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Letter:

NIED's V-net, the Fundamental Volcano Observation Network in Japan

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In response to the recommendation of the Council for Science and Technology (Subdivision on Geodesy and Geophysics), the National Research Institute for Earth Science and Disaster Resilience (NIED) constructed a network of stations to observe 11 volcanoes: Tokachidake, Usuzan, Tarumaesan, Hokkaido-Komagatake, Iwatesan, Kusatsu-Shiranesan, Asamayama, Asosan, Kirishimayama, Unzendake, and Kuchinoerabujima. At each new station, a borehole seismograph and tiltmeter, a broadband seismograph, and a GNSS (GPS) were installed. Now, NIED has established 55 stations at 16 volcanoes, adding five volcanoes, namely, Izu- Oshima, Miyakejima, Ogasawara Iwoto, Mt. Fuji and Nasu-dake, and has constructed a new volcano observation network linking the 11 original volcanoes. NIED calls the combination of the new and earlier network the fundamental volcano observation network (V-net).

Under a fully open policy, data from the borehole seismographs and tiltmeters, broadband seismographs, rain gauges, barometers,and quartz thermometers in the pressure vessels of the borehole seismographs and tiltmeters are distributed to institutes such as the Japan Meteorological Agency and universities in real time over NIED's conventional seismic observation data distribution system. GNSS (GPS) data are regularly distributed to relevant research institutes, such as the Geospatial Information Authority of Japan, using file transfer protocol (FTP). In addition, since everyone can use these data for the promotion of volcano research and volcanic disaster prevention, it is now possible to view seismic waves and download data from NIED's website.

Keywords: V-net, volcano, observation system, NIED

1. Introduction

The National Research Institute for Earth Science and Disaster Resilience (NIED) started its observational studies of volcanoes at Ogasawara Iwoto in 1968 [1]. After that, following its participation in the volcanic eruption prediction plan that began in 1974 and following the launch of "the research project to predict volcanic eruptions" in 1989, NIED started constructing a volcano observation network, making thermal observations using infrared rays, and doing observational research using remote sensing technologies [2].

A volcano observation network based mainly on seismic activity and crustal deformation was sequentially installed in the five volcanoes of Izu Oshima, Miyakejima, Ogasawara Iwoto, Mt. Fuji, and Nasudake during the 1970s and in 2007 [2, 3]. This observation network revealed the movements of the tiltmeters that were associated with the Izu Oshima eruption of 1986 [4], Miyakejima eruption of 2000 [5], and the existence of deep low frequency earthquakes beneath Mt. Fuji [6].

In 2008, the volcano observation research system of the future and the policy behind its development were discussed in the volcano subcommittee of the Council for Science and Technology, Subdivision of Geodesy and Geophysics. The results of the discussions were summarized as a proposal, "The promotion of an observational research program for earthquake and volcanic eruption prediction" [7], and a report "On the immediate progress of volcano observation research in universities, etc." [8]. In response to these recommendations, NIED took charge of developing a volcanic observation network and a system of distributing and sharing volcanic data in order to promote the monitoring of volcanoes having a high possibility of eruption.

Below, we present an outline of the fundamental volcano observation network (V-net) and the distribution and sharing of V-net data. In addition, we report the main research result of V-net data for recent volcanic activity.

2. The Fundamental Volcano Observation Network (V-net)

The volcano subcommittee of the Council for Science and Technology (Subdivision on Geodesy and Geophysics) decided to select 11 volcanoes that should be intensively monitored. The eleven volcanoes selected were Tokachidake, Usuzan, Hokkaido-Komagatake, Tarumaesan, Iwatesan, Kusatsu-Shiranesan, Asamayama, Asosan, Kirishimayama, Unzendake, and Kuchinoerabu-

Table 1. The types of observation equipment at 16 volcanoes.

		Station number	Borehole-type seismograph and tiltmeter	Broadband seismograph	GNSS (GPS)	Rain gauge(RG) and Atmospheric pressure(AP)
pre-existing volcano observation network	Izu- Oshima	4	4	2	0	RG 4, AP 1
	Miyakejima	4	4	2	4	RG 3, AP 2
	Ogasawara Iwoto	3	Only surface type seismometer(3)	1	3	RG 0, AP 0
	Fujisan	6	6	4	6	RG 4, AP 4
	Nasu-dake	6	3 and surface type seismometer(3)	3	3	RG 3, AP 3
new volcano observation network	Tokachidake	3	3	3	3	RG 3, AP 3
	Usuzan	3	3	3	3	RG 3, AP 3
	Tarumaesan	3	3	3	3	RG 3, AP 3
	Hokkaido-Komagatake	3	3	3	3	RG 3, AP 3
	Iwatesan	3	3	3	3	RG 3, AP 3
	Kusatsu-Shiranesan	3	3	3	3	RG 3, AP 3
	Asamayama	3	3	3	3	RG 3, AP 3
	Asosan	4	4	4	4	RG 3, AP 3
	Kirishimayama	2	2	2	2	RG 3, AP 3
	Unzendake	3	3	3	3	RG 3, AP 3
	Kuchinoerabujima	2	2	2	2	RG 3, AP 3

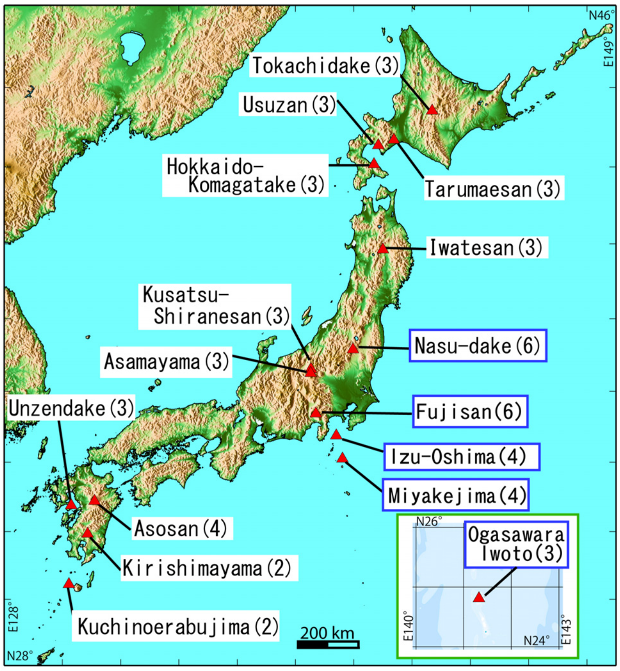

Fig. 1. Volcano map in V-net station. The numbers in parentheses indicate the number of V-net observation points. The five names outlined in blue indicate the volcano observation network stations constructed before 2007.

jima (**Fig. 1**).

The volcano subcommittee decided to set up several stations at eleven volcanoes. These stations are equipped with a borehole seismograph and tiltmeter, a broadband seismograph, and GNSS (GPS), because these measuring instruments are expected to detect the seismic activity and crustal deformation associated with magma accumulation and movement.

Before constructing the above network, NIED established 23 stations at five volcanoes (Izu-Oshima, Miyakejima, Ogasawara Iwoto, Mt. Fuji, and Nasu-dake) before 2007. The types of observation equipment are shown in **Table 1**.

As of June 2017, NIED continues observations at a total of 16 volcanoes over a newly constructed observation network of 11 volcanoes and a pre-existing network of five volcanoes. NIED decided to call the network consisting of these new and pre-existing networks together the fundamental volcano observation network (V-net).

The volcano data obtained on the V-net is to be shared in order to promote volcanology and strengthen the volcano monitoring system for volcanic disaster mitigation under a fully open policy [9–11].

To these ends, we have decided to build a data sharing system in real time among related organizations, including universities and municipalities, utilizing the data distribution network of NIED and the Japan Meteorological Agency (JMA).

2.1. V-net Station

In this chapter, we present an overview of the 11 volcano monitoring stations built after 2007. For pre-existing five volcanoes, refer to documents [1] to [6].

Two observation points are shown in **Fig. 2**. The facility covers an area of about 200 m^2, and each station is equipped with a borehole seismograph and tiltmeter, a broadband seismograph, GNSS (GPS), a barometer, and a rain gauge. Control devices for each sensor and telemetry devices are stored in a hut.

A highly sensitive borehole seismograph and tiltmeter lie at the bottom of the borehole at a depth of around 200 m in order to reduce the influence of surface noise,

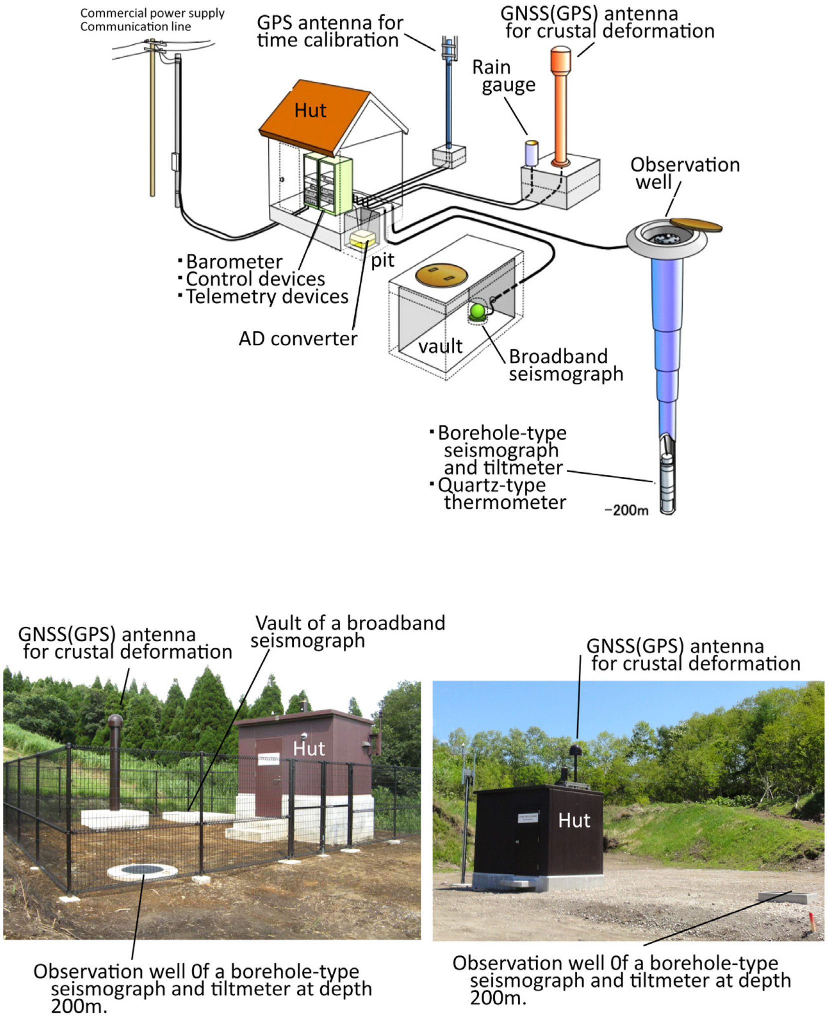

Fig. 2. Conceptual diagram and photograph of V-net station.The left photograph shows the Asosan V-net station in the Kyushu area. The right photograph is the Hokkaido-Komagatake V-net station in the Hokkaido area.

such as vibrations from cars, wind, and rain. These instruments are contained in a pressure vessel 2.4 m in length and 114 mm in diameter. The seismometer is composed of three short-period velocity seismometers (natural period 1 Hz, 170 V/m/s, $h = 0.7$), and the tiltmeter, consisting of two components, is of a force-balance type (frequency characteristic DC to 5 Hz, output sensitivity 5 mV/μrad) [9]. In order to check the stability of the instruments, there is a quartz thermometer in a pressure vessel, and the temperature is measured to an accuracy of 0.1°. These instruments have almost the same specifications as the equipment used in the high sensitivity seismic observation network (Hi-net) of NIED [9–11]. One of the reasons is that it is convenient to unify the characteristics of seismographs when analyzing mechanism solutions together with the short-period velocity seismometer data of V-net and Hi-net.

Rock samples are collected at full depth when an observation well is drilled to hold a borehole seismograph and tiltmeter. Volcanic geological analyses of the samples have been conducted in collaborative research with universities, etc. [12, 13].

Broadband seismographs are sensitive to fluctuations in temperature, so they are usually installed in lateral holes [10]. However, it is difficult to excavate lateral holes in volcanic areas, so we constructed a 2.5 m L $\times$ 1.5 m W $\times$ 3 m D concrete vault and a semi-basement under a hut in the Hokkaido area, installing a broadband seismograph on the base of the vault. Broadband seismographs are velocity-type seismographs and have flat velocity amplitude response characteristics in the range of 0.1 second to 120 seconds.

In GNSS (GPS) observation, it is important to secure visibility, avoiding the effects of snow cover and/or trees. Therefore, the GNSS (GPS) antennas were installed at a height of 3 m or 4 m on 1.5 m W $\times$ 1.5 m L $\times$ 1.7 m D concrete blocks in Honshu and Kyushu. In Hokkaido, the antenna was set up on a stand on the roof of the hut, 4 m from the surface of the ground. This was done in order to avoid radio wave delay due to snow cover and to avoid any inclination of the antenna's base due to freezing. The satellite and the corresponding channel to be received are GPS (L1 / L2 / L5) and GLONASS (L1 / L2); the sampling frequency is 30 seconds.

It is well known that the observation of crustal deformations is susceptible to weather noise, such as rainfall and atmospheric pressure changes. We therefore installed a rain gauge and a barometer on V-net in order to appropriately correct the effects of rain and atmospheric pressure fluctuations superimposed on observation data.

The rain gauge is a "tipping bucket" type of gauge with an accuracy of ±0.5 mm if the rainfall is 20 mm/hour or less. The barometer is installed in the hut. The measurement range is 700 to 1100 hPa with an accuracy of ±0.3 hPa at 20°C. The frequency response is 2 Hz from DC.

2.2. Acquisition and Transmission of V-net Data

The data from V-net is digitized with a high precision AD system similar to that of Hi-net [10, 11]. Borehole seismograph data are set to 24-bit resolution with a sampling rate 100 Hz and effective dynamic range 130 dB or more. On the other hand, tiltmeter and barometer data are set to 12-bit resolution with a sampling rate of 1 Hz. The effective dynamic range is 65 dB or more. Rain gauge data of no-voltage contact output (0.5 mm/pulse) is difficult to digitize directly. Therefore, by using a converter that outputs the non-voltage contact output signal (cumulative precipitation amount; 0–100 mm) to the analog signal (0–5 V), we digitize the rain gauge data in the same way as we did the above data. These data are compressed to the WIN-format [14].

In order to reduce the influence of temperature change, this high-precision AD converter is placed in a pit or a semi-basement 1.6 m under a hut. Moreover, in order to minimize the effects of data missing due to power outages, we have data storage in the CF card as a backup function.

Each station of V-net is connected to the data centers in NIED via an Internet protocol virtual private network (IP-VPN) network, and TCP/IP can be used for data transmission and network management.

GNSS (GPS) data are temporarily stored in the receiver and transferred to NIED through two IP-VPN lines by using ftp or telephone lines (analog line, FOMA line, a satellite phone) via a modem. The reason for there being two available lines is so that a stable communication method may be selected if there is poor communication capacity in the mountainous area, and so that that communication method can be used for monitoring crustal deformation due to volcanic activity by collecting a second sampling of observation data in real time.

Using this IP-VPN network, we can easily control each V-net station and monitor the status of all equipment connected to the network.

2.3. Archiving and Distributing V-net Data

At NIED, the acquiring, monitoring, processing, and archiving of Hi-net, F-net, K-NET, KiK-net, and V-net data are controlled by a database management system [10]. The operator of the volcano observation control section manages the quality of V-net data, checking for noise or missing data, for example, and checks seismic activity and crustal deformation using the volcano observation system [3] and its successor system. At the five volcanoes, namely, Izu-Oshima, Miyakejima, Ogasawara Iwoto, Mt. Fuji, and Nasu-dake, the volcano observation system makes an automatic hypocenter determination, and the precise hypocenter is redetermined by the operator reading the seismic wave. For tiltmeter data, automatic detection of volcanic abnormal crustal deformation and an automatic provisional source model estimation technique are applied in real time [15].

The automatic and redetermined hypocenter and continuous waveform images are displayed on the web page of the VIsualization system for Volcanic Activity (VIVA 2) [16] on our website. To use the published data, users must first register to receive their own ID and password. After acknowledging the purpose and method on the "V-net" page [17], users select the time period and station and then download the data as needed. On the VIVA2 web page, users can get an understanding of the volcanic activity from figures such as seismicity (ex. seismic waves) and crustal deformation (ex. tiltmeter and GNSS (GPS)).

In order to distribute and share observation data efficiently and promptly, we utilize the data distribution and sharing system for the earthquake research promotion that NIED has developed.

V-net data are transmitted directly to the JMA through the IP – VPN communication network, and these data are used for monitoring in volcanic disaster prevention work. Distribution to universities and institutions is done using NIED's data exchange system (TDX). The server of the Earthquake Research Institute of the University of Tokyo (ERI) and those of other institutions, such as the Japan Agency for Marine-Earth Science and Technology, the National Institute of Advanced Industrial Science and Technology, local governments, etc., can directly exchange data by being connected to TDX. Other universities can receive and transmit data for education and research through ERI's server. All of these data are processed in real time, just as they are on Hi-net and F-net.

GNSS (GPS) data is automatically distributed to the servers of the institutions such as the Geospatial Information Authority of Japan, JMA, and universities via the file transfer protocol (FTP).

3. Recent Results Using V-net Data

Valuable observation data from activities at several volcanoes were obtained during and after the building of the V-net stations. For example, in 2011 there were magma eruptions, the first in 300 years, in Kirishimayama Shinmoedake. The change in distance between the two V-net stations that started observations in April 2010 revealed an expansion of the volcano corresponding to its magma accumulation and the subsequent contraction due to the eruptions [18].

In Kuchinoerabujima, there were eruptions in 2014 and 2015. Only GNSS (GPS) and broadband seismograph data were from the two V-net stations during the 2014 eruption because the borehole seismographs and tiltmeters were just being installed. The seismic activity be-

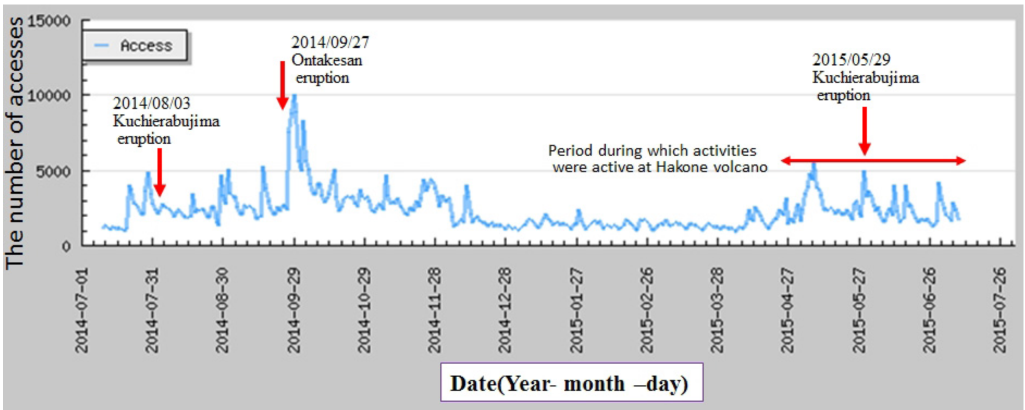

Fig. 3. The number of accesses of VIVA2 on our website.

fore and after the 2014 eruption and the state of the pressure change due to the eruption were observed [19].

At Asosan, the level of activity has been high since 2014 and there have been repeated eruptions since 2016. We have been able to monitor the increase in volcanic tremors, as evidenced by the 10-minute averages of the amplitude of the vertical motion, based on the short-period seismograph and recorded by V-net [20].

Moreover, a large-scale earthquake occurred in the vicinity of the volcano, so there was concern about how the earthquake fault movement might affect the magma reservoir.

The Shizuoka Eastern Earthquake ($M_{JMA} = 6.4$), considered to be one of the earthquakes induced by the earthquake off the Pacific coast of Northeastern Japan in 2011, occurred on the southern foot of Mt. Fuji on March 15, 2011. A fault model was estimated from crustal deformation data, including GNSS (GPS) data of V-net, and the stress field was calculated to evaluate the influence on the magma reservoir. For this, the finite element method was used based on this fault parameter [21].

Magnitude 6.5 (4/14) and 7.3 (4/16) earthquakes occurred in Kumamoto in 2016. As this series of earthquake faults reached the Asosan caldera, the associated influence on the magma reservoir of Asosan was a concern. Therefore, by using both SAR interference analysis and V-net's GNSS (GPS) data, the seismic fault model was estimated, and the effect on the magma chamber was evaluated [22].

Finally, the number of accesses of VIVA2 on our website is shown in **Fig. 3**. The display period is from July 1, 2014 to August 27, 2015. There are about 2000 accesses when volcanic activity is in the normal state, but it can be seen that the number increases rapidly when a volcanic eruption occurs.

4. Summary

In response to the recommendation of the Council for Science and Technology (Subdivision on Geodesy and Geophysics), NIED constructed V-net to monitor the activity of 11 volcanoes. Under a fully open policy, all V-net data are distributed to research institutes such as the JMA and universities in real time. In addition, everyone can display and download data from NIED's website so that this data may be used for volcano research and volcanic disaster prevention.

Acknowledgements

In constructing V-net, we gained tremendous cooperation from universities, the Japan Meteorological Agency, livestock industry and forestry land users, and the disaster prevention officials of local governments. We received technical advice on data distribution and sharing from researchers and staff members of the Network Center for Earthquake, Tsunami, and Volcano in NIED. In addition, the researchers of the Volcanic Disaster Resilience Research Division provided assistance, such as work site observations during the construction of V-net. As V-net could not have been completed without the cooperation of these people and related organizations, the authors wish to express their deep appreciation. The reviewers of this manuscript are also appreciated, as their comments helped to raise its quality.

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