Building local capacities for monitoring eruptive and catastrophic landslide activity at Pacaya volcano (Guatemala), through international partnership and collaboration.

Final report.

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Executive summary

The project “Building local capacities for monitoring eruptive and catastrophic landslide activity at Pacaya volcano (Guatemala), through international partnership and collaboration” has successfully achieved the goal of improving volcanic hazard mitigation at Pacaya volcano, through collaborative work with several Guatemalan counterparts. The project included three main components: 1. Instrumentation for monitoring volcanic activity, which was mainly implemented in partnership with the “Instituto Nacional de Sismologia, Vulcanologia, Meteorologia e Hidrologia” (Institute of Seismology, Volcanology, Meteorology and Hydrology - INSIVUMEH), the institution in charge of volcano monitoring and hazard assessment in Guatemala. 2. Rising volcanic hazards awareness, which was mainly implemented in collaboration with the Parque Nacional Volcan de Pacaya y Laguna de Calderas (Pacaya Volcano and Laguna de Calderas National Park - PNVP). 3. Building technical capacity through involvement of student thesis projects, which was mainly implemented with students from the San Carlos University.

The instrumentation components included the installation and operation of 3 seismic stations, 3 continuous GPS stations, and one webcam, which will be transmitting in real-time to the INSIVUMEH headquarters. The hazard awareness component included building a three-dimensional model of the volcano and surrounding towns, as well as hazard information panels to be displayed in the new PNVP museum and visitor center. The thesis projects with the San Carlos university students includes three thesis projects, one on the analysis of the seismic data being produced by the newly installed instruments, and the other two on the lava flow hazards and the ballistic projectiles and tephra fall hazards associated to Pacaya’s activity. Although individual project components were mainly focused at particular counterpart institutions, inter-institutional collaboration was key to the success of the project, particularly the involvement of the PNVP in supporting the infrastructure building, and INSIVUMEH’s support for the student’s thesis projects.
1. Introduction

Pacaya volcano is one of Guatemala’s most active volcanoes, and it is located near very densely populated areas, including the country’s capital, Guatemala City. Volcanic hazard at Pacaya include ballistic projectiles, air-fall tephra, lava flows, lahars and debris avalanches (Banks, 1987, JICA, 2003). Recent eruptions at Pacaya have cause loss of life and damage to property and infrastructure, for instance the May - June 2010 eruption caused widespread destruction in the surrounding villages, and produced tephra fall in Guatemala City, leading to close the airport for several days (Wardman et al. 2012). Nearby towns were hit by ballistic projectiles which destroyed houses, infrastructure and crops. Similar eruptions happened in 2000, 1998, and 1987. Large volcanic collapses have also formed part of Pacaya’s geologic history (Vallance et al. 1995). Recent Interferometric synthetic aperture radar (InSAR) studies have shown that the flanks of the Pacaya volcano has experienced significant slope instability along with volcanic eruptions (Schaefer et al. 2015; Schaefer et al. 2016; Schaefer et al. 2017). Pacaya is also a very important destination, with an annual tourist flux of > 50,000 visitors. Figure 1 shows a map with the nearby towns and the active vent.

![Figure 1. Map showing the location of towns and estimated population with respect to the active vent (Escobar-Wolf, 2010).](image)
The Guatemalan Institute of Seismology, Volcanology, Meteorology and Hydrology (INSIVUMEH) is in charge of monitoring the volcanic activity and assess the volcanic hazards in the country. The Guatemalan National Agency of Coordination for Disaster Reduction (CONRED) is in charge of volcanic risk management and volcanic crisis response. INSIVUMEH and CONRED work together to mitigate risk and respond to volcanic crisis when they arise. Pacaya volcano on the other hand is also within the Pacaya Volcano and Laguna de Calderas National Park (PNVP), which is the administrative authority in charge of managing the access of tourists to the volcano. Based on advice received by INSIVUMEH and CONRED, the PVNP is responsible for restricting access to the volcano during episodes of heightened activity.

Volcanic risk mitigation and crisis management has to be based on solid technical and scientific advice about the evolution of volcanic hazards, and such advice requires input from the best volcano monitoring capabilities available (Fournier d'Albe, 1979; Tilling, 1989; Tilling 2008). In that sense, INSIVUMEH’s monitoring activities constitute the cornerstone of the risk mitigation and crisis management process, and the availability of adequate monitoring and forecasting tools is critical for them. Until recently, the volcano was permanently monitored only by one seismic station and by visual observations from a nearby observation post. Loosing the signal from that single seismic station meant losing all instrumental monitoring capabilities for that volcano.

Several international collaboration efforts have helped Guatemalan agencies in developing their technical capacity and build volcano and other hazard monitoring capabilities, some of these efforts have focused on technology transfer, sometimes neglecting the human capacity building element. Long-term sustainability of such endeavors are limited, as the technical capacity relies on continual support from external sources. In the past, the restricted number of technical personnel imposed a limit to the transfer of know-how along with the technological aid, but INSIVUMEH’s technical staff has recently increased thanks to hires of young professionals and university students (in their finishing year), mainly from the national San Carlos University, who now participate in the monitoring of Pacaya’s activity. This has opened the possibility of further training and capacity building of the technical personnel, which should help in the long-term sustainability of the technology transfer projects.

Monitoring and hazard information generated by INSIVUMEH has to reach other agencies involved (e.g. CONRED) for it to be useful for volcanic risk mitigation and crisis response. Established communication protocols and procedures assure that this happens, but the
information should also reach a broader audience, not in a highly technical format, but in a more easily digestible and understandable format. Hazard awareness and education components are key in long term efforts to mitigate risk, and the PNVP can play an important role in that sense. Park visitors, both local and international, learn about the volcano’s history, local culture and other interesting topics, through the Park’s visitor center, the guides and written material, both in print and on the web. This makes the PNVP an ideal channel to disseminate specific information on hazards and risk mitigation. Currently a large infrastructure expansion is underway at the PNVP, which includes the building of a volcano visitor center and museum, this venue will be the right environment to host information on risk and hazard and transmit it to visitors in an effective way.

The project for building local capacities for monitoring eruptive and catastrophic landslide activity at Pacaya volcano (Guatemala), through international partnership and collaboration, aimed to help with the main issues related to volcano monitoring, capacity building, and hazard awareness through outreach. Collaborative work with INSIVUMEH, the San Carlos University, and the PNVP made this project possible, and ensured long term sustainability of the project products.

2. Volcano monitoring component

Volcano monitoring has evolved through the years into a highly technical and specialized activity. A wide array of monitoring techniques are used by volcano observatories worldwide, but the use of such techniques depends on the resources available to the monitoring agency. Seismic and deformation monitoring are amongst the oldest and most widely used monitoring techniques at active volcanoes. Visual monitoring has probably been the oldest monitoring method, but with the advent of digital webcams, visual monitoring can be complemented with webcam monitoring, allowing a continuous record (weather permitting) of the volcanic activity. After consultations with INSIVUMEH it was decided that seismic, deformation (using continuous GPS), and digital video monitoring would be most beneficial for the monitoring purposes at Pacaya.

In agreement with INSIVUMEH, it was decided to install three seismic and GPS instruments, collocating them at the same sites. This would leave INSIVUMEH with 4 seismic stations (the three new ones plus the existing one) and 3 continuous GPS instruments to measure deformation at Pacaya volcano. It was also decided to install one real-time webcam at Pacaya.
2.1 Site location selection

The selection of sites for the installation of the instruments is also guided by a trade off between the quality of information we hope to gather and the practicality of the locations where we can install the instruments. From a data quality perspective, the closer to the volcano we can install the instruments, the better. From a practical point of view, several criteria were considered, including safety, noise levels, telemetry data transmission availability, availability of power, and accessibility. Extensive fieldwork and testing was conducted to find places where those criteria would be met and to locate them as close to the volcano as possible. Eventually, one of the GPS locations had to be changed due to concerns for the safety and potential obstruction of the GPS antenna, resulting in 5 different locations for the installation of instruments (see figure 2).
Figure 2. Map showing the location of the instrumentation installed as part of the project. Each number corresponds to a station in the following locations. 1 El Rodeo (Seismic and GPS), 2 Los Pocitos (Seismic and GPS), 3 Calderas (Seismic), 4 San Francisco de Sales (GPS), 5 San Vicente Pacaya (Webcam).
2.2 Monitoring infrastructure

To be able to deploy permanent seismic and GPS instrumentation near to the volcano it was necessary to consider building some basic infrastructure, to assure the safety and good operation of the equipment. After consultations with INSIVUMEH and USGS experts who have worked in Guatemala and many other countries, under similar conditions, it was decided that a small cinder block and reinforced concrete structure, called “caseta” in Spanish, would be build to host the instruments at locations where this was needed. At locations where existing structure was present to place the instrumentation safely a caseta was not build. An agreement was reached between the local municipality and Michigan Tech that the labor for the construction of casetas would be provided by municipality and Michigan Tech through the project funding will provide the material. Three casetas were build at locations 1, 2 and 3 shown in the map in figure 2.

![Image of caseta and equipment](image)

**Figure 3.** View of the caseta and equipment in the process of being installed. Left panel shows the interior of a caseta, with equipment being installed and tested. Right panel shows the caseta exterior, with the information banner and equipment in the process of being installed.

2.3 Data telemetry

Real-time monitoring requires the telemetric transmission of the monitoring signals. Several options were explored, including radio wave transmission, but after consultation with INSIVUMEH and USGS experts it was decided that cellular modem data transmission would be a better option. The recent expansion and widespread coverage of cell-phone (and modem internet) services in Guatemala provided an opportunity to use this new technology for data transmission. Commercial cell-phone providers offer data plans for transmission of a certain data volume at a fixed price.
One year data plans between 2 and 4 GB were purchased for real-time telemetry of seismic, GPS, and webcam data. INSIVUMEH agreed to take over the payment of these plans after the expiration of the yearly data plan.

Modems provided by cellphone companies and which usually come, or can be bought with the data plans in Guatemala are not sturdy enough for deployment in rugged outdoor conditions. For that reason we purchased separate Sierra Wireless Raven-X modems, which hosted the cellphone provided SIM cards, for all the sites that required this type of modem.

### 2.4 Seismic monitoring

Instrument selection and purchase was guided by monitoring needs and budget constraints. The number of instruments that could be deployed depended on a trade off of the type of instruments that were acquired and the available budget to buy them. Broadband seismic instruments provide the most amount of information for monitoring, but are very expensive. Short period and intermediate period instruments are much less expensive and can still provide the needed information for monitoring purposes. After consultations with INSIVUMEH three OSOP Sixaola short period instruments were purchased (see figure 4). The Sixaola is a self contained sensor, digitized, data logger and processor that can be directly connected to a modem for data transmission. These are 6 component (3 velocity and 3 acceleration) instruments with a 24 bit digitizer.

![OSOS Sixaola short period seismometer](image)

*Figure 4. OSOS Sixaola short period seismometer (image courtesy of OSOP).*

All three seismic instruments were installed in casetas, which have a specially designed foundation for the instrument, to avoid interference with the caseta structure. Casetas were also located far enough from houses to minimize the anthropogenic noise. One of the instruments is
powered by a solar panel and batteries, while the two other instruments are powered through the power grid.

Seismic monitoring data are streamed directly to INSIVUMEH’s SeisComp server, and is integrated with other INSIVUMEH seismic stations. The data then are used for localization and other routine tasks, as part of the Guatemalan national seismic network. The data are also being used in the thesis project by one of the San Carlos University students being co-advised by Co-PI (G. Waite), as described in the corresponding section of the report.

![Figure 5. Screenshot of seismic records from the three stations installed at Pacaya.](image)

2.5 Continuous GPS deformation monitoring

The selection and acquisition of GPS deformation monitoring equipment was also driven by the monitoring needs and budget constraints. Michigan Tech Geologic department donated two Trimble NetRS receivers with Zephyr Geodetic antennas, and a third Trimble NetR9 receiver and Zephyr Geodetic antenna was purchased by the project, to have three fully functioning, continuous
GPS stations for monitoring volcanic displacement. This high-quality geodetic GPS is a standard for continuous GPS stations and can detect mm scale displacements over periods of days.

Due to equipment safety, accessibility, and other constraints previously explained, originally the plan was that the GPS stations would be installed in the same locations as the seismic stations, to be able to use the casetas infrastructure, however the antennas have to be outside of the casetas. In one location (the Calderas station) local hosts raised concern that having the antenna outside the caseta may be too risky for looting or vandalism reasons, and there were also some sky-line obstructions (e. g. trees). This led us to decide to move the location for that GPS station to a new site. Since GPS is less affected by anthropogenic noise, we chose the house of one of the local INSIVUMEH collaborators on a village very close to Pacaya, as the installation site. For the new location a concrete pile had to be built. GPS data processing is done by UNAVCO.
Figure 6. GPS equipment like the one installed at Pacaya volcano. Upper left panel: Trimble NetRS receiver. Upper right panel: NetR9 receiver. Lower panel: Zephyr geodetic antenna. (images courtesy of UNAVCO).

The INSIVUMEH counterparts were trained in the installation of the GPS antenna and other components (see figure 7), so that they can install the station that is pending, once the concrete pile is finished. Daily files are pushed to the UNAVCO ftp server and from there the processing algorithms grabs the file and produces position solutions. INSIVUMEH has access to the files and can therefore track displacement changes at the Pacaya volcano. If needed, they can also generate higher rate files, to track more closely the evolution of deformation.
2.6 Webcam monitoring

An Axis Q1604 network camera was purchased by the project for video monitoring of the volcanic activity. The camera has a dual night and day viewing modes (visible and NIR), which makes it very useful as a daytime, but also nighttime monitoring tool, as the hot volcanic material can easily be seen. Images are taken every 10 seconds and sent to a Michigan Tech server where they are temporarily stored, and later moved to another archiving server. The webcam is publicly accessible through the following URL:
http://ovfuego-norte.geo.mtu.edu/ovpac.php

All the data are made available in real time to INSIVUMEH. Periodically, time-lapse videos are generated from the nighttime images and posted on a dedicated YouTube page
https://www.youtube.com/channel/UCNobZgJISZ0x5-EwXvZUSkg
3 Volcanic hazards outreach component

The volcanic hazards outreach component was developed in collaboration with the Pacaya Volcano National Park (PNVP) administration, but with input and help from INSIVUMEH. The original proposal was adapted to the plan that PNVP has developed surrounding a newly proposed museum and visitor center. The proposed museum and visitor center, the construction of which will be funded by the Guatemalan government, includes some of the ideas that were previously considered as part of our proposal. This led us to reassess the proposed ideas and focus on better complementing the PNVP efforts. The PNVP’s design for the new museum and visitor center (fig 9) includes an area for a scaled model of the volcano, and a room to present about the volcanic hazard, it was on those areas that we focused our efforts.

A 1:10,000 3D scaled model of the volcano and surrounding areas, covering the volcanic cone and the nearby villages. The scaled model was funded by the project and is being built by one of the contractors working with the PNVP. At that scale the model covers an area of 1 x 1.2 meters, highlighting key features, like the volcanic vent, the nearby towns, roads, and other important landmarks. The model will give the visitors to the museum and visitor center a three-dimensional feeling of the volcano terrain and surrounding landscape.
Figure 9. Design plan of the new PNVP museum and visitor center being built in 2017 - 2018, with spaces for the three-dimensional scaled model and hazard panel information labeled in blue (design plan courtesy of PNVP).

The volcanic hazards section will also include two 1.2 x 1.8 panels funded by the project, and which are also being made by a contractor working with the PNVP. The panels contain information on hazards and hazard mitigation, as well as the monitoring efforts at Pacaya volcano. The scaled model and the hazard information panels will be temporarily hosted at the San Vicente Municipality, but will be moved to the new museum and visitor center, when it opens to the public (projected to happen in late 2018).

4 Volcanic hazards training component

The volcano hazard training has focused on the work being done with three students from the San Carlos University, and who were recently hired as permanent staff by INSIVUMEH. The students are being co-advised by a Michigan Tech advisor and a local Guatemalan advisor. Thesis topics
aimed to work with data generated by the project and related to hazard assessment needs. One project is focused on analyzing the seismic data being produced by the newly installed stations, and two other projects focus on using physical models to assess tephra, ballistic volcanic projectiles, and lava flow hazards.

4.1 Thesis project on lava flow hazard modeling and assessment

The thesis project being developed by Carla Chun Quinillo, titled “Actualización de mapas de Amenaza por flujos de lava del volcán Pacaya, San Vicente Pacaya: una actualización por modelos de procesos físicos y validación de campo.” (Lava flow hazard maps updating at Pacaya volcano, San Vicente Pacaya: and updating using physical process modeling and field validation), will use numerical models implementations based on the DOWNFLOW and FLOWGO models, to assess potential hazard scenarios for future eruptions, taking into account the lava flow properties (mainly effusion rate and physical properties of lava, like temperature, viscosity, etc.) of previous eruptions, and the terrain characteristics. Importantly, the variation in the locations of potential future vents will be explored, to assess how this important parameter may play into the spatial distribution of the hazard. This will result in estimates that lava flows may reach the nearby villages, infrastructure or agricultural land.

Carla Chun Quinillo is an undergraduate student at the San Carlos University who recently was hired as permanent staff at the INSIVUMEH volcanology department, and who as part of her degree requirements has to write a thesis. She is also required to work on hazard assessment problems as part of her work in INSIVUMEH, therefore combining both activities into a thesis was a natural idea. She has presented her thesis project to the evaluation committee at the San Carlos University and has received some comments and corrections. After addressing the comments and corrections she is re-submitting her thesis project and awaiting the response of the evaluation committee to start working on the project. Meanwhile, Co-PI (R. Escobar-Wolf) has been holding weekly to bi-weekly virtual meetings (over the internet) with Carla, to discuss the thesis project, train her in the processing methods and help her with the thesis proposal. Her planned schedule aims for an 8 month project, finishing next spring.
4.2 Thesis project on ballistics and tephra fall hazard modeling and assessment

Dulce Gonzalez Dominguez is developing a thesis project titled “Modelamiento de Amenaza por caída de ceniza y proyectiles balísticos en el área del volcán Pacaya.” (Ash fall and ballistic projectile hazard modeling at Pacaya volcano). This thesis project will use numerical models implementations based on the models EJECT and TEPHRA, to assess potential hazard scenarios for future eruptions, taking into account the ballistic and tephra properties (mainly size, grain size distribution, density, etc.) of previous eruptions, and typical wind field (velocity, direction, etc.) and terrain characteristics. Wind field variations will be sampled from available meteorological datasets (e. g. from the Global Forecast Model). This will result in estimates of the likelihood of moderate impacts over large urban areas, including Guatemala City (in the case of tephra), and very intense impacts on small populated centers, including the villages at less than 5 km from the vent (in the of tephra and ballistics).

Dulce Gonzalez Dominguez is an undergraduate student at the San Carlos University who recently was hired as permanent staff at the INSIVUMEH volcanology department, and who as part of her degree requirements has to write a thesis. She is also required to work on hazard assessment problems as part of her work in INSIVUMEH, therefore combining both activities into a thesis was a natural idea. She has presented her thesis project to the evaluation committee at the San Carlos University and has received some comments and corrections. After addressing the comments and corrections she is re-submitting her thesis project and awaiting the response of the evaluation committee to start working on the project. Meanwhile, Co-PI (R. Escobar-Wolf) has been holding weekly to bi-weekly virtual meetings (over the internet) with Carla, to discuss the thesis project, train her in the processing methods and help her with the thesis proposal. Her planned schedule aims for an 8 month project, finishing next spring.

4.3 Thesis project on changes in seismic ambient noise

Amilcar Roca is finishing his Bachelors Degree in Physics at the Universidad de San Carlos, Guatemala. He has chosen to investigate temporal changes in ambient seismic noise at Pacaya volcano for his thesis project. The method has proven to be effective in detecting small changes, on the order of a fraction of a percentage, in the seismic velocity structure beneath volcanoes. These changes are most likely attributed to changes in crustal stress related to pressure variations
in the magmatic system. The stress changes alter the density of open microcracks leading to small changes in seismic velocities. These small changes are revealed in the coda of multiply scattered waves. The autocorrelations of data from a single station and cross correlations between channels from two stations carry information about the seismic structure. By comparing daily auto or cross-correlations over many weeks or months, small changes in the upper crustal magmatic system can be detected as the time lag to various features in these correlation functions grows or shrinks. The changes in time lags are directly related to changes in the average velocity.

In this work, Amilcar is using data from the three new permanent seismic stations to examine autocorrelations and cross correlations. The data from these instruments are being stored at INSIVUMEH in their SeisComp system. Amilcar has been working on this project for most of the last year and has nearly finished the analysis. As a physics student, Amilcar did not have a background in volcanology or seismology, so we began by working through some of the basics of volcano seismology. He then rapidly progressed on his specific research tasks. Thus far, he has learned how to organize a database in MySQL, preprocess data for correlation (deconvolve instrument responses, normalize in the time domain, whiten spectra, bandpass filter), obtain auto and cross-correlations for all the recorded data. He is currently working to measure any temporal variations and then will interpret correlation results. He should be finished by the end of July 2017.

5 Conclusions and recommendations

The project’s aim to build capacities for monitoring eruptive and catastrophic landslide activity at Pacaya volcano, through international partnership and collaboration has successfully accomplished its main goals, in three areas: technology and instrumentation transfer, helping to create hazard awareness, and technical hazard training. Although some of the project goals had to be adapted to the needs of our counterparts the collaboration was highly successful, opening further venues for future collaboration. The involvement of several Guatemalan agencies in the collaborative work, as well as students and local participants further enhanced the project’s achievements, and will contribute to the long-term sustainability of goals.

Seismic, GPS, and webcam equipment will greatly improve the instrumental monitoring capabilities at Pacaya Volcano, and allow INSIVUMEH to produce better volcanic activity forecast and hazard information for long term use, and during crisis. The three-dimensional scaled volcano model and hazard information panels build for the new PNVP museum and visitor center will contribute to generate hazard awareness amongst local and foreign visitors to the National Park.
The ongoing thesis work with three San Carlos University students, who also work for INSIVUMEH will further expand the technical capacities of INSIVUMEH through the know-how transfer, and produce specific hazard and research products (the outcome of the thesis projects) focused on Pacaya.

This project shows the potential of international technical collaboration on hazards and risk reduction projects. Continuing with similar projects in the future could be of immense benefit in reducing the impact of hazards. Expanding the Pacaya project or duplicating it for other volcanoes has the potential for a high humanitarian payoff. This project illustrates in a very tangible way, how humanitarian efforts by the technical and scientific community can have a direct impact in reducing the impact of natural hazards.

6 References


