京 都 大 学 防 災 研 究 所 年 報　第48号C　平成17年4月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 48 C, 2005

Automated Classification of Volcanic Earthquakes and Tremors -Outline of the system and preliminary experiment-

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Synopsis

A seismic data processing system for automated classification of volcanic earthquakes and tremors is developed, and preliminary experiment was done using seismic data at Kuchinoerabujima volcano. The outline of the system and the results and evaluation of the preliminary experiment are described.

Keywords: volcanic earthquakes and tremors, automated classification

1. Introduction

It is well known that most of volcanic eruptions will be accompanied with some of precursors, those are, increases in seismic and geothermal activity, and so on. Significant precursors, for example, seismic swarm however appear immediately before eruption, a few days or a few hours before, even for large eruptions. To mitigate volcanic disaster, it is important to evaluate volcanic activity *in real-time*, and inform of the result of evaluation instantly for local authorities, residents and scientists.

Some of volcanologists have developed automated data processing system of volcano-monitoring data. At Sakurajima volcano, Kamo and Ishihara (1989) developed an automated warning system for summit explosions, using ground-tilt and strain data. The system composed of a personal computer (PC) classifies *in real-time* stages of volcano into three: 'inflation', 'deflation' and 'minimal change' in ground deformation, and monitors continuously stages. Once inflation stage starts, the PC watches the amount of inflation, and issues three kinds of information: 'caution', 'critical' and 'warning'. The prediction rate of the system for strong explosions during 1987 -1991 was 87 % (Kamo et al., 1994). The data and system has been used at the Kagoshima Local Meteorological Observatory and Japan Airlines. The success however based on a high-quality data collected by instruments installed in a deep underground tunnel, which is not common at other volcanoes. Development of automated data processing system using seismic data is practically more important, as seismic observation is the most common and fundamental technique for volcano monitoring.

Volcanic earthquakes and tremors generally increase in number, and change their waveforms, locations and amplitude with progress of activity. For examples, it is commonly observed at many andesitic volcanoes in the world, that volcano-tectonic earthquakes called as A-type originated at deeper portion, and then low-frequency volcanic earthquakes called as B-type increase before eruptions. Such a classification of volcanic earthquakes has been used as a one of evaluation methods of volcanic activity at Asamayama, Sakurajima, Merapi in Indonesia, Arenal in Costa Rica and other volcanoes. Until now, the classification of volcanic earthquakes has been done by observers.

The first attempt for an automated data processing of classification was done by Nishi (1988) at Sakurajima. We tried to expand and improve his system so as to be commonly used at other volcanoes. As the first test field of the system, we selected Kuchinoerabujima volcano in

Satsunan islands, as illustrated in Fig. 1. Among them, Satsuma-Iwojima and Suwanosejima have erupted for several years, and volcanic activity at Kuchinoerabujima has gradually approached toward its critical stage (Iguchi et al, 2002).

Fig. 1 Active volcanoes in southern Kyushu

In this paper, the outline of system and the result of an experiment on automated classification of volcanic earthquakes at Kuchinoerabujima volcano are introduced as the preliminary report.

2. Outline of the system

Seismic and infrasonic data collected at volcanoes are transmitted in digital form (sampling rate: 200Hz) to Sakurajima Volcano Research Center. Some of these data are transferred to a Linux work station for Automated Classification of Volcanic Earthquakes and Tremors (ACVET). In case of Kuchinoerabujima volcano, a station 0.5 km apart from the summit is used as a main station for classification, and the other at the foot of the volcano is used as a reference station which works to discriminate tectonic earthquakes out of the volcano. The main functions of the system are as follows:

[1] Detection of seismic events and their classification using some of parameters which characterize wave form of events,

[2] Transmission of the result by e-mail, and

[3] Evaluation of volcanic activity using the dataset.

At present, functions [1] and [2] are in operation.

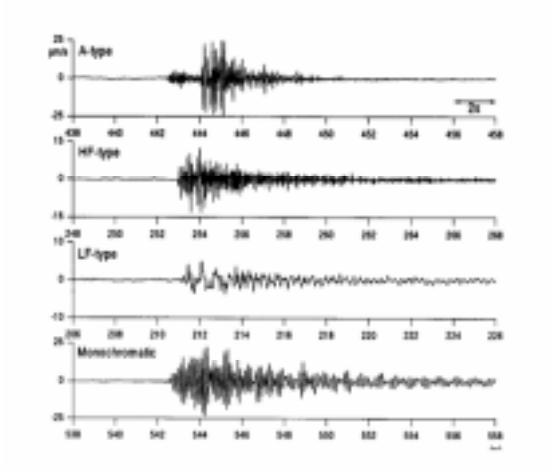

Fig. 2 Some of typical volcanic earthquakes observed at Kuchinoerabujima volcano

2.1 General classification of volcano-seismic events

Volcanologists have no unique and clear definition on classification of volcanic earthquakes, since the types of seismic events are different at each volcano, and change according with activity even at one volcano. However, basic concepts for classification are similar.

[1] Volcanic earthquakes and tremors

Seismic events which have significant phases and shorter duration are classified into volcanic earthquakes. In contrast, seismic events which have unclear peak in amplitude and longer duration are generally called as volcanic tremors.

[2] HF, LF, monochromatic and harmonic

When events have both clear P-phase and S-phase similar to tectonic earthquakes, it is called as volcano-tectonic earthquakes or A-type earthquakes. From the predominant frequency, seismic events, the predominant frequency of which is high, in general higher than around 5 Hz may be called as HF. In contrast, events with lower predominant frequency are called as LF. Occasionally, peculiar volcanic earthquakes or tremors have been observed. The one has seismic signals mainly composed of a single frequency and called as ‘monotonic’. The other is ‘harmonic ‘, composed of several frequencies, a fundamental and integer-multiples.

At Kuchinoerabujima volcano, several types of events have been observed, as illustrated in Fig.2. The data processing system, ACVET, must include

calculation of parameters to discriminate these events.

2.2 Data processing and classification

When the velocity amplitude of seismic signal at the main station exceed over a certain level, 2.5 μm/s during 0.1s, the system recognizes the onset of a seismic events, and calculates some parameters. The system judges that the event terminated when the amplitude decreases below a certain level for 0.1 second. Parameters calculated are as follows (numerical values indicate those applied at Kuchinoerabujima volcano):

[1] Onset times, maximum amplitude and duration at both the main and reference stations are examined. The amplitude ratio of the main station to the reference is used to discriminate shallow volcano-seismic events from A-type earthquakes and tectonic earthquakes. Events with duration longer than 120 seconds are classified into 'tremors'. Some of LF and HF earthquakes are accompanied with tremor. Then, they are named as LF-tremors and HF-tremors.

[2] Several peak frequencies and amplitudes obtained by FFT for the initial part of data from at the main stations. If the predominant frequency is higher than 5 Hz, it is classified into 'HF-type', and lower frequency events are into 'LF-type'. In addition, the ratio of the amplitude of first peak frequency to that of the second one is calculated. If the ratio is more than five, it is categorized into 'monochromatic'. The relationship among peak frequencies is examined. If higher peak frequencies are integer-multiples, the event is categorized into 'harmonic'.

[3] These parameters calculated step by step, and temporary classification is done at 10, 30 and 120 seconds after the onset. When events terminate, final classification is done, combining parameters mentioned above with other parameters, air-shock data and decay rate of amplitude. In case of Kuchinoerabujima volcano, seismic events have been classified into 'tectonic', 'A-type', 'HF-type', 'LF-type', 'monochromatic', 'HF-tremor', 'LF-tremor', 'monochromatic tremor' and 'explosion'. Tiny events, the maximum amplitude of which are smaller than 5 μm/s, are accounted as 'trigger' events but deleted from classification.

2.3 Information of results

The result of classification has been transmitted as daily reports by e-mail to staffs of the Sakurajima Volcano Research Center. Additionally, e-mail messages are instantly transmitted as 'real-time report' when large volcanic earthquakes or explosions are detected, and when volcanic earthquakes swarm (more than 15 events within 3 hours). In the next stage, we have a plan to include reports on some kinds of alerts, based on the evaluation of present stage, compared with past activity.

Kuchinoerabu daily report [2004-11-02]
A-type : 0
HF tremor : 0
HF-type : 3
LF tremor : 0
LF-type : 0
Monocromatic : 1
Monocromatic tremor : 0
Tectonic : 0
trigger : 3

Fig. 3 An example of daily report

3. Results of experiment and evaluation

Since May 2004, experimental operation of auto mated classification of volcanic earthquakes (ACVET) at Kuchinoerabujima volcano has been run. Here, results of the experiments during the period from May 1 to December 31, 2004 are summarized and compared with the classification done by researchers. The daily numbers of volcanic earthquakes counted by researchers are illustrated in Fig. 4.

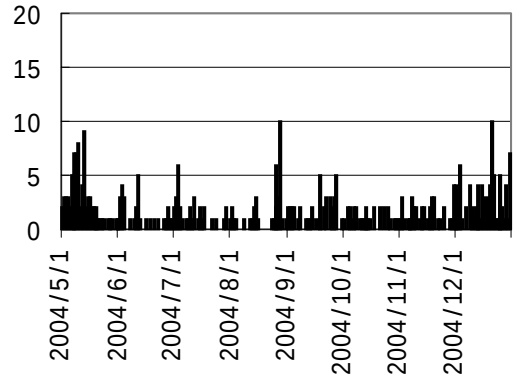

Fig. 4 Daily numbers of volcanic earthquakes at Kuchinoerabujima volcano counted by researcher

ACVET counted 353 HF-type earthquakes, 175 LF-type earthquakes, 3 monochromatic earthquakes, 6

HF-tremors and 57 LF-tremors during the six months, totally 593 events. ACVET identified no tectonic earthquakes.

In contrast, observers identified 446 seismic events on paper records: 345 HF-type earthquakes, 36 LF-type earthquakes, 3 monochromatic earthquakes and 62 tectonic earthquakes. Daily numbers of volcano-seismic events except for tectonic earthquakes is 384. Large discrepancy in daily number of events appeared on June 20, August 29 to 30, September 5 to 7, September 29 and October 20, 2004. On these days, strong typhoons approached the volcano, and ACVET counted ground vibrations excited by storms mostly as LF-type earthquakes and LF tremors, totally 124 events. If these 124 events are eliminated from the dataset of ACVET, the discrepancy in number becomes small, and general trend in seismic activity matched with that (Fig. 4) counted by researchers, as illustrated in Fig. 5.

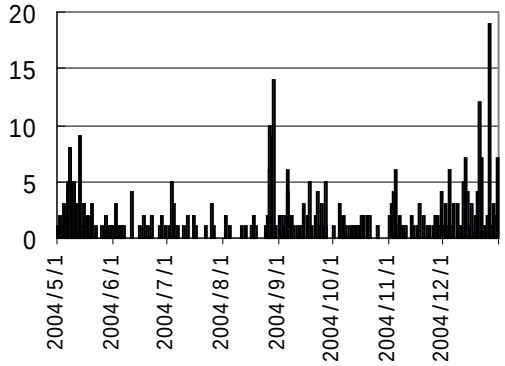

Fig. 5 Daily number of volcano-seismic events at Kuchinoerabujima volcano counted by the system of automated classification of volcanic earthquakes and tremors. 124 misjudged events on 8 days when typhoons passed near the islands are deleted.

There is a still discrepancy in number between volcano-seismic events counted by ACVET and that identified by researchers, as shown in Table 1. Numbers of HF-type earthquakes and monochromatic earthquakes almost coincided with each other. However, ACVET could not discriminate tectonic earthquakes from LF-type earthquakes. Principally, tectonic earthquakes are defined by the time difference of onset time and the amplitude ratio between the main station and the reference one. Events with earlier onset and larger ratio at the reference station at the foot of the volcano should be categorized into tectonic earthquakes. However, higher noise level at the reference stations probably masked earlier onset of tectonic earthquakes. Seismic stations at other islands, for examples, Yakushima and Nakanoshima might be better as reference stations to discriminate both disturbances due to storms and tectonic earthquakes from LF-type earthquakes and tremors.

Table 1 Comparison in numbers of each type of earthquake and tremor classified by the system ACVET with those identified by researchers

Type of seismic events	ACVET	Researcher
HF-type earthquake	352	345
LF-type earthquake	113	36
Monochromatic	3	3
HF-tremor	1	0
Tectonic	0	62

4. Conclusion

Preliminary experiment of the data processing system on an automated classification of volcanic earthquakes and tremors was done using seismic data at Kuchinoerabujima volcano. Volcanic earthquakes and tremors originating at the volcano were well detected and classified. However, tectonic earthquakes out of the volcano and disturbances due to typhoons were also counted as volcanic events. It is the most important in the improvement of the reliability of the system to distinguish these non-volcanic events and noises from volcano-seismic events.

Acknowledgements

This research was supported by the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) 21st Century COE Program for DPRI, Kyoto University (No.14219301, Program Leader: Prof. Y. Kawata).

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火山性地震の自動分類・評価システムの開発（序報）

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要旨

火山性地震・微動を即時自動判別するシステムのプロトタイプを作成し，口永良部島火山を対象に試行を行った。分類には，基準観測点の震動継続時間，最大振幅，スペクトルなど波形を特長付けるパラメータに加えて参照観測点との震動開始時刻の差や振幅比を用いている。8ヶ月間の試行では，台風時の擾乱と島外で発生する構造性地震の識別が出来なかった。その原因は，主として，参照観測点の選定が不適切であったことによると考えられる。台風時の擾乱と構造性地震を除けば，ほぼ適切な分類がなされた。

キーワード:　火山性地震、火山性微動、即時自動分類