Earth-Science Reviews 106 (2011) 63–91

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Volcano surveillance using infrared cameras

Letizia Spampinato [a,b,*], Sonia Calvari [a], Clive Oppenheimer [b], Enzo Boschi [c]

[a] Istituto Nazionale di Geofisica e Vulcanologia, sezione di Catania, Piazza Roma 2, 95123, Catania, Italy
[b] Department of Geography, University of Cambridge, Downing Place, Cambridge CB2 3EN, UK
[c] Istituto Nazionale di Geofisica e Vulcanologia, sezione Roma 1, Via di Vigna Murata 605, 00143, Roma, Italy

ARTICLE INFO

Article history:
Received 17 February 2009
Accepted 10 January 2011
Available online 19 January 2011

Keywords:
remote sensing
infrared camera
active volcano surveillance
thermal imaging

ABSTRACT

Volcanic eruptions are commonly preceded, accompanied, and followed by variations of a number of detectable geophysical and geochemical manifestations. Many remote sensing techniques have been applied to tracking anomalies and eruptive precursors, and monitoring ongoing volcanic eruptions, offering obvious advantages over in situ techniques especially during hazardous activity. Whilst spaceborne instruments provide a distinct advantage for collecting data remotely in this regard, they still cannot match the spatial detail or time resolution achievable using portable imagers on the ground or aircraft. Hand-held infrared camera technology has advanced significantly over the last decade, resulting in a proliferation of commercially available instruments, such that volcano observatories are increasingly implementing them in monitoring efforts. Improved thermal surveillance of active volcanoes has not only enhanced hazard assessment but it has contributed substantially to understanding a variety of volcanic processes. Drawing on over a decade of operational volcano surveillance in Italy, we provide here a critical review of the application of infrared thermal cameras to volcano monitoring. Following a summary of key physical principles, instrument capabilities, and the practicalities and methods of data collection, we discuss the types of information that can be retrieved from thermal imagery and what they have contributed to hazard assessment and risk management, and to physical volcanology. With continued developments in thermal imager technology and lower instrument costs, there will be increasing opportunity to gather valuable observations of volcanoes. It is thus timely to review the state of the art and we hope thereby to stimulate further research and innovation in this area.

Contents

* Corresponding author at: Istituto Nazionale di Geofisica e Vulcanologia, sezione di Catania, Piazza Roma 2, 95123, Catania, Italy.
E-mail address: spampinato-l@ct.ingv.it (L. Spampinato).

0012-8252/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.earscirev.2011.01.003

1. Introduction

The study of heat fluxes, temperature variations, and cooling rates in active volcanic areas provides a fundamental contribution to understanding volcanic processes, and to volcanic hazard assessment and risk management (e.g., Calvari et al., 1994; Pinkerton and Wilson, 1994; Harris and Maciejewski, 2000; Crisci et al., 2003; Del Negro et al., 2008). Thermal data, especially in combination with geophysical and geochemical signals, have proved to be useful precursors of eruption onsets (e.g., Oppenheimer, 1998; Andronico et al., 2005). At many volcanoes, changes in temperatures of fumaroles, (e.g., Chrétien and Brousse, 1989; Stoiber and Williams, 1990; Connor et al., 1993; Oppenheimer et al., 1993a; Chiodini et al., 1995; Matthews et al., 1997; Varley and Johnson, 2005), open-conduit vents (e.g., Bonneville and Gouze, 1992; Calvari et al., 2005a, 2005b; Burton et al., 2008), pre-existing fractures (e.g., Thórarinsson and Sigvaldsson 1962; Friedman and Williams, 1968; Calvari et al., 2003a; Tedesco et al., 2007), groundwater (e.g., Bonfanti et al., 1996; Carapezza et al., 2004), and lava domes (e.g., Dehn et al., 2002; Dean et al., 2004; Steffke et al., 2004; Carter et al., 2008) were followed by eruptions.

During effusive eruptions, temperature together with other physical properties of magma (e.g., viscosity, density, crystallinity, and vesicularity) plays a crucial role in lava emplacement and potential flow length (e.g., Booth and Self, 1973; Gauthier, 1973; Pinkerton and Sparks, 1976; Cigolini et al., 1984; Pieri and Baloga, 1986; Calvari et al., 1994; Pinkerton and Norton, 1995; Harris and Rowland, 2001; Harris et al., 2007a). Previous studies have highlighted the significance of lava tubes for lava insulation (e.g., Atkinson et al., 1975; Greeley, 1987; Calvari and Pinkerton, 1998). By limiting heat losses, they can substantially increase flow run out length, potentially accentuating associated hazards (e.g., Peterson and Swanson, 1974; Atkinson et al., 1975; Keszthelyi and Pieri, 1993; Hon et al., 1994; Kauahikaua et al., 1998, 2003). The temperatures of lava flows (e.g., Archambault and Tanguy, 1976; Pinkerton and Sparks, 1976; Lipman and Banks, 1987; Neal et al., 1988; Pinkerton, 1993; Corsaro and Miraglia, 2005), lava lake surfaces (e.g., Krafft and Keller, 1989), and fumaroles (e.g., Le Guern et al., 1980) have been measured in-situ using thermocouples but such proximity to active lava bodies can be challenging. The use of satellite-borne infrared imagers has enabled remote tracking of thermal anomalies and volcano surveillance (e.g., Francis, 1979; Lo Giudice et al., 1980; Bonneville et al., 1985; Archambault et al., 1989; Bianchi et al., 1990; Oppenheimer and Rothery, 1991; Rothery et al., 1992; Harris et al., 1997a; Oppenheimer and Francis, 1997; Wright et al., 2000, 2004; Watson et al., 2004), and is especially valuable for monitoring inaccessible active volcanoes (e.g., Oppenheimer and Francis, 1997, 1998; Harris et al., 1999a; Dehn et al., 2000; Dean et al., 2004; Ramsey and Dehn, 2004; Patrick et al., 2005a).

The first applications of infrared imaging to volcanology focused on qualitative detection and mapping of thermal anomalies (Moxham et al., 1965; Williams et al., 1968a; Friedman et al., 1969a, 1969b; Moxham, 1970; Williams, 1972; Eichelberger et al., 1976; Shimozuru and Kagiyama, 1978; Williams, 1980; Kagiyama, 1981; Kieffer et al., 1981; Ballestracci and Nougier, 1984; Mongillo and Wood, 1995). Fischer et al. (1964) used an electromechanical imaging infrared radiometer to scan the surface of Kīlauea and Mauna Loa volcano (Hawai'i). However, between 1959 and 1969, infrared air-borne surveys by U.S. scientists were carried out also at Irazú and Turrialba volcanoes in Costa Rica, Mt. Rainier (Moxham et al., 1965), Mt. St. Helens and Mt. Adams, Lassen Peak, Mt. Shasta and Mono Lake in California (Friedman, 1968), Taal, Cañlaon and Mayon volcanoes in the Philippine Islands (Moxham and Alcarez, 1966; Moxham, 1967), Mt. Etna and Vesuvius in Italy (Friedman and Williams, 1968), Surtsey and Jólnir (Friedman et al., 1967, 1969a; Williams et al., 1968b; Friedman and Williams, 1969), Mt. Hekla (Friedman et al., 1969b), Askja Caldera (Thórarinsson and Sigvaldsson, 1962) and Kverkfjöll volcanoes (Friedman et al., 1969a) in Iceland, Mt. Erebus and Mt. Melbourne in Antarctica (Parker et al., 1968), and Kamchatkan volcanoes (Shilin and Komarov, 1968; Shilin et al., 1970). In addition, infrared surveys were carried out also for monitoring geothermal areas such as the geysers geothermal steam field in California (Moxham, 1969), the Yellowstone National Park (McLerran and Morgan, 1964; Miller, 1966), and the Mývatn and Torfajökull thermal areas in Iceland (Chaturvedi and Pálmason, 1967; Saemundsson, 1969).

In Italy, volcanological thermal remote sensing surveys were carried out mainly in the 1970s. Such remote sensing investigations were commonly performed by air-borne surveys (Lo Giudice et al., 1974, 1975; De Carolis et al., 1975; Lechi and Lo Giudice, 1976, 1977; Lo Giudice and Tonelli, 1976a, 1976b). In the 1980s, a number of thermal infrared campaigns and air-borne surveys were performed in southern Italy for monitoring the temperature distribution on Mount Etna and the active volcanoes of the Aeolian Archipelago (e.g., Lo Giudice, 1981; Lo Giudice and Tonelli, 1981; Caltabiano and Romano, 1985; Tabbagh et al., 1987; Capaccioni et al., 1989; Bianchi et al., 1990; Bogliolo et al., 1996). Helicopter- and ground-based surveys using an Agema Thermovision 750 thermal camera were used for monitoring temperature distribution at active volcanoes (Bianchi et al., 1987), and for tracking the linear development and thermal behaviour of ground fractures connected to active vents at Mount Etna (Geraci et al., 1985).

Since satellite-based surveys with multispectral imagers (e.g., Patrick et al., 2003a; Pieri and Abrams, 2004; Wright and Flynn, 2004; Carter et al., 2007) are expensive, they are rarely used for systematic thermal monitoring, and instead the application of lighter, hand-held infrared instruments has proliferated recently. Many volcano observatories and scientists are now using spot radiometers (allowing only a single point, or spot, measurement) and imaging systems (allowing for synoptic views of the target) for monitoring and research. Infrared thermometers (non-imaging systems) have been used for measuring temperatures of active lava flows (e.g., Friedman and Williams, 1968; Flynn and Mouginis-Mark, 1992; Pinkerton et al., 2002), explosive vents (e.g., Johnson et al., 2004; Harris et al., 2005a; Scharff et al., 2008), lava lakes (e.g., Flynn et al., 1993; Burgi et al., 2002; Harris et al., 2005b), and fumaroles (e.g., Oppenheimer et al., 1993b; Harris and Maciejewski, 2000; Harris et al., 2009). Imaging systems are more sophisticated and expensive devices but have been rapidly adopted during the last decade because they are vastly more capable and costs have decreased substantially.

Thermal cameras have been used in hand-held, tripod-mounted, and helicopter-based modes or from permanent installations, and