Available online at www.sciencedirect.com
ScienceDirect
Communications in Nonlinear Science and Numerical Simulation 14 (2009) 174–181
Communications in Nonlinear Science and Numerical Simulation
www.elsevier.com/locate/cnsns

Fisher information measure of temporal fluctuations in satellite advanced very high resolution radiometer (AVHRR) thermal signals recorded in the volcanic area of Etna (Italy)

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Received 23 November 2006; received in revised form 17 May 2007; accepted 4 July 2007
Available online 20 July 2007

Abstract

The time dynamics of long-term time series of satellite thermal signal, measured at Mount Etna, has been investigated. The signal has been analyzed by means of a recently proposed multi-temporal and robust technique (RST), which has already shown to be better capable to detect and monitor volcanic hotspots, compared to traditional satellite approaches. The temporal fluctuations of the thermal signal detected by RST over a long series (1995–2006) of advanced very high resolution radiometer (AVHRR) satellite data, have been investigated by means of the Fisher information measure, which is a powerful tool to investigate complex and nonstationary signals. The preliminary obtained results indicate that the proposed nonlinear approach can be used to dynamically characterize the volcanic phenomena and to recognize possible pre-eruptive temporal patterns.

PACS: 91.40.Yt; 91.40.Zz

Keywords: Etna; Satellite thermal signal; Fisher analysis

1. Introduction

Satellite remote sensing, thanks to operations of many satellite platforms orbiting around Earth and providing repetitive data at a global scale and generally at low costs, represents nowadays an indispensable tool for volcanic activity monitoring, especially useful in remote areas where volcanoes still remain largely unmonitored by ground-based techniques.

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doi:10.1016/j.cnsns.2007.07.006

Several studies have shown that satellite sensors having channels in shortwave and mid-infrared bands may be successfully used to detect and monitor volcanic thermal anomalies such as fumaroles emissions, lava flows, lava lake, lava dome etc. (e.g. [1–8]).

Sensors like the Advanced Very High Resolution Radiometer (AVHRR) aboard National Oceanic and Atmospheric Administration (NOAA) satellites, or Moderate Resolution Imaging Spectroradiometer (MODIS) aboard Earth Observing System (EOS) platforms, have been, in fact, largely employed to study thermal volcanic activity, even if some problems, such as false alarms, still represent an issue, especially for an operational hot spot detection and monitoring system.

Recently, a new satellite approach named robust satellite techniques (RST), based on multitemporal analysis of satellite data, has been successfully applied to study some recent eruptive events of Etna and Stromboli volcanoes, showing to be capable of correctly detecting hot volcanic features strongly reducing false identifications [9,10].

A satellite monitoring system, based on this multitemporal approach, has also been developed at Institute of Methodologies for Environmental Analysis (IMAA) to monitor active Italian volcanoes in near real time using AVHRR mid-infrared (MIR) data. This monitoring system allows us to promptly identify volcanic thermal anomalies both in their correct geographic location and intensity [11].

The RST approach, applied to a long time series of satellite records, has shown to be also suitable to dynamically characterize the thermal signal of active volcanoes [12].

In this paper, we present a new approach in analyzing satellite thermal signals of active volcanoes, by means of the Fisher information measure (FIM), which was introduced by Fisher in 1925 in the context of statistical estimation [13]. In a seminal paper, Frieden has shown FIM to be a versatile tool to describe the evolution laws of physical systems [14]. FIM permits to accurately describe the behavior of dynamic systems and to characterize the complex signals generated by these systems [15]. This approach has been used by Martin et al. [16] to characterize the dynamics of EEG signals. Martin et al. [17] have shown the informative content of FIM in detecting significant changes in the behavior of nonlinear dynamical systems, characterizing, thus, FIM as an important quantity involved in many aspects of the theoretical and observational description of natural phenomena.

The objective of the present paper is the analysis of the time series of the thermal satellite signal, associated with volcanic activity of Mt. Etna, in order to dynamically characterize the volcanic phenomenon and to recognize possible temporal patterns that could be associated to pre-eruptive phases.

2. Data description

The AVHRR sensor, flying aboard NOAA satellites since 1978, thanks to: (i) a channel in the MIR spectral band (the most suitable to identify hot surfaces at magmatic temperatures), (ii) a spatial resolution of 1.1 km at nadir view and (iii) a temporal resolution of 6 h, represents one of the best satellite instruments for thermal volcanic activity monitoring. Moreover, this sensor offers more than 20 years of satellite records, suitable for statistical analysis devoted to dynamically characterize thermal signals of active volcanoes.

All the satellite images considered for the statistical analysis were calibrated using a standard procedure [18], navigated by specific tools [19,20] and processed following the RST prescriptions [10]. RST approach, first named robust AVHRR technique (RAT), widely described in [9,10,21–24], has been applied on more than 10 years of AVHRR records acquired in night-time in order to identify possible thermal anomalies within an area selected over the volcano edifice.

According to RST, in order to automatically detect volcanic hot spots, an index called Absolute Local Index of Change Environment (ALICE) was computed as:

$$\otimes_{\mathrm{MIR}}(x,y,t) = \frac{[T_{\mathrm{MIR}}(x,y,t) - \mu_{\mathrm{MIR}}(x,y)]}{\sigma_{\mathrm{MIR}}(x,y)} \tag{1}$$

where $T_{\mathrm{MIR}}(x,y,t)$ represents the brightness temperature measured in AVHRR MIR channel (3.55–3.93 μm) at time t (i.e. on the image at hand) , while $\mu_{\mathrm{MIR}}(x,y)$ and $\sigma_{\mathrm{MIR}}(x,y)$ respectively represents the arithmetic average in the time domain, computed for each pixel (x,y) of the whole MIR satellite image and the temporal standard deviation for the same pixel (x,y), both calculated putting together satellite data according to the