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Eruption chronologies, plume heights and eruption styles at Tungurahua Volcano: Integrating remote sensing techniques and infrasound

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ABSTRACT

Satellite remote sensing allows volcanic ash plumes to be detected and tracked and routinely aids in hazard mitigation, especially to the aviation community. Although satellite imagery provides valuable information about volcanic plume processes (i.e. plume heights, plume composition and plume transport), it has its limitations. In addition to the observational gaps produced by meteorological clouds as well as temporal and spatial resolution restrictions, large volcanic clouds often obscure the vent during an eruption. Therefore, some key information about eruption dynamics and processes are impossible to obtain from satellite images. In this paper we investigate four eruptions at Tungurahua Volcano, Ecuador during the 2006–2008 time period. We integrate satellite-derived eruption chronologies, plume heights and plume aspect ratios with infrasound data, primarily acoustic power and hand-held thermal imagery when available. Integrating these datasets allows us to identify accurate eruption onsets, durations and cessations as well as define different types of eruption styles ranging from plinian to weak vulcanian. Transitions between the different eruption styles were also documented. Results show that there is a positive correlation between plume height and acoustic power. We conclude that combining the two datasets allows better constraints on eruption processes and source parameters. Using these methods in real-time monitoring will allow more accurate eruption monitoring and ash hazard mitigation.

1. Introduction

Explosive volcanic eruptions produce ash plumes and pyroclastic flows that create hazards to surrounding communities. In addition, volcanic plumes pose a threat to the aviation community and can affect air traffic routes hundreds of kilometers away from the volcano (Casadevall et al., 1992; Rose et al., 1995; Casadevall and Krohn, 1995; Dean et al., 2004). Effective monitoring of these plumes is difficult due to the dangerous nature of explosive eruptions, often remote location of volcanoes, and the inability to view large eruption plume dispersal patterns from the ground. The synoptic view of satellites allow for the detection of volcanic plumes irrespective of light conditions and the opportunity to detect changes in the transport and dispersion of a plume as it traverses the globe (Matson, 1984). Without the use of satellite data, eruption plume dispersal could not be accurately monitored. Satellite remote sensing techniques are routinely used to identify and track these plumes and thereby aid in hazard management (e.g. Kienle and Shaw, 1979; Holasek and Self, 1995; Holasek et al., 1996a; Schneider et al., 1999). Integrating satellite data with other observations of eruptions producing volcanic plumes (e.g., visual observations, ground-based thermal imagery, radar, seismic and infrasound data) enables different eruption regimes to be better identified and classified, thereby enhancing monitoring efforts.

The purpose of this research is to use Geostationary Operational Environmental Satellite (GOES) and Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data to develop eruption chronologies, determine eruption dynamics, and estimated ash plume ceilings during different eruption regimes at Tungurahua Volcano, Ecuador, during the 2006–2008 study period. This paper will expand on the previous investigation of monitoring efforts using infrasound and satellite data at Tungurahua (Garces et al., 2008) and incorporate the infrasound observations presented in a companion paper of Fee et al. (in press). Both data types allow remote monitoring of volcanic activity at different temporal and spatial resolutions, and their synergy enables both continuous near-vent overpressure (infrasound) and ash plume dispersal (satellite) process to be quantified. The integration of infrasound data as well as visual observations and thermal camera imagery enables us to constrain: (1) what types of eruptions can be identified using satellite data and (2) what changes in eruption mechanisms can be inferred using satellite imagery, infrasound data, and ground-based thermal imagery.

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2. Background

2.1. Tungurahua Volcano

Tungurahua Volcano (1.476 S, 78.442 W) is located in Ecuador approximately 140 km south of the capital city of Quito (Fig. 1). The 5023 m andesite–dacite stratovolcano is considered one of the most active volcanoes in Ecuador (BGVN, 2008). Tungurahua is composed of three major volcanic edifices constructed in the mid-Pleistocene. The active cone (Tungurahua III) is located inside a large horse-shoe shaped caldera (Fig. 1) that formed during a large debris avalanche ~3000 years ago (Hall et al., 1999). All historic volcanic activity has occurred at the summit vent and has been generally characterized by strombolian to vulcanian explosions, occasionally accompanied by pyroclastic flows, lava flows and lahars that have inundated populated areas surrounding the flanks of the volcano (BGVN, 2008). Although there was a hiatus in the historic eruptive activity from 1918 to 1999, since 1999 eruptive activity has resumed and is characterized by vulcanian activity and associated convective plumes from the central vent (Johnson, 2003; Arellano et al., 2008; BGVN, 2008). During the 2002–2008 period the volcano has experienced several alternating periods of increased activity, with the most energetic periods starting in the spring of 2006 and continuing today (Arellano et al., 2008).

2.2. Satellite data

A variety of satellite sensors are used to detect volcanic plumes including the Advanced Very High Resolution Radiometer (AVHRR) (Wen and Rose, 1994; Holasek et al., 1996a), Total Ozone Mapping Spectrometer (TOMS) (Krueger, 1982; Robock and Matson, 1983), GOES (Glaze et al., 1989; Dean et al., 2004) and MODIS (Dean et al., 2004; Watson et al., 2004). Image selection depends on the desired time period, temporal and spatial resolutions, location, and properties of the plume. For this project the GOES Imager and MODIS sensors were utilized to gather temperature and velocity measurements of the plumes erupted at Tungurahua. GOES data was used to determine an eruption chronology and plume heights at a high temporal resolution while MODIS data were used, when available, for more spatially robust observation of the plumes.

The GOES Imager is carried on the NOAA GOES geostationary satellite. Because the satellite is located at a high altitude (35,786 km) it is able to acquire images at a high temporal resolution by sweeping the entire earth disk at a high temporal frequency, thus trading spatial resolution for increased field of view and temporal resolution. The sensor acquires images of South America once every 30 min and collects data in five spectral bands. These bands are located in the visible (Band 1: 0.6 μm), mid-infrared (Band 2: 3.9 μm), water vapor

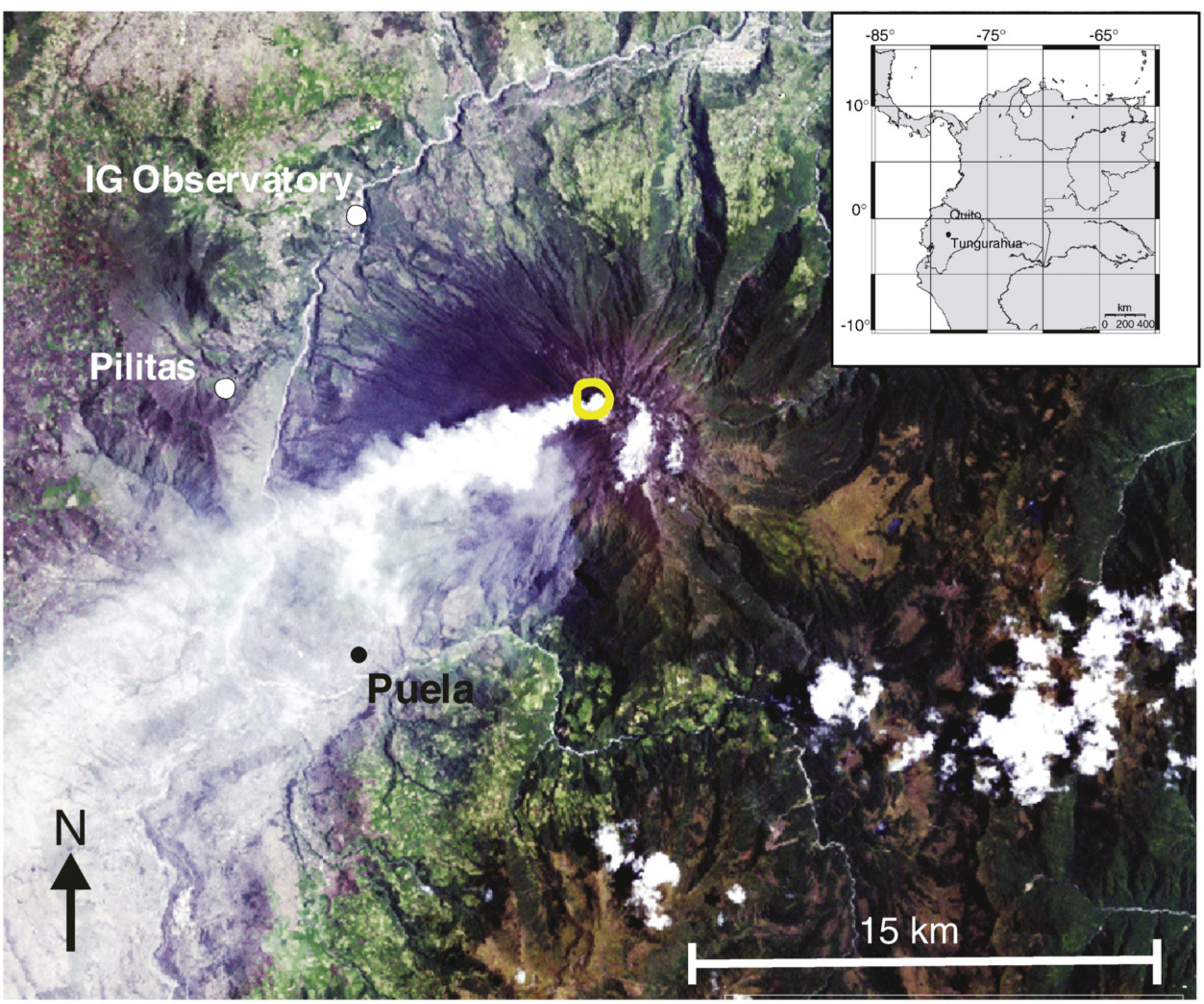

Fig. 1. Location map of Tungurahua Volcano. Map showing location of Tungurahua in Ecuador (inset) and a Landsat ETM+ image (1/28/2004) showing location of Tungurahua, summit crater (yellow circle) and IG observatory.