International Association of Seismology and Physics of the Earth's Interior

Commission on Earthquake Sources: Modeling and Monitoring for Prediction

Activity Report 2011-2012

Compiled by
Prof. Alexey Zavyalov, Commission Chairman

Introduction

The basic attention of Commission is concentrated on researches of physics of destruction process at different scales, since experiments in laboratory on samples of rocks and finishing researches of a seismic regime. The activities of the Commission in the frame of the scope during 2011-2012 are presented bellow.

1. Scientific collaboration field

1.1. In 2012, IPE RAS, Moscow, Russia and NGRI, Hyderabad, India have launched a joint research project "Seismic regimes in areas of strong natural and human-induced impacts: analysis of field observations and laboratory modeling" with Dr. A.Ponomarev and Dr. R.K.Chadha being the project coordinators. The seismic zone of Koina-Warna water reservoirs located in West India is selected as the main region of the study. The key objectives of the project are to widen the qualitative understanding and to improve the quantitative description of excitation and relaxation of induced seismicity, the preparatory processes, formation, and development of seismic anomalies, as well as to identify and generalize the regularities in transient seismicity.
The results of the project are expected to foster elaboration of the physical basis for forecasting the induced earthquakes, monitoring the aftershock activity, and mitigating the seismic hazards.

1.2. The following activities have been carried out in the period 2011-2012 at DMG-University of Trieste and ICTP-SAND Group (Trieste, Italy), in collaboration with INFN (Rome, Italy) and IEPT-RAS (Moscow, Russia).

1.2.1. Prospective testing of time-dependent neo-deterministic scenarios of ground motion: the prediction of the 20 May 2012 Emilia earthquake.

A fully formalized experiment is ongoing, since July 2003, aimed at a real-time test of M8S and CN earthquakes prediction in the Italian region. The results of the intermediate-term middle-range predictions in Italy are routinely updated every two months and are made accessible to a number of scientists, thus allowing for rigorous real-time testing of the predictive capability of the applied algorithms. Along with CN and M8S real-time predictions, the associated neo-deterministic scenarios of ground motion [*Peresan, Zuccolo, Vaccari, Gorshkov, Panza, (2011) - Pure Appl. Geophys. 168 (2011), 583–607*] are regularly updated and made available to the Civil Defence of the Friuli Venezia Giulia Region (NE Italy).

A strong earthquake (Mw=6.1) hit the Emilia region, Northern Italy, on 20th May 2012. The epicentre was localized inside the Northern Region, alerted by CN algorithm for an earthquake with magnitude M≥5.4, starting on 1 March 2012, whereas it occurred outside the areas alerted by M8S algorithm for the corresponding magnitude interval. Therefore the earthquake scores as a successful real-time prediction, for CN algorithm only. The time-dependent ground shaking scenario associated to CN Northern region (defined for the period 1 March 2012 – 1 May 2012), correctly predicted the ground shaking, as large as ~0.25g, recorded for this earthquake. Notably, the ground shaking for this earthquake systematically exceeded the values expected at the bedrock in the area according to current Italian seismic regulation (i.e. PGA<0.175g), which is based on a classical

PSHA map [*Peresan A., Magrin A., Vaccari F., Panza G.F. (2012) - Proceedings of 31th GNGTS, 429 – 433, ISBN 978-88-902101-2-9*].

1.2.2. Analysis of possible relations between seismic activity and uranium, radium and tritium groundwater content in the L'Aquila area (Central Italy)

Uranium groundwater anomalies, which were observed in cataclastic rocks crossing the underground Gran Sasso National Laboratory (LNGS) before the L'Aquila earthquake (April 6th, 2009), have been studied versus radium and tritium contents. The radionuclide analysis supports the role of endogenic fluid dynamics for uranium content in groundwater rather than percolation processes, due to meteoric events occurring above the water table of the Gran Sasso aquifer. The uranium anomalies represent a key geochemical signal of a progressive increase of deep fluids fluxes at middle-lower crustal levels associated with the geodynamics of the earthquake. Moreover, the uranium represents a more precise strain-meter than radon as its presence can be modulated during the preparation phase of the earthquake, and only successively released by micro-fracturing during the main shock and aftershocks.

A preliminary comparison of the time series of the monitored parameters has been carried out with the seismic activity characterizing the area (i.e. within 50 km from the LNGS), prior and after the L'Aquila earthquake, including aftershocks activity. The results from this analysis support the hypothesis that the uranium anomalies represent a key geochemical signal of the progressive increase of deep fluids fluxes at middle-lower crustal levels associated with the geodynamics of the earthquake [Plastino et al. (2012) – J. Radioanal. Nucl. Chem. DOI 10.1007/s10967-012-1818-7].

1.2.3. Debate on Operational Earthquake Forecast/Prediction: the ICEF Report

The operational and decision-making problems, related to earthquake forecast/prediction and seismic hazard assessment, are nowadays a matter of significant debate. While it is recognized that operational tools must demonstrate their capability in anticipating large earthquakes by rigorous verification and validation process, only few methods proved effective so far. In view of the inherent uncertainties in predicting predictable, the usefulness of any forecast/prediction method can then be judged, taking into account the wide range of possible mitigation actions of different levels (from increased preparedness to evacuation).

The Summary and Recommendations by the International Commission on Earthquake Forecasting (ICEF Report), established after the earthquake in L'Aquila (M=6.3, 6 April 2009) have motivated a debate on different aspects of earthquakes prediction methods and of their assessment. The issues related with the definition, validation, and possible use of forecasting/prediction methodologies have been addressed, with special emphasis on existing operational practice in Italy, in Peresan, Kossobokov & Panza [2012- Rend. Fis. Acc. Lincei, 23, 131-138]. Critical comments on the conclusions of the ICEF report have been also expressed based on the analysis of precursory shear-waves splitting [Crampin (2012) Annals of Geoph., 55, 5-11; doi: 10.4401/ag-5516].

The open panel discussion "Earthquake Prediction and Forecasting: State of the Art" was held on General Assembly of IUGG 2011 in Melbourne under auspice of IASPEI Commission on Earthquake Sources: Modeling and Monitoring for Prediction. There were 2 invited speakers: Prof. Ragnar Stefansson, Iceland and Prof. Thomas Jordan, USA. Moderator of this meeting was Prof. David Jackson.

1.3. Multi-parametric earthquake forecasting in Italy

In Italy the project on "Short-term earthquake forecasting" (Seismological Project S3, DPC-INGV 2012-2013) has been launched on July 2012. The project, coordinated by D. Albarello (University of Siena), involves ten research groups and deals with a variety of possible precursors, ranging from the identification of underground fluids anomalies to the routine testing of seismicity patterns.

The bulk of the project is the reappraisal of data collected in the last years to provide a comprehensive multi-parametric database for retrospective validations and fixing observational protocols and standards. The project is developing along the following lines:

- Exploration of new promising research lines, internationally considered as feasible, but so far less considered in Italy for monitoring seismogenic processes are of major concern;
- Two specific geographical areas (Po Plain and Southern Apennines) are focused on;
- Observables relative to wide areas (e.g., those provided by observation networks or remote sensing) and characterized by good temporal continuity are of special interest;
- Application of statistical testing procedure to validate effectiveness of proposed observations for monitoring seismogenic process are of paramount importance.

Of major relevance in this framework is the identification, at the intermediate space-time scale, of areas most prone to next future earthquakes, based on formally defined pattern-recognition analysis and geodynamic modeling, where institution of specific observational networks will allow, in the next years, more effective testing of proposed protocols.

1.4. Renewal models and co–seismic stress transfer in the Corinth Gulf, Greece, fault system

Statistical modeling of interevent times and Coulomb stress transfer on the rupture segments along the Corinth Gulf, based on the definition of a probability density distribution of interevent times (Brownian passage–time and Weibull distributions are tested). The time–dependent hazard rate thus obtained is then modified by the inclusion of a permanent physical effect due to the Coulomb static stress change caused by failure of neighboring faults since the latest characteristic earthquake on the fault of interest. The validity of the renewal model is assessed retrospectively, using the data of the last 300 years, by comparison with a plain time–independent Poisson model, by means of statistical tools including the ROC diagram, the R–score, the probability gain and the log–likelihood ratio. We find that the BPT and the Weibull renewal models yield comparable results, and both of them perform significantly better than the Poisson hypothesis. No clear performance enhancement is achieved by the introduction of the Coulomb static stress change into the renewal model (*Rodolfo Console, Rome Italy; Giuseppe Falcone, Rome, Italy; Vassilis Karakostas, Thessaloniki, Greece; Maura Murru, Rome, Italy; Eleftheria Papadimitriou, Thessaloniki, Greece; David Rhoades, Lower Hutt, New Zealand*).

2. Interesting scientific results and publications

2.1. More than a decade of experience of Kamchatka Branch of Expert Council for Earthquake Forecasting, Assessment of Seismic Hazards and Risk is reflected in the book by V.Chebrov, V.Saltykov and Yu.Seraphimova "***Earthquake Prediction in Kamchatka***" [Moscow: Svetoch Plus, 2011. 304 p. (in Russian)]. Acquisition and analysis of earthquake precursors is one of the main functions of the Council. The total amount of used methods is more than 20. The data about precursors were received by many scientific institutions of RAS. Activity of the Council includes notification of local government about seismic situation in Kamchatka.

2.2. Monograph Book "***Seismological and geophysical studies in Kamchatka"*** dedicated to 50-th anniversary of regional seismological research / Eds. E.I. Gordeev, V.N. Chebrov. Petropavlovsk-Kamchatsky: Novaya kniga, 2012. 480 p. (In Russian).

The book summarizes main results of seismological and geophysical studies of 1961-2011. Different aspects of investigation connected with problem of earthquake prediction are considered in 9 from 18 chapters.

2.3. A series of laboratory experiments in the Institute of Geosphere Dynamics Russian Academy of Sciences (IDG RAS) were done on saturated porous samples loaded by fluid injection under high pressure to study a relation between fluid pressure sharp drop and seismic activity induced by that drop. It was found, that the seismic activity in that case is governed by fluid pore pressure gradient and that the induced seismicity variations can be described with the help of non-linear pore-elasticity model.

2.4. By scientists from the Institute of Geosphere Dynamic RAS the relation between ore blasting and seismicity was considered based on data on mine seismicity in Tashtagol Iron-Ore Mine (Russia). It was found that duration of blasting seismic aftereffects depends on the blast power. The numbers of seismic events and their cumulative energies in the periods of explosion aftereffect

duration depend on the charge capacity. The dependences look like a power law. The post-blasting seismic events concentrated at the blast site area during three days after the blasting. The influence of the most powerful explosions on the seismicity was considered. It was shown that in some cases the energy of the seismic events considerably exceeds the blasting seismic energy.

2.5. Development of broad-band seismic networks and high speed internet access to continuous records of seismic noise provide the possibility to estimate and visualize evolution of low-frequency seismic noise (periods from 2 up to 500 minutes) properties in the form of their spatial maps within moving time windows of different lengths. Two statistics of noise waveforms are considered: multi-fractal singularity spectrum support width *D* and minimum normalized entropy *En* of squared orthogonal wavelet coefficients. The experience of using these maps for the data from Japan network F-net (1997-2012) and for regional broad-band networks in California (2008-2012) shows that seismically danger regions correspond to relatively low values of *D* and high values of *En*. This approach was the basis for prediction Tohoku mega-earthquake 11 March 2011 which was published in advance in the number of papers and abstracts of international conferences in 2008-2010. The analysis of seismic noise after March 2011 extracts the region of Nankai Trough by low values of *D* and high *En*, which could be an indicator of the next mega-earthquake near Japan Islands. The danger period of this event is estimated 2013-2014 *(IPE RAS, Moscow, Russia*).

2.6. The seismic process is usually treated as an example of development of self-organized criticality (SOC). However, no mechanism of SOC occurrence in the case of a seismic process was proposed yet. The alternative model of the seismic regime as a sequence of stochastic episodes of avalanche-like relaxation of metastable subsystems was suggested. In this model, the following parameters are used: the parameter of the spatial hierarchy of the system (correlating with the fractal dimension values); the parameter of metastability of the medium; and a set of parameters describing the memory of the system. The model reproduces the Gutenberg–Richter earthquake recurrence law and the Omori law. The model reproduces also the confinement of the strong earthquakes to the time intervals of decreased b-value, the average relationship between the magnitude of the main event and the number of aftershocks, the weak tendency of seismic cycle occurrence; and the precursory activity which manifests itself in the irregular increase of number of earthquakes and released seismic energy before the strong event. The model was applied for parameterization of the seismic regime of the south part of Sakhalin Island and the expected anomalous increase of the parameter of metastability in connection with the Gornozavodsk and Nevelsk earthquakes occurrences was found (*Institute of Earthquake Prediction Theory and Mathematical Geophysics of RAS, Moscow, Russia*).

2.7. In 2006–2007, a doublet of great earthquakes (Mw>8) ruptured the center of the Kuril subduction zone: first, the interpolate thrust event, then the intraplate extensional event on the outer rise. The affected region was a seismic gap since 1915. Our observations of the Kuril GPS Array in 2006-2009 outline a broad zone of postseismic deformation with initial horizontal velocities to 90 mm/a, and postseismic uplift. We show that most of the postseismic signal after the great Kuril doublet is caused by the viscoelastic relaxation of shear stresses in the weak asthenosphere with the best-fitting Maxwell viscosity in the range of $(5\text{-}10)\times10^{17}$ Pa×s, an order of magnitude smaller than was estimated for several subduction zones. We predict that the postseismic deformation will die out in about a decade after the earthquake doublet. Our results suggest large variations among subduction zones in the asthenospheric viscosity, one of the most important rheological parameters [Kogan M.G., Vasilenko N.F., Frolov D.I., Freymueller J.T., Steblov G.M., Levin B.W., Prytkov A.S. The mechanism of postseismic deformation triggered by the 2006-2007 great Kuril earthquakes // Geophysical Research Letters, 2011 doi: 2011GL046855 http://www.agu.org/journals/gl/] (*Institute of Marine Geology and Geophysics Far East Branch of RAS, Yuzhno-Sakhalinsk, Russia*).

2.8. The triggering and phase synchronization of acoustics generated by stick-slip process on the laboratory scale can be a model of large scale seismic processes. For example, application of varying frequencies and intensities of forcing allow compiling of Arnold's tongue. It was found that both the onsets/maxima of a definite kind of acoustic signals are phase synchronized with forcing,

but also acoustic wave train terminations. Two kinds of high order synchronization of acoustic emission with weak forcing are discovered: **i.** one or more AE bursts during one forcing period and **ii.** a single AE burst during many forcing periods. Similar effects can be expected during dynamic triggering of local seismicity by remote earthquakes and other weak forcings. These microseismic events at present are ignored by routine seismological processing and are not included in traditional catalogues. At the same time, events contain very important information on geodynamics of processes and can give clues to understanding fine mechanism of nonlinear seismic process and even contribute to the problem of earthquake prediction. Some results were presented at conference of IUGG Working Group EMSEV2012 and EGU 2012 and published in monograph "Earthquakes: triggers, environmental impact and potential hazards" (Nova Publ., 2013) (*Institute of Geophysics of Georgian Academy of Sciences, Tbilisi, Georgia*).

2.9. In the All-Russian Scientific Research Institute for Civil Defense and Emergency Situations Ministry of Emergency Situations of Russia conducted work in the field of seismology and geophysics:
1. Methods and apparatus for current monitoring and inspection of buildings and structures after earthquakes. Action by the Department of Development of technologies to improve earthquake resistance of buildings and structures, working in operational mode. Over recent years, department's experts visited and worked in Italy (2012), in the Republic of Tuva (2012), in the Sochi in 2012.

2.10. The geometry of the main geomagnetic field controls a spatial distribution of seismicity around the globe. This becomes apparent when geomagnetic field components are analyzed using the geocentric solar magnetospheric (GSM) coordinate system. Earthquakes prefer occur in the regions where geomagnetic ZGSM-component reaches large positive value, that takes place at low and middle latitudes. In the areas of strongest seismicity, that takes place at low and mid latitudes in the eastern hemisphere, the ZGSM values are largest compared to all other regions of the planet. The possible maximal magnitude of earthquake (Mmax) has a linear dependence on the logarithm of absolute ZGSM value in the epicenter in the moment of earthquake occurrence [Khachikyan G., Inchin A., and A. Lozbin. Spatial distribution of seismicity: relationships with geomagnetic Z-component in geocentric solar magnetospheric coordinate system. International Journal of Geosciences. 2012. V.3. № 5. Pp.1084-1088.] (*Institute of seismology, Almaty, Kazakhstan*).

2.11. There is a geomagnetic conjugacy between certain tectonic structures. In particular, the middle ocean ridges located in the southern hemisphere along the boundary of the Antarctic tectonic plate are magnetically conjugate with the areas of junction of continental orogens and platforms in the northern hemisphere. Close magnetic conjugacy exists between southern boundary of the Nazca tectonic plate and northern boundaries of the Cocos and Caribbean plates [Khachikyan G.Ya., N.S. Zhakupov, and N.Zh. Kadyrkhanova. Additional evidence that earthquake is element of global electric circuit. Book of Abstract, European Seismological Comission 33rd General Assembly. 19-24 August 2012. Moscow. p.84.] (*Institute of seismology, Almaty, Kazakhstan*).

3. Associated activities

- 25th IUGG General Assembly, Melbourne, Australia, June-July 2011.
  Business meeting of Commission on Earthquake Sources: Modeling and Monitoring for Prediction was held on Saturday, July 2, 2011 in the room MR213 in Melbourne Convention and Exhibition Center (MCEC). Commission discussed suggestions to the scientific programme for the IASPEI 2013 General Assembly in Gothenburg, Sweden.
- 33rd ESC General Assembly, Moscow, Russia, August 2012.
- 9th ASC General Assembly, Ulaanbaatar, Mongolia, September 2012.
- 3rd scientific conference «Problems of complex geophysical monitoring in the Far East of Russia», Petropavlovsk-Kamchatsky, Russia, October 9-15, 2011.
- Scientific conference "Geodynamic processes and natural disasters in the Far East region", Yuzhno-Sakhalinsk, Russia, September 26-30, 2011.

- All-Russia conference “Modern geodynamics of Central Asia and the hazardous natural processes: the results of research on a quantitative basis”, Irkutsk, Russia, September 23-29, 2012.
- SEMEP Pre-earthquake final meeting, Yuzhno-Sakhalinsk, Russia, 17-19 September 2012.
- The 16th International Conference "Oil and gas of Sakhalin", Yuzhno-Sakhalinsk, Russia, 25-27 September 2012.

4. Acknowledgements

The data for this report were presented by

Prof. Alexander V. Ponomarev, Moscow, Russia;
Dr. Antonella Peresan, Trieste, Italy
Prof. Giovanni Martinelli, Emilia Romagna, Italy;
Prof. Eleftheria E. Papadimitriou, Thessaloniki, Greece;
Prof. Sregey B. Turuntaev, Moscow, Russia;
Dr. Vadim A. Saltykov, Petropavlovsk-Kamchatsky, Russia;
Prof. Alexey A. Lyubushin, Moscow, Russia;
Prof. Michael V. Rodkin, Moscow, Russia;
Prof. Ivan N. Tikhonov, Yuzhno-Sakhalinsk, Russia;
Prof. Boris W. Levin, Yuzhno-Sakhalinsk, Russia;
Prof. Tamaz L. Chelidze, Tbilisi, Georgia;
Dr. Galina Ya. Khachikyan, Almaty, Kazakhstan