Scientific fundamentals of creation and diversification of the global aerospace systems

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Basic scientific and technical problems solved for the 50-year history of creation and operations of various-purpose global aerospace systems are systematized.

1. Introduction

The development of complex global aerospace information and control systems in Russia has a long history. Among such systems there are, first of all, global space systems for observation of dynamic objects in the Earth's atmosphere, space systems for ocean monitoring, space systems for providing the ecological safety in space, aerospace systems for detailed survey of the atmosphere, ocean, land, and terrestrial space, systems for monitoring of the chemical and radiative situation, and many others.

The development, manufacture, and operation of aerospace systems gave rise to various complicated scientific and technical problems. These problems are mostly caused by the unique character of technologies used in the development of aerospace systems. To create a global aerospace system, it is first needed to conduct large-scale experimental and theoretical studies and accumulate a great bulk of information about the objects and phenomena to be observed on both regional and global scales. The information is needed for formation of adequate initial data to be used by systems and their subsystems and components.[1–9,12–15]

The Institute of Atmospheric Optics, Siberian Branch of the Russian Academy of Sciences (former Academy of Science of the USSR) under the leadership of Academician V.E. Zuev has contributed significantly to solution of the majority of these problems. Scientists at this Institute have made a considerable progress in construction of models of optical (and laser) radiation propagation through the atmosphere and statistical models of cloud fields, climatic zoning of the globe, development of the methods of remote sensing of the atmosphere and ocean, as well as in many other important research fields.[10,11,28–31,112–114,124–128] The results obtained at the Institute are being used in the development and operation of the global and regional aerospace systems.

Creation of aerospace systems induced extensive growth of the scientific and technical potential and the development of new high technologies. Diversification of these technologies allows one to solve complicated problems in the following fields:

– ecological monitoring of the environment;

– monitoring of extraordinary situations caused by technogenic emergencies and natural disasters;

– development of techniques and instrumentation for remote sensing and up-to-date space communication systems;

– development of methods, software, and hardware for processing dense information flows;

– mathematical, physical, and imitation simulation;

– fundamental studies of the atmosphere, ocean, land, and terrestrial space; and others.

2. Scientific problems solved in the process of creation of global aerospace systems

Numerous large-scale theoretical and experimental studies have been conducted in the process of creation of the global aerospace systems. As a results, many difficult scientific problems have been solved. Below we list some of these problems.

1. General principles of construction of many-purpose aerospace systems have been developed based on the theory of construction of complex systems.[1–8] The principles are as follows:

– the whole system should be divisible into a finite number of subsystems, each consisting of separate elements (groups of spacecraft, equipment for remote sensing, control tools, spaceborne and ground-based information processing systems, communication facilities, etc.);

– subsystems operate not independently, but as a whole combined system, and are controlled by a central control unit;

– subsystems are linked by means of a communication system, which transfers control commands and supplies customers with information at different levels;

– obeying principles of open systems (capability of increasing the number of functions executed, easy upgrading, integrability of the information resources, capability of upgrading hardware and software in the process of system evolution, etc.).

2. New technologies have been developed for creation of complex aerospace systems, their components, devices, and elements based on the methods of mathematical and imitation simulation, models of background situations, databases of characteristics of

different objects of the environment, onboard technologies and highly integrated circuits. This allows the decrease in the number of very expensive bench and field tests, miniaturization of bulky ground-based systems, and more economical operation of systems.[1–3]

3. The techniques have been developed for simulation of signal fields at the input of aerospace systems. The techniques are based on the information approach and developed statistical, structure, and multivariate methods. These provide for adequate description and synthesis of stochastic fields of electromagnetic radiation recorded using different-type remote sensing instruments, as well as systematic accumulation of the initial data on observed objects and backgrounds.[12–21] The techniques have been used for construction of the models of power-spectral and spatial-frequency characteristics of various objects and backgrounds, the models of electromagnetic radiation propagation through the atmosphere and ocean, a wide variety of hydrodynamics and electrodynamics models, as well as geographic, climatic, meteorological, and other models.[1,6,12–32] The data on characteristics of different processes and phenomena observed by use of aerospace systems have been accumulated.[14,15,20,21]

The techniques and models developed have given scientific justification of the field of experimental and theoretical investigations aimed at obtaining the initial data needed for the seeking physical grounds, principles, and developing technical ways for creation of the global and regional aerospace systems, as well as providing for their tests and operation.[1–8,12–18]

4. The methods and computer technologies for synthesis of stochastic fields of radiation have been developed based on the proposed method of "phase spectrum.B They allowed adequate simulation of images of spatially homogeneous and spatially inhomogeneous objects on the surface and in the atmosphere in different spectral regions with the use of 2D spatial spectral models, hypotheses on phase distribution, and other *a priori* information.[14,15,19] These methods and technologies are successfully applied to imitation simulation in the process of development, test, and operation of aerospace systems.[1,4–8,12–15] They can also be widely used in many other fields.[1,2,13–15,17,33–38]

5. Unique methods of conducting complex field experiments with the use of spaceborne, airborne, ground-based, shipborne, and other measurement means capable of acquiring statistically reliable data on the observed objects, processes, and phenomena have also been developed.[1,14,15,18] As a result of unique experiments, problem-oriented databases have been compiled on characteristics of various objects and backgrounds in the atmosphere and ocean, on land, and in the terrestrial space. The total size of the database is about 10^8 Tbyte (Refs. 1, 6, 14, 15, 20, and 21). The use of information compiled in the experiments allowed us to justify the principles of construction of a system as a whole, its elements and units, as well as to create new models of objects and backgrounds, development of methods of information processing implemented in the ground-based and onboard systems, and large-scale computer tests of aerospace systems.

6. Earlier unknown processes, phenomena, and effects associated with interactions of hydrophysical fields of the ocean water in depth with its surface have been discovered, supported by numerous field and laboratory experiments, and thoroughly studied.[14,15,17,18,22–25,39,41–43,50,51,72–85]

Structure formations on the sea or ocean surface have been found, which are stable to the changes in hydrometeorological conditions. They exist in the area of interaction with the in-depth hydrodynamic processes and can be identified by changes in the spatial-frequency spectra of the sea surface roughness. The types of these formations and topological and dynamic properties providing for their reliable identification from aerospace platforms have been determined.[13–15,39–42]

Earlier unknown effects have been discovered and their existence confirmed in many experiments. These effects are associated with the suppression of high-frequency spectral components and generation of additional components, change of orientation of 2D spatial spectra in the areas of interaction between the surface waves and trails of the inner waves, stream fields, turbulence, convective motions, circulation, vortices of different scale, etc. The results obtained make it possible to study these in-depth phenomena by their manifestation on the sea surface.[3,6,7,13–18,39–41,50,51,72–75]

Fields of the foam activity have been formed and changed under the effect of different hydrodynamic processes in the near-surface sea layer.[60,61]

7. As a result of large-scale complex experimental and theoretical investigations, some earlier unknown regularities have been revealed in such fields as[14,15,18,27–31,45,47,53–59,62–71,124–128]

– formation of fields of electromagnetic radiation reflected, emitted, and scattered by different objects and backgrounds in the optical and radio wave spectral regions;

– interaction of hydrophysical fields in the ocean depth with its surface;

– gas-dynamics and thermodynamics phenomena accompanying formation of gas and dust clouds due to volcanic eruptions, fires, etc.;

– interaction of laser radiation with different substances;

– formation of cloud fields in the Earth's atmosphere;

– the upper atmospheric glow;

– solar-terrestrial relations;

– propagation of electromagnetic waves through various media;

– interaction of radio waves with the ionosphere.

8. New methods of remote sensing of the atmosphere, ocean, land, and terrestrial space have been developed and implemented. Among these methods there are the following ones:

– methods of remote spatial-frequency spectrometry[7,14–18,25,39,40] providing for acquisition of 2D and 1D spatial spectra of different objects on the ocean surface, on land, and in the atmosphere, for separation and classification of areas with anomalous characteristics and determination of significant parameters of the medium by informative indices of the spectra, as well as for supplying the technology of synthesis of stochastic brightness fields with the initial data;

– methods of radio wave recording and radio tomography of sea and near-surface phenomena associated with variation of stream boundaries, inner waves, and stratification characteristics. These methods provide the ability to create computer images of surface and under-surface phenomena from the data of aerospace radio sounding of the ocean by solving the set of equations describing interaction of radio signals with the spatial spectrum of sea and fields of under-surface streams[1,3,7,17,41–43];

– methods of IR and SHF radiometry[16,41–44];

– visible and IR multispectral methods[1,15,16];

– Fourier transform spectrometry[18,46];

– laser sounding of the atmosphere and ocean[27–29,38,45];

– multifrequency radio wave transmission sounding of the ionosphere.[47,48]

The methods developed are being successfully used to observe variety of objects. Besides, they can be efficiently used for monitoring of the environment and effects of the natural and anthropogenic factors on various ecosystems, exploration of natural resources, detection of emergency situations, global monitoring of the ozonosphere, monitoring of heat sources, such as fires and volcanic eruptions, determination of the sea bottom relief over large areas, short-term forecast of catastrophic earthquakes, monitoring of helio-geophysical situation, ecological safety in the terrestrial space, solution of various problems in meteorology, geodesy, mapping, agriculture, town-planning, basic sciences about the Earth, and many other fields.[5–8,14–18,23,24,38–49]

9. New methods, algorithms, and programs have been developed for processing dense flows of information coming from various remote sounding devices.[14,15,19,36,39,41,86–91] The methods are intended for solving the following problems:

– separation and classification of low-contrast spatially extended and small-size objects against the background of stochastic noise with the use of parametric and non-parametric methods, as well as procedures of adaptive clusterization, and others;

– calculation of power, spatial, and dynamic parameters of fields of signals from the objects sounded;

– processing of highly informative images in order to obtain and analyze statistically multidimensional arrays of informative indices needed for classification of images by different criteria and determination of significant parameters of observed objects and phenomena;

– onboard smart image processing techniques employing the procedure of cluster separation in the index space;

– synthesis of samples of 2D and 3D stochastic brightness fields recorded by different remote sensing devices;

– service and support of databases intended for storage of bulky information obtained in remote sensing of various objects;

– support of the operation of expert systems of real-time analysis of the information from various sensors, detection of objects and phenomena in the monitored space, their identification, estimation of their parameters, and prediction of the evolution of observed situations, as well as formulation of recommendations on optimal control.

10. The methods, algorithms, and programs have been developed for spacecraft control, including recording and processing of telemetric information, as well as control over a group of spacecraft at different orbits from one control post.

11. The new architecture has been developed, as well as the principles of construction of technical means for processing of dense information flows. Among these means there are the following[1–6,14,15,18,24,38–41,80,86,92]:

– ground-based systems for processing of a series of highly informative digital images in order to isolate small-size dynamic objects against the background of random noise on almost real-time scale;

– ground-based optical, optical-digital, and digital systems for processing the flows of highly informative images (up to 10^9 bit/frame) in order to obtain significant parameters of objects and backgrounds;

– specialized onboard calculators for pre-processing of bulky data in order to filter out information and decrease the data flow density transmitted to the ground-based stations;

– onboard optical-digital and digital image processing systems for spatial spectral analysis, separation and recognition of various anomalies on the ocean and land surface on almost real-time scale.

12. The principles have been developed for construction of space communication systems with high-directional multilobe, large-diameter antennas that are unfolded in space, which allow various types of communication (personal, movable, fixed) to use many times the working, provide for ecological safety of customers due to the low emitted power (~0.03 W), and these antennas provide their compatibility with all the existing commercial communication systems at low cost and low rates.[1,9,95–100]

13. Physical principles have been developed and high-efficiency onboard power sources have been created, which allow active and passive remote sensing devices to operate aboard a spacecraft.[1,93,94]

The results obtained were discussed at scientific councils on geophysics, image processing, and space at the Presidium of the Russian Academy of Sciences (former Academy of Sciences of the USSR) and received wide recognition.

3. Technical problems solved in the process of creation of global aerospace systems

In the process of development, test, and operation of aerospace systems, many of the very complicated technical problems have been solved.[1,4–7,15,41,42,47] The main problems solved are listed below.

1. Development and implementation of the original principles of orbital construction for solution of various problems, such as global real-time monitoring of dynamic objects in the atmosphere, monitoring of the situation in the Global Ocean, providing for ecological safety in space, and others.[1–4,49,93,94] One of the examples of implementation of these principles is combination of geostationary and highly elliptic orbits for continuous global round-the-clock observation over the globe.[1]

2. Implementation of the single-post method of control over a group of spacecraft, that significantly reduces the expenses of creation of the system without loss in accuracy of determination of the trajectory parameters[1,3,93,94] and allows creation of ground-based control stations for control over spacecraft at highly elliptic, geostationary, and other orbits, as well as acquisition and processing of data from spacecraft.[1,3,9,95]

3. Creation of a series of unique spacecraft which can be equipped with complex systems of remote sensing devices, onboard computers, communication facilities, onboard measuring and executing equipment, power supply systems, systems of orientation and stabilization, etc. They allow implementation of the developed general principles of construction of various global aerospace systems.[1,3,93,94]

4. Creation of a unique system of orientation and stabilization of geostationary and highly elliptic spacecraft. This system ensures high-accuracy guidance of narrow-band remote instrumentation to the observed trajectories and objects thus increasing the accuracy of determining the coordinates of the observed objects.[1–3]

5. Creation of a unique system for control over accelerators and orbiting spacecraft for interception of damaged space objects in a wide range of altitudes.[3,93]

6. Development of technically realizable method for launching spacecraft to geostationary and highly elliptic orbits with the use of the gravity force of the moon. This method allows one to weaken the requirements imposed on the carriers and increase the useful load of a spacecraft.[3,4,93]

7. Creation of a multipurpose unified Earth–space radio channel and implementation of the digital transfer of information, which not only provides for solution of systems' functional problems, but also for use of the obtained technical solutions in creating special and general-purpose space communication systems.[1–4,93]

8. Creation of unique systems of aerospace IR, radar and TV equipment, including multiscale broad band IR equipment, radar and radio direction finding systems, equipment for remote spatial-frequency spectrometry, spectrometers, Fourier transform spectrometers, etc. Such systems provide for the ability of observation over various objects under conditions close to physical limits.[1–8,16,39–46]

9. Creation of unique airborne (IL–76, AN–12, TU–134, AN–30 aircraft) and helicopter-borne (MI–26, MI–6, MI–8 helicopters) laboratories equipped with a wide set of remote sensing devices (photographic, multizonal photographic, TV, termovision, and lidar equipment), spatial-frequency spectrometers, multichannel SHF radiometers, side-looking radars, coherent multifrequency radars with aperture synthesizing, Fourier transform spectrometers, etc. This equipment is intended for studying the characteristics of various phenomena in the ocean, atmosphere, and on land.[7,14,15,17,44,93]

10. Implementation of the multilevel hierarchy principle of data acquisition, processing, and distribution over global aerospace systems with the use of analytical centers, and different-level space and ground-based communication channels.[1–9]

11. Implementation of the module technology of construction of the onboard equipment. This technology is based on separation of the executing and measuring equipment and common interfaces. It allows realization of the methods of unification and standardization of facilities, as well as ground-based tests of the onboard systems with the use of imitation procedures.[1–4]

12. Development of a new highly efficient technology of preparation of spacecraft for launching. The technology ensures complex adjustment of the onboard and ground-based facilities with estimation of the system characteristics. This decreases the number of bench and field tests and makes the system less expensive.[1–4]

The above-listed scientific and technical problems (the list is not complete) solved in the process of creation, test, and operation of aerospace systems provides for the use of the results obtained and the aerospace systems created in various fields, what allows us to say about diversification of the developed technologies and systems. Below we give the main directions of such diversification.

4. Creation of systems for monitoring of the environment and emergency situations

One of the most important field for possible diversification of aerospace technologies and systems is organization of ecological monitoring of the environment, as well as emergency situations of technogenic and natural origin. This is caused, on the one hand, by the similarity of the construction principles of already created systems and those to be developed for solution of the above-mentioned problems and, on the other hand, by the urgency of these problems, which have increased drastically in numbers in recent years.[1–8,14–17,47–49,101,111,115–122]

Below we describe the construction principles of the global and regional systems of environmental monitoring and the International Center of Ecological Monitoring and give some examples of the use of developed technologies and systems for monitoring of various objects of the environment, such as anthropogenic impact on coastal waters and heat sources (volcanic eruptions and fires); for prediction of catastrophic earthquakes; for monitoring of the helio-geophysical situation, anomalies in the Earth's ozonosphere, and tropical cyclones; for detection of radioactive emissions; and for other purposes.

4.1. International system of global ecological monitoring

Ecological problems are global in their nature.[103–118] Therefore, international cooperation plays a decisive part in their solution, for example, when planning and undertaking environmental protection measures, especially, when organizing ecological monitoring, which gives independent information about the environment at all levels from local to global. The urgency of solution of the problems associated with the development of environmental monitoring systems was repeatedly emphasized at many representative international forums.[110,111,120,121]

The experience gained at creation and operation of global aerospace systems allowed us to put forward the concept of International System of Global Environmental Monitoring. This concept is based on the multilevel hierarchy principle of using a wide set of measuring instrumentation from onboard a spacecraft orbiting at different orbits, as well as airborne, ground-based, and shipborne equipment, with a wide network of information reception and processing. Such a set of instrumentation should provide information on most objects of the environment both for separate countries and the globe on the whole.[5–8,16] This system would enable making observations on a wide range of spatial scales with various spatial resolution and various information renewal periods. Its construction principles are based on the idea of functional integration of the national monitoring systems, which function independently now, into a joint international global information-control system under joint coordination and with existing and new information-analytic centers of different levels, a wide network of local user's terminals joined via communication lines. Integration of the existing national systems into such a system requires significantly lower expenses than that for creation of national systems.[5–8,119,120] The general block diagram of the system is shown in Fig. 1.

The proposed international system of global monitoring is capable of supplying the needed ecological information for every country and the globe as a whole. For each country taking part in its creation, it gives a powerful means for justification of ecologically dependent economic decisions.

For such a system to be created, some organizational and technical problems should be first solved. These problems are associated with creating international and inter-branch cooperation of the existing centers and systems at both national and international level.

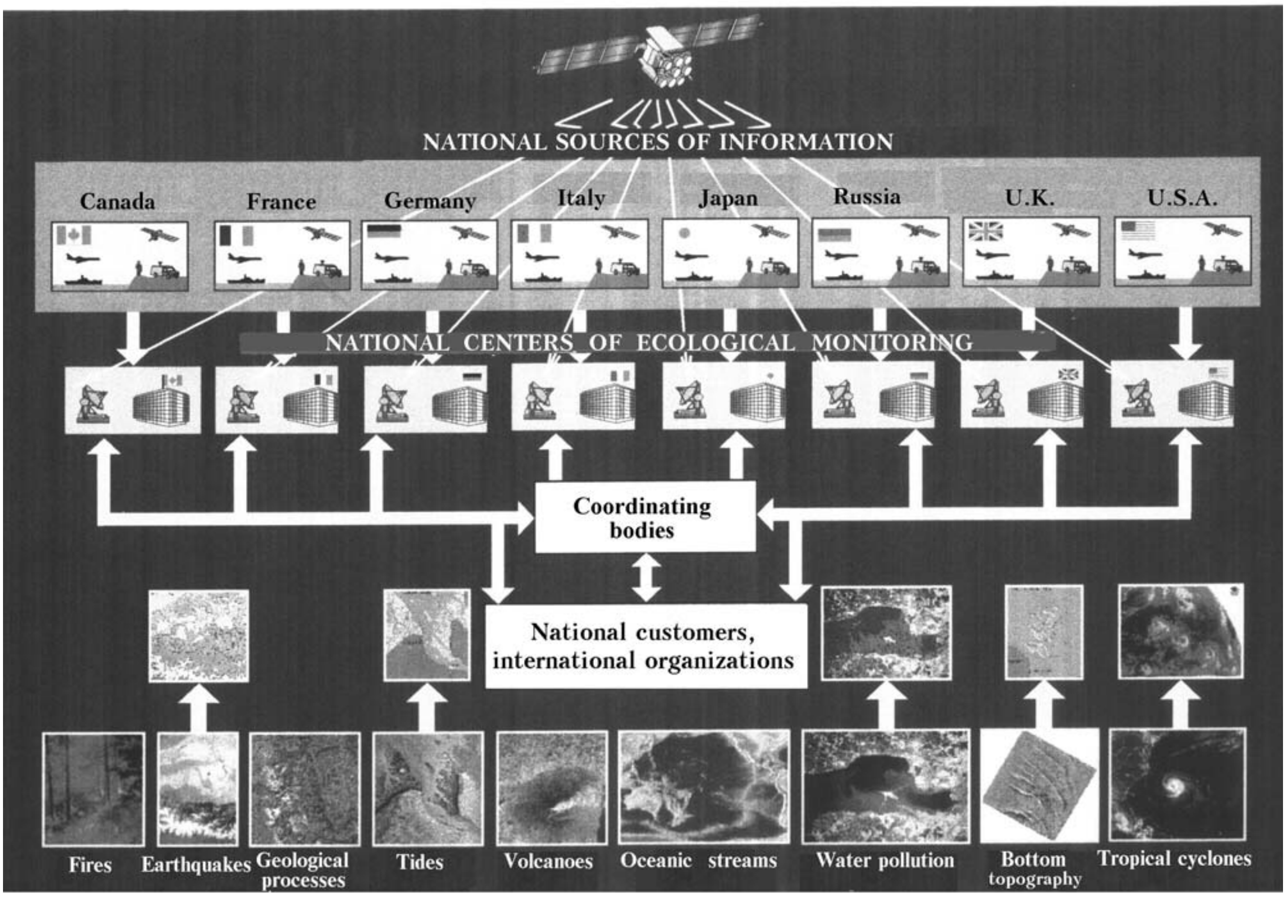

Fig. 1. International system of global ecological monitoring.

The idea of creating such a system was discussed and supported at the meeting of leaders of the Great Eight countries in 1997 (Ref. 119), sessions of the Russian–American Commission on Cooperation in Economy and Technology,[4,8,16,20] European Intergovernmental Meeting on the Development of the System of Ecological Monitoring in Europe,[120] and at many International conferences.

4.2. International system of global monitoring of the territory of the Commonwealth of Independent States

To organize environmental monitoring at the territory of the Commonwealth of Independent States (CIS), the International System of Ecological Monitoring (ISEM) is now under development. It is being formed on the basis of the existing national and regional monitoring systems in accordance with the International Agreement about Cooperation in Ecological Monitoring.[122]

The main purposes of the ISEM are the following:

– cooperation among national, regional, and branch monitoring services and structures;

– formation of a unified system of collecting, processing, and transfer of ecological information based on the existing communication systems and databases and those to be developed;

– development of the unified techniques and software for acquiring, processing, and transfer of the ecologically significant information;

– prediction of the state of the environment taking into account the transborder transport of pollutants, electromagnetic radiation, and sonic oscillations, spread of biological objects, sources of ecological danger, and other anomalies;

– simulation of critical situations and revealing of sources of ecological threats;

– detection of emergencies and disasters of natural and technogenic origin and timely warning;

– formulation of recommendations and distribution among administrative bodies and interested organizations for solving global and local ecological problems and for fast taking of due measures in order to warn people and protect them against emergencies and disasters;

– joint scientific research and design in the field of ecological monitoring.

The generalized scheme of the system is shown in Fig. 2.

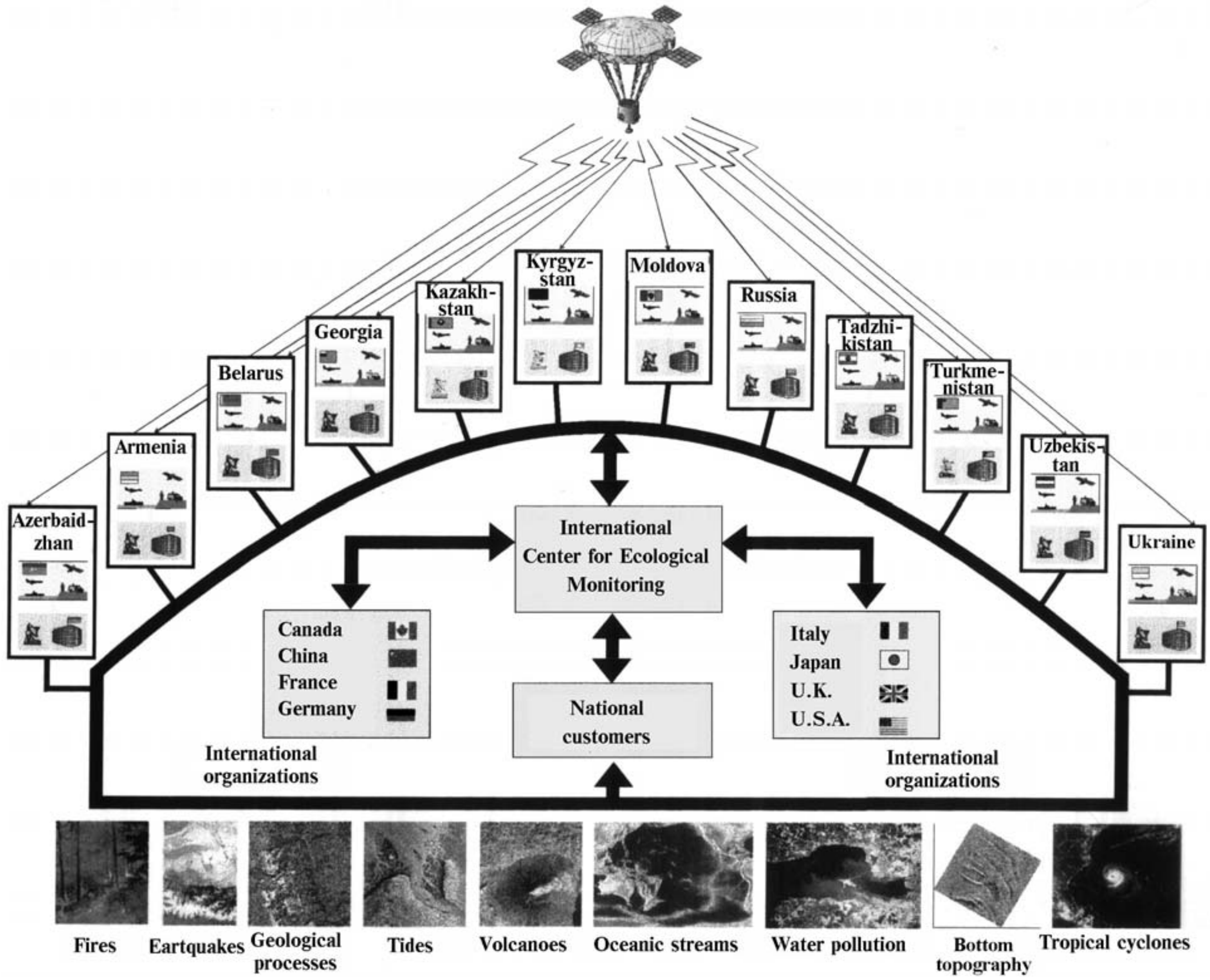

Fig. 2. International system of ecological monitoring.

In creating the ISEM, it is worth using the experience and technologies accumulated at the development and operation of global aerospace systems.

The concept of ISEM construction is based on unifying functions and stage-by-stage development of the existing national and branch systems and those under development into a joint international information-control system with a common international center for ecological monitoring. The common center co-operates with national information-analytical centers of different level and the wide network of local-level user's terminals joined via communication facilities. In this case it is assumed that capabilities of diversified global information-control systems are fully used.

4.3. International Center for Ecological Monitoring

The International Center for Ecological Monitoring (ICEM) is the main coordinating unit.

The scheme of functioning of the Center for Ecological Monitoring is shown in Fig. 3.

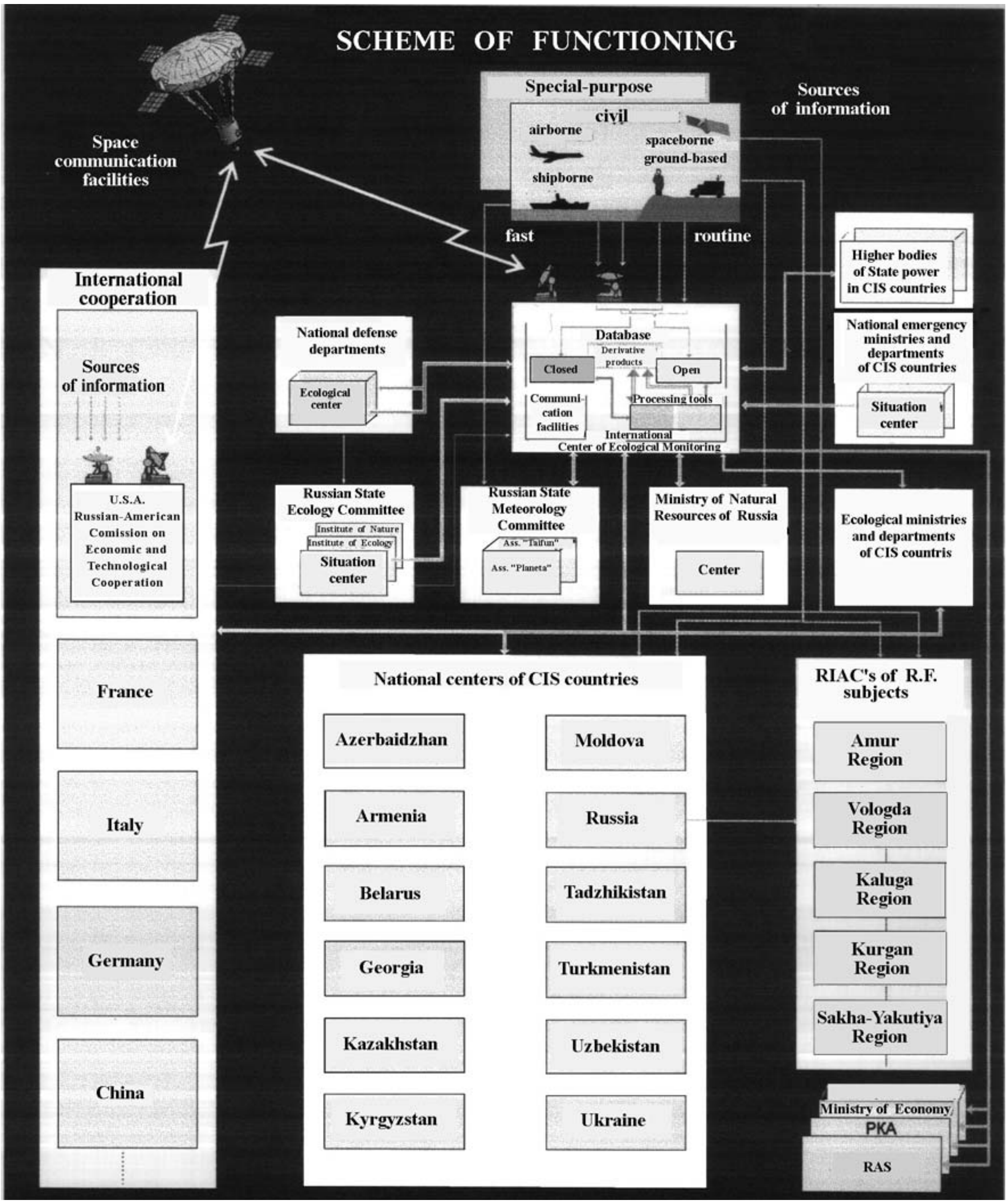

Fig. 3. International Center for Ecological Monitoring.

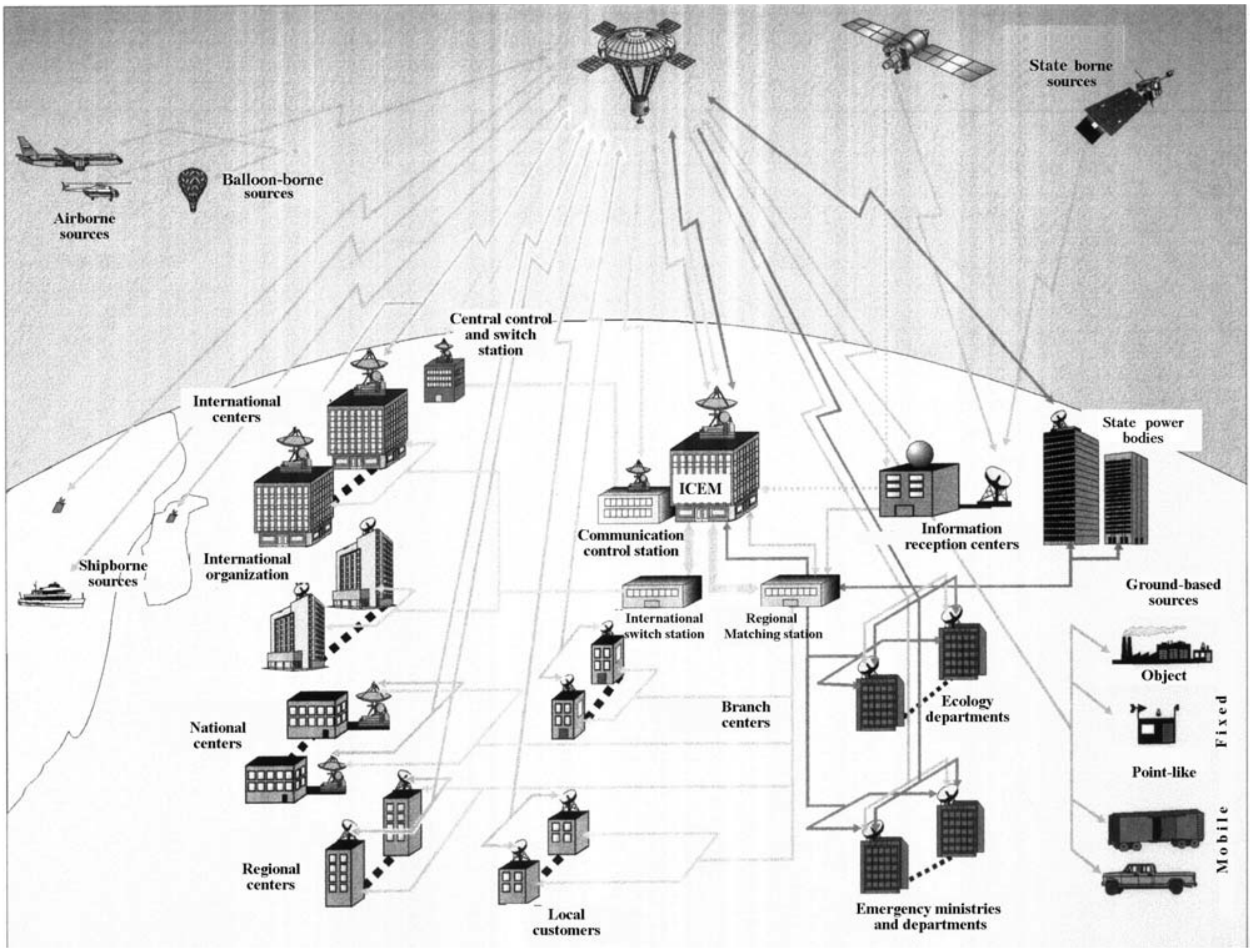

Fig. 4. Organization of data collection and transfer in the systems of ecological monitoring.

The primary goal of organizing the monitoring over the territory of CIS countries is to organize interaction between the ICEM and national information-analytical centers of CIS countries, as well as regional centers of these countries, including regional information-analytical centers (RIAC's) of the R.F. Relations with information-analytical centers of ecological departments and national emergency departments, as well as defense departments are also assumed. These relations allow the use of the software developed there and data obtained within these departments.

To fulfil international environmental protection projects, which are mostly associated with transborder problems, the capability of directly receiving the information (both current and routine) from different sources for its further processing and analysis is provided. For the ICEM to function, the data transfer between different centers and local customers should be provided for through existing communication facilities and those to be developed.[99] The scheme of organization of the data collection and transfer in the systems of ecological monitoring is shown in Fig. 4.

Now the first stage of the Center is created based on the experience of the Russian-American Commission on Cooperation in Ecology and Technology.[8,16,101]

5. Use of aerospace technologies and systems for monitoring of different objects of the environment

5.1. Remote monitoring of coastal waters

The technologies developed and systems created can be used to organize complex monitoring of sea waters. For this purpose a system is needed whose structure is shown in Fig. 5.

The system should include remote sensing instrumentation deployed onboard a spacecraft and orbital stations, airborne laboratories carried by IL–76 aircraft or MI–8 and KA–32 helicopters equipped with remote sensing instruments and onboard means for data processing, specialized ecological ships, buoy stations, hydroacoustic systems, communication facilities, high-efficiency means for image processing allowing solution of a wide variety of problems of sea sounding and simulation of coastal ecosystems.

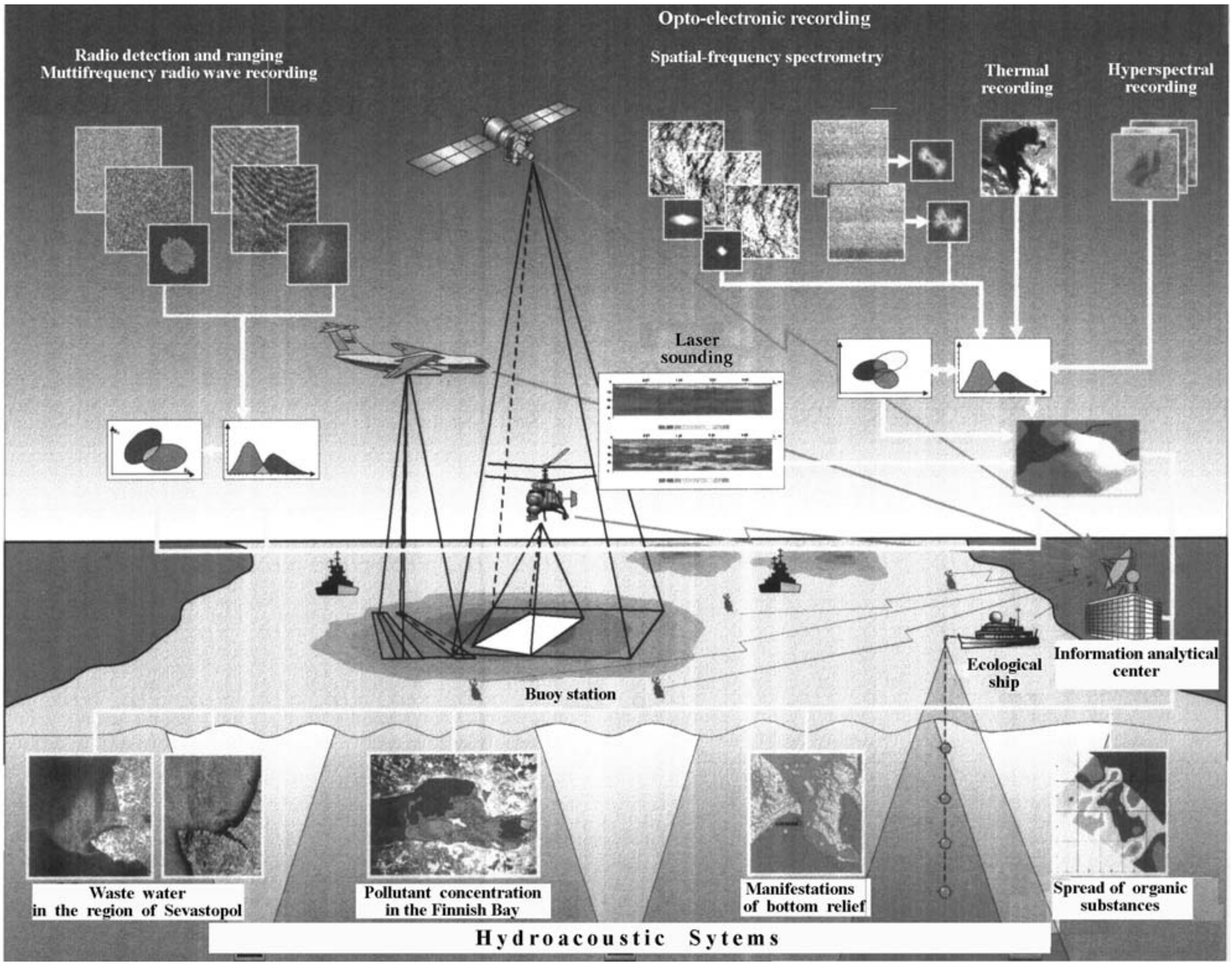

Fig. 5. System for complex monitoring of coastal waters.

For monitoring of the water medium, the methods and instrumentation of remote optical spatial-frequency spectrometry, multifrequency radio wave recording, and laser, multispectral, and hyperspectral sounding are used.

The system is intended for:

– detection of anthropogenic pollution (waste water discharges, oil spills, heavy metals, organic substances) in coastal waters;

– measurement of physical, chemical, and biological parameters of the water medium and their spatiotemporal variations;

– analysis and prediction of evolution of ecological situations and evaluation of anthropogenic impact on the ecosystems of coastal waters.

The system allows observation of coastal waters, data processing in ground-based computer centers, and transfer of the results to customers.

The information obtained is processed in the ground-based computer centers, and the results are used for the following purposes:

– identification of pollution sources and evaluation of their intensity;

– evaluation of the ecological risk for coastal ecosystems caused by different anthropogenic factors;

– obtaining information needed for monitoring of regional climate changes;

– development of recommendations on taking due measures to prevent further pollution of the environment;

– compilation of databases on characteristics of various phenomena in coastal waters.

Now some projects with the use of fragments of this system have already been reduced to practice, including the Project of Monitoring of Anthropogenic Impact on the Ecosystem of the Florida Bay within the framework of the Ecology Workgroup of the Russian-American Commission on Cooperation in Economy and Technology.[101,121,123]

5.2. Monitoring of thermal sources

The capabilities of space global observation systems can be used for detection of thermal sources, such as, for example, volcanic eruptions and forest fires.[1,4–7]

Monitoring of these thermal sources is based on IR recording of electromagnetic radiation with wide-field-of-view devices deployed onboard a spacecraft orbiting at highly elliptic, geostationary, and medium-height orbits and high-resolution devices onboard low-orbit spacecraft.

Monitoring of volcanoes includes evaluation of the smoke content, determination of the particle concentration in emissions, and prediction of the plume spread with the help of high- and low-orbiting spacecraft equipped with IR instrumentation.

The system for monitoring of forest fires includes the fire-fighting means carried by airborne laboratories. The proposed technology allows large-scale and local fires to be detected within 10 s and from 10 min to 1 hour, respectively.

5.3. Ground-to-space system for short-term forecast of catastrophic earthquakes

The scheme of the system for short-term forecast of catastrophic earthquakes is shown in Fig. 6.

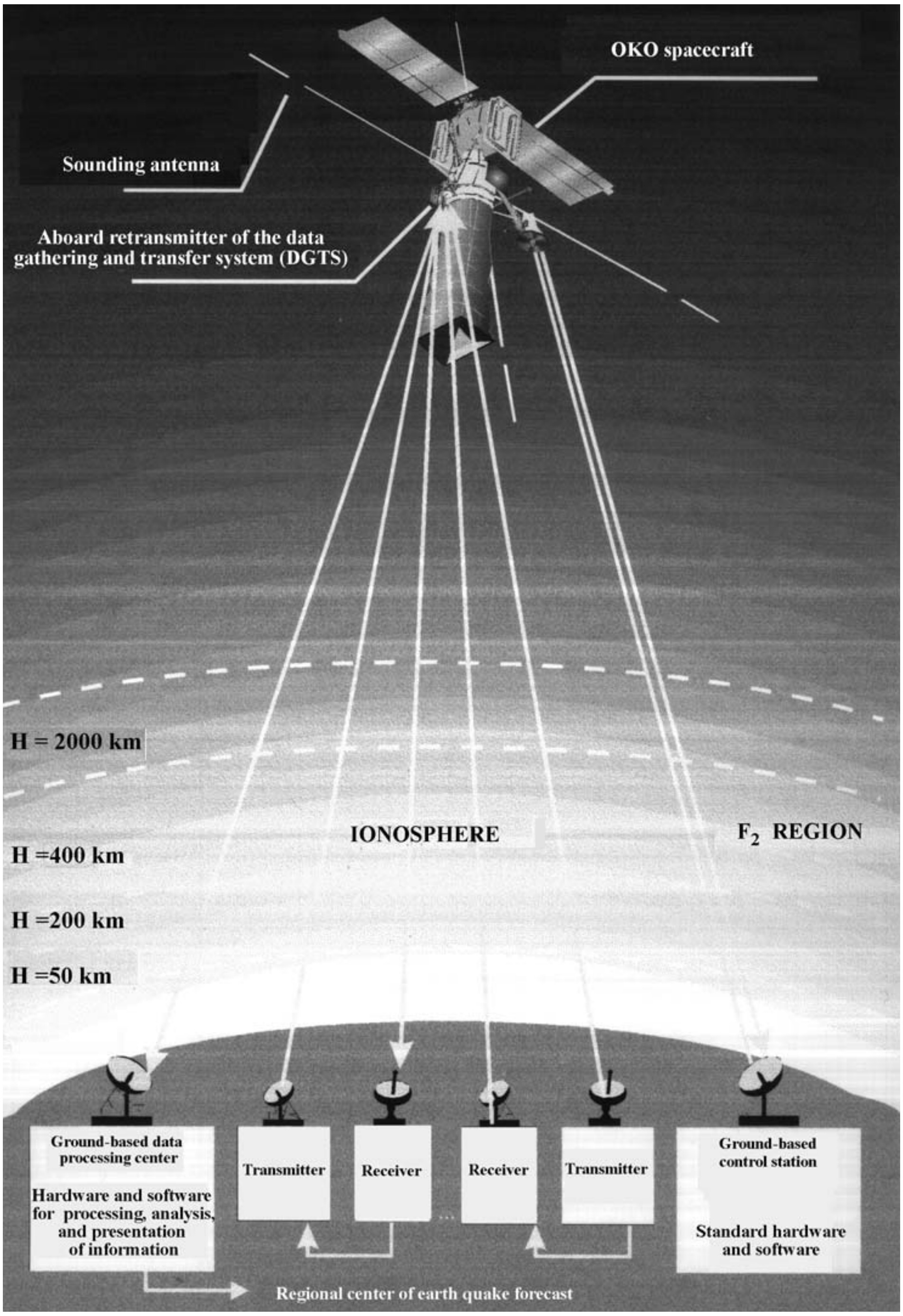

Fig. 6. Ground-to-space system of short-term forecast of catastrophic earthquakes.

The system is based on the method of multifrequency transmission radio sounding of the Earth's ionosphere from a spacecraft. The radiation having passed through the ionosphere is then received by ground-based stations. Precursors of earthquakes of the magnitude greater than 5 can be detected from the received signals about three days before an earthquake. The probability of correct forecast is, in this case, about 0.7. The forecasts obtained in such a way are then distributed among the bodies responsible for taking the corresponding measures.[47,48]

The system includes (a) geostationary spacecraft (stand points of 35 and 130°E) which monitor the ionosphere within ±65° from the stand point both in latitude and longitude, (b) BMatritsaB an onboard system for multifrequency radio sounding of the ionosphere and the onboard equipment (retransmitter) of the data collection and transfer system operating in the millimeter region, (c) spatially distributed network of 20 to 25 ground-based automatic signal receivers separated by 300 to 500 km, (d) network of ground-based transmitters topologically coincident with the network of receivers; (e) ground-based stations of information reception and processing; at the information level these stations coincide with the customers' information-analytical centers.

The methods of earthquake forecast from a spacecraft have been experimentally tested.

5.4. Monitoring of helio-geophysical situation

Monitoring of the helio-geophysical situation is in fact radio sounding of the ionosphere and recording of the parameters of electric and magnetic fields, waves in the magnetosphere plasma, power and density of fluxes, and spatiotemporal characteristics of charged particles in the Earth's magnetosphere from geostationary and highly elliptic spacecraft.[1,5–7,48]

In such a way the following problems can be solved:

1. Prediction of breaks in operation of radars, including aviation radars (this is especially urgent in high latitudes).
2. Prediction of possible failures in functioning of navigation electronics, defense, and communication spacecraft.
3. Prediction of failures in operation of distributed computer networks, wire and cable communication lines, automatic control systems, and safety systems of various ecologically dangerous objects, in particular, atomic power plants.
4. Real-time detection of nuclear tests in all media, including underground nuclear explosions.
5. Prediction of optimal radio communication frequencies in the short-wave and ultra-short-wave ranges and determination of the current conditions of radio wave propagation for air and sea traffic control centers.
6. Prediction of the probability of the following events:
   - emergencies at ecologically dangerous objects of oil and gas industry and transportation;
   - current overloads and emergency power cuts in power lines.
7. Prediction of biologically significant changes in geomagnetic field, as well as periods of unfavorable geophysical situation in order to decrease the risk of disease spread among population.

5.5. Radar detection of radioactive emissions from atomic power stations

In the process of creation of aerospace systems, the method has been developed for monitoring of the radioactive objects. This method is based on comparison of radar signals reflected from ionized clouds of radioactive emissions with those reflected from the surface, non-radioactive emissions, and natural clouds. The method was experimentally tested after emergency at the Chernobyl Nuclear Power Plant and when observing objects of radioactive danger in Chelyabinsk Region. The results of field experiments have shown that the method allows reliable detection of radioactive emissions and their distinguishing against the background of meteorological formations and emissions from thermal electric power plant.[1,7]

The method can be used for the following purposes:

- remote evaluation of the state of objects of radioactive danger by their emission clouds,
- remote monitoring of territories contaminated with radioactive materials by detecting ionized clouds over them, determination of trajectories of these clouds and coordinates of regions where the clouds precipitate,
- detection and monitoring of underground disposal of nuclear wastes,
- exploration of mineral resources by changes in the radioactive background, etc.

Ecological safety of cooling pools of the nuclear power plants is monitored based on the data obtained by remote sensing and simulation. This allows the following characteristics to be evaluated: the temperature distribution over the surface of a cooling pool, its time variability in the discharge zone, and ecological danger of thermal discharges of nuclear power plants.

6. Simulation of physical fields caused by objects of the environment

As was noted above, in the process of creation of global and regional aerospace systems, simulation methods have been developed, which use statistical, analytical, structure, statistical-structure, linguistic-structure, and other approaches.[12–15] Besides, various models have been constructed, including:

– complex models of signal fields at the input of different-type remote instruments being a part of global information systems; these models allow estimation of the input effects under any conditions of functioning and in any regions of observation, as well as imitation of any physical fields caused by objects of the environment;

– spatial spectral models of objects of the land, cloudiness, and sea surface;

– models of spectral brightness of radiation from various natural objects in the optical region;

– regional geographic and climatic models of the Earth as a planet.

These models can be used for the following purposes:

– design of the global information-control systems;

– scientifically justified selection of specifications of aerospace systems and characteristics of onboard instrumentation;

– definition of the functioning principles of systems and indices for recognition of observed objects.

The technology of simulation and its program realizations can be used for digital imitation of the information channel as applied to the systems of global remote monitoring of the environment.

7. Simulation of anthropogenic impact on coastal water ecosystems

The proposed technique of simulation has been used in developing of the mathematical model of anthropogenic impact on coastal water ecosystems.

The coastal ecosystems belong to the class of complex systems. They can be studied and their state monitored using methods of mathematical simulation.

Simulation of ecological problems is based on the system approach in which the relations between phenomena are of primary significance, while phenomena themselves are of secondary importance.

A versatile mathematical model of a coastal ecosystem under conditions of anthropogenic load is based on the interrelations that have been established among the processes of different nature: physical, chemical, biological, and geological.

The model of an ecosystem is characterized by a set of parameters which determine the input and output parameters of state, as well as control and perturbation parameters.

The *input* parameters of the model are the following: particular models describing the state of the main components of an ecosystem (climatic model of a region, model of the source of anthropogenic impact, hydrothermodynamic and hydrodynamic models, admixture diffusion model).

The *output* parameters are calculated results describing the spatiotemporal variations of biotic components of the ecosystem and pollutants (chemical compounds, suspensions, biological pollutants), numerical estimates of the ecological risk, as well as optical, acoustic, and physical fields (hydrology of forces).

The *perturbation* parameters are anthropogenic and natural exogenous factors acting on ecosystems.

The *control* parameters are the system of measures (technical, legislative, social), which ensure the effective regime of existence of the ecosystem.

The model has a three-level block structure. At the first level of simulation, empirically found separate processes are taken into account. The corresponding equations are available for hydromechanics, optics, thermodynamics, chemical reactions, photosynthesis, growth of the biomass.

Interaction between processes is described by the second-level models being parts of the hydrodynamic, hydrobiological, and hydrochemical blocks.

Ecological processes are simulated with a third-level model, which joins the second-level models into a closed system.

The model gives (a) evaluation of the actual state of the coastal ecosystems, (b) prediction of changes in the parameters of the ecosystems, (c) detection of critical situations and sources of ecological danger, (d) sufficiently long-term forecast of pollution spread under the effect of various factors (wind, stream, diffusion, etc.), (e) estimation of the polluted area and pollutant concentration, (f) analysis of possible scenarios of evolution under varying hydrometeorological conditions, (g) recommendations for normalizing the ecological situation in specific regions, (h) improvement of the existing systems of ecological monitoring.

8. Simulation of hydrodynamic perturbations of sea medium by deep discharges of waste water

Based on the developed simulation principles and models, the complex model has been constructed. This model is intended for evaluating the influence of waste water discharge on coastal water ecosystems, changes in the parameters of water medium, the capabilities of remote monitoring of these phenomena.[7,16,22]

The complex model describes how the water medium is affected by the following processes caused by deep discharges of waste water[7,16,17,22]:

– rise of admixture jets in a stratified medium (the models allow calculation of the depth of jet rise, the degree of dilution, and of the area polluted with waste water at some level in depth);

– formation of convective motions caused by distillation of water at low levels of the medium that can lead to formation of “salt fingersB;

– turbulization of the layer of density jump (the model estimates deformation of the density jump layer as a function of the layer parameters and characteristics of the acting flow of a liquid);

– formation of vortex structures (the model calculates vortex size, rise speed, and the rise horizon);

– generation of inner waves (the model estimates the amplitude of inner waves induced by deep discharge of waste water below the thermocline).

The model allows calculation of the sea surface deformations caused by the considered mechanisms of the discharge effect on the sea medium. This is very important for estimating the possibilities of remote detection of waste water discharges. Model calculations use the data on parameters of a discharger and hydrometeorological characteristics in the region.

The adequacy of the developed models has been checked experimentally. The general scheme of the complex model has been developed, and software for calculation of hydrodynamic perturbations as well as software blocks for estimation of surface deformations realized.

9. Conclusion

The scientific potential gained in the process of creation of aerospace systems, as well as technologies developed and system solutions obtained can be successfully applied in various fields of high-tech human activity. This facilitates solution of a wide variety of urgent problems, which is otherwise rather expensive.

This paper illustrates only some examples of diversification of the developed technologies and created aerospace systems. The Institute of Atmospheric Optics SB RAS has contributed significantly in the development of scientific foundation for creation of such systems.

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