SHORT-TERM SEIMIC HAZARD ASSESSMENT BY USING A MULTIPARAMETRIC APPROCH: TEN YEARS AFTER THE L'AQUILA EARTHQUAKE

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Real-time integration of multi-parametric observations is expected to accelerate the process toward improved, and operationally more effective, systems for time-Dependent Assessment of Seismic Hazard (t-DASH) and earthquake short term (from days to weeks) forecast. However, a very preliminary step in this direction is the identification of those parameters (chemical, physical, biological, etc.) whose anomalous variations can be, to some extent, associated to the complex process of preparation of major earthquakes. During the phases of earthquake preparation, a dynamic process could involve a large energy transfer due to crust displacements and, at the time of the shock, a break down between the source and the environment occurs. This change, prior to the earthquake or along with it, may have different physical and chemical effects on the lithosphere, atmosphere and ionosphere, and accordingly makes it possible to be detected.

Among the different parameters acclaimed as possible indicators of an impending seismic activity, the fluctuations of Earth's thermally emitted radiation, as measured by sensors aboard a satellite system operating in the Thermal Infra-Red (TIR) spectral range, have been being proposed for a long time. Since 2001, a general approach called Robust Satellite Techniques (RST- Tramutoli, 1998; 2005; 2007) has been being used to discriminate anomalous thermal signals, possibly associated to seismic activity, from normal fluctuations of Earth's thermal emission related to other causes (e.g. meteorological) independent on the earthquake occurrence. Being based on a statistical definition of *TIR anomalies* and on a suitable method for their identification even in very different local (e.g. related to atmosphere and/or surface) and observational (e.g. related to the time/season or satellite view angles) conditions, the RST approach has been widely applied to tens of earthquakes, covering a wide range of magnitudes (from 4.0 to 7.9) and occurred in very different geo-tectonic contexts (compressive, extensional and transcurrent) in 4 different continents.

The effects of the pre-seismic activity on the ionosphere has been being investigated also for a long time, looking in particular at the anomalous variations of the ionospheric electron content (TEC) and ion densities (e.g., Liu *et al*., 2006; Li and Parrot 2013). As an empirical phenomenon, the anomalous fluctuation of the Total Electron Content (TEC), before strong earthquakes (from 10 to 15 days) has been being observed repeatedly since the mid-sixties. TEC is the integrated number of the electrons within the path between a satellite and a receiver or between two satellites. Recently the extending network of Global Positioning System (GPS) receivers has generated an increasing amount of data regarding the ionosphere state. Thanks to the technological progress and economic efforts that different countries of the world have made to increase the quality and quantity of satellite observations, today this parameter could be one candidate to be considered in the framework of a multi-parametric approach to time-Dependent Assessment of Seismic Hazard (t-DASH).

However, as for other physical parameters, daily ionosphere variations depend on natural and observational factors such as, for example, the solar and geomagnetic activities, season, latitude and longitude and other unknown parameters.

The RST_{TEC} proposed approach is based on the general Robust Satellite Technique (RST; Tramutoli, 1998; 2005; 2007) approach reformulated in order to be applicable to the TEC measurements. RST_{TEC} has been conceived for the purpose of overcoming the great limitation of the classical single image, fixed threshold, change detection approaches, by exploiting historical observations for computing the values to be taken as a reference. In fact, the behaviour of any parameter cannot be defined anomalous in an absolute sense, but only and exclusively

in relation to a standard behaviour of the parameter itself which has to be pre-calculated for each specific observational condition (place, time, sensor, etc.). Thanks to its full exportability on different satellite packages, the RST methodology has been implemented, for the first time in this work, to TEC measurements recorded by the GPS satellite constellation, in order to discriminate anomalous signals from normal fluctuations of the signal itself. In this paper, more than six years (since 2003 up to 2009) of TEC anomaly fluctuations - generated by applying the RST approach over Italy at the time of the Abruzzo earthquake (6 April 2009 Mw 6.3) have been analyzed and faced looking for possible relations of persistent space-time anomalous transients with local seismic patterns and/or major (single) seismic events.

Achieved results will be discussed and faced with *TIR anomalies* detected in the same period by using independent RST analyses carried out over the Italian peninsula on three different satellite sensors: MSG/SEVIRI (Meteosat Second Generation/Spinning Enhanced Visible and Infrared Imager, by Genzano *et al*., 2009, Lisi *et al*., 2015), NOAA/AVHRR (National Oceanic and Atmospheric Administration/ Advanced Very High Resolution Radiometer, by Lisi *et al*., 2010) and EOS/MODIS (Earth Observing System/ Moderate Resolution Imaging Spectroradiometer, by Pergola *et al*., 2010).

Results achieved, and particularly the rate of false positives registered on the whole long testing period, will be discussed to qualify TEC anomalies (identified by the RST_{TEC} approach) and the impact of the joint use of both parameters (TIR and TEC) in the framework of a multi-parametric approach to time-Dependent Assessment of Seismic Hazard (t-DASH).

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