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# BROADBAND SEISMIC OBSERVATION AT THE SAKURAJIMA VOLCANO, JAPAN

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*Abstract.* We installed a portable broadband seismometer (Streckeisen STS-2) at the Sakurajima volcano, which has been very active in the recent years. The recorded seismograms show a wide variety (both in temporal and spectral contents) of seismic events, from explosions to tremors, and exhibit the importance of such broadband seismometry at volcanos. We present examples of seismograms to show the potential of broadband seismic observation in monitoring volcanic activities.

## Introduction

The Sakurajima volcano, located in the southernmost part of the Kyushu island, Japan, is an andesitic volcano, and has had activity in the Minamidake crater during the current eruptive period which began in 1955. On the average, there have been more than 150 explosions annually, and in 1991 there were 295 explosions reported by the Japan Meteorological Agency (JMA). Continuous geophysical monitoring has been performed by the Sakurajima Volcanological Observatory (SVO) of Kyoto University and the Kagoshima Meteorological Observatory of JMA. Because of the continuous activity of the Sakurajima volcano, the nature of seismicity is well studied [e.g., Ishihara and Iguchi, 1989; Ishihara, 1990] and a practical warning system for summit explosions is becoming available.

Since most seismic monitoring is done using short-period seismometers, seismic activity below 1Hz (and above where geodetical measurements can cover) is not well understood at volcanos. In order to fill such a gap in seismic observation and to assess the usefulness of broadband seismometry at volcanos, we installed a portable broadband seismometer, Streckeisen STS-2, at the E-observation point of JMA, located 4.4 km northeast of the Minamidake crater (Figure 1).

## Data

The observation was conducted from December 9, 1991 to the end of February, 1992. We used a Teledyne Geotech PDAS-100 with a 16-bit digitizer to record the velocity output from the STS-2. The pre-amplifier gain and sampling interval were set to 10 and 50 Hz, respectively, and the trigger recording was adopted with a maximum length of 2 minutes. There were over 2000 events (including ~100 explosions) with minimum peak-to-peak amplitude of $1.4\times10^{-6}$m/s recorded during the observation period.

## Broadband waveforms of an explosion

Figure 2 shows an explosion event that occurred at 0h55m of December 10 (Japan Standard Time, JST, hereafter all times are given in JST). According to SVO, hypocenters of explosion-quakes are located in a depth range between 1 and 3 km beneath the active Minamidake crater [Ishihara, 1990]. Figure 2a is the vertical displacement record observed at the same point by JMA, and Figure 2b is the corresponding raw velocity waveform from the STS-2. Both high and low frequency motions are well recorded by the STS-2. Figure 2c shows three-component displacement records obtained by integrating the raw data. The horizontal components are rotated taking the Minamidake crater as the origin. It is interesting to note that the transverse component shows a large amplitude wave train, which is also observed in other explosion records. An explosion thus cannot be modeled simply by either a vertical single force or an isotropic moment tensor. Waveform

Sakurajima volcano

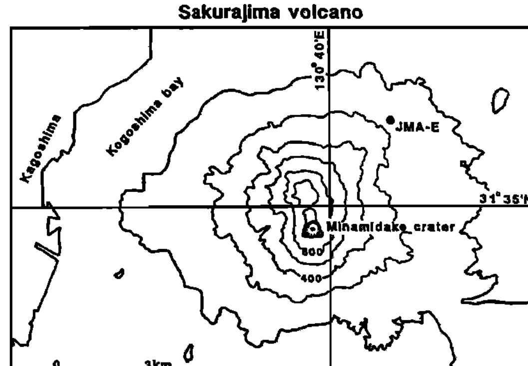


Fig. 1. Sakurajima volcano and the location of the E-observation point of JMA .



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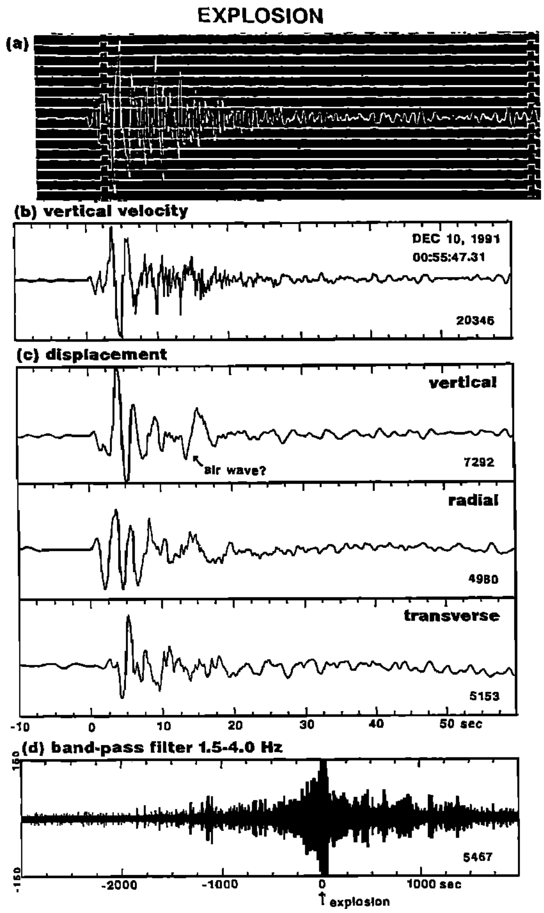


Fig. 2. Waveforms of an explosion: (a) Vertical displacement record of JMA on smoked paper. (b) Vertical raw velocity output of STS-2. (c) Three-component displacement records obtained by integrating raw velocity data. (d) Vertical velocity record band-pass filtered between 1.5 and 4.0 Hz. The origin times are set to the same time in (b), (c), and (d), indicated at the upper-right corner of figure (b). Note that the time scale is different in (d) from the others. Number at the lower-right corner of each box indicates the peak-to-peak amplitude given in a unit of (b), (d) $10^{-8}$m/s and (c) $10^{-8}$m.

modeling of the long-period portion of the explosion records will help to quantify the explosion activity, as well as to understand its physical mechanism. Figure 2d shows the record band-pass filtered between 1.5 and 4.0 Hz, where the dominant frequencies of volcanic earthquakes exist. Seismic activity gradually increases from ~2000 seconds before the explosion, and the steep increase ~200 seconds prior appears to lead to the explosion. The extreme broadband content of the explosion process is well manifested in the single STS-2 record.

## Earthquake swarm associated with explosions

We present a series of seismograms observed in an earthquake swarm associated with explosions. The swarm started around 20h of December 14th, and continued to 02h of 15th. During the period, two explosions were observed, and after the cessation of the swarm a large explosion took place at 6h07m. Figure 3 shows vertical component seismograms of the major events recorded during the swarm. We note that these events (except b5 and

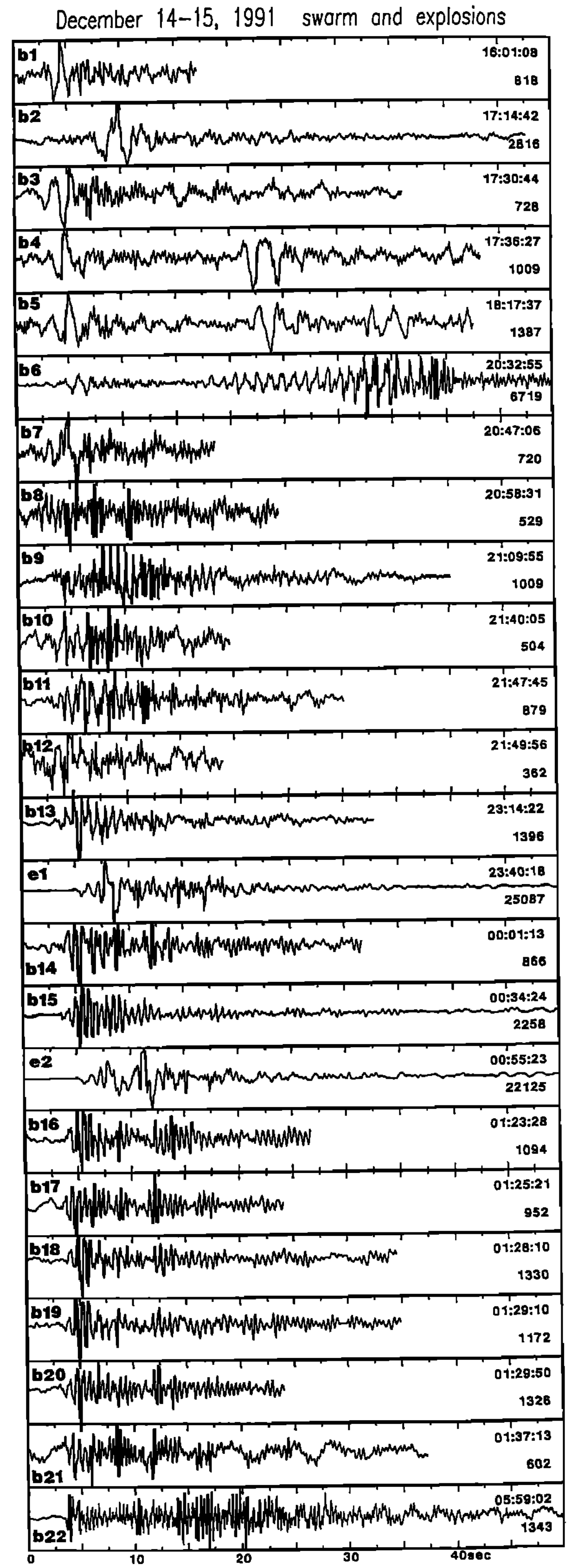


Fig. 3. Vertical velocity seismograms observed in an earthquake swarm. Origin times and peak-to-peak amplitudes (in $10^{-8}$m/s) are given at the upper-right and lower-right corners, respectively.

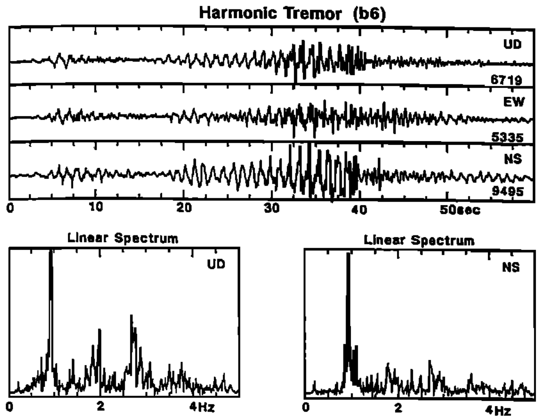


Fig. 4. Three-component velocity records of the harmonic tremor. In the bottom, linear spectra of the vertical and north-south components are given in arbitrary units.

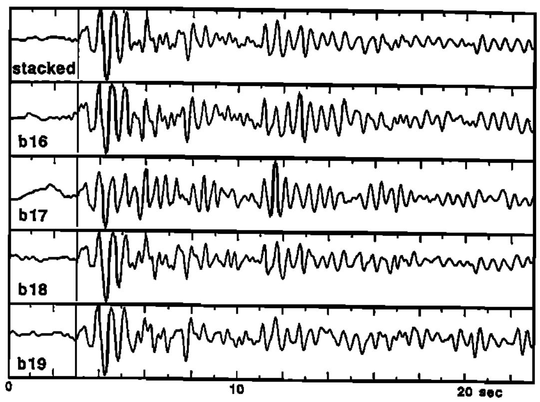


Fig. 5. Similar waveforms of events b16-19 of Figure 3, and the stacked seismogram.

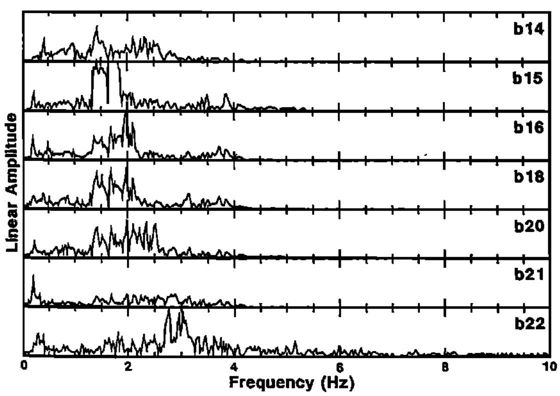


Fig. 6. Change of the predominant frequency in the final stage of the swarm. Linear spectra of some events in Figure 3 are shown. Although the vertical unit is arbitrary, the relative amplitude among all spectra is retained.

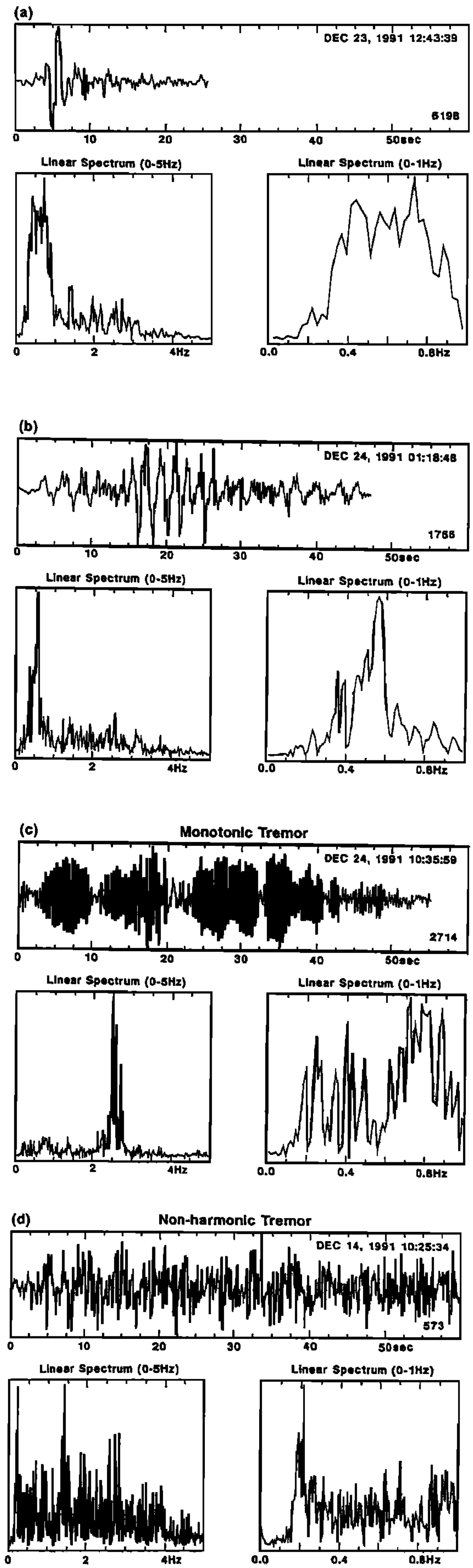


Fig. 7. Vertical velocity records and corresponding linear spectra are shown for four more curious events. The origin time and peak-to-peak amplitude (in $10^{-8}$m/s) of each seismogram are given at the upper-right and lower-right corners. Vertical scales of spectra are arbitrary.

e1-2) are all classified as B-type events despite the wide variety of waveforms, and that B-type events appear to occur in the magma conduit in a similar depth range where explosion-quakes occur [Ishihara and Iguchi, 1989].

The events b1-b5 are isolated ones which took place prior to the initiation of the swarm. The distinct waveforms with a period of 2.5 seconds would not have been so peculiar if they were recorded by a conventional short period seismometer. Two pairs of events in b4 and b5 are especially interesting, because the polarities within each pair appear to be reversed. Because of the low-frequency nature of these events, some waveform modeling should be possible to reveal the force system responsible for these events. Such studies may contribute to understanding the physical processes occurring in the preparation stage of summit eruptions.

Event b6 is the typical harmonic tremor as reported by Kamo et al. [1977], and its Fourier spectra have equally spaced distinct peaks (Figure 4). The swarm activity appears to start from this event. The events b7-13 show very complex waveforms, and then the first explosion e1 took place. After this explosion, event waveforms became rather monotonic with the dominant frequency of 1-2 Hz (e.g, b15). We note that the waveforms of these events (b15-20) are very similar to each other even for the later phases. The top trace in Figure 5 is a stacked seismogram of four such traces. Study of these later phases may bring us new information regarding the structure beneath the Sakurajima edifice. Figure 6 shows the change of the predominant frequency in the final stage of the swarm. The predominant frequency increases from 1.3-2.0 Hz for b15 to 2.5-3.2 Hz for b22 just prior to the large explosion. This change may correspond to the gradual change of the physical condition (e.g., gas pressure) in the magma conduit in a preparation stage of the summit eruption.

## Other curious events

Although many different types of waveforms were recorded, here we present four other examples of such curious events. Figure 7a shows a non-explosion (according to JMA) event which has a similar frequency content with explosion events. Considering the low-frequency nature, it may be caused by a movement of some material in the magma conduit. The event in Figure 7b has a predominant frequency of 0.4-0.6 Hz, and may correspond to a continuous activity of events b1-5.

Two different types of tremors other than event b6 are presented in Figure 7c and 7d. The monotonic tremor in Figure 7c has a spectral peak at 2.5 Hz, and is very similar to the one reported by Nishi [1984] as a B-type event occurring at the last stage of a swarm preceding an explosion, although no explosion took place for four days after this event. The non-harmonic tremor in Figure 7d does not have any strong spectral peaks, and seems to be a rather stochastic continuation of B-type events.

## Broadband seismometry at volcanos

Although a single station observation with an STS-2 seismometer is not enough to permit definite conclusions about physical processes occurring at the Sakurajima volcano, our records seem to prove the importance of such observation at volcanos. Many curious events have seismic energy below 1 Hz, which is likely to be missed by the conventional observation with short period seismometers. The explosion process itself has a very broadband frequency content as shown in Figure 2.

We plan to start a multi-station broadband observation at the Sakurajima volcano in the near future. Some of the peculiar events presented in this study will be quantitatively analyzed to understand the basic physical processes taking place at the volcano. We believe that broadband seismometry at volcanos is very promising to give us a better understanding of volcanic activities. We hope that similar observation will be conducted at other volcanos, so that comparable studies of volcanic activities based on broadband seismic data will become available in the near future.

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