REPORT
VOLCANICA

Monitoring of active volcanoes in Peru by the *Instituto Geofísico del Perú*: Early warning systems, communication, and information dissemination

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Abstract

Volcano monitoring in Peru is carried out by the *Instituto Geofísico del Perú* (IGP), through its *Centro Vulcanológico Nacional* (CENVUL). CENVUL monitors 12 out of 16 volcanoes considered as historically active and potentially active in southern Peru and issues periodic bulletins about the volcanic activity and, depending on the alert-level of each volcano, also issues alerts and warnings of volcanic unrest, ash dispersion, and the occurrence of lahars. The information generated by CENVUL is disseminated to the civil authorities and the public through different information media (newsletters, e-mail, website, social media, mobile app, etc.). The IGP volcanology team was formed after the eruption of Sabancaya volcano in 1988. Since then, geophysical and geological studies, volcanic hazards assessments, and multidisciplinary monitoring realized by the IGP, have provided a comprehensive understanding of volcanic activity in Peru and forecast future eruptive scenarios. Currently, 80 % of the historically active and potentially active volcanoes in Peru are equipped with networks of multiparameter instruments, with the seismic monitoring being the most widely implemented. In this report, we present the situation of volcanic monitoring in Peru, the monitoring networks, the techniques employed, as well as efforts to educate and inform the public and officials responsible for disaster risk management.

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1 Introduction

The active volcanic arc of southern Peru results from the subduction of the Nazca plate beneath the continental South American plate. The subduction is accompanied by a high level of seismicity [Kumar et al. 2016] and volcanism along the active continental margin. The active volcanoes of southern Peru are part of the Andean Central Volcanic Zone (CVZ) [de Silva and Francis 1991], a segment associated with a steeply dipping (25–30°) slab extending from 16° S (Southern Peru) to 28° S (Northern Chile). This segment hosts large rhyolitic calderas and many composite volcanoes of andesitic-to-dacitic composition, both of Pliocene and Quaternary ages [de Silva and Francis 1991; Sébrier and Soler 1991; Mamani et al. 2010; Thouret et al. 2016]. The Quaternary volcanic arc is calc-alkaline and is predominantly andesitic, although high-silica products (dacites and rhyolites) are present (e.g., Misti and Huaynaputina volcanoes), indicating high explosive activity in the recent past.

In this part of the Andes, 127 villages and more than 1,400,000 people are exposed to volcanic hazards. For example, the city of Arequipa (with over 1 million inhabitants; 2017 INEI census†), one of the main cities of Peru, is exposed to a high volcanic risk associated with a potential reactivation of Misti volcano [Thouret et al. 2001]. Considering this scenario, it is essential to have an early warning system for volcanic activity that ensures that all active volcanoes are monitored, in order to identify any sign of volcanic unrest or reactivation.

1.1 Volcanism in Peru

In southern Peru, as result of an extensive work [e.g., de Silva and Francis 1991; Fidel Smoll et al. 1997; Thouret et al. 2001; Mariño Salazar 2002; Thouret et al. 2002; Mariño Salazar and Thouret 2003; Gerbe and Thouret 2004; Thouret et al. 2005; Rivera et al. 2010; Harpel et al. 2011; Siebert et al. 2011; Rivera et al. 2014; Aguilar 2015; Samaniego et al. 2015; Macedo Sánchez et al. 2016; Samaniego et al. 2016; Bromley et al. 2019; Manrique et al. 2020; Prival et al. 2020; Rivera Porras et al. 2020; Rivera et al. 2020], 16 volcanic centres have been listed as active (at least with an eruption in historical times ∼550 yr) and potentially active (with activity in the Holocene), as shown in Figure 1. Significant explosive eruptions have occurred in this arc segment

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†http://censo2017.inei.gob.pe/resultados-definitivos-de-los-censos-nacionales-2017/

during the late Holocene, including the last Plinian eruptions of Misti volcano (~2030 years BP) [Thouret et al. 2001; Harpel et al. 2011; Cobeñas et al. 2012], Ubinas (~1000 years BP) [Thouret et al. 2005], and Huaynaputina (1600 CE) [Thouret et al. 2002], as well as the explosive eruption and collapse of the NE flank of Tutupaca (1787–1802 CE) [Samaniego et al. 2015]. In addition, Ubinas and Sabancaya, which are among the most active CVZ volcanoes, during the last centuries have presented several periods of eruptive activity with Volcanic Explosivity Index (VEI; [Newhall and Self 1982]) from 1 to 2. In Ubinas, the most recent eruptions occurred during 2006–2009, 2013–2017, and 2019 CE, and in Sabancaya between 1990–1998 CE. Currently, Sabancaya volcano presents continuous eruptive activity since November 2016.

During the last 550 years, there have been at least 45 eruptions at Misti, Ubinas, Sabancaya, Huaynaputina, Ticsani, and Tutupaca volcanoes, in southern Peru [e.g., Rivera et al. 1998; Thouret et al. 2001; Mariño Salazar 2002; Thouret et al. 2002; Gerbe and Thouret 2004; Siebert et al. 2011; Samaniego et al. 2015]. A recent example of highly explosive volcanism occurred at Huaynaputina volcano 421 years ago. Indeed, on February 19, 1600 CE, a VEI 6 Plinian eruption began. During the next 17 days a succession of explosions and emissions of volcanic products occurred causing total devastation in an area of 5400 km^2. The total bulk volume of the tephra-fall was estimated as 13–14 km^3 [Thouret et al. 1999; Prival et al. 2020]. This eruption resulted in the deaths of more than 1500 people, the destruction of more than 16 villages, and had devastating effects throughout southern Peru [Thouret et al. 1999].

1.2 Brief history of volcano monitoring at IGP

The Sabancaya volcano unrest in 1986 was the main catalyst for the development of modern volcanology in Peru. This episode generated the initiative to establish a research program to monitor and study active volcanoes in the country. In 1988, after the onset of the Sabancaya crisis, the *Observatorio Vulcanológico del Sur* (OVS) was created as part of the *Instituto Geofísico del Perú* (IGP) in Arequipa. At that time, the IGP through OVS implemented some monitoring networks at Sabancaya volcano, which included five seismic stations. In those early years, and thanks to the support of institutions such as the *Institut de Recherche pour le Développement* (IRD, France), the *Universidad Nacional de San Agustín* (UNSA), and the *Autonomous Authority of Majes-Siguas* (AUTODEMA), a research team was created. Unfortunately, this first seismic network was removed after the eruption.

Years later, in 2005, in a joint effort between IGP and IRD, a network of five short-period permanent telemetered seismic stations was installed at Misti volcano. A further two telemetered stations were added in 2014 at this volcano. In 2006, Ubinas volcano started a new eruptive process that lasted until 2009. In response to this crisis, and with the support of the Ubinas village, the first permanent telemetered seismic station was installed at that volcano (station UBI1). In addition, three new telemetered seismic stations and tiltmeters were installed in 2007 at this volcano. Later in 2019, two further telemetered seismic stations were added. The data collected by this network have allowed the detailed and accurate documentation of the evolution of volcanic activity of Ubinas since 2006, including the 2006–2009, 2013–2017, and 2019 eruptions [e.g., Macedo et al. 2009; Inza et al. 2014]. This, in turn, enabled the OVS to issue accurate communications about the status and the probability of occurrence of an eruption of Ubinas to local and national civil authorities, and the to the population of Ubinas valley. In 2013, in response to a new reactivation of Sabancaya volcano, three permanent telemetered broadband seismic stations were installed at this volcano, and later in 2015, 2016 and 2018 a total of four new stations were added, allowing to show valuable observations during the unrest and eruption phase on this volcano. Later in 2015, four seismic stations were installed around Ticsani volcano, and one station was added in 2018.

In 2013, the IGP began the formulation of the public investment project "Improvement and Expansion of the Volcanic Risk Warning System in Southern Peru", and reached feasibility in 2015 with the support of the ministries of the *Presidencia del Consejo de Ministros* (PCM), the *Ministerio de Economía y Finanzas* (MEF), and the *Ministerio del Ambiente* (MINAM) of Peru. Through this project, IGP has upgraded and expanded its monitoring networks with modern geophysical instruments and digital telemetry in 12 volcanoes with highest risk in southern Peru (Table 1). The project made it possible to monitor more volcanoes and implement other monitoring methods. In August 2019, the *Centro Vulcanológico Nacional* (CENVUL) was formally created and attached to OVS, to continue monitoring and hazard-assessment program of the IGP. CENVUL is the official service of the Peruvian State responsible for monitoring and providing early warnings of future volcanic eruptions in the country to emergency managers, officials, and the public. This is one of the most ambitious projects developed by the IGP and the Peruvian government in recent years, and has also included the build of a modern building (being finalized) in Sachaca village, Arequipa.

2 Monitoring

Monitoring volcanoes involves the integration of a number of disciplines, to know of volcanic reactivation or eruption. Thus, CENVUL makes use of seismology, ground deformation, gas geochemistry, video camera, infrasound, and satellite-based techniques to detect eruption precursors in order to provide timely scientific advice and warnings to civilian authorities. Of the 16 Peruvian volcanoes listed as active or poten-

Figure 1: Map of southern Peru and the active and potentially actives volcanoes. Red triangles show the location of monitored volcanoes. Blue triangles show volcanoes that are not currently monitored. From 1 to 16 the following volcanoes are 1) Quimsachata, 2) Auquihuato, 3) Sara Sara, 4) Coropuna, 5) Andahua, 6) Huambo, 7) Sabancaya, 8) Chachani, 9) Misti, 10) Ubinas, 11) Huaynaputina, 12) Ticsani, 13) Tutupaca, 14) Yucamane, 15) Purupuruni, and 16) Casiri.

tially active, 12 are currently monitored by CENVUL. Given the variety of volcano types and volcanic hazards in Peru [Macedo Sánchez et al. 2016], the level of monitoring differs from volcano to volcano as described in Table 1. The data are transmitted to CENVUL as 24-bit digital signals by UHF radio telemetry where it is acquired by different data acquisition systems. The implementation of monitoring networks continues today, and it is contemplated to carry out the monitoring of the 16 volcanoes in the future.

2.1 Monitoring methods used

2.1.1 *Seismic network*

Seismic monitoring on Peruvian volcanoes goes back to the 1990s, when the first seismic network became operational on Sabancaya volcano. Today, CENVUL operates 45 seismic stations which are distributed on 12 volcanoes, six of them are short period (Lennartz 3DLite) and 39 are broadband seismometers (3 are Guralp 40T, 4 are Guralp 3ESP, and 32 are Trillium Compact 120s). All seismic stations are telemetered. The number of stations at each volcano depends on its lev-

Table 1: Distribution of permanent monitoring sensors at Peruvian volcanoes owned and operated by the IGP. With the exception of DOAS and Infrasound sensors, all of them are telemetered.

Volcano	Instrument							
	Seismometer	Tiltmeter	Camera	GPS	DOAS	Infrasound	Multi-Gas	Total
Sabancaya	7	–	4	2	2	–	1	16
Ubinas	7	3	3	2	2	1	1	19
Ticsani	5	1	1	–	–	–	–	7
Misti	6	–	2	1	–	–	–	9
Coropuna	5	2	1	–	–	–	–	8
Yucamane	3	2	1	–	–	–	–	6
Sara-Sara	2	1	1	–	–	–	–	4
Tutupaca	3	1	–	–	–	–	–	4
Huaynaputina	3	1	–	–	–	–	–	4
Casiri	2	1	–	–	–	–	–	3
Cerro Auquihuato	1	1	–	–	–	–	–	2
Chachani	1	1	–	–	–	–	–	2

els of activity. For example, Ubinas and Sabancaya have both seven seismic stations (Figure 2), whereas Casiri and Chachani volcanoes have one station each due to their low-level of activity. Additionally, we use data from the *Red Sísmica Nacional* (RSN) of Peru (operated by IGP) to reinforce the volcano monitoring of all active volcanoes in Peru, and *vice versa*. For their part, seismometers deployed at volcanoes complement the national seismic network for the analysis of regional earthquakes.

2.1.2 *Ground deformation*

CENVUL uses different methods to detect ground deformation of the flanks of the volcanoes. These include: Global Navigation Satellite System (GNSS), tilt, Electronic Distance Measurement (EDM), and satellite-based measurements. Due to the level of volcanic activity and risk, five telemetered GNSS units (Trimble NetR9 receiver and choke ring antenna) are distributed around Sabancaya, Ubinas and Misti volcanoes, with a sampling interval of 30 s and 0.2 s for telemetric transmission and onsite storage, respectively. These instruments have been operating since 2018. Two temporary GNSS units (Trimble R10) are used for periodical measurements during field surveys (at least twice by year) at 37 campaign sites distributed around 12 volcanoes. In addition, CENVUL has 14 telemetered analog tiltmeters (with ±0.46 degrees of dynamic range) are distributed at 10 volcanoes, and one Leica Total Station is used to temporarily measure horizontal displacements at Misti, Ubinas, and Sabancaya volcanoes. Additionally, we use Interferometric Synthetic Aperture Radar (InSAR) technique, using Sentinel-1 radar images, to monitor all volcanoes periodically.

2.1.3 *Gas geochemistry*

CENVUL uses Differential Optical Absorption Spectroscopy (mini-DOAS), Ultra Violet (UV) cameras, and Multi-GAS analyzer for monitoring volcanic gas emissions (SO_2, H_2S, and CO_2). Two telemetered Multi-GAS stations are installed at Ubinas and Sabancaya volcanoes to collect data to measure volcanic gas emissions rates and concentrations over time. Recently, four UV cameras and six mini-DOAS were purchased. The mini-DOAS will be installed with telemetry in the near future, while the UV cameras are used in punctual field campaigns (at least twice a year).

2.1.4 *Video cameras*

CENVUL has 13 cameras distributed on seven volcanoes, which provide one image every 30 or 60 seconds depending on the level of activity of each volcano. Thanks to these cameras, the plume elevation, ash dispersion, and characteristics of volcanic products emitted from the crater are monitored. In Ubinas and Sabancaya volcanoes, two cameras have been installed very close to the main ravines to monitor the descent of lahars. Likewise, we monitor the volcanoes through portable thermal cameras (FLIR T1020) in campaigns, that help us observe the dynamics of the explosions, such as the range of temperatures of ballistic blocks

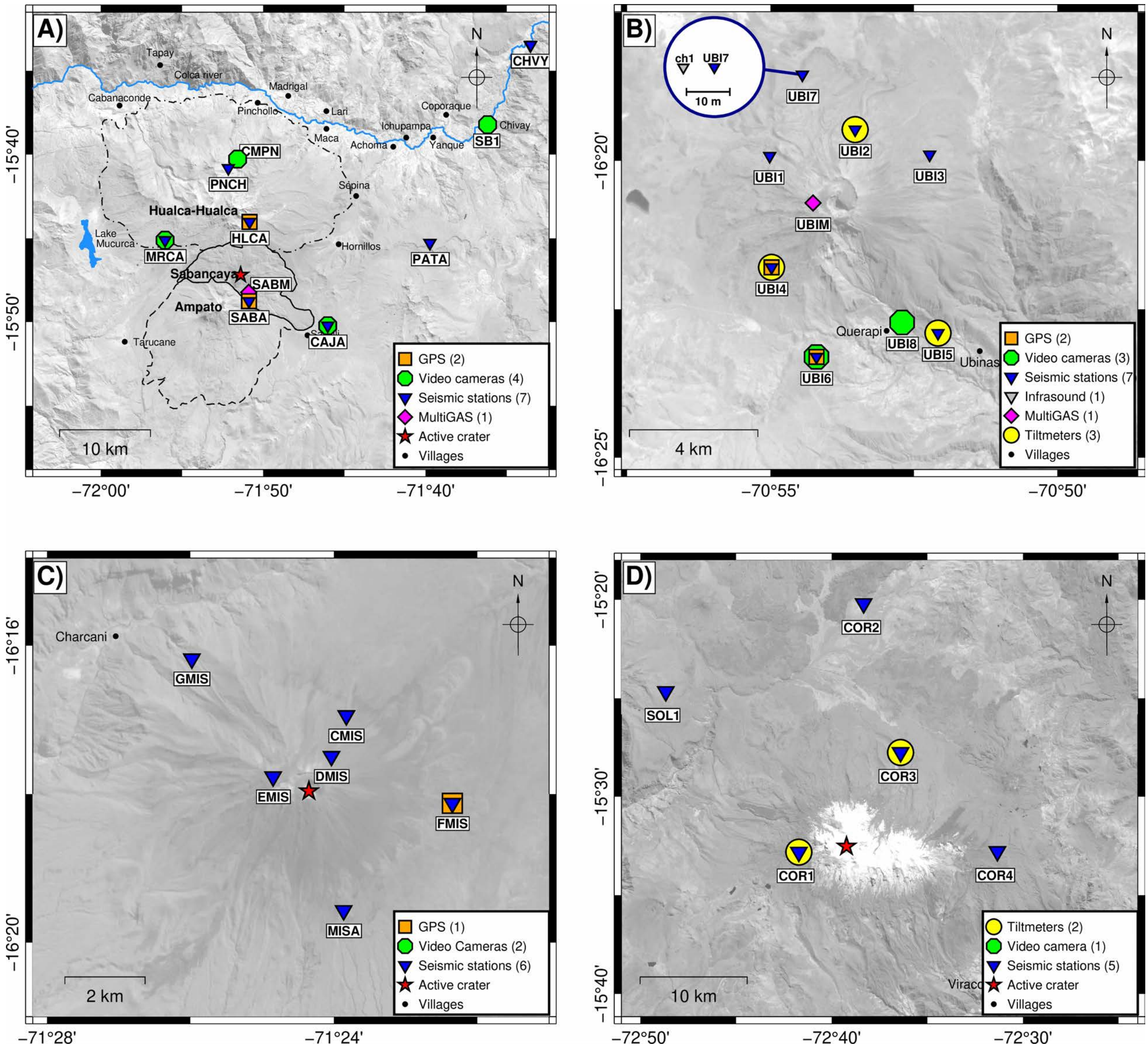

Figure 2: Maps of the instrument monitoring network operated by CENVUL at the top four highest-risk volcanoes in Peru: [A] Sabancaya, [B] Ubinas, [C] Misti, and [D] Coropuna. The black line indicates the limit of Sabancaya volcano in [A]. Some cameras are located outside of the map. All sensors with the exception of infrasound sensor in [B], are telemetered to Arequipa.

ejected and morphology changes in the crater, especially at night.

2.1.5 *Infrasound*

CENVUL is beginning to monitor volcanoes with infrasound sensors. At the moment, only one not-telemetered infrasound sensor is in operation at Ubinas volcano, due its high eruption rate and explosive style. However, thanks to the USGS Volcano Disaster Assistance Program (VDAP) support, a telemetered 5-element infrasound array will be installed at this volcano soon.

2.1.6 *Remote sensing observations*

CENVUL uses satellite-based remote-sensing for volcano monitoring on a local and regional scale. Monitored parameters include SO_2 flux, detection of hot spots in the crater, ash dispersion, topographic changes, and ground deformation. For example, to detect the topographic changes and the emplacement of the lava dome in the summit crater of Sabancaya volcano, using 13-bands Sentinel-2 Playground images, obtained every five days Planet images that delivers one image every day. We also use Planet images obtained every day, PERUSAT-1 satellite images, and aerial photographs taken with drones (in campaigns). To track ash plumes from eruptions, we use meteorological imagery (e.g., SEVIRI, GOES, and MTSAT). To detect thermal anomalies, we use the MIROVA system (Middle InfraRed Observations of Volcanic Activity) of the University of Turin, which is based on the analysis of infrared data acquired by the Moderate Resolution Imaging Spectroradiometer sensor (MODIS), and uses the Middle InfraRed Radiation (MIR) recorded with 1 km^2 resolution in order to detect, locate, and measure the heat radiated by hot bodies (e.g., lava flow, dome, etc.) in MW [Coppola et al. 2015]. The SO_2 gas fluxes are obtained through platforms such as the MOUNTS system and also processing TROPOMI data via Google Earth Engine. These data are updated daily and correlated with ground-based monitoring methods (see Figure 3).

2.2 Staff of volcano observatory

The CENVUL staff consists of 24 scientists and technical specialists in different disciplines such as: geology and hazard assessment (two geologists), volcano monitoring (six seismologists, two geodesists, two specialists in remote sensing), technical support (three electronics engineers, two technicians in electronic and computer sciences), and administrative support (four professionals and three drivers). Additionally, we have administrative, logistic, and technological support from the staff of IGP in Lima.

2.3 Data storage and access

CENVUL collects data in near real time from its seismic, GPS, tiltmeter, infrasound, video cameras, and Multi-GAS instruments. All information is stored internally in a database using MySQL. In the case of seismic data, for example, acquisition and data processing is performed by several modules of the `Earthworm` [Friberg et al. 2010] via RTPD (Real Time Protocol Daemon) protocol on a DELL Power Edge R320 server. Additionally, we also use `Winston` software to store long-term data and `SEISCOMP3` for pre-processing. The raw data can be accessed locally and remotely only by the monitoring staff, however, requests can be made through the National Geophysical Data Center (Spanish acronym: CNDG). In the case of agreements for research, access to information is free for all team members.

3 Volcanic risk management

Volcanoes in Peru provide great benefits, but also threaten the communities settled in surrounding areas. Today, about 1.4 million people live in zones directly subject to volcanic risk. Thus, volcanic risk assessment and management are important scientific, economic, and political concerns in these regions. Since 2011, disaster risk management in Peru has been governed by the *Sistema Nacional de Gestión del Riesgo de Desastres* (SINAGERD). SINAGERD has as operational members the *Instituto Nacional de Defensa Civil* (INDECI) and the *Centro Nacional de Estimación, Prevención y Reducción del Riesgo de Desastres* (CENEPRED). INDECI is responsible for implementing preparedness and response actions, while CENEPRED is in charge of disaster risk reduction. INDECI is responsible for the *Red Nacional de Alerta Temprana* (RNAT, i.e., National Early Warning Systems), including volcanic hazards. The RNAT has four components: (1) risk knowledge, (2) monitoring and warning, (3) dissemination and communication, and (4) response capability. CENVUL contributes to the first two elements of the RNAT.

Hazard maps are a common component of volcanic warnings. Thus, between 1990–2003, IGP in cooperation with the IRD has produced the first volcanic hazard maps of Misti [Thouret et al. 1995; Suni 1999; Thouret et al. 2001], Ubinas [Rivera et al. 1998], Sabancaya [Thouret et al. 1994], and Ticsani [Mariño Salazar and Thouret 2003] volcanoes, based on geological studies aiming to reconstruct the eruptive chronology of the volcanoes and volcanic hazard evaluation. Currently, hazard maps are mainly being developed by the *Instituto Geológico, Minero y Metalúrgico* (INGEMMET). These maps (official and the earlier ones) show three hazard zones represented in colors: the red color corresponds to high danger zones, orange color to moderate danger zones, and yellow color to low danger zones. These maps are used as communication tools for education and planning, providing information on areas most likely to be affected, for example, by ash fall, pyroclastic flows and other hazards.

Monitoring and warning are essential components of the RNAT. Thus, CENVUL has been expanding and increasing the level of monitoring at highest risk volcanoes in Peru. Data collected by the CENVUL is invaluable for providing timely and accurate information on volcanic behavior, forecasting imminent eruptions, and identifying community impacts. CENVUL has the mandate to provide official information (reports, bulletins, and warnings) of volcanic activity to local, regional and national officials and the public. CENVUL through its Knowledge Management program, assists authorities in developing mitigation action plans to reduce volcanic risk. All these actions contribute to volcanic risk management plans in Peru, towards the protection of life and property from volcanic events.

4 Information dissemination and outreach

CENVUL generates periodic bulletins, alert notification, and warnings on the changes in activity of the 12 monitored volcanoes in southern Peru. Once issued, these products are delivered immediately to the national head of the INDECI, the *Centro de Opera-*

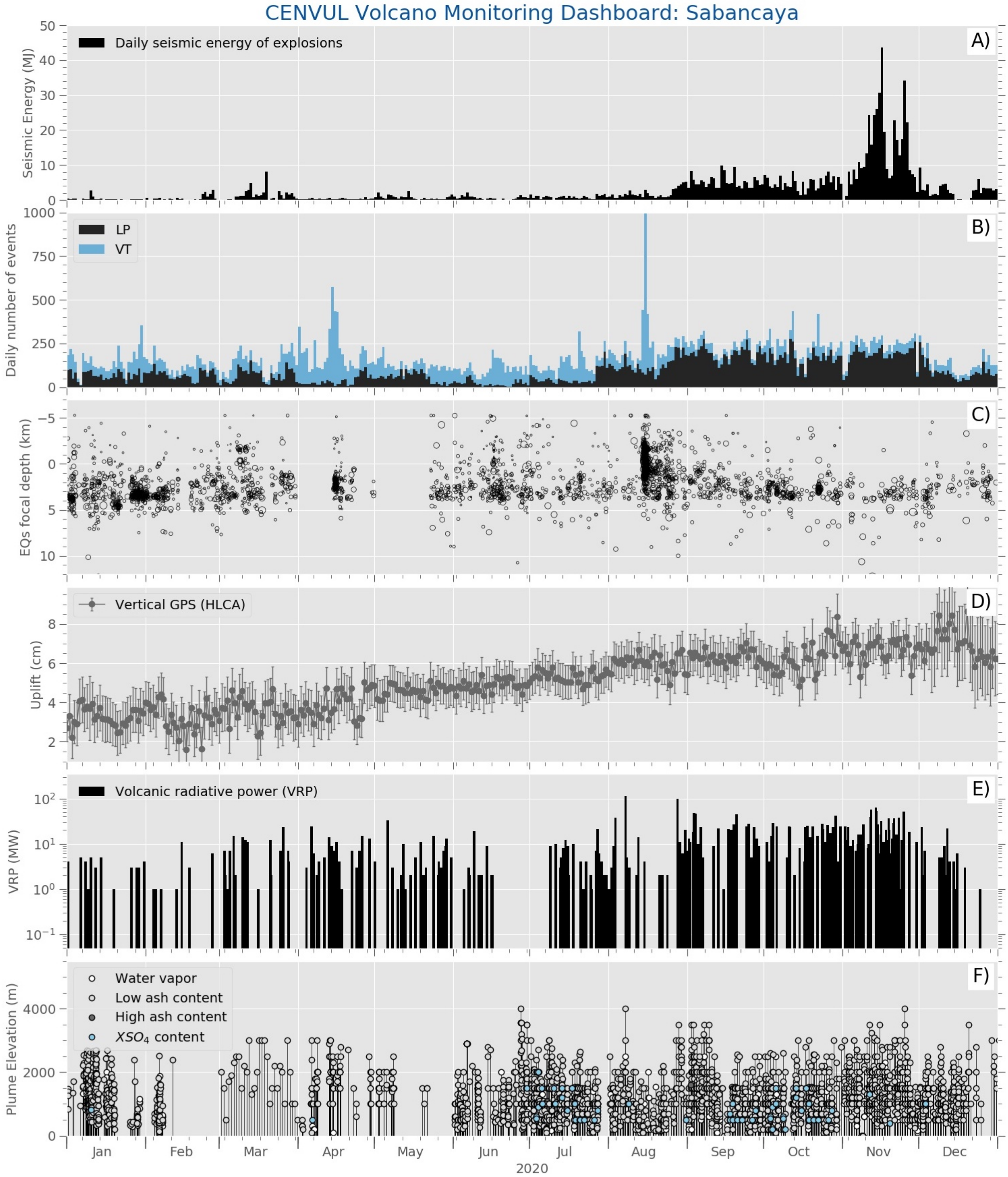

Figure 3: Example of Dashboard with the main multiparametric data obtained at Sabancaya volcano during 2020: [A] daily seismic energy of explosions; [B] daily count of seismic events; [C] volcano-tectonic seismicity focal depth; [D] uplift of the vertical component of the GPS located at HLCA station (Figure 2A); [E] satellite thermal anomaly measured by Volcanic Radiative Power (VRP); and [F] plume elevation with respective ash content.

ciones de Emergencia Nacional (COEN), and locally to regional governments and to the decentralized addresses of INDECI depending on where the volcanoes are located. Between 2013 and 2019, the volcanological reports were issued by a joint committee composed of IGP, INGEMMET, and UNSA. However, since 2019, official information has been issued by CENVUL.

4.1 Bulletins and volcanic alerts

4.1.1 *Volcanic activity bulletins*

Volcanic activity bulletins are technical scientific documents that contain information based on the analysis and interpretation of multiparametric data that describe the activity of a volcano in a given period. Bulletins are issued regularly for a fixed period (i.e., weekly, monthly), depending on the level of volcanic activity*. These bulletins are short and simple, written in easy to understand language, addressed to the general public, and to the authorities and technical institutions that are part of SINAGERD.

4.1.2 *Ash alerts*

Ash alerts are communications sent by CENVUL that describe the occurrence of explosions, in case the ash columns exceed 2000 m above the crater level. They indicate the direction of ash dispersion and the possible urban areas affected. These alerts are available only in volcanic crises when a volcano is in eruption. They are also sent to the regional Volcanic Ash Advisory Centre (VAAC), and local authorities, and those that are part of the disaster risk management system.

4.1.3 *Lahar alerts*

Lahars occur frequently during the rainy season at Misti, Ubinas, Huaynaputina, and Sabancaya volcanoes, affecting valleys farther downstream. CENVUL designed a lahar detection and warning system based on the processing of seismic data and video cameras. Both seismic stations and video cameras are installed in the upstream basin areas, where lahars are usually generated. Once the lahar is detected, an automated lahar warning message is broadcast to civil defense authorities at local and regional levels. These alerts warn of the descent of a lahar through the ravines of a volcano, indicating the ravine's name where the lahar is descending and the urban areas possibly affected.

4.1.4 *Volcano alert levels*

The volcano alert levels (VAL) system is an effective means of communication about the different levels of activity at a particular volcano and the general prevention measures that the population and its authorities must adopt to protect its integrity. In Peru, the VAL system consists of a color 'traffic light' scheme, from green (low level) to red (high level) which corresponds to a level of activity of a volcano and the measures to be taken, following the practice of most of other volcano observatories around the world [Gardner and Guffanti 2006]. However, the thresholds for determining an activity level differ from one volcano to another. The green level corresponds to a normal, non-eruptive state, while the yellow level corresponds to an increase in volcanic activity, and the orange level corresponds to a further increase in volcanic activity, with recurrent seismic activity, height of eruptive columns greater than 3000 m, constant ash fall, frequent and strong explosions that can eject ballistic blocks. The red level corresponds to a critical volcanic activity with imminent risk of a major eruption, with the occurrence of intense and prolonged earthquakes, constant ejection of ballistic blocks and ash emissions, formation of eruptive columns >4 km in height, and formation of pyroclastic density currents (PDCs) that can reach distances greater than 5 km. IGP periodically communicates to the civil defense authorities of the regional and local governments about the state of activity of the volcanoes, suggesting the level of volcanic alert. In case a volcano shows signs of reactivation or increased activity, CENVUL issues a bulletin or report recommending to the civil defense authorities of the regional governments the change of alert level, since they are in charge of assisting the inhabitants of the localities at risk.

4.1.5 *Outreach*

CENVUL generates diverse educational materials (brochures, booklets, flyers, etc.) to the officials and public. These are designed using simple language and distributed during the visits to the OVS by students, authorities, and community groups. They are also distributed at dissemination events organised by the OVS, such as: in training talks, conferences, evacuation drills, science fairs, etc. Requests must be made by contacting the official email channels of IGP. Additionally, to exchange the knowledge in volcanic risk, forums, meetings, and workshops are frequently organized by IGP.

4.2 Communication channels

CENVUL disseminates the bulletins and alerts over different communication channels. (1) Official email address*. (2) The VOLCANES PERÚ mobile application (Android and iOS). Through this application, notifications are issued notifications every time a new bulletin is published. (3) The website†, in which the information obtained from the different monitoring methods is published. The website also publishes the latest notifications and bulletins issued on volcanic activity. (4) The IGP social media: Facebook‡ and Twitter§ and (5) WhatsApp, through which information about volcanic activity is sent, mainly to the authorities of several public institutions. In addition, this last medium is used

*https://www.igp.gob.pe/servicios/centro-vulcanologico-nacional/productos-boletines

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†http://www.igp.gob.pe/servicios/centro-vulcanologico-nacionaleruptions

‡https://www.facebook.com/igp.peru

§https://twitter.com/igp_peru

for communication with the inhabitants of localities near volcanoes with eruptive activity, for information exchange through images, videos and documents.

Information from volcanic monitoring is sent to the national head of the INDECI and to the directors of the decentralized addresses of the INDECI of the regions of Ayacucho, Arequipa, Moquegua, and Tacna, according to the monitored volcano. The bulletins are also sent to the regional governors and those responsible for the *Centro de Operaciones de Emergencia Regional* (COER) of each region.

5 Cooperation with public institutions for disaster risk management

CENVUL cooperates with the national, regional, and local government agencies to disseminate information on volcanic hazards and risks. Warnings issued by CENVUL are sent to the RNAT and its member agencies. INDECI is responsible for emergency management in Peru, providing technical advice in the processes of prevention, response, and rehabilitation of natural disasters. It also provides technical assistance to competent authorities at different levels. Based on the alert issued, response mechanisms are established by the agencies in charge of risk management. CENVUL maintains close cooperation with the Local and Regional Emergency Operations Centers (COEL and COER, respectively). The decision of these agencies is made using the technical scientific information issued by CENVUL for the adoption of measures for the benefit of the population (change of the volcanic alert level, potential evacuations of people, request for declaration of state of emergency, preparation of emergency plans, etc.).

6 Needs, challenges, and future perspectives

CENVUL is a growing IGP service attached to the OVS. Currently, improvements to the monitoring networks are being carried out, for which new multi-parametric monitoring equipment are being installed. However, one of the major necessities is to acquire more equipment to complete the monitoring of the 16 active or potentially active volcanoes in Southern Peru. The main challenge in the near future for CENVUL will be the integration of the different monitoring methods such as seismic, geodetic, geochemical, visual, tiltmeter, infrasound, and remote sensing for better characterization of volcanic activity and eruption forecasting, as well as automation in the processing of all signals coming from volcano monitoring.

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Author contributions

R.M. and M.R. wrote the manuscript. M.R. and L.M. wrote about volcanic hazard management. J.D.C. and J. C. wrote about information dissemination. H.T. wrote the brief history of IGP. R.M., J.D.C., I.L., R.C., N.P., J.T., K.V., J.C., and L.V. wrote about the monitoring networks and provided information for Table 1, Figure 1, and Figure 2. A.M. and J.V. wrote the data storage and access, and provided information for Table 1. All authors reviewed the final manuscript.

Data availability

Data are available through the CENVUL website (https://www.igp.gob.pe/servicios/centro-vulcanologico-nacional/), and through the corresponding author upon reasonable request.

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