Commission on Earthquake Sources: Modeling and Monitoring for Prediction

Activity Report 2007-2008

Compiled by
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Introduction

The scope of Commission was renovated in the end of 2007 and lay out on IASPEI web-site. In the new scope the basic attention 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 are presented bellow.

1. In the field of scientific collaboration

1.1. Cooperation agreement between the Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences (GFZ) and the Schmidt Institute of Physics of the Earth RAS (IPE RAS) for period of five years was signed in October 2008. The cooperation should be focused on a large range of Earth sciences problems including Earthquake Physics, Global Earth dynamics, Earth's structure, Seismotectonics, Lithosphere Stresses, Geoinformatics and Mathematical Geophysics. In particular according the scope of Commission the project "Physics of Rock Fracture Processes on Different Scales" will be carry out.

1.2. In the frame of Integrated Long Term Programme (ILTP) of cooperation in science & technology between India and Russia two new projects were started in 2008:

- "The transient geophysical processes in areas of strong natural and human-induced impacts: field observations and physical modeling" The objectives are: a) investigation of the time-space structure of seismicity and related geophysical fields after strong natural/technogenic influences, b) developing the technique, methods and algorithms for revealing time series regularities on the base of modern earthquake physics, scaling conception and laboratory verification of related subjects.
- "Preparation of catalogue of Indian earthquakes and test for its completeness". The objective of this project is development of catalogue of earthquakes of India on the basis of the available national, regional and local network data generated by various organizations/agencies and test for its completeness. The catalog so generated would serve as a basic input for research in the area of Earth Sciences.

1.3. The earthquake seismology group in Edinburgh University has led or been involved in several major projects in involving earthquake physics and statistics. These include EU-funded projects in triggering processes generally (as part of the TRIGS network) and specifically for earthquake forecasting (as part of the NERIES infrastructure project), and as part of the EPSRC-funded NANIA consortium on developing numerical methods for modelling and analysing complex systems in physics, earth science, biology and economics. Highlights include:

- successfully testing the thermodynamic hypothesis of maximum entropy production as a potential driver for earthquake populations to a near but sub-critical state, explaining the low but finite stress drop and seismic efficiency, a seismic b-value near 1, and allowing a degree of predictability in forecasting [*Main, I.G & M. Naylor*, Geophys. Res. Lett. 35, L19311, 2008];

- demonstrating that the best-fitting global frequency-moment distribution changed from a gamma form to a pure power law after the 2004 Boxing day mega-earthquake [*Main, I.G., L. Li, J. McCloskey & M. Naylor,* Nature Geoscience 1, p142, 2008];

- formally demonstrating the error distribution in incremental and cumulative frequency data is Poisson [*Greenhough, J. & I.G. Main,* Geophys. Res. Lett., 35, L19313, 2008];

- Quantified the effect of fracture density and length distribution on wave scattering (coda-Q) in realistic models of complex fractured media [*Vlastos, S., E.Liu, I. G. Main & C. Narteau*, Geophys. J. Int. 171, 865-880, 2007].

1.4. In the frame of new ESC Working Group "Earthquake Physics: Field Observations, Experimental and Numerical Modeling and Comprehensive Analysis" under leading of Prof. Alexey Lyubushin (Russia) and Prof. Giovanni Martinelli (Italy) next few results can be highlighted:

- Synchronization phenomena of background microseismic oscillations before series of strong earthquakes were investigated by estimating different measures of coherent behavior (based on Fourier and orthogonal wavelet expansions of the signals) within multiple time series in a moving time windows. Properties of multifractal singularity spectra of low-frequency microseismic noise based on the analysis of broad-band seismic stations F-net data in Japan, 1997 - November, 2008, were investigated. Singularity spectra were estimated by DFA-method for vertical components with 1-sec sampling (LHZ-records) within adjacent time intervals of 0.5 hour length. Two parameters are analyzed: a width of singularity spectra argument interval and an argument providing maximum to singularity spectra. For each of 0.5-h time interval a median values (over all stations which have registration) of these 2 multifractal parameters create two averaged time series, gathering information from all stations. The time series of variations of width of singularity spectra argument interval has a statistically significant change of its mean value which began 0.5 years before Hokkaido earthquake M=8.3, 25.09.2003. Using analogies with singularity spectra behavior of return-time sequences produced by a system of coupled chaotic oscillators and for financial time series behavior before and after stock markets crushs these results are interpreted as a synchronization of low-frequency microseismic noise after Hokkaido event in 2003 which is continuing till now. These analogies arise a question whether Hokkaido 2003 earthquake could be a foreshock of future even more strong event in Japan [by *Alexey Lyubushin*, Inst. of Physics of the Earth, Moscow, Russia].

- The spring-slider system is considered as a proxy of geological faults under tectonic stress; we also guess that the AE during stick-slip is a proxy of seismic activity on the active fault. So it is clear why the spring-slider system is the object of intensive research in seismology and tectonics as it can reveal the intimate features of seismic process.

  The experimental set up for recording acoustic emission during slips as well as synchronizing (forcing) signal at various velocities of slip and various spring stiffness is assembled and more than hundred experiments on stick-slip under different conditions (velocity of drive, spring stiffness, strength and frequency of periodic forcing, normal stress,) are performed. Experiments on the standard spring-slider system (fixed and sliding basalt samples), subjected to a constant pull and superimposed to it weak electromagnetic or mechanical (normal and tangential) periodic forcing in dry environment show that, at definite conditions, the system manifests the effect of phase synchronization of microslip events with the weak periodic excitation. In order to measure the strength of synchronization several tools of modern theory of nonlinear dynamics were used,

namely, calculation of phase difference, the mean effective phase diffusion coefficient, Shannon entropy based characteristic phase synchronization measure (γH-Sh), recurrence plots (RP) and % determinism (%DET) from the recurrence quantitative analysis (RQA).
The regular phase shift is observed between mechanical forcing sinusoid and the onsets of acoustic pulses; at the forcing, normal to the slip plane the initiation of motion is concentrated in the minimum area of the forcing sinusoid, which differs from the case of forcing, parallel to the slip plane, when the concentration of AE pulses takes place on the rising section of forcing sinusoid. The high order synchronization was observed; the winding number, i.e., the ratio of (mechanical) forcing frequency to observed stick-slip average recurrence frequency is high. At weak forcing the ratio is $n{:}m$ = 140:1 for normal forcing and $n{:}m$ = 220:1 for tangential forcing. The synchronization effect on the large scale was revealed in the local seismicity at the Enguri High Dam reservoir area [by *Tamaz Chelidze*, Inst. of Geophysics, Tbilisi, Georgia].

- Italian participants of working group were continuing experimental activity of terrestrial fluid monitoring oriented to researches on possible earthquake precursors. In particular monitoring activity was carried out on thermal waters and gaseous emissions. The meanwhile laboratory experiments were carried out to simulate rock destruction and following gas emissions in faulted areas [*Colangelo G., Heinicke J., Martinelli G., Mucciarelli M., Telesca L.* (2007). Investigating correlations of local seismicity with geoelectrical, hydrogeological and geochemical anomalous signals jointly recorded in Basilicata region (Southern Italy). Annals of Geophysics, 50, 527-538; *Colangelo G., Lapenna V., Martinelli G., Mucciarelli M., Telesca L.* (2007). Anomalous pattern of geochemical data recorded in the seismically active site of Pieschi (Southern Italy). Annals of Geophysics, 50, 539-545; *Etiope G., Martinelli G., Caracausi A., Italiano F.* (2007) Methane seeps and mud volcanoes in Italy: gas origin, fractionation and emission to the atmosphere. Geophysical Research Letters, 34, L14303, doi:10.1029/2007GL030341; *Cremonini S., Etiope G., Italiano F., Martinelli G.* (2008) Evidence of Possible Enhanced Peat Burning by Deep-Origin Methane in the Po River Delta Plain (Italy). The Journal of Geology, 116, 401-413; *Italiano F., Martinelli G., Plescia P.* (2008) CO_2 Degassing over Seismic Areas: the Role of Mechanochemical Production at the Study Case of Central Apennines. Pure and Applied Geophysics, 165, 75-94; *Italiano F., Martinelli G., Bonfanti P., Caracausi A.* (2008) Long term geochemical monitoring of gases from the active area of the Umbria-Marche region: 1997-2007. Tectonophysics, in press].

This working group includes 11 participants from Russia, Italy, Greece, Germany, Georgia and Poland.

1.5. The New Zealand Earthquake Forecast Testing Center was established at GNS Science, with real-time tests on the New Zealand earthquake catalogue commencing at the beginning of 2008. Models on three time scales are being tested: long-term (five years), medium term (three months) and short-term (24 hours). International researchers are invited to submit models for testing. Two long-term, three medium-term and two short-term models have so far been submitted. Models will be tested over at least five years, using the same likelihood tests adopted by the Collaboratory for the Study of Earthquake Predictability (CSEP) in the California testing centre. For medium and short-term forecasts, the only authorised database is the previous earthquake catalogue. Modellers must submit a computer program which will produce the forecasts from the catalogue as it evolves during the test period.

2. Some highlighted scientific results

2.1. A rupture model for the AD 365 great earthquake, occurred in the southwestern part of the Hellenic Arc, is constructed by assuming an elastic medium and calculating the theoretical surface displacements for various fault models that are matched with the observed surface deformation gleaned from historical reports. The resulted fault model concerns thrust faulting with a rupture length of 160 km and a seismic moment of $5.7 \cdot 10^{28}$ dyn·cm, an average slip of 8.9 m and a corresponding moment magnitude equal to 8.4, in excellent agreement with the macroseismic estimation. The absence of such events recurrence is an indication of the lack of complete seismic coupling that is common in subduction zones, which is in accordance with the back arc spreading of the Aegean microplate and with previous results showing low coupling for extensional strain of the upper plate. [In "**Rupture model of the great AD 365 Crete earthquake in the southwestern part of the Hellenic Arc"** by *Papadimitriou, E. E. & Karakostas, V. G.*, Acta Geophysica, 56, 293–312, 2008].

2.2. Coulomb stress changes associated with the strong earthquakes that occurred since 1904 in Sichuan and Yunnan provinces of China are investigated. The study area comprises the most active seismic fault zones in the Chinese mainland and suffers from both strong and frequent events. The seismic hazard assessment in this region is attempted by calculating the change of the Coulomb Failure Function (ΔCFF) arising from both the coseismic slip of strong events ($M \geq 6.5$) and the stress built–up by continuous tectonic loading on major regional faults. At every step of the stress evolutionary model an examination of possible triggering of each next strong event is made and the model finally puts in evidence the fault segments that apt to fail in an impending strong event, thus providing future seismic hazard evaluation. [In **"Implication of fault interaction to seismic hazard assessment in Sichuan–Yunnan Provinces of Southeastern China"** by *Gkarlaouni, Ch., Papadimitriou, E. E., Karakostas, V. G., Xueze Wen, Xueshen Jin and Kilias, A.*, Acta Seismologica Sinica, 21, 181–201, 2008].

2.3. Seismic hazard assessment in mining areas is of paramount importance for the nearby built-up environment since local events, although of small or moderate magnitude, have caused serious damage and often loss of life, and on the other hand their occurrence rate is very high. Based on the facts that this activity exhibits time dependence, as has been shown by several authors previously, and that small stress perturbation can enhance or prohibit future occurrences, we have applied the Coulomb stress transfer technique to investigate interactions among seismic events induced by mining works in the Rudna Mine in the Legnica-Głogów Copper District in south–west Poland. The results of this study indicate that in many cases strong mining tremors produce changes in the state of stress of a sufficient magnitude to influence subsequent events. [In **"A study of the interaction among mining induced seismic events in the Legnica-Glogow Copper District, Poland"** by *B. Orlecka–Sikora, E. E. Papadimitriou, G. Kwiatek*].

2.4. Institute Seismology of Academy of Science, Republic Uzbekistan continued monitoring of seismicity on the territory of Uzbekistan by complex: hydrogeoseismological (geochemical compositions, levels of the underground water, temperatures, isotope of elements and etc.) and geophysical methods for the aim prognosis of earthquakes.

- There are separated long-term, mid-term, short-term forerunners, connected with the preparation stages of earthquakes, and also the anomalous variation reflecting the attenuation of aftershocks process in the sources of strong earthquakes.
- Around the Charvak water reservoir (near Tashkent city) in the last 30 years repeat route magnetic survey had been conducted. Magnetic variations depended from values deformations that influence on seismicity in this region.
- 2 models of strong earthquakes realization on territories of Middle and Southern Tian-Shan have been suggested. **Model-1:** Gigantic tectonic/seismic energy as strong earthquakes occurred in the form foreshock and then main event by double or triple shocks, examples: Uratube 1897, M=6.7 – 2 shocks; Andijan, 1902-1903, M=6.5 – 2 shocks; Karatag 1907 г., M=7.3 – 3 shocks; Gazly M=7.0-7.3 – 3 shocks and etc. **Model-2:** Increase of a weak seismicity, that often accompanied with double swarm weak earthquakes and then main shock examples: Pap 1984, M=5.7; Kayrakkum 1985, M=6.4 and others.

2.5. About Kamchatkan branch of Russian Advisory Council for earthquake prediction, seismic hazard and risk estimation activity.

Kamchatka (Russia) is one of the most seismoactive areas in the Russia, so the problem of the earthquake prediction is important. Kamchatkan Branch was established in 1998 as regional subdivision of Russian Advisory Council on the base of Kamchatkan Branch of Geophysical Survey (Russian Academy of Sciences). Its basic function is operative estimation of the seismic hazard, prediction of strong earthquakes and volcanic eruptions. Weekly conclusions of expert council are sent to the Ministry of Emergency, Kamchatkan local administration, Geophysical Survey and Russian Advisory Council. Nine scientific organizations including all Kamchatkan research institutes and Institute of Physics of the Earth (Moscow) take part in the work of the Council.

Analysis of large earthquake precursors is one of the main tasks of the council. The long-term, intermediate and short-term precursors are detected by various kinds of observations and by different methods. Total number of used methods is more than 20. Among them there are seismological precursors (temporal variations of the coda decay rate of small earthquakes; algorithm M6; detection of the seismic quiescence by RTL and Z-test methods; variations of seismic wave velocity), geophysical precursors (variations of electro-telluric field; variations of electromagnetic emission (f=9-17 kHz); variations of high frequency seismic noise (HFSN) parameters; hydrogeodynamic monitoring; variations of water level in the wells; vertical ionospheric sounding; VLF-emission; electromagnetic field variations; athmospheric electroconductivity in near-surface layer), geochemical precursors (variations of water chemical composition; variations of radon (222Rn) and hydrogen volumetric activity in the underground gas).

Strongest Kamchatkan earthquakes 2007-2008 have magnitude $6.4m_b$ (2007-05-30, Southern Kamchatka), 7.7Mw (2008-07-05, H=590 km, Sea of Okhotsk), 6.2Mw (2008-07-24, Southern Kamchatka), 7.3Mw (2008-11-24, H=560 km, Sea of Okhotsk). Deep earthquakes have not precursors. Earthquake 2007-05-30 has 5 precursors and earthquake 2008-07-24 – 2 precursors in real-time.

2.6. A Multi Parameter Geophysical Observatory (MPGO) is established by the Wadia Institute of Himalayan Geology, Dehradun at Ghuttu, Western Himalaya. The observatory is equipped with high-precision instruments, like magnetometer, magnetotelluric, super-conductivity gravimeter, broadband seismometer, GPS, radon, ULF emission, and also to monitor deep resistivity, density, elastic deformation, inert gas, electromagnetic emission and water level fluctuation. The MPGO is fully functional on continuous monitoring of geophysical parameters to detect earthquake precursory signals. No research paper or successful prediction is yet made.

2.7. Prof H K Gupta and his group in NGRI have made a successful forecast of an earthquake M 4+ at the Koyna reservoir in western India in 2007 [Gupta et al., 2007; Curr Sci.]. They reported that earthquakes of magnitude M=4–5 are often preceded by well-defined clusters of foreshocks of $M \leq 3$, referred to as nucleation that is found to last typically for 100–400 h. Based on continuous monitoring of seismic activity, a nucleation pattern was identified and an earthquake of M 4+ was forecasted on 16 May 2006. An earthquake of M 4.2 did occur on 21 May 2006 within the forecasted parameters. They concluded that the Koyna reservoir is a suitable locale to pursue meaningful study of earthquake precursors.

2.8. The Geological Survey of India (Govt of India) has established a permanent geophysical / seismological observatory in Gangtok, Eastern Himalaya for precursor study. In addition to these, some investigators in Universities proposed to carry precursor studies using ULF technique, radon emission etc on MoE (Ministry of Earth Sciences, Govt of India) sponsored projects. Establishment of two more MPGOs, one in northeast India and the other in Andaman Island, are approved under the MoE sponsorship.

3. Associated activities

Many participants of the Commission actively participated in different international meetings and workshops including the next:

- 24th IUGG General Assembly, Perugia, Italy, July 2007;
- Evison symposium on seismogenesis and earthquake forecasting, Wellington, New Zealand, February 2008:
  The Evison Symposium on Seismogenesis and Earthquake Forecasting was held in Wellington, New Zealand, 18-22 February 2008. This symposium was held in memory of the pioneering contributions to earthquake forecasting by the late Professor Frank Evison, a former Chair of the IASPEI Sub-commission on earthquake forecasting. It attracted over 80 delegates from New Zealand, the USA, Canada, United Kingdom, France, Switzerland, Italy, Greece, Russia, Japan, China, India, and Australia, including altogether more than 50 from overseas. It comprised 28 invited talks, 12 contributed talks and 20 contributed posters. It was well supported by former students and colleagues of Frank Evison, and also by the growing international research community in the fields of seismogenesis and earthquake forecasting, including both physical and statistical modellers. A special volume of Pure and Applied Geophysics, entitled "Seismogenesis and Earthquake Forecasting: the Frank Evison Volume", is being prepared. This will include many papers from the Symposium together with submissions from the wider scientific community.
- 31st General Assembly, Hersonissos, Crete, Greece, September 2008;
- 7th General Assembly, Tsukuba, Japan, November 2008.
- 9th International Conference on Gas Geochemistry, Taipei, Taiwan, October 2007.

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