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PHYSICAL METHODS AND MEANS OF ENVIRONMENTAL MONITORING

INFORMATION TECHNOLOGIES FOR PREDICTING NATURAL CATASTROPHES, ECOLOGICAL CALAMITIES, AND TECHNOGENIC EMERGENCIES BASED ON OKO GLOBAL MONITORING SYSTEM

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Radiophysical methods for monitoring heliogeophysical and seismic conditions are used for creating a real-time information support of high-reliability short-term prediction of the location and time of very strong earthquakes, detection of high-power underground and atmospheric nuclear explosions, and prediction of short-wave radio signal propagation conditions determining the performance of communication and radar systems.

INTRODUCTION

At present, contradictions between the modern civilization and biosphere reached the level when the very existence of man as a biological species is at stake.

Indeed, the second half of this century witnessed the accumulation of enormous destructive potential which is still growing posing a hazard of a global catastrophe. Nevertheless, in spite of a menace to the very existence of life on the Earth, people still regard practical ecology as a problem for the future. The present-day emergency state of the biosphere, however, shows that postponing the solution of this global problem is exceedingly dangerous for human civilization and therefore, inadmissible.

In a broad sense, ecology is a science of the existence of living matter on the Earth. Physical ecology is a science of physical and biophysical processes controlling vital activity of biological species. Social ecology concentrates on means of preserving life on the Earth such as restrictions on man's economical, military, and exploratory activities.

Apart from natural catastrophes such as earthquakes, volcanic eruptions, tsunamis, hurricanes, etc., the major hazards to mankind are believed to be [1]:

— chemical, nuclear, electromagnetic, and thermal pollution of the environment;
— pollution of the surface of the lithosphere and of the ocean by petroleum products;
— destruction of the ozone layer;
— depletion of natural resources of the Earth;
— local military conflicts and the threat of a nuclear-missile war.

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The OKO system for global monitoring gives information necessary for taking prompt measures to prevent or minimize damage from natural catastrophes, of which devastative earthquakes, because of their suddenness, are most hazardous in terms of their ecological and economical consequences.

According to UN data, averagely 20 thousand people perish and not less than 30 million suffer from catastrophic earthquakes in the world annually. The total economic damage of the world community amounts to more than 12 billion US dollars a year. Moreover, there is a discernible tendency toward an annual 6–7% increase in damages [1].

The attend participants of a summit in Denver (USA, June 20–22, 1997) from eight leading industrial countries defined a close international cooperation in ecological monitoring and short-term forecasting of catastrophic earthquakes in the Northern Pacific as one of the urgent problems.

A prominent position in solving the ecological problems of the Asia–Pacific Ocean region is held by the scientific and technological potential of Russia, which doubtless has a priority in developing theoretical problems of the physics of tectogenesis and lithosphere–ionosphere relations and in creating advanced technologies for the high-reliability prediction of the location and time of ruinous earthquakes [2].

In addition to seismic processes, there exists a complex of natural phenomena responsible for extreme situations and many quasiregular man-made emergencies and catastrophes. These are geophysical processes controlled by the solar activity and human activities in the space near the Earth.

These processes often disturb the functioning of intricate engineering systems and complexes such as control and navigation systems, telecommunication networks, means of automatic control of various technological processes, and systems controlling air and sea traffic [3].

It has been noted that, under unfavorable heliophysical conditions (equinoctial periods, magnetic storms), the human effect on emergencies in operating complex technical systems and on the frequency of disastrous events in traffic increases by a factor of 1.5–2, because geomagnetic factors affect the psychophysical and psychoemotional state of operating personnel.

The OKO System offers a possibility of obtaining real-time radiophysical information about the state of the ionosphere–magnetosphere system. It can, therefore, be used to forecast unfavorable heliogeophysical conditions and, through this, contribute to decreasing the number of accidents and damages.

Since 1990, a number of institutions (KOMETA Central Research Institute, Lavochkin Research and Production Association, Joint Institute of Geophysics of Russian Academy of Sciences, Institute of Terrestrial Magnetism, Ionosphere, and Radiowave Propagation of Russian Academy of Sciences, Faculty of Physics of Moscow State University, and Institute of Applied Geophysics) have been involved in research and engineering development directed toward creating a MATRITSA land- and space-based system as the first phase of the project of a global system for the short-term prediction of the location and time of very strong earthquakes and some ecological calamities [2, 4, 5].

The MATRITSA project conforms with the Russian Federation Program for the "Development of a Federal System for Seismological Observations and of Earthquake Prediction in 1995–2000" and with the program for the "Creation of Interstate System for Seismological Monitoring in Seismically Dangerous Regions of the Union of Independent States," which is now under development. Moreover, the MATRITSA System will be an integral part of an "International Geophysical Test Site" that is created for the improvement of methods and means for earthquake prediction. The creation of this Test Site in the Far East was initiated by the governments of Russia, USA, and Japan. The MATRITSA System therefore acquires the status of an international project.

During its future operation, the MATRITSA System will perform the following functions:

1. Direct observation of the ionosphere and collection of real-time radiophysical information necessary for promptly diagnosing and estimating the dynamics of the preparatory and postshock earthquake stages.

2. Informational support of the Federal System for Seismological Observations by radiophysical data for the high-reliability and short-term forecasts of the location and time of earthquakes of magnitudes larger than 5.5 on the twelve-point MSK-7 scale.

3. Real-time detection and determination of the location and time of high-power atmospheric and underground nuclear explosions.

4. Prompt prediction of the conditions of radiowave propagation in the short-wave region for ensuring reliable radio communication between control centers of national and foreign airplanes and ships.

The technical basis of the MATRITSA System is the operating land-space OKO System for global monitoring, which incorporates ground control stations and an orbital system of high-ellipticity and geostationary spacecrafts. As concerns the composition and parameters of orbits, this group of spacecrafts is optimal for solving the problems specified above. The use of the OKO System and the stable cooperation of responsible research and production centers create all necessary conditions for the fulfilment of the MATRITSA Project in the shortest possible time (in 27 months). The time fixed for accomplishing the job is so short because powerful scientific-methodological and algorithmic support of the project has already been developed, and the most important technical solutions have been tested under natural conditions using the on-board equipment of Interkosmos-19 and Kosmos-1809 low-orbit spacecrafts and the Mir station.

NEW METHOD FOR DETECTING SEISMO-IONOSPHERIC EARTHQUAKE PRECURSORS

The method of the multifrequency radio-sensing of the ionosphere from high-orbit spacecrafts, developed in Russia and patented abroad, can be used to monitor a $\sim$ 1500 $\times$ 1500-km region of the ionosphere and collect radiophysical information about seismo-ionospheric earthquake precursors virtually in real time [2, 3].

The measured parameter is the critical $F2$ layer frequency (the ionosphere virtually does not transmit lower frequencies). The regular $F2$ layer of the ionosphere covers altitudes of 200 to 400 km and is situated between the $F1$ layer (140–200 km) and the upper atmosphere (400–2000 km).

MATRITSA SYSTEM EQUIPMENT

The MATRITSA Equipment consists of the following components.

1. A geostationary spacecraft of the OKO System (fixed position at 160° E) monitoring the atmosphere in the longitude and latitude ranges of $\pm 65°$ with respect to its stationary point.

The zone of continuous monitoring of earthquake precursors and locating high-power explosions includes the region of the ionosphere above the Far East regions of Russian Federation (where the experimental zone of the Federal System for Seismological Observations and the International Geophysical Test Site are being created), the eastern provinces of China, Republic of Korea, Japan, Indonesia, Philippines, Malaysia, New Zealand, and Australia.

The geostationary spacecraft is equipped with on-board system for multifrequency radio-sensing of the ionosphere and a millimetric wave band on-board relay unit of the system for collecting and transmitting data (Fig. 1).

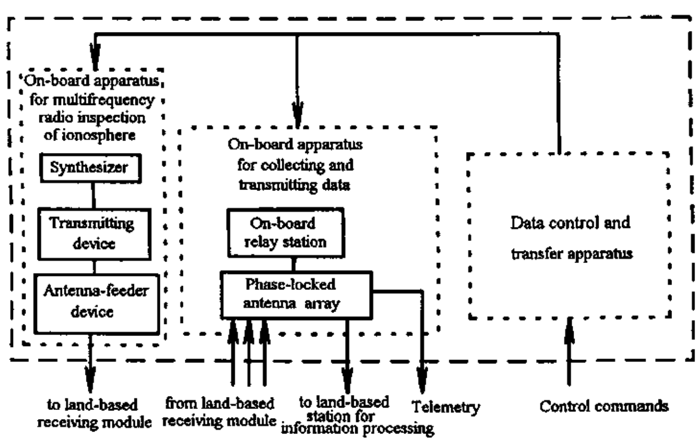

Fig. 1

Geostationary spacecraft OKO-2.

2. A spatially distributed network of 20–25 automated land-based receiving modules receiving radio-sensing signals. The modules are placed at intervals of 300–500 km over the territory of the experimental

zone of the Federal System for Seismological Observations at the sites of the complex seismological control of the Federal System for Seismological Observations and the ionosphere-monitoring sites of the Russian Academy of Sciences and Rosgidromet (Fig. 2).

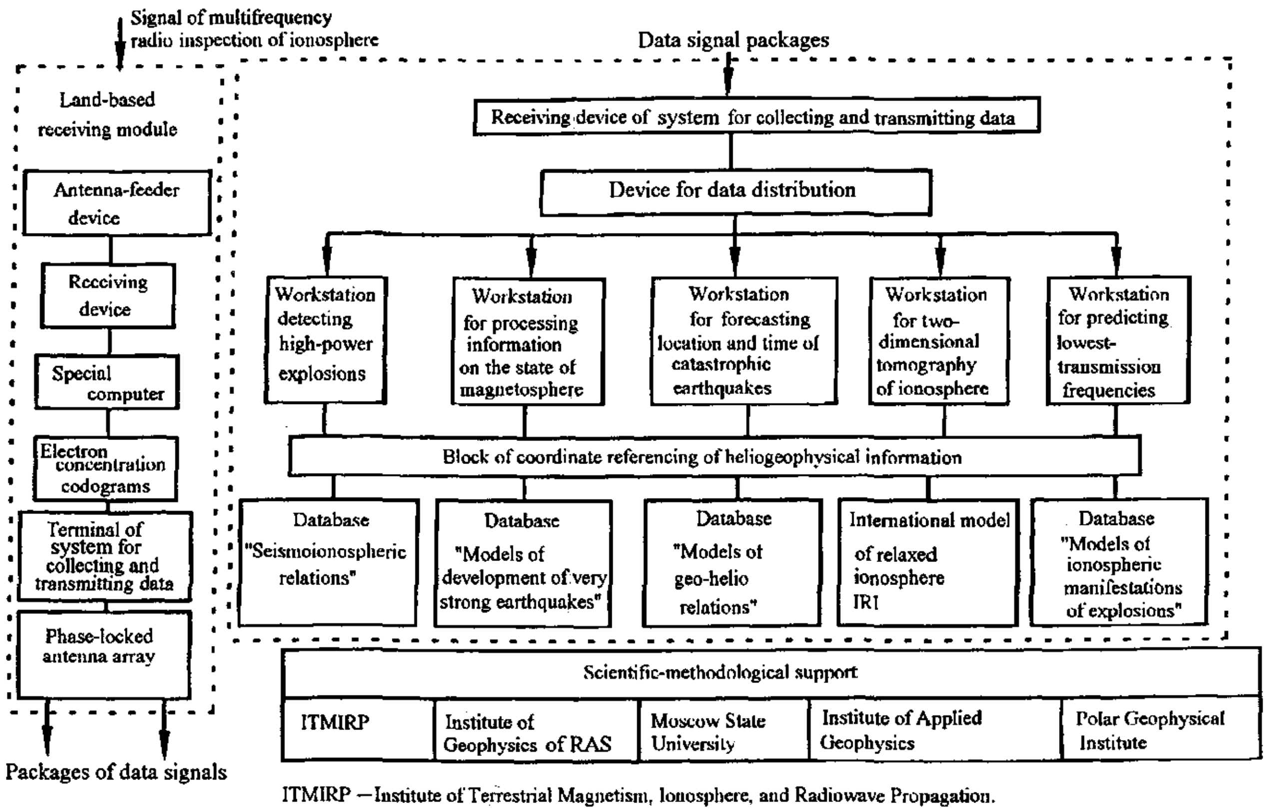

Fig. 2

Land-based station for information processing.

3. A network of land-based transmitting and receiving stations (terminals) of the system for collecting and transmitting data topologically combined with the network of land-based receiving modules.

The technology of the data collection and transmission system maintains the real-time operation of the MATRITSA System.

4. Land-based stations for data receiving and processing linked at the data level with the regional and federal centers of the Federal System for Seismological Observations and Earthquake Prediction.

OPERATION OF MATRITSA SYSTEM

The on-board transmitter of the spacecraft emits variable-frequency decameter-range noiselike signals. Having passed through the ionosphere, a sequence of these signals arrives at the land-based receiving module, where they are subjected to primary processing to estimate the following parameters:

— instantaneous critical frequency f_{oF2} values for the $F2$ regular ionosphere layer;

— absorption coefficients l_i of signals from the system of multifrequency radio-sensing of the ionosphere at several frequencies close to a cut-off frequency, functionally related to the f_{oF2} critical frequency;

— group delay t_i values for signals from the system of multifrequency radio-sensing of the ionosphere along the path of their propagation.

Packages of data signals on the parameters of the ionosphere are transmitted from the land-based receiving modules to the land-based station of data collection and processing through the transmitting stations (terminals) of the latter through the on-board relay station.

At the land-based station of data collection and processing, the radiophysical data (f_{0F2}, l_i, and t_i) are fed into a computer system for data processing, analysis, and display, where these data are used to reproduce the altitude profile of the concentration of electrons in the $F2$ ionosphere layer for a given session of radio-sensing.

The main goal of comprehensive processing of radiophysical data is to detect space-time anomalies in the ionosphere caused by seismogenic or technogenic processes. Anomalies are identified with the use of algorithms for correcting the IRI international model of undisturbed ionosphere using the combined data obtained in a sequence of radio-sensing sessions.

Under complex noise conditions caused by solar activity and man-made interference, the MATRITSA System solves the problems listed below in real time with a probability of $P \geq 0.8$.

1. Detection of seismo-ionospheric precursors of catastrophic earthquakes at time intervals of 1.5 to 72 h and the determination of their coordinates with an accuracy not lower than 200 km.

High-reliability prediction of the time and location of earthquake epicenters is provided by the Federal Center for Earthquake Prediction through the joint processing of geophysical data from land-based data processing stations and other sources of seismological information of the Federal System for Seismological Observations and Earthquake Prediction.

2. Location of high-power atmospheric and underground nuclear explosions and the determination of their coordinates with an accuracy not lower than 50 km.

3. Determination of the current conditions of radio wave propagation and optimal short-wave band frequencies for radio communication accurate to ± 100 kHz.

FUTURE PROSPECTS OF MATRITSA SYSTEM

The OKO System is an information-expert system designed as an open system optimizing its infrastructure based on accumulated data and the results of a multifactorial analysis of solar-terrestrial and lithosphere-ionosphere interrelations.

This self-organization principle is believed to be the only possible means of resolving many uncertainties involved in the physics of seismo-ionospheric relations. The point is that the spatial nonuniformity of ionospheric fields and their instability in time are to a great degree determined by the geological features of seismically active regions.

The advantage of the information path of the MATRITSA System is that it combines measurement data on current ionosphere conditions with mathematical (predictive) models of the dynamics of the ionosphere. This combination constitutes a unified technological basis for creating a two-dimensional disturbed ionosphere model for the accurate and virtually real-time estimation of seismo-ionospheric conditions in particular regions and, through this, for the prediction of the location and time of catastrophic earthquakes.

Seismo-ionospheric precursors of catastrophic earthquakes are detected against the background of fairly intense noise predominantly caused by heliogeophysical processes. This imposes severe requirements on the probability of detecting earthquake precursors. Their detection with a probability lower than 0.8 appears to be meaningless, because this probability value is one of the basic parameters of the Federal System for Seismological Observations.

The probability of detecting earthquake precursors as high as this can only be attained by combining the radiophysical data of the MATRITSA System and data from other sources such as information about increasing solar activity (flares) from land-based solar survey stations of Rosgidromet and the Center for Space Monitoring.

The problem of detecting seismo-ionospheric earthquake precursors requires the estimation of the number of false alarms and the frequency of failures to detect earthquake precursors during a certain period of time, for instance, a year. For calculating these probability characteristics under noise conditions (solar or thunderstorm activity), criteria for selection of false alarms were developed; false alarms may arise in the information path including the ionosphere, on-board measurement devices, and paths of data acquisition and processing at land-based receiving modules and land-based data processing stations.

The scientific and technical potential of the OKO System is high enough to reliably select signals in large-scale survey fields under extremely high noise.

In the course of operating the MATRITSA System, a database of seismo-ionospheric relations will be created to be used in elaborating high-accuracy geoinformation technologies for determining the space and time coordinates of probable catastrophic earthquakes and high-power explosions.

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