

Special issue

Advances in Multi-Parametric, Time-Dependent Assessment of Seismic Hazard and Earthquakes Forecast

Foreword

Until now proposed Operational Earthquakes Forecast (OEF) methods suffer of strong limitations in terms of their actual (too low absolute value of estimated probabilities) and general (forecast is substantially limited to earthquakes which are preceded by foreshocks) operational applicability [e.g. Wang and Rogers, 2014; Panza et al., 2014]. They become of some (unfortunately still marginal) usefulness just when such a low-probabilities are multiplied for very high exposure and/or vulnerability factors in order to obtain significant amounts of the estimated seismic risk.

Mostly, due to these limitations, they have been scarcely used in the past while the interest of the scientific community for the study of additional, not just seismological, geophysical/geochemical parameters that could provide useful indications about the evolution of seismic hazard in the medium/short term, is every day increasing.

If the deterministic earthquake prediction remains in our times “The Holy Grail of Earth Physics and Seismology”, the real-time integration of multi-parametric observations is, day by day, demonstrating to have a huge potential for the development of operational systems for a time-Dependent Assessment of Seismic Hazard (t-DASH) suitable for supporting decision makers with continuously updated forecasts and seismic hazard scenarios.

A preliminary step in this direction is the identification of those parameters (seismological, geophysical, geochemical, etc.), whose multi scaled space-time dynamics and/or anomalous variability, could be associated with the complex process of preparation of major earthquakes.

Several of them (chemical, physical, biological, etc.) have been since long time proposed in literature [see for instance Tronin, 2006 and reference herein; Cicerone et al., 2009] together with physical models [e.g. Scholz et al., 1973; Tronin, 1996; Freund, 2007; Pulinets and Ouzounov, 2011; Huang, 2011b; Tramutoli et al., 2013] suitable for explaining their possible correlation with earthquake preparation phases.

However, until now, no one single measurable parameter, no one single observational methodology, has demonstrated to be sufficiently reliable and effective for the implementation of an operational earthquake prediction system [already in Geller, 1997]. But, moving from the deterministic prediction to a probabilistic forecast goal, a multi-parametric approach could offer, already today, forecast probabilities orders of magnitude higher than the ones offered by traditional OEF approaches strongly reducing the “alerted” space-time windows.

To this aim, long-term correlation analyses are required in order to qualify each selected parameter in terms of its actual information content (in particular false positive rates), and application range (earthquake magnitude, affected space-time volume, etc.).

For some of them preliminary studies already exist - like for plasma frequency at the ionospheric F2 peak foF2 [e.g. Liu et al., 2006], ionospheric ion density [e.g. Li and Parrot, 2013] recorded by DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) satellite, ULF (UltraLow Frequency) geomagnetic signal [e.g. Han et al., 2014; Xu et al., 2013], Earth’s emitted thermal radiation measured by geostationary satellites [e.g. Elefteriou et al., 2015] – offering the indication of achievable false positive rates (i.e. anomalous transients occurring in absence of EQs of a prefixed minimum magnitude M within a pre-established, parameter-specific,

space-time volume) lower than 50% (up to 7% for selected areas/parameter). So, as far as the number of combined parameters increases, it is easy to expect a progressive reduction of the combined probabilities of false alarms (even if not at the lowest limit expected for completely independent processes) as well as a strong reduction of the alerted space-time volumes (intersection of the ones associated to individual parameters).

It is then already possible to generate real-time 3D (in the space time domain) representations of the time-dependent seismic hazard with specific (combined) probabilities of EQ occurrence for different areas and time-intervals starting from the probabilities (weights) of individual forecasts associated with each selected parameter. Products for earthquake forecasting based on the analysis of seismic data, will be also incorporated in the same scheme provided that, like for all the other parameters, their correlation with earthquake occurrence, have been pre-qualified (in particular in terms of false positive rates) on a long-term training database.

In this evolving scenario, we are honored to present this Special Issue which provides, through its collection of original papers, the state of the art of the emerging worldwide research potentially contributing to the development of t-DASH systems.

Such contributes can be grouped in a) long-term analyses devoted to qualify specific parameters also in terms of reliability of associated forecasts; b) preliminarily studies devoted to emphasize the contribution to the reduction of the space-time forecast volume by a multi-parametric approach; c) preliminarily studies devoted just to support the use of specific parameters and/or new data analysis methodologies for specific areas/period of time. To the first group belongs the papers by Genzano et al. [2020], An et al. [2020] and Fidani et al. [2020]. The first one offers - also for Italy (after Greece [Elefteriou et al., 2016]) - a full qualification of a parameter (anomalies in thermally emitted Earth's radiation estimated by the Robust Satellite Technique/RST approach [Tramutoli 1998; 2005; 2007]) already suitable for inclusion in a t-DASH system. Main characteristics of this parameter are: a) space forecast window ranging from 150km to R_D (being R_D the Dobrovolsky radius, [Dobrovolsky et al., 1979]) depending on the expected earthquake ($M > 4$) magnitude; b) time forecast window from days to few weeks before event; c) false alarm rate around 40% (it was 7% for Greece [Elefteriou et al., 2015]) after a 11 years' long-term correlation analysis. An et al. [2020] analyze more than 10 years of GEF (Geo-electromagnetic field) data from a single station in Pingliang (China). Main characteristics of the correlation test for this parameter are: a) space window ranging from 200 to 365 km, $M > 3.5$, time window 60 days before and after the event; c) significant correlation found in the 200km/30 days space/time window (but not along all the directions).

Fidani et al. [2020] on the base of 11 years of electron bursts (30-100 keV) data obtained from NOAA 15 satellite, evaluate the correlation with EQs ($M > 6$) occurred in the Indonesia and Philippines regions. In two cases (over 63) anomalous EBs are reported in a very short (4-2 hours) time window before EQ's occurrence.

To the second group of papers belong the papers by Arabelos et al. [2020], Contadakis et al. [2020], Ouzounov et al. [2020], who combine different parameters and/or measuring methods to reduce space-time forecast volumes (from regional/annual to very local/short-term scales) as well as those by Huang et al. [2020] mostly devoted to better discriminate among signals possibly related to earthquake occurrence.

In Arabelos et al. [2020] two different parameters and three measuring methods (tidal seismicity compliance parameter p , and high-frequency limit, f_0 of the ionospheric turbulence, deduced directly from GPS-TEC observations and, indirectly, through a VLF transmission network) are jointly applied to the forecast of earthquake with $M > 5.5$ occurred in Greece in the years 2013-2015.

The same ionospheric parameters are investigated by Contadakis et al. [2020], in a limited period of time (from 24/07/2016 to 25/09/2016 from 25/10/2016 to 25/11/2016) around the major earthquakes that hit Central Italy (Amatrice sequence) on August 24th ($M_W = 6.2$, 42.71°N, 13.17°E), October 26th ($M_W = 6.1$, 42.96°N, 13.07°E) and October 30th ($M_W = 6.6$, 42.86°N, 13.09°E), emphasizing their potential in contributing to reduce (up to 15 days) the forecast time window.

In their paper Ouzounov et al. [2020] compare ground (air temperature T , relative humidity RHU and atmospheric chemical potential ACP) and satellite based (outgoing longwave radiation OLR measured from polar and geostationary platforms) observations around the time of 3 main earthquakes occurred in Xinjiang province (China) on 02.12.2014 ($M7.3$), 08.12.2012 ($M6.2$) and 03.20.2008 ($M7.2$). Forecast time windows, from few days up to 3-4 weeks, over a spatial range up to few hundreds kilometers, are reported moving from one parameter/measurement technique, to another, from one event to another one.

To the third group of papers belong the ones of Huang et al. [2020], Novikov et al. [2020], Scordilis et al. [2020], Stănică et al. [2020], Zhai et al. [2020], and Zhu et al. [2020].

In the paper of Huang et al. [2020] the variations of the flux of high energetic particles from 300 to ~2000 km altitudes are analysed using data from WIND, Cluster II and GOES satellite systems, in order to investigate their occurrence in relation with M9.0 Tohoku earthquake (March 11th 2011) in presence and absence of geomagnetic storms.

In the paper of Novikov et al. [2020] the possible triggering effects of strong solar flares are analyzed at the global scale starting from the case of the strongest flare over the past twelve years occurred on September 6, 2017. The time window for forecast is quite short (less than a week for earthquakes with $M > 2.5$) compared with the global dimension of the alerted area.

In their paper Scordilis et al. [2020] consider the possible relation between ionospheric TEC anomalies (and related turbulence frequency limit f_0 and turbulent period limit P_0) measured by 5 GPS stations and strong earthquakes (M5.1 - 6.6) occurred in the Eastern Aegean in 2017. Reported forecast time windows range from few days up to 2 weeks, over a spatial range from few hundreds up to 1000 kilometers and more.

Stănică et al. [2020] analyze a continuous time-series of geomagnetic data, collected during 2016 to emphasize possible relationships with two M5.7 and M5.6 earthquakes occurred in the seismic active Vrancea zone on September 24 and December 28, 2016. Reported forecast time window range from 3 to 7 days over a spatial range from 100 to 300 kilometers.

Zhai et al. [2020] compare six different data analysis methods to identify significant IR-OLR anomalies from annual time-series of HIRS4 radiances and HIRS4 OLR data/products. The best selected method (ARIMA) is then used to identify several pre-earthquake anomalies occurring from 1 to 12 days before two strong events occurred in China (Jiuzhaigou, $M_L = 7.0$, August 8th, 2017) and in Mexico ($M_L = 7.1$, September 20th, 2017) in a spatial window of $1^\circ \times 1^\circ$ around the corresponding epicentres.

Zhu et al. [2020] analyse about 3 years of continuous records of stress and strain measured by a borehole strainmeter installed deeply into bedrock at the the Guza Station 153 km far from the epicentre of Wenchuan earthquake (May 12th, 2008, $M_S = 8.0$). By applying PCA (Principal Component Analysis) they identify a noticeable acceleration starting about 4 months before.

All these papers, in different ways, contribute to the exploration and understanding of the complex earthquake related processes. Most of the investigated parameters still requires long-term correlation analyses in order to qualify their false alarm rates in a prefixed space-time-magnitudes range, others, even without an actual predictive usefulness (e.g. too large alerted space windows compared with very low magnitude limits), still provide new stimulating insights on physical relations among phenomena apparently far each other.

This is not unexpected considering that the construction of long-term observational dataset, having the required continuity in time and a sufficient density in the space domain, would require human and economic resources rarely devoted to such studies.

We dedicate this volume to the memory of Proff. Oleg Molchanov and Alexander (Sacha) Rozhnoi brilliant examples for young geoscience researchers on the possibility of seriously applying to Science, following their curiosity even when it takes them out of the safe waters of the research mainstream where it is sometimes easier to make a career and get financial support, not always achieving significant goals for humanity.

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