Russian-Mongolian scientific initiative for assessing the seismic hazards of the Baikal region and Mongolia

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Abstract

The territories of the Baikal Region and Mongolia belong to the areas with evaluated seismic activity. In turn, these territories are at heightened risk of potentially damaging events for human socio-economic activity. Consequently, seismic activity recording and forecasting would allow us to minimise possible damages. These issues require collecting and processing large volumes of heterogeneous data. In order to effectively process such datasets, it would be necessary to use state-of-the-art information technologies and expandable analytical systems. Such systems should have a set of tools to enable collection, generation, transformation, visualisation and analysis of data. However, while implementing products of these types, developers, normally tend to use low-level tools for programming (various general-purpose programming languages and standard DBMS capabilities). On the other hand, developers tend to create highly specialised systems that are closely related to a specific automation object and focus on certain data structures. The paper considers an approach to the development of an information-analytical system as an infrastructure element for assessing the seismic hazard of large lithospheric blocks of the Baikal region and Mongolia.

Keywords

Information technologies, information and analytical system, services, spatial data, seismicity, seismic hazards modelling

1. Introduction

Baikal territory and Mongolia belongs to the territories of high seismic activity [1, 2]. The assessment and forecast of seismicity in the region plays a great role in the planning of different

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economic activities. At present, scientific institutions, engineering companies, departments of regional divisions of the Ministry of Emergency Situations of the Russian Federation and Mongolia, territorial authorities, and management agencies all create and use large volumes of spatial and thematic data of hazardous natural processes, earthquakes etc. Normally, these datasets are localised and not linked with each other. In turn, it makes it difficult to use them collaboratively. In order to solve this challenge, it is necessary to significantly modernise the territorial management systems through introduction of the state-of-the art in the field of modelling of hazardous natural processes, earthquakes, modern information and telecommunications technologies and services for processing, searching, storing, and transmitting the information.

All the above justifies the urgency of creating distributed service-oriented information and analytical system (IAS) for zoning of the territories with seismic hazards. This system uses modern standards of software interaction, database application models and tools for spatial data analysis. Features of the developed system include services provide processing of large volumes of heterogeneous thematic data of monitoring. The services are a complex of interrelated mathematical models of earthquakes and predicting their consequences using modern information and telecommunications infrastructure.

According to the state-of-the art understanding of geophysical properties, the majority of strong earthquakes are concentrated on the boundaries of lithospheric plates due to large and mobile fault systems framing these plates. However, seismicity and strong earthquakes are quite often realised far from the plate boundaries, especially in continental intraplate regions, in which there are fault structures inherited from previous tectonic episodes and stages and activated at present. In the intraplate Mongol-Baikal region, according to the scale of development and length, there are general (length L>80 km), regional (L=35-80 km) and local (L<35 km) faults. In the fault zones of this hierarchy, large paleoseismodislocations and paleoseismostructures have been identified, which occurred during strong and catastrophic earthquakes with a magnitude up to 9.0. In the Baikal region, general faults are deep structures with a backstage structure and pronounced Cenozoic activation. The structures have a predominant north-eastern and sublatitudinal strike and determine the orientation of individual connectivity of the Baikal Rift System (BRS) and the largest depressions. Regional faults form a large group of faults with a predominance of discharges oriented along the general strike of the BRS. Local faults, mainly of Cenozoic origin, determine the internal structure of depressions. In the zones of general faults of the Baikal region, earthquakes with a magnitude higher than 8.0 have occurred in historical times. On the territory of Mongolia, the general fault structures include the components of the system of deep lineaments of Central Asia: the Mongol-Okhotsk-Bolnai fault, the Main Mongolian-Bogdinsky fault, the Western Mongol-Altai-Fuyun fault, the Eastern Mongol-Altai-Kobda fault zone. It should be noted that fault structures and realised earthquakes are in a certain relationship: rare strong earthquakes occur in some large faults, and a large number of less significant seismic tremors occur on numerous small faults. Therefore, the main faults and fault structures make it possible to characterise the general structure and energy of seismotectonic deformation of the lithosphere of the Mongol-Baikal region. At the same time, it should be emphasised that earthquakes with different types of movement in the focus are formed in the fields of tectonic stresses of the Baikal region and southwestern and central Mongolia. Thus, in the BRS, these are mainly normal and oblique-normal shocks, whereas in Mongolia — strike-slip

and thrust shocks. This difference is confirmed by field observations of geological seismogenic structures and physical modelling. The modelling techniques and approaches are used in the created IAS.

From the points outlined above, it is apparent that there is a need for distributed information-analytical system that has tools for uploading and processing spatial data. The system could also act as a platform for scientific collaboration. For example, scientists would have an opportunity to create and supplement services that implement the developed methodology.

2. Background

2.1. Motivation

The territories of the Baikal Region and Mongolia are located at the junction of large lithospheric blocks, which causes the high seismic activity of the region. The assessment of the seismic potential, including the creation of maps of the energy of seismotectonic deformation of the lithosphere, is important for the long-term socio-economic development of the region. The seismic hazard map helps in the estimation of ground acceleration of any location, that is used by the civil and earthquake engineers in designing buildings and large infrastructure [3]. This justifies the need to monitor and process a large volume of spatio-temporal data on the seismic activity of the Baikal region and Mongolia over significant time intervals. Also, for the joint use and integration of data obtained from various sources, it is necessary to carry out their pre-processing and cleaning [4, 5]. In this regard, the task of creating infrastructure and technology, supporting the creation of an information and analytical system (IAS) is justified. Ideally, this kind of IAS should have features for spatial analysis and a set of tools for collecting, creating, transforming, visualising and analysing data.

Traditionally, when implementing such tools, developers use low-level tools for programming (various general-purpose programming languages and standard DBMS capabilities) or create highly specialised systems that are closely related to a specific automation object and focus on certain data structures. The first point leads to a significant increase in costs at the design stage, and the second point causes large costs that arise during the maintenance and upgrade of the IAS.

2.2. Related works

Tasks of assessment and prediction of seismic hazards present significant challenges world-wide. Especially, there is a demand in regions with high seismicity [3, 6, 7, 8] Many different information systems based on various models and approaches exist of such tasks. The reason for this is that each region has its own properties related to seismicity [6, 9].

The paper [10] notes that the Internet is a powerful tool for broadcasting near- and real-time hazard information to, potentially, an almost global audience. The use of this environment allows to significantly expand abilities for interaction between interested parties. The use of distributed service-oriented informational systems based on Internet technologies allows extending their possibilities. Using standardised services allow providing the distribution and scalability of IAS.

For example, interoperability between information systems and software packages through Internet, based on OGC (Open Geospatial Consortium) [11] standards, is actively developed as well. One of the most well-utilised standards for this work is OGC WPS (Web Processing Service) [11] standard, which unifies the way clients interact with web services that deal with geospatial data analysis and processing. For instance, it could be the service for raster and vector data processing, service for geomodeling and statistics. This standard is simple, it defines metadata distribution and supports long-lasting service execution. These kinds of services are actively used in tasks of seismic activities analyses [12].

3. Models and methods of seismic hazards estimation

Based on the materials from the "Catalogue of earthquakes of the Baikal Region" and the "Bulletin of Earthquakes of the Baikal Region", regional databases on the seismicity of the Baikal region and faults of the Mongol-Siberian region were created in this research. The databases are adapted to the solution of the following tasks: "Database of amplitudes, periods, epicentral distances for earthquakes of the Baikal region" and "Database of faults active in the Cenozoic of the Mongol-Siberian region".

In order to refine the models of the medium of seismic wave propagation, a model calculation of the average dynamic parameters of elastic vibrations of rock soil from earthquakes in the southern Baikal region was performed for three cities in the south of the Eastern Siberia–Irkutsk, Angarsk and Usolye-Sibirsky. It is established that:

- If the value of the maximum possible energy class of earthquakes in the southern Baikal region is assumed to be Kmax=18, then the recurrent intervals of shocks with K=16 will be about 120 years. The probability of an earthquake of this class occurring in the study area within 50 years is P=0.34 and is high enough to consider the possibility of such a shock in the southern Baikal region as real.
- The correlation equations of the seismic source and the energy class of earthquakes are calculated for the totalities of earthquakes that occurred within the elementary sites with a size of 1.0°1.0°. On the basis of the equations, the calculations of the average values of the maximum amplitude and the period of vibrations of the rocky soil in the time period are performed. Irkutsk, Angarsk and Usolye-Sibirsky. It is established that with the same energy class of earthquakes, the strongest concussions in Irkutsk, Angarsk and Usolye-Sibirsky can be caused by tremors from the zone of the Main Sayan Fault.
  It is shown that the model with changes in the quality factor of the medium in the form of a power function weakly corresponds to the laws of attenuation of seismic waves in the Baikal region. Perhaps, it is necessary to apply a different type of frequency dependence of the Q-factor of the lithosphere blocks when clarifying the patterns of attenuation of seismic waves. The close correspondence of the elastic lithosphere model to real data makes it possible to apply it when evaluating the dynamic parameters of seismic source.

Estimates of recurrent intervals and the probability of large-magnitude earthquakes were refined, taking into account the influence of clustering seismicity. When calculating these parameters for the southern Baikal region, it was found that clustering seismicity (aftershock

and swarm sequences of earthquakes) have a significant impact on the assessment of recurrent intervals and the probability of large-magnitude earthquakes. As in the classical solution of seismic zoning problems (within the framework of the project, this task sounds like “zoning of the seismic hazard of large lithospheric blocks”), it is necessary to take into account the clustering seismic tremors, which are associated induced events and therefore fall out of the Poisson distribution, within which the estimation of recurrent intervals and the probability of large-magnitude earthquakes is performed.

We have developed a method for determining the kinematic type of movements in earthquake seismic source, in which a map of earthquake epicentres of the studied territory is built from experimental materials of seismic stations spaced on the surface, the kinematic and dynamic parameters of the earthquake under study are determined from the amplitudes and periods of seismic vibrations at each seismic station, while the seismic moment is calculated from the hypocentral distance. Maximum amplitude and period of seismic vibrations on the records of the body transverse S–wave of each seismic station, according to the data of all seismic stations, a sample–an array of seismic moments of this earthquake is created, the average seismic moment of the earthquake and its standard deviation are calculated from the sample–an array of seismic moments, calibration graphs of the dependence of the logarithm of the seismic moment on the energy class of earthquakes in the Baikal region with different kinematic types of movement in the seismic source are set in accordance with the calibration value of the seismic moment of an earthquake of the same energy class are built, according to the location of the value of the average seismic moment of an earthquake on the calibration graph, the kinematic type of movement in the earthquake centre is determined, taking into account the standard deviation.

4. Information-analytical system for estimation of the seismic hazards of the Baikal region and Mongolia

4.1. Infrastructure of information-analytical system

The institutes of the Siberian Branch of the Russian Academy of Sciences and the Mongolian Academy of Sciences have many years of experience in joint interdisciplinary research in the field of seismic activity of large lithospheric blocks of the Baikal Region and Mongolia. The study of seismic activity is a time-consuming process associated with monitoring, accumulation and processing of a large volume of spatio-temporal data. This serves as the basis for the introduction of modern information technologies in the study of the problems of the stress-strain state of the lithosphere and the determination of the size of a potential seismic focus. For the input, storage, and effective processing of seismic activity data, it is necessary to form an appropriate infrastructure that ensures the formation of analytical information in a convenient and visual form. As an infrastructure component, it is proposed to use the geoportal created by us [13]. The geoportal is the core of the IAS. It is used as an entry point for searching and using infrastructure services. The geoportal includes services for publishing and creating maps, a catalogue of geoprocessing services, a subsystem for planning and executing services.

4.2. Information system technologies

Geoportal, as a service-oriented system, is the basis for the formation of the infrastructure for research of seismic activity in the Baikal and Mongolia regions. It allows us to develop data processing capabilities almost unlimited, interacting with other distributed services available on the Internet. The main requirement for these services is their compliance with the WPS — Web Processing Service standards [14]. This made it possible to define a universal interface to web services for processing spatial data. Within the framework of the developed IAS, services for loading and editing, cleaning and storing data are implemented, as well as services for calculating the density of point objects in regular grid cells, calculating the density of linear objects in regular grid cells, interpolating point data into regular grid cells by the natural neighbours' method, etc. As a part of the IAS some of the legacy software for analysing earthquake data, zoning, and predicting seismic hazard, implemented in the FORTRAN programming language, were converted in the form of services. This approach allowed us to minimise facilities for adaptation and usage of legacy models and software.

4.3. Services of the system

For data analysis, we created different WPS services that implement basic methods of analysing seismic zoning data. For example, WPS services for assessing the influence of the lithosphere model on the dynamic parameters of ground vibrations from earthquakes in the Southern Baikal region with spatial analysis functions have been developed. They allow monitoring and comprehensive analysis of the seismotectonic situation to make decisions on preventing and minimising risks as a result of dangerous geological processes. An open specialised catalogue of earthquakes for the tasks of general seismic zoning of the Russian Federation has been uploaded to the IAS database. Based on this catalogue, a WPS service for assessing the seismic hazard of the Baikal natural territory based on the macroseismic equation was developed.

Ways of integrating WPS services are also proposed. In particular, the integration of WPS services is carried out in the form of scripts that determine the sequence of application, the parameters passed, etc. To develop scripts for WPS services, the JavaScript language is used, where access to WPS services is performed using special functions. To interpret scripts in JavaScript and directly access WPS services, a special module has been developed, written in C++ using the Google V8 JavaScript interpreter.

The organisation of a distributed "cloud" information and computing process with elements of pluralisation is carried out. The tasks of processing a large amount of data require the involvement of significant computing resources, which are usually located in different locations. Thus, computing resources form a distributed computing environment. Such an environment provides the ability to perform computing and analytical services on various computing nodes. Processing a large amount of data within the environment requires the organisation of the computational process, taking into account the heterogeneity of computing nodes and data transmission. To implement this task, a distributed "cloud" information and computing process with pluralisation elements was created. The service execution management subsystem is used as the core, where pluralisation is provided by dividing spatial data along a certain grid and executing for each cell of the WPS service on a separate computing node, including a remote

one. To deploy WPS services, a cluster of virtual machines on various platforms has been created and is being used. The use of several platforms is due to different requirements (often contradictory to each other) for software and hardware platforms for the software tools used for storing and processing spatial data.

The prototype of the information and analytical system was integrated with Jupyter notebook, which is the most modern and powerful tool for interactive analysis. It combines program code, mathematical equations, and visualizations into a single document. The JupyterHub system is deployed in the cloud environment, which is a multi-user implementation of Jupyter Notebook. The connection of a data storage system, a catalogue of satellite images, relational data of geoportals and the allocation of computing resources was carried out. Jupyter Notebook has been integrated with WPS services. Integration with Jupyter Notebook made it possible to use the most modern methods of data processing and machine learning in the form of ready—made program code.

5. Conclusion

The received experience and close Russian-Mongolian scientific cooperation allowed us to create the prototype of information and analytical systems with spatial analysis functions. This system provides the ability to use different models for earthquakes occurrences. The IAS allows the researchers to accumulate different heterogeneous datasets with spatial components and provide services for their processing. This system is a platform used for seismic hazards of large lithospheric blocks of the Baikal Region and Mongolia assessing. The platform allows generalising large values of accumulated seismic data, use distributed services for their processing.

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