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TECTONIC REGIME OF KOYNA-WARNA INTRAPLATE RESERVOIR TRIGGERED SEISMIC ZONE FROM SURFACE AND SUBSURFACE FEATURES

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The Koyna-Warna region in western India is a well-known site of reservoir triggered seismicity (RTS), where the world's largest triggered earthquake of M6.3 occurred in 1967. The seismogenic faults are inferred to be in the depth range of about 4-15 km and generally have a strike-slip or normal faulting mechanism dominantly in the NE-SW and NW-SE directions respectively. The sustained seismicity in the region and its correlation with the Koyna and Warna reservoir loading cycles has been a subject of study for several decades. The region of seismicity is located on the crest of the Western Ghats in the southern part of the Deccan Volcanic Province (DVP) of India; the Ghats, at average heights of 700-800 m, are formed from 1 km thick pile of Deccan basalts.

Surface morpho-tectonic features in the Koyna-Warna region have been examined on the basis of high-resolution terrain data as well as extensive field observations. The ASTER DEM data has been used for the Konkan plains to the west of the Western Ghat Escarpment (WGE), while for the Deccan plateau region to the east of WGE airborne LiDAR along with orthophotos acquired over an area of 1064 sq km (~25 cm accuracy) was used. Surface drainage patterns, preferential groundwater infiltration zones, their correlations with lineaments and lava flow architecture as well as core studies are being conducted to assess the hydrological conditions which influence hydro-seismicity of the Koyna-Warna regime. Structural data and lithological data recovered from oriented cores of a 1500 m deep borehole has provided depth control to the configurations of the features seen on the surface. Structural information from Acoustic Televiewer logs have been examined to assess the faulting patterns and hence, the paleo and present stress patterns.

Structural information of the seismogenic fault systems in the basement has been derived from analysis of seismological data from a local broadband network, operational since 2005. Compilation of this large multi-parametric dataset has yielded significant correlations between the surface and subsurface structural patterns, which form crucial inputs to model the observed reservoir triggered seismicity and to decipher the link between seismicity patterns and fracture physics. Advancements in understanding the processes of earthquake genesis is planned through rock mechanical laboratory experiments to assess the role of heterogeneities of the medium and observe the effects of stepwise loading or rapid buildup of load on initiation of seismicity.

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SATELLITE MONITORING OF NATURAL HAZARDS

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In the present work we consider capabilities of state-of-the-art satellite methods and technologies to monitor such natural disasters as earthquakes, volcanic eruptions, tropical cyclones, wildfires, floods, etc. For urgent prediction of these natural hazards, the approaches based on acquisition and analysis of remote and in situ monitoring data, as well as on mathematical modelling, are suggested. We have analyzed generation mechanisms and behaviors of catastrophic natural processes, ways of their prevention and mitigation. Many examples of monitoring of various disasters using satellite methods, technologies, and systems, as well as the methods of processing of large satellite data flows have been considered here.
The effort is supported by the RSF grant 16-17-00139.

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THE DYNAMICS OF THE STRESS STATE OF SOUTHERN CALIFORNIA BASED ON GEOMECHANICAL MODEL AND CURRENT SEISMICITY: SHORT-TERM EARTHQUAKE PREDICTION

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The three-dimensional geomechanical model of Southern California was developed including a mountain relief, fault tectonics and internal border characteristics such as the roof of the consolidated crust and Moho surface.

During the last six years on the basis of the developed geomechanical model and current seismicity is realized an approbation of technology for the estimation of possible future seismicity on a two weeks interval. All four strongest events with M ~ 5.5–7.2 occurred in South California during the analyzed period were prefaced by the stress anomalies in peculiar advance time of weeks-months.

Inside the stress state background level investigation it was identified the feature of the large-scale interaction between two seismically active tectonic provinces of Southern California.

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ASSESSMENT OF TSUNAMI HAZARD FOR THE BLACK SEA COAST BASED ON HISTORICAL DATA AND NUMERICAL MODELING

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The coast of the Black Sea has a long and extensive history of destructive tsunamis in the past.
The tsunami catalog for the Black Sea [1] lists 22 historical events occurred in its basin since 20 BC. Recent search in historical archives has extended this list up to 39 events covering the period of nearly 2,500 years (from 485 BC till 2014) with large a variety of source mechanisms. Some of these events were destructive and resulted in considerable damage and human fatalities as in the source areas and on the opposite coast. Almost all the Black Sea coast is densely populated and its infrastructure is rapidly developing, so the demand for estimating long-term tsunami hazard for the Russian part of the Black Sea coastline is obvious. In turn, obtaining these estimates demands a consideration of potential tsunami-prone zones along the whole of the Black Sea coastline since its basin is limited in size and almost completely closed. In our work we have built the system of model earthquake sources with different magnitudes (varying from 7.0 to 8.0) that was used for the scenario calculation of tsunami impact along the coast of the Crimea and Krasnodar region. Calculation of initial displacement in a source area and its further propagation in the Black Sea basin within the non-linear shallow water model is based on the algorithms and program packages described in [2, 3]. The results of calculations are presented in the form of diagrams of tsunami energy distribution, integral energy characteristics of source areas and distribution of maximum tsunami amplitudes along the parts of the coast under consideration. Analysis of the results obtained shows that dangerous (more than 1 m) wave amplitudes along the Crimea and the Krasnodar coast can result both from the nearby seismic sources with magnitudes over 7.2 and from remote sources with magnitudes over 7.8 located along the southern (Turkish) coast of the Black Sea. Earthquakes with these and even higher magnitudes repeatedly occurred along the Black Sea coast in the past. The work is supported by the RSF Grant 14-17-00219.

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SEISMIC ZONATION AND SYSTEMS ANALYSIS

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With time, seismic zoning is getting an ever more important field of inquiry. It includes fundamental seismological component and applied component, oriented towards seismic engineering. By now seismic zoning is mostly done by statistical analysis of earthquake catalogues, strong ground motion's accelerations and field studies of the already known recent and historical disaster areas. The topic of this paper is to widely increase the scope of seismic zoning methodology by introducing advanced and applied systems analysis.

The research method used is integration of strongest, strong and moderate earthquake prone-areas recognition into seismic zonation. Such integration is proposed to be done by using systems analysis approach which includes elements of artificial intelligence and fuzzy logic.

The focus of the investigation is four seismically dangerous regions: Andes, California, Caucasus and Crimea. They are used as samples to illustrate how systems analysis comes up with integration of seismic zonation statistical methods, classical EPA approach and innovative FCAZ recognition technique.

The result of the study shows that proposed systems analysis approach can significantly increase reliability of both seismic zonation and strongest, strong and moderate earthquake-prone areas identification.

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MAXIMUM MAGNITUDE: THE LIMITS OF WHAT CAN BE LEARNED FROM DATA

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In the present study, we summarize and evaluate the endeavors from recent years to estimate the maximum possible earthquake magnitude M_{max} from observed data. In particular, we use basic and physically motivated assumptions in order to identify "best cases" and "worst cases" in terms of lowest and highest degree of uncertainty of M_{max}. We demonstrate in a general framework that earthquake data and earthquake proxy data recorded in a fault zone, provide almost no information about M_{max}, unless numerous seismic cycles aresupported by reliable and homogeneous data. Even if detailed earthquake information from some centuries including historic and paleo-earthquakes are available, only very few, namely the largest events will contribute at all to the estimation of M_{max} and result in unacceptable high uncertainties. As a consequence, estimators of M_{max} in a fault zone, which are based solely on earthquake-related information from this region, have to be dismissed.

GEOHAZARD MODELING AND ASSESSMENTS FOR DISASTER RISK REDUCTION

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Understanding of lithosphere dynamics and associated tectonic stress localization, earthquake occurrence, volcanic eruption, and lava flow as well as seismic and volcanic hazard assessments are greatly advanced for the last several decades. Meanwhile despite the major advancements, yet we are not seeing significant disaster risk reduction and a concomitant decline in disaster impacts and losses. This talk will highlight the importance of integrated co-productive research on disaster risk and try to answer the basic question: where, when and why does geophysical hazard turn to become a disaster? A novel approach to data-enhanced seismic hazard assessment and a contribution of hazard and vulnerability to earthquake risk will be presented [1]. Also advancements in modelling of lava flow due to effusive volcanic eruptions will be discussed [2]. Economic and political factors, the factors of awareness, preparedness and risk communication will be briefly analyzed in the framework of transdisciplinary approach to disaster risk research and risk assessment [3]. The work was supported in parts by the Russian Science Foundation (RSF project 14-17-00520) and the German Science Foundation (DFG project IS 203/4-1).

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STATE-OF-THE-ART ASSESSMENT OF SEISMIC HAZARD AND RISKS

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Contemporary Science is responsible for not coping with challenging changes of Exposures and their Vulnerability inflicted by growing population, its concentration, etc., which result in a steady increase of Losses from Natural Hazards. Scientists owe to Society for lack of special knowledge, education, and communication. It appears that a few hazard assessment programs and/or methodologies were tested against real observations before being endorsed for estimation of earthquake related risks. The fatal evidence and aftermath of the past decades prove that many of the existing wide-spread methodologies are grossly misleading and evidently unacceptable for any kind of responsible risk evaluation and knowledgeable disaster prevention.
In contrast, the confirmed reliability of pattern recognition aimed at earthquake prone areas and times of increased probability, along with realistic and exhaustive scenario modeling, allow concluding Science can better disclose Natural Hazards, assess Risks, and deliver the state-of-the-art knowledge of looming disaster in advance catastrophes. Better understanding seismic process in terms of non-linear dynamics of the Earth's hierarchical system of blocks-and-faults and deterministic chaos, progress to new approaches in assessing seismic hazard based on multiscale analysis of seismic activity and reproducible intermediate-term earthquake prediction technique. The algorithms, which make use of multidisciplinary data available and account for fractal nature of earthquake distributions in space and time, have confirmed their reliability by statistical testing in the on-going regular real-time application lasted for more than 25 years.

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SEISMIC MONITORING AND PREDICTION OF LARGE SCALE CATASTROPHIC EVENTS AT MINES OF THE VERKHNEKAMSKOYE POTASH DEPOSIT

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The Verkhnekamskoe potash deposit (VPD) in Ural region (Russia) has a long mining history. Significant amount of potash ore was extracted in the last 80 years (more 1 billion tons in total with the rate up to 35 million tons/year). Such a large scale mining activity resulted in changes in the stresses and strains around the excavated ore bodies and occurrence of catastrophic events (large scale pillar failures, karst processes).
Twenty years of seismic monitoring allowed to quantify the characteristics of induced seismicity at mines. It was shown that the magnitude-frequency distribution of seismic events is bimodal. The other important feature is that induced seismicity is generally associated not with the current active parts of the mine, but rather with areas where mining was completed five or more years ago. Therefore seismic monitoring must cover the entire mine, providing comprehensive information about the spatial distribution and dynamics of potentially hazardous zones. The prompt detection of these zones makes it possible to apply a number of mining actions (especially backfill) aimed to reduce the negative consequences of possible large seismic events and decrease the surface subsidence above the revealed active zones. The cases of early detection of hazardous zones are presented.

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GRACE DATA ON TEMPORAL VARIATIONS OF THE EARTH GRAVITY FIELD REVEALED LARGE-SCALE ASEISMIC CREEP IN THE AREA OF MAJOR EARTHQUAKES

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Increase in precision and resolution of the satellite GRACE monthly gravity models and accumulation of more than 10-years time- series of such models, enabled us to reveal earlier unexplored processes in the areas of major ($M_w \geq 8$) earthquakes. Gravity time variations in the regions of giant earthquakes (Sumatra-2004, Chile-2010, Tohoku-2011) showed coseismic gravity jump followed by long post-seismic changes reaching almost the same amplitude [e.g. Mikhailov et al., 2014]. The coseismic gravity jumps resulting from the smaller events are almost unnoticeable [Mikhailov et al., 2004, deViron et al., 2008]. However, we have established a long steady growth of gravity anomalies after a number of such events [Mikhailov et al., 2016].
The detailed analysis of the growth of the positive gravity anomaly after 15/11/2006 Simushir earthquake is presented. The growth started a few months after the event synchronously with the seismic activation on the downdip extension of the coseismic rupture and the approximately simultaneous change in the direction and average velocity of horizontal surface displacements at the regional GPS sites. It indicates that this earthquake induced postseismic creep in a huge area extending to the depths below 100 km. The total displacement since 03/2007 up to 07/2012 is estimated at 3.0 m in the upper part of the plate contact and 1.5 m in its lower part up to a depth of 100 km. The released total energy is equivalent to the earthquake of M_w = 8.5.
Such processes have not been previously revealed by the ground-based techniques. Hence, the time series of the GRACE gravity models are an important source of the new data on the locations and evolution of the locked asperities of subduction zones and their seismic potential.

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NTEGRATION OF GEOSTRUCTURAL AND TECTONOPHYSICAL DATA INTO THE 2D/3D GIS-BASED GEODYNAMIC MODELS OF THE ARGUN TERRANE, TRANSBAIKALIA, RUSSIA

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The 2D/3D models of stressed-strained state of the Argun terrane rock massifs are presented. The models are based on geostructural, geophysical, lithological, and petrophysical data amplified by information on fault kinematics, stress axis orientation, drift velocities and surface motion direction from GPS measurements. All the input data were integrated into the GIS project. Numerical tectonophysical modelling by the method of finite elements was carried out. The simulation results were verified at the regional (Klichka seismogenic fault) and local (the deep seated Antei Mo-U deposit) scales.
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NANOSEISMOLOGY AS A TOOL FOR THE STUDY OF NATURAL AND TECHNOGENIC HAZARDS

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The GS RAS developed domestic equipment and a number of techniques that allow to study the oscillation amplitude in nanometers. This made it possible to create a new trend of seismic monitoring (nanoseismology), based on the registration and processing of not only the seismic events, but also of seismic noise. Nanoseismology allows the study of Earth using powerful vibrators, monitor seismic stability of buildings and operation of large industrial equipment. New technologies have allowed to understand the causes of the accident at the Sayano-Shushenskaya HPP and propose measures to control vibration of hydraulic units and dams, examine the physical condition of hydroelectric power stations, bridges, apartment buildings and industrial objects. Work has begun on the establishment of monitoring systems in the Kuzbass region of technogenic seismicity.

SEISMIC HAZARD FROM AFTERSHOCKS OF LARGE EARTHQUAKES

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After every major earthquake when it occurs in a populated area or in close proximity to some energy or other important objects in any country, important questions arise. Should we expect large aftershocks? How long? Where? How strong can be the largest aftershock? Correct answers to those and other questions are important to take necessary measures to reduce human and material losses. During first several hours after large earthquakes destructive aftershocks are naturally expected in any case. Thus, the information about the current aftershock process during first hours after the main shock can and should be used to answer the questions. Our goal is to construct an automatic system that will collect necessary information and issue appropriate recommendations for decision makers. In parallel we construct and test four different approaches: theoretical combining of known statistical properties of seismicity (Gutenberg-Richter and Omori laws), empirical analysis of the known case histories, Monte-Carlo simulations using known models like ETAS, study of the physical properties of the aftershock processes. Here we concentrate on empirical relations that helped us to establish a set of simple rough express estimates. Even those rough estimates after large earthquake may provide an important view on the real danger of destructive aftershocks.
The work was supported by Russian Science Foundation (Project No. 16-17-00093).