Hydrometeorologic and geologic hazards at Pico de Orizaba volcano, Mexico

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FollowUp Form

Basic Information

Project Name*
Name of Project
Hydrometeorologic and geologic hazards at Pico de Orizaba volcano, Mexico

Project Start Date*
Select the date when your project was started.
07/31/2018

Project End Date*
Select the date when the project ended.
08/31/2021

Report Author(s)*
List the names of the primary author(s) of this final report.
Katrin Sieron, Blake Weissling

Executive Summary
The Executive Summary section of the report should succinctly, yet comprehensively, summarize the project and its outcomes. Greater detail on the project will be provided as outlined in the additional sections of the report.

Introduction*
Provide a brief, focused introduction to the project and its need.
The project focuses on the lahar hazard along the Jamapa River basin, draining the Pico de Orizaba volcano (5675 m asl) glacier, by studying the high mountain meteorological and geological conditions.

Project Goals and Objectives*
Describe the project goal(s) and objectives as they were outlined in the Phase II application or subsequent project revisions approved by the GWB Committee.
1. Evaluate the secondary lahar hazard. Investigate the hydrological and geological controls leading to the generation of flows through geological and geophysical surveys.
2. Elaborate hazard maps. Identification of lahar inundation areas towards an updated hazard map.
3. Install and evaluate a lahar warning system. Instrument the upper river valley for precipitation.
4. Expanding the knowledge. Research opportunities (students) and involvement of communities and risk reduction agencies.

**Project Participants**

List all project participants, with title and affiliation.

- Katrin Sieron, Phd, Center of Earth Sciences, UV
- Blake P. Weissling, Department of Geological Sciences, UTSA
- Carlos M. Welsh Rodriguez, Phd, Center of Earth Sciences, UV
- Carlos Ivan Tellez Gutierrez Lecturer, Master deg, Veracruz University
- Dolors Ferrés López, Phd, ENCIT–UNAM
- Marco A. Morales Martínez, Master deg, Center of Earth Sciences, UV
- Cristian Martínez Báez, B.S. thesis student in Environmental Engineering, Faculty of Chemical Sciences, UV
- Federico G. Casarin Puglia, B.S. thesis student (Geography), Faculty of Economics, Geography and Statistics, UV
- Ángel J. López González, B.S. thesis student in Geography, Faculty of Economics, Geography and Statistics, UV
- Emilio J. Cruz García, B.S. thesis student in Geography, Faculty of Economics, Geography and Statistics, UV
- Edwin Ulices Monfil León, Research Assistant and Master student, UNICACH
- David Francisco Arellano Olivo, B.S. thesis student in Geography, Faculty of Economics, Geography and Statistics, UV
- Dafne Perdomo de la Presa, B.S. thesis student in Geography, Faculty of Economics, Geography and Statistics, UV
- Sergio Terán, Research Assistant and Master student, Department of Geological Sciences, UTSA
- Juan Campos, Research Assistant, UTSA
- Asunción Castillo Rojas, Center of Earth Sciences, UV
- Julio C. González Hernández, Master deg, BUAP
- José Serrano Ortiz, Master deg, BUAP University
- Román Gutiérrez Anguiano, B.S. thesis student in Geophysics, BUAP
- Priscila Esquinca Sol, B.S. thesis student in Geophysics, BUAP
- Pamela B. Marquez Arellano, B.S. thesis student in Geophysics, BUAP
- Jesús Ortízgoza González, B.S. thesis student in Geophysics, BUAP
- José Luis Sílvan Cárdenas, PhD, Centro Geo
- Karime González-Zucolotto, Master deg, Research assistant, Centro Geo
- José Manuel Madrigal Gómez, cand. Master, Technician, Centro Geo
- Pasquinel de la Fraga Chávez, Master deg, Civil Protection Agency
- Isabelle Barois, Phd, INECOL
- Adrián Sosa Medellín, Master student, LANIA
- Fátima P. Carreto Peralta, Master student, COLVER
- etc.

**Methods Used**

List all methods used, including application and specific instrumentation.
**Summary of Results and Key Findings**

Provide a summary of the project's results and key findings.

- Geophysical measurements of the glacier thickness (Georadar) and comparison with earlier data of similar trajectories. Thickness estimations in non-sampled glacier areas was based on these direct data. The Jamapa glacier radargrams showed thicknesses between 80 cm at the edges up to more than 17 meters. In general, the glacier thickness is around 10 meters, and the area covered by the glacier ice is 0.56 km2. The data was used to finally calculate the ice volume (0.0056 km3 in 2019) and for estimating additional water during extreme lahar scenarios (partial or total glacier breakoff).

- Georadar and seismic measurements of the unstable sediment sources at the proglacial ramp area; several m-thick horizons of unconsolidated material have been identified, although total sediment thickness is estimated to be higher than the measured 6 (upper ramp) and 15 m (lower fan/talus composed of volcaniclastic material) max.

- The lahar forming proximal area above 3600 m asl was studied by drone flights (providing high resolution DEMs), field observations and GIS work. The susceptibility of lahar bulking processes and deposition was evaluated. Multivariate logistic regression models showed that lithology, channel width, and channel shapes are significantly related to observations of bulking and debulking.

- We studied the exact lahar formation process of the 2012 event and published the results in Frontiers (effect of glacier retreat by uncovering unstable high mountain slopes, together with extraordinary rain).

- We built a meteorological and seismic high mountain lahar monitoring network in order to effectively study each event, the previous conditions that led to it and this way eventually warn the rural population downslope. The data is shared with the National Center of Disaster Prevention (CENAPRED).

- We produced new lahar scenario maps and are in the process of elaborating a new lahar hazard map for the whole volcano (not just our study area).

**Conclusion and Implications**

List the conclusions that the project team derived and the implications those conclusions have.

- The effort of installing a meteorological-conditions monitoring network within the lahar inception area of the highest Mexican volcano will not only unravel the real precipitation in these high mountain conditions, but also be the base for precipitation threshold determination during future lahar events, which itself will be used for a alert system for the population that lives within the Jamapa river gorge further downslope.

- Installed seismic sensors (Raspberry shake) along the lahar inception area, together with the previously existing broadband seismic station Halcon, will be used to detect lahars, but also other phenomena related to slope instability.

- Seismic and precipitation data are transmitted real time to the Earth Sciences Center (Seismic and Volcano Observatory), and re-transmitted to the National Center of Disaster Prevention (CENAPRED) – this integration also allows longer term sustainability.

- The importance of the effort to undertake real-time lahar monitoring on the highest volcano of Mexico is crucial and important (only active Popocatépetl and Colima volcano count on such a system until now).
The only Mexican glacier at Pico de Orizaba’s upper northern flank poses an additional hazard, as parts of it could collapse, apart from the fact, that glacier retreat exposes highly unstable sediments, which combined with almost no vegetation cover (treeline at 4000 masl) and more often occurring extraordinary rain events (related to tropical storms etc) is a internationally recognized mix causing more frequent mass movement in high mountain environments.

Several outreach events in variable media inform authorities and general public of the processes and hazards related to high mountain conditions and processes.

Over 20 students have been involved in different project phases and some of them are still contributing (follow up studies). We think that local student involvement has a longer-lasting effect on their formation and their environment.

**Deliverables**

List all deliverables that will be discussed in the final report, including those that were given to the in-country partners and participants.

- High mountain monitoring network installed between 3600 and 4500 m asl within the Jamapa gorge draining the volcano’s glacier.
- Telemetry system that transfers precipitation and seismic data from the volcano to the Earth Sciences Center and retransmission via internet to the National Center of disaster prevention (CENAPRED)
- Lahar scenario maps
- Vulnerability studies of exposed villages
- Students thesis (2 finished master thesis; 1 additional one will be finished before December 2021; 6 finished Bachelor thesis; 1 additional one before December 2021)
- Scientific products (1 paper published in Frontiers of Earth Sciences and 2 manuscript drafts)
- Outreach products (webpage; notes, interviews, events, conferences etc)
- Technical report handed in to GWB-SEG, but also to local institutions, translated to Spanish

**Final Report**

The final report should be comprehensive and provide enough information for assessment of whether the project has accomplished the technical, humanitarian, educational, and sustainability goals outlined in the Phase II application. You are expected to write the report with the care and attention to detail that a published paper requires. Reports are published (with confidential information removed, including financial data) on the GWB website to help educate the public on the program and its impact. Reports should be proofread to ensure accuracy of language and data.

Figures and pictures should be original, high quality graphics and must include captions and appropriate scales. All maps should be oriented with north at the top. All field data and interpretations should be shown on logs, maps, and sections within the same georeferenced projection system, datum, and scale. All maps and sections are to have distance scales in the same unit system. Include color legends, if appropriate.

If you would like additional guidelines to help you prepare your report, please email us at withoutborders@seg.org and ask for more specific instructions.
Reports that have not been written with the highest attention to detail and accuracy will be returned to draft status for editing and any pending payments will be delayed until an acceptable report is received.

**Project Location and Geologic Setting***
In the space below, provide a description of the project's location, including its geologic setting. Using the upload button, attach a Word document, pdf, jpeg or preferably, a geotiff with a map of the area where the team is working. Include a bounded polygon around the area where studies are being conducted. Include the title “Project Location” at the top of the document.

StudyArea2.jpg

This project’s working area lies on the northern flank (Jamapa watershed) of the 5,675 m high Pico de Orizaba (Citlaltépetl) active stratovolcano, located between Veracruz and Puebla states in east-central Mexico. The volcano is part Trans-Mexican Volcanic Belt (TMVB) stretching roughly from West to East, which itself is the surface expression of the Cocos (- and Rivera) plate subduction underneath the North American Plate. the mainly andesitic-dacitic volcano has a glacier on its top.

**Project Location continued***
Upload a Google Earth kmz file that outlines the boundaries of the project location. This file will be used to display the project location on a master map of GWB projects, including the project map on the GWB website.

study_area_GWB_project.kmz

**Humanitarian Need and Benefit***
Summarize the reason, need(s) and benefit(s) of the project (humanitarian, community, environmental, etc.)

Pico de Orizaba the highest active volcano in Mexico. Due to its elevation, steep slopes, glacial terrain, scarce vegetation on the upper slopes, and its proximity to the Gulf of Mexico and associated tropical storm rain events, it is very prone to secondary lahar and debris flow hazards, which has occurred several times recently. Especially mountain villages and infrastructure are highly vulnerable. The theoretical destructive potential of lahar flooding events is much higher if additional water sources (like the melting glacier) and increased prevalence of high altitude rain events are taken into account. Only a sustainable long-term monitoring system can help to understand the triggers of such events and hence effectively protect people.

**Project Goals and Objectives***
Describe the project goal(s) and objectives as they were outlined in the Phase II application or subsequent project revisions approved by the GWB Committee and the methods used to accomplish the goal(s).

Our project goals involve 1) the evaluation of secondary lahar hazard, 2) elaborate hazard maps 3) install and evaluate a lahar monitoring (warning) system 4) expanding the knowledge

In order to accomplish our goals we applied geophysical methods, as refraction seismics and GPR, in order to get glacier ice and loose sediment thicknesses in the lahar formation area and installed rain-monitoring devices (1); studied past lahar deposits, general lahar susceptibility and modelled the most recent lahar event (2012-Ernesto related) using Flo2D software and GIS to produce maps (2); installed raspberry shake sensors and a Mobotix camera to detect lahars upstream, whose data, together with the precipitation data, is being telemetered, using Airfiber, LocoM5, and Litebeam antennas to transfer the data to the Observatory located at Centro de Ciencias de la Tierra at Universidad Veracruzana (3). Many students have been involved and outreach (talks, webpage, interviews) was undertaken (4).
Previous Studies in the Project Area*

Provide a summary of the pertinent previous studies by others in the project area. Describe how the current project goals complemented previous work or filled a void.

The structure, geology and eruptive history of Pico de Orizaba has been studied for several decades now (e.g. Robin and Cantagrel, 1982). Hazard maps have been provided by Höskuldsson and Cantagrel (1994) and Sheridan et al. (2002). This study adds to the outdated hazard maps, providing lahar hazard scenario maps, as well as information on trigger mechanisms.

Especially the occurrence of large lahar events during Pico de Orizaba’s eruptive history, related to cone-collapse events attributed mainly to hydrothermal alteration and glacial erosion exposing areas of altered unstable rocks have been described (e.g. Carrasco-Núñez et al. 1993; Capra et al. 2001). Ice-capped volcanoes, as Pico de Orizaba, hold a significant hazard potential (Capra et al., 2015), especially together with extreme meteorological events (Capra et al., 2018). In this particular case, glacier loss, possibly due to climate warming but also potentially to volcano warming, and related geomorphological changes, have been observed during the last decades (Heine, 1988; Palacios and Vázquez-Selem, 1996). But, high-mountain rain monitoring is scarce in Mexico and therefore we will provide important data, not only in the area of hazard assessment. Lahar hazard monitoring systems only existed previously at Popocatépetl and Colima volcanoes, and here we provide a new lahar monitoring system. Smaller recent lahar events have been observed and described (Rodríguez et al., 2006; Morales-Martínez, et al., 2016; Palacios et al., 1999), to which we add to. Only one study (Delgado Granados 2007) shows actual Jamapa glacier thickness, to which we can add to with 2019-measurements. The comparison to previous studies allows glacier retreat and volume analysis. Previous geophysical studies on proglacial ramp area are not known.

Field Studies*

Using the space below, describe the field studies conducted during the course of the project. Be sure to include the following:

- Approach(es) used, including your rationale for the particular approach(es), the application mode applied, and instrumentation used (manufacturers and models, number of electrodes, etc.);
- Brief description of methods used;
- Who conducted the field work (professors, students, locals, professionals?)? Be sure to clearly indicate who did what;
- Provide maps of data acquisition and acquisition dates;
- Provide evaluation of data quality and usefulness;
- Describe inversions applied and software used;
- Provide field results, including pertinent samples with inversion residual error values)
- Describe any field challenges or problems and the actions taken to mitigate them.

Use the upload button to attach a Word document or pdf appendix with the maps and figures referenced in your summary, including captions. Include the title "Figures for Field Studies" at the top of the document.

Figures_for_field_studies_compressed.pdf

In this study, lahar formation and triggers were the driving interests that focused the geophysical effort. As lahars are gravity-driven mixtures of loose pyroclastic and volcanoclastic sediment and water, our field work was focused on determining glacier thickness change (to parameterize possible melt rates) and
assessing thickness of the unconsolidated material in the vicinity of the historical moraines. We applied geoelectrics, georadar (GPR), refraction and HVSR (Horizontal Vertical Spectral Ratio) seismics at varying altitudes (4200 – 5300 m asl). Field session 1 was undertaken in March 2019 using an ARES single channel resistivity meter, a Zond 12e GPR with 300 MHz antenna (Fig 1), a GEODE-12 and TROMINO 3G ZERO seismometers for refraction and HVSR surveys, respectively. BUAP provided the ARES, ZONDE, and GEODE systems, Veracruz State Civil Protection provided the TROMINO field work. Field work 2 was carried out later in June 2019, and was aimed at the higher altitude profiles, including the glacier (Fig 3). A GSSI 350HS antenna (Fig 2), provided by Exploration Instruments, was deployed specifically for the ice work. The initial survey involved an attempted resistivity profile, utilizing a Wenner array. Extremely high background resistivities, upwards of 50,000 ohm-meters, resulted in high voltage overload errors and unacceptably high noise levels. The geoelectric surveys were subsequently abandoned. In total, 2 GPR and 2 seismic refraction profiles (co-located) were acquired on the lower proglacial ramp area (March), along with 2 more co-located GPR and seismic profiles on the ramp and 4 GPR profiles on the glacier (June). Eighteen HVSR soundings were also acquired on the proglacial ramp in March. In both occasions, the geophysical campaigns were led by Blake Weissling and Julio González; the geophysical measurements were undertaken by BUAP students and on the glacier (above 5000 m asl) by Blake Weissling, technician Marco Morales (UV) and master student Edwin Monfil. UV-students helped out during the geophysics studies (portage of equipment, site prep, etc). GPR radargrams were processed using Prism2 software to include the application of a static correction (for pulse delay), background filter to remove antenna ringing, gain adjustments, application of an Ormsby bandpass FIR filter, and finally application of migration to more accurately adjust the dielectric used for proper depth scaling. In some cases the radargrams were re-processed to account for topography (Figs 4 to 10). Refraction seismic data source was a 12 lb hammer and a metal plate, with multiple strike stacking. A minimum of 5 shot locations were utilized along each line. P-wave first arrival (direct and head wave) data was processed using SeisImager modules Pickwin™ (bandpass filters were applied when necessary) and for the refraction analysis Plotrefa™ was used for tomographic inversion and subsequent generation of velocity profiles (Figs 12-15). As mentioned previously, 18 HVSR soundings were acquired in this study. Ambient seismic noise recordings were sampled at 128 Hz for 16 minute intervals at 17 locations on the proglacial ramp. Data were processed using GRILLA software to generate HV ratio plots, spectral amplitude plots, time based HV stability plots, and azimuthal HV plots (Figs 16-19). These plots were analyzed for indications of depth of unconsolidated material above bedrock using the freq(resonance) = Vs / 4Z relationship, where Vs is shear wave velocity and Z is depth. Finally, a 3-d model of the lahar formation area and upper Jamapa channel was obtained by drone photogrammetry using Phantom and Mavic Pro drones flown by CGeo and UTSA. Data was processed using DroneMapper software and GIS (Figs 20-24). Other field work sessions involved the installation of telemetered meteorological (Campbell ClimaVue) and seismic stations (Raspberry Shake).

**Interpretation of Data**

In the space below, describe the interpretation of data for the project. Be sure to include all of the following:

- Describe the interpretation process applied, including data integration, borehole comparisons, 2D surfaces developed, 3D interpretative images, fence diagrams, voxels, etc.;
- Provide examples of representative final interpretations including maps, sections, images, charts, tables, etc.;
- Provide an evaluation of the data quality and usefulness as application to interpretation;
- Include discussion on whether the data support the goals, objectives, and hypotheses and discuss what additional data would be useful.

Use the upload button to attach a Word document or pdf appendix with any figures or pictures referenced in your summary, including captions. Include the title "Figures for Interpretation of Data" at the top of the document.

Figures_for_data_interpretation_compressed.pdf
Glacier - GPR profiles traced along the lower half (vertical and horizontal profiles) of the Jamapa glacier (Figs 25 and 26) showed glacier thicknesses varying between 0.80 m to 2 m at the edges up to a maximum of 17 m; in average glacier thickness in this lower half was found to be around 10 m only. These results allowed comparisons with earlier studies by Blake Weissling in 2010, being the average glacier thickness in that same area about 20 m. The obtained glacier thicknesses (Fig 27) were used to interpolate ice thickness values for the whole Jamapa glacier by using the ice-temperature – thickness relationship (using satellite thermal images and GIS) (Figs 28 and 29) and volume estimations (Fig 30). The estimation of a volume loss rate will be used to parameterize future water sourcing models for lahar generation.

Ramp and fan sediments - As a result of both GPR and seismics, fan (site 1 – near hut at 4200 m asl) sediment thickness was determined to be minimum 8 m (no contact with underlying lava was found), subdivided in at least 3 layers of unconsolidated volcaniclastic sediment derived from previous eruptions, erosion material and glacial debris (Fig 31). At site 2 (proglacial ramp area), a thickness of at least 6 m of unconsolidated material was determined with both geophysical methods (Figs 32 and 33) - below this depth, attenuation of the signal occurs. Of the 18 HVSR recordings, #1 and #18 were repeats at the hut location. These data, along with #17 across the channel (at the same elevation as the hut), were the only results with significant H/V peaks (and statistically significant by SESAME standards) (see Figs 16-19 in “field studies”). These peaks at approx. 4 Hz indicated sediment column thicknesses of 12 – 16 m, using estimate S-wave velocities of 200 – 250 m/s (based on 60% of P-wave velocities derived from the refraction results). No other HVSR recording yielded significant results, possibly attributed to excessive topographic slope. The results described above were on relatively flat terrain.

Drone mapping - High resolution drone images were used to obtain different morphology based variables (e.g. channel shapes classified into trapezoidal, circular, v-shaped and rectangular, Fig 34), which together with geology for example were used for a logistic regression analysis for bulking and debulking processes of a lahar in proximal zones. The bulking models developed show that lithology, a proxy for sediment availability as measured in this study, trapezoidal and circular shaped channels, and changes in slope (Figure 35) are significant predictors.

The acquired geophysical data together with the precipitation values derived from the monitoring provide input parameters for lahar simulation used for hazard map scenarios (Figs 36-41). Apart from the already simulated 2012 hurricane Ernesto lahar scenario, glacier thickness and volume derived from GPR will be used as input parameter for lahar simulation with Flo-2D for an extreme lahar scenario involving glacier breakoff. It would have been desirable to get deeper geophysical profiles in the future to get the total amount of unconsolidated sediment at Pico de Orizaba’s flanks.

Human Element*
Describe the involvement of participants. Include all participants, such as college professors, professional consultants, students (either local or from outside the local region), local residents, local governments, and others.

Professors and technicians from UV, BUAP, UTSA, CGEO conducted field work (geophysics, geology, drone mapping, vulnerability studies, periodical data download, telemetry), with the help of students and research assistants from UV, BUAP and UTSA. In the case of telemetry installation (conducted by UV) we received help from ITSX. Logistical support for field work and contructions of the shelters came from local and regional authorities (municipality, state Civil protection, Park-authorities) and especially local residents from mountain communities. External consultants belong to UNAM and ITSX. Students from UV, BUAP, UTSA, UNICACH, COLVER were and are (UNICACH) involved with Bachelor and Master thesis projects.
Project Sustainability*
It is a goal of GWB that funded projects continue sustainably after their end dates. To receive GWB funding and achieve that goal, funded projects proposed sustainability goals and objectives to achieve them. Describe measures taken to ensure the sustainability of the project beyond the end date. What methods did you use and what objectives were accomplished to ensure project sustainability?

We chose strategic locations for our network (seismic sensors, camera and meteorological stations) to be able to connect to the existing seismic broadband station HALCON (belongs to UV, supported by CENAPRED and Seismological National Survey SSN). HALCON is already transmitting to the Centro de Ciencias de la Tierra and data are being shared with Cenapred and SSN. Telemetry will provide almost or real time data flux to CCT and also safe field work costs. All new installations will be included into the Seismological and Volcanological Observatory of Veracruz (run already by GWB-project collaborators). As data derived from the new installations will also be shared with CENAPRED, long-term maintenance will be supported not only by the local university, but also by external institutions (CENAPRED and SSN). Further, we are in the process of requesting more regular funds (from UV) for the “Geophysical monitoring” which includes efforts of the Observatory.

Education*
What educational institutions within the host country have been involved in the project? What other educational institutions have been involved? Describe any specific educational opportunities that have been provided during the project to any stakeholders (local residents, professionals, students, government officials, etc.) within the host country.

In the host country, Mexico, Universidad Veracruzana (UV), Benemérita Universidad Nacional de Puebla (BIAP), Instituto Tecnológico Superior de Xalapa (ITSX), CentroGeo (C GEO), UNAM and indirectly Universidad de Ciencias y Artes de Chiapas (a shared Master student) are involved educational institutions. From the USA, UTSA has been involved (Co-I, 2 research assistants and 1 master student, talks). Students from all national and international educational institutions were involved during field work, several meetings, and outreach, and most of them had their own research thesis projects (BSc and master). Two Mexican students further had an academic stay at UTSA – the academic stay for UTSA students in turn had to be cancelled because of Covid. In order to reach out to stakeholders and public in general we presented parts of the project and knowledge through different media (radio, web, in person, conferences, publications, lectures) These efforts have not concluded and will continue.

Lessons Learned*
Describe the positive and negative lessons learned while conducting the project. What you recommend to do and not to do during future projects?

Negative: A lot of time was lost during bureaucratic procedures (as purchase), especially combined with the COVID-pandemic. At the end we could speed up procedures, by not awaiting the general “university-chain” but by contacting the individual department-leaders; for future projects I would do that immediately after the project start to avoid these setbacks.

Positive: A positive experience with SEG-GWB was the support received by getting the one-year extension and the liberty of switching grant money from one item to the other – this flexibility permitted the overall success of the project.

Also positive was the extensive collaboration with Universities (professors and students) and authorities – with the help of these parties, potential problems arising out of “lack of personnel” and logistic issues in general could be overcome, including sustainability. Living in rural communities during the extensive field work and relying on support of the community members, created confidence.
**Financials**
Provide a categorical comparison of the actual expenses versus the proposed expenses (as outlined in the project budget submitted for inclusion in the grant agreement).

You may upload a file showing the budget to actuals comparison or use the space below to describe the financials.

**Deliverables**

**Access to Data**
As a program of the SEG, a society devoted to advancing an applied science, GWB encourages its project participants to foster transparency and further educational goals of the program by providing access to data collected during the course of the project. In the following question, you will be asked to share the status of the availability of your project's data for others to use for educational purposes.

**Access to Data**
Please select the option that describes the status of the availability of your project's data for others to use for educational purposes and type it in the space below:

- Data associated with this project are available and can be accessed via the following URL:____. Note: A digital object identifier (DOI) linking to the data in a general or discipline-specific repository is strongly preferred.
- Data associated with this project are available and can be obtained by contacting the following project participant:_____ at _____.
- Data associated with this project are confidential and cannot be released for the following reason(s):_____. Note: Confidentiality should be limited to 1 to 2 years after project completion. (If you choose to keep it confidential, please describe a way for the GWB Committee to have access to the raw and processed data for three years.
- Your own custom statement of data and materials availability.

Data associated with this project are available and can be obtained by contacting the following project participant: Katrin Sieron at Universidad Veracruzana (meteorological data, geophysical data).

**Photos and Videos**
Please provide the GWB office with relevant photos and videos of people, places, and activities to document the project and for later use on the website, social media and other venues for sharing about the GWB program’s impact. In the space below, describe how you will make the media available and when the office can expect to receive the items.

We can share photos via our institutional drive (UV) as soon as we get a contact we should share it with. We would prefer if you could give the credits of the photos to the person indicated (folder_name), if that is possible.
References

List all references to previously published work cited in the report. Provide complete citations, following the SEG guidelines to authors for articles in Geophysics and The Leading Edge. We encourage use of the digital object identifier (DOI) number for citations, when available.

- Capra et al. 2015, Glacier melting during lava dome growth at Nevado de Toluca volcano (Mexico): Evidences of a major threat before main eruptive phases at ice-capped volcanoes: J Volcanol Geotherm Res, 294, 1-10
- Delgado Granados 2007, Climate change vs volcanic activity: forcing Mexican glaciers to extinguish and related hazards: Proceedings First Intern Conf on the impact of climate change on high-mountain systems
- Heine 1988, Late Quaternary Glacial Chronology of the Mexican Volcanoes: Geowissenschaften 7, 197-205
- Morales Martínez et al. 2016, Afectaciones por posible asociación de eventos hidrometeorológicos y geológicos en los municipios de Calcahualco y Coscomatepec, Veracruz: Teoría y Praxis, 31-49
- Palacios and Vázquez-Selem, 1996, Geomorphic effects of the retreat of Jamapa glacier, Pico de Orizaba volcano (Mexico): 78, 19-34
- Palacios et al. 1999, Paraglacial and postglacial debris flows on a Little Ice Age terminal moraine: Jamapa Glacier, Pico de Orizaba (Mexico): Geomorphology, 28, 95-118
- Rodríguez et al. 2006, Flujos de baja concentración asociados con lluvias de intensidad extraordinaria en el flanco sur del volcán Pico de Orizaba (Citlaltépetl), México: Boletín de la Soc Geol Mexican, LVIII, 223-236
- Sheridan et al. 2002, Mapa de peligros del Volcán Citlaltépetl (Pico de Orizaba), UNAM

Current and Planned Abstracts, Articles, and Presentations

List all current and planned abstracts, journal articles, and presentations based on the project.

- 1 article in an indexed journal (2 more are planned)
- 1 outreach article (2 more planned)
- 1 full conference paper
- 1 extended abstract (SEG conference)
- 2 Master thesis (1 more in progress)
- 7 bachelor thesis
- 5 Conference presentations

(*note: there was not enough character space to fully cite all articles, thesis and conference presentations)
GPR data acquisition

Figure 1 Zond 12 e 300 Mhz (Photo taken by Roman Gutiérrez)

Figure 2. GSSI Utility scan 350 Mhz equipment (Photo taken by Katrin Sieron (left) and Marco Morales (right))
Figure 3 - GPR profiles within the study area

GPR - data processing

Figure 4 - Radargram without processing
Figure 5 - Radargram with pulse delay and 0 applied

Figure 6 - Radargram with application of pulse delay, 0, noise removed and gain
Figure 7 - Application of Ormsby filter to radargram

Figure 8 - Radargram with pulse delay, 0, noise removal, gain and Ormsby filter applied
Figure 9 - Radargram with pulse delay, 0, noise removal, gain, Ormsby filter and filter to soften topography and permittivity adapted

Figure 10 - Radargram with pulse delay, 0, noise removal, gain, Ormsby filter and filter to soften (filter pasa bajas) topography and permittivity adapted
Refraction Seismics data acquisition

Figure 12 - GEODE (Geometrics) equipment

Refraction Seismics data processing

Figure 13 - Seismogram without filtering the noise (a) and through low filter for noise attenuation (B)
Figure 14 - Complete Seismogram with filter applied (a) and filtered seismogram without seismic traces.

Figure 15 - Seismogram with identified P-waves (red lines indicate P-wave arrival for each geophone; green lines indicate P-wave arrival of former profiles.)
Tromino data

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Drone mapping

Data acquisition

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