THE SPATIAL EXTENT OF THERMAL ANOMALIES AT LASCAR VOLCANO

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1. INTRODUCTION

The monitoring of active volcanoes provides important insights into physical and chemical processes above and below the Earth's surface. It is also a vital component of hazard assessment and associated risk management. Due to technical and logistical challenges and cost of installing and maintaining equipment in the field, remote sensing has been widely applied to the monitoring of active volcanoes.

Many volcanic processes occur over extended time scales (i.e. years). Monitoring of such phenomena thus requires sustained and consistent observation. Space-based sensors are well-suited from this perspective and provide the further advantage of a synoptic view.

With the launch of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), onboard the Terra satellite in 1999, the civilian community was provided with the first orbital, medium-spatial resolution (90 m), multispectral, thermal infrared (TIR) sensor. The TIR wavelengths (8 – 14 μm) are sensitive to changes in temperatures typically found at the Earth's surface. Consequently, the TIR can provide useful information on volcanic thermal behaviour in between strong eruptive episodes (which are generally better observed in the mid- and shortwave infrared), by detecting thermal anomalies, and subtle changes within them, which are not discernible at shorter wavelengths. Furthermore, due to the spectral characteristics of terrestrial materials, multispectral TIR sensors can be used to calculate surface temperatures.

To be able to model volcanic thermal features as dynamic processes it is necessary to be able measure (e.g. by estimating temperature) and relate these features through time. This requires the definition of some thermal parameter(s) that can be used to quantitatively compare scenes in a temporal sequence. Here we propose a parameter that describes the overall size of a thermal anomaly as well the relative proportion of pixels within different temperature ranges. This can be used to distinguish, for example, between large warm anomalies and small hot anomalies, or to detect if the anomaly is expanding or contracting through time. Such information can contribute to the development of models for heat transfer from volcanoes

2. STUDY AREA

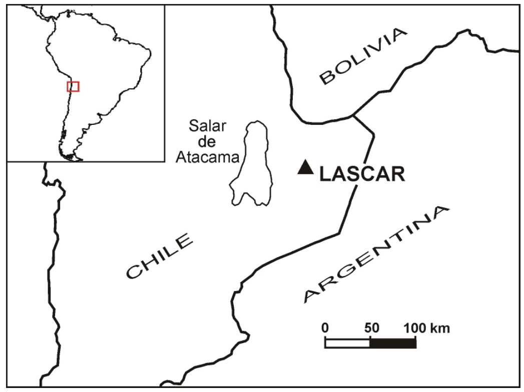

Figure 1. The location of Láscar volcano

Láscar (23°22'S , 67 ° 44'W , 5592m) is a calc-alkaline stratovolcano situated in the Chilean Altiplano to the East of the Salar de Atacama (Fig. 1). This high and arid environment is associated with limited cloud, vegetation, snow and ice cover, making it a very suitable terrain for geological remote sensing [1]. These environmental factors, coupled with the fact that the volcano is characterized by persistent degassing and frequent small-to-moderate explosive eruptions, have encouraged numerous remote sensing studies of Láscar volcano over the past quarter century [e.g. 2-4].

3. METHODOLOGY

We estimate surface temperatures in and around the summit of the volcano from multispectral ASTER TIR imagery. This was achieved using the Normalized Emissivity Method [5]. Temperature estimates of active volcanoes are best interpreted in relation to a contemporaneous background temperature so that non-volcanic variations (e.g. due to seasonal and diurnal cycles) can be suppressed [6]. We can relate the temperature of a volcanic pixel to the ambient ground temperature by defining a background area, calculating the mean temperature from that region and then subtracting this temperature from each pixel (eq. 1)

$$dT_{i,j} = T_{i,j} - \overline{T}_{background} \qquad (1)$$

Where $dT_{i,j}$ is the above background temperature for a given pixel within the i^{th} column and j^{th} row of a two dimensional array, $T_{i,j}$ is the original temperature estimate for that pixel and $\overline{T}_{background}$ is the average temperature estimate within a background area. The spatial extent of thermally anomalous regions can then be determined by counting the number of pixels that fall into given above background temperature ranges (or bins).

4. RESULTS

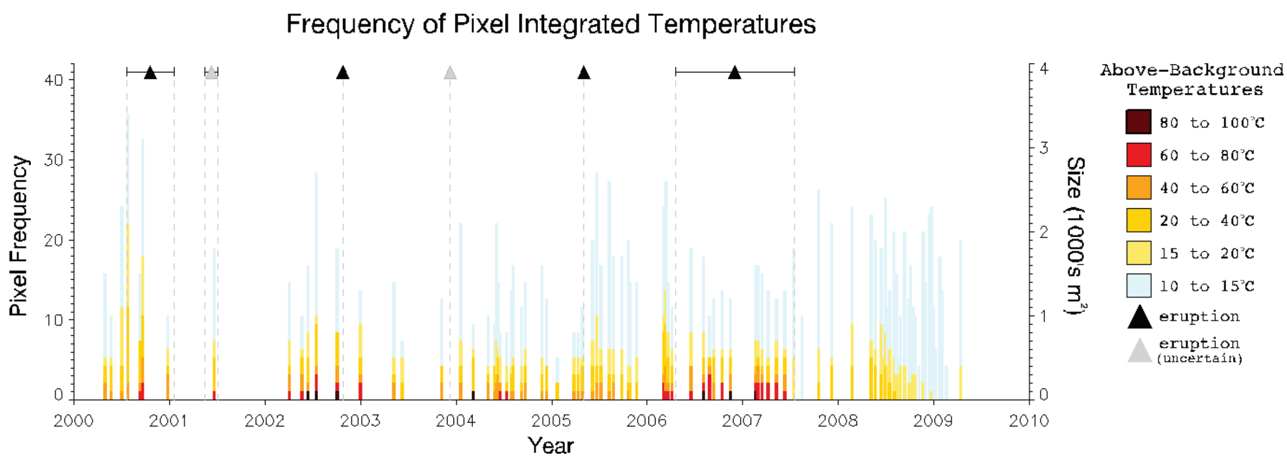

Figure 2. A frequency plot of temperatures above background from Láscar volcano, determined using ASTER TIR images taken between May 2000 and April 2009. The number of anomalous pixels and size of these anomalies (in 1000's of metres squared) are given on the left and right y-axes respectively. Black triangle represent eruptions, grey triangles represent potential, although uncertain, eruptions.

The dataset consists of 92 cloud-free, night-time ASTER scenes of Láscar volcano taken between May 2000 and April 2009. The size and relative proportion of thermal anomalies at different temperatures can be represented as a stacked frequency plot (Fig. 2). The overall height of an individual column equates to the total spatial extent of anomalous regions. The number of pixels which fall into each temperature range gives the proportional contribution of those temperature ranges to the overall anomaly. We consider pixels to be 'thermally anomalous' when they are 10^{o}C or more above background. The triangles represent the occurrence of an eruptive episode as reported by the Smithsonian Institute [7-12]. Black triangles represent a fair degree of certainty whilst grey triangles represent some uncertainty in the occurrence of an eruption. If the start and stop date of an eruption extends beyond the width of the triangle symbol then they are represented by a horizontal bar with wings.

It can readily be appreciated that the overall size of thermal anomalies is not constant, nor are the relative contributions from different temperature ranges. This is interpreted as predominantly representing fluctuations in one or more of the following: 1) the number of active fumarole sites, 2) the quantity of gas being emitted and/or 3) the temperature of emitted gas. The ability to indirectly measure volcanic gas emissions is important because of the critical role that volatiles play in supplying the overpressure necessary to cause explosive eruptions.

High temperature pixels (i.e. those greater than 60^{o}C above background) are generally contemporaneous with eruptive episodes although the occurrence of such pixels also takes place before the October 2002 and April

2006 eruptions, in the former case there is an increase in the size of high temperature anomalies. These may represent precursory signals.

5. CONCLUSION

This innovative, straightforward method of computing and displaying thermal information provides us with the ability to extract and visualize information regarding the spatial extent of thermally significant areas and how they relate to eruptive events. We have given an example from Lascar volcano; however, this methodology can be readily applied to other volcanoes given that enough cloud-free scenes can be acquired. The global applicability of this method and the insights it offers into the thermal state of a volcano both spatially and temporally promises to provide a useful monitoring tool and to facilitate the modelling of volcanic thermal processes.

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6. REFERENCES

[1] S.L. de Silva, P. W. Francis, *Volcanoes of the Central Andes*, Springer, 1991

[2] P.W. Francis, and D. A. Rothery, “Using the Landsat Thematic Mapper to detect and monitor active volcanoes: An example from northern Chile”, *Geology*, pp. 614-617, 1987.

[3] C. Oppenheimer, P.W. Francis, D.A. Rothery, R.W. Carlton and L.S. Glaze, “Infrared Image Analysis of Volcanic Thermal Features: Láscar Volcano, Chile, 1984-1992”, *Journal of Geophysical Research*, pp. 4269-4286, 1993.

[4] M.J. Wooster, “Long-term infrared surveillance of Lascar Volcano: contrasting activity cycles and cooling pyroclastics”, *Geophysical Research Letters*, pp. 847-850, 2001.

[5] V.J. Realmuto, “Separating the effects of temperature and emissivity: Emissivity spectrum normalization,” in *Proc. 2nd TIMS Workshop*. Pasadena, CA: Jet Propul. Lab., JPL Publication, pp. 90-55, 1990.

[6] J. Stix and H. Gaonac’h, “Gas, Plume and Thermal Monitoring” in *Encyclopedia of Volcanoes* (eds) H. Sigurdsson, B.F. Houghton, S.R. McNutt, H. Rymer, J. Stix, Elsevier, pp. 1141-1165, 2000.

[7] Smithsonian Institute, Lascar, Bull. Global Volcanism Network, 2000 25 (6): 1

[8] Smithsonian Institute, Lascar, Bull. Global Volcanism Network, 2003 28 (3): 10-11

[9] Smithsonian Institute, Lascar, Bull. Global Volcanism Network, 2004 29 (1): 2-4

[10] Smithsonian Institute, Lascar, Bull. Global Volcanism Network, 2005 30 (4): 1

[11] Smithsonian Institute, Lascar, Bull. Global Volcanism Network, 2006 31 (4): 6

[12] Smithsonian Institute, Lascar, Bull. Global Volcanism Network, 2007 32 (9): 4-5