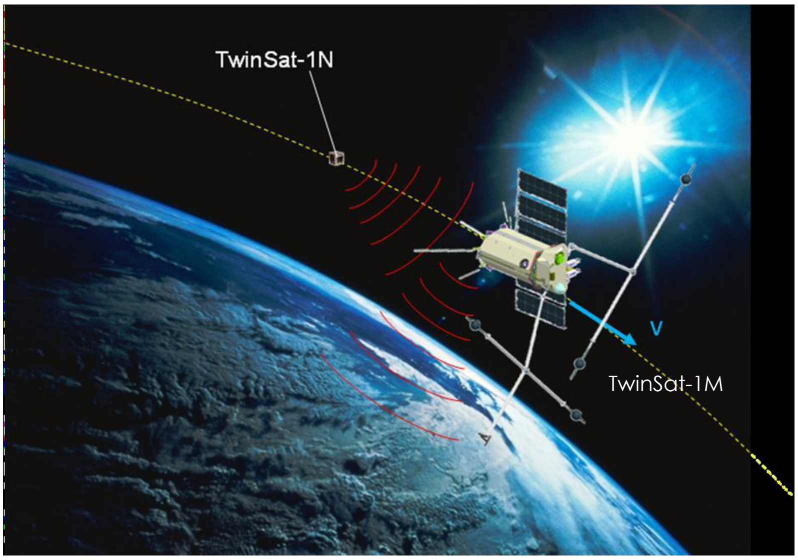

TWINSAT project profile

Application of micro and nano satellites for detection and monitoring of earthquake precursors
(Russia-UK space project)

Moscow, 2013

Content

1. NAME, BRIEF DESCRIPTION AND GOALS OF THE PROJECT

1.1. Full name of the Project: Application of micro and nano satellites for detection and monitoring of earthquake precursors (TWINSAT – a Russia-UK space project).

1.2. Brief summary of the project: TWINSAT is R&D project destined for the development and practical implementation of integrated aerospace and ground technologies for early detection and monitoring of large magnitude earthquake precursors and demonstration of the possibilities of their practical use to improve an accuracy and reliability of short-term forecasting of impending earthquakes. The research program includes the development, launching on orbit and 2 year operation of two experimental spacecraft, the micro satellite TwinSat-1M and the nano satellite TwinSat-1N, coordinated with accompanying ground-based observations on geophysical polygons in selected seismically active zones. The satellites and ground stations will observe a range of signals that have been shown to be related to earthquake precursors and search for new precursory signals. The innovation scheme, which foresees usage of two satellites with controlled separation and information exchange will allow obtaining the data on the spatial structure and the dynamic characteristics of studied phenomena and therefore significantly improved recognition and discrimination of earthquake precursor signals from other naturally occurring phenomena in the ionosphere. This R&D project concludes with the conceptual design and feasibility determination of a follow-on satellite constellation and issue of CDR for the System of Early Detection and Monitoring of Earthquake Precursors composed from space, aerial and ground segments.

1.3. End product

1.3.1. The end product that should be developed as a result of implementing all project stages:

- Specialized space platforms of micro-and nano-satellite classes with the useful payload, passed the tests in orbit, as a prototype of the elements of future space constellation for the monitoring of disasters and other applications.
- Experimentally proven technologies of early detection and monitoring of earthquakes precursors with the use of space, aerial and ground-based measuring platforms.
- Methodology of short-term prediction of strong earthquakes.
- The concept, structure and the method of constructing the System for Early Detection and Monitoring of Earthquake Precursors as the main element of future global system for prevention of emergency situations related to large magnitude earthquakes.

1.3.2. The outcomes of research activity at the given stage:

- Development, manufacture and ground testing of experimental (technological) samples of micro and nano satellites.

1.4. Project Stage:

- Stage 1. Development, manufacture and ground testing of experimental (technological) samples of micro and nano satellites.

2. THE PROBLEM AND PROPOSED SOLUTION

2.1. The problem addressed by the project:

2.1.1. Problem description and its relevance for the global market:

Annually mankind suffers huge financial losses associated with earthquakes and other natural disasters, huge loss of life, loss of livelihood and social disruption. The sad statistics shows that economic impact can be enormous – it is estimated that the Kobe earthquake alone caused ~$100 billion in damage. The Chinese government has spent about $150 billion to rebuild areas ravaged by the Sichuan earthquake. An estimated three million people were affected by the 2010 Haiti earthquake, 316 000 people had died and 1 000 000 made homeless. The March 2011 earthquakes and tsunami in Japan killed more than 20 000 people, destroyed many costal cities and caused damage to atomic power plant and leaks of radioactive substances into the atmosphere and sea water. According to The New York Times (March 15, 2011) Japanese insurance companies, global insurers and reinsures, hedge funds and other investors in catastrophe bonds all expected to bear a portion of the losses that seem likely to exceed $100 billion. One of the largest reinsurance companies Munich Re has estimated the losses of world economy caused by the March 11 catastrophic event in Japan at $265 billion. All this is an evidence of topicality of the project and a strong motivation to the development of efficient aerospace and ground technologies for detection and monitoring of earthquake precursors as the most important element of disasters forecasting system. With an effective early warning system much of this loss could be avoided. The cost of such a system would be extremely small compared to its benefits.

Until now major part of experimental results on the ionospheric precursors to earthquakes has been acquired in uncoordinated satellite missions designated for the investigation of different phenomena in space plasma while the earthquake effects on the ionosphere have been obtained as attendant scientific findings. An only purposeful experimental study of earthquake related phenomena in space was recently carried out within the DEMETER satellite project by the cooperation of French institutions with participation of numerous collaborators including the Institute of Physics of the Earth and Institute of Geophysical Survey of Russian Academy of Sciences. Such a study is necessary given the complex interaction of the phenomena observed and their often indirect character. Though it was successful mission the nature of lithosphere-ionosphere coupling, and the mechanisms for the transformation of seismic processes into electromagnetic and plasma disturbances in space and the modification of chemical composition and electrodynamic parameters of the atmosphere are not completely understood. The value as predictors of many phenomena and processes considered to be related to earthquake precursors needs to be confirmed and assessed. Due to the small magnitudes of seismic related disturbances there is a problem of detection sensitivity above a background of strong interfering signals related to other natural or man-made phenomena. Therefore, the way to the main goal of the project - the creation of an early warning system, should begin with the development and launch on orbit of specialized spacecraft and the carrying out together with the coordinated ground-based observations of the target experiments for the validation of the technology of early detection of earthquake precursors and demonstration of a possibility of its use for short-term prediction of strong earthquakes. This project is directed to solution of this task.

2.1.2. References to studies and materials from reliable sources, which confirm the relevance of the problem:

- Relevance of the TWINSAT project has been confirmed by Royal Aeronautical Society at Yuri Gagarin's Legacy Space Conference (London, 16th March 2011). The Katerva World Innovation Challenge (www.katerva.org) announced that TwinSat project has been nominated for a 2011 Katerva Award and included in the top 5 finalists in the Human Development category. "These 5 finalists represent the most promising new ideas and initiatives on the planet" (see: http://katerva.org/nominees/katerva-awards-finalists-for-2011-announced/ and http://www.forbes.com/sites/jacquelynsmith/2011/09/19/the-worlds-best-sustainability-ideas).

2.1.3. Major global trends in the industrial sector and references to appropriate studies and materials from reliable sources:

While the Earth observation technologies progress rapidly and are widely implemented for collecting numerous practically used data on the state of Earth surface, the atmosphere and ocean, an application of satellites for earthquake prediction still remains at the research stage. There was alone successful purposeful space mission DEMETER designated for studying the ionospheric response on earthquake preparation processes. Several separate satellite programs are planned for next decade in different countries for investigation of seismic related disturbances in the ionosphere. Only one of them (CSES) in a case of successful completing was declared to be continued in a frame of R&D work to develop the methods and tools for detection of earthquake precursors from space. We can assume that the further development of DMC space constellation, built by SSTL, will be carried out with consideration of the demand for monitoring of earthquakes.

It is expected that future impending earthquake detection technologies will include high resolution InSAR (Interferometric Synthetic Aperture Radar) and IR (8-12 microns) observations as an important part of multi-parametric satellite system for monitoring of earthquake and volcano activity. Further advance in remote sensing technique will make it possible to monitor the altitude distributions of some atmospheric gas components and aer-osols, which are sensible to seismic impact on the atmosphere.

2.2. The proposed solution:

2.2.1 Product description, the description of the proposed solution:

- Development of specialized space platforms of micro-and nano-satellite classes with target payload, launch and tests on orbit, the proof of the efficiency of their use as a prototype of the elements of future space constellation for disasters monitoring and other applications.
- Development and validation of the technology for early detection and monitoring of earthquake precursors with the use of space, aerial and ground-based measuring platforms. Formation of experimental data base, development on its basis of the theory of generation of precursors and the creation of a comprehensive model of the lithosphere-atmosphere-ionosphere coupling, believe in the foundation for the theory of short-term forecasting of earthquakes.
- The short-term and medium-term precursor signal information service delivered to international, nation-al/regional organizations and authorities responsible for earthquake forecasting and announcement of warning (alarm) signals, as well as to other customers;
- Development of the method for short-term prediction of strong earthquakes.
- Development of the concept, structure and method of constructing the System for Early Detection and Monitoring of Earthquake Precursors as the main element of future global system for prevention of emer-gency situations related to large magnitude earthquakes.

2.2.2. How does the Project implementation solve the problem:

- Implementation of the project and obtaining the main products described above (item 2.2.1), will allow to proceed to the creation of practical system for early detection and monitoring of earthquake precursors composed of the space, aerial and ground-based segments and the deployment of the global system for the prevention of emergency situations due to large-scale natural disasters.

2.2.3. How is the problem addressed now:

- At the present time mainly used are seismic data and information on the Earth deformations obtained with the help of GPS/GLONASS signals. In the experimental order attempts are being made to the issuance of short-term forecasts of earthquakes by processing the data of thermal (infrared) imagery from the remote sensing satellites and the ionosphere disturbances found from GPS/GLONASS signals analysis.

2.2.4. Brief outline of the approach innovativeness:

- Use of two satellites with controlled separation and information exchange will allow obtaining the data on the spatial structure and the dynamic characteristics of studied phenomena and therefore significantly im-proved recognition and discrimination of earthquake precursor signals from other naturally occurring phe-nomena in the ionosphere.
- Multi-parametric analysis of wide variety of precursor signals detected synchronously through diverse methods in three media (in space plasma, in the atmosphere and on the Earth surface) substantially in-creases accuracy and reliability of earthquake prediction compared to the modern methods using only a few of the observational parameters for the elaboration of a forecast.

2.2.5. Application areas for the proposed solution:

- Prediction of earthquakes.

2.2.6. Justification for the relevance of the Project for the global market:

- Relevance of the project for global market is defined by enormous (exceeding 150 billion US dollars for 1 earthquake) economy losses of the countries in the risk zones and loss of life, which can exceed hundred thousand people at strong earthquakes. The project implementation will lead to decrease of risks and minimization of human and economic losses caused by earthquakes and volcanic eruptions.

3. MARKET

3.1. Application area and key customers:

3.1.1. Main customers for the product (technology):

- The target market is international, national and regional organizations and authorities with the responsibility for earthquake prediction and distribution of early warning signals. Additional targets include insurance companies, owners of oil and gas pipelines, electric power producers (including atomic power stations), railway companies, defense agencies, and air traffic control authorities and others interested in solving the problem of prevention of emergency situations connected with large-scale natural disasters.

3.1.2. Key factors in their decision making:

- Successful implementation of this project, a demonstration of the effectiveness of the pilot micro-and nano-satellites (prototypes) created in the framework of this project and the technologies of early detection and monitoring of earthquake precursors in order to improve the accuracy and reliability of short-term forecasting of earthquakes.

3.2. Target markets and their indicators:

3.2.1. Evaluation of potential market volume:

Though the demand for early warning service related to strong earthquakes is very high the supply is insignificant due to lack of the data (first of all of the space data) required for working out forecast. The successful implementation of the TwinSat project will enable to form new market of information services and occupy leading position in this market.

Intermediate products, which will be offered to the market as a result of realization of this project are as follows:

- services on the development and manufacture of specialized micro and nano satellites with useful payloads for the monitoring of the effects of natural disasters and technological impacts on the ionosphere, as well as other applications (commercial contracts, sale of licenses);
- technologies of early detection and monitoring of earthquake precursors (sale of licenses);
- methods for short-term prediction of strong earthquakes on the basis of integrated aerospace and ground technologies (sale of licenses);
- method for building a 3-tier (space, aerial and ground) system for early detection and monitoring of earthquake precursors (sale of licenses).

Description and assessment of the potential size of the prospective market, which will be formed after the deployment and the start of operation of a full-size working System for early detection and monitoring of earthquake precursors (approximately 2018-2020), are made in the Annex to this document (see additional materials). It is estimated that the expected volume of sales by the end of the 1st year of operation of the System is approximately US$250 million. The level of sales, exceeding 400 million dollars a year, is planned to the end of the 2nd year of operation of the System. Deducting from this amount, approximately $50 million in annual operation and further development of the System, we obtain an estimate of the expected revenue: US$350 million a year. Thus, we can predict the return of the invested money of investors at the beginning of the second year of operation of the System and to ensure further yield at the level of $350M per year.

3.2.2. Market trends description:

We can expect gradual growth of the market due to the increase of confidence in the data of TWINSAT System and demonstration of the high quality of the forecasts. An important growth factor is the statistics demonstrating the trend to increase of a number of large scale natural disasters. For the last 10 years the catastrophic earthquakes killed by 42% more people than in the previous 50 years.

3.2.3. Description of the market positions for companies that implement competing technologies:

As noted there are no active competitors on the market of described above information service because there are no required data, at that the market can be formed only after launching the TWINSAT system for early detection and monitoring of earthquake precursors or its analogue. Therefore it is reasonable to indicate the potential competitors who perform R&D works approximately in the same direction as the TwinSat team. The most probable competitive project of such kind is CSES (China Seismo-Electromagnetic Satellite) – the project developed by the Institute of Earthquake Science and the Institute of Crustal Dynamics, China Earthquake Administration, together with DFH Satellite Co., Ltd, China Academy of Space Technology (see ref.: Wang Lanwei, Shen Xuhu, Yuan Shigeng, Zhang Yu, Yan Rui. Introduction of the First China Seismo-Electromagnetic Satellite Project, paper presented at the 2nd INTERNATIONAL DEMETER WORSHOP, October 10-12, 2011, Paris, France). Tentative date of this satellite launch is 2015. In a case of successful realization of the satellite research program, further advancement of the CSES project is declared to be targeted at the development of satellite constellation for earthquake monitoring.

3.2.4. Target segments:

First of all it is planned to develop domestic market of services on the fabrication of specialized spacecraft and payload for a number of enterprises of the Federal Space Agency and some other departments, and also in the interests of foreign customers. With regard to the prospective market:

- The list of the basic segments of the market is presented in Annex (additional materials).
- The target market is international, national and regional organizations and authorities with the responsibility for earthquake prediction and distribution of early warning signals
- Among the first users are the governmental structures in the Russian Federation and other countries in areas of high seismic risk, as well as the insurance business.

3.2.5. Barriers and success factors in entering the target market:

- Barriers may be associated with mistrust to the supplier at the initial stage of entering the market.
- The first to create a practical system for early detection and monitoring of earthquake precursors and confirm its effectiveness will retain a market lead for a considerable time. The system creation is impossible without intense R&D works, the first stage of which is launch of targeted satellites and carrying out a series of coordinated space and ground experiments to reveal the mechanisms of the formation and interconnection of different types of the precursor signals. On the basis of obtained experimental results and the development of comprehensive theoretical model of the phenomena we can define the principles of building the natural hazard early warning system. It is exactly the task formulated for the TwinSat-1 program, which is the first stage of the project. This is why the most important factor of success is the soonest beginning and successful implementation of this program.

3.2.6. Target geographical markets for the Project and the schedule for entering these markets:

- The geography of a target market corresponds to the distribution of devastating earthquakes over the globe, which covers huge areas in all continents. Such countries as Japan, China, Indonesia, India, Pakistan, Myanmar, Iran, Turkey, Russia, Bulgaria, Romania, the Balkan countries, USA, Mexico and several nations of Central and South America are in the risk zones. The governments of these countries are ex-

pected to be potential users of the warning data and subscribers of the information products provided by the TwinSat system.
- The first it is planned to develop the market in Russia, where zones of high seismic hazard (M>6) occupies about 40% of the total area and about 9% are related to the zones with M~8-9.

4. BENCHMARKING AGAINST COUNTERPARTS

4.1. Competing solutions on the market and at development stage:

4.1.1. The closest counterparts, existing on the market:

Until now there was only one dedicated space mission on the search for electromagnetic and plasma disturbances initiated in outer space by earthquake preparation processes. It was French DEMETER mission terminated in December 2010 after successful completing its research program. No any plans for further development of this program were announced. Preparation of several other earthquake related research projects was declared in different countries including UNAMSAT-3 (Mexico), Quakesat (Stanford University nanosatellite program, USA), Esperia (Italy), OMIR (Kazakhstan) and CSES (China). We argue that these projects do not comprise payloads that are sufficient for a thorough study of the precursor signals. In Russian Federation at present there are no special-purpose space projects destined for investigation of earthquake precursors from space. As accompanying scientific results, some data on the disturbances related to earthquakes can be obtained from the satellites of IONOZOND space complex to be launched on orbits in 2012 and 2013. Besides there are two experiments, “Seismoprognoz-SM” and “Hydroxyl”, destined for the observation of possible earthquake effects in VHF radio band and in emissions of hydroxyl (727-1103 nm) and atomic oxygen (557,7 nm) from the Russian Segment of International Space Station to be realized in near future. These observations in a case of successful implementation of the experiments will make a contribution to studying the earthquake precursors. However it is necessary to note that this mission presents very limited set of experiments, which leaves without attention major part of electromagnetic and plasma disturbances generated in near Earth space on the eve of earthquake.

CSES (Chinese Seismo-Electromagnetic Satellite) is our greatest competitor in that it is a special - purpose space mission to be realized in near future. Though the date of launch still is not defined it is assumed that the satellite will be delivered on orbit at 2015. After successful completing this mission China intends to start R&D works on the creation of a satellite constellation as a part of practical earthquake forecasting system in China.

Thus the TwinSat project has a real opportunity to ensure the leadership in the formation and development of new practically not existing now service market providing short-term earthquake forecasting data from space-based, airborne and ground facilities. The first to create a practical system for early detection and monitoring of earthquake precursors will retain a market lead for a considerable time.

4.1.2. Characteristics of the market for the existing counterparts and references to the sources of market research:

The market is currently practically not formed. From analogues deserves mention only the Chinese project CSES (see 4.1.1)

4.1.3. Scientific groups, institutes, organizations that carry out similar or close developments, with brief description of solutions being developed:

The most probable competitive project is CSES (China Seismo-Electromagnetic Satellite) – the project developed by the Institute of Earthquake Science and the Institute of Crustal Dynamics, China Earthquake Administration, together with DFH Satellite Co., Ltd, China Academy of Space Technology (see ref.: Wang Lanwei, Shen Xuhu, Yuan Shigeng, Zhang Yu, Yan Rui. Introduction of the First China Seismo-Electromagnetic Satellite Project, paper presented at the 2nd INTERNATIONAL DEMETER WORSHOP, October 10-12, 2011, Paris, France).

4.1.4. References to close (competing) Russian and foreign patents of other authors:

There are few foreign patents related to application of space technologies for earthquake forecasting. Most interesting are US Patent 6288396 of November 9, 2001 (“Satellite thermal infrared technique for short-term and impending prediction of strong earthquakes") and Patent 6873265 of March 29, 2005 ("Satellite and ground system for detection and forecasting of earthquakes"). The last is based on the results of satellite observations of ELF electromagnetic radiation over the earthquake center before earthquakes published by our team members (Serebryakova et al., Geophys. Res. Lett. 19, 91-94, 1992; Chmyrev et al., J. Atmos. Solar-Terr. Phys. 59, 967-973, 1997). American patent 7777797 of 20 October 2007 ("Method and system for prediction") uses the ionosphere radio tomography method for detection of the disturbances related to earthquakes. Applicability of these patents is questionable because each of them uses only one parameter for prediction. Russian patents on the short-term earthquake prediction are based on the analysis of seismic and acoustic signals (see, for example patents 2130195 and 2181205), seismo-synoptic disturbances (patent 2206110) and the variations of the parameters of radio waves in the Erth-ionosphere wave guide (patent 2037162). Russian patent 2092877 ("Method for prediction of catastrophes, caused by accumulation of energy in the Earth's spheres") suggests to use the measurements of low frequency electromagnetic waves and high energy particle fluxes on high altitude satellites for discrimination of precursors. This method is not productive because it does not allow localizing the source of the disturbances. Detailed description of existing patents in this field is presented in the Report on Project Stage "0" Grant, an Agreement #7, Space cluster.

4.2. Benchmarking:

4.2.1. Key advantages of the project Participant's solution over its counterparts, existing on the market and in development stage:

Comparison between the CSES and TwinSat-1 projects reveals the following advantages of the TwinSat:

- Using a twin satellite configuration in orbit allows to define a spatial structure and the dynamic characteristics of seismic related phenomena in the ionosphere and therefore significantly improve recognition and discrimination of earthquake precursor signals from other naturally occurring ionospheric phenomena and enhance a reliability of onboard measurements;
- The project structure and the composition of TwinSat experiments are defined basing on comprehensive theoretical model for the generation and interaction of earthquake precursors confirmed by the results of previous observations;
- There is a wider set of wave and plasma parameters to be measured on board TwinSat;
- A weight of the TwinSat satellites is substantially less and therefore the cost of launch is much lower;
- TwinSat is a more comprehensive project in that it includes the deployment of a network of stations for accompanying ground-based observations of precursory signals in the zones of high seismic and volcanic activity. This significantly enhances the value of satellite measurement and the efficiency of the project as whole. The envisaged incorporation of the aerial platforms at the stage of full deployment of the early warning system creates additional advantages for the TwinSat project approach.

Thus the advantages of the TWINSAT program are determined by economic expediency, multidisciplinary approach to the exploration and use of earthquake precursors and creation of the integrated (ground, aerial and space) system for early detection and monitoring of earthquake precursors.

5. TECHNOLOGY

5.1. Description of the Technology

The Project is founded on three basic principles:

- Reliable short-term earthquake prediction can be achieved through a combination of integrated observations and analysis of the wide variety of precursors signals, detected through diverse methods in different media: on the ground; in the atmosphere and in space;
- Use of a twin satellite (master/slave) structure of space segment with controlled separation between the satellites in a pair enables synchronous measurements of the precursor signals in separated points along

the orbit to determine their spatial distribution and the dynamic characteristics that, in combination with ground and aerial measurements, will allow significantly improved recognition and discrimination of earth-quake precursor signals from a background of other sources.

- Miniaturization of the payloads and the platforms, maximal use of standard elements together with the development and test of a scheme of joint operation and in-orbit information exchange between two very small platforms will enable future cost efficient satellite constellation for monitoring of large-scale natural disasters.

5.2. Novelty justification:

5.2.1. The essence of scientific-and-technical novelty of your solution and key distinctions from its counterparts:

Synchronous measurements in the three environments and the use of 2-satellite (master/slave) structure of space segment allow to determine the cause-and-effect relation between the observed phenomena and to ensure the identification and recognition of signals connected with earthquake preparation processes from the background signals of non-seismic origin. Such a scheme of measurements will create significant advantages over analogues and will allow to provide higher accuracy and reliability of the forecast of earthquakes in comparison with currently used methods based on measurements of a limited number of parameters.

5.2.2. References to scientific publications of team members, which are relevant to the Project topic:

- Vitaly Chmyrev, Alan Smith, Dhiren Kataria, Boris Nesterov, Christopher Owen, Peter Sammonds, Valery Sorokin, Filippos Vallianatos (2013). Detection and Monitoring of Earthquake Precursors: TwinSat, a Russia-UK Satellite Project // Advances in Space Research (in press).
- Sorokin V.M., Ruzhin Yu.Ya., Yaschenko A.K., Hayakawa M. (2011). Generation of VHF radio emissions by electric discharges in the lower atmosphere over a seismic region // J. Atmos. Solar – Terr. Phys. doi:10.1016/j.jastp.2011.01.016.
- Sorokin V.M., Chmyrev V.M. (2010). Atmosphere – ionosphere electrodynamic coupling. In: "The Atmosphere and Ionosphere: Dynamics, Processes and Monitoring". (Eds.: V.L. Bychkov, G.V. Golubkov, A.I. Nikitin). Springer. Dordrecht, Heidelberg, London, New York pp.97-146. ISBN: 978-90-481-3211-9.
- Sorokin V. M., Pokhotelov O. A. (2010), Generation of ULF geomagnetic pulsations during early stage of earthquake preparation //J.Atmos. Solar-Terr. Phys. 72, pp. 763-766.
- Tronin A. (2010). Satellite remote sensing in seismology. A review // Remote Sens. 2, 124-150.
- V. M. Sorokin, I. Yu. Sergeev, O. A. Pokhotelov (2009). Low latitude gyrotropic waves in a finite thickness ionospheric conducting layer // J. Atmos. Solar-Terr. Phys. 71, 175-179.
- Schekotov A.Yu., Molchanov O.A., Hayakawa M., Fedorov E. N., Chebrov V. N., Sinitsin V. I., Gordeev E. E., Belayev G. G., Yagova N. V. (2007). ULF/ELF magnetic feld variations from atmosphere induced by seismicity // Radio Sci. 42, RS6S90, doi:10.1029/2005RS003441.
- Tronin, A.A.; Hayakawa, M.; Molchanov, O.A. (2002). Thermal IR satellite data application for earth-quake research in Japan and China // Journal of Geodynamics 33, 519-534.
- Sorokin V.M., Chmyrev V.M., Yaschenko A.K. (2001). Electrodynamic model of the lower atmosphere and the ionosphere coupling // J. Atmos. Solar-Terr. Phys. 63, 1681-1691.
- Chmyrev, V.M., Isaev, N.V., Serebryakova, O.N., Sorokin, V.M., Sobolev, Ya.P. (1997). Small - scale plasma inhomogeneities and correlated ELF emissions in the ionosphere over an earthquake region // Journal of Atmos. Solar-Terr. Phys. 59, 967-973.

Total more than 100 papers published in refereed international scientific journals.

5.2.3. Relevant patents and (or) patent applications:

- Patents: 2263062 – «Container», priority December 26, 2003, authors: Zubarev A.E., Ziuzin O.M., Ivanov N.N., Nesterov B.F., SechenovYu.N.; 2291827 – «Container», priority September 7, 2004, authors: Nesterov B.N., Podzorov V.N., Sechenov Yu.N.; 2293688 – "Mini satellite for group and piggy-back launches", priority June 14, 2005, authors Nesterov B.F., Blinov V.N., Ivanov N.N.; 2302364 – «Container», priority September 20, 2005, authors: Vokhmin A.G., Nesterov B.F., Podzorov V.N., Sechenov Yu.N., Polevko I.B.; 2273597 – «Container», priority October 4, 2006, authors: Sechenov Yu.N., Nesterov B.F.; 2362714 – "Mechanism for fastening spacecraft", priority October 9, 2006, autorth: Podzorov V.N., Kiriliuk A.I., Abushenko S.N., Evteev A.N., Evropeitsev A.A., Nesterov B.F., Ivanov N.N.; 2376212 – «Space platform», priority May 19, 2008, authors: Ivanov N.N., Markelov V.V., Murakhovsky G.M., Nesterov B.F., Sechenov Yu.N.

- Author certificate 843576: "Method for investigation of the ionosphere and/or magnetosphere", Priority: year 1981, authors: Alperovich L.S., Gokhberg M.B., Kevlishvili P.V., Pokhotelov O.A., Sorokin V.M., Fedorovich G.V., Khristoforov B.D.
- Russian patent 2126137: "Method for determination of angular position of spacecraft with use of measurements of thermo-sensitive plate temperature", priority: 26 February 1998, authors: Kostenko V.I., Semena N.P., Logvinenko S.P.
- Russian patent 2122761: "Photoelectric module", priority: 7 May 1998, authors: Aleshin V.N., Kopylov O.G., Kozlov A.I., Prokhorov G.V., Kostenko V.I. and Chmyrev V.M.

5.3. Technical description (Stage 1)

TwinSat-1 program is configured basing on the achievements in experimental study of earthquake precursors and the most recent results of underlying modeling activity. A major part of the program would involve the correlation of space and ground-based observations so as to optimize the ability to distinguish earthquake precursor signals from signals of an anthropogenic, magnetospheric or other non-seismic origin.

For the proposed Sun synchronous orbit, the passage over a particular region will occur approximately 5 times in a two day period. The expected number of earthquakes with magnitude 6 to 6.9 in the Richter scale in 3 years for which data will be taken is ~400.

The space segment consists of two master/slave platforms - the micro satellite TwinSat-1M and the nano satellite TwinSat-1N, operated at a controllable separation. An inter-satellite radio link provides transmission of scientific information from TwinSat-1N to TwinSat-1M, where it is stored in high capacity onboard memory for the subsequent delivery of the whole data set from the two satellites to an appropriate ground telemetry station.

After launch and orbital insertion, the TwinSat-1N would be separated from TwinSat-1M with a relative velocity of ~ 3 cm/s. Differences in the ballistic coefficients of the two satellites will cause the TwinSat-1N to lose altitude more quickly (and therefore speed up) and so some orbital control will be needed to maintain a useful separation between the two spacecraft. It is foreseen that this control will be on the TwinSat-1M spacecraft in the form of, for instance, a thruster. Results of ballistic calculations made for the separation velocity of nano satellite ~3cm/s in the direction of the orbital movement have shown that the distance between two spacecraft in a state of free flight remained within 400km during approximately 8 months (240 days). Use of thruster on board the TwinSat-1M will provide staying of micro and nano satellites within mutual visibility zone at the separation ≤400km, which is acceptable for communications between two spacecraft during all time of operation on orbit.

<u>TwinSat-1M characteristics:</u>

Characteristic	Value
Satellite dimensions (without booms)	Ø46 x 53 cm
Mass (including payload)	~50 kg

Power	
- Average	90 W
- Maximum	140 W
TwinSat-1N separation velocity	
- Linear	3 cm/s
- Angular	< 6 deg./s (TBD)
Attitude Control	3-axis, 8 arc min stability
Orbit	Sun-synchronous, altitude 700-800 km, ~100min period
Telemetry to ground	
- Fast channel (1.7-2.7 GHz) (TBD)	>50 Mbit/s
- Slow channel (145/435 MHz)	20 Kbit/s
Onboard memory	> 50 Gbyte
Inter-satellite link frequency	2-3 GHz (TBD)
Active lifetime	>3 years

<u>TwinSat-1N characteristics:</u>

Characteristic	**Value**
Dimension	10 x 10 x 22.7 cm
Mass	2.5 kg
Power	
- Average	2.2W
- Peak	4.0W
Attitude control	3 axis stabilized, $\sim 1^0$ accuracy
Telemetry to TwinSat-1M	>64 Kbit/s
Telemetry to Ground (145/435 MHz)	4.8 Kbit/s
Active lifetime	>3years

Basic parameters to be measured by the TwinSat-1M spacecraft

- Vector of DC electric field;
- Spectral and wave characteristics of 6 electromagnetic field components in ULF/ELF range (0.5 – 500 Hz);
- Spectrum and sample waveforms of electric field oscillations in VLF/LF (0.5-300 kHz) range; amplitude and phase variations of ground based VLF/LF transmitter signals;

- Spectrum and sample waveforms of electromagnetic waves in VHF range (22 – 48 MHz);
- Variations of thermal and supra thermal (0.3 - 20 eV) plasma parameters;
- Energy distributions of electron and ion fluxes with energies 0.3 – 300 eV for two directions;
- Lightning activity in the sub-satellite regions (optical measurements) – needed to discriminate against lightning-related events. Structure of optical observations including measurements of outgoing long wave (8-12 microns) radiation intensity to be determined. The thermal imaging and measurements of the night luminosity due to lightning activity can be performed by the multi-spectral scanning radiometer of medium resolution while ensuring sufficient weight and power characteristics of the platform. It is planned to use the scanner in 3 spectral channels (0.5-1.0, 10-11 и 11-12 microns) with spatial resolution 200-300 m.

Basic parameters to be measured by the TwinSat-1N spacecraft

- Variations of thermal and supra thermal (0.3 – 20 eV) plasma parameters*;
- Energy distributions of electron and ion fluxes with energies 0.3 – 300 eV for two directions*;
- Wave form of ULF/ELF magnetic field oscillations (0.5 – 500 Hz), one or two components.

* TwinSat-1M and TwinSat-1N instruments will be the same design.

* We additionally consider the issue of the measurement of neutral gas density variations in the ionosphere on two spacecraft.

Data from other satellites

To augment the TwinSat-1 science return it will be advantageous to have data from other space assets including:

- Outgoing long wave (8-12 μm) radiation intensity and thermal images of seismically active zones from EOS (Terra and Aqua) and NPOESS.
- Space Weather monitoring to be able to take account of magnetospheric effects.
- Spatial strain maps of potential earthquake areas from InSAR data.

Existing and planned space assets can provide this data.

Ground Stations

The ground segment consists of the network of geophysical stations situated in several zones of high earthquake and volcano activity. The two satellites will be in a fast operation mode during the passages over these zones, where supporting ground-based measurements of relevant electromagnetic field and the atmosphere parameters should be performed. Comparison of the ground-based and two-satellite observation results with seismic data will allow us to define the existence (or absence) of correlation between the measured parameters and their cause-sequence links with seismic activity.

Parameters to be measured by ground stations include:

- Atmospheric gas composition;
- Characteristics of radon emission and variations of radioactivity;
- Dynamics of aerosol injection;
- Atmospheric DC electric field and current variations;
- Spectral and wave characteristics of ULF/ELF/VHF electromagnetic emissions including the arrival direction finding and locating the radiation sources;
- Remote sensing of the ionosphere disturbances through the registration of amplitude and phase variations of VLF/LF signals from ground-based transmitters at appropriate propagation routes and the GPS/GLONASS signals;

- Earth deformation data (with use of GPS/GLONASS signals);
- Debit, temperature and chemical composition of underground waters;
- Air temperature, humidity and pressure and wind velocity;
- Seismic and magnetic oscillations.

It is supposed the deployment of a multi-discipline ground network in the Kamchatka/Kuril region, which is characterized by the strongest earthquake and volcano activities in the world. 29 active Kamchatka volcanoes annually produce 3 to 4 eruptions of explosive type. Taking into account the high occurrence rate of eruptions in the selected area, we can expect the formation of a unique set of data on the precursory signals obtained from coordinated ground and twin-satellite observations.

Aerial platform is equipped with specialized payload for monitoring of the disturbances excited in the atmosphere over seismically active areas on the eve of impending earthquake, which include the atmosphere chemical composition and aerosol distribution, DC electric field and current, ULF/ELF/VLF/LF and VHF/UHF electromagnetic radiation and atmospheric emissions. A set of onboard instruments also includes the aviation analogue of a satellite multispectral scanning radiometer for measurements of the ground temperature and monitoring of lightning activity. The best solution in a choice of aerial platform is to use the stratospheric aircraft M55 GEOPHYSICA. Its advantage is an altitude of flight up to 21 km, which is unavailable to any other piloted aircraft. However, the cost of its operation is quite high and can create limitations in the possibilities of applying for regular observations. Use of conventional (tropospheric) aircraft is considered as a possible alternative. Intense development of tropospheric aircraft laboratory equipped with a set of instruments for geophysical monitoring are carried out at present on the program of Russian Hydrometeorology Agency. As the alternative (or additional) platforms we consider the tethered balloons operating at the altitudes up to 5 km in the zones of ground geophysical stations.

6. BUSINESS MODEL

6.1. Areas for the Project commercialization (in the short term and in the future):

Feature of business development in the TWINSAT project is a 2-levels scheme of commercialization:

LEVEL 1 (the end of 2013, and further): engineering services for the design, manufacture and supply of scientific devices, elements and systems of the spacecraft and the satellites weighing from 1 kg to 50 kg, as well as devices for their manual and automatic launching;

LEVEL 2 (beginning from 2014): patenting in Russia, the USA, Canada, EU, Japan and Israel. License agreements.

Commercialization at the *Level 1* will begin at the 1st stage of the work on the Project. The first sales will be associated with the development and production of launching devices.

The commercialization of *Level 2* is based on the patenting the results of the work on the project and the subsequent sale of licenses. At Stage 1 of the project implementation it is planned:

1. Patenting the results of the project development on:
   - Mechanical system for the booms deployment;
   - The system for separation of nano satellite TWINSAT-1N;
   - The way to control the movement of 2-satellite grouping TWINSAT-1;
   - Onboard system for video monitoring of the separation of nano satellite and the deployment of the construction elements of micro satellite;
   - The TwinSat thruster.

(5 patents)

2. Patenting the results of the project development on:

- The power supply system of the micro satellite with novel accumulator and solar batteries;
- The channel of information exchange between micro and nano satellites in the TWINSAT grouping;
- The method for short-term prediction of large magnitude earthquakes on the basis of data from space, aerial and ground based segments of the TwinSat system.

(3 patents).

With regard to the perspective (2018-2020) global market, a detailed description of the products promoted on the market, schemes of their implementation, the price and the expected sales volumes are shown in Annex (additional materials). Estimated volume of sales by the end of the 2nd year of the operation of the System provides a yield at the level of US$ 350 million per year.

We can expect that international organizations such as the UN and their structures will be interested in getting the forecast information from TWINSAT system and its distribution in humanitarian purposes among the less developed and poorer States, in which there is a threat of destructive earthquakes. In this case, the international organizations may participate in the costs for the operation of the System and the analysis of data.

6.2. Competitors' business model (and revenue for each product (technology)):

- At the present time, there is no real competition on the market of information services on earthquake forecast.

.

6.3 Sales result

6.3.1 Expected date to start the sales: 2014.

6.3.2 Sales result:

SALES DIRECTIONS	**2013**	**2014**	**2015**	**2016**	**Итого**
Total sales, RUR		**26 000 000**	**40 000 000**	**75 000 000**	**121 000 000**
Area 1		**16 000 000**	**15 000 000**	**15 000 000**	**46 000 000**
Area 2		**10 000 000**	**25 000 000**	**40 000 000**	**75 000 000**

The expected volume of sales by the end of the 1st year of operation of the System (2018/2019) will amount to about US$ 250 million. Estimated volume of sales by the end of the 2nd year of the operation of the System (2019/2020) provides a yield at the level of US$ 350 million per year.

7. PROJECT TEAM

7.1. Description of organizational structure and corporate management model in the project Participant organization:

7.1.1. Organizational structure. Brief description of major structural departments, number of employees, including separate figures for scientific personnel:

The administration, engaged in the management of the company (see п.7.1.2), Chief accountant, Department of the development of spacecraft, including the design - engineering division, the units of the power supply systems, the onboard systems of the control, orientation and stabilization and the information technologies, the laboratory of space device engineering, the laboratory of data analysis and theoretical modeling, the laboratories of ground and flight testing and the laboratory of remote monitoring. The total number of employees at the present time (January 2013) is 19 persons, 15 are scientific and engineering personnel. It is planned an additional recruitment of specialists on the Project Stage «1».

7.1.2. Corporate management model employed in the project Participant organization (specifying the list of governing bodies and their authorities):

Management of the company is exercised by the Director General, Director – the Chief Designer and the Business Development Director.

7.2. Key team members:

a. Vitaly CHMYREV

b. Role in Project. Head of the Project on Russian side, Director General at the GEOSCAN Technologies.

c. Functions, tasks and works in Project. Head of the Project on Russian side. Overall project management, coordination of work and negotiations with investors and partners on the issues of the research program, the structure and the schedule of works and their interface with the possibilities of co-financing of the project.

d. Field of activity and professional achievements. Geophysics and Space Science. Participation in several space projects including MAGIC (Intercosmos-18), APEX (Intercosmos-24), Intercosmos – Bulgaria 1300 and COSMOS-1809. Fundamental scientific results on the propagation and interaction of ULF/VLF waves in space plasma, the generation of nonlinear Alfven vortex structures and related phenomena in high-latitude ionosphere and magnetosphere, the wave and plasma effects of artificial injection of electromagnetic waves and electron beams into the ionosphere, and the atmosphere – ionosphere coupling effects connected with natural and technological disasters.

e. Key experience related to the field of the Project. Participation in several research projects granted by International Science and Technology Center, which were devoted to study of ionospheric and atmospheric precursors to earthquakes. Implementation of several satellite and ground experiments on seismic and technological impact on the ionosphere. Awarded the order «Sign of honour», medals and diploma of the Federation of Cosmonautics, the diploma and the joint prize of the Russian and Bulgarian Academies of Sciences for work in the field of space research. For the time of the company's leadership Vitaly gained considerable experience in organization and implementation of international business projects in the sphere of high technologies.

f. Education, science degree, title. Leningrad State University, Faculty of Physics, Department of Geophysics, PhD (Radio Science), Doctor of Sciences (Geophysics), Chief Scientist.

g. Places of work and positions for last 5 years. Director General at the GEOSCAN Technologies and Senior Scientist in the Institute of Physics of the Earth of Russian Academy of Sciences.

h. Science publications. More than 70 publications in refereed scientific journals including three most recent publications:

Chmyrev V.M., Sorokin V.M., Shklyar D.R. (2008). VLF transmitter signals as a possible tool for detection of seismic effects on the ionosphere. J. Atmos. Solar-Terr. Phys. 70, 2053-2060.

Sorokin V.M., Chmyrev V.M. (2010). Atmosphere-ionosphere electrodynamic coupling. In: The Atmosphere and Ionosphere. Dynamics, Processes and Monitoring. Series: Physics of Earth and Space Environment. Eds: V.L.Bychkov, G.V.Goloubkov and A.I.Nikitin. Springer Dordrecht Heidelberg London, New York, pages 97-146.

Chmyrev V.M., Sorokin V.M. (2010). Generation of internal gravity vortices in the high-latitude ionosphere. J. Atmos. Solar-Terr. Phys. 72, 992-996.

i. Science Citation Index. 805 (Sum of the Times Cited), 40 (Cited in 2012). Numerous reports at international scientific conferences, including:

Sorokin V.M., Chmyrev V.M.. Aerospace monitoring of natural and technological disasters. International EU-Russia/CIS Conference on technologies of the future: Spain-ISTC/STCU cooperation. Madrid, 22-23 April 2010.

Chmyrev V.., Smith A., Balikhin M., Belyaev G., Boytchev B., Kataria D.. Proposal for TwinSat electromagnetic and plasma measurements. Third Workshop "Solar influence on the magnetosphere, ionosphere and atmosphere", Sozopol, Bulgaria, 6-10 June 2011.

j. Intellectual property rights in the field of activity. Russian patent 2122761: "Photoelectric module", priority: May 7, 1998, authors: Aleshin V.N., Kopylov O.G., Kozlov A.I., Prokhorov G.V., Kostenko V.I. and Chmyrev V.M.

a. Boris NESTEROV

b. Director on the development – Chief Designer.

c. Development of the construction and onboard systems of micro and nano satellites.

d. Designing and building the micro satellites. Participation in several Russian space projects including PREDVESTNIK, KANOPUS-VULKAN, RUSLO-2020-MKA, OTRABOTKA, BAUMANETS-2, STERKH, KANOPUS-ST, Quick Launch, MOZHAETS-4, UNIVERSITETSKY, DEMONSTRATOR, OBZOR and STORY. 35-years experience of design and construction works on the development of space technologies.

e. Participation in several international campaigns on the group launching the micro satellites and their adaptation to the rocket-carrier:

- «Astrid-1» (Swedish Space Corporation) and "Faisat-1" ("Final Analysis, Inc.", USA) piggy-back launch with SC «Tsikada» (January 24, 1995);
- «Astrid-2» (Swedish Space Corporation) with SC «Nadezhda» (December 10, 1998);
- «UNAMSAT-B» (Mexico) with SC «Parus» (September 5, 1996г);
- «SNAP-1» and «Tsinghua-1» (SSTL, UK) with SC «Nadezhda-M» (June 28, 2000);
- «ALSAT-1» (SSTL, UK), «Mozhaets-3» and Rubin-3-DSI (OHB, Germany) (November 28, 2002);
- «UK-DMC» (SSTL, UK), «NigeriaSat-1», «BILSAT-1» (Turkey), «KAISTSAT-4» (Korea), «Mozhaets-4» and «Larets» (September 27, 2003);
- «TopSat» (SSTL, UK), «Beijing-1» (China), «Mozhaets-5», «Cina-1» (ISA), SSETI-Express +«Ncube-2»+ UWE-1+CubeSat XI (October 27, 2005);
- «Orbcomm» (5 units, USA) + CDS (USA) – group launch with RC «Cosmos-3M» (June 19, 2008).

f. Faculty of flying vehicles in Omsk Aviation College and Electrical and Radio Technologies Faculty in Omsk Polytechnic Institute, Department of instrument design and manufacture. Awarded with title "Honored developer of rocket – space techniques" and medals of Federation of Cosmonautics.

g. Chief designer in JSC POLYOT Design Bureau and in Science and Technology Center "Micro and nano technologies in the rocket-space field", Director on the development-Chief designer in the GEOSCAN Technologies.

h. Numerous publications in scientific journals proceedings of conferences including:

- Evropeitsev A.A., Zolotarev N.I., Nesterov B.F. (2000). Some problems of designing mechanical systems of spacecraft. Omsk, POLYOT Design Bureau, 54 pages.
- Ivanov N.N., Blinov V.N., Nesterov B.F., Karasev R.N., Pankratov P.N., Shumsky V.V. (2004). Application of electromechanical drivers in micro satellite developments. Materials of first regional conference "Problems of the development, building and exploitation of rocket-space and aviation techniques". Omsk State University.
- Markelov V.V., Ivanov N.N. Blinov V.N., Nesterov B.F. (2001). Main trends of the development of small spacecraft. Modern technologies at the creation of products of military and civil destinations. Proceedings of Technological Congress, Part 2, Omsk State Technical University.

i. Science Citation Index is unknown. Number of reports at international conferences including:

- Alan Smith, Vitaly Chmyrev, Dhiren Kataria, Boris Nesterov, Christopher Owen, Peter Sammonds, Valery Sorokin, and Filippos Vallianatos. TwinSat: A Russia-UK satellite project to study ionospheric disturbances associated with earthquake and volcanic activity. 2nd INTERNATIONAL DEMETER WORSHOP, Paris, France, October 10-12, 2011.
- Trushlyakov V., Lopatento L, Nesterov B, Zabrudskiy O. Formation of innovative solutions for the attitude control system of low sized educational satelliteы. 1st IAA Conference, University Satellites Missions and Cubesat Workshop. Rome, Italy, January 24-29, 2011.

j. Intellectual property rights in the field of activity: Russian author's certificate 154278 – "Device for control of position of the mass center of SC", priority March 24, 1980, authors: Nesterov B.N., Blinov V.N., Alle A.Yu.. Patents: 2263062 – «Container», priority December 26, 2003, authors: Zubarev A.E., Ziuzin O.M., Ivanov N.N., Nesterov B.F., SechenovYu.N.; 2291827 – «Container», priority September 7, 2004, authors: Nesterov B.N., Podzorov V.N., Sechenov Yu.N.; 2293688 – "Mini satellite for group and piggy-back launches", priority June 14, 2005, authors Nesterov B.F., Blinov V.N., Ivanov N.N.; 2302364 – «Container», priority September 20, 2005, authors: Vokhmin A.G., Nesterov B.F., Podzorov V.N., Sechenov Yu.N., Polevko I.B.; 2273597 – «Container», priority October 4, 2006, authors: Sechenov Yu.N., Nesterov B.F.; 2362714 – "Mechanism for fastening spacecraft", priority October 9, 2006, autorth: Podzorov V.N., Kiriliuk A.I., Abushenko S.N., Evteev A.N., Evropeitsev A.A., Nesterov B.F., Ivanov N.N.; 2376212 – «Space platform», priority May 19, 2008, authors: Ivanov N.N., Markelov V.V., Murakhovsky G.M., Nesterov B.F., Sechenov Yu.N.

a. **Oleg Pokhotelov**

b. Chief scientist, theoretical modeling.

c. Development of theoretical models for the ionosphere-magnetosphere interaction and investigation of atmospheric precursors to earthquakes, analysis and interpretation of experimental data.

d. Geophysics and space science. Development of theoretical models of the atmosphere-ionosphere coupling and their application for study of plasma and electromagnetic effects of natural and technological disasters.

e. Participation in several research projects financed by Russian Foundation of Basic Research, International Science and Technology Center and EU FP-7 programs, which have been devoted to study of ionospheric and atmospheric precursors to earthquakes.

f. Novosibirsk State University, Faculty of Physics, PhD (geophysics), Doctor of sciences (geophysics), professor (physics and mathematics).

g. Head of laboratory in the Institute of Physics of the Earth of Russian Academy of Sciences and Chief scientist in the GEOSCAN Technologies.

h. More than 300 publications in refereed scientific journals including three most recent publications:

Sorokin V. M., Pokhotelov O. A. (2010). The effect of wind on the gravity wave propagation in the Earth's ionosphere. J. Atmos. Solar – Terr. Phys. 72, 213-218.

Sorokin V. M., Pokhotelov O. A. (2010), Generation of ULF geomagnetic pulsations during early stage of earthquake preparation, J.Atmos. Solar-Terr. Phys. 72, pp. 763-766.

Pokhotelov O. A., Onishchenko O. G. (2011) Magnetic curvature driven Rayleigh-Taylor instability revisited, Annales Geophysicae, 29, pp. 411-413

i. Science Citation Index: 2108 (Sum of the Times Cited), 161 (Cited in 2012). Numerous reports at international scientific conferences including:

Pokhotelov O. A., Ionospheric Alfven resonator: Theory and observations, Artificial intelligence in the study of the Earth's magnetic field. Russian segment of Intermagnet, Uglich, 26-29 January, 2011.

j. Intellectual property rights in the field of activity: Author certificate 843576: "Method for investigation of the ionosphere and/or magnetosphere", Priority: year 1981, authors: Alperovich L.S., Gokhberg M.B., Kevlishvili P.V., Pokhotelov O.A., Sorokin V.M., Fedorovich G.V., Khristoforov B.D.

a. **Valery KOSTENKO**

b. Head of Ground Testing Laboratory.

c. Ground testing of satellite useful payloads and technological support of space experiments.

d. Development, manufacture and ground testing of micro satellites and the spacecraft payloads. Successfully realized are 8 satellite missions.

e. Participation in preparation and implementation of numerous space programs including Vega 1 and 2, Phobos, Mars 94-96, MIRAS, SRG, Yamal 100 and Calibri 2000.

f. Moscow Aviation Institute, Department of Aircraft Mechanical Engineering, PhD (Information Systems and Instrument Making), Doctor of Sciences (Instruments and Methods of Experimental Physics).

g. Head of Laboratory in Institute of Space Research of Russian Academy of Sciences and Head of Laboratory in GEOSCAN Technologies.

h. More than 50 publications in refereed scientific journals including:

Sagdeev R.Z, Szabo F., Avanesov G., Kostenko V.I, et al. (1986). Television observations of comet Halley from VEGA spacecraft. Nature 321, 262-266.

Avanesov G.A., Bonev B.I., Kempe F., Kostenko V.I., et al. (1989). Television observation of Phobos. Nature 341, 585-587.

Kostenko V., Chernenko A., Loznikov, et al. (2000). Optimal cooling of HPGe spectrometers for space borne experiments. Nuclear Instruments and Methods in Physics Research A442, 404-407.

i. Science Citation Index: unknown. Numerous reports at international scientific conferences including:

Kostenko V.I., Titov A.V., Lazarev V.I., et al. The increase of the scientific payload thermo-vacuum testing efficiency. Spacecraft Structures, Materials and Mechanical Testing Conference, ESA, Nordwijk, Netherlands, 27-29 March 1996.

Kostenko V.I. Principles of technological degassing of onboard scientific instruments. Third Belarusian Space Congress. Minsk, Belarus, 23-25 October 2007.

j. Intellectual property rights in the field of activity. More than 30 author certificates and patents including:

Russian patent 2126137: “Method for determination of angular position of spacecraft with use of measurements of thermo-sensitive plate temperature”, priority: 26 February 1998, authors: Kostenko V.I., Semena N.P., Logvinenko S.P.

Russian patent 2122761: “Photoelectric module”, priority: 7 May 1998, authors: Aleshin V.N., Kopylov O.G., Kozlov A.I., Prokhorov G.V., Kostenko V.I. and Chmyrev V.M.

a. <u>Valery SOROKIN</u>

b. Data Analysis and Theoretical Modeling, Head of Laboratory.

c. Development of theoretical models for generation and interconnection of ionospheric and atmospheric precursors to earthquakes, analysis and interpretation of experimental data.

d. Geophysics and Space Science. Development of electrodynamic model of the atmosphere – ionosphere coupling and its application to the investigation of plasma and electromagnetic effects related to natural and technological disasters.

e. Participation in numerous research projects granted by the Russian Foundation of Basic Research and the International Science and Technology Center, which were devoted to study of ionospheric and atmospheric precursors to earthquakes.

f. Moscow Engineering Physical Institute, Faculty of Theoretical and Experimental Physics, PhD (Theoretical and Mathematical Physics), Doctor of Sciences (Physics and Mathematics), Professor (General and Applied Physics).

g. Head of Laboratory in Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation of Russian Academy of Sciences and Head of Laboratory in the GEOSCAN Technologies.

h. More than 150 publications in refereed scientific journals including three most recent publications:

Chmyrev V.M., Sorokin V.M. (2010). Generation of internal gravity vortices in the high-latitude ionosphere. J. Atmos. Solar-Terr. Phys. 72, 992–996.

Sorokin V. M., Pokhotelov O. A. (2010). The effect of wind on the gravity wave propagation in the Earth’s ionosphere. J. Atmos. Solar – Terr. Phys. 72, 213-218.

Sorokin V.M., Ruzhin Yu.Ya., Yaschenko A.K., Hayakawa M. (2011). Generation of VHF radio emissions by electric discharges in the lower atmosphere over a seismic region. J. Atmos. Solar-Terr. Phys. 73, 664–670.

i. Science citation index: 704 (Sum of the Times Cited), 31 (Cited in 2012). Numerous reports at international scientific conferences including:

Sorokin V.M., Ruzhin Yu.Ya. Kuznetsov V.D., Yaschenko A.K.. Generation of the seismic related VHF electromagnetic radiation in the atmosphere. EMSEV 2010 Workshop, Chapman University, Orange, CA, USA. 02 -07 October 2010.

Sorokin V.M., Chmyrev V.M.. Aerospace monitoring of natural and technological disasters. International EU-Russia/CIS Conference on technologies of the future: Spain-ISTC/STCU cooperation. Madrid, 22-23 April 2010.

j. Intellectual property rights in the field of activity: Author certificate 843576: “Method for investigation of the ionosphere and/or magnetosphere”, Priority: year 1981, authors: Alperovich L.S., Gokhberg M.B., Kevlishvili P.V., Pokhotelov O.A., Sorokin V.M., Fedorovich G.V., Khristoforov B.D.

a. <u>Andrew Tronin</u>

b. Head of the laboratory of remote methods for monitoring of earthquakes.

c. Development of satellite thermal infrared methods for seismic activity research. Determination of satellite remote sensing thermal infrared device specifications.

d. Geophysics**,** seismology and remote sensing. Discovery of outgoing longwave infrared radiation of the Earth as an indicator of seismic activity. Development of satellite thermal infrared methods for seismic activity research.

e. Japan space agency project «Earthquake Remote Sensing Frontier Project», European project SISMOSAT – «Regular Update of Seismic Hazard Maps through Thermal Space Observations», global UNESCO project: Integrated Global Observing Strategy – GEOHAZARD.

f. The Schmidt Institute of Physics of the Earth of Russian Academy of Sciences (Moscow), geothermal laboratory, PhD in geophysics; Saint-Petersburg state university, geological department, professor in geophysics.

g. Deputy director in science of Institution of Russian Academy of Sciences Saint-Petersburg Scientific-Research Centre for Ecological Safety and head of laboratory in Geoscan Technologies.

h. More than 40 publication in peer reviewed journals including last three:

Saraf A. K., Rawat V., Das J. D., Tronin A., Choudhury S. And Sharma K. (2011). NOAA-AVHRR Data Displaying Thermal Line in the Himalayan Foothills and Its Association With Frontal Thrust and Chamoli Earthquake. *Memoir of the geological society of India*, No. 77, ISBN: 978-81-907636-2-2, p. 195-204.

Tronin A.A. (2010). Satellite Remote Sensing in Seismology. A Review. *Remote Sensing* 2(1), p. 124-150.

Tronin A.A. (2006) Remote sensing and earthquakes: A review // *Physics and Chemistry of the Earth*, Parts A/B/C, Vol. 31, p. 138-142.

i. Science citation index: 357 (Summary), 45 (in 2012). Numerous reports on international science conferences including:

Tronin A.A. Satellite remote sensing in seismology. International Workshop on Earthquake Anomaly Recognition (IWEAR 2011). Shenyang, China, 18 -20 September 2011.

Tronin A.A. Satellite methods for earthquake explorations. The Eighth All-Russian Open Conference “Actual Problems In Remote Sensing Of The Earth From Space”. Space Research Institute Of The Russian Academy Of Sciences, Moscow, 15–19 Nov 2010.

Tronin A.A. Remote sensing applications for Sumatra earthquake 26 Dec 2004. International Workshop on Validation of Earthquake Precursors by Satellite, Terrestrial and other Observations (VESTO), Chiba University, Japan, March 26-28, 2009.

j. No.

7.3. Partners and co-executors:

- The main partner on the UK side is the MSSL, Mullard Space Science Laboratory - Department of Space and Climate Physics, University College London (www.mssl.ucl.ac.uk). MSSL is the leading research organization of a world level and the largest space laboratory of the UK universities. MSSL was founded in 1966 and has since participated with their equipment in 35 satellite projects and more than 200 rocket experiments. Their role in the project is development and creation of the nano satellites with useful payload. The Director of the MSSL Professor Alan Smith is the Co-Leader of the TwinSat project.
- At the stage of development of the operational space constellation the SSTL (Surrey Satellite Technology LTD, www.sstl.co.uk) is expected to join the project. SSTL is a world leader in the building of small spacecraft for various applications, including Earth remote sensing. Their role is the creation of a TwinSat-RS satellite constellation, which is a part of the TWINSAT space segment, participation in the development of the overall structure of the space segment, the management and securing of its functioning.
- RSC “Energia”, IKI RAS, IPE RAS, SPA “Kvant”, GlobalTel, Design Bureau “Fakel”, Center of Nanotechnologies of SKGTU and JSC SPE “SAIT” – participation in testing, manufacturing and delivery of elements, devices and systems of spacecraft, ground experiments, etc.

8. CURRENT STATUS OF THE DEVELOPMENT

8.1. Project history and background, Project implementation dynamics by now:

An idea of this project has been first sounded in the report by V.M.Chmyrev and V.M.Sorokin “Aerospace monitoring of large scale natural disasters” presented at the meeting of the UK and Russia space scientists occurred between 30 June and 2 July 2010 in London. The meeting was organized by University College London (UCL) and International Science and Technology Centre (ISTC) and was hosted by UCL Department of Space and Climate Physics and UCL Mullard Space Science Laboratory. In final Memorandum of Understanding the parties agreed to investigate and seek to pursue collaborative research in areas including the following: “To undertake an instrumentation-based project to the detection of natural disaster precursors through observations of effects in the Earth’s ionosphere and magnetosphere”. During two subsequent meetings occurred in London (7-9 December 2010) and in Moscow (16-17 February 2011) the discussions addressed scientific requirements and objectives, satellite design and payloads, operation and programmatic issues. An appearance of the TwinSat project was developed and joint project team headed by Prof. Alan Smith and Dr. Vitaly Chmyrev was formed. The UK team members are Profs. Peter Sammonds and Filippos Valionatos of UCL Institute for Risk and Disaster Reduction, Prof. Christorpher Owen and Dr. Dhiren Kataria of UCL Mullard Space Science Laboratory. The Russian team is described above. All team members have an established track record in the development and implementation of satellite projects and experiments in the fields of space plasma physics, the influence of human activity on near Earth environment, the effects of natural and technological disasters on the ionosphere, etc. The TWINSAT program is based to a large extent on experimental studies and theoretical modeling performed by the project team members.

Officially the Project was presented in Royal Aeronautical Society at Yuri Gagarin’s Legacy Space Conference (London, 16th March 2011) in the report by Vitaly Chmyrev and Alan Smith “Detection and Monitoring of Earthquake Precursors: TwinSat, a Russia-UK Satellite Project”. In 2012 in a frame of the Stage “0” Grant of Skolkovo Space cluster we performed completion of the TWINSAT Innovation project and submitted a package of documents for a Grant of Project Stage «1».

8.2. Current Project Status:

To the present time the prototypes of the micro satellite and the nano satellite have been developed. In a frame of the preparatory work on the project the following results were achieved:

- The project structure and general performance of the TwinSat-1 satellite system elements were outlined;
- The constructive appearance of the micro and nano satellite was defined;

- Preliminary layout of the micro/nano satellite pair and its 3D model were developed;
- The composition of useful payloads and technical requirements for scientific instruments to be installed on the micro and nano satellites were determined;
- The concept of the deployment, function and operations of the paired satellites was developed; preliminary ballistic calculations have been performed, which confirmed the possibility for creation of such grouping of micro and nano satellite;
- Kinematical scheme for the deployment of booms with scientific sensors and the scheme of nano satellite separation were worked at;
- A preliminary model of the lithosphere-atmosphere-ionosphere coupling needed for the development of a structure of the monitoring system has been constructed;
- A concept of the integrated system including space, aerial and ground-based segments for early detection and monitoring of earthquake precursors has been developed.

8.3. Project implementation history:

- Until now the preparatory works on the TWINSAT project were carried out unilaterally at the expense of own funds of GEOSCAN Technologies and grant of the Stage «0» (Agreement no. 7 with cluster of Space Technologies and Telecommunications, Skolkovo Foundation, May 24, 2012).

8.4. Project risks and opportunities for their mitigation:

8.4.1. Technological and other key risks for the Project:

- The technology risks connected with loss of spacecraft due to damage, failure or outage of launch system and also caused by partial or full not delivery of spacecraft on targeted orbit.
- The technology risks connected with functioning of main systems of spacecraft in a flight and correspondingly with the life time of micro satellite on orbit.
- The financial risks connected with possible breach of schedule for financing the project that can cause the delay in project implementation and related lag behind competitor and market development.

8.4.2. Opportunities and planned measures on mitigating the Project risks:

- The choice of reliable launching company and the carrier rocket for the delivery of the micro satellite on orbit.
- Selection of certified components of the highest quality with the local protection of important elements, the use of program-algorithmic methods of protection against failures and the implementation of the program of experimental testing in terrestrial conditions and in the open space.
- Sustainable financing of the project from the SKOLKOVO Foundation and Co-investor.

8.4.3. Likelihood of achieving the Project results at its current stage (with justification; if available, provide statistics on similar studies referencing the sources):

- When fulfilling the requirements of the paragraph 8.4.2 the probability of achievement of the project Stage “1” results is 98%.

9. INTELLECTUAL PROPERTY

9.1. Legal protection and registration of rights on the results of intellectual activity:

9.1.1. Summary of options for legal protection of intellectual property:

At the project Stage “1” we plan:

- Patenting of the project development results on:
  - Mechanical system for the booms deployment;
  - The system for separation of nano satellite TWINSAT-1N;
  - The way to control the movement of two satellite grouping TWINSAT-1;
  - Onboard system for video monitoring of the separation of nano satellite and the deployment of the construction elements of micro satellite;

- The TwinSat thruster.

(5 patents)

- Patenting of the project development results on:
  - The power supply system of the micro satellite with novel accumulator and solar batteries;
  - The cannel of information exchange between micro and nano satellites in the TWINSAT grouping;
  - The method for short-term prediction of large magnitude earthquakes on the basis of data from space, aerial and ground based segments of the TWISAT system.

(3 patents)

9.2. IP protection strategy:

Patenting the results of the work on this project in Russia, UK, France, Germany, Japan, the USA and Canada.

10. DEVELOPMENT PLAN

10.1. Outline development plan:

10.1.1. R&D plan:

<u>*Stage 1:*</u>

Phase 1.1:

- Development of Technical Assignment, Issue of Preliminary Design Review and of Critical Design Review (2013);
- Building and ground testing of experimental (technological) samples of onboard micro satellite devices and systems and the useful payload (2013-2014);
- Assembling and ground testing of experimental (technological) sample of the micro satellite with useful payload. Deployment of the mission control, telemetry and data processing center. Development of theoretical model for earthquake precursors and software for experimental data analysis (2014);

Phase 1.2:

- Deployment of the network of geophysical stations in seismic and volcanic zones (2015);
- Assembling and joint ground testing of the micro and nano satellites with useful payloads (2015);
- Piggy-back launch and the flight testing of the micro and nano satellites and their joint operation with the ground geophysical stations (Year 2015);
- Operation of twin satellite system and the ground stations network, experimental data processing, analysis and theoretical modeling (2015-2016);
- The conceptual design and feasibility determination of a follow-on satellite constellation for reliable earthquake prediction taking into consideration the danger of false alarms and ambiguity. Development of the concept, structure and method of constructing the System for Early Detection and Monitoring of Earthquake Precursors, as the main element of the future global system for prevention of emergency situations related to large magnitude earthquakes of magnitude (2016).

10.1.2. Finance raising plan:

Participation in competitions of the Federal Space Agency and other departments, and also in the international competitions, active negotiations with the insurance business and the authorized governmental bodies of the countries in the areas with high seismic risk, the conclusion of commercial contracts.

11. ANY ADDITIONAL INFORMATION

Additional information: Analysis of the prospective market of products of the TWINSAT project (attached)