TIR anomaly possibly related to the large earthquake using MT-SAT data

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1. Introduction

Looking toward the development of **multi parametric approaches**, which could be able to improve our capability to assess the seismic hazard in the short-term (from weeks to days before the earthquake), a preliminary step is to identify those parameters (chemical, physical, biological, etc.) whose anomalous variations can be, to some extent, associated with the complex process of preparation of earthquakes.

The **fluctuations of Earth's thermally emitted radiation**, measured by satellite sensors operating in the thermal infrared (TIR) spectral range, have been proposed since eighties as a potential earthquake precursor. Since 2001, the general change detention approach Robust Satellite Techniques (RST), used in combination with RETIRA (Robust Estimator of TIR Anomalies) index, showed good ability to discriminate anomalous TIR signals possibly associated to seismic activity, from the normal variability of TIR signal due to other causes (e.g. meteorological).

In this work, the RST (Robust Satellite Technique, Tramutoli 1998) data analysis approach has been implemented on TIR satellite records collected over Japan by the geostationary satellite sensor **MTSAT** (Multifunctional Transport SATellites) in the period June 2005 - December 2015 in order to evaluate its possible contribute to an improved multi parametric system for a **time-Dependent Assessment of Seismic Hazard** (t-DASH).

For the first time, thermal anomalies has been identified comparing the daily TIR radiation of each location of the considered satellite portions, with its historical expected value and variation range (i.e. RST reference fields) computed using a moving window (i.e. 30 days) instead than fixed monthly window.

2. RST methodology and RETIRA index

The RST approach is based on a **multi-temporal analysis** of historical data set of satellite observations acquired in similar observational conditions (e.g. same hour of the day, same sensor, etc.). Such preliminary analysis is devoted to characterize the measured signal in terms of its expected value and variation range (i.e. RST reference fields) for each pixel of the satellite image to be processed.

In order to reduce meteorological effects in the computation of the reference fields, for the first time, instead of a fixed monthly window criteria, a 30 days moving window (i.e. 15 days before and 15 days after the considered day of the year) has been used.

To identify **TIR Anomalies**, RETIRA index was computed on the image at hand as in the following expression:

$$\otimes_{\Delta T_{box}}(x,y,t) \equiv \frac{\Delta T_{box}(x,y,t) - \mu_{\Delta T_{box}}(x,y)}{\sigma_{\Delta T_{box}}(x,y)}$$

where:

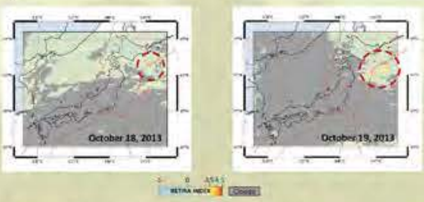
- x,y represent the coordinates of the centre of the ground resolution cell corresponding to the pixel under consideration on a satellite image;
- t is the time of the measurement acquisition with $t \in \tau$, where τ defines the homogeneous domain of multi annual satellite imagery collected in the same time-slot of the day and period of the year;
- $\Delta T_{box}(x,y,t)$ is the spatial average of $\Delta T(x,y,t)$ within a region of 3x3 pixels centered at location x,y. It is computed only if at least 55% of pixels are clear or not close to cloud;
- $\Delta T(x,y,t)=T(x,y,t)-T(t)$ is the value of the difference between the punctual value of TIR brightness temperature $T(x,y,t)$ measured at the location x,y on the acquisition time t and its spatial average $T(t)$ computed on the investigated area considering only cloud-free* locations, all belonging to the same, land or sea, class (i.e. considering only sea pixels if x,y is located on the sea and only land pixels if x,y is located on the land);
- $\mu_{\Delta T_{box}}(x,y)$ is the time average value of $\Delta T_{box}(x,y,t)$ at the location x,y computed on cloud-free records belonging to the selected data set ($t \in \tau$);
- $\sigma_{\Delta T_{box}}(x,y)$ is the standard deviation value of $\Delta T_{box}(x,y,t)$ at the location x,y computed on cloud-free records belonging to the selected data set ($t \in \tau$).

* Cloud-detection is performed by using the One-channel Cloud-detection Approach (OCA) described in Cuomo et al., 2004

3. Identification of Significant Sequences of TIR Anomalies (SSTAs) in a possible relation with Earthquakes (M≥5)

As discussed in previous papers (e.g. Tramutoli et al., 2005) significant TIR Anomalies (TAs) possibly related to an impending earthquake are spatially and temporally persistent. To identify **Significant Sequences of Thermal Anomalies** (SSTAs) the following requirements must be satisfied:

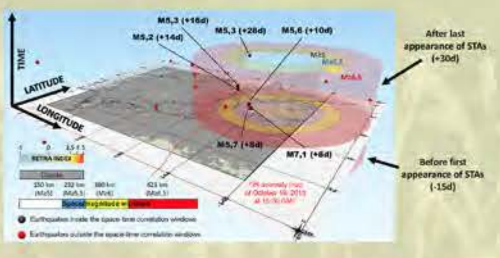
- Relative intensity: $\otimes_{\Delta T_{box}}(x,y,t) \geq K$ (in this study K=3,5)
- Images affected by particular meteorological conditions (e.g. wide cloudy coverage), navigation errors (Filizzola et al. 2004), and/or know spurious effects (e.g. cold spatial average effect, Aliano et al. 2008, Genzano et al. 2009, Eleftheriou et al. 2016) have to be discarded;
- Spatial persistence: it is not isolated being part of a group of TAs covering at least 150km² within an area of 1×1°;
- Temporal persistence: previous conditions (i.e. the existence of a group of TAs covering at least 150 km² within an area of 1×1° around x,y) are satisfied at least one more time in the 7 days preceding/following t.



In order to evaluate the possible correlations existing among the appearance of SSTAs and time, location and magnitude of earthquakes, empirical rules were applied (which were mostly based on the long-term experience on TIR anomaly maps analyses, see Tramutoli el al. 2015).

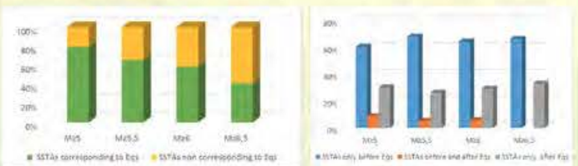
By this way each single Significant Thermal Anomalies (STA) observed at the time t in the location (x,y) will be considered possibly related to seismic activity if:

- It belongs to a previously identified SSTA;
- an earthquake of M≥5 occurs 30 days after its appearance or within 15 days before (temporal window);
- an earthquake with M≥5 occurs within a distance D, from the considered STA, so that $150km \leq D \leq R_D$ being $R_D=10^{0.43M}$ the Dobrovolsky et al. (1979) distance (spatial window).



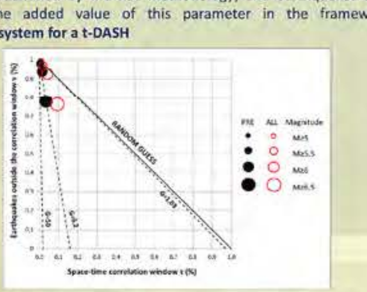
4. Results of long term correlation analysis and Conclusion

The analysis performed by applying previously established correlation rules to all the **29 SSTAs** identified on the whole time series of MTSAT TIR observations highlighted that the **80%** of SSTAs are **in apparent space-time relations with earthquake** (M≥5) occurrence and the 20% of SSTAs apparently are not related to documented seismic activity (false positives).



The Molchan error diagram (Molchan 1997) was implemented by plotting the fraction ν of missed earthquakes (i.e., apparently non preceded/followed by SSTAs) against the fraction of alerted space–time volume τ.

It is quite evident, in comparison with the random guess, the not casual relations between SSTAs (identified by the RST methodology) and earthquakes occurrence which testify the added value of this parameter in the framework of a **multiparametric system for a t-DASH**



$$\nu(M)=\frac{\text{number of EQs with magnitude} \geq M \text{ outside the correlation window (missed)}}{\text{total number of EQs with magnitude} \geq M \text{ occurred within the whole space} \times \text{time volume}} \qquad \tau(M)=\frac{\text{alerted space} \times \text{volume for EQs with magnitude} \geq M}{\text{whole investigated space} \times \text{time volume}}$$

REFERENCES

- Aliano C et al. (2008). Robust TIR satellite techniques for monitoring earthquake active regions: limits, main achievements and perspectives. Ann Geophys 51:303–317.
- Cuomo V et al. (2004). A self-sufficient approach for GERB cloudy radiance detection. Atmos Res 72:39–56.
- Dobrovolsky IP, Zubkov SI, Miachkin VI (1979). Estimation of the size of earthquake preparation zones. Pure and Applied Geophysics, 117, 1025–1044.
- Eleftheriou A et al. (2016). Long-Term RST Analysis of Anomalous TIR Sequences in Relation with Earthquakes Occurred in Greece in the Period 2004–2013. Pure and Applied Geophysics, 173(1), 285–303.
- Filizzola C et al. (2004). Robust satellite techniques for seismically active areas monitoring: a sensitivity analysis on September 7, 1999 Athens's earthquake. Phys Chem Earth 29:517–527.
- Genzano N et al. (2009). RST analysis of MSG-SEVIRI TIR radiances at the time of the Abruzzo 6 April 2009 earthquake. Nat Hazards Earth Syst Sci 9:2073–2084.
- Molchan GM (1997). Earthquake prediction as a decision-making problem. Pure and Applied Geophysics, 149, 233–247.
- Tramutoli V (1998). Robust AVHRR Techniques (RAT) for Environmental Monitoring: theory and applications. In: Zilioli E (ed) Proc. SPIE, pp 101–113
- Tramutoli V (2005). Robust Satellite Techniques (RST) for natural and environmental hazards monitoring and mitigation: ten year of successful applications. In: Liang S, Liu J, Li X, Liu R, Schaepman M (eds) 9th Int. Symp. Phys. Meas. Signatures Remote Sensing, ISPRS, Beijing, China, XXXVI, pp 792–795
- Tramutoli V (2007). Robust Satellite Techniques (RST) for Natural and Environmental Hazards Monitoring and Mitigation: Theory and Applications. 2007 Int. Work. Anal. Multi-temporal Remote Sens. Images. IEEE, pp 1–6
- Tramutoli V et al. (2005). Assessing the potential of thermal infrared satellite surveys for monitoring seismically active areas: The case of Kocaeli (İzmit) earthquake, August 17, 1999. Remote Sens Environ 96:409–426.
- Tramutoli V et al. (2015). From visual comparison to Robust Satellite Techniques: 30 years of thermal infrared satellite data analyses for the study of earthquake preparation phases. Bollettino Di Geofisica Teorica Ed Applicata, 56(June), 167–202.

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