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The 2006 eruptions of the Tungurahua volcano (Ecuador) and the importance of volcano hazard maps and their diffusion

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Introduction

The Tungurahua volcano (5023 m asl) is a steep-sided, andesitic stratovolcano, located in central Ecuador, ranking as one of the most active volcanoes of the Northern Andes. During historical times Tungurahua experienced important (VEI ≥ 3) pyroclastic flow-forming eruptions in AD 1640, 1773, 1886, and 1918 (e.g. Hall *et al.*, 1999; Le Pennec *et al.*, 2008).

In October 1999, after about 75 years of quiescence, the Instituto Geofísico of the Escuela Politécnica Nacional (IG-EPN) registered a renewal of the eruptive activity. During the next six years, this activity was cyclical, with small to moderate explosions responsible for important ash emissions, the most voluminous of which occurred on November-December 1999, August 2001, September 2002 and October-November 2003. In 2006, seismic activity increased dramatically and culminated with the 14-16th July (VEI 2) and 16-17th August 2006 (VEI 3) explosive eruptions. For the first time since the beginning of this eruptive cycle, Tungurahua volcano produced pyroclastic flows, which swept over the western half of the cone, as well as giving rise to eruption columns greater than 15 km in height.

Hazards mitigation during an eruption depends on a continuous monitoring, as well as a reliable hazard map. The latter is the starting point for develops risk maps, territorial planning and emergencies management. In fact, the early warning provided by the IG-EPN to the local authorities allowed the evacuation of thousands of people living in the high-hazard zone. As a result, human loss was limited to 6 fatalities. In this abstract, we will describe the 2006 eruptions, and the importance of the volcano hazard maps and their diffusion for hazard assessment and emergency planning.

14-16th July eruption

The seismic activity rapidly increased since 14h30 local time (= GMT-5). At first time, a train-like sound and a continuous shake were feel around the volcano. The eruption started at 17h33, with strong cannon-like periodical explosions, which were followed by continuous roars (bramidos), related with a 3-4 km-high eruption column. An almost continuous lava fountain, reaching up to 300 m-high, produced the first pyroclastic flows at 18h00 (Fig. 1). These flows descended toward the Cusúa and Juive Grande villages. The paroxysmal phase occurred between 19h40 and 01h00 giving rise to eruption columns greater than 20 km in height. During the paroxysm, at least 11 pyroclastic flows were generated, which descended on the north-western flank and the Vazcun valley (Fig. 2).

The activity decreased progressively at 15th July, registered only a few explosions. At least 6 small to moderate pyroclastic flows were produced at 16th July; all them were associated with vulcanian explosions.

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Fig. 1 A photo of Tungurahua's vulcanian eruption, with accompanying pyroclastic flows, that occurred on July 14, 2006. Credits: BBC

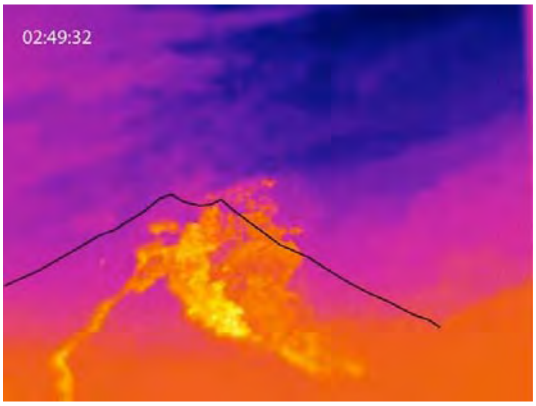

Fig. 2 Thermal image (FLIR) obtained from TVO. A pyroclastic flow descending to Cusúa town during the climatic phase.

16-17th August eruption

Eruptive activity increased from the morning of August 16th. At 14h30, eruptive activity was characterized by a continuous ash and steam emission, reaching 2-3 km above the crater. First small pyroclastic flows occurred around 17h00 and descended down the western flank, following the Cusúa and Chontapamba gullies (Fig. 3). An almost 300 m-high continuous lava fountain, associated with a 3-4 km-high eruption column produced several small pyroclastic flows, those descended toward Cusúa, Juive Grande and Vascún valleys. Other sporadic, but probably bigger, pyroclastic flows were generated between 21h00 and 24h00, mostly related to explosions and/or an increase of the lava fountain, the flows affected the northern and western flanks. The flow most extensive in the Vascún valley, stopped 1.5 km before Baños city.

Fig. 3 Tungurahua volcano in eruption during August 16, 2006.

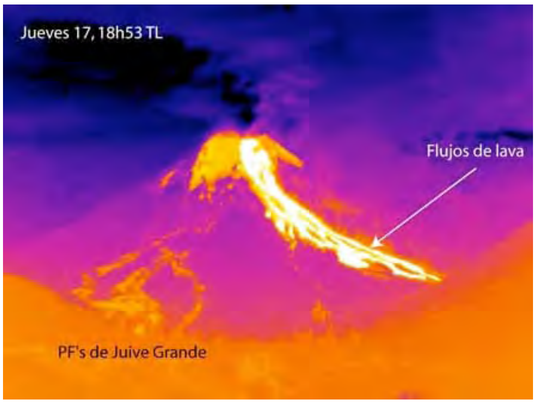

Fig. 4 FLIR image showing the lava flow, which marked the end of the eruptive cycle of July-August, 2006.

The paroxysmal phase initiated at 00h15 (August 17) and ended around 40 minutes after. Eruptive activity was characterized by a powerful lava fountain up to 1000 m above the crater, a 15 km-high eruption column, and the contemporaneous generation of the most important pyroclastic flows, which descended by 17 ravines on the north, north-west, west and south-west flanks. The flows reached up to 8.5 km until get the base of the volcano after a descent of 2600-3000m from the summit crater. The pyroclastic flows of the Rea, Romero and

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Chontapamba ravines formed important deltas in the Rio Chambo valley; this was dammed for several hours after the eruption. The pyroclastic flows that followed in Mapayacu and Juive Grande ravines also dammed the Puela and Pastaza rivers, respectively.

No pyroclastic flow was witnessed on the eastern flank of the cone and no deposits were observed over this region during the helicopter observation done by the staff of IG-EPN. After the paroxysmal phase both the seismic and the volcanic activity rapidly decreased. On the afternoon of August 17th, IG thermal images of the NW flank confirmed the effusion of an important blocky lava flow which was emitted some hours after the paroxysmal phase and stopped at 2700 m asl (Fig. 4).

Use of Tungurahua hazard map

The first Tungurahua volcano hazard map was published by IG-EPN in 1988 (Hall *et al.*, 1988). Based on an extensive study of the volcano by scientific of IG-EPN and IRD, an improved version was published 14 years later (Hall *et al.*, 2002). Local authorities used these maps for emergency planning during the unrest of the volcano and during the 2006 crisis, respectively.

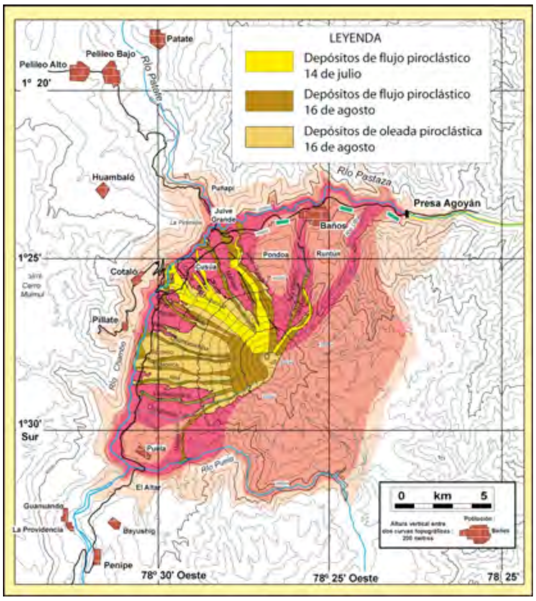

Fig. 5 The distribution of pyroclastic flow and surge deposits shows a good agreement with the high-hazard zone depicted in the 2002 map. The July 14th PF deposits (yellow) are showed on the August 16th PF (brown) and surges (beige) for a better visualization.

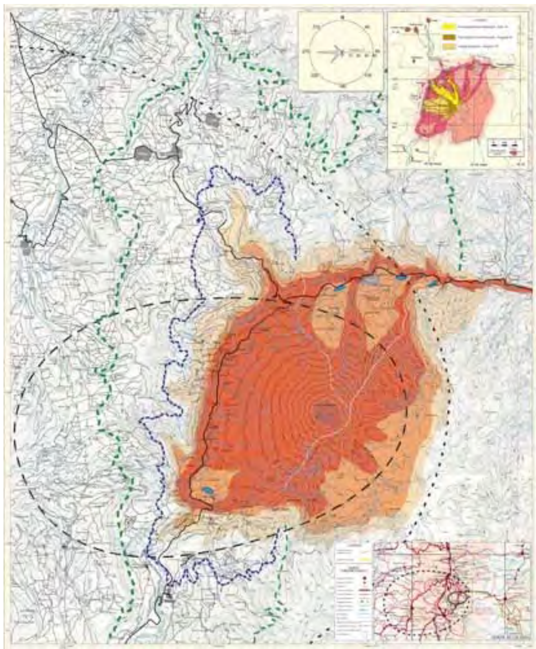

Fig. 6 Third edition of Tungurahua hazard map. Samaniego *et al.*, in press.

Figure 5 shows the distribution of pyroclastic flows and surges for the 14thJuly and August 16th eruptions. A good agreement exists between these deposits and the high-hazard zone defined by the 2002 map. This comparison highlights the relevance and validity of this hazard map. The experience obtained during the current eruption, allow us to incorporate different eruptive scenarios (Fig. 6). This fact is extremely important for emergency management. Moreover, the well-constrained information from the 2006 eruptions is also being used to calibrate numerical simulations for pyroclastic flows. This constitutes a first step towards a new generation of dynamic volcano hazard maps for Ecuadorian volcanoes.

Conclusion

The deployment of a monitoring system by the IG-EPN since 1988, and the installation of the Tungurahua Volcano Observatory in 1999 at a location close to the volcano, allowed IG scientists to communicate to the authorities the course of the volcanic events during the seven years process, and finally to successfully issue early warnings to national and local authorities and to the people before the July and August, 2006 explosive eruptions.

The relevant use of the hazard map of Tungurahua during the 2006 emergency period is undeniably due to constant scientific improvement of the hazard map. In parallel, the volcanological information has been popularized by the publication of a booklet authored by IG-EPN and IRD scientists, and the work *with* the community in the framework of an European-funded DIPECHO project.

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