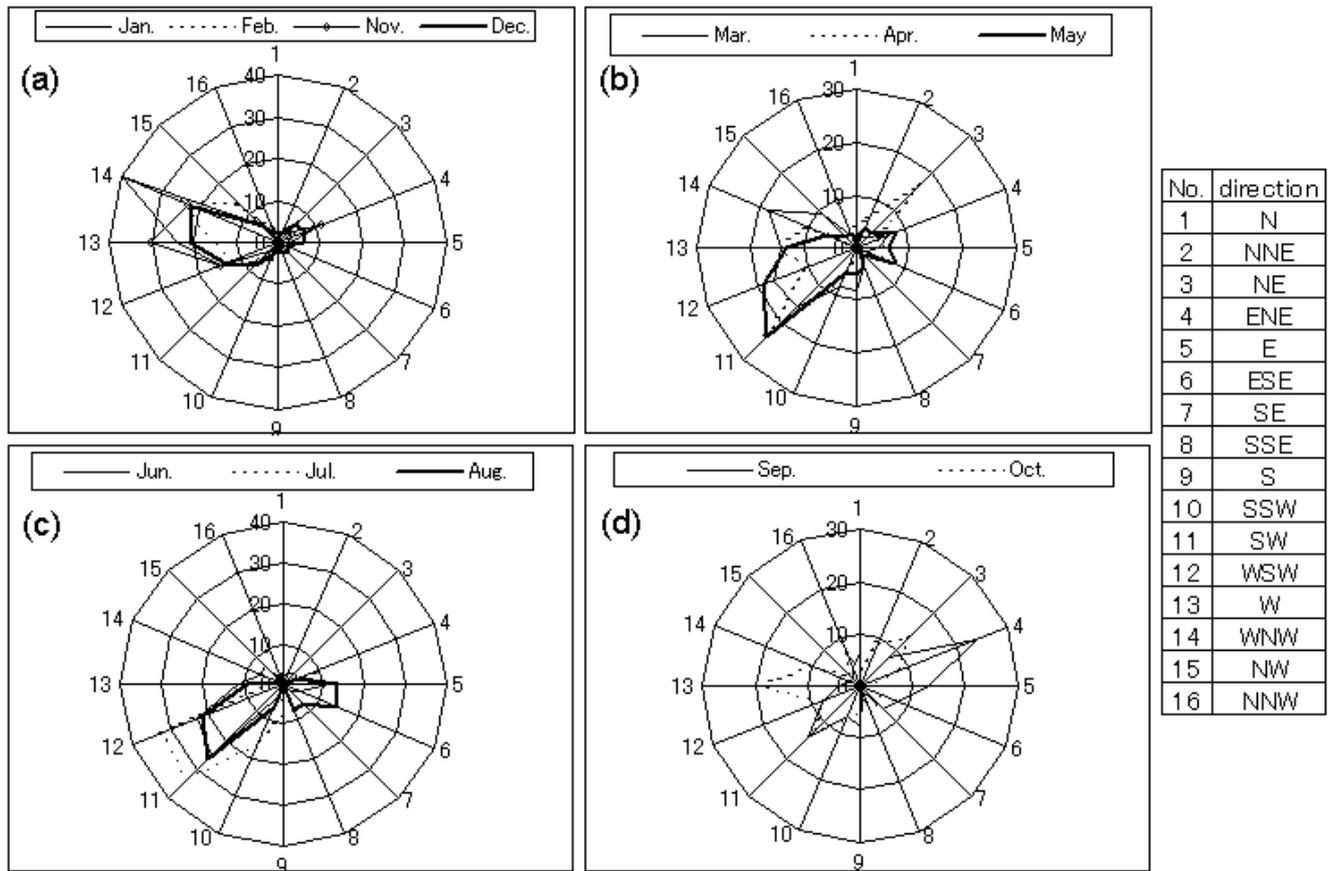


Fig.3. The wind rose of Hachijojima wind at 925 hPa in 2002. (a), (b), (c) and (d) are winter, spring, summer and autumn, respectively.

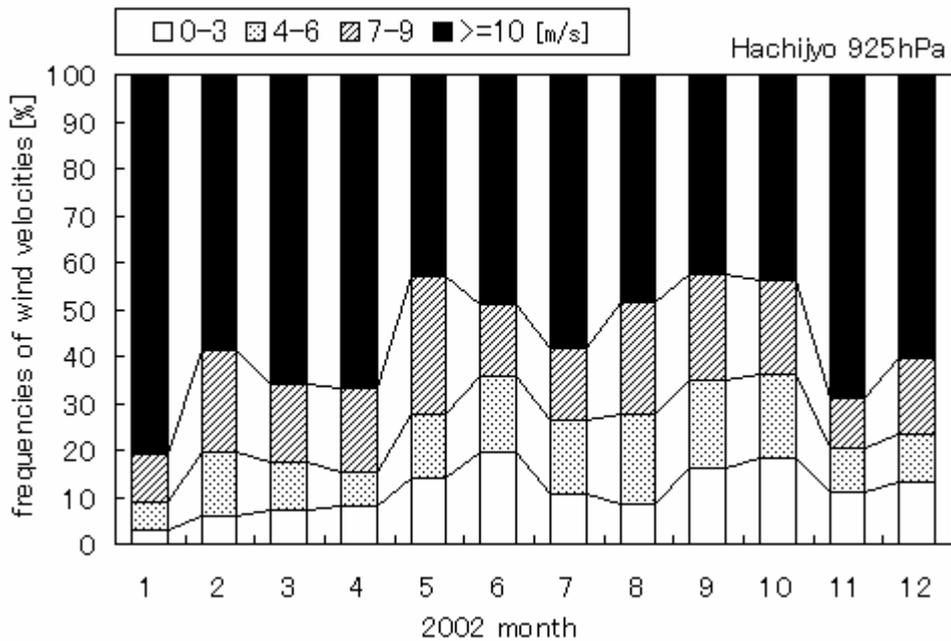


Fig.4. The frequency of wind velocity at Hachijojima 925 hPa in 2002.

Table 1. Direction of Miyakejima vent from each station, observation rate of SO<sub>2</sub> high concentration events and the mean value and standard deviation of winds when the events were observed.

Gas-measuring station	Branch Office	Ainohama	Miike	Yakuba	Airport	Tsubota	Akacoccco	Usuki	Ako	Igaya
Station number	A1	B1	C1	C2	A2	C3	B2	C4	A3	B3
direction to the vent [deg]	170	245	256	272	288	320	357	47	71	123
rate of high concentration events defined by 1 ppm [%]	0.4	5.6	8.7	7.7	9.7	0.4	0.2	2.6	0.8	0.6
wind direction [deg]	mean	166	243	257	270	283	282	296	34	75
	standard deviation	11.9	16.7	17.0	26.3	21.7	27.5	39.6	79.5	58.2
wind velocity [m/s]	mean	13.0	12.2	12.0	13.2	14.0	10.6	13.0	8.4	11.2
	standard deviation	4.9	4.2	4.0	4.6	4.8	3.2	9.6	4.7	5.7
rate of high concentration events defined by 0.1 ppm [%]	1.5	20.9	31.3	19.0	20.2	3.3	4.4	13.0	6.5	5.5
wind direction [deg]	mean	179	254	268	270	279	290	328	52	78
	standard deviation	38	25	39	26	24	41	73	74	57
wind velocity [m/s]	mean	10.5	11.9	12.4	12.4	13.2	9.0	10.3	10.3	9.4
	standard deviation	6.3	4.7	5.0	4.9	4.9	4.9	6.3	6.5	5.3

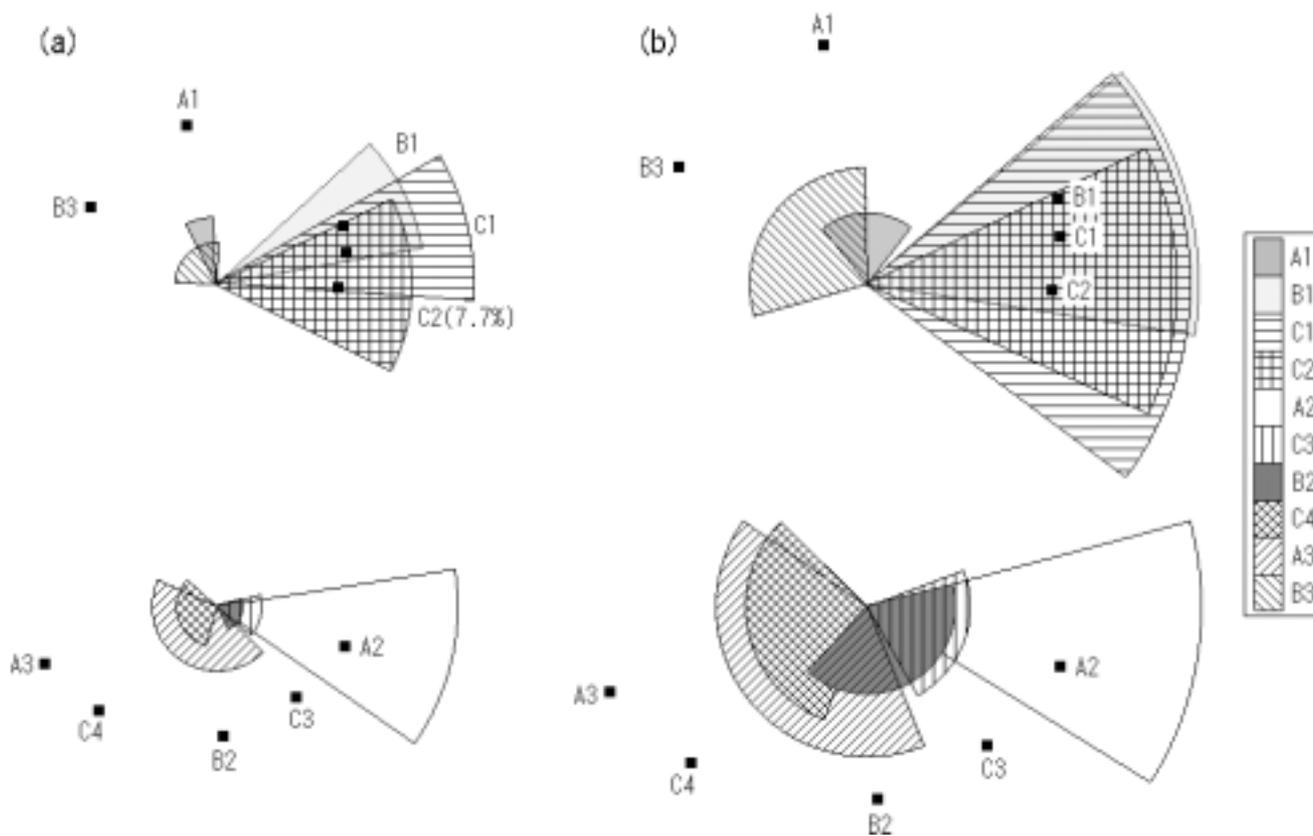


Fig.5. The correspondence between high SO<sub>2</sub> concentration event and Hachijojima 925 hPa wind in 2002. (a) and (b) show the results defined above 1 and 0.1 ppm, respectively, for northern (southern) stations in the upper (lower) diagrams

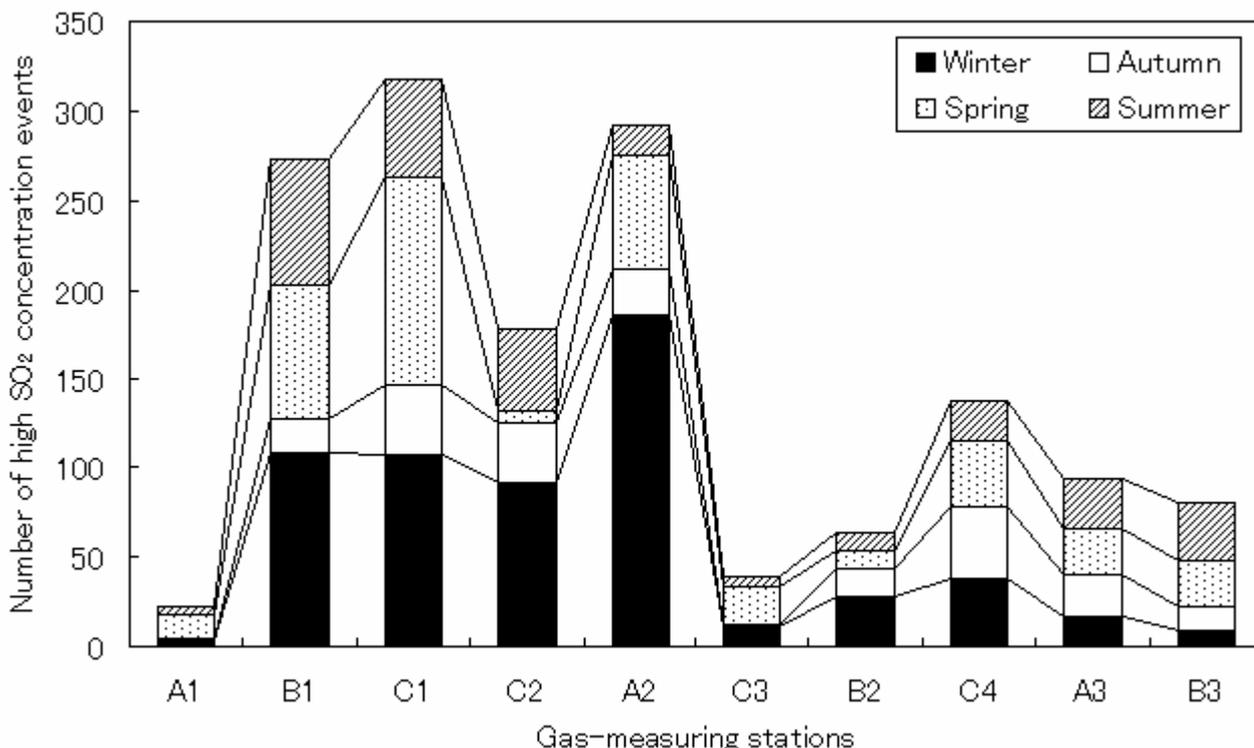


Fig.6. The observation times of high SO<sub>2</sub> concentration events defined above 0.1 ppm at each station.

the relationship between high concentration events and winds is similar for the cases above 1 ppm and 0.1 ppm, though the standard deviation of the wind directions becomes large in 0.1 ppm. It is evident that high concentration events are observed at the leeward station. The events, which were defined above 1 ppm and 0.1 ppm, respectively, were observed when the wind velocities exceeded approximately 7 m/s and 5 m/s, respectively.

#### Seasonal characteristics of high SO<sub>2</sub> concentration events

Fig. 6 shows the number of times of high SO<sub>2</sub> concentration events defined above 0.1 ppm at each station described in clockwise order. The events were observed for many hours at stations located east, while, at stations in the north and south parts of volcano, those were less observed. The seasonal rate of the events at each station corresponds well to the seasonal characteristics of wind rose shown in Fig.3. For instance, the rates in spring and summer are larger than the other seasons in northern stations, such as Branch office (A1), Igaya (B3) and Ainoama (B1). At airport station (A2), winter monsoon brought high SO<sub>2</sub> concentrations for long times, resulting the rate over 60 % in winter. We may expect similar tendency at the other eastern stations, Miike (C1) and Yakuba (C2), taking account of the lack of data in early months. Here, it should be also noted that the high concentration events were observed almost equally at any season at stations located in the southwest part of the volcano, and that the observation rate is somewhat large there (A3, C4).

#### CONCLUDING REMARKS

In this study, we focused on high SO<sub>2</sub> concentration events observed at the foot of Miyakejima volcano in conjunction with seasonal wind characteristics near the summit height. The following results were obtained. The wind around the summit of Miyakejima is relatively strong throughout the year, due to the geographical situation as a sea-isolated island. Fresh wind is the main cause of high SO<sub>2</sub> concentration at the foot of the volcano. The seasonal rate of high concentration events at each station corresponds very well to the seasonal characteristics of wind rose. In winter, prevailing westerly wind brings high concentrations of SO<sub>2</sub> to the stations located east of the volcano for many hours. In summer, southerly wind is dominant, thus the rate become large at stations located at the northern part of the volcanic island. In spring and autumn, high concentration events caused by changeable wind are observed at the stations in various directions.

#### ACKNOWLEDGEMENTS

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