On Volcano Eruption Plumes Observed by Meteorological Satellites

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1 Introduction

We have been observed volcano eruption plumes with GMS and NOAA satellites these several years. With the IR sensing of satellites we obtained images of the distributions of the brightness temperature in the plumes and analysed them from aerological radio sounding (raob) data and other data.

2 Plume surface temperature and plume dispersion

In a plume image the brightness temperature is of the plume surface and is generally considered that an estimate of the plume altitude can be obtained through the relationship between environmental air temperature and height. In estimating the plume height we should , however, consider the effect of the atmospheric diffusion in our case. The plume gets thinner at longer downwind distances, and in the satellite IR sensing it appears to get warmer in temperature and hence lower in altitude.

This fact is presented in Fig. 1 regarding a large eruption which occurred on Mt. Pagan (18.13N,145.80E) in the Central Pacific on May 14 and 15, 1981. Fig.1 clearly shows the gradual increase of plume temperature. This should not be due to the true decrease of plume altitude but to the dispersion. Hence, we have to use the temperature sensed in the vicinity above the crater, as far as we use the IR sensing for the altitude determination.

3 Plume temperature and height estimate

Mt.Mihara on Oshima Is., which is located about 100km south of Tokyo, had a great eruption at 4pm, 21 November, 1986. The image of plume three hours later,which was taken by the NOAA satellite(see T. Sakata,et al.,(1986)),is illustrated in Fig.2.In this case the plume temperature at distances of 30-50km was found to be 10-15C higher than above the crater. This is similar to the case shown in Fig.1.

Raob data available from the Hachijō Is. and Tateno stations, which are both about 200km away from the volcano, are shown in Fig. 3. In this figure, an observation of Mt. Fuji is given as a referpence, which shows that the raob data obtained at the two stations are applicable to the plume of Mt. Mihara.

We compared a few IR plume temperatures near the crater with the raob temperature and obtained plume height estimates ranging from 4,500 to 6,000m with an average of about 5,200m.

In addition we tested a climatological model profile of atmospheric temperature. Since R. A. MacClatchey, et al.(1972), gave models for summer and winter at middle latitudes, we averaged their model profiles to arrive at an autumn profile, which is shown as Model T in Fig. 3. This model gives an average plume height in the order of 5,500m.

Thus it may be concluded that the temperature method is used for estimating the altitude within a difference of 1,500m or so through either the raob or climatological profile.

4 Gradual ascent of an eruption plume

As seen in Figures 2 and 3,the drift direction of the Mihara plume in the vicinity above the crater coincided with the raob wind direction at nearly the same altitudes in the order of 5,000m as the plume height which was estimated in the preceding section. At the downwind distances of about 150km, however, the plume changed its direction gradually toward the east north-east, which is in accord with the raob wind direction at higher altitudes of more than 8,000m in Fig.3.

This means that the eruption plume initially rose rather rapidly to altitudes in the order of 5,000m and then continued very gradually to ascend while drifting farther. We should not conclude that the plume loses its buoyancy completely during the initial rise. In Fig.3 there are no significant changes of the raob profiles from the altitude of about 7,000 to 10,500m, but a significant singularity of wind speed is seen at an altitude of about 10,500m. There is, hence, a possibility that some material of the plume may have ascended as high as 10,500m.

5 Use of parallax from the views of two satellites

If two satellites view a plume simultaneously,the two images give rise to a parallax of views, which would be used to determine the plume altitude. In the plume case, however,it is not easy to identify the same point of plume in the two images. In addition it can hardly be expected that two satellites observe a plume without any time differernce. The parallax method, therefore, would not be accurate to determine the altitude in our case.

Despite these restrictions we will give an example of parallax, since the parallax observations in general have rarely been made. In addition to the NOAA observation described in the preceding section, the Mt.Mihara's eruption was also observed by the GMS satellite an hour earlier. In the GMS observation the plume image touched on the southernmost area of the Bōsō Peninsula shown in Fig. 2 and along its eastern coast, which is very diferent from the NOAA image clearly due to the parallax. This parallax would indicate that the plume was present at an altitude in the order of 10,000m or more at the downwind distance of about 150km.

It would be worthwhile to note here that, according to unofficial information at the Japan Meteorological Agency,a weather radar at Mt. Fuji detected the plume at an altitude of 10,500m or more. On the other hand, however, a pilot of Japan Air Lines reported, with his naked eye, a plume altitude of about 8,000m.

6 Horizontal displacement speed of an eruption plume

With the use of the successive change in plume profiles as shown in Fig.1,horizontal displacement speeds of plume at various altitudes are obtained by observing the head of the downwind plume of the contours at temperatures.In Fig.4 concerning the Pagan plume a broken line shows the variation of displacement speed against the vertical axis indicating the temperature which corresponds to the height of the contour.

We should not conclude that the profile of the displacement speed thereby obtained is entirely the same or similar to that of the wind, though the plume material moves with the ambient air. A solid line in Fig.4 shows a wind profile observed at Guam Is. which is located about 500 km south of Pagan.

The difference between the two profiles in this figure is characterized by two facts as follows.

(1) Near the maximum altitude of plume,the displacement speed is much slower than the ambient wind. This should be caused by the plume dispersion as stated in section 2: the head of the plume at its highest becomes thin to the point of becoming invisible with the increase in time and distance, and, consequently, the horizontal movement of plume becomes slow in appearance.

(2) At lower altitudes the displacement speed is much faster than the ambient wind. In order to explain this fact we have to consider the time required for the plume to rise from the lower to higher altitudes. This plume rising takes a rather long time even in the intial stage of the rise, the speed of which was found to be of the order of less than 0.1m/s at the higher part of the plume. The horizontal displacement of plume consequently starts earlier at the lower altitudes,where some plume parcels lose their buoyancy. That is, the plume parcels at lower altitudes travel in advance and hence appear to move faster. Thus it is worth noting that the displacement speed is equal to the wind at a height a little lower than the plume top.

7 Thermal energy release through the rise in the plume

G. A. Briggs (1969) proposed a formula for the thermal energy release through the rise in plume of a high power stack at an industrial plant, as follows.

Q = 0.0264 • h**3 • u**3 • x**(-2) ,

where Q is the thermal energy release rate in mega watts, h the plume rise in meters above the stack top, u the mean wind speed in m/s and x the horizontal diatance of plume in meters from the stack, and the double asterisks indicate the power or exponent.

The above formula is derived under certain conditions which are not generally applicable to the eruption plume. In addition,the satellite determination of h and u is very approximate, as stated in the the preceding sections. As a trial for the distance x less than 100 or 150 km, however, we used the above formula to estimate the value of Q with the use of h obtained from the satellite image and u estimated from the raob data. Without the raob wind data, the fact on the plume displacement, described at the last part in Section 6, would be used in estimating the value of u. Concerning the eruption duration we used information given from the sequential satellite observations or ground reports, and obtained values of the thermal energy release in the eruption plume (Tpl) at several volcanos.

For comparison we obtained values of the thermal energy release through juvenile ejected material (Tej), which are calculated by a conventional method with the use of ground data, as described in Y. Sawada's report(1987). Those values of Tpl and Tej have been plotted in Fig. 5, in which the two kinds of energy release are surprisingly well correlated with each other. The relationship between the two quantities is expressed by the following equations(Erg in unit).

$$Tej = 10^{2.92} \cdot Tpl^{0.91}$$

$$Tpl = 10^{(-3.21)} \cdot Tej^{1.1}$$

It should be noted here that these equations are not applicable to some special volcanos such as those in Hawaii, Iceland and others in which a large lava flow is not usually accompanied with a great eruption plume in their geological nature. Since such equations as expressed in the above will be very important practically, we need more satellite data for the verification.

8 Application to air navigation

With the increase of airliners service the eruption plumes have been reported to be big hazards to air navigation.There are many well-known active volcanos in the world,but some of them are not always monitored by ground stations. In addition conventional ground observations are especially not considered to be accurate in estimating the plume altitude. Consequently the satellite observation is very useful in monitoring eruptions in order to avoid aircraft damage. It should be stated here that, without the satellite monitor,there is generally a big delay in the information on eruption in certain areas of the world.

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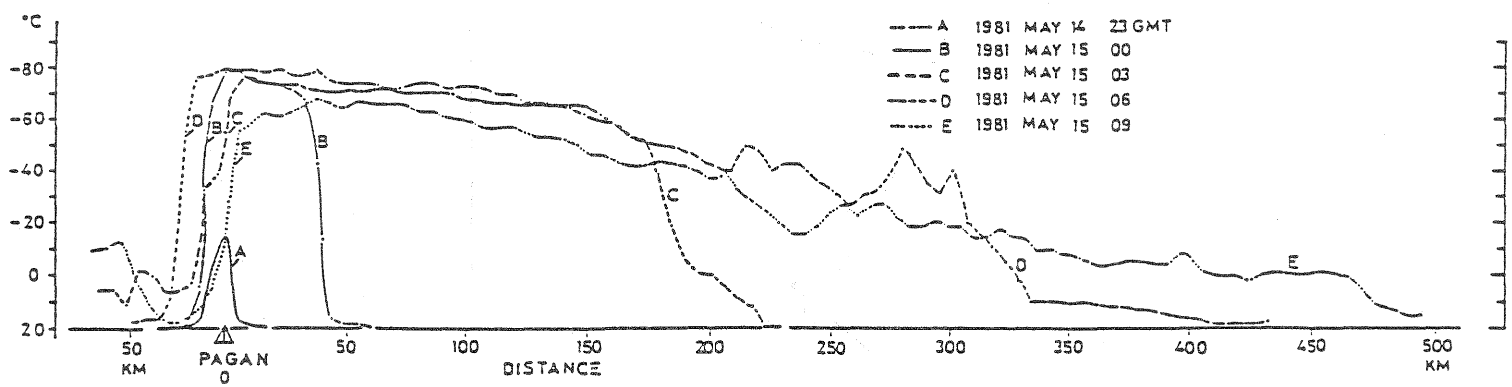

Fig. 1 Time variation of eruption plume profiles at Pagan volcano. The vertical axis indicates plume surface temperature sensed with GMS satellite and corresponds to altitude. The horizontal axis shows downwind distance of plume.

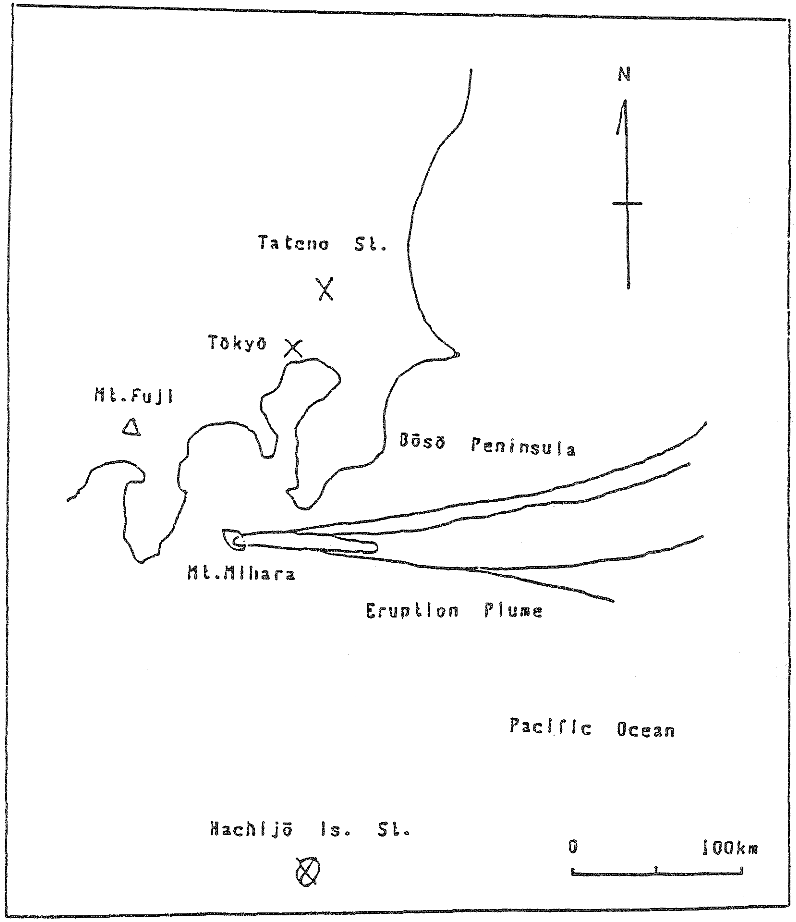

Fig. 2 Illustration of an eruption plume image at Mt. Mihara, 7 p.m.,21 November, 1986 and aerological observation stations.

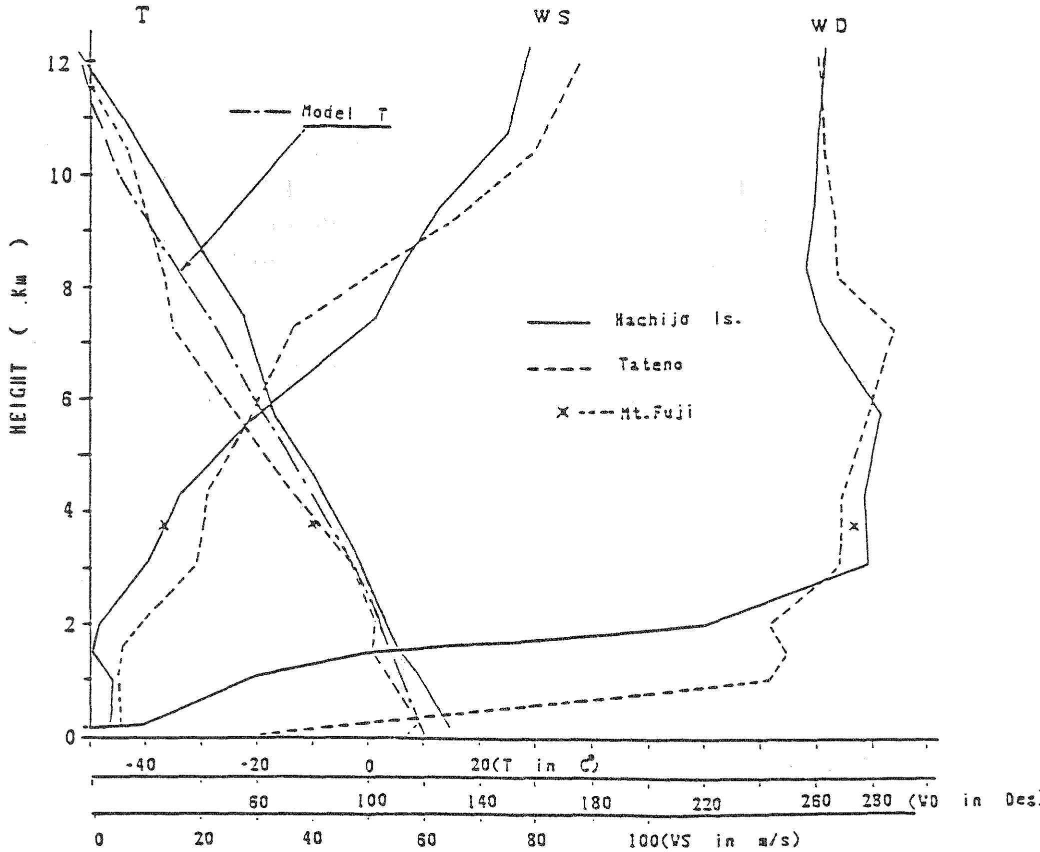

Fig. 3 Profiles of aerological data used in the analysis of Mt. Mihara plume.

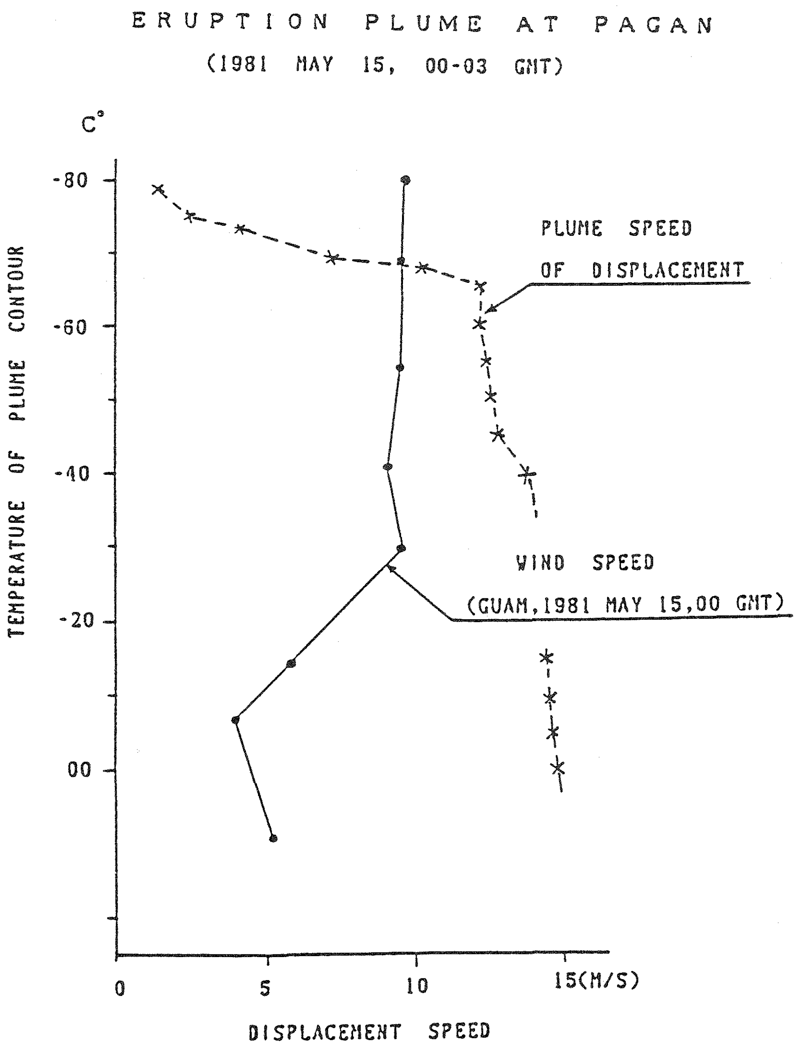

Fig. 4 Profiles of horizontal displacement speed of Pagan plume and wind speed at Guam. Temperature at the vertical axis corresponds to altitude.

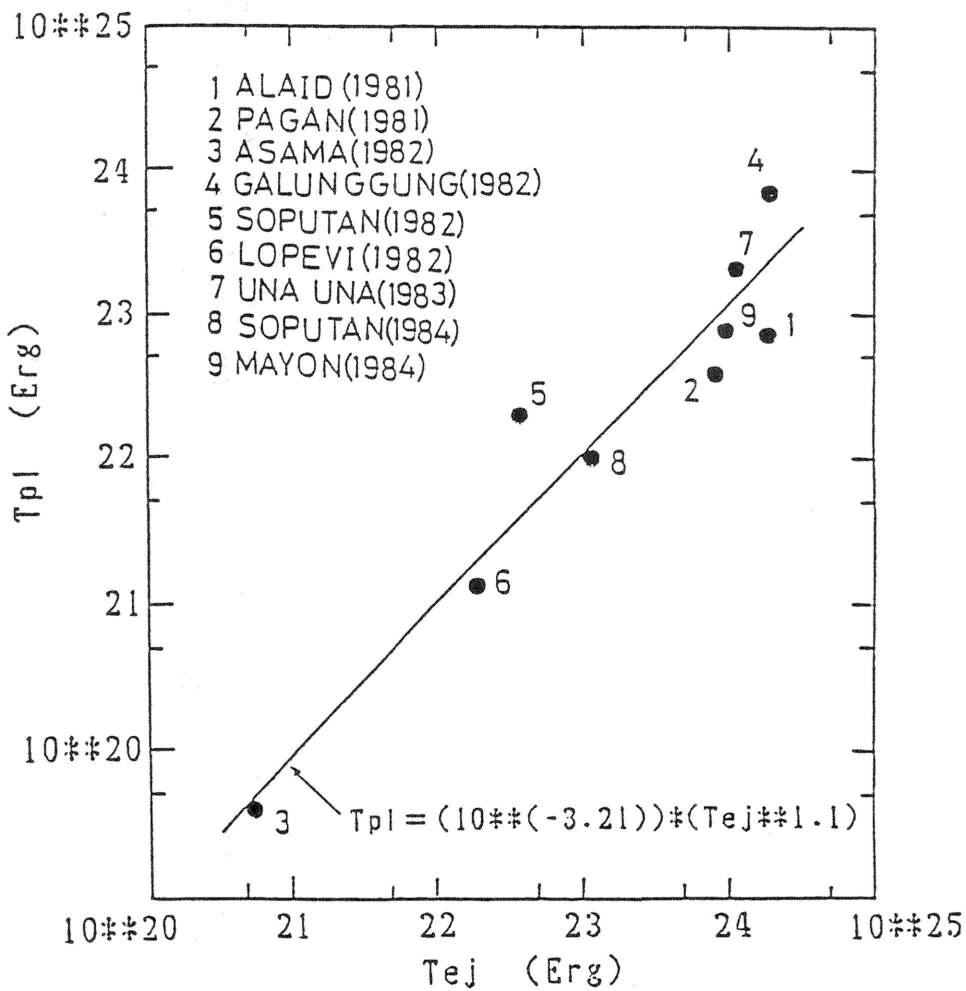

Fig. 5 Relation between two kinds of thermal energy release. One is energy through the eruption plume (Tpl) and the other through juvenile ejecta (Tej).