Estimation of the Amount and Dispersal of Volcanic Ash-fall Deposits Ejected by Vulcanian type Eruption

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Estimation of the Amount and Dispersal of Volcanic Ash-fall Deposits Ejected by Vulcanian type Eruption

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Keywords : Vulcanian type eruption, Sakurajima, Amount and dispersal of volcanic ash-fall deposits, Wind velocity and leeward.

Abstract

A practical method to estimate the amount and dispersal of volcanic ash-fall deposits was reviewed for evaluation of Vulcanian type eruptions at Sakurajima Volcano. Distribution functions of ash-fall deposits in and out of Sakurajima were represented in an exponential function and in a power function, respectively.

It is found that dispersion of volcanic ash-fall deposits depend mainly on wind velocity and leeward direction in the lower troposphere.

1. Introduction

Recent eruptive activity at Minami-dake (South peak) crater of Sakurajima Volcano has been continuing since October 1955. The amount of volcanic ash-falls began to increase again in 1973 accompanied with intense Vulcanian type eruptions at the summit crater.

This paper reviews a practical method to estimate the amount and dispersal of volcanic ash-fall deposits ejected from Sakurajima Volcano for fundamental evaluation of magma discharge associated with eruptive activities as well as for contribution to counter-measures against volcanic disasters.

2. Data

Observation of volcanic ash-fall deposits at 58 stations in and out of Sakurajima began on June 1978 by Kagoshima Prefectural Government. 58 monitoring stations in Kagoshima Prefecture were grouped into 8 sectors, each having a 45-degree angle, with origin of co-ordinates at the active crater of Sakurajima as shown in Figure 1.

Volcanic ash and rain fell into a plastic bucket set each station outside. Monthly volcanic ash-fall deposits in plastic buckets were dried in a constant temperature bath, weighed (straight data) and changed to ash-fall data in gr/m^2 at every station. In this paper, these data (gr/m^2 per month) were used to estimate the total amount and dispersal of volcanic ash-fall deposits in and out of Sakurajima Volcano.

3. Estimation of the total amount of volcanic ash-fall deposits

3.1 In Sakurajima ($x < 5$ km)

Kamo et al. (1977) reported that dispersal of volcanic ash-fall deposits in Sakurajima coincides qualitatively well with leeward direction in the lower troposphere at the height of about 1,000 m～2,000 m. They also examined the relation between thickness of ash-fall deposits [d(x) cm] and the distance from the active crater (x km < 5 km) during the period from 1970 to 1975. They found that an exponential function fits well to the distribution function

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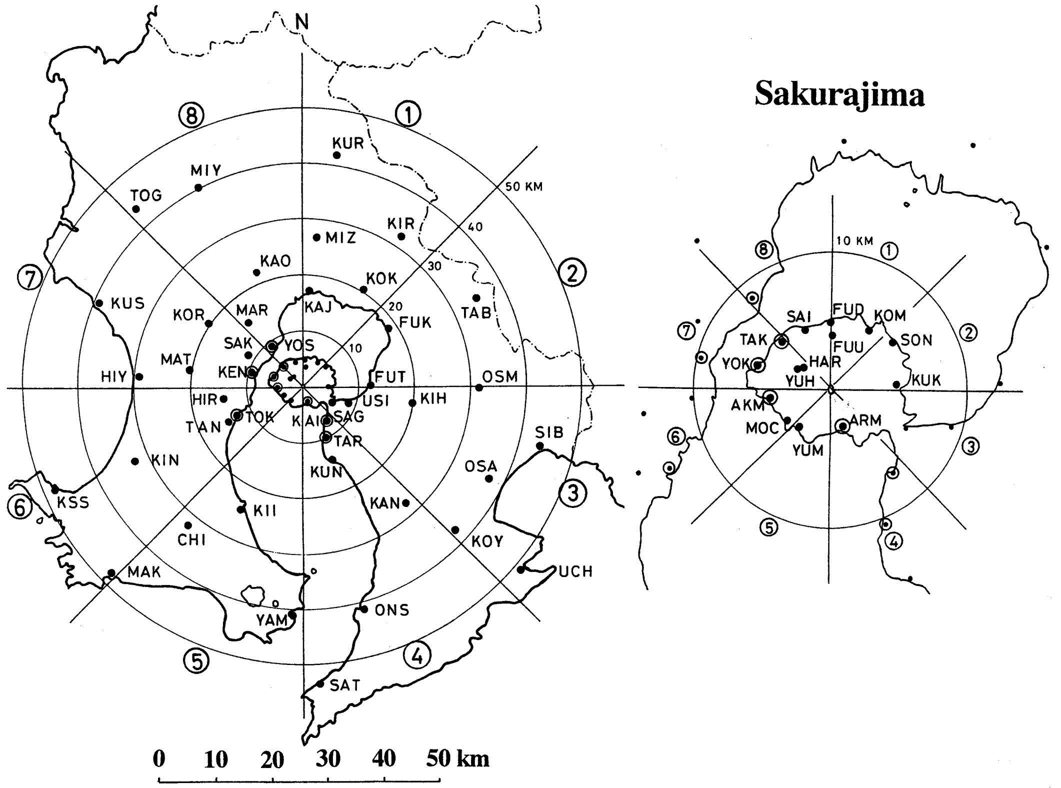

Figure 1. Observation stations (solid circles) of volcanic ash-fall deposits in Kagoshima Prefecture and the number of sectors. Double circles show daily observation stations. Origin of co-ordinates is at the active crater of Sakurajima.

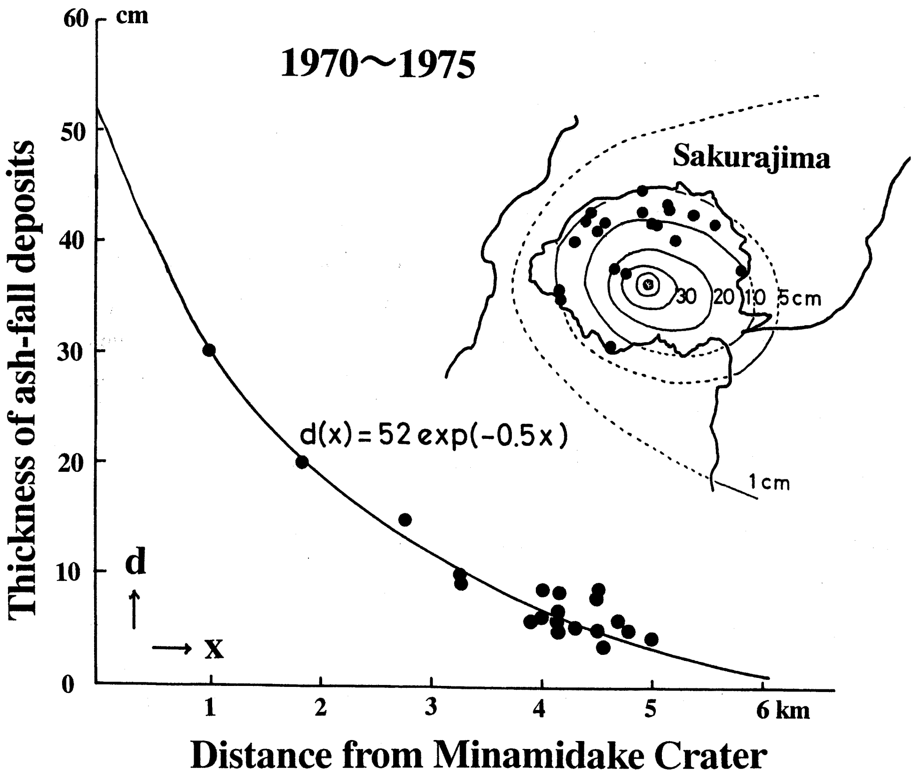

Figure 2. Relation between thickness of ash-fall deposits at Sakurajima and distance from the active crater during 1970 to 1975 (adapted from Kamo et al., 1977).

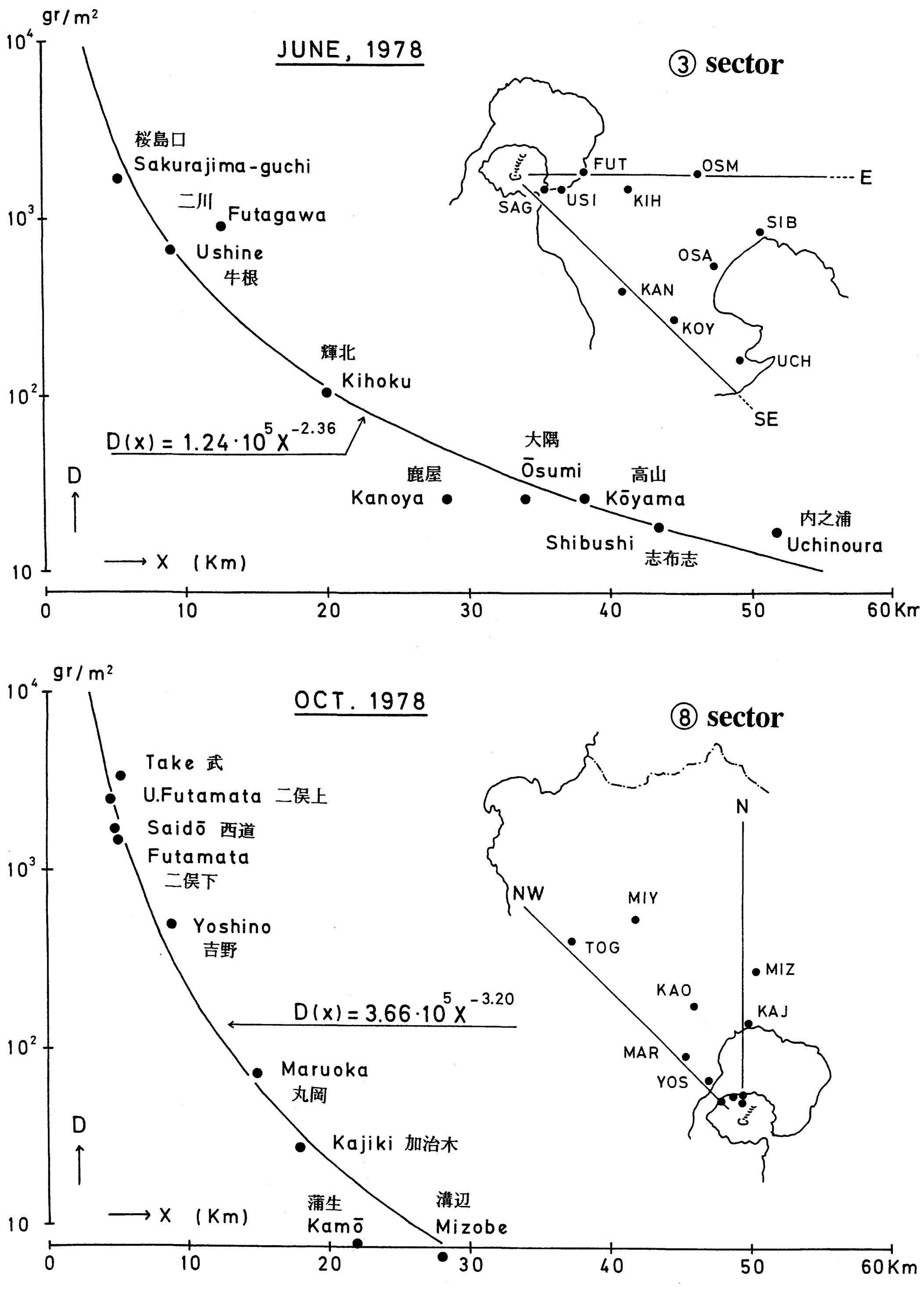

Figure 3. Distribution of ash-fall deposits (gr/m²) with distance (x km) from the active crater in (3) sector on June 1978 (upper), and in (8) sector on October 1978 (lower).

of ash-fall deposits within 5 km from the active crater. They expressed this empirical equation as follows,

$$d(x) = d_0 \exp(-ax) \qquad \text{-----------------}(A)$$

In this equation, constant d_0 and a are to be determined each month and each sector. Figure 2 (adapted from Kamo et al., 1977) shows an example during the period from 1970 to 1975.

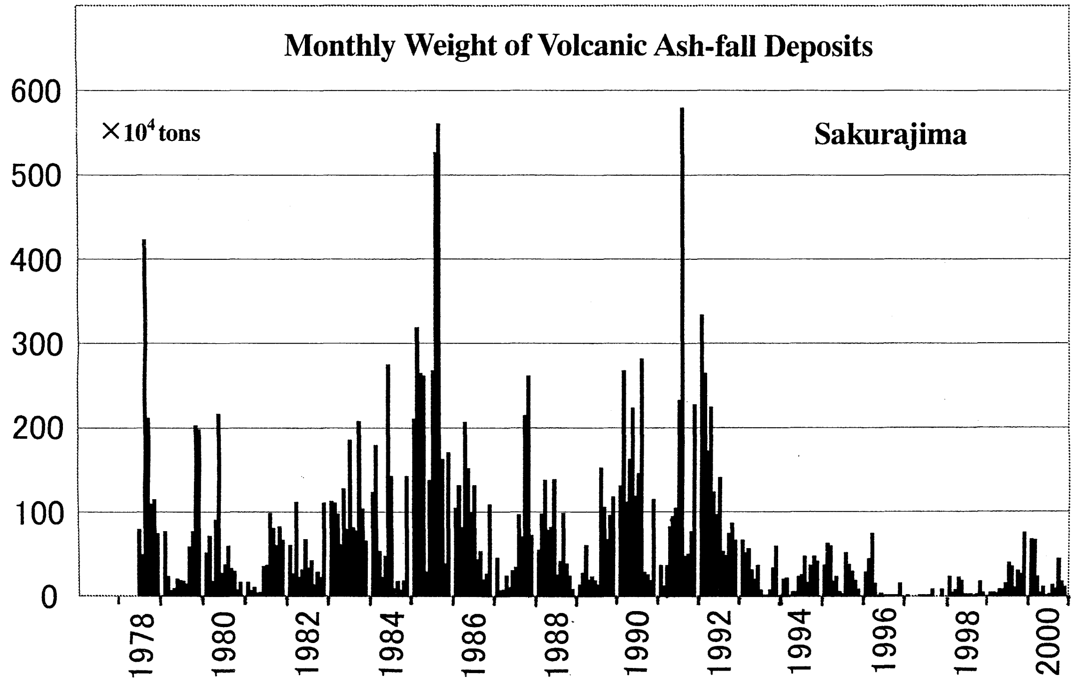

Figure 4. Monthly weights of volcanic ash-fall deposits during 1978 to 2000 (after Ishihara and Nishi, 1998).

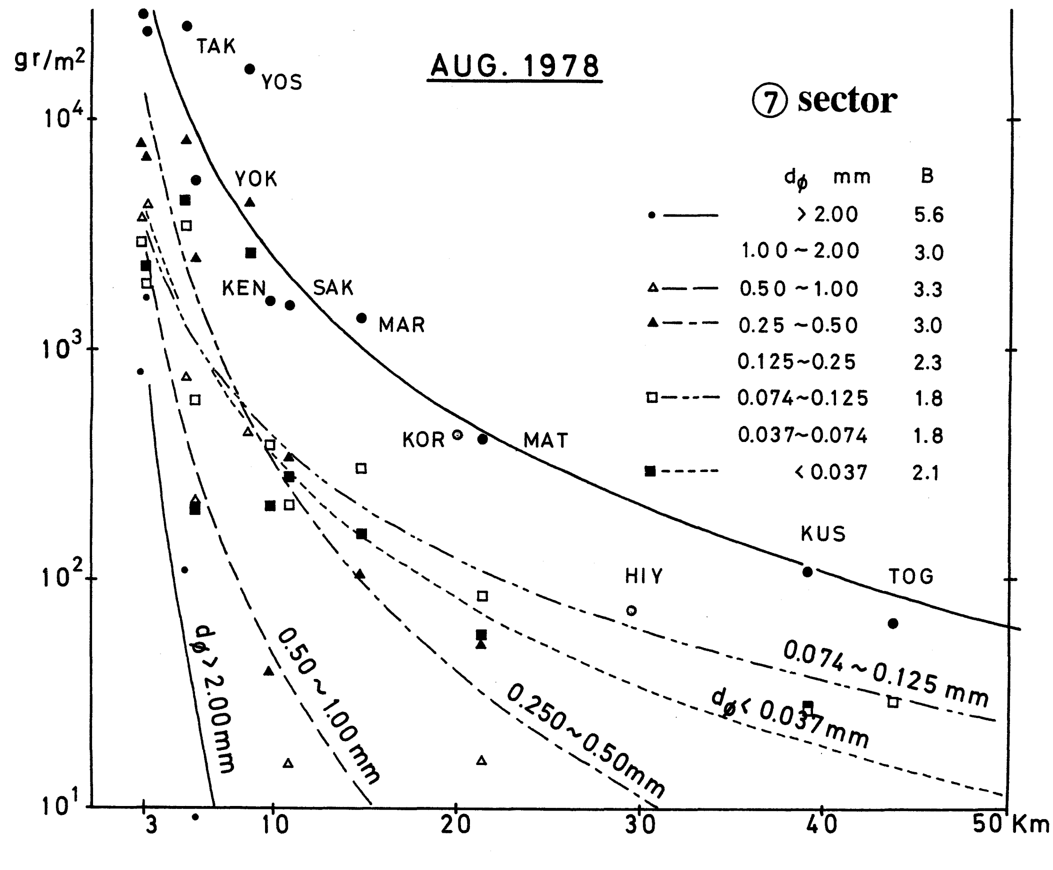

Figure 5. Grain size distribution curve in (7) sector on August 1978.

3.2 Out of Sakura-jima (3 km < x < about 50 km)

Eto and Ishihara (1979) studied relations between the distance from the vent (x km) and the monthly weight of ash-falls [D(x) gr/m^2] in every sector by the regression analysis. As the result of analysis, they concluded that the most reasonable distribution function is a power function to explain the weight of ash-falls in the range of 3 km to about 50 km from the active crater. They expressed this empirical equation as follows,

$$D(x) = D_0 x^{-B} \qquad \text{--------------------}(B)$$

where, constant D_0 and B are to be determined each month and each sector. Figure 3 shows two examples in (3) sector on June 1978 and in (8) sector on October 1978.

3.3 Calculation of the total amount of volcanic ash-fall deposits

Constant D_0 and B in equation (B) can be calculated by the regression analysis each month and each sector. Constant d_0 and a in equation (A) are also determined by the least square method using estimated amount of ash-falls by equation (B) and observed data within 5 km from the active crater. Integration of the empirical equation (A) and (B) gives the monthly weight of volcanic ash-falls in a single sector.

Amounts of ash-falls within 3 km from the vent (T_1), and beyond 3 km from the vent (T_2) in a single sector are calculated by,

$$T_1 = \int_0^{3km} \frac{\pi}{4} x \cdot d_0 \exp(-ax) \cdot dx \qquad \text{------------}(C)$$

$$T_2 = \int_{3km}^{bkm} \frac{\pi}{4} x \cdot D_0 x^{-B} \cdot dx \qquad \text{---------------}(D)$$

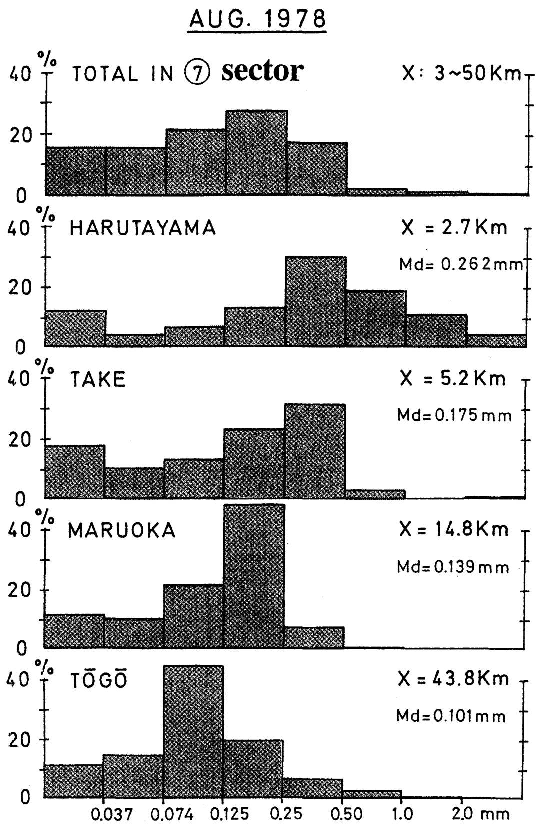

Figure 6. Histograms of grain size variations with median diameter (Md) in (7) sector on August 1978.

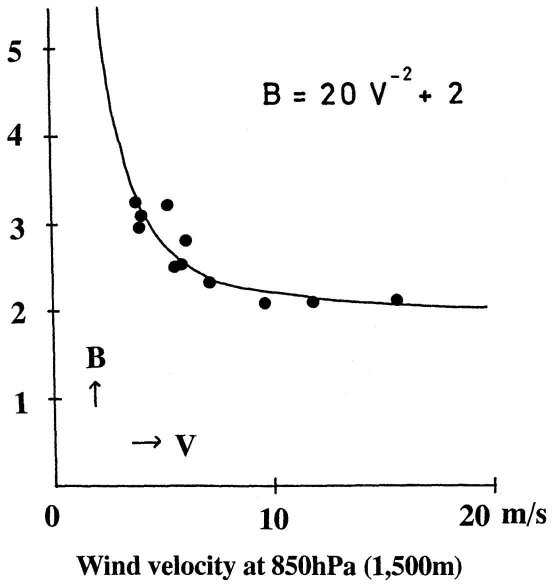

Figure 7. Relation between constant B and wind velocity V (m/sec) at 850 hPa in the lower troposphere (Eto and Ishihara, 1979).

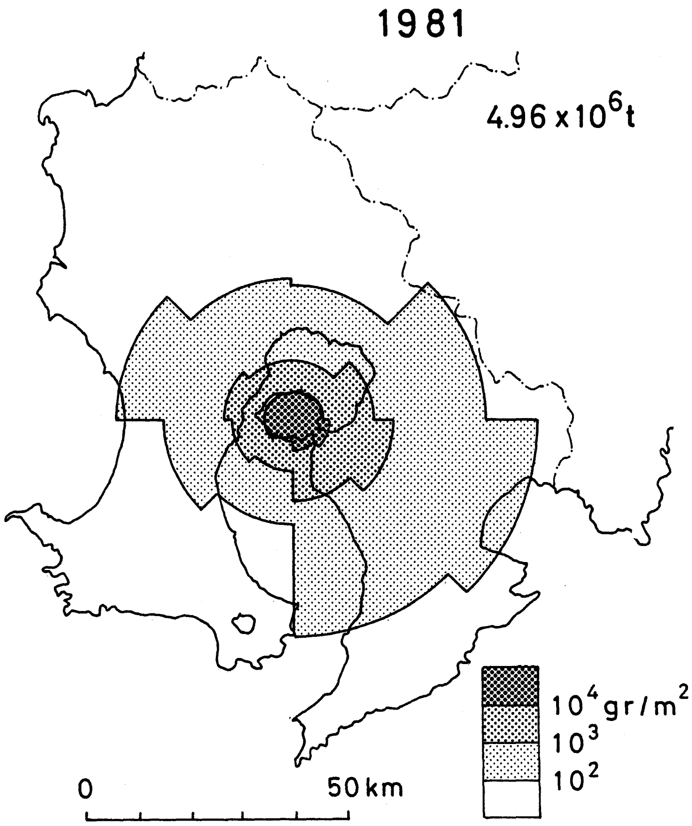

Figure 8. Distribution of volcanic ash-fall deposits in 1981 (4.96×10^6 tons).

Considering the observed minimum data of ash-falls in the distance and the weight of soil dust transported by the wind, b km distance where the amount of ash-falls presumes to be 10 gr/m^2 per month is supposed as the limit of ash-covered area. Monthly total weights of ash-fall deposits within all sectors (T) are calculated by,

$$T = \sum_{i=1}^{i=8} (T_{i1} + T_{i2}) \qquad \text{-------------------}(E)$$

where, i is the number of sectors.

Monthly amounts of volcanic ash-fall deposits since June 1978 have been calculated at Sakurajima Volcano Research Center, Disaster Prevention Research Institute, Kyoto University (Figure 4: after Ishihara and Nishi, 1998). It is estimated that 1.89×10^8 tons of ash-falls were deposited during the period from June 1978 to June 2000. Assuming specific gravity of volcanic ash as 1.3 gr/cm^3, total volume of these ash-fall deposits becomes about 0.14 km^3 during the last 22 years.

4. Discussions on dispersion of volcanic ash-fall deposits

4.1 Grain size distribution of volcanic ash-falls

Grain size analysis was carried out for volcanic ash-fall deposits at 11 observation stations in (7) sector on August 1978 (Figure 11). Samples were dried, weighed, and then sieved with water in a set of 7 kind sieves with a size range of 2 mm to 0.037 mm. Fractions in each size class were then dried and weighed. As the results of analysis, distribution curves of each grain size and histograms of grain size variation at 4 stations are shown in Figures 5 and 6, respectively.

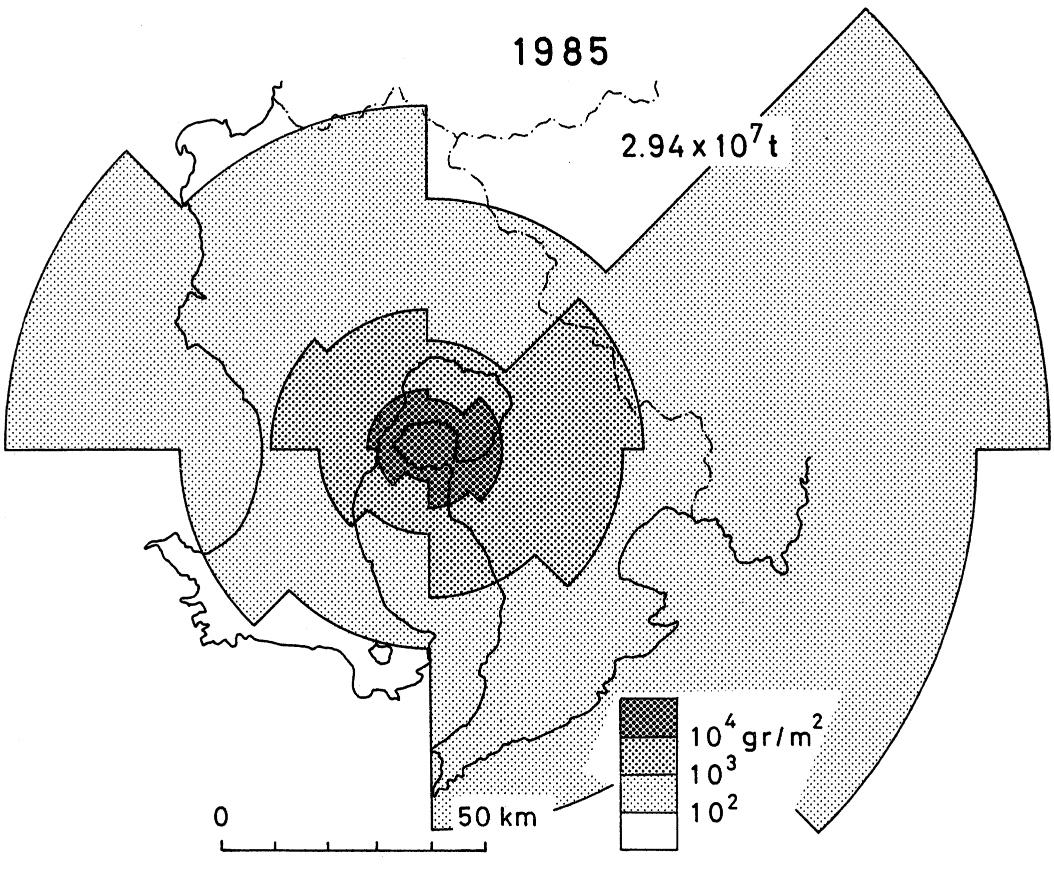

Figure 9. Distribution of volcanic ash-fall deposits in 1985 (2.94×10^7 tons).

In Figure 5, volcanic lapilli larger than 2 mm in grain diameter (d_ϕ) falls within 6 km from the active crater by the effect of gravity force. In this case, constant B in equation (B) was calculated as 5.6. On the contrary, volcanic ash smaller than 0.037 mm in grain diameter is transported to the distance more than 50 km (B = 2.1). The difference of distribution functions in equations (A) and (B) seems to be related to the grain size distribution of air-falls with distance.

4.2 Wind velocity in the lower troposphere and distribution of ash-fall deposits

The distribution function of ash-falls out of Sakurajima is expressed in equation (B). Eto and Ishihara (1979) analyzed the relation between a constant B in equation (B) and wind velocity (V m/sec) at 850 hPa in the lower troposphere as shown in Figure 7. They represented this relation as follows,

$$B = 20 \cdot V^{-2} + 2 \qquad \text{------------------} (F)$$

Then, equation (B) is rewritten in the following equation,

$$D(x) = D_0 \cdot x^{-\left(2+\frac{20}{V^2}\right)} \qquad \text{------------------} (G)$$

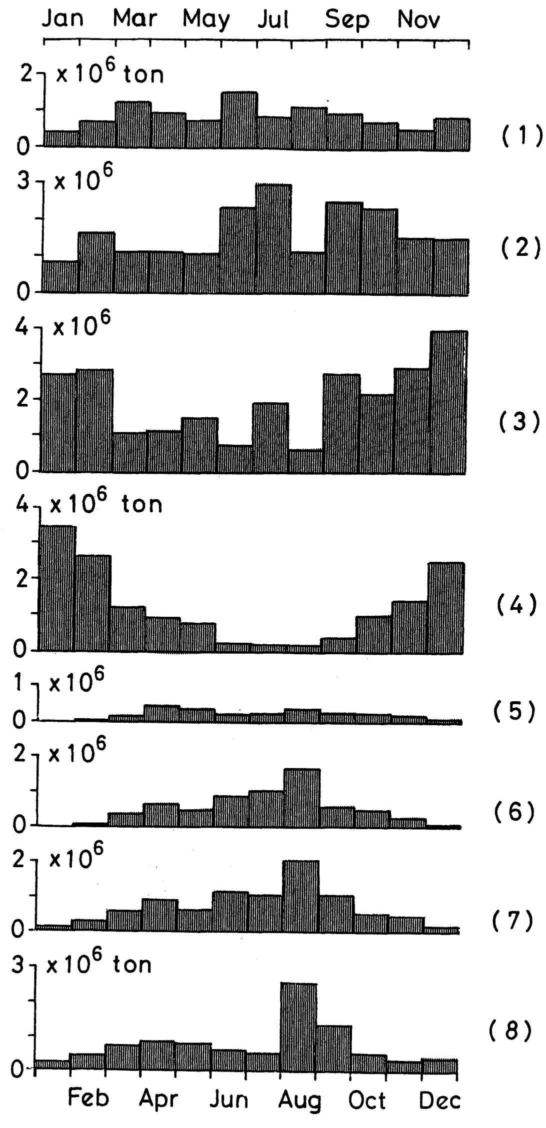

Figure 10. Seasonal variations of volcanic ash-fall deposits in each sector during 1979 - 1987.

This equation implies that strong wind transports volcanic ash to the distance and volcanic ash falls in the neighborhood of Sakurajima in calm wind. It is evident that the dispersion of ash-fall deposits depends on wind velocity in the lower troposphere.

4.3 Seasonal distribution of volcanic ash-falls in Kagoshima Prefecture

Figures 8 and 9 show yearly distributions of volcanic ash-fall deposits in 1981 and 1985, respectively (Eto, 1989). Total weights of volcanic ash-fall deposits in 1985 are estimated to be 2.94×10^7 tons. This is the maximum amount of yearly volcanic ash-fall deposits since 1978.

Estimated weights of monthly volcanic ash-falls in each sector accumulated during the period from 1979 to 1987 are shown in Figure 10. This Figure shows the seasonal variation of volcanic ash-fall deposits in 8 sectors around Sakurajima. In Figure 10, amounts of ash-falls at (3) and (4) sectors in Oosumi Peninsula increase from autumn to next spring and decrease in summer season. On the contrary, weights of ash-fall deposits at (6) and (7)

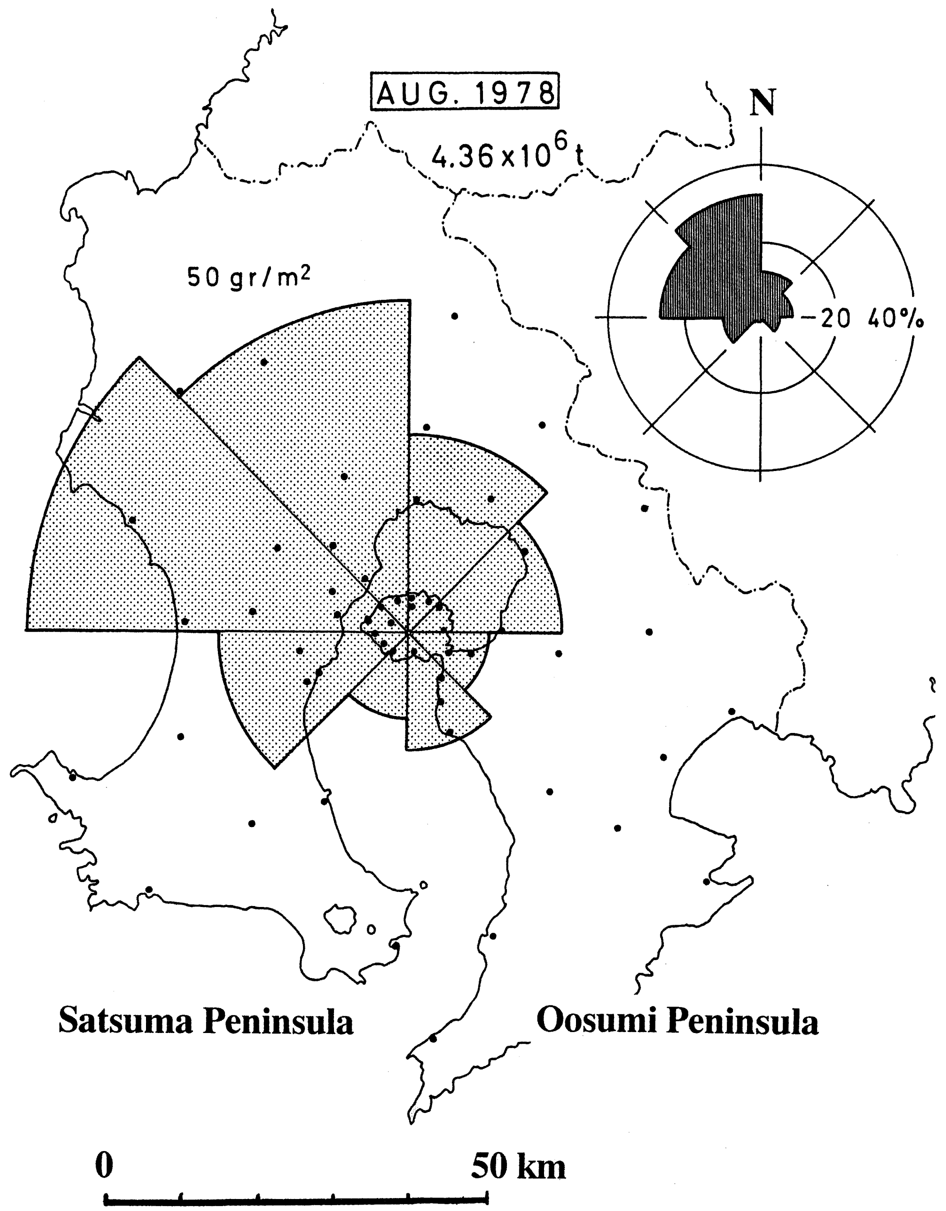

Figure 11. Area covered with ash-falls more than 50gr/m² and percentage distribution of leeward directions at 850 hPa (upper right-hand corner) on August 1978.

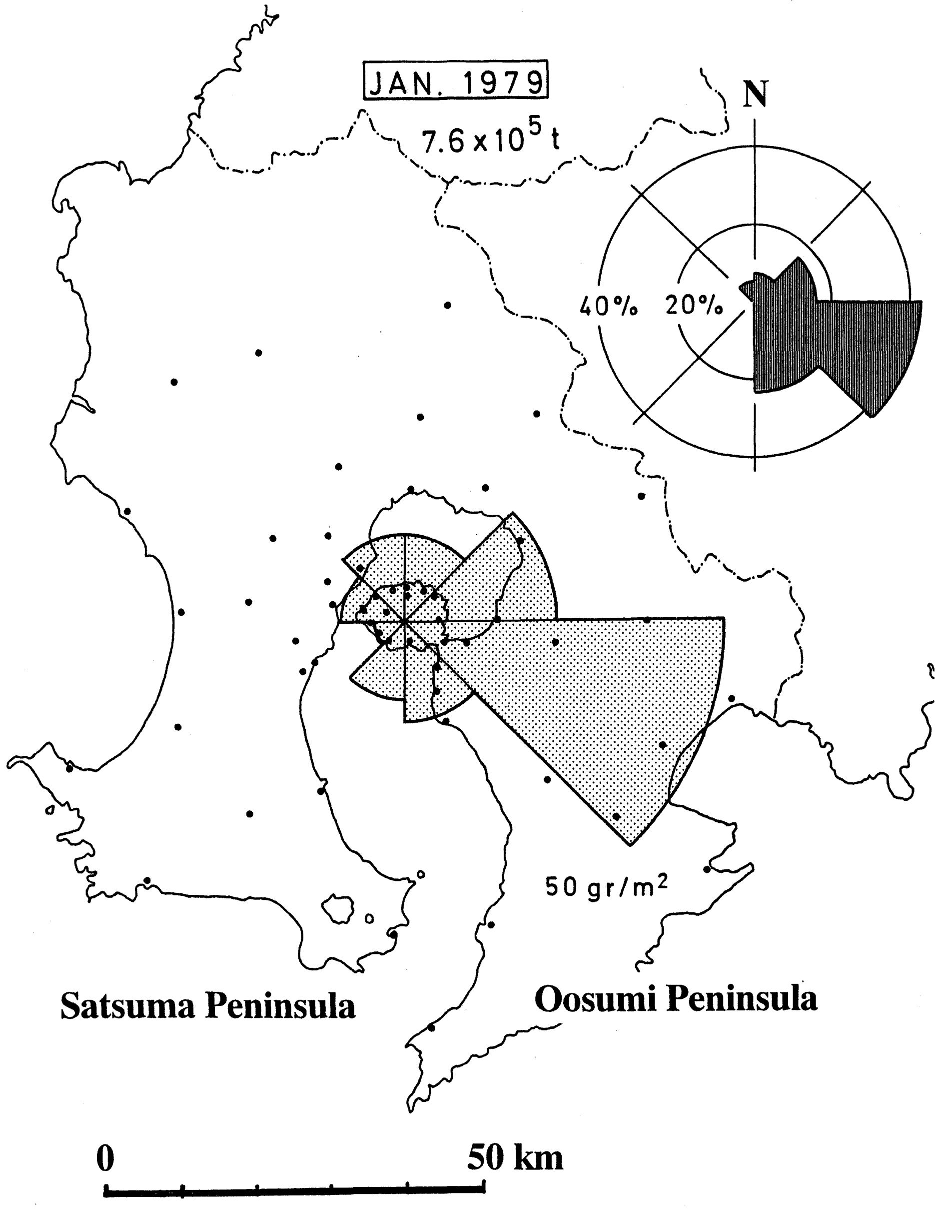

Figure 12. Area covered with ash-falls more than 50gr/m^2 and percentage distribution of leeward directions at 850 hPa (upper right-hand corner) on January 1979.

sectors in Satsuma Peninsula increase from early spring to summer and decrease from autumn to winter season. There were much ash-falls in (2), (3) and (4) sectors than other sectors. During the period from 1979 to 1987, about 62 % of total ash-falls were deposited in (2), (3) and (4) sectors. On the contrary, only 9 % of total ash-falls were deposited in (5) and (6) sectors during the same periods.

In Southern Kyushu, southern wind and eastern wind are frequent in summer season owing to high atmospheric pressure in the Northwestern Pacific Ocean. Therefore, in summer season, volcanic ash is likely to fall to western and northern directions from the active crater (Figure 11). In winter season, however, volcanic ash is transported to eastern and southern directions from the active crater by northwestern seasonal wind (Figure 12). In Figure 13, weight percentage of ash-falls in each sector during 1979 to 1987 is compared with the percentage of leeward direction at 850 hPa (about 1,500 m high) in the lower troposphere above Kagoshima city during 1971 to 1980 (Kagoshima Local Meteorological Observatory, 1983). The amount and dispersion of volcanic ash-fall deposits

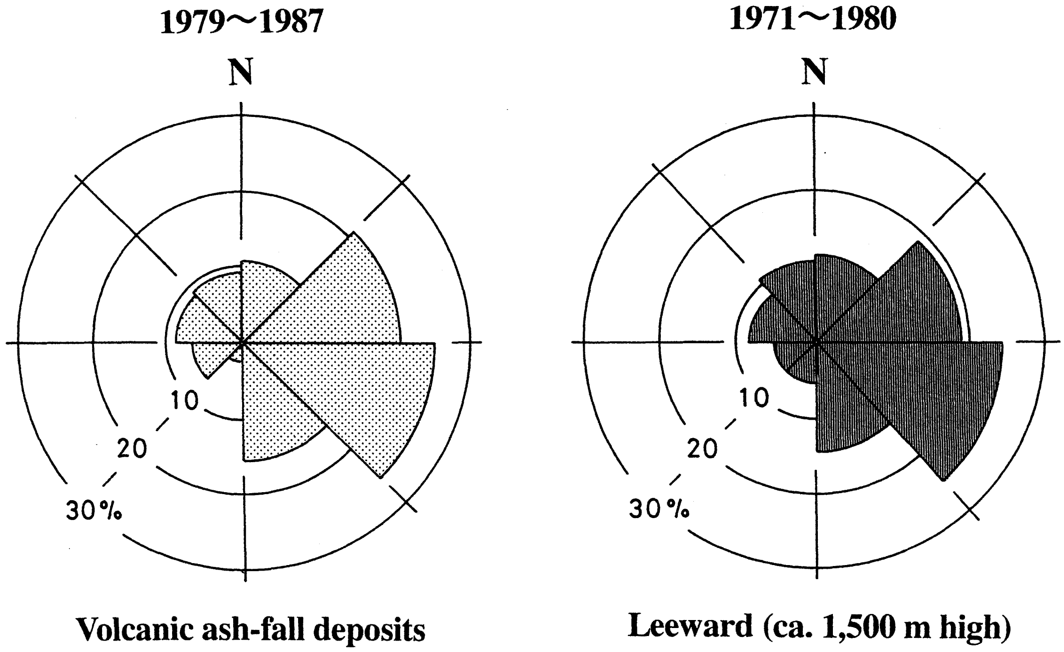

Figure 13. Percentage distribution of total ash-falls in 8 sectors during 1979 - 1987 (left), and leeward direction at 850 hPa (about 1,500 m high) during 1971 - 1980 (right).

in and out of Sakurajima have positive correlation coefficient with leeward direction in the lower troposphere.

5. Conclusions

A practical method is reviewed to estimate the amount and dispersion of volcanic ash-fall deposits from Sakurajima Volcano, and we get the following results.

(1) Distribution functions of ash-falls in and out of Sakurajima are expressed in an exponential function and in a power function, respectively.

(2) Monthly weight of ash-fall deposits can be calculated by the equation (E).

(3) The difference of two distribution functions seems to be related to the grain size of air-falls with distance.

(4) The amount and dispersal of volcanic ash-fall deposits depend mainly on wind velocity and leeward direction in the lower troposphere.

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References

Kamo, K., Eto, T., Ishihara, K. and Kawaharada, R. (1977): On the Accumulation of volcanic ash-falls in Sakurajima, Mudflow and debris-flow disasters in Kagoshima Prefecture associated with the heavy rain on June, 1976, Special Rep., Grant-in-Aids for Natural Disaster Science, Ministry of Education, Culture and Sports, Japan, pp. 77-86. (in Japanese).

Eto, T. and Ishihara, K. (1979): On the volcanic ash-falls in Kagoshima Prefecture - Jan. 1978 to Feb. 1979 -, Seismicity and Volcanic Activity in Kagoshima Prefecture, 11, pp. 77-94. (in Japanese).

Kagoshima Local Meteorological Observatory (1983): Weather in Kagoshima during 100 years, Centennial Anniversary Issue, p. 206, (in Japanese).

Eto, T. (1989): An estimation of the amount and the dispersal of volcanic ash-falls ejected by summit eruptions at Sakurajima Volcano, Proceedings, Kagoshima International Conference on Volcanoes 1988, pp. 448-451.

Ishihara, K. and Nishi, K. (1998): Sequence of volcanic activity - 1994～1996-, Rep. 9th Joint Observation of Sakurajima Volcano in 1996～1997, Sakurajima Volcanological Observatory, D.P.R.I., Kyoto University, pp.1-10, (in Japanese).