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Digital Transformation Activities in Geological Survey of Japan, AIST: Development of Volcanic Hazards Information System

Shinji Takarada[1*], Joel Bandibas[1], Yuhki Kohno[1], Shuho Maitani[1,2], Emi Kariya[1], Yasuaki Kaneda[1,3], Misato Osada[1,3] and Fumihiko Ikegami[1,4]

[1]*Geological Survey of Japan (GSJ), Tsukuba City, Japan,*

[2]*Meiji University, 1-1 Kanda Surugadai, Chiyoda-ku, Tokyo, Japan,*

[3]*Ibaraki University, 2-1-1 Bunkyo Mito 310-8512, Ibaraki, Japan,*

[4]*University of Tasmania, Churchill Avenue, Hobart, TAS 7005, Australia*

**Corresponding author: s-takarada@aist.go.jp*

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Abstract

The Geological Survey of Japan, AIST, has implemented the new project "Development of High-Precision Digital Geological Information for Hazard Prevention and Mitigation" in 2022, Volcanic Craters DB, High-resolution Active Faults, Slope Disaster Risk Assessment, Digital Marine Geology, and Geological Digital Transformation (DX) of various geological information are project components. The Geological Hazards Information Database is included in the Geological DX project. Volcanic Hazards Information System, part of the Geological Hazards Information Database, aims to provide a user-friendly, WebGIS-base, open-access information tool for potential and risk mitigation involving the Quaternary volcanoes in the world. This system is useful for evaluating volcanic hazards affected area assessment, estimating future eruption styles and eruption scenarios, and making evacuation plans for various stakeholders.

Keywords: Digital Transformation, Geoinformation, Hazard, Information System, Simulation, Japan, AIST

1. Introduction

The new project "Development of High--Precision Digital Geological Information for Hazard Prevention and Mitigation" (2022-2026) has been developed based on “Five-years Acceleration Measures for Disaster Prevention and Mitigation, and National Resilience (Cabinet Office, 2020) to protect people’s lives, property, and livelihood from natural disasters, to maintain the important functions of the nation and society, to analyze, evaluate, consolidate and provide information that contributes to disaster prevention planning, and to promote the development of a resilient national land that will not succumb to natural disasters. The “Development of High-Precision Digital Geological Information for Hazard Prevention and Mitigation” project is subdivided into “Active Faults”, “Volcanoes”, “Slope Disasters”, “Marine Geology” and “Geological Digital Transformation (DX)” projects.

The Geological DX project team is working on data distribution using API, data download service, making a viewer, and developing the Geological Hazards Information Database to promote the digital transformation of various geological information based on FAIR (Findable, Accessible, Interoperable, and Reusable) data principles. The Geological Hazards Information Database plans to provide data browse and search functions, data download of GIS data, and an online simulation system for real-time hazard assessment and connection with other databases to activate the digitized geo-information. An outline of the Volcanic Hazards Information System (https://geohazards-info.gsj.jp/vhazard/HazardAssessment/), part of the Geological Hazards Information Database, is introduced.

A total of 111 active volcanoes are distributed in Japan (Japan Meteorological Agency, 2013). During volcanic eruptions, eruption points, styles, volume, and distribution of eruptive products vary according to the conditional change after the eruption. Therefore, a real-time hazard assessment system is needed to change various parameters during eruptions. Digitization of the distribution of volcanic products such as tephra falls, pyroclastic flows, and debris avalanches is crucial for hazard assessment. An online rapid eruptive volume estimation system to calculate the tephra fall deposits is also requested for tephra fall hazard assessment. The Volcanic Hazards Information System aims to provide a user-friendly, WebGIS-base, open-access information tool for potential and risk mitigation involving the Quaternary volcanoes in the world. This system is useful for evaluating volcanic hazards affected area assessment, estimating future eruption styles and eruption scenarios, and making evacuation plans for various stakeholders, such as volcanic disaster mitigation committees and local government. The Volcanic Hazards Information System is also expected to be used at research institutes, universities, and geopark staffs.

WebGIS-based hazard information online system is becoming important in Southeast Asian countries. PHVOLCS and DOST in the Philippines provide "HazardHunterPH," showing earthquakes, volcanoes, and typhoon information on the webGIS-based online system (https://hazardhunter.georisk.gov.ph/). The Center for Volcanology and Geological Hazard Mitigation (CVGHM), Geological Agency of Indonesia, provides "MAGMA Indonesia", which contains various volcanic hazard information in Indonesia (https://magma.esdm.go.id/).

2. Construction of Volcanic Hazards Information System

The project of the Volcanic Hazards Information System aims to develop (1) real-time hazard assessment using online numerical simulations, (2) eruption parameter analysis at various volcanoes, (3) digitization of tephra falls, pyroclastic flows, and debris avalanche distributions, (4) online tephra falls volume estimation, (5) display of volcanic crater distributions, and (6) integration of various volcano databases. The outline of online numerical simulations, eruption parameter analysis, and digitization of volcanic products are introduced in this paper.

The previous version of Volcanic Hazard Assessment Support System (VHASS; Takarada, 2017) can execute Energy Cone (Sheridan, 1980; Malin & Sheridan, 1982), Titan2D (Pitman *et al.*, 2003; Sheridan *et al.*, 2004), and Tephra2 (Bonadonna *et al.*, 2005; Connor, 2006) numerical simulations on about 3000 Quaternary volcanoes in the world using ASTER GDEM and GSI 10 m DEM. Energy Cone and Titan2D models are suitable for evaluating volcanic density flows such as pyroclastic flow and debris avalanches. Tehpra2 is made for evaluating tephra falls. The latest version of the Volcanic Hazards Information System (Fig. 1; Geological Survey of Japan, 2024) includes new modules for displaying the result of the Tephra2 simulation on the map, uploading GeoTiff DEM data on the Energy Cone model, listing eruption parameters of major eruptions, displaying volcanic crater distributions, and providing Open Geospatial Consortium (OGC) compliant simulation result outputs that can be rendered using other OGC-compliant websites and GIS software. The examples of eruption parameters for major volcanoes are useful for comparing past eruptions of different volcanoes. These parameters are also essential for numerical simulations even after eruption initiation to determine the appropriate parameters, hazards and risk assessment, and future prediction of eruption scenarios. This system makes quasi-real-time hazard assessment possible due to a more rapid assessment of volcanic eruption products. OGC-compliant simulation results, as Web Map Service (WMS), can be displayed using other websites, Google Maps, and GIS software.

The Volcanic Hazards Information System and its GIS data are expected to be used by many stakeholders, such as volcanologists, the Volcano Disaster Prevention Council, and Geoparks staff, for volcanic hazards assessment, eruption scenario formulation, evacuation plan revision, revision of volcanic disaster prevention map, and education purposes.

3. Simulation results

【*Energy Cone model*】

A simulation result using the energy cone model at Tarumae Volcano, Hokkaido, Japan, is shown on the Volcanic Hazards Information System in Fig. 1 as an example of an online simulation system hazard assessment. Eruption parameters are evaluated to simulate the 1739 pyroclastic flow deposit distribution limit. The eruption point is at the current dome, the column collapse height is 1,000 m, and the equivalent coefficient of friction is 0.22–0.4 (step 0.02) cases are shown. Ten m-resolution DEM published by the Geospatial Information Authority of Japan is used for simulation. The user can upload their own DEM by themselves on the system. Therefore, if the user has a higher resolution DEM (e.g., 2 m-resolution DEM), it can be used for the simulation.

A new API (Application Program Interface) is implemented in the Volcanic Hazards Information System. The user can display the simulation result directly on the other WebGIS server and a GIS software. Using this WMS parameter, simulation results can be shown on other calculation systems, GIS software (e.g., QGIS or ArcGIS), and Google Earth. Online resource WMS (Web Mapping Service) parameters are shown when clicking the “G” icon at the upper left corner of the simulation result tab (Fig. 2). Fig. 3 shows an example of displaying the simulation results of Tarumae Volcano on the QGIS using the WMS parameter directly shown from the Volcanic Hazards Information System (using new API: WMS/WMTS connection and enter the WMS parameter). The geological map of Tarumae Volcano (Furukawa & Nakagawa, 2010) is also shown on the QGIS using this WMS parameter, and it is possible to compare the simulation result and geological map. The distal distribution limit of the SE direction of the 1739 pyroclastic flow deposit shown on the geological map of Tarumae Volcano is relatively good and coincident with the simulation case with column collapse height = 1,000 m and the equivalent of coefficient of friction (H/L) = 0.22-0.26.

The shapefiles and KML files can be downloaded from the Volcanic Hazards Information System simulation result tab and used for hazard assessments. For example, the results of the Energy Cone simulation are shown on Google Earth in 3D view. The 3D view is helpful for hazard assessment, such as understanding the relationship between the distribution of simulation results and roads and refugees, even if GIS software is not accessible.

【*Tephra2 model*】

The tephra fall simulation result at Mount Fuji Volcano, Japan, in the case of eruption column height = 20,000 m, erupted mass = 1.0×10^{12} kg (about 1 km^3) using the Tephra2 model on the Volcanic Hazards Information System is shown in Fig. 4. In this case, estimated thickness of tephra fall deposit is about 2 cm at Haneda International Airport and about 10 cm at Yokohama (may change with wind speeds and directions). The simulation result is

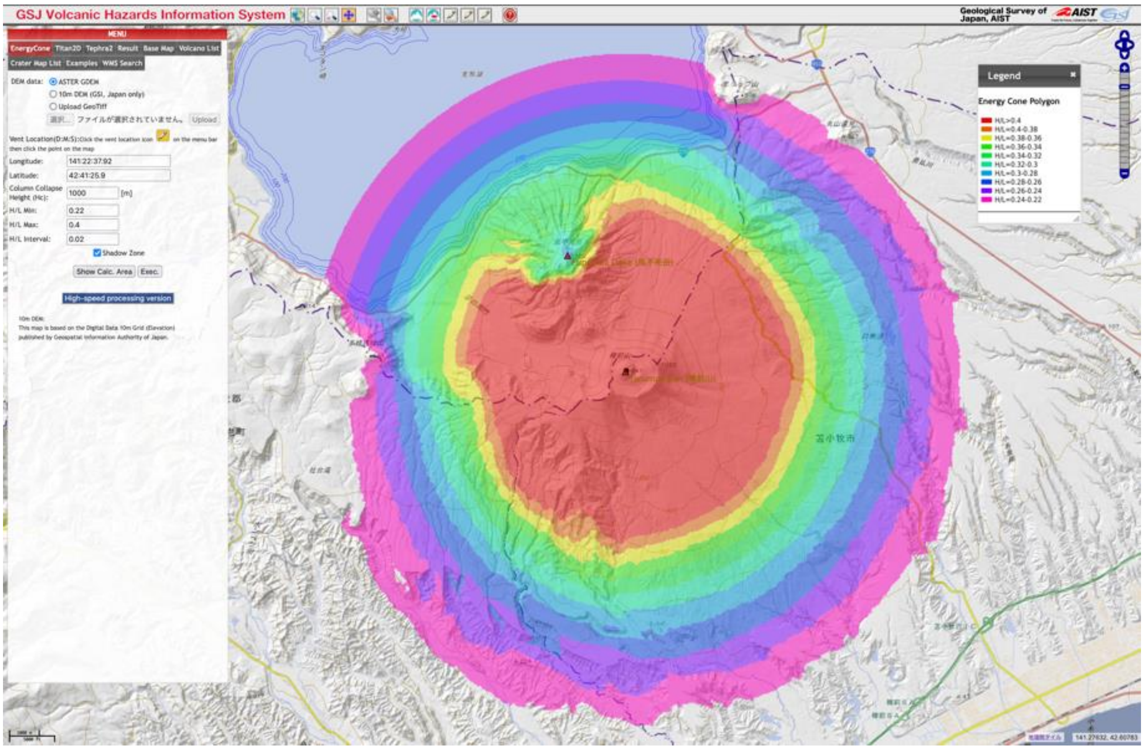

Fig. 1: Example of pyroclastic flow distribution analysis at Tarumae Volcano using Energy Cone model on the Volcanic Hazards Information System. The GSI Maps (Standard and Shaded Maps) published by the Geospatial Information Authority of Japan are used.

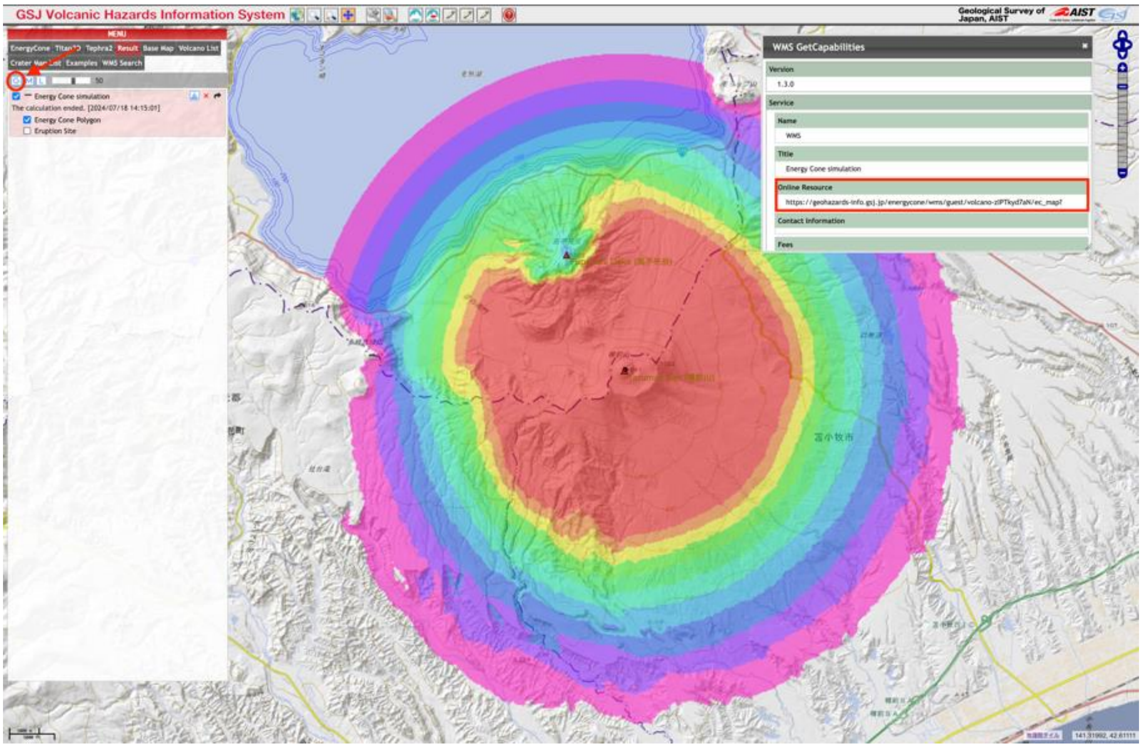

Fig. 2: Providing the API (WMS parameter) for the usage of simulation results in the outside system and GIS software. WMS parameter is shown from the G button. The GSI Maps (Standard and Shaded Maps) published by the Geospatial Information Authority of Japan are used.

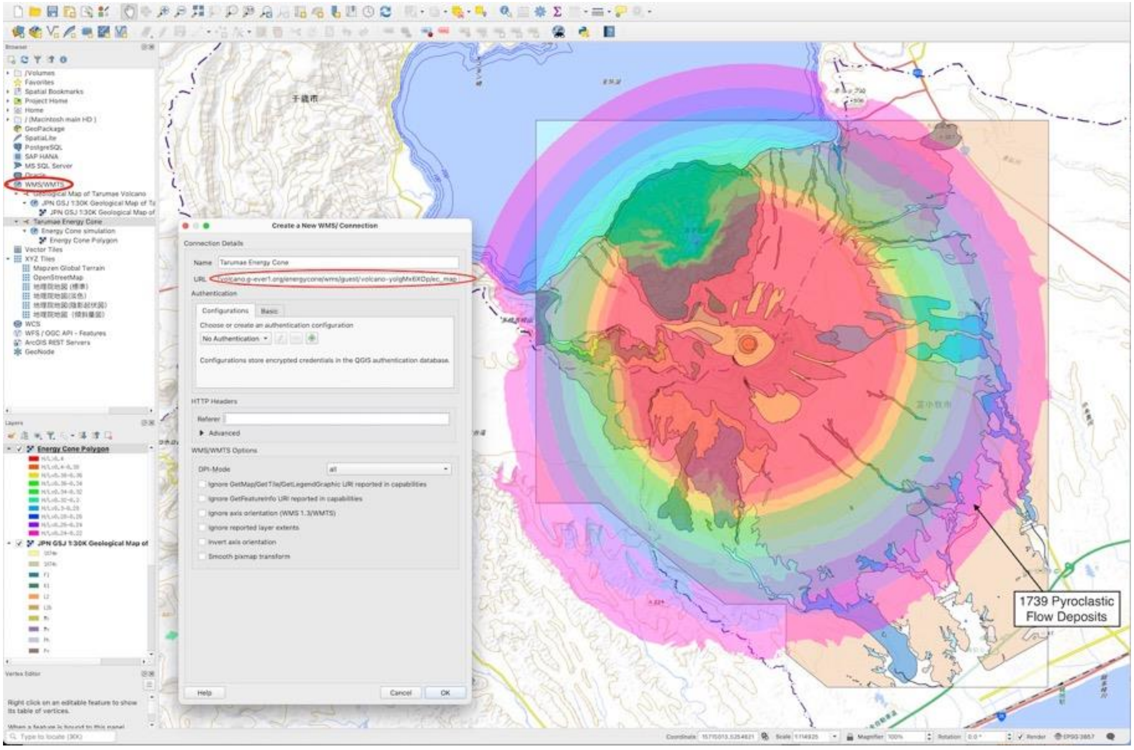

Fig. 3: Overlay of pyroclastic flow distribution simulated by the Energy Cone model and the Geological Map of Tarumae Volcano using GIS software (QGIS). Using the newly introduced API (WMS parameters), the calculation results on the volcano hazard information system are directly displayed in QGIS. The GSI Map (Standard Map) published by the Geospatial Information Authority of Japan is used.

displayed directly on the system (the previous system had to download the data initially). Therefore, tephra fall hazards and risk assessments are possible by evaluating the simulation results using the Volcanic Hazards Information System as many as possible online with changing parameters. The isopach map of tephra fall deposits can be shown on other servers and GIS software using WMS parameters (new API). For example, the Tephra2 simulation result can be displayed on ArcGIS Pro directly from the Volcanic Hazards Information System (Fig. 5). This is useful for hazards and risk assessments to compare with the user's data (e.g., evacuation site, railways, and populations).

【Titan 2D model】

A pyroclastic flow simulation result at Fuji Volcano, Japan, using the Titan 2D model on the Volcanic Hazards Information System is shown in Fig. 6. The red lines are the distributions of craters on Fuji Volcano (Ishizuka et al., 2022; Takada et al., 2016). The simulation assumed the pyroclastic flow was formed by collapsing pyroclastic cone at 200 m × 200 m × 150 m in size at Kenmarube 2 Crater. The simulation result (basal friction = 10º) suggests the pyroclastic flow can reach the foot of Fuji Volcano. Using the real volcanic craters and fissures distributions, the assessment of new vent positions and the simulation results are more reliable. The Titan 2D simulation result overlays on the Geological Map of Fuji Volcano in the QGIS software using the WMS parameter (Fig. 7). It is possible to assess the simulation results with the past distributions of Takizawa, Maborigawa, Subashiri b-stage, and Subashiri c-stage Pyroclastic Flow Deposits. Detailed hazard assessment of affected areas from pyroclastic flow and debris avalanches is possible by changing the parameters such as eruption site, volume, direction, and basal frictions using the Titan 2D model on the Volcanic Hazards Information System.

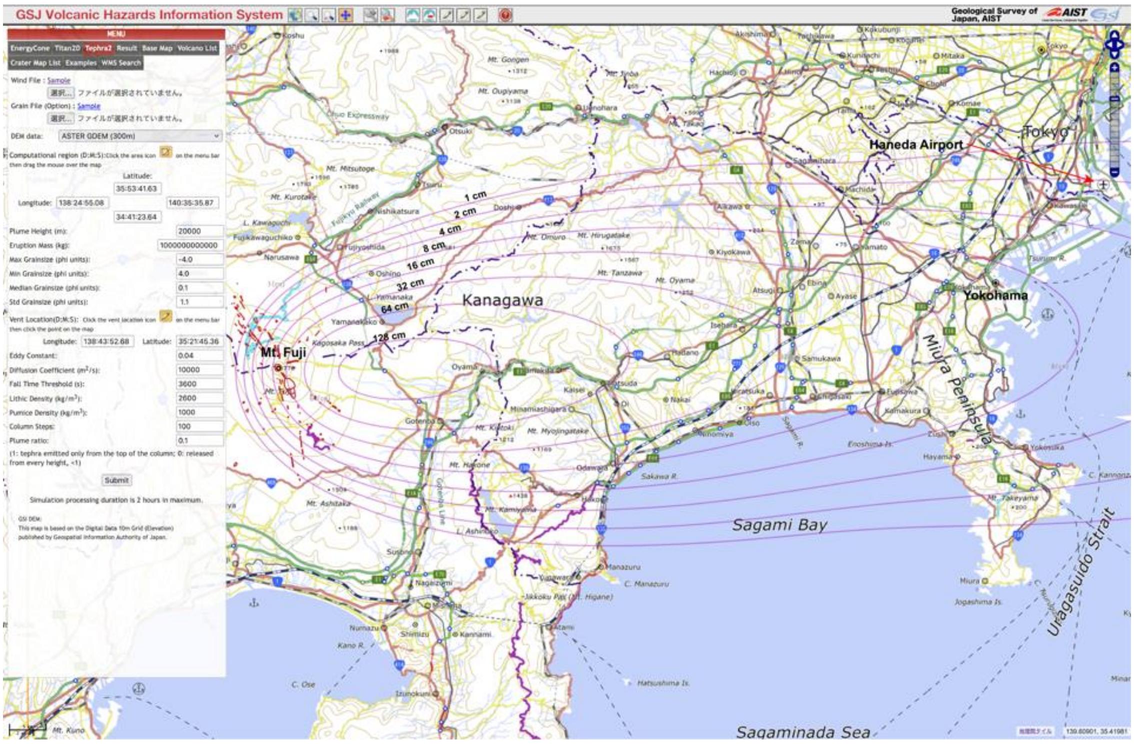

Fig. 4: An example of analysis of ash fall thickness distribution due to the eruption of Fuji Volcano, Japan, using the Tephra2 model. The GSI Map (English Map) published by the Geospatial Information Authority of Japan is used.

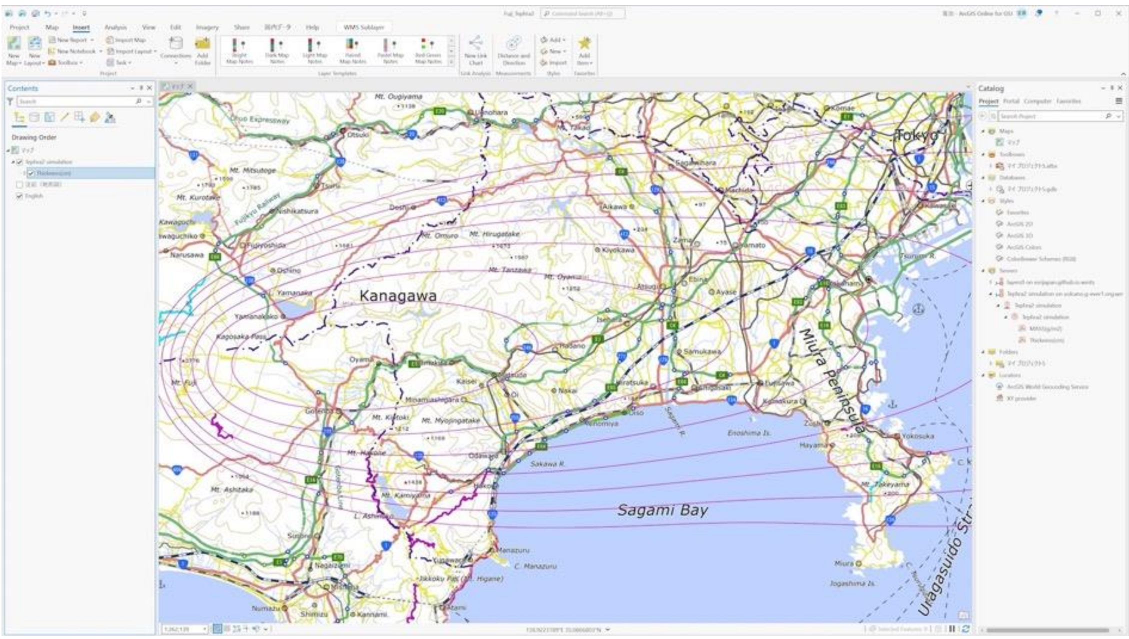

Fig. 5: The tephra fall thickness distribution from the Fuji volcanic eruption is analyzed by the Tephra2 model, and the results are displayed on ArcGIS Pro using the API (WMS parameters). The GSI Map (English Map) published by the Geospatial Information Authority of Japan is used.

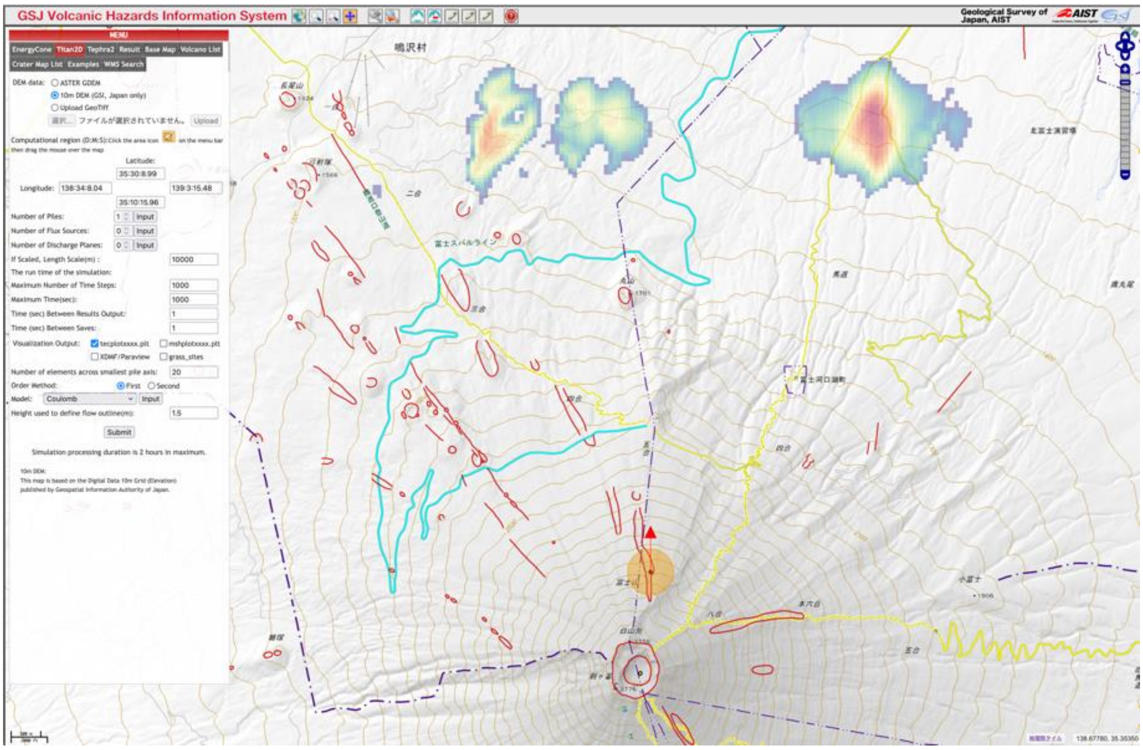

Fig. 6: An example of pyroclastic flow analysis at Fuji Volcano using Titan 2D model. A case study of the distribution of pyroclastic flow deposits derived from Kenmarubi 2 Crater. Red lines are newly-added crater distributions of Fuji volcano. The GSI Maps (Standard, Shaded Map) published by the Geospatial Information Authority of Japan are used.

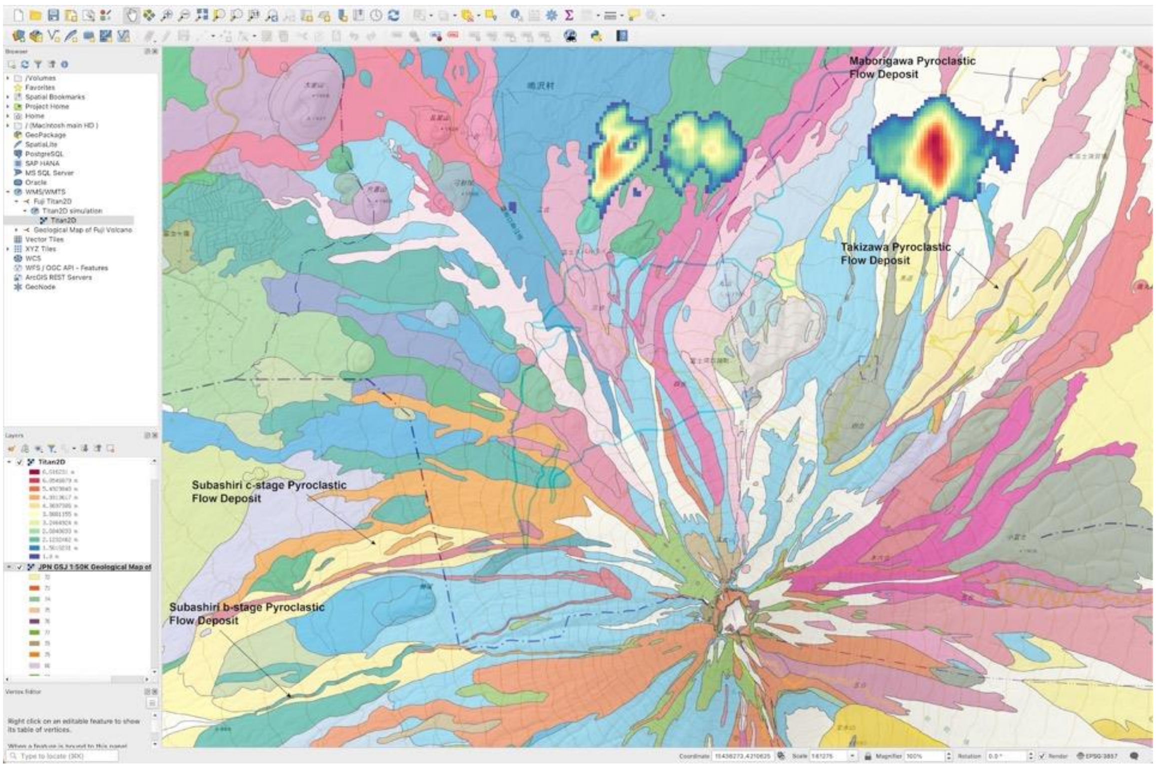

Fig. 7: Overlaid display of the pyroclastic flow distribution calculated by Titan2D model and Geological Map of Fuji Volcano on QGIS using API (WMS parameters). The GSI Map (Shaded Map) published by the Geospatial Information Authority of Japan is used.

4. Eruption parameters analysis

Representative eruption parameters and simulation results at major volcanoes are listed on the Volcanic Hazards Information System (Fig. 8). These eruption parameters of case studies are helpful to compare with past eruptions and eruptions at other volcanoes for real-time hazards and risk assessment after starting eruptions with choosing appropriate eruption parameters. Tephra2 simulation results at Vesuvius Volcano with eruption parameters: column height = 20 km, erupted mass = 1.0×10^{13} kg (about 10 km^3) is shown in Fig. 8. The energy cone results to simulate the possible affected area by pyroclastic flows at Asama Volcano, Japan, with eruption parameters (column collapse height=1000 m; H/L=0.2–0.4; step=0.02) is shown in Fig. 9. Currently, 184 cases of Energy Cone, 76 cases of Tephra2, and 53 cases of Titan 2D models, totally 313 cases were analyzed (March 2025). In the previous VHASS system (Takarada, 2017) only the user's simulation results were available. These presentative eruption parameters, along with case studies on the Volcanic Hazards Information System, are helpful for the hazards and risk analysis. These simulation results can be downloaded and also can be used on other servers and GIS software using WMS parameters.

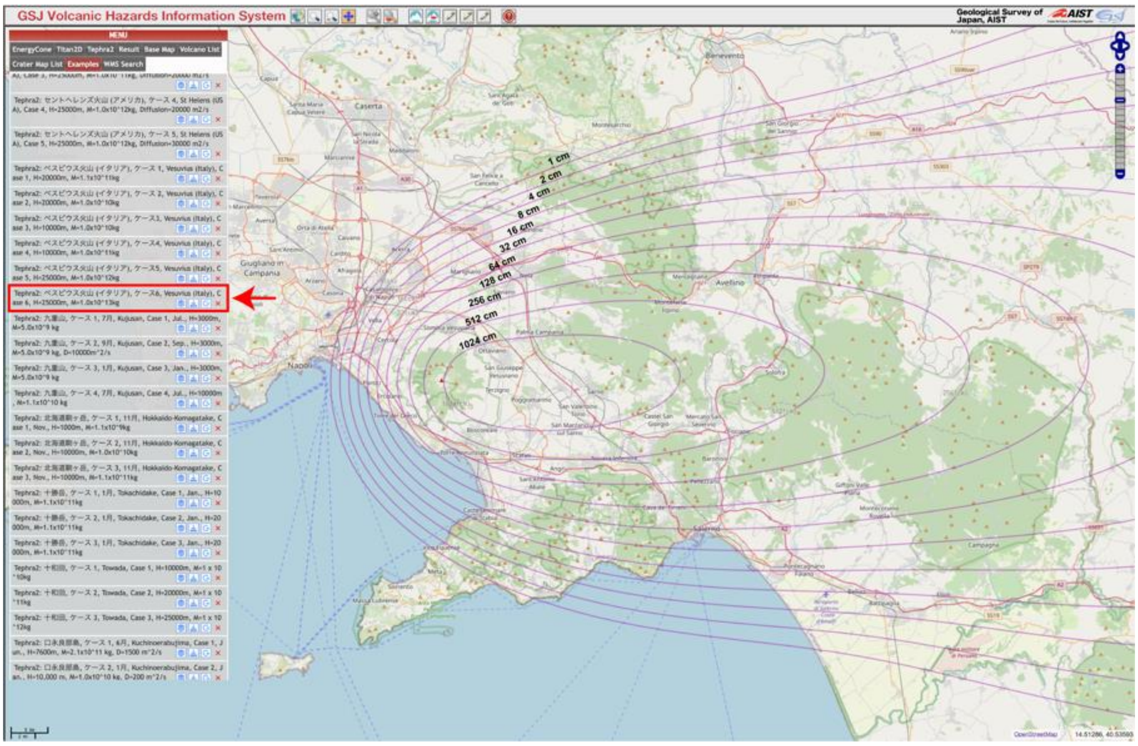

Fig. 8: Results of ash fall simulation for the world's major volcanoes are listed together with the analysis of eruption parameters. The figure shows an example of a tephra fall calculated using the Tephra2 model (ca. 10 km^3 case) at Vesuvius Volcano, Italy. The OpenStreetMap is used for the base map.

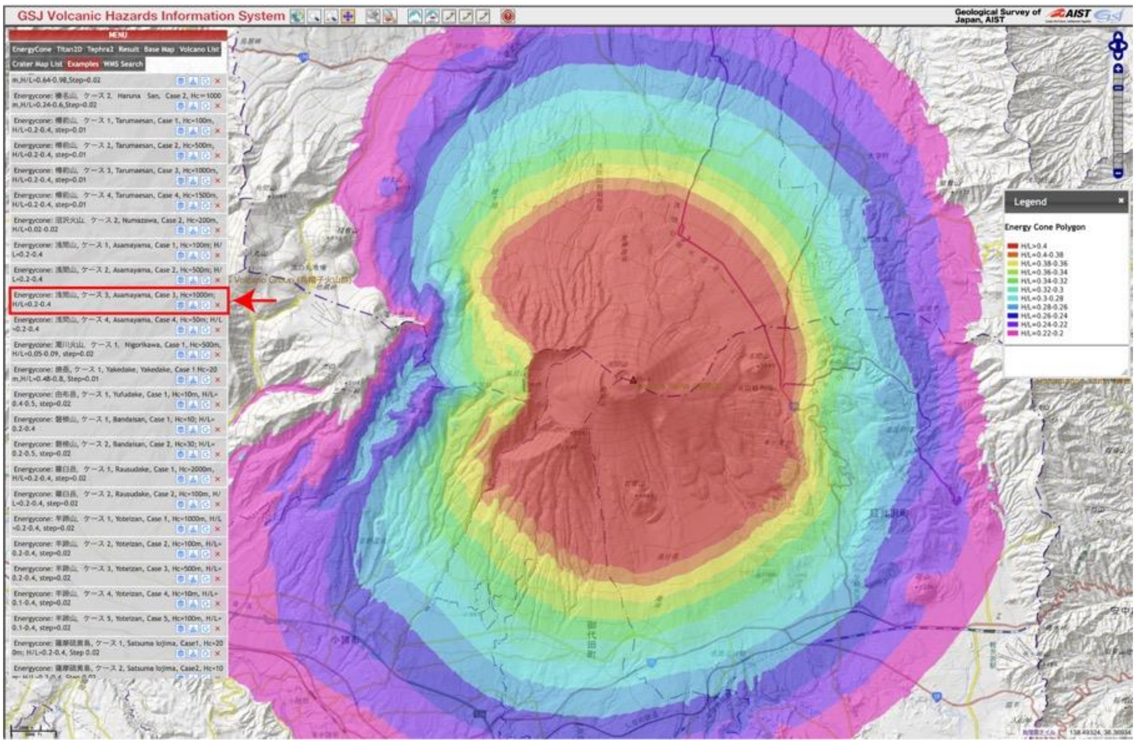

Fig. 9: Results of pyroclastic flow simulation for major volcanoes in the world are listed together with the results of the analysis of eruption parameters. The figure shows possible affected area by pyroclastic flows using Energy Cone at Asama Volcano, Japan. The GSI Maps (Standard and Shaded Maps) published by the Geospatial Information Authority of Japan are used.

5. Digitization of volcanic eruption products

Digitized GIS datasets of volcanic eruptive products such as tephra fall, pyroclastic flow, and debris avalanches and providing them to the public are essential for volcanic hazards and risk assessments. Therefore, the digitization of major eruption products at volcanoes in Japan and abroad is being processed. Currently, 172 isopach map data of tephra fall deposits at Rausu, Kutcharo, Mashu, Tokachi, Tarumae, Usu, Toya, Yotei, Hokkaido Komagatake, Asama, Fuji, Aso, Kirishima, Sakurajima, Aira, Ata, Kutchi-noerabujima, Calbuco, and Kelud Volcanoes are digitized (as of 22 February 2024). Examples of digitized isopach maps of tephra fall deposits from Aira and Sakurajima Volcanoes are shown in Fig. 10. Digitized GIS data are now registering on the viewer and preparing to download the GIS data and KML files, and available using API with WMS parameters.

6. Discussions

The advantages of Volcanic Hazards Information System are the following: (1) it provides a user-friendly interface, which does not require any complex installation procedure and Unix command operation; (2) it is developed based on WebGIS technology, which make it easy to compare the simulation results with other maps; (3) it is implemented using a volcano search system and digital elevation model covering almost all Quaternary volcanoes in the world; (4) it provides 3 deterministic simulation models, such as Energy Cone, Titan2D, and Tephra2, which can estimate affected area caused by major volcanic events such as pyroclastic flows, debris avalanches, lahars, and tephra falls; (5) representative eruption parameters and simulation results at major volcanoes are useful to assess affected area and comparing results with similar type volcanoes, (6) it is helpful for real-time hazards assessment and revision of volcanic hazard maps;

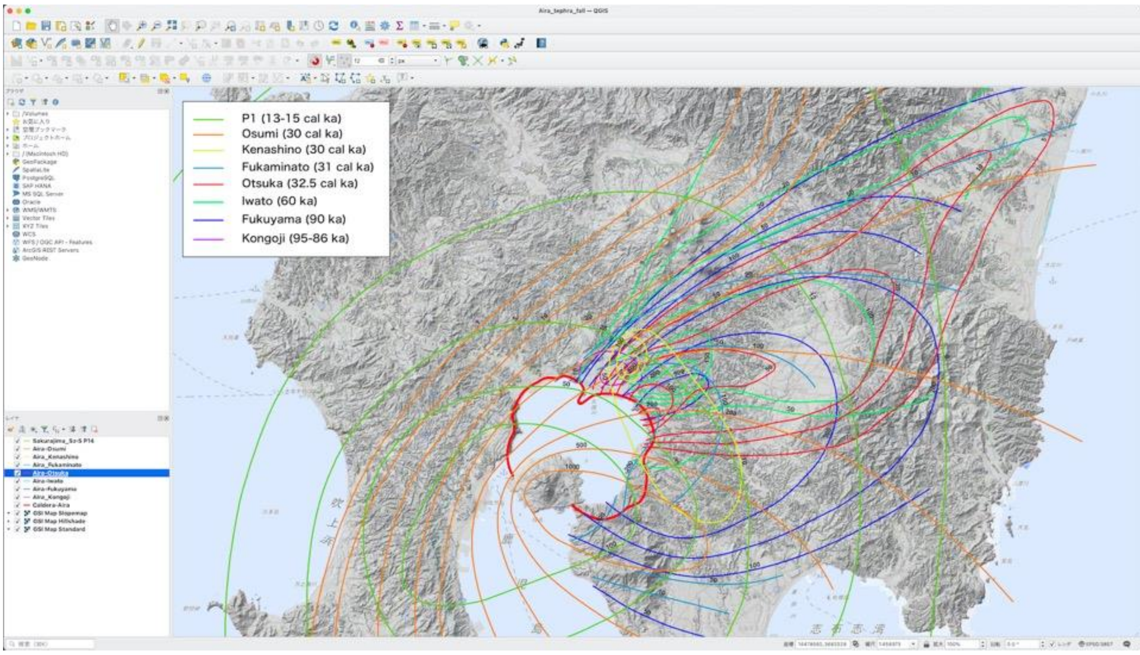

Fig. 10: Digitized distributions of isopach maps of tephra fall deposits derived from Aira Caldera and Sakurajima Volcano. The GSI Maps (Standard, Shaded, and Slope Maps) published by the Geospatial Information Authority of Japan are used.

(7) it provides easy to understand graphical input interface (e.g., simulation area and start point are assigned on a map or satellite image); (8) the base maps are accessible (e.g., Google, GSI and Open Street maps); (9) it provides useful data download (e.g., kml and shape files); (10) it is built on a freely available open-access system, and (11) digitized GIS datasets of past volcanic eruption products will be provided and useful for comparison with the simulation results.

The Volcanic Hazards Information System users only need a browser and an internet connection. Therefore, many researchers could use this system, including observatory staff in developing countries and undergraduate students interested in volcanic hazard assessment. It is suitable for real-time hazard assessment and revision of volcanic hazard maps. The Volcanic Hazards Information System currently provides deterministic hazard assessment tools to make the system less computationally expensive and maximize the number of users online. The probabilistic volcanic hazard assessment tools such as PyBetVH (Tonini et al., 2015) and HASSET (Sobradelo et al., 2014) still need to be implemented in this system. An online user-friendly interface and functions are necessary for an easy-to-use and highly accessible volcanic hazard assessment system. However, it is highly recommended to consult with specialists when simulation results are used on real hazard assessments.

7. Conclusions

The Volcanic Hazards Information System is a user-friendly, Web GIS-based, open-access online useful tool for potential hazards assessment and risk mitigation of Quaternary volcanoes in the world. The Volcanic Hazards Information System Project continues to develop (1) real-time hazard assessment using online numerical simulations, (2) eruption parameter analysis at various volcanoes, (3) digitization of tephra falls, pyroclastic flows, and debris avalanches distributions, (4) online tephra falls volume estimation, (5) display of volcanic crater distributions, and (6) integration of various volcano databases. The interaction among the current volcanic databases (https://gbank.gsj.jp/volcano/index_e.htm) such as Quaternary Volcanoes, Active Volcanoes, Geological Map of Volcanoes in Japan, Large-scale Eruption, Eruption Sequence, and Volcanic Ash Databases are planning. The Geological Hazards Information System will be developed in collaboration with other projects on "Development of High-Precision Digital Geological Information for Hazard Prevention and Mitigation," such as Volcanic Craters DB, High-resolution Active Faults, Slope Disaster Risk Assessment, Digital Marine Geology, and Geological Digital Transformation projects.

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