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STUDY GROUP 4.9

INTERNATIONAL AEROSPACE SYSTEM FOR MONITORING OF GLOBAL GEOPHYSICAL PHENOMENA AND FORECAST OF NATURAL AND MAN-CAUSED DISASTERS

SUMMARIES OF STUDY GROUP REPORTS

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<u>IAA STUDY GROUP REPORT</u>

INITIATION OF THE PROJECT TO CREATE INTERNATIONAL AEROSPACE SYSTEM FOR MONITORING OF GLOBAL GEOPHYSICAL PHENOMENA AND FORECAST OF NATURAL AND MAN-CAUSED DISASTERS (IGMASS)

SUMMARY

The forecast of birth and evolution of negative natural phenomena on Earth is becoming a pressing issue. The most common and hazardous natural disasters today are global warming, Earth's seismicity increasing, and relating to them earthquakes, floods, tsunamis, volcano eruptions, landslides, storms, droughts forest and steppe fires. Man-caused disasters which reach the rate of natural disasters are serious danger for people as well.

In accordance with report of Secretary General of UN concentration of carbon dioxide now is three times as much that it was at the beginning of industrial era. As a result of this annual temperature on planet has increased more than one degree. In 2008 there were 137 natural and 174 man-caused disasters which resulted in more than 240,000 deaths and US$ 269 billion of economic losses. International Strategy for Disaster Reduction (ISDR) reported in 2008 that for the thirty-year period the International Emergency Disasters Database EMDAT recorded 8,866 events killing 2,283,767 people. Of these, 23 mega-disasters killed 1,786,084 people, mainly in developing countries. In the same period, recorded economic losses were US$ 1,527.6 billion that is comparable with costs for creation of corresponding aerospace system which have to provide short-term prediction of their birth. Alerting of natural and man-caused disasters on the base of forecast, weakening of their consequences and readiness for preventing actions is more economically sound than responding to their consequences.

Prediction of the birth and evolution of the natural and man-caused disasters as base for further decision making is very complex task. At present owing to the fact that there is worldwide space system for hydro meteorological monitoring number of victims resulted from climate disasters decrease, at least in developed countries. But unfortunately human toll and economic losses due to earthquakes, tsunamis and volcanic eruptions steadily increase. Such situation deals first of all with that till present there is no reliable methods and instruments for forecast, especially short-term, of birth and growth of dangerous seismic phenomena. For decades of development of geologic, seismology, geophysics and other Earth sciences it was not created methods for short-term forecast of the urgent seismic events on the base of data obtained from ground stations. But up-to-date researches show that the birth of catastrophic events are preceded by determined physical effects which are locally revealed in the Earth spheres – lithosphere, atmosphere, ionosphere, magnetosphere. Analyzing characteristics of such effects it is possible, less or more accurately, to forecast magnitude, place and time of the future possible event. Combination of ground, air and space facilities which have opportunity for global and local monitoring of the Earth lithosphere, atmosphere, ionosphere, and magnetosphere can provide detection of the short-term signs of natural and man-caused disasters and transmitting necessary data practically to the any point on the Earth.

The following facts give some causes for optimism. For last 5 – 7 years considerable progress was achieved in understanding of processes predetermining of the birth of negative geophysical phenomena, in determination of their signs. Russian scientists revealed relations between ionosphere characteristics and the state of the earth's crust tectonic. The advent of dense geodetic networks in seismically active regions (e.g., SCIGN, the Southern California Integrated Global Positioning System Network), and satellite interferometric synthetic aperture radar (InSAR) from the European Remote Sensing (ERS) satellites, have resulted in great progress in understanding fault ruptures, transient stress fields, and the collective behavior of fault systems, including transfer of stresses to neighboring faults following earthquakes.

Ever more attention is given of late to the creation of international systems for monitoring of natural disasters based on multiple-satellite systems. Projects and initiatives for building of the global space-based systems for monitoring of hazardous geophysical phenomena are in various stages of implementation in USA, Europe and Asia.

IAA Study Group has analyzed systems, projects and programmes which directly deal with monitoring of natural and man-caused disasters from space:

- Global Earth Observation System of Systems (GEOSS),
- Global Monitoring for Environment and Security (GMES),
- Disaster Management Support System in Asia-Pasific Region “Sentinel Asia”,
- Charter on Cooperation to Achieve the Coordinated Use of Space Facilities in the Event of Natural or Technological Disasters, so-called International Charter "Space and Major Disasters" (Charter Disaster),
- Disaster Monitoring Constellation (DMC).

In common, analysis of projects of international space-based multi-satellite systems used for disaster monitoring showed that their special feature is dedication to recovery efforts following natural and man-made disasters and, to a lesser extent, the short-term forecast of such events.

The short-term forecast of natural and man-made disasters and earthquakes needs dedicated operational information from across the globe concerning the changes in the Earth’s lithosphere, atmosphere and ionosphere. Such information must be processed in a special way and transmitted to relevant decision-making organs. This can be achieved by building an optimum in-orbit complex with an adequate instrumentation package in conjunction with airborne systems, sensing equipment and efficient on-land infrastructure. None of the considered projects fully meets these requirements.

DMC is focused on obtaining information only in the visible specter, which precludes forecasting of natural and man-made disasters.

GEOSS does not imply the creation of its own in-orbit assets. Thus the spacecraft, built under the IGMASS will make a significant contribution to that system of systems. In its turn, the on-land infrastructure being created under the GEOSSS can be used by the IGMASS.

GMES, Sentinel Asia, and Charter Disaster programmes are not supposed to comprehensively predict earthquakes because of the limited onboard instrumentation and the specific orbital structure of the systems.

Results of conducted analysis allow concluding that creation of the International aerospace system for monitoring of global phenomena in the interesting of short-term forecast of natural and man-caused disasters is urgent and current importance task.

Purpose of IGMASS creation is global monitoring of Earth's surface, Earth's atmosphere and near-Earth environment from space with the possibility to transfer observation data to ground situation centers which carry out forecast and warning in quasi-real time to prevent natural and man-caused disasters.

Prior structure, prior pattern of proposed system is on attached figures.

Beginning such complex work to create it is necessary to remember two important aspects. First, problem of forecasting and preventing natural and man-caused disasters has obvious international character. Second, during creation of the international aerospace system for monitoring of global phenomena we must resolve a number of scientific and applied tasks dealing with development, test and utilization of special facilities for registration of global phenomena signs. At that, these tasks may be resolved by the mutual efforts of scientists and engineers from different countries.

Therefore, it's necessary and very important:

- To have support from UN during realization of the proposed project and,
- Proposed project has to be initialized and conducted by IAA as organization which accumulates world scientific potential in the field of space sciences and engineering, first of all in the interesting of humanity.

Taking into consideration that problem of forecasting and prevention of natural and man-caused disasters has global character it's proposed to realize project to create IGMASS in the frame of UN programmes, such as SPIDER-UN, and to submit it for examination by concerned UN committees and commissions.

<u>**IAA STUDY GROUP REPORT**</u>

RESULTS OF RESEARCHES OF NATURAL DISASTERS SIGNS AND POSSIBILITIES OF UP-TO-DATE EQUIPMENT FOR THEIR REGISTRATION

S U M M A R Y

Reliable forecasting, first of all short-term, of the natural and man-caused disasters is complex task which unfortunately till now hasn't its positive decision. Such state deals from one side with absence of corresponding methods and instruments to get reliable results of forecast, and from other side, clear understanding which factors are signs of birth and evolution of the negative natural phenomena and man-caused disasters.

Catastrophic events relating to geodynamic processes (in the first place, earthquakes, tsunamis, and volcanic eruptions) are most difficult for forecasting and prevention.

For past years of observation of destructive earthquakes and powerful volcanic eruptions great number of physical effects which forestalled these seismic events were registered and monitored. Some of these effects were observed time and again and were considered as signs of earthquakes and volcanic eruptions. But their relevance and reliability requires statistical verification that it is difficult to carry out because of rare repeatability of these events and using only ground and air facilities for registration of exposed signs.

During study analysis of main earthquake signs which can be used for short-term forecast was carried out. At that, earthquake signs were classified as lythospheric, atmospheric, ionospheric and magnetospheric, and conclusion that reliable forecast is possible in the case of simultaneous measurements of signs in all Earth spheres.

Analysis has shown that short-term forecast on the base of monitoring of Earth crust ruptures with use of contact and remote methods and facilities during last 100 years are not so reliable for taking preventive measures directed at rescue people and property. But such state of affairs means that it's necessary to find new decisions to forecast earthquakes on the base of up-to-date achievements in geology, geophysics, and other natural science.

Powerful disturbance in lithosphere are appeared on its surface, in surface layer and even in ionosphere. For their registration it is necessary to carry out global geophysical monitoring of the Earth surface, atmosphere and ionosphere with use of both ground and aerospace facilities.

Conducted study has shown that for the purpose of reliable forecast it is important to take into consideration the following observed phenomena and effects:

- A several hours before earthquake value of electric field strength begins to increase, and then, directly before earthquake, falls till background level,
- Aerosol dispersion before earthquake increases by 30-50%, and after earthquake deeply falls,
- Aerosol flow before earthquake increases,
- Type of cloudiness above ruptures of the Earth crust is informative sign of earthquakes. On the base of fifty years period of observation it was determined

correlation between cloudiness and earthquakes, and signs appearing a 24 – 30 hours and 42 – 66 hours before earthquake. At that, feature type of cloudiness is well observed from space,

- Variations of ionospheric plasma density as compared with undisturbed value are observed since 5 day till several hours before earthquake,
- New natural phenomena related to influence of seismic activity upon inner bound of radiation belt was discovered. Existence of this correlation allows to develop new method of the earthquake forecast,
- A discovered phenomenon of correlation between seismic activity of the defined regions and coronal holes on the Sun was experimentally confirmed. Sun signs be registered long before first tremor with use of satellite with equipment for Sun-Earth correlation studies,
- Empirical dependence between number of earthquakes and moon high tides with period of 18.6 years was obtained. This result allows to determine period of time which more or less dangerous in relation to earthquake threat.

For detection and registration of these and other signs of natural disasters aerospace system for global monitoring of the Earth state such as IGMASS has to be created. IGMASS has to be comprised of satellites (as rule, small and micro) completed with equipment for remote sensing (optical, microwave, radar, laser with high and middle spatial, spectral and radiometric resolution), geophysical equipment to measure characteristics of the Earth physical fields, equipment to monitor Sun activity.

For instance, to monitor and register such signs of earthquakes as anomalous low frequency (ULF-ELF-VLF) electromagnetic radiation, disturbed quasi constant electrical fields, local variations of temperature plasma, anomalous geomagnetic pulsations on frequencies about 1 Hz, eruption of high energy particles, satellites can be maintained with:

- ULF/VLF wave complex to measure and analyze wave disturbances in the range of frequencies 0,1 ÷ 23 Hz,
- HF wave complex to measure spectrum of electromagnetic radiation in range of frequencies 0,1 ÷ 15 MHz and to measure electronic density,
- Device to measure three component of quasi constant electrical field,
- Spectrometer of energetic particles to measure energetic distribution and variations of intension of electron and ion streams with energy 20 - 2000 keV,
- Optical complex to measure characteristics of atmosphere emissions,
- Plasma complex to measure ion and neutral composition, density, variations of density and speed components of plasma drift.

It is necessary to say that part of mentioned on-board equipment has been already created and can be used in the interesting of IGMASS. These are:

- LF wave receiver - Signal Analyzer and Sampler,
- HF device to measure altitude distribution of electronic concentration from atmosphere base to altitude of satellite orbit,
- Radio frequency analyzer,
- Scientific equipment to register and study radiation,
- Fourier spectrometers with low mass and dimension,
- Hyperspectral Imager,
- Jason – Poseidon type radar altimeter,
- Total Ozon Mapping Spectrometr,
- XUV Photometer System.

Furthermore, IGMASS satellites must be fitted with suites of equipment based on:

- ULF-VLF wave system (30 ÷ 100 Hz) for monitoring the tension of the quasi-stable electric field,
- High frequency wave system for monitoring the electric field oscillation specter in the range of 0,05 ÷ 15,1 MHz or 0,05 ÷ 6,35 MHz,
- Plasma complex for monitoring the transversal and longitudinal speed of ion drift in the range of 0,02 ÷ 5,0 km/s, ion density in the range of 102 - 106 cm^{-3}, ion temperature in the range of 300 ÷ 10 000°K; ion density oscillation in the range of 0,5 ÷- 1,000 Hz and ion component disturbance,
- Video-photometric complex for monitoring the intensity and frequency of lightning discharge occurrence, TV image of areas of atmospheric glow in direction towards the Earth's limb, which image is obtained by a TV camera based on the CCD (charge-coupled device) matrix and brilliance amplifiers; for monitoring the intensity of atmospheric emissions in chosen specters measured by photometers oriented towards the Earth's limb and nadir,
- System for monitoring energy particles for observation of electrons' energy specters in the range of 15 ÷ 350 keV (kiloelectron-volt) and ions in the range of 15 ÷ 3,200 keV registered in two directions, of time variations of particle flows in the chosen energy ranges,
- Constant field magnetometer for monitoring three components of the geo-magnetic field in the range of +/-60 microtesla with an error not exceeding 0,015 microtesla,
- Mass-analyzer for monitoring ions' and neutral particles' distribution by weight in the range of 1 ÷ 1,000 AMU (atomic mass unit) with time resolution of up to 30 millisecond;
- Spectrometer for monitoring the intensity of hydroxyl emissions in the specter in the range of I = 727 ÷ 1,103 nm (nanometer) and in altitude from 85 to 110 km.

Hereby, now in the world there are many devices and equipment which can be used to monitor and register signs of earthquake for the purpose of their further prediction. That is now we have technical base to begin deployment of the space-based segment in the interesting of forecasting of global geophysical and man-caused disasters.

IAA STUDY GROUP REPORT

RESULTS OF PILOT PROJECT TO DIAGNOSE IN EARTHQUAKE SIGNS ON THE BASE OF DATA OBTAINED FROM NAVIGATION SATELLITES

S U M M A R Y

Recent studies evidently demonstrated that specific variations in the atmospheric and ionospheric parameters are observed before strong earthquakes (magnitude $M > 5$) in the region of earthquake preparation.

The appearance and main morphological characteristics of these variations as well as the interrelation between atmospheric and ionospheric anomalies are based on the recently developed Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) model. Activation of tectonic structures in the preparation region results in an increased gas (including radon) emission onto the surface.

Alfa particles with an energy of about 5.8 MeV, emitted by radon, ionize air molecules. These newly produced ions become condensation centers of water vapor, which is always present in the atmosphere. Condensation (or rather attachment of water molecules to ions: ion hydration) makes these ions stable since a high dipole moment of water molecules prevents ions from recombination.

Ionization and hydration result in a number of effects that can be identified as atmospheric and ionospheric signs of earthquakes. Condensation leads to a decrease in the number of water vapor free molecules in the air, which can be registered as a decrease in humidity at a sufficient intensity of the process.

When water molecules are attached to ions, their phase state changes from free to bound, which is accompanied by a release of the latent evaporation into the ambient space. Anomalous fluxes of the latent evaporation heat were registered for a number of the last strong earthquakes.

Energy released into the atmosphere leads to an increase in air temperature. In spite of the fact that the radon concentration in the air is very insignificant, the energy effectiveness of the ionization process is so high that these variations result in variations in the atmospheric parameters registered using both ground-based meteorological equipment and satellite remote sounding methods. The extension of an earthquake preparation region is the second factor of no small importance. For strong earthquakes ($M \approx 7$), the preparation region area is about several hundreds of thousand kilometers squared. This is confirmed by not only the priory estimates but also by the direct measurements using the satellite remote sounding methods. A change in the near Earth conductivity in such wade areas leads to an upset of the balance in the global electric circuit. Since the vertical resistance of the boundary atmospheric layer (the first 5 km) accounts for 70–90% of the resistance of the entire column to ionospheric heights of about 60 km, resistance variations lead to changes in the vertical gradient of the atmospheric electric field and in the ionospheric potential above the region of impending earthquake.

Heat releases in the near-Earth atmosphere, and an increased electric potential gradient result in a removal of hydrated ion clusters into the upper layers, where these clusters become condensation centers for formation of clouds above active tectonic ruptures.

A change in the ionospheric potential results in the generation of horizontal compensating electric fields, which cause drift of ions and formation of ionospheric inhomogeneities. In addition to the formation of large-scale electron density inhomogeneities, the horizontal electric field induced in the ionosphere, will result in the generation of the current in the dynamo region, heating, and generation of acoustic gravity waves.

The main aim of the complex experiment was to experimentally confirm the scientific principles of a complex diagnosis of earthquake signs in the seismic region (Sakhalin and adjacent zones) based on the data of remote sounding the Earth from the space; the methods and algorithms of selection, processing, and distribution of monitoring information including data from existing Russian and foreign navigation, meteorological, and resource satellites; and the heliogeophysical data.

In the scope of the experimental works, it was assumed not only to select new data on signs of strong earthquakes, which manifest themselves in variations in the LAIC system parameters, but also to profoundly analyze the experimental data on strong earthquakes obtained previously.

For August–September 2007, the temperature and humidity variations, the satellite data on anomalous cloud structures (obtained on the TERRA and AQUA satellites), and the outgoing flux of the long-wave IR radiation (OLR) in the range 10–12 μm according to the NOAA satellite data were analyzed. The vertical reconstruction of electron density using the meridional chain of tomographic stations on Sakhalin was performed, and the total electron content (GPS TEC) for four Far East stations was calculated.

In 2007 the sign phenomena were diagnosed in the scope of the unique complex experiment, using the data obtained based on the methods and equipment for remote sounding the Earth from space.

The scientific program of the complex experiment, performed in the scope of the pilot project on the trial operation of equipment samples, using the data of the Russian and foreign navigation systems intended for automatic diagnosis of strong earthquake signs was mainly fulfilled.

The data on the state of the atmosphere and ionosphere were selected and analyzed, and the anomalies of the following parameters of the lithosphere–atmosphere–ionosphere system confirming the interaction model were revealed.

The character of the simultaneous temperature and air humidity variations in the near-Earth atmosphere in Nevelsk and Khabarovsk corresponds to the conclusions on the radon emanation zones and humidity and temperature variations in 1985 in Michoacan, Mexico is analyzed.

The distribution of integral OLR in the studied region during July 2007 indicates that a significant anomaly was registered over the tectonic fault zone. The character of the revealed OLR features indicates that it is necessary to continue processing (calculating the OLR dynamics before the earthquake) more thoroughly analyzing the results.

The ionospheric variability index variations, confirmed by the vertical electron density distribution in the ionosphere according to the data of the low-orbiting navigation satellites, correspond to the revealed index anomalies before the earthquake that occurred on Sumatra in 2004 and are significant even against a background of strong magnetic storms previously observed in the Far East region of Russia.

We should note that the time coherence is observed in the manifestation of all registered anomalies, which were observed during a week (from August 24 to August 31) before the seismic shock of August 2. Based on gathered information and on an analysis presented in this work, we can conclude that the morphology of the detected variations in the atmospheric and ionospheric parameters before the earthquake that occurred on Sakhalin on August 2, 2007, completely corresponds to the indications detected previously for other strong earthquakes.

This indicates that the physics of the process is common. At the same time, we should note that the amplitude of the registered variations in the atmospheric and ionospheric parameters is rather small. This can most probably be explained by the regional geology, which is responsible for a low radon concentration in the Earth’s crust.