APPLYING ROBUST SATELLITE TECHNIQUES (RST) TO MEDIUM-SHORT TEMPORAL SCALE MONITORING OF SEISMIC HAZARD IN ITALY: PRELIMINARY RESULTS ACHIEVED IN THE FRAMEWORK OF THE INGV-DPC-S3 PROJECTS

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TIR signal and noise

TIR signal is strongly variable depending on the observation time $t$ and place $r$!
What “anomaly” means? 

V_{\text{ref}}(r) \pm \sigma(r)

Observed Signal

Time or distance

anomalies?
TIR Anomaly Monitoring by RST (Robust Satellite Technique) RETIRA (Robust Estimator of TIR Anomalies) index

\[
\bigotimes_{\Delta T} (x, y, t) \equiv \frac{\Delta T(x, y, t) - \mu_{\Delta T}(x, y)}{\sigma_{\Delta T}(x, y)}
\]

- **reducing site effects**
  
  Signal time-average \( \mu_{\Delta T}(x, y) \) and standard deviation \( \sigma_{\Delta T}(x, y) \) are computed at the pixel level in similar observational conditions (same month of the year, same time slot, etc.)

- **reducing year-to-year variability and seasonal-drift effects**
  
  The local signal excess \( \Delta T(x, y, t) = T(x, y, t) - \langle T(t) \rangle \) (compared with the spatial average on the scene) is the considered signal instead of its absolute local value \( T(x, y, t) \)

- **space-time persistence required**

- **Known spurious effects discarded**
  
  (Filizzola et al., 2004, Aliano et al., 2008, Genzano et al., 2009)

- **Validation/confutation approach always applied**
Space–time persistence analysis

significant TIR anomalies

natural outliers (local warming due to night-time cloud passages)

observational outliers (errors in image navigation/co-location process)


Increased greenhouse effect associated to abnormal degassing of optically active gases (CO$_2$, CH$_4$ etc.) (Qiang et al., 1991; Tramutoli et al., 2001, 2005, 2013; Tronin, 1996; Zhang et al., 2010)
Local greenhouse effect from abrupt changes in degassing of CH4 and CO2 in the preparation and subsequent phases of EQs (e.g. Sholz, model)
Long-term analysis of TIR anomalies (Geostationary satellite observations)

TIR radiances (10.80-11.80 μm) provided by MSG/SEVIRI (Geostationary satellite observations) at 00:00 GMT

✓ since June 2004 up to now

✓ 10 years of thermal images (more than 3500 images)
### Significant Sequences of TIR Anomalies (SSTAs)

#### Intensity constraints:
- \( \text{RETIRA} \geq 3 \)

#### Space-time persistence constraints:
- Affected area \( \geq 150 \text{km}^2 \)
- With at least one repetition approximately in the same area in the following 7 days

#### Exclusion rules:
- Known spurious or extreme events

<table>
<thead>
<tr>
<th>TIR anomaly code (TAC)</th>
<th>Explanation</th>
<th>Details</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANP</td>
<td>NO Persistent Anomalies</td>
<td>single image showing space extended TIR anomalies with RETIRA( \geq 3 )</td>
<td>![Example Image]</td>
</tr>
<tr>
<td>AP</td>
<td>Persistent Anomalies</td>
<td>( \geq 2 ) images showing spatially extended-time persistent TIR anomalies with RETIRA( \geq 3 )</td>
<td>![Example Image]</td>
</tr>
<tr>
<td>AVP</td>
<td>Very Persistent Anomalies</td>
<td>( \geq 3 ) images showing spatially extended-time persistent TIR anomalies with RETIRA( \geq 3 )</td>
<td>![Example Image]</td>
</tr>
<tr>
<td>NA</td>
<td>NO Anomalies</td>
<td>Valid data processing without spatially extended TIR anomalies detected</td>
<td>![Example Image]</td>
</tr>
<tr>
<td>ND</td>
<td>NO DATA (clouds)</td>
<td>Clouds presence over the testing area prevent data analysis</td>
<td>![Example Image]</td>
</tr>
<tr>
<td>SAN</td>
<td>SPURIOUS-ANOMALIES-NAV</td>
<td>Spurious TIR anomalies (typically along coastlines) due to image navigation errors (Aliano et al., 2008)</td>
<td>![Example Image]</td>
</tr>
<tr>
<td>SAC</td>
<td>SPURIOUS-ANOMALIES-COLD-SPATIAL AVERAGE EFFECT</td>
<td>Spurious TIR anomalies due to the asymmetric distribution of clouds covering mostly the southern part of the scene (Genzano et al., 2009)</td>
<td>![Example Image]</td>
</tr>
<tr>
<td>SCP</td>
<td>SPURIOUS CLOUD-PASSAGE</td>
<td>Spurious TIR anomalies due to a nocturnal clouds passages (Aliano et al., 2008)</td>
<td>![Example Image]</td>
</tr>
</tbody>
</table>
Validation rules

accepted also by CSEP (Collaboratory Study on Earthquakes Prediction)

Space-Time “distance” from EQ

\[ 150 < D \text{ [km]} < R_D \]

\[-15 < \Delta t \text{ [days]} < 30 \]

\[ R_D = 10^{0.43M} \text{ Dobrovolsky radius} \]

-15d

623 km

R_D (6,5<M<7)

380 km

R_D (6<M<6,5)

232 km

R_D (5,5<M<6)

232 km

R_D (5,5<M<6)

380 km

R_D (6<M<6,5)

623 km

R_D (6,5<M<7)

+30d

Days before EQ

Distance from future epicentre
EQs features vs TIR anomalies

Abruzzo Eq (6 Apr 2009 Mw 6.3)

Pollino Eq (25 Oct 2012 Mw 5.3)

12 Oct 2012

13 Oct 2012
### EQs features vs TIR anomalies

<table>
<thead>
<tr>
<th></th>
<th>Number of SSTAs</th>
<th>TIR sequences in a possible connection with earthquakes</th>
<th>Sequences of false positive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Italy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June 2004-December 2012</td>
<td>51</td>
<td>28</td>
<td>23</td>
</tr>
<tr>
<td>&gt; 2800 nighttime TIR images</td>
<td>1,8%</td>
<td>55%</td>
<td>45%</td>
</tr>
</tbody>
</table>
EQs features vs TIR anomalies

ITALY

2861 nighttime MSG/SEVIRI TIR images (1 June 2004 – 31 December 2012)
Activities during INGV-DPC Project S3
Activities during INGV-DPC Project S3
1st year (2012-2013)

Reliability Analysis

<table>
<thead>
<tr>
<th></th>
<th>Southern Apennines</th>
<th>Po Plain</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of SSTAs</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Corresponding to EQ</td>
<td>2 (67%)</td>
<td>1 (100%)</td>
<td>3 (75%)</td>
</tr>
<tr>
<td>NON Corresponding to EQ</td>
<td>1 (33%)</td>
<td>0 (0%)</td>
<td>1 (25%)</td>
</tr>
</tbody>
</table>

Sensitivity Analysis

<table>
<thead>
<tr>
<th></th>
<th>Southern Apennines</th>
<th>Po Plain</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of seismic sequences (M≥4)</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Associated to SSTAs</td>
<td>3 (100%)</td>
<td>1</td>
<td>4 (67%)</td>
</tr>
<tr>
<td>NON Associated to SSTAs</td>
<td>0 (0%)</td>
<td>2</td>
<td>2 (33%)</td>
</tr>
</tbody>
</table>
Activities during INGV-DPC Project S3
2nd year (2014-2015)

January 2012 – September 2014
Po plain

Distribution of RETIRA values in the day before the Emilia earthquakes of 20 and 29 May 2012
The added value of Integration

2-sigma, non persistent TIR anomalies
7 days before Emilia May 20, 2012 EQ (M=6.1)

THERMAL ANOMALIES on 13 May 2012 at 00:00 GMT

NOT ENOUGH FOR REQUIRING ATTENTION!
CN prediction in Italy (Peresan et al., 2002)
Alert given March 1, 2012, confirmed May 1, 2012

http://www.ictp.trieste.it/www_users/sand/prediction/prediction.htm
9 years of MSG-SEVIRI TIR images over Italy (2861 since June 2004 up to December 2012) have been analyzed:

- Based on predefined validation rules (accepted also by CSEP):
  - Only 51 TIR sequences (< 2% of images) with significant TIR anomalies (they are actually rare!)
  - 55% of TIR sequences occurred (45% NOT) in the prescribed time/distance window from earthquakes (M≥4)

The presence of clouds prevent to observe the space-time continuity of the TIR anomalies, reducing the sensibility of the considered parameter. In this sense a use of multi-parametric approach could be able to reduce the number of false positive

Achieved results seems already sufficient (at least) to qualify TIR anomalies (identified by RST approach and RETIRA index) among the parameters to be considered in the framework of a multi-parametric approach to time-Dependent Assessment of Seismic Hazard (t-DASH)