ANNALS OF GEOPHYSICS, 67, 4, S436, 2024; doi:10.4401/ag-9181
OPEN ACCESS

A Case for Improved Global Coordination of Volcano Observatories

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Article history: received October 01, 2024; accepted October 15, 2024

Abstract

The distribution of volcano monitoring networks and volcano expertise does not correlate well with the global distribution of volcanic risk. All countries have cultural, financial, bureaucratic, political, and logistical barriers to effective risk reduction. The lack of parity amongst volcano observatories jeopardizes public safety and curtails scientific research and understanding. Having global data compiled daily to retain a full record of volcanic unrest would lead to large and meaningful improvements in future eruption forecasts. To make progress on these issues, the volcanological community needs greater collaboration, standardization, and support.

Keywords: Volcano; Risk Reduction; Observatory; Monitoring; Coordination

1. Introduction

As natural science trends progressively more global, computational, and data-driven in scope, we face a growing gap between the cutting edge of science and decision-making at a local scale. Perhaps nowhere is this issue more evident than with respect to volcanoes. Key data are collected by **local** seismic and instrumental networks, cameras, meteorological stations, and human observers. Sometimes data are shared widely, but particularly in nations with limited resources, data may not be shared, even within the country. Farther away, researchers (and sometimes volcano enthusiasts) around the world download **globally available** satellite data, including imagery, gas emissions, meteorology, and deformation data. Their ability to share their insights with local officials near a volcano is often limited by technological, sociological, and cultural barriers, as well as a lack of accepted standards and protocols. The result can be an artificial separation of local and global data that can forestall the advancement of science, while simultaneously leaving populations at risk.

My perspective is primarily through my experience as director of Volcano Disaster Assistance Program (VDAP), which is supported by an interagency agreement by the United States Agency for International Development (USAID) to support volcano observatories worldwide through donations and training, as well as aid in data interpretation during volcanic unrest (Lowenstern and Ramsey, 2017). We observe a tremendous range in the capacities of our foreign counterparts and are concerned that there are too few coordinated means to provide support. Tupper and Bear-Crozier (2022) made the case that international cooperation in volcanology is held back by the lack of international treaties and agreements for operational forecasting, as opposed to the well-coordinated field of hydrometeorology. They provided a four-point plan to align volcanology with the Sendai Framework for Disaster Risk

Reduction (United Nations Office for Disaster Risk Reduction, 2015). They argued that although efforts to create best practices for volcano observatories are required (Pallister et al., 2019; Lowenstern et al., 2021; Barsotti et al., 2024; Engwell et al., 2024), these efforts fall short of formalizing the operational needs for volcanic hazards warnings on a global basis. In essence, scientific understanding and public safety would increase if there were agreed-upon global standards for observatories with respect to monitoring and reporting. Once those standards are created, there would ideally be organizational support to reach them, either by domestic/internal or international/external financial incentives.

This paper supports the vision of Tupper and Bear-Crozier (2022), that greater ties and shared protocols can be created amongst the many institutions, large and small, rich and poor, that undertake volcano monitoring. Implicit in this vision is the assumption and goal that a common approach to standards and protocols, even if difficult to achieve, could benefit both small under-resourced observatories and those currently closer to the state-of-the-art. This vision requires an effort to arrange for resources, standards, and institutions that define the path forward (Brown et al., 2015). In this paper, however, the primary goal is to explore some of the issues that hold us back from reaching better coordination: the cultural, financial, and logistical differences that affect our ability to respond. By understanding some of these diverse outlooks and priorities, we will be better positioned to understand the benefits of increased coordination and to create workable solutions.

2. Defining some common goals

I believe a few key goals would be beneficial both to the volcanology research community as well as to local volcano observatories focused primarily on public safety.

- Goal 1: Monitoring infrastructure and observations on volcanoes support science through open citable data available globally (Thelen et al., 2022; Hanson et al., 2024), potentially with a reasonable embargo period.
- Goal 2: Local observatories are supported by observations from space and global networks (Coppola et al., 2020; Poland et al., 2020; Pritchard et al., 2022; Cassidy and Mani, 2022).
- Goal 3: Global databases are expanded and improved to foster volcano forecasts, situational awareness, and expertise by volcano professionals worldwide (Costa et al., 2019; Andrews et al., 2022).

These goals are straightforward and perhaps obvious, but they aren't always realized. In the following sub-sections, I'll explore some of the complications and hesitancy of these goals.

3. What constitutes a volcano observatory?

Volcano observatories are groups, usually with associated facilities, that monitor volcanic activity and provide information to civil protection and the public regarding potential hazards and outcomes (see Robertson, submitted). Currently, there is an enormous diversity in the organization, function, capability, and available resources at volcano observatories around the world (Lowenstern et al., 2022). In Italy and the United States for example, there are multiple observatories coordinated by a single well-funded national institution. Scientists and engineers are hired and trained to perform a range of operational and research activities. Data are archived and shared with the global community. Staff have funding to attend international meetings and to publish their findings in leading scientific journals. However, in other countries—even ones with the world's most active and threatening volcanoes—observatories may exist but have minimal resources. Some observatories lack funds for station maintenance and fieldwork. Others lose data because they cannot pay for telemetry or internet service, and salaries can go unpaid for months, demoralizing the staff and their collaborators. In some countries, it is challenging to hire qualified scientists because there are no existing local graduate-level programs in geology or geophysics, or any universities that teach volcanology. Other countries with clear volcanic risk still lack any institution that undertakes volcano monitoring. Volcano-risk reduction is then in the hands of agencies with little familiarity with volcanoes and little potential for efficient response. The disparity in preparedness is tied somewhat to a country's GDP (gross domestic product) and the strength of its government institutions, but it's also a reflection of the lack of international prioritization, coordination, standards, and resources. Suffice it to say that the goals and aspirations of observatory staff can be limited by specific financial, sociological, and administrative constraints that may be opaque to potential outside collaborators.

4. Inconsistent Standards

These variations in volcanic context, resources, educational opportunities, and organizational priorities mean that it can be challenging to agree upon international common practices. Here are some examples of information for which we currently have no agreed-upon standards.

Volcano Alert Levels: There are dozens of variations of alert level systems at observatories around the world (Fearnley and Beaven, 2018). Some countries do not use alert levels while others are released by civil protection and not the volcano observatory. Some countries have both observatory and civil defense defining the level of alert, with occasional differences that must be explained to the public. The international aviation industry has an established and globally accepted four-level system that could be widely adopted (Guffanti and Miller, 2013). In coming years, the International Civil Aviation Organization (ICAO) alert level system will be a recommended and then required practice.

Terminology and units: Observatories may use different names for earthquake types and ways to describe earthquake intensity. Some relative scales are based on a single seismometer at the volcano and cannot be converted to a magnitude. Gas discharge, deformation, and many other parameters can be reported in different units or with different reference frames. Ash plume elevations might be reported relative to sea level, the eruptive vent, or the volcano summit. Times can be local (daylight or standard) or UTC. Terminology issues are also a problem in the more established hydrometeorological community (Tupper and Fearnley, 2023). Additional problems can arise from translating terms from the local language, or by an observatory describing activity with English terms, but in a way that could be variably interpreted.

Bulletin releases: Although most observatories release monthly, weekly, daily, or special written bulletins, there are no established standards. More importantly, there is no standard method to report the information so that it can be automatically parsed to populate databases. For this reason, most volcano reports cannot be archived in a consistent manner so that the volcanological community can take advantage of the observations. Some countries do not or cannot archive their own bulletins. Some alerts and briefings are posted only to social media, leaving archiving in the hands of corporations without motivation to preserve the information.

Data policy: Seismic, geodetic, and geochemical data can be exported to international archives, or saved locally on disk drives or paper records. Some observatories have no means to store data that are older than a few months. Some archives lack metadata that would allow export to international archives. Standards are being developed within individual observatories (Coombs et al., 2024), countries (Beauducel et al., 2020), or geographically based communities (e.g., in Europe: Puglisi et al., 2022), but large parts of the world are left behind.

5. Paucity of Volcano Data for Forecasting

This lack of standards holds us back. Without consistent terminology, or standards for reporting, then most of the observations of volcanic activity are lost to posterity. As it is, only 43% of the 1337 volcanoes thought to have Holocene activity have erupted since 1500 C.E, with only 32% having erupted since 1900. That leaves 68% of “active” volcanoes without eruptions since 1900. To forecast events when these poorly understood volcanoes awaken (as every year some do), we rely on those active and recently active volcanoes as analogues (e.g., Tierz, 2020). But analogue data are incomplete because of the lack of monitoring, lack of standard protocols and definitions, or because much of the useful monitoring and event data (the latter being explosion times, observations, alert level changes, etc.) are not recorded and saved for the scientific community and are unavailable except for specific volcanoes and geographic regions. Our existing global databases are either updated weekly in text format (e.g., the Smithsonian/USGS Weekly Volcanic Activity Report) or focus solely on geophysical monitoring (Earthscope). We need growth of databases that include fields such as alert level changes, explosion types and sizes described with consistent metrics, information from Volcanic Ash Advisory Center (VAAC) reports, earthquake types, evacuations, exclusion zones, and outcomes. We recognize the need to do so, and to work together to make it a reality (e.g., Andrews et al., 2022), but progress is slow.

6. The Occasional Tension Between Risk Reduction and Science

Working for a group that is funded by an international aid organization, my colleagues and I frequently observe fundamental differences in protocols, standards, and expectations. But as I'll explain below, aid organizations can only partially contribute to providing platforms to unify and standardize volcano monitoring. Our team at VDAP has a few longstanding practices to avoid ethical complications: 1) We only assist if invited, 2) We don't share our counterpart's data with third parties (assuming we have access), 3) Data from equipment we donate is used completely at the discretion of the recipient, and 4) Only rarely do we talk to the media about volcanic activity in other countries.

These practices are useful toward creating long-term trust between donor and recipient, but they can limit our ability to broker scientific efforts by third parties. Moreover, the focus on service to the foreign counterpart can be at odds with our employees' own career goals as researchers, and with our training as scientists. Nevertheless, with much of our funding coming from a governmental aid organization (USAID), our primary goal is direct assistance and risk reduction, and the four practices listed above are important to follow.

In other words, our focus on risk reduction for the citizens living on and near volcanoes and our support for local observatories is not always fully consistent with the goals of the global scientific community. We do not request that observatories use the same standards and protocols that we use. Other donor countries frequently provide different equipment, with different software, different databases, and alternative data formats. With this already existing hodgepodge of options, we do not insist upon any required format or policy for our donations.

7. Remote Monitoring During Volcanic Crises

A big challenge during crises is to link the global scientific community with an observatory in need. An excellent example is the January 2022 eruption of Hunga Volcano (also known as Hunga Tonga-Hunga Ha'apai). Prior to the eruption there was no functional monitoring infrastructure, and the nearest seismic station was 750 km to the northwest in Fiji (Kintner et al., 2022). The responsible monitoring agency, Tonga Geological Services, was small, and had limited familiarity with volcano monitoring, and few connections to the international volcanological community. Notwithstanding the loss in telecommunications due to submarine debris flows that severed submarine cables (Clare et al., 2023) radically diminishing communications between Tonga and the rest of the world for weeks, the potential for information sharing *even prior to the eruption* was minimal. With global data, numerous important science publications were completed, and lessons were learned from this massive eruption, but the lack of local data both hindered readiness by the local communities and reduced the information available for scientific insights.

There are thousands of academic researchers at universities and government research agencies around the world who are focused on Earth science data related to volcanism. They often have the time, interest, and knowledge to synthesize the abundant free (and commercial) data that exist from satellite assets, meteorological stations, seismic, infrasound, geodetic, and other Earth science data. There is a massive amount of key information collected every second on virtually every part of the Earth. Volcanoes are tracked by research/monitoring groups and sensor platforms such as MIROVA, MOUNTS, TROPOMI, COMET, SENTINEL and many others. Seismic and geodetic data are often archived by Earthscope and EMSC. Volcanic ash can be tracked by HIMAWARI and MODIS, and ash detections are reported by the nine VAACs and provided to the aviation community. Eruption source parameters are available from the Independent Volcanic Eruption Source Parameter Archive (IVESPA). Unless a volcano observatory has the time, expertise, and internet bandwidth to take advantage of this information, it can be challenging to assimilate during a crisis.

To help countries manage disaster response, satellite data can be made freely available through the International Charter Space and Major Disasters (https://disasterscharter.org/). This requires that an agency, presumably one tied to the disaster, is available to manage the data and is an authorized user. In practice, this can work well, even if the authorized user is in a different country, provided that they have close ties with the agencies reacting to the crisis.

When the response is more *ad hoc*, scientists who take advantage of the immense volume of global data may seek to contact a volcano observatory to request local data for corroboration of observations, or for eventual field support on site once the situation is safe. It's my observation that such requests frequently go unanswered and even offers of free data and assistance may not be acknowledged.

This tendency to avoid outside help can be due to a variety of issues. There may be a lifetime of local experience on the volcano that renders less compelling a more distant perspective. There could be some centuries-old distrust of former colonizers. Alternatively, and more likely, the local staff may simply be overwhelmed: observatory responses in all countries are exhausting and the staff may have little ability or desire to add additional tasks to their already busy agenda. There may be intense pressure to provide information to local authorities, to meet with citizens groups, and to ensure that monitoring instrumentation is properly functioning. In terms of long-term science goals, there may be minimal expectations or desire to archive and export data, or to publish models. Finally, some agencies may have interagency or intergovernmental agreements that require data embargoes for months or years.

8. Coordination of Volcanology and Volcano Observatories

To progress beyond the current economic, cultural, educational, and logistical issues that block collaborations and standard development, it is important to create improved protocols, resources, and platforms. Below is a list of key international organizations and projects that are *currently* either major partners of volcano observatories or could play a key role in future advancements.

The International Association for Volcanology and Chemistry of the Earth's Interior (IAVCEI) has been an important coordination body for volcanology since its formation in 1922. It is an association within the larger International Union of Geodesy and Geophysics (IUGG); both are non-governmental organizations dedicated to pursuit of scientific knowledge. IAVCEI raises funds through membership fees and meetings. Its limited resources are often used to support travel to meetings and workshops by early career researchers and individuals from resource-limited countries. *Ad-hoc* IAVCEI subcommittees have produced publications that outline guidelines for external support of observatories during volcanic unrest and eruption (IAVCEI 1999, 2016).

The World Organization of Volcano Observatories (**WOVO**) is a network within IAVCEI that provides a platform for interaction among volcano observatories. In recent years it has been largely inactive but has announced plans for increased coordination. It currently has no independent funding. Regional coordination has been assumed through groups like the Latin American Association of Volcanology (**ALVO;** Agusto et al., 2022), Asian Consortium of Volcanology (**AVC**), and similar groups in Europe and Africa that are independent of WOVO but would participate in its activities.

The International Network for Volcanology Collaboration (**INVOLC**) is another IAVCEI network focused on improving collaborations in volcanology, especially for scientists working in a resource-constrained context. Their membership extends beyond volcano observatory staff and includes researchers at universities. Their recent paper (IAVCEI-INVOLC, 2024) provided guidelines for best engagement protocols.

Volcano Observatory Best Practices (**VOBP**) is a series of meetings (currently 5) started by the USGS and the Istituto Nazionale di Geofisica e Vulcanologia (INGV) to discuss and prioritize protocols and practices for volcano observatory operations (Pallister et al., 2019; Lowenstern et al., 2022). Recently, VOBP has been formalized as one of the three core programs within WOVO.

The Global Volcanism Program (**GVP**) is run through the National Museum of Natural History of the Smithsonian Institution and is the pre-eminent database for basic volcano information, including eruption dates and descriptions, locations, references and photos. A weekly volcanic activity report is compiled through a collaboration with the USGS. The GVP Bulletin provides more in-depth coverage of individual eruption episodes. A daily volcanic activity report is planned for the near future (H. Wright, USGS personal communication, September 2024).

WOVOdat (Newhall et al., 2017; Costa et al., 2019) is a multiparametric database of volcanic unrest, currently funded and operated at the Earth Observatory of Singapore. The database includes materials gathered from the GVP database, from participating observatories and from available open-access sources. WOVOdat is aimed at fostering understanding of pre-eruptive processes and improving eruption forecasts. Though operated independently, WOVOdat is an official program within the WOVO network of IAVCEI.

The International Federation of Digital Seismograph Networks (**FDSN**) is set up to assist seismic network through best practices and data standards.

The European Plate Observing System (**EPOS**) is a growing distributed infrastructure for storing Earth science data and is currently used by the European volcano observatories for distribution of volcano-based data.

The Committee on Earth Observation Satellites (**CEOS**) is a large group of space agencies who coordinate their work (Earth tracking and data use) to assist society, including through disaster risk reduction. Their coordinated work on volcanoes was discussed in Pritchard et al. (2018).

Volcanic Ash Advisory Centers (**VAAC**s) are tasked by the International Civil Aviation Organization to track volcanic ash clouds and provide warnings to the aviation community. Their alerts are public, and most VAACs work closely with local volcano observatories to keep each other aware of potential or ongoing volcanic activity.

Governmental and non-governmental aid agencies: A variety of nationally based and international aid agencies are important partners of volcano observatories in different sectors of the world. They can be critical sources of funds for equipment and facilities, and when partnered through scientific agencies, can provide critical long-term support. The World Bank has assisted volcano observatories through numerous temporary projects.

Insurance Market: In recent years, a great deal of attention has been paid to parametric insurance options (e.g., Oramas-Dorta et al., 2021) that could raise funds to support volcano observatories. These are typically catastrophe bonds that trigger as a result of a measured parameter such as eruption plume height.

The United Nations Education, Scientific and Cultural Organization (**UNESCO)** is part of the United Nations, occasionally providing assistance to volcano observatories and associated seismic networks through coordination and training, primarily with the goal of disaster risk reduction.

9. Conclusions: Where Next?

The above organizations are all working on solutions to reduce volcanic risk and improve the capacity of monitoring agencies. As discussed above, progress is slow and hindered by many financial, logistical, and historical roadblocks. Many stress the urgency of addressing volcanic risk (Cassidy and Mani, 2022), and many look to increased coordination through global initiatives. Tupper and Leonard (2024) described a half-day workshop organized at the 2023 IAVCEI Scientific Assembly in New Zealand to discuss multi-hazard warning in the context of the Sendai Framework and "Early Warning for All" initiative. They brought together leaders from the World Meteorological Organization (WMO), volcanologists, and meteorologists to prepare a future vision and roadmap to allow for multi-hazard operations that include volcanic hazards such as tsunamis, lahars, glacial floods, pumice, and gas. The workshop was a first step toward the goal of a United Nations treaty-level organization structure with the goal of world operational volcanology (Tupper and Bear-Crozier, 2022). Yet, it's also important to look to a more bottom-up approach; Tupper and Fearnley (2023) pointed out the limitations of an UN-dominated approach, where UNESCO, WMO, and other organizations all coordinate the different geohazards currently covered. They write: "This organizational patchwork, combined with differences between countries and regions, hinders the smooth running of early-warning systems across the world. Plugging the gaps will rely on the involvement of the scientific community, as well as people at all organizational levels, from the UN to local communities."

I believe this last sentence is crucial. Though greater coordination seems necessary, it is likely unrealistic to expect a single entity to supervise and fund the solutions. Yet we can start to make progress through our existing networks and agencies, stretching beyond our own organizational and national bureaucracies to support the volcano community on a worldwide basis. Before implementing bespoke monitoring and archiving, we might consider ways to ensure that data are available for export to other communities with common standards. When working on research projects in resource-limited countries, we might seek ways to support our counterparts through financial assistance with publication costs, editing, and software implementation (e.g., IAVCEI-INVOLC, 2024). WOVO and more regional observatory networks could support temporary visits and exchanges funded by third parties and aid

agencies. And everyone can work toward standards where volcano alerts/warnings are released through formats such as the Common Alerting Protocol, and regular bulletins are produced and released consistently so that the information can be collected and archived for use in databases that will aid overall volcanological understanding and future volcano forecasts. Progress may be slow, but we will move forward only if we recognize that volcanic risk is an international problem that requires international solutions.

Acknowledgments. The manuscript was substantially improved by the thoughtful reviews of N. Deligne and M. Poland of the USGS. J.J. Major and C. Magirl edited the manuscript with rigor prior to USGS approval. S. Ogburn queried the volcano statistics from the GVP database. Discussions with VDAP staff and foreign counterparts over the years greatly informed my viewpoint. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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