**iVolcán;**

**developing integrated volcano monitoring and hazard mitigation programs at persistently degassing volcanoes**

There were delays in beginning this work due to illness of one of the staff, but the project is now up and running and we have had a very successful first year. A summary of the results so far are presented on the accompanying poster.

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**Summary**

The aim of the fieldwork was to quantify persistent volcanic degassing from source to sink, connecting gravity measurements of subsurface processes to emissions, atmospheric concentrations and their impact on the ecosystems downwind of the volcano. To achieve this we have trained and involved a wide range of citizen scientists. In addition, we have started to grow the knowledge and communications base between the scientific and local communities through our work. Our interim results show that continued monitoring of the subsurface and subaerial processes operating at Masaya volcano will be key to generating a solid understanding of how these relate and how they can best be mitigated in collaboration with local communities.
Gravity

The microgravity data collection in the volcanic crater area contributes to a long time series of data collected at points within the Masaya volcanic caldera (Figure 1). One of the aims of this project is to determine the environmental impact of changes in volcanic activity and to establish which environmental indicators can be used as a proxy for geophysical monitoring.

Figure 1. The points used for gravity measurements. 1, 2, 3 and 4 denote the San Pedro, Nindiri, Santiao and Masaya Pit craters respectively. The Santiago crater is where the currently active vent is located.
The gravity data collected as part of this project are shown in Figure 2 and demonstrate the changes that have occurred over the period of observation. There has been a small increased in gravity at points close to the active vents over the recent period.

Figure 2. Microgravity data collected at points around the summit craters.

**Gas monitoring**

Gas concentrations were monitored using diffusion tubes and sulphation plates (Figure 3). Diffusion tubes were deployed at the sites shown in Figure 4. These were placed in schools, local community buildings with the permission and engagement of the local communities. Volcanic gases measured by diffusion tubes included SO₂, H₂SO₄, HCl and HF. Other acid gases were measured in December 2013 and February 2014 (NO₃, HBr, NH₃ and H₃PO₄).

The sampling in February 2013 showed high levels of volcanic gases (>300 ppm of SO₂) with very high deposition levels for sulphate (>3000) in the most affected area. In December 2013, HBr and H₃PO₄ were below the limit of detection for all sites with the exception of 33 for HBr (9.94 g m⁻³) and 13 for H₃PO₄ (15.56 g m⁻³), however none of these acid gases show any relationship with the volcanic degassing. Variable levels of NO₃ were found during this sampling season, with some high concentrations found at the beginning of the vegetation survey transect (see next section; Figure 5) but low or below the limit of detection elsewhere including at the crater. In February 2014 all of these gases were below the limit of detection. Some of the high NO₃ values found may be as a result of anthropogenic pollution.
Figure 3. Sulphation plate (center) and diffusion tubes (green and purple capped tubes).

Figure 4. Location of Diffusion Tube deployment (green diamonds). The crater that contains Masaya National Park is indicated by the dashed outline and the active vent is denoted by the red triangle.
Environmental monitoring was achieved through conducting 33 plant community surveys along a 2 km transect through the plume located approximately 2 km downwind from the volcano (Figure 5). The entire transect was located on the same substrate of a late quaternary lava flow. Using 4 m × 4 m quadrats as many plants as possible were identified to see which species can better tolerate volcanic gases. Soil pH, substrate type and leaf litter layer were also recorded. Citizen Scientists from the local community and volunteers from overseas were engaged to collect and perform preliminary analysis of the data.

Data were first collected in February 2013, in addition to the transect sampling areas were established near the vents and upwind of the degassing. Subsequent sampling trips across different seasons (December 2013, February 2014 and May-June 2014) used these sampling areas, though the exact locations of sampling sites was not always the same. This was because it was found that diffusion tubes placed in visible locations might be stolen by local passers-by and for the May-June 2014 sampling season a wider transect was used. The transect followed a path at the base of the caldera wall, which provides an approximate cross section through the plume. It’s exact shape was restricted in places by access due to the caldera wall to the East and an agricultural area to the North when some samplers were stolen as more people pass through this part of the park.

Figure 5. Map of the main sampling areas. Upwind sites are in green, crater sites are in red and the transects sites are in orange. Precise locations for each field season are described in the relevant sections. The red dot is the actively degassing crater and the black arrow shows the prevailing wind direction.
In the most affected areas the soil pH was as low as 3.7 which is caused by the deposition of sulphate and other acid gases such as chlorides and fluorides, and can be correlated to the data recorded by the sulphation plates. The pH was typically greater than 5.5 in unaffected areas. In the downwind zone lava and ash dominate as the main substrate, and outside of this area there is a well-developed soil and leaf litter layer. The total number of species and the Shannon diversity recorded in each quadrat decreases in the area downwind of the volcano, where the soil is more acidic and there is higher sulphate deposition. Woody species are replaced with herbaceous and weedy species under and near the area disturbed by the plume (Figure 6). The whole sampling area covered the same lava flow, and it is apparent that colonization of the area under the plume has been slower that surrounding areas due to a lack of trees and high percentage of bare lava exposed here. This suggests that degassing from Masaya has been important for centuries. This work was presented at IAVCEI in Japan and INTECOL in London.

Figure 6. Photographs illustrating the change in vegetation on a transect through the plume: left, out of the plume there is tropical woodland, right in the center of the plume the vegetation is dominated by grass species.

Results from December 2013 were similar results to those in February with respect to the degassing and dry deposition of sulphur. The plant communities were however different because this sampling was done at the end of the wet season, so there were more annual species found. Despite this, the overall patterns of species decrease under the plume remains the same. Additionally, canopy photos were taken and this ranged from an open canopy under the plume to only 20% open in the unaffected forest area (Figure 7). This was highly correlated with the leaf litter layer depth.
In February and March 2014 these surveys were again repeated to establish a time series and compare the data with the previous year. Preliminary results suggests that there has been an increase in volcanic degassing. The plant *Dalechampia scandens* was also studied to see how it responds to the presence of the volcanic plume. Previous studies in greenhouses have found that its leaf size increases under better nutrient conditions. Interestingly, the largest leaves are found under the plume which suggests that this species is benefitting from the presence of the volcanic plume. It is hoped that further work will help to understand the mechanisms behind this.

Figure 8. *Dalechampia* measurements.
Interim conclusions

Thanks to the 176 Earthwatch volunteers that have worked with us we have collected and continue to obtain a wealth of information. This allows us to start to combine geophysical, geochemical and social science data to develop a better understanding of how the persistent gas flux from Masaya impacts humans, animals and the environment and how rapidly the local environment responds to changes in volatile flux. However, the results also highlight that to develop a thorough understanding of these processes long-term monitoring is essential due to the timescales on which these mechanisms operate and various systems influence each other.

The next field work is planned for February 2015 when further measurements will be made and we will present preliminary findings to the local community.
Citizen science

Volcanic degassing is an unexpected but major hazard to communities at persistently active volcanoes. Continued long-term exposure to the primary volcanic gases can result in a range of chronic ailments, reduced agricultural output and acidification of rain and groundwater that contaminates water supplies. The activity also indirectly impedes development and poverty reduction efforts. This research seeks to understand and mitigate the impact on the local environment and population of the persistent volcanic activity at Masaya (Nicaragua).

Masaya is a bimodal shield complex consisting of a number of nested calderas approximately 25 km southwest of Nicaragua’s capital Managua. Its current activity is characterized by periodic cycles of intense gas emission that last years to decades.

Methods

This work specifically seeks to integrate and cross-correlate a wide variety of volcanic and environmental monitoring parameters from micropneumatic measurements of degassing subsurface magmas to the impact of the gases observed. The results shown here are a subset of the data collected so far, and illustrate the wide range of parameters we have been able to obtain.

Results

Citizen science

Citizen scientists, defined as data collection and processing by volunteers as part of a scientific enquiry, is at the heart of this project. As part of this work, we provide Earthwatch volunteers, who range from pre-college school groups to retired individuals, with basic geoscience and environmental training and education, which enables them to act as field assistants. This increase in individuals capable of collecting reliable field data results in a significant increase of the data collected and our understanding of the processes operating at Masaya.

Gravimetry

An established gravimetric network is resurveyed annually. A reference station is measured and the gravity value at each field station is measured and expressed as a gravity difference relative to the base station. The measured value of gravity depends on the sub-surface mass distribution and on the elevation of the station. Therefore, changes in gravity are corrected for any elevation changes and the residual gravity change is interpreted in terms of sub-surface density variations.

Gas monitoring

SO$_2$ gas flux at the vent is measured with a FLYSPEC spectrometer. Scans of the plume provide absorption spectra that in conjunction with wind speeds provide a measure of SO$_2$ flux. To investigate dissolved gases and amounts of gas deposition, aspiration plates and diffusion tubes have been used. These are exposed for a specific period to produce a reliable rate of ambient gas concentration and sulphation and chloride deposition.

Environmental monitoring

Soil, crop and vegetation samples of Tillandsia webbii (Bromeliaceae) and Tillandsia usneoides (Bromeliaceae) have been collected at Masaya. This enables analysis of plant communities that grow close to or even within the active fumaroles. The chemical signatures these plants have the potential to be used as biomarkers.

Social science and engagement

Key to effectively mitigating the hazards posed by the persistent degassing is a thorough understanding of the socio-economic setting of the hazard. To date, semi-structured interviews have been used to establish an understanding of local hazard and risk perception. In addition initiatives for collaborative participatory disaster risk management and a further citizen science initiative are being field-tested in Costa Rica, with an eye on employing these techniques in Nicaragua in the next 1-2 years.

Conclusions

Thanks to the 175 Earthwatch volunteers that have worked with us we have collected and continue to obtain a wealth of information. This allows us to combine geophysical, geochemical and social science data to develop a better understanding of how the persistent gas flux from Masaya impacts humans, animals and the environment and how rapidly the local environment responds to changes in volcanic fume. Future initiatives seek to actively include the local population in the continued monitoring of Masaya and the response to the impacts of its persistent degassing.