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Thermal anomalies at Stromboli volcano from MODIS data

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Abstract. Satellite remote sensing is a convenient way to monitor changes in the thermal budgets of Earth's subaerially active volcanoes. Following its launch on 18 December 1999, the moderate resolution imaging spectroradiometer (MODIS) sensor, aboard NASA's Terra platform, has captured images of volcanic eruptions worldwide. MODIS is NASA's flagship sensor system with 36 spectral bands in the visible and infrared (from near to thermal) region of the spectrum (0.4-14.4 μm). We investigated the 16 thermal bands included between 3.660 μm and 14.385 μm through a time-series of more than 1800 nighttimes. MODIS images allowed us to analyse the infrared radiation of Stromboli volcano during the period spanning between 1 January 2006 and 31 October 2007. Our analysis focused on a spatial mask centered on the volcano summit and we analysed the radiance emitted at 3,959 and 12,02 μm (MODIS band 22 and 32, respectively) for each pixel. A clear seasonal pattern is evident in both regions of spectrum, probably due to the variation of the background temperature over the year. Nevertheless, by using an appropriated threshold that followed this seasonal trend we were able to identify the pixel contaminated by volcanic activity with accuracy. This occurred during the last effusive eruption in February 2007, when a lava flow emplaced along the Sciara del Fuoco. In addition, during periods of moderate to high strombolian activity (April 2006, August 2006, January 2007) we recognised less pronounced thermal anomalies, that were produced by the combined effect of frequent and intense strombolian explosions. Our data are validated with the number of explosions measured by the radiometer positioned near the summit of Stromboli. In addition a clear correlation between satellite thermal anomalies and seismic data, particularly with VLP (signal seismic long period). Both data radiometer and VLP are measured by University of Florence.

Key words. MODIS – Thermal anomalies – Stromboli

1. Introduction

Volcanoes represent a serious potential danger for both the environment and population.

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In earlier times, volcanic eruptions have often caused great loss of lives and damage to the surrounding environment. The launch of new satellites each year and new developments in remote-sensing techniques have expanded the capability of scientists worldwide to monitor volcanoes using satellites. For the purpose of studying volcanoes, remote sensing is the detection by a satellite's sensors of electromagnetic energy that is absorbed, reflected, radiated, or scattered from the surface of a volcano or from its erupted material during an eruption. In particular, the identification of thermal anomalies from space has several applications, including the detection of volcanic eruptions (Rothery et al. 1988), (Harris et al. 1997).

A variety of sensors are used to measure wavelengths of energy that are beyond the range of human vision. MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites MODIS was launched into a sun-synchronous polar orbit on-board NASA's first EOS platform, Terra, in December 1999. A second MODIS sensor is been launched in April 2002 on the EOS platform "Aqua". Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon so that are acquired 2 daytime images and 2 nighttime images for one day. The nadir spatial resolution is 1 km, and the nominal swath is 2330 km. The MODIS three MIR bands (20,22 and 23) are centered around 3.75, 3.95 and 4.05 μm, and the three TIR channels (29, 31 and 32) are centered around 8.55, 11.03 and 12.02 μm. The spectral radiance measured in thermal emission by MODIS was used in different environments volcanic. The MODIS Thermal Alerts Web site[1], developed and maintained by the Hawaii Institute of Geophysics and Planetology's MODIS Thermal Alert Team (Flynn et al. 2002), (Wright et al. 2002), (Wright et al. 2004) hosts the first truly global high-temperature thermal monitoring system. Wright et al. (2002) provide a full description of how the MODVOLC algorithm was developed, tested and implemented. The MODVOLC (MODIS Volcano alert) algorithm (NTI) is a point operation which analyses the Level 1B MODIS radiance data from three wavebands (21, 22, and 32) using an index simmetry. Surfaces that are thermally homogenous at the pixel scale can be discriminated on the basis of differences in the amount of radiance they emit at 4 and 12 μm.

If NTI is more than -0.8 the pixel can be defined as thermal anomaly. In this paper, we have applied this methodology for monitoring Stromboli thermal anomalies. They have been recorded for both strombolian activity and the last eruption (February-April 2007), through Level 1B MODIS radiance. An accurate fluctuating-threshold for NTI has been used to allow a better distinction of thermal anomalies from background (sea, land and clouds) so we were able to detect with accuracy strombolian activity not distinguishable if threshold NTI is fixed.

2. Stromboli

Stromboli volcano, a 924 m high stratovolcano located at northeast end of the Aeolian Arc. It is the only island of this archipelago which has been in permanent activity in the last 2000 years. Its activity is characterized by an open-conduit system, with explosive event at regular intervals of 10-20 minutes, ejection of scorias, lapilli, bombs and constant gas emissions (H_2O, SO_2 and CO_2) from the crater area. This activity is periodically interrupted by eruptive crisis, such as lava flows and major explosions or paroxysms.

3. MODIS Analysis

Alert detection

We analysed nighttimes MODIS level1b granules (available at[2] (Xiong et al. 2006)), acquired over Southern Tyrrenian during the period spanning between 1 January 2006 and 30 October 2007. These dataset consist of more than 1800 granules. The location, radiances

[1] http://modis.higp.hawaii.edu/

[2] http://ladsweb.nascom.nasa.gov

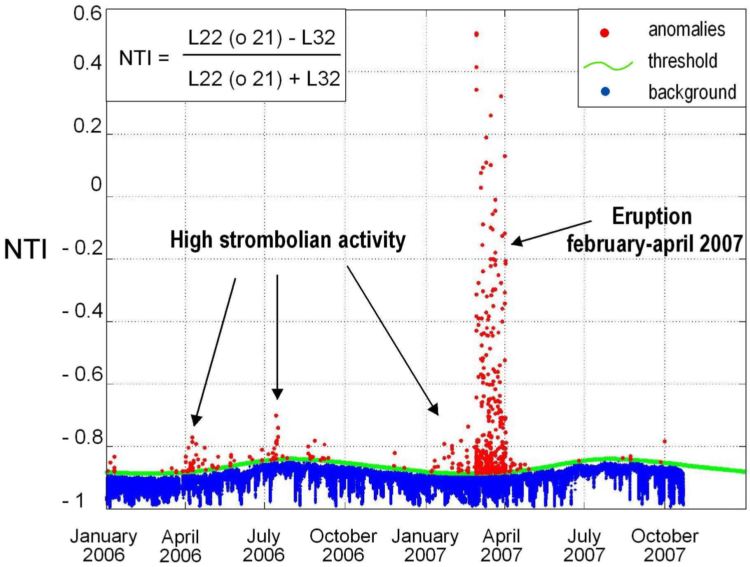

Fig. 1. NTI time series for all Stromboli pixel.

and the viewing geometry data were extracted for a spatial mask centred on Stromboli volcano in order to analyse the thermal anomalies due to the volcanic activity occurred in this period. We investigated the spectral radiance at 3.960 μm (L_4 = Band 22 or 21 when this latter is saturated) and 12.032 μm (L_{12} = Band 32) which are currently used for global monitoring of volcanic activity. In particular we apply the Normalised Thermal Index NTI, which is the difference between the radiance received at 3.960 and 12.032 μm, weighted by their sum ($[L_4\text{-}L_{12}]/[L_4\text{+}L_{12}]$). This algorithm (developed by the MODIS Alert Team) is based on the fact that a sub-pixel hotspot causes the amount of radiance emitted at 4 μm to increase at a much greater rate than at 12 μm (Flynn et al. 2002), (Wright et al. 2002), (Wright et al. 2004). According to this principle, the MODVOLC trigger an alert whenever a pixel has an NTI higher than a fixed threshold (-0.8); such thresholds were settled in order to avoid false alarms on a global scale according to the global monitoring aim of this system. Nevertheless, since the NTI is based on absolute radiance values, variations in geography and season will influence its value following to the variations in the ambient background temperature (Wright et al. 2002). At Stromboli volcano a clear seasonal pattern is evident in both the spectral radiances as well as in the NTI (Fig. 1). By using an appropriated threshold that envelop this seasonal trend which periodically oscillate between -0.84, in the hottest season and -0.88, in the colder season, we were able to identify with accuracy the pixels contaminated by the volcanic activity. These latter are recorded when NTI is above floating threshold. Therefore we detected thermal anomalies for the last eruption which occured between 28 February 2007 and 3 April 2007 (Fig. 1). During periods of moderate to high strombolian activity we recognised less pronounced thermal anomalies, that were pro-

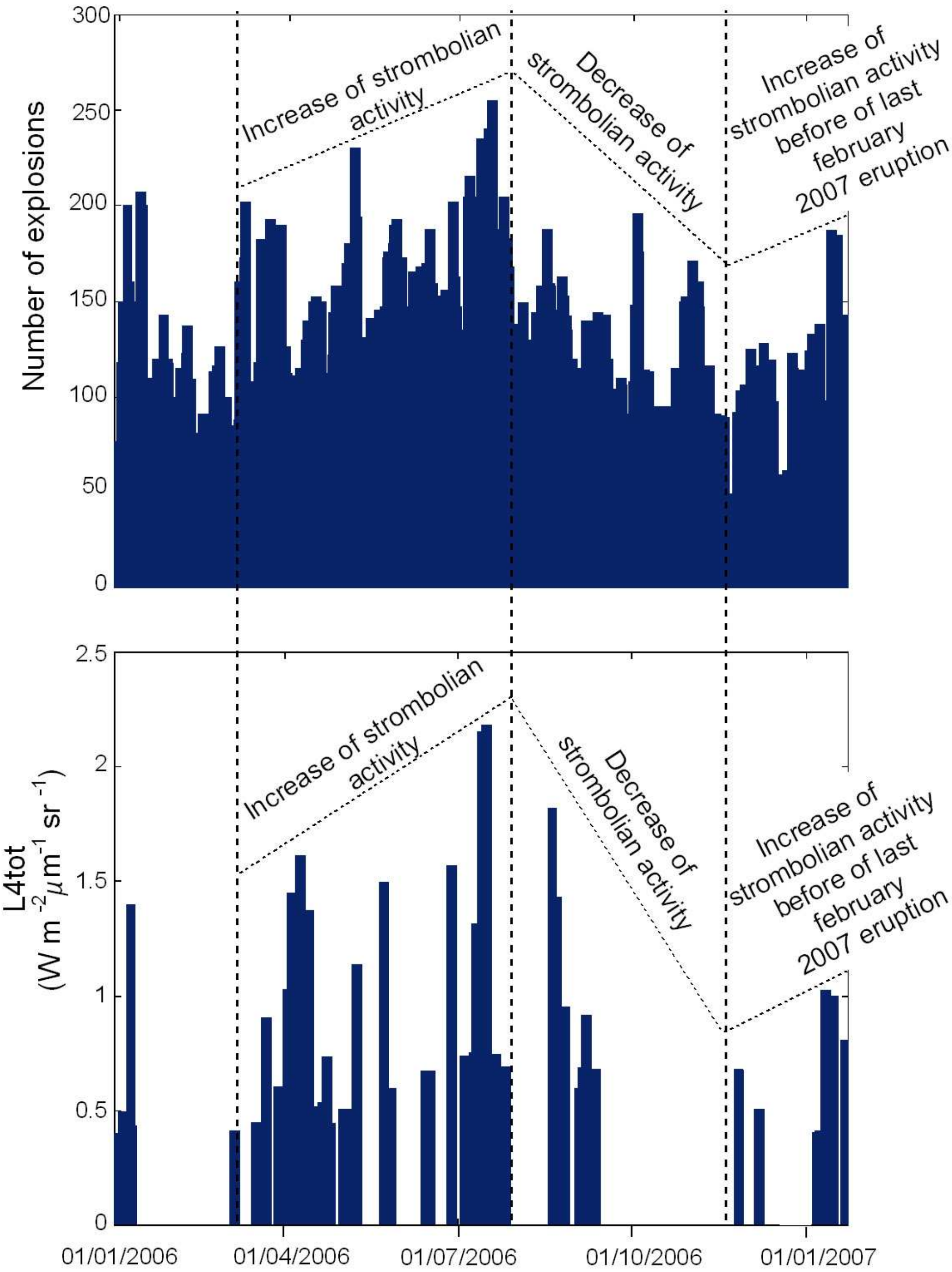

Fig. 2. comparison between number explosions measured by radiometer (University of Florence) and the sum of the radiance at 4 μm for all pixel alerted during a single satellite overpass.

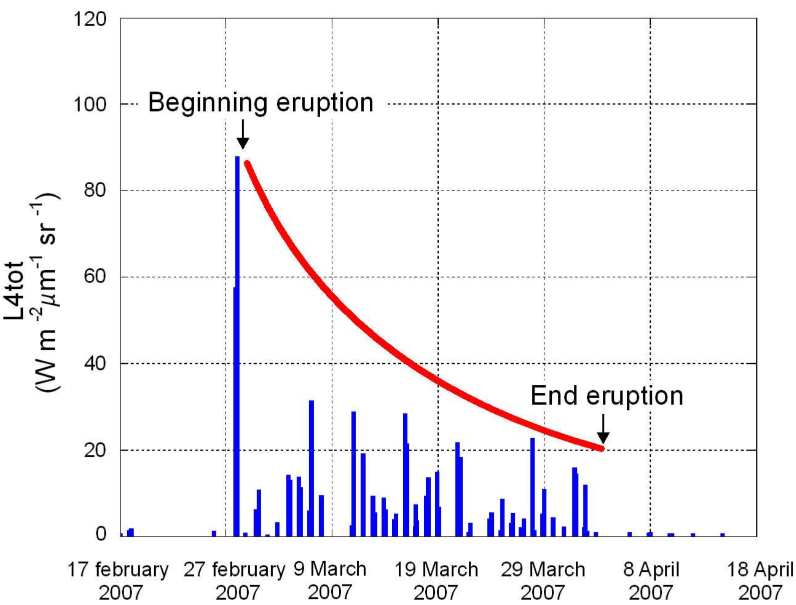

Fig. 3. Decrease exponentially of the thermal budget during the last eruption occurs at Stromboli (27 February -3 April 2007).

duced by the combined effect of frequent and intense strombolian explosions. These thermal anomalies are occurred during April and August 2006 and before of the last eruption (January 2007).

Analysis

The total radiative emission of an hotspot shared between more than one MODIS pixels (L4TOT) is calculated by summing the corresponding radiance of all the pixels alerted (L4PIX) during a single satellite overpass (Wright and Flynn 2004). This methodology allowed us to quantify the thermal volcanic anomalies in terms of budget energy for each satellite overpass where are included pixel with thermal anomalies. In this way besides quantifying with precision the energy for the last eruption, we were able to define strombolian activity (Fig. 2). For this latter we have found a good correlation with data of the radiometer installed on the outskirts of Stromboli summit. This instrument measure the explosions number when thermal anomalies exceeded a fixed threshold. Another good correlation is with VLP (very long period) seismic data (Neuberg et al., 1994). At Stromboli VLP inferred to reflect a rapid expansion of a gas slug in the magma conduit, just before the explosion (Ripepe et al. 2001), (Chouet et al. 2003).

The correlations abovementioned are good for moderate and high strombolian activity. Furthermore the identification of thermal anomalies from floating NTI allowed us to observe a decrease exponentially in terms of thermal energy (Fig. 3) for the last eruption (27 February-3 April 2007).

4. Conclusion

The analysis of about 1700 MODIS Stromboli image allowed us to discriminate with accuracy the thermal anomalies of strombolian activity. Our data has been compared with both, the number of explosions, and the number of very long period events (data are courtesy of University of Florence). The last eruption occurs from 27 February to 3 April 2007 shows a decrease exponentially in terms of budget thermal.

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