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Invited Decade Review

Volcanology 2020: How will thermal remote sensing of volcanic surface activity evolve over the next decade?

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ABSTRACT

Volcanological remote sensing spans numerous techniques, wavelength regions, data collection strategies, targets, and applications. Attempting to foresee and predict the growth vectors in this broad and rapidly developing field is therefore exceedingly difficult. However, we attempted to make such predictions at both the American Geophysical Union (AGU) meeting session entitled *Volcanology 2010: How will the science and practice of volcanology change in the coming decade?* held in December 2000 and the follow-up session 10 years later, *Looking backward and forward: Volcanology in 2010 and 2020*. In this summary paper, we assess how well we did with our predictions for specific facets of volcano remote sensing in 2000 the advances made over the most recent decade, and attempt a new look ahead to the next decade. In completing this review, we only consider the subset of the field focused on thermal infrared remote sensing of surface activity using ground-based and space-based technology and the subsequent research results. This review keeps to the original scope of both AGU presentations, and therefore does not address the entire field of volcanological remote sensing, which uses technologies in other wavelength regions (e.g., ultraviolet, radar, etc.) or the study of volcanic processes other than the those associated with surface (mostly effusive) activity. Therefore we do not consider remote sensing of ash/gas plumes, for example. In 2000, we had looked forward to a "golden age" in volcanological remote sensing, with a variety of new orbital missions both planned and recently launched. In addition, exciting field-based sensors such as hand-held thermal cameras were also becoming available and being quickly adopted by volcanologists for both monitoring and research applications. All of our predictions in 2000 came true, but at a pace far quicker than we predicted. Relative to the 2000–2010 timeframe, the coming decade will see far fewer new orbital instruments with direct applications to volcanology. However ground-based technologies and applications will continue to proliferate, and unforeseen technology promises many exciting possibilities that will advance volcano thermal monitoring and science far beyond what we can currently envision.

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1. Introduction

At the December 2000 meeting of the American Geophysical Union (AGU), a special session entitled, "Volcanology 2010: How will the science and practice of volcanology change in the coming decade?" proposed that speakers should "imaginatively extrapolate from emerging trends in instrumentation, information sciences, and telecommunications to describe how the more highly wired society of 2010 will better respond to volcanic danger". For thermal remote sensing, we made an attempt to meet the session goal by stating that "monitoring active volcanoes at the end of the next decade will most likely rely on increasing volumes of data made available in real-time" (Harris et al., 2000). We also looked ahead to the many planned orbital sensors and argued that, "the flood of remote sensing data over many wavelengths and resolutions is becoming globally available, and future research needs to capitalize on the strengths of these instruments to provide new ways of monitor volcanic activity" (Wessels and Ramsey, 2000). We went on to propose that, because thermal data from geostationary satellites had already been shown to be of value for tracking hour-by-hour activity changes at volcanic hot spots, "higher temporal resolution (at least minute-by-minute) data is needed to better characterize the activity". Our presentations focused on both the construction and deployments of ground-based thermal sensors to track thermal activity as well as data to be returned from the Earth Observing System (EOS) sensors. We went on to suggest that "such ground-based systems should be installed on other volcanoes by 2010 in order to better monitor ongoing eruptions". The installation of such systems over the next five years led to many advances in the thermal remote sensing science of hot volcanic targets. A final prediction was that the next generation of satellite-based sensors launched as part of the EOS-era would furnish us with never-before-available TIR data sets (Wessels and Ramsey, 2000; Ramsey and Flynn, 2004). These would allow us to expand our measurement capabilities, allowing for example, the implementation of near real-time algorithms such as MODVOLC (Wright et al., 2002a).

In retrospect, we see that thermal remote sensing was poised to make the transition from an experimental to an operational activity both from the ground and from space at the time of our recommendation. That is, methodologies tried and tested during the 1980s and 1990s were about to go online using improved data from a new generation of IR capable satellites and ground-based thermal cameras, coupled with access to high speed internet and wireless systems. One caveat was that, although the data were new, the data processing, reduction techniques, and background principles used, were not. For example, MODVOLC was based on the MIR (3.9 μm) minus TIR (11 μm) band differencing *(ΔT)* detection approach, as initially proposed for fire detection by Flannigan and Vonder-Haar (1986). Other algorithms could be deemed similarly off-the-shelf, and/or based on principles that had been well-established by work completed by the fire and volcano remote sensing communities during the preceding 40 years. The dual-band method for extracting thermal structures from mixed pixels was, for example, proposed by Dozier (1981), and initially applied to volcano data by Rothery et al. (1988). It was then modified according to various combinations of data limits during the 1990s (e.g., Oppenheimer et al., 1993; Wooster and Rothery, 1997; Harris et al., 1999), to be further applied to data offering a larger number of wavebands and higher dynamic ranges in the 2000s (e.g., Harris et al., 2003; Lombardo and Buongiorno, 2006; Hirn et al., 2008). In summary, the advances made over the previous decade were much more rapid than we initially anticipated, so that by 2005 our predictions had been mostly realized and new operational paradigms were already evolving.

In this paper we re-examine our predictions made in 2000, as well as the trends from 1960 to 2010 in the discipline of thermal remote sensing of lava effusion, fumarolic activity, open vent degassing, and persistently activity between. In so doing, we focus specifically on developments in volcano remote sensing using thermal infrared data spanning 3 μm to 20 μm, (i.e., the midwave [MIR: 3 to 5 μm] and longwave [LWIR: 5 to 20 μm] infrared). This analysis allows us to assess the directions in which the volcano thermal remote sensing community moved. We thus look back over the last 50 years to establish a foundation from which to project into the next decade.

2. Background

2.1. The pivotal year 2000

We can divide thermal remote sensing of volcanic surfaces into two general classes: satellite-based and ground-based. Of these, ground-based can be further split into studies that use sensors capable of point-based measurements (i.e., radiometers) and those capable of imaging (i.e., thermal cameras). If we examine the literature database for these sensor groupings, we find approximately 200 papers were published between 1960 and 2005 in the international, peer-reviewed literature, as collated by Harris (2012).

2.2. The publication time-line: satellite-based studies

If we plot the number of publications per year from 1960 to 2005 we see that volcanic hot spot research using satellite-based sensors began in the mid-1960s and developed quite slowly (at a rate of 0.2 publications per year) until 1985, when the rate of publication began to increase, attaining a rate of 2 publications per year between 1985 and 1992 (Fig. 1). Thereafter, the rate of publications continued to increase at a relatively steady rate of ~8 publications per year. Thus, by the year 2000, satellite remote sensing of volcanic hot spots had reached a degree of maturity, with the publication rate being high and steady. This maturity meant that a number of established methodologies were available for application to the new datasets thus creating a recipe book and background library that could be quickly applied to improved temporal, spatial, and/or spectral resolution datasets allowing quick start up and rapid progress. A similarly quick adaptation to new data occurred when volcanologists were faced by new operational requirements and real-time data availability.