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Reducing atmospheric noise in RST analysis of TIR satellite radiances for earthquakes prone areas satellite monitoring

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ABSTRACT

Space–time fluctuations of the Earth's emitted Thermal Infrared (TIR) radiation observed from satellite from months to weeks before an earthquake are reported in several studies. Among the others, a Robust Satellite data analysis Technique (RST) was proposed (and applied to different satellite sensors in various geo-tectonic contexts) to discriminate anomalous signal transients possibly associated with earthquake occurrence from normal TIR signal fluctuations due to other possible causes (e.g. solar diurnal–annual cycle, meteorological conditions, changes in observational conditions, etc.). Variations in satellite view angle depending on satellite's passages (for polar satellites) and atmospheric water vapour fluctuations were recognized in the past as the main factors affecting the residual signal variability reducing the overall Signal-to-Noise (S/N) ratio and the potential of the RST-based approach in identifying seismically related thermal anomalies. In this paper we focus on both factors for the first time, applying the RST approach to geostationary satellites (which guarantees stable view angles) and using Land Surface Temperature (LST) data products (which are less affected by atmospheric water vapour variability) instead of just TIR radiances at the sensor.

The first results, obtained in the case of the Abruzzo earthquake (6 April 2009, $M_W \sim 6.3$) by analyzing 6 years of SEVIRI (Spinning Enhanced Visible and Infrared Imager on board the geostationary Meteosat Second Generation satellite) LST products provided by EUMETSAT, seem to confirm the major sensitivity of the proposed approach in detecting perturbations of the Earth's thermal emission a few days before the main shock. The results achieved in terms of increased S/N ratio (in validation) and reduced "false alarms" rate (in confutation) are discussed comparing results obtained by applying RST to LST products with those achieved by applying an identical RST analysis (using the same MSG-SEVIRI 2005–2010 data-set) to the simple TIR radiances at the sensor.

1. Introduction

Over the last two decades several studies (see, for example, Gorny et al., 1988; Qiang and Dian, 1992; Tronin, 1996; Qiang et al., 1997; Tronin et al., 2002; Ouzounov and Freund, 2004) reported the appearance of space–time anomalies in TIR (Thermal Infra-Red) satellite imagery before (from weeks to days) severe earthquakes. Such anomalies, observed near the place and time of an earthquake, were attributed to different genetic causes like the increase of green-house gas (such as CO_2, CH_4) emission rates (e.g. Quiang et al., 1991; Tronin, 2000; Tramutoli et al., 2001a, 2009, 2013, and references therein), the modification of ground water regime (e.g. Hamza, 2001), and more complex phenomena (e.g. Pulinets et al., 2002, 2006, 2007; Ouzounov and Freund, 2004) all including, among the others, pre-seismic effects, increased near surface temperature and TIR emission.

Despite numerous studies reporting pre-seismic TIR anomalies, rigorous definitions of TIR anomaly have only recently been given (e.g. Tramutoli et al., 2001a; Ouzounov and Freund, 2004; Piroddi and Ranieri, 2012). In the last decade more attention was paid to other (e.g. meteorological) possible causes of TIR anomalies and to their possible occurrence also in the absence of significant seismic activity (confutation). Among other methods, the Robust

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Satellite Technique (RST, Tramutoli, 2005, 2007) – formerly RAT (Robust AVHRR[1] Technique, Tramutoli, 1998) – was successfully applied to investigate possible relations between earthquake occurrence and space–time fluctuations of the Earth's emitted TIR radiation observed from satellite.

The RST approach is based on a statistical definition of "TIR anomalies" and on a suitable method for their identification even in very different natural (e.g. related to atmosphere and/or surface) and observational (e.g. related to the time/season of a satellite pass) conditions. Since its first application to the study of earthquakes the RST approach has been used with a validation/-confutation method to verify the presence/absence of anomalous space–time TIR transients in presence/absence of seismic activity.

Several earthquakes in different continents (Europe, Asia, America and Africa), in various geo-tectonic settings (compressive, extensional, and transcurrent) and with a wide range of magnitudes (from 4.0 to 7.9) were analyzed applying the RST approach to different satellite TIR sensors (e.g. Tramutoli et al., 2001b, 2005, 2009; Di Bello et al., 2004; Filizzola et al., 2004; Corrado et al., 2005; Genzano et al., 2007, 2009a; Aliano et al., 2007, 2008a,b,c; Lisi et al., 2010; Pergola et al., 2010).

Variations in satellite view angle depending on satellite's passages (for polar satellites) and atmospheric water vapour fluctuations were recognized in those previous works as the main factors limiting the Signal-to-Noise (S/N) ratio and the possibility for the RST-based approach to more clearly identify seismically related thermal anomalies.

The use of a sensor on board geostationary satellites allowed us to overcome the first problem (as a geostationary attitude guarantees stable view angles). The second could be dealt with using LST data products (which are less affected by atmospheric water vapour variability) instead of just TIR radiances at the sensor.

LST estimations from remotely sensed data are generally obtained from one or more channels within the thermal infrared atmospheric window from 8 to 13 μm (Dash et al., 2002). Operational LST retrievals often make use of split-window algorithms (see, e.g., Prata and Barton, 1993; Wan and Dozier, 1996), where LST is obtained through a semi-empirical regression of top-of-the-atmosphere (TOA) brightness temperatures of two pseudo-contiguous channels (i.e., the split-window channels). The Land SAF (Satellite Application Facility on Land Surface Analysis) LST algorithm is based on the generalized split-window (GSW) formulation initially developed for AVHRR and MODIS[2] by Wan and Dozier (1996) and later adapted to SEVIRI split-window channels by Madeira (2002).

The GSW algorithm mainly exploits the direct proportionality between the atmospheric Total Columnar Water Vapour Content (TCWVC) and the brightness temperature difference measured in two adjacent TIR spectral bands centred at 11.0 and 12.0 μm (split-window bands). In fact, the atmospheric attenuation is greater in the 12.0 μm channel than in the 11.0 μm channel and, as the attenuation increases (primarily as a result of increasing atmospheric water vapour content), the difference in the radiance measured in the two bands increases.

The error of LST retrievals via GSW mostly depends on:

(1) the residual uncertainty about the surface emissivity;
(2) the representativeness of atmospheric profiles used to determine calibration coefficients when applied at a local scale;
(3) the satellite view angle, which also determines the total optical path. LST estimations are often limited to satellite zenith angles (SZAs) below ~60°, where retrieval errors are still acceptable (see, e.g., Wan and Dozier, 1996; Sun and Pinker, 2003).

LST products are generated by Land SAF through the application of a generalized split-window algorithm to data acquired by the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board Meteosat Second Generation (MSG) satellites.

We used the algorithm proposed by Trigo et al. (2008a) on the basis of the formulation first developed by Wan and Dozier (1996) for AVHRR and MODIS data. Thus, LST is estimated as a linear function of clear-sky TOA brightness temperatures measured by SEVIRI split-window channels centred respectively at 10.8 μm and 12.0 μm.

The Land SAF LST product (operationally retrieved, archived and disseminated since February 2005) provides an estimation of the ground surface temperature corrected for the variable contribution of water vapour in the atmosphere (see Filizzola et al., 2004; Di Bello et al., 2004), thus reducing the natural noise associated with simple TIR brightness temperature analyses.

In this paper we present the results of the first application of the RST approach to Land Surface Temperature products (LST) obtained from geostationary satellite data. The approach was used to study the L'Aquila earthquake (6 April 2009, $M_W \sim 6.3$).

As usual, the results obtained by the RST analysis at the time of this earthquake (validation) are compared with those obtained by an identical analysis performed over the same area, in similar observational conditions and same period of the year but in a seismically unperturbed (i.e. without earthquakes of a similar magnitude) period of a different year (confutation).

2. The RST methodology for a robust estimation of thermal anomalies

The RST approach is a general change detection method for satellite data analysis. It has already been successfully applied to monitor major natural and environmental hazards related to: flood risk (Tramutoli et al., 2001a; Lacava et al., 2005, 2006, 2010); volcanic activity (Pergola et al., 2001, 2004a,b; Tramutoli et al., 2001c; Di Bello et al., 2004; Bonfiglio et al., 2005; Marchese et al., 2006; Filizzola et al., 2007); forest fires (Cuomo et al., 2001; Mazzeo et al., 2007), etc. Since its first application to the 1980 Irpinia-Basilicata's earthquake (Di Bello et al., 2004; Tramutoli et al., 2001b), the RST has been applied to seismically active areas while monitoring several other major ($M > 5$) earthquake events: Athens on 7 September 1999 (Filizzola et al., 2004), Izmit on 17 August 1999 (Tramutoli et al., 2005), Gujarat on 26 January 2001 (Genzano et al., 2007), Boumerdes/Thenia on 21 May 2003 (Aliano et al., 2007), Hector Mine on 16 October 1999 (Aliano et al., 2008a), Umbria – Marche in October 1997 (Aliano et al., 2008b), Mestia Tianeti (Georgia) on 23 October 1992 (Genzano et al., 2009a), and various seismic events (with $4 < M_b < 5.5$) occurred in Greece and Turkey in May and June 1995–1996 (Corrado et al., 2005).

The RST methodology is based on the following logic: space–time transient anomalies can be defined and identified only by comparison with a normal behaviour of the measured signal that has to be preliminarily defined. Since such "normal" behaviour is variable in the space–time domain, it is impossible to establish any *a priori* fixed threshold suitable to establish when a signal has to be considered anomalous independently from the observation time and location. A signal, which is normally observed at a specific time and place, could in fact prove to be anomalous when observed in a different time and/or place.

[1] AVHRR (Advanced Very High Resolution Radiometer) is a sensor flying on board NOAA (Nationaland Oceanic Atmospheric Administration) satellites.

[2] MODIS (or Moderate Resolution Imaging Spectroradiometer) is a sensor on board Terra (EOS AM) and Aqua (EOS PM) satellites.