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Paper:

Development of a Data Sharing System for Japan Volcanological Data Network

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In Japan, a number of universities, research institutes, and administrative organizations continue to conduct observations on volcanoes according to their respective roles. They also promote the distribution and sharing of observation data and have collaborated with each other. Japan Volcanological Data Network (JVDN) is a framework that strengthens this cooperation, promotes volcano research, and contributes to volcanic disaster mitigation. In this paper, we report the overview, progress, tasks, and future prospects of the system being developed for JVDN that was initiated in 2016. The observational data collected from each organization is stored in a database and shared using visualization tools to promote collaborative research, (e.g., multi-disciplinary research for eruption prediction) and cooperation between organizations. Furthermore, this database will contribute to volcanic disaster mitigation measures through collaboration between the volcano research community and administrative organizations responsible for volcanic crisis management. Adaptation to the standards of the international WOVOdat database will also promote cooperation with research institutes worldwide.

Keywords: database, volcano observation, seismometer, GNSS, visualization tools

1. Introduction

Volcanology encompasses the science related to understanding volcanic phenomena, as well as geophysics, geology, and geochemistry. Volcanological data comprises of data collected on volcanic phenomena that occur as magma reaches the Earth's surface or near it (including volcanic eruptions) [1], and has been the subject of intellectual curiosity for many years due to the occurrence of volcanic disasters. Pyroclastic flows, ejection of ballistic rocks, lava flows, ashfalls, and mudflows associated with volcanic eruptions are considered particularly dangerous phenomena.

Many independent organizations in Japan have acquired volcanological data for multiple purposes including understanding volcanic phenomena and monitoring volcanoes to mitigate volcanic disasters. For example, in the fields of geophysical and geochemical research, observations of earthquakes, crustal deformation, the electromagnetic field, the gravitational field, and volcanic gas and chemical composition in hot spring water are conducted using a variety of equipment. In the field of geological and petrological research, samples obtained by drilling outcrops and ejecta generated by an eruption are also analyzed.

These volcanological data are the fundamental basis for decision-making during volcanic disaster mitigation. In Japan, volcanic hazard maps and eruption scenarios are created based on geological data and previously recorded volcanic activity at the volcano disaster prevention councils, established in each region surrounding an active volcano. Based on this, regional disaster prevention plans corresponding to the volcanic alert level are developed in each municipality. Japan Meteorological Agency (JMA) monitors active volcanoes 24 hours a day and issues volcanic alerts according to the data collected on volcanic activity. The disaster response as well as the disaster prevention plan is executed based on the volcanological data.

In order to use the volcanological data effectively for decision-making in volcanic disaster mitigation, volcanological knowledge, both observational and theoretical derived from volcanology research is essential. Therefore, scientific advice based on volcanological data is being provided at the volcano disaster prevention councils and at Coordinating Committee for Prediction of Volcanic Eruptions (CCPVE) of JMA. However, information on volcanic disasters is highly uncertain because the volcanic phenomena that trigger these disasters are complex, diverse and are not well understood. In order to provide information with an adequate scientific basis, an advance in the understanding of volcanic phenomena is crucial. Additionally, in Japan, several organizations independently conduct volcano monitoring and volcanological research, giving rise to challenges in terms of collaborative research across organizations and different fields of research, which is necessary for dealing with problems such as disaster mitigation.

In November 2016, Ministry of Education, Culture, Sports, Science and Technology (MEXT) initiated a project titled "Integrated Program for Next Generation Volcano Research and Human Resource Development (INeVRH)." Under this framework, a project titled Project A: "Centralization of Various Observation Data" with the aim to establish a sharing system for volcanological data between organizations and researchers was initiated. By sharing volcanological data, we aim to promote collaborative research among multiple organizations and different fields of research, and to contribute to the development of volcanology and volcanic disaster mitigation. This project will continue for 10 years, until 2027. In this paper, we report the overview, progress up to the third year, tasks, and future prospects of this project.

2. Background

In Japan, each organization conducts observations on volcanoes according to their respective roles and collaborates with each other to contribute to volcanic disaster mitigation. As of 2018, JMA is monitoring 50 of the 111 active volcanoes in Japan. The universities observe 43 active volcanoes for academic research, and National Research Institute for Earth Science and Disaster Resilience (NIED) conducts observations and surveys of 16 active volcanoes for research and development concerning disaster mitigation. Geospatial Information Authority of Japan (GSI) operates a nationwide Global Navigation Satellite System (GNSS) network called GEONET that creates topographic maps and conducts volcano observations. The National Institute of Advanced Industrial Science and Technology (AIST) publish geological maps and investigate ejecta generated by eruptions. Japan Coast Guard (JCG) investigates submarine volcanoes and island volcanoes. Ministry of Land, Infrastructure, Transport and Tourism (MLIT) conducts observations on the amount of volcanic ash generated pertaining to the preservation of rivers and roads. Local governments and research institutes under their jurisdiction also conduct volcanic observations and surveys.

Individual researchers and organizations have been sharing volcanological data so far, whenever the need arises. Here is an outline of the background concerning the nationwide data sharing effort. Each organization shares the results of its volcanic observations during CCPVE, which was founded in 1974 by JMA. CCPVE was established to exchange the outcomes of research conducted and information collected on volcanoes by related organizations, as well as to provide a comprehensive judgment of volcanic phenomena. Regular meetings are held three times a year, and supplementary meetings are held to discuss volcanic activity when abnormalities such as eruptions occur. When necessary, a unified opinion is announced. The shared data in this committee is in the form of electronic files of the Portable Document Format (PDF) and reports containing mainly images of the observational data. Technical discussions on data distribution and sharing were held in 2009 during a working group of CCPVE. The discussions took place due to the need for volcanic eruption prediction research and refinement in the ability to monitor volcanoes, in order to communicate more advanced and accurate volcano information. In December 2007, JMA introduced a volcanic alert level that is announced in five stages, along with the area required to be on alert and the disaster response countermeasures to be taken by the disaster prevention organizations and residents, according to the status of the volcanic activity. Additionally, in March 2008, the Cabinet Office established a policy to create a disaster prevention plan according to the volcanic alert level [2]. The working group discussed real-time sharing of seismic data, but the discussion about other data such as the GNSS data was postponed. Seismic data collected from seismic observation stations has been distributed in real time via a system operated by NIED, and this data is available online to the public at that time. Based on the results of the discussion in the working group, NIED has helped in the distribution of seismic data from the volcano observation stations using this system since 2009. Furthermore, since January 2012, NIED has begun to make seismic data of the volcano observation stations of NIED and JMA open to the public via the Internet.

Seismic data is shared in real time between JMA, universities, NIED and other organizations based on their agreement, and other data such as tiltmeter and infrasound data are also shared in the same format. The databases of NIED and JMA are open to the public via the Internet. The GNSS data is made available by GSI and NIED. Some observational data is available on the website of each organization. However, a large amount data is not openly available and users need to directly contact the researchers who own the data in order to access it. It is difficult for each user to know which organization is carrying out observations and what kind of data is being collected. Therefore, it makes it even more difficult to access such data.

In the seismological community of Japan, the Headquarters for Earthquake Research Promotion was established after the Southern Hyogo Prefecture Earthquake (Kobe earthquake) in 1995, and nationwide data sharing was carried out based on their policies. Data from seismometers installed at the seismic observation stations are acquired in WIN or WIN32 format and are telemetered to each organization through the Internet or a private line service. WIN32 format is an improvement over the WIN format [3]. Seismic data in WIN32 format are then shared in real time among organizations through the Virtual Private Network (VPN) [4, 5]. A part of this data is used for a unified hypocenter catalog and Earthquake Early Warning (EEW) system maintained by JMA. The exchange of data between the organizations is conducted on a server called Tokyo Data Exchange (TDX) based in NIED. The data is archived at NIED and is openly accessible to the public via the Internet [4, 5].

In the volcanological community of Japan, data collected through seismometers, tiltmeters, strainmeters, infrasound microphones and meteorological observatory equipment, such as barometers installed at volcano observation stations, are also acquired in WIN or WIN32 format, and are shared using the same data distribution network. However, the volcano observation data includes data that is not telemetered, but is recorded on a local memory card. Additionally, images, text, and original binary files cannot be shared via the data distribution network because of the incompatibility of their data formats.

This research project aims to share data and enhance collaborative research projects among researchers in Japan, as well as to facilitate international cooperation. WOVOdat database is an existing effort to aid in international data sharing [6]. In some cases where volcanoes have similar properties, similar patterns of eruption have been observed. WOVOdat database shares observational data when a volcano becomes active and compares it with the data from other target volcanoes, so that it can be utilized for forecasting eruptions in different countries. WOVOdat database does not collect raw data; only information on observation stations, equipment, and processed data is collected. The format of the WOVOdat database is defined [7]. The WOVOdat database has been maintained at Earth Observatory of Singapore (EOS) in Nanyang Technological University, Singapore, since 2009.

3. Interviews and Data Sharing Working Group

To establish a system for JVDN, we conducted interviews with each organization in 2017 and identified the issues faced during the process of data sharing. We conducted interviews with a number of universities (Hokkaido University, Tohoku University, Tokyo University, Tokyo Institute of Technology, Nagoya University, and Kyoto University), JMA, AIST, GSI, JCG, Mount Fuji Research Institute of Yamanashi Prefecture, and Hot Spring Research Institute of Kanagawa Prefecture.

The main issues and requests raised during these interviews were as follows:

- The observational data on volcanoes consisted of both good data and noisy data. Therefore, it was requested that all data collected should not be treated uniformly.
- There was a concern that the response to inquiries about raw data requires long periods of time.
- It was pointed out that it is difficult to convert data to the specified format at each observatory and to save it in the database each time.
- When a volcano becomes active, the local observatory is actively engaged in correspondence with the mass media and local governments, and therefore, has very little time to examine the data. Additionally, other users of the database who examine the openly accessible data provide different sources of information and comments, which cannot be responded to in time.
- The researchers wanted to be able to archive raw data and processed data at NIED.
- They also wanted to be able to examine different sources of observation data side by side.
- They also decided that an agreement between the data owner and the users is necessary before the utilization of raw data.

The interviews aimed to elicit concerns and requests about data sharing from each organization and explain the need for data sharing. We found that most interviewees had already understood the necessity for data sharing. However, most university researchers objected to the utilization of their data by other researchers without their permission. They stated that there was no problem if the data used was for the purpose of collaborative research. Most interviewees stated that they could not afford to invest more money and time on new ways of data sharing. More specifically, in universities, observational data is not passed on to the young generations, and thus, is no longer accessible after the researcher who collected the data retires. This data loss could be prevented if there was a common database.

We organized a data distribution working group and discussed the framework for data sharing in the volcanological research field in Japan, based on the issues and requests raised during the interviews. The working group consisted of 18 members from universities and research institutes. These discussions are summarized in this report [8].

The working group first confirmed and agreed to work towards certain principles. The principles include the advocacy of data distribution and sharing to promote volcanological research, the strengthening of cooperation between different fields of research and organizations, and the promotion of data utilization, volcanic disaster prevention, and human resource development. In system development, we make effective use of the budget and human resources and start from where we can. Further, the group agreed to respect the role of contributors, especially those who provide the data. One of the reasons for establishing these principles was to avoid having someone use the data without permission and to ensure that data sharing does not waste resources such as time and money during research. Furthermore, it was agreed that if each researcher did not benefit from data sharing, there would be no cooperation in a larger perspective. The group also agreed to maintain the system in the future, even though this project would continue only for 10 years. Therefore, the decision was made to use the budget and the availability of human resources as effectively as possible.

Based on the discussions during the working group, an agreement was made on a design that is illustrated in **Fig. 1**. In the JVDN system, raw data is treated differently from other data (observation station information,

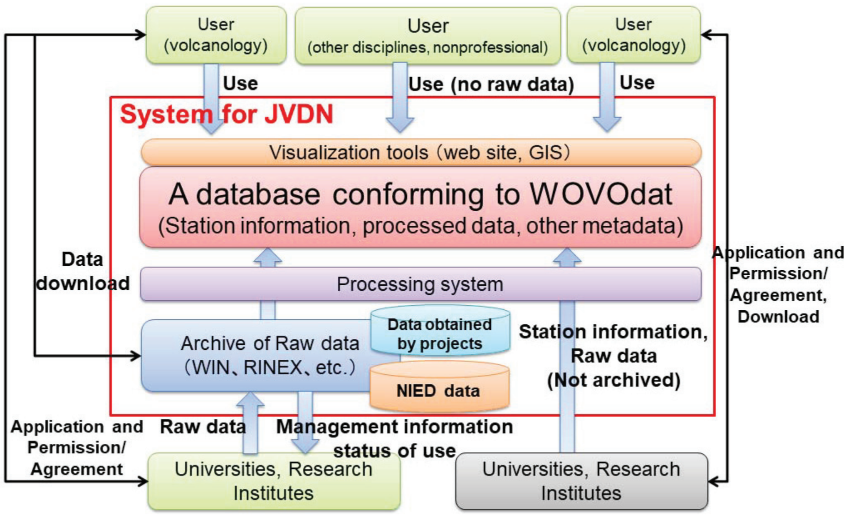

Fig. 1. Design for the system for the JVDN.

processed data, and other metadata). The raw data, in this case, refers to the data obtained directly from devices, or data obtained after format conversion, such as WIN data and RINEX data of GNSS. Processed data denotes processed raw data such as the hypocenter catalog and seismometer amplitude data obtained from seismic data. Data such as observation station information, processed data, and other metadata are stored in a database conforming to the WOVOdat database standard and shared with users through visualization tools such as geographic information system (GIS). This design will enable users to visualize the multiple sources of data and promote the use of volcanological data for research and disaster mitigation. The data owners can archive the raw data to NIED. NIED will then perform basic processing such as hypocenter determination and store the data in the database. Once the data owner has provided permission, users can download the raw data from the JVDN website. Even if the data owner does not archive raw data to NIED, the information from observation stations will be stored in the database, and users can refer to it and request the data owner for information using the visualization tool.

The decision was made to address this framework as JVDN. The name of this project is "Centralization of Various Observation Data," where the word "centralization" seemed to give the impression of centralization of power. Some researchers seem to have misunderstood that they are forcibly required to provide observational data. Therefore, we did not want to use the words "centralization," "data center," or "database," but instead have used the word "data network." This demonstrates that the volcanological data is not centralized in one place, but links organizations and researchers who have collected the data.

The JVDN system is being developed by the NIED development team, but the inter-organization coordination on technical issues will continue to be implemented in the working group. The reconciliation of interests between organizations and important decisions are made using a steering committee aimed at coordinating research projects, and with the help of a general council for the operation of the entire project of INeVRH.

4. System Development

We are developing a system for JVDN based on the results of the interviews and the discussions with the working group. **Fig. 2** illustrates the structure of this system. The system consists of the volcano observation data distribution/sharing system, the real-time data processing system, the volcano observation data unification/sharing system, and the disaster prevention information system for data utilization. The network described in Section 3 is the volcano observation data distribution/sharing system. We are advocating for the distribution and accessibility of data to the public from newly installed observation stations and instruments. In October 2018, we updated the agreement with JMA and are planning to release the data from tiltmeters and infrasound microphones. Advances have been made since 2016 concerning the processing of seismic data and GNSS data in real time. The volcano observation data unification/sharing system for data visualization, archiving and sharing has been under development since 2018. The disaster prevention information system for data utilization is part of the system's foundation and is used for collaboration with subproject D-3, as described in Section 5.4.

4.1. The Real-Time Data Processing System

The real-time data processing system processes WIN and WIN32 format data, including seismic and tiltmeter data transmitted through the volcano observation data distribution/sharing system. This system plans to incorporate standard processing such as hypocenter determination, resampling processing, as well as run newly developed spectrum algorithms, root mean square (RMS) amplitude

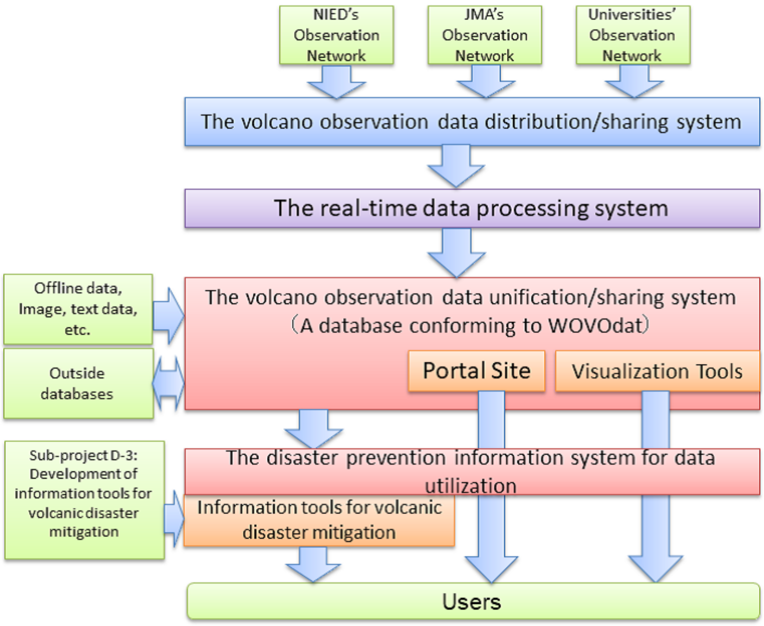

Fig. 2. Structure of the system for JVDN. The colors of the boxes are in correspondence with the system in **Fig. 1**.

and processing algorithms in the future. In addition to the volcano observation network (V-net) [9], NIED operates the high sensitivity seismograph network (Hi-net) [4, 5], the broadband seismograph network (F-net) [10, 11], and the seafloor observation network for earthquakes and tsunamis along the Japan Trench (S-net) [12–14]. These observation networks share data distribution networks and data storage servers. The real-time data processing system also shares its processing system with other observation networks. This process of sharing reduces the burden on the staff managing the system for each network. Additionally, by using the processing system of other networks, new development costs can be reduced. However, volcano observations and seismic observations are different in several respects, and hence, require additional developments. In the case of volcanoes, the seismic velocity structure of the ground below differs for each volcano. Therefore, a hypocenter determination processing system for each volcano must be established. We also made it possible to attach labels, such as volcanic tremor and low-frequency earthquake, to each volcano-specific earthquake. The results after processing are saved in the database of the unification/sharing system (Section 4.2) and can be easily visualized.

The GNSS data processing is one of the key functions of the real-time data processing system and processes the data to obtain observations on crustal movement. NIED collects data via the telephone every hour from the volcano observation stations. Some stations collect data in real time using the same data distribution network as the seismic data. The observation data collected is then converted to RINEX data, which is a common format for the GNSS data, and then stored. Based on various agreements and data policies, we have acquired the GNSS data from JMA and GSI, and integrated it with the GNSS data processing system.

One form of processing the GNSS data is using the daily position analysis by Bernese GNSS Software 5.2. We also conduct hourly analyses using the PPP-AR and the RTK methods. Real-time analysis is carried out for some of the data acquired in real time, and the results after processing are also stored and visualized in the database of the unification/sharing system (Section 4.2).

4.2. The Volcano Observation Data Unification/Sharing System

The volcano observation data unification/sharing system collects, stores and shares raw data indices, offline data, image data, and text data in a database, after processing the raw observation data. This system incorporates various functions based on the requests raised at the interviews and the results of the subsequent discussions in the working group.

The JVDN portal site (https://jvdn.bosai.go.jp) is a website that will be a gateway for users to access all the data (**Fig. 3**). Users can check, browse, download and inquire about the data available on this page, and can confirm the progress status of the development of this system. It is possible for anyone to view the progress information on system development and the general information on the observational data. However, user registration is required for downloading, browsing and inquiring about specific data. At the time of registration, the user needs to agree to the terms of use.

There are different types of users: general users, data owners, and group administrators. A general user can browse, download data and ask the data owners about data. A data owner can upload, browse and download data. A group administrator can manage the access rights

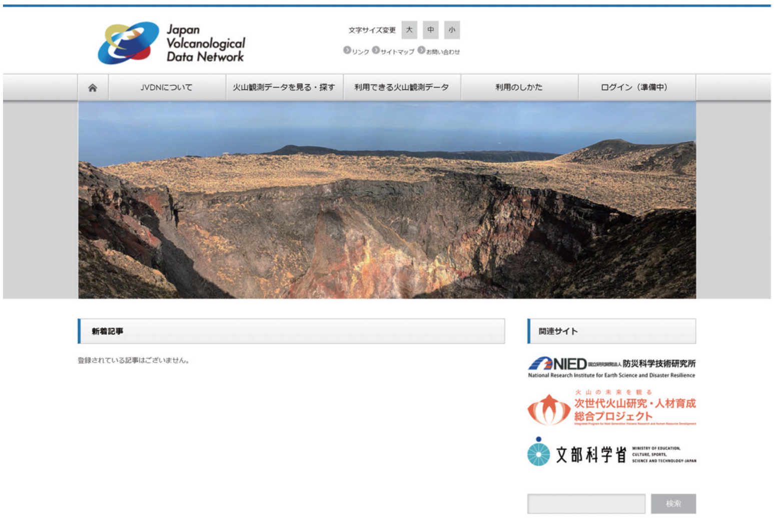

Fig. 3. Portal website for JVDN.

of a closed data sharing group, as well as browse and download data. Details about the group will be described later. The personal information of the users is strictly managed by the server and protected using security measures.

In order to submit the data acquired at a station, it is necessary to first register the station information and the instruments. Next, it is necessary to register the position and name of the station, the name of the instrument used and the data format used. Then, the data is uploaded to a specifically allocated server. In the WOVOdat database, it is necessary to register station names and position information for each instrument. In this system, it is assumed that the observation station is a multi-parameter station, and multiple instruments can be registered to one station. There is also volcanological data, such as remote sensing data, that is not acquired at observation stations. This data can be uploaded separately.

Registered stations, instruments and data are made accessible with the help of visualization tools. The visualization tools used are GIS, time-series data display, scatter charts and tables. Geographic information such as observation station information and epicenter information is displayed using GIS software. Using graphs, we can compare, for example, the amplitude of the seismometer, baseline length change between the GNSS stations, and tiltmeter data. This visualization tool can hypothetically also be used by experts to advise the volcano disaster prevention councils.

In this system, we provide a function that helps sharing of data within specific groups. The data owner can designate a group and make their data accessible specifically to that group. General users can also join some of these groups. The group administrator can specify whether or not a general user is permitted to participate in the group. This group usually comprises of a collaborative research team, organization or committee, such as the volcano disaster prevention council. The need for such a function arose because requests were made to share data among limited members of a group and to be able to select whether to make the data available to the public or not, depending on the quality of the data. By providing this function, we would like to help address such requests from our users. During the collaborative research period, data can be shared with limited members of the group, and after a certain period, we hope to remove that restriction and release it to other users.

Observation data, such as seismic data that is distributed by the volcano observation data distribution/sharing system, will also be shared by the system. Regarding other data, the data owners can upload it to a cloud server. The volcano observation data unification/sharing system will associate the data with the registered observation information and store it in an archive. Additionally, the system processes the data so that it can be displayed using a visualization tool. Therefore, the data owner uploads the data without any special processing.

A general user can view and download the observation station information and processed data using a visualization tool. A general user belonging to a group can also access data that is shared only within the group. When a general user wishes to use raw data, a request for provision of data is issued to the data owner using an inquiry function, and the data can be downloaded after receiving approval. For raw data that is not archived in NIED, the visualization tool will guide the user to the webpage of the organization providing the data. When raw data is used, the records used are always saved. Additionally, general users can register deliverables, such as research papers and reports, using downloaded data. Data owners can also confirm the usage status of the data and the deliverables.

Various inquiries are expected from the user when using the observation data. The system administrator can respond to the inquiries related to system usage. However, only the data owner can respond to questions about

Table 1. Proposed data archive.

Seismometer	Barometer	Magnetometer
Tiltmeter	Infrasound microphone	Gravimeter
GNSS	Rain gauge	SAR
Strainmeter	Gas sensor	Photos
Thermometer	Volcano ash	Core samples

the data, including the characteristics of observation instruments and data abnormality. Although it is possible to register this information together with the observation station information and the observation items, the possibility of receiving inquiries from the user could persist. Therefore, we are developing a function that sends inquiries from the general user to the data owner so that he or she can respond to them directly. Using these functions, we have been able to deal with most of the issues and requests that were brought up. Other issues and requests will continue to be improved upon in the future.

Table 1 describes the current plan for creating a data archive. Gas sensors, like multi-gas sensors (CO_2, H_2, SO_2, and H_2S), are being developed by AIST, along with SO_2 sensors. We plan to expand the archive as necessary. The data format can be registered at the time of registration of the observation item so that any data format can be archived.

5. Research Using the System, Expected Outcomes and Future Issues

5.1. Promotion of Collaborative Research on Multi-Disciplinary Projects Such as the INeVRH

One of the aims of this project is to facilitate collaboration between projects in INeVRH. The system collates the data acquired by the following projects – B: "Development of advanced volcano observation technology," C: "Development of prediction technology for volcanic eruption," and D: "Development of countermeasure technology against volcanic disasters." This data can then be utilized to provide information and countermeasures in the event of volcanic disasters, for subproject D-3: "Development of information tools for volcanic disaster mitigation." The system will also be used for projects proposed to commence in the future. This system helps visualize the kind of research being carried out and promotes new collaborative research. This system also considers the use of such research for disaster mitigation. The feedback provided based on the needs of the disaster mitigation field will promote problem solving collaborative research.

5.2. Utilization for Eruption Event Trees

Eruption event trees represent the transition of events and states related to eruption activities [15]. It is used to share recognition on the transition of eruption activity among stakeholders and to calculate the probability of eruptions and disasters. However, since it is only an event tree sketched on paper, it is hard to share and coordinate with real-time data, databases, simulation technology, or automatic processing. Utilizing the data sharing system, we plan to construct an eruption event tree system that resolves these problems. In order to construct such an eruption event tree, it is necessary to be able to integrate observations from multiple sources, compare volcanoes, collect diverse sets of volcanological data and perform statistical analyses. We believe that the database constructed with this system can contribute immensely to such scenarios.

5.3. Promotion of International Collaborative Research Projects

This system is developing databases in compliance with the WOVOdat database and aims to coordinate with this database. By utilizing the volcanological data from across the world, it will be able to promote international volcano comparison studies and international collaborative research. This cooperation is particularly important for building eruption event trees.

5.4. Utilization of the Research Field for Disaster Mitigation

Volcanological data collected by this system and its visualization tools can be used for research to mitigate volcanic disasters. Subproject D-3: "Development of Information Tools for Volcanic Disaster Mitigation" – utilizes research results, such as observation data, and analyzes the results stored in the volcano observation data unification/sharing system to develop information tools. These tools can then support experts in the volcanic disaster prevention council to advise local governments and stakeholders to take necessary action for disaster mitigation. Project A will work closely with subproject D-3 to provide data and infrastructure for this information tool. The information tool incorporates all the content developed by subproject D-3 in the disaster prevention information system for data utilization. Empirical research and development will be conducted during the occurrence of the volcanic disaster. The problems encountered will be addressed via feedback and more practical research solutions will be produced. In the introduction (Section 1), we defined volcanological data as scientific data related to volcanic phenomena. However, this data alone is insufficient for usage during disaster mitigation. Natural disasters occur based on disaster triggers and predispositions. Therefore, in order to predict natural disasters and mitigate them, data on the impact of ash fall and mudflow on infrastructure, for example, is also essential. It is also necessary to study disaster occurrence processes using this data. Therefore, volcanological data should include data related to volcanic phenomena as well as data on the process of volcanic disaster occurrence. JVDN should deal with such data as well in the future.

5.5. Future Issues

This project aims to strengthen the cooperation between organizations and different fields of research through data sharing, with the aim to promote collaborative research and to advance volcanological research. These aims cannot be fulfilled merely by developing a system. After developing the system, systematic effort to promote collaborative research by utilizing this system is necessary.

This project will continue for ten years, but this system must continue to be maintained after that for the progress of volcanological research and to contribute to volcanic disaster mitigation. Sharing the processes with existing systems and replacing the processes with more efficient systems will help reduce the costs of development. However, in order to maintain the system in the future, it may be necessary to consider the adoption of beneficiary charges.

6. Summary

This paper characterizes the outline, background and progress up to the third year of the project A: "Centralization of Various Observation Data" of the INeVRH that commenced in November 2016. This project is developing a system that shares volcanological data among organizations and researchers. Before proceeding with the development, we conducted interviews and discussion with a working group, and identified and discussed issues raised. This framework is called JVDN and is based on the results of these discussions. This network will promote collaborative research through cooperation between organizations and multi-disciplinary collaborations, and can contribute to the development of volcano research and volcanic disaster mitigation.

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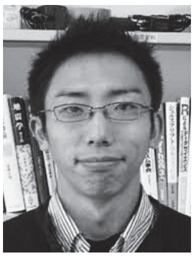

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