Report on the field campaign to Guatemala, Fuego and Santiaguito volcanoes, in June-July 2008

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1. Introduction

The original goals for this field campaign were to analyze the activity of Fuego volcano using seismono-acoustic data, high-time resolution SO2 fluxes, infrared (FLIR) videos and normal video recordings. This new data set was to complement the data collected in January 2008 by an MTU team, and was of particular interest because the style of eruptive activity had changed significantly since January. In addition, FLIR images of the growing dome of Santiaguito volcano had to be recorded to build onto an increasingly rich dataset of thermal images that are being used to track dome growth and effusion rates. Bad weather conditions in the field, however, restricted our chances to apply certain techniques and to obtain the data originally planned. The following sections present a summary of the data collected along with some relevant observations of the activity of Fuego and Santiaguito volcanoes.

2. “Visual” observations

During the 5 days spent on La Meseta ridge between Volcan de Fuego and Volcan de Acatenango (Figure 1), the timing of audible explosions and related activity was obtained. Unfortunately, direct visual observations of the summit of Fuego volcano was impeded by persistent cloudy and foggy conditions. From the camp site in the saddle between Acatenango and La Meseta, at ~3290 m a.s.l. and 1700m from the summit vent of Fuego (3800 m a.s.l.), only big explosions could be heard. However, from La Meseta, at ~3590 m a.s.l. and ~950 m north of the crater, a wider range of noises could be associated with the explosive and degassing activity taking place at the summit. Three different types of activity were identified based on the characteristics of the noises observed:

a) Big explosions: loud explosion (‘bang’) noise + falling bombs

b) Gas exhalations: relatively quiet noises of “less explosive” outgassing activity, probably associated with pulses of gas escaping from a shallow magma free-surface.
c) Chugging: regular gas exhalations similar to the steady sound of a steam engine (found in the dictionary: a dull explosive sound, usually short and repeated, made by or as if by a laboring engine.) See also Benoit and McNutt, 1997 and Johnson et al., 1998.

![Fuego - Acatenango Volcanic Complex](image)

Figure 1. Digital elevation model of the Fuego-Acatenango complex. Shown are the location of our base camp, the seismo-acoustic station, and the INSIVUMEH observatory.

On the evening of 26 June 2008 (18:30:24 local time), during a short period of visibility of the crater, a big explosion was observed (Figure 2). This was ash and bombs rich. It started with a strong, impulsive explosion sound and a dense, dark ash plume rising along with some visible bombs with ballistic trajectories. This was followed by a short-lived (several seconds) fountain of incandescent (red) material that reached several tens of meters above the crater.
Figure 2. Photograph taken seconds after the onset of strong strombolian explosion from the summit crater of Fuego at 18:30 local time on June 26. Notice the incandescent jet of pyroclasts reaching tens of meters above the crater rim. View is to the south from the seismo-acoustic station. Photo by Kyle Brill.

Aerial photographs taken in March 2008 by Gustavo Chigna (INSIVUMEH) show that the main crater of Fuego volcano is now open to west (Figure 3), where an active lava flow was active during our visit (26 June-7 July). According to reports from the INSIVUMEH observers, this lava flow began in the second week of June 2008. By the end of June it had descended the western flank of the volcano, towards Zanjon Barranca Seca, to a length of less than 300 m. At the time of this document the short lava flow continues at ~150m length and similar strombolian explosions have been seen and heard from Panimache.
Figure 3a. Photograph of Fuego volcano taken in March 2008. View is to the north and shows the upper several hundred meters of the south flank of the volcano with the crater open to the west (left in the photo) and La Meseta behind. Note that the highest point is on the north-east side of the crater rim. Photo courtesy Gustavo Chigna (INSIVUMEH).

These photos also reveal changes in the morphology of the interior of the crater since January 2008 (Figures 3b,c,d). In March 2008 the main crater seemed to be divided in two depressions, each with a lowest point that could indicate the position of a vent (Figure 3b,c). These two craters are better defined in March 2008 (Figure 3c), compared to January 2008 (Figure 3d), essentially by the way the new tephra has been filling up the crater. Similar funnel-shaped craters in which the walls grow by deposition of new pyroclastic material from persistent strombolian explosions have been seen at Stromboli volcano (e.g. Patrick et al. 2007).
Figure 3b. Photograph of the crater of Fuego volcano, March 2008. View is to the east. It shows the crater and west flank of the volcano. Note the two depressions (craters) inside the main crater, with a small ridge in between. Also note the multiple sources of gas emissions; most of them located on the walls/rim of the main crater (see Figure 3c). Photo courtesy Gustavo Chigna (INSIVUMEH).
Figure 3c. Closer view of the crater of Fuego volcano, March 2008. View is to the north. This photo shows in more detail the morphology of the crater and the depressions on the east and west side. Note the gas emanations from the interior of the crater walls. Photo courtesy Gustavo Chigna (INSIVUMEH).
3. FLIR and video recordings

At Fuego volcano, videos of the activity observed from La Meseta were recorded for a time period of one hour in the evening of 26 June 2008. Only small ash explosions were observed during this time. In addition, night time videos were recorded from the observatory in Panimache during the night of 3 July. These night-time videos were complemented with FLIR imagery (Figure 4a). During the two hours of recording (1hr 40min with FLIR) 16 explosions were observed; most of them exhibited mild intensity. This yields an average activity of 9.6 explosions per hour. With the normal video camera the ‘glow’ of the active lava flow on the western side of the crater was clearer than with the FLIR. Conversely, the ash explosions, generally taking place on the middle-eastern side of the crater, were more evident in the FLIR images than in the normal video (Figure 4a). A synchronized movie with both the FLIR imagery and normal video in night-time setting can be found in `\server\folder` (will be available in the near future). Another interesting observation is that the top part of the lava flow (near the crater) seemed more active during periods where the ‘glow’ was more intense. This was manifested as incandescent blocks breaking off the lava flow; sometimes these blocks would start falling directly from the crater on the south-west side rather than on the west side next to the active flow.
Figure 4a. Night time video still and FLIR image of an explosion. In the FLIR image the bright long stripe on the left side corresponds to the active lava flow originated on the west side of the crater. The still image is zoomed in on the upper portion of the cone, corresponding to the bright stripe and above in the FLIR image.

Observations of the location of the glow, the explosions, and the relatively hot gas emanating from the crater reveal some degree of alternation in the type of activity associated with the western and eastern craters/vents. An example of this activity is illustrated in Figure 4b. Using the software ThermaCam Researcher Professional, two square objects were located above the western and eastern (left and right) side of the crater rim, and the maximum temperature within these two objects was recorded for about 20 minutes. In this example different episodes of mild explosive activity, herein called puffing, take place in the west and east vents (Figure 4b). This activity is characterized by the absence of major amounts of pyroclastic material, unlike the typical ash explosions, which is recognized as short but repetitive flame-like profiles as well as small gas puffs, probably generated by gas bursts at very shallow levels. In Figure 4b a mild gas puffing is observed in the western crater, with a few bursts on the eastern crater; this activity ends or decreases in intensity and a few minutes later a larger ash explosion is seen coming from the east vent. After the explosion it is the east vent that shows puffing, with relatively higher intensity, but it suddenly ends and the west vent resume puffing. This ‘puffing’ activity observed with the FLIR is not always evident within the almost 2 hours of measurements. Nevertheless, the fact that it was possible to identify two sources of puffing and variations in the intensity (and type) of activity can be valuable in the interpretation of other type of data. For instance, the ‘exhalation’ noise heard from La Meseta may be explained by these episodes of stronger puffing in either crater.
At Santiaguito volcano, FLIR measurements of the dome were obtained in the morning of the 07 July 2008. Measurements at night were not possible due to bad weather conditions. Maximum temperature obtained was 160 °C on the outer hot rim of the dome (Figure 5). Active fumaroles can also be seen on the outer rim of the crater. The image in Figure 5 was acquired about 20 min after an explosion that occurred in the dome. Most of the FLIR measurements were recorded with clouds passing by in the field of view, between the camera and the dome. High humidity was also observed at the elevation of the dome, evidenced by the condensation of the fumaroles.

Analysis of Santiaguito FLIR observations are consistent with a continued decrease in the eruption rate at the Caliente Vent, which is now less than 0.1 m³/s. More about the thermal structure in this poster: [http://www.geo.mtu.edu/~raman/FLIRSantiaguito.pdf](http://www.geo.mtu.edu/~raman/FLIRSantiaguito.pdf)
4. Seismicity and infrasound recordings

One CMG-3ESPC (60 s-50 Hz) seismic station and three infrasonic microphones were deployed on La Meseta, at ~3590 m a.s.l. and about 950 m from the crater of Fuego volcano. The three components vertical, north and east were identified as channels 1, 2 and 3, respectively. The seismometer was oriented based on geographic north, but it was estimated that the orientation was 2-3 degrees off to the west. In the raw data time is GMT. The microphones were placed near the seismometer in an L-shape, with one microphone (channel 4) located next to the digital acquisition system (DAS), a second microphone (channel 6) about 2.5 m to the west (downhill) of the DAS, and the third microphone (channel 5) about 1.4 m to the north (away from the volcano) of the DAS. The configuration of the microphones was limited by the length of the wire that they were shipped with from New Mexico Tech. In future deployments longer wires will be needed to locate the microphones farther from each other.

The seismicity was characterized by persistent tremor and sporadic bigger events that were related to big explosions (Figure 6a). Variations in amplitude of the tremor can be seen in the RSAM of the signal (Figure 6b). The RSAM was calculated with a 15 sec duration window moving with a step of 10 sec (33% overlap). Big explosions heard from La Meseta coincide with higher amplitude RSAM of seismicity and infrasound time series (Figure 6b). However, the correlation between the seismicity and infrasound is not good. It is noteworthy that during the period of measurements there was strong wind and, occasionally, the sound of fireworks could be heard from the summit. These two can be a source of noise in the recorded signal.
Figure 6a. Example of a one-hour duration vertical-component seismic signal collected on the 26 June (18:29-19:29 local time). Each row shows 10 minutes of the signal. The event at ~1.5 min corresponds to the explosion shown in Figure 2. Note also the persistent tremor. All times in Figure 6 are local (GMT -6).

Figure 6b. RSAM plot of the seismic signal, vertical (top) and radial (middle) components. RSAM (absolute amplitude) of the infrasound (bottom plot) is also shown. Vertical lines identify timing of explosions.
Figure 6c. RSAM of seismic vertical component (top) and spectrogram (bottom) for one day of measurements.

Examples of the spectrogram of the seismic signal are shown in Figures 6c and 6d. The spectrogram in Figure 6c was calculated with a moving window 600 sec duration and 450 sec step, and the spectrograms in Figure 6d and 6e were calculated with a moving window of 20 seconds duration and a step of 15 seconds (25% overlap). In each window the calculated spectrum of the seismic signal (vertical component) is normalized to the highest value.

The seismic signal shows a broad frequency range, with frequencies as low as .05 Hz and as high as 20 Hz (Figure 6c). In general, the predominant frequencies are within the range 2-6 Hz and 0.1-0.4Hz. Frequencies over 6 Hz and at ~0.13 Hz and ~0.35 Hz seem stronger when the amplitude of the seismicity (vertical component) is lowest, which perhaps is the result of noise and surface waves (??) (Figure 6c). As mentioned earlier, the correlation between the amplitude of infrasound signal and amplitude of tremor is not clear, although big explosions can be seen in both time series (Figure 6d). The spectral energy of tremor is highest at 2-6 Hz but the position of highest peaks varies with time. The frequency content of the seismicity also shows interesting variations related to individual events and segments of the tremor (Figures 6d-6e).
Figure 6d. Vertical component of the seismicity (top), infrasound trace (middle) and spectrogram of the seismic signal (bottom) for 1.8 hours of measurements. Note the explosion near the middle of the seismic and infrasound traces (time ~182.425). The crosses in the top figure represent the timing of observed (heard) “exhalation” (red) and chugging (green) activity.
5. Closure

Data collected:

<table>
<thead>
<tr>
<th>Volcano</th>
<th>Technique</th>
<th>Location</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuego</td>
<td>Seismic + 3 microphones</td>
<td>La Meseta, WGS84: 14.48218°, -90.88053°</td>
<td>26 June 2008 (evening) to 1 July 2008 (morning)</td>
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<tr>
<td>Fuego</td>
<td>Video</td>
<td>La Meseta, Panimache</td>
<td>1 hour, 26 June 2008</td>
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<tr>
<td>Fuego</td>
<td>FLIR</td>
<td>Panimache, NAD27(15) 0722804E,1596945N</td>
<td>2 hrs, night 3 July 2008</td>
</tr>
<tr>
<td>Santiaguito</td>
<td>FLIR</td>
<td>Santa Maria, summit</td>
<td>1 hr, morning 7 July 2008</td>
</tr>
</tbody>
</table>

Note: The raw infrasound data, channel 4, shows up to 5-10 Pa of long-term variations.
6. References

