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Space technologies for short-term earthquake warning

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Abstract

Recent theoretical and experimental studies explicitly demonstrated the ability of space technologies to identify and monitor the specific variations at near-earth space plasma, atmosphere and ground surface associated with approaching severe earthquakes (named as earthquake precursors) which appear several days (from 1 to 5) before the seismic shock over the seismically active areas. Several countries and private companies are in the stage of preparation (or already launched) the dedicated spacecrafts for monitoring of the earthquake precursors from space and for short-term earthquake prediction. The present paper intends to outline the optimal algorithm for creation of the space-borne system for the earthquake precursors monitoring and for short-term earthquake prediction. It takes into account the following:

1. Selection of the precursors in the terms of priority, considering their statistical and physical parameters.
2. Configuration of the spacecraft payload.
3. Configuration of the satellite constellation (orbit selection, satellite distribution, operation schedule).
4. Different options of the satellite systems (cheap microsatellite or comprehensive multisatellite constellation).

Taking into account that the most promising are the ionospheric precursors of earthquakes, the special attention is devoted to the radiophysical techniques of the ionosphere monitoring. The advantages and disadvantages of such technologies as vertical sounding, in-situ probes, ionosphere tomography, GPS TEC and GPS MET technologies are considered.

Keywords: Ionospheric precursors of earthquakes; Short-term earthquake warning; Satellite constellation

1. Introduction

The beginning of the 21st century was marked by important transition – from discussions on the physical reality of the ionospheric precursors of earthquakes to the practical realization of the dedicated space projects for registration of these precursors from space. Up to now there are three space vehicles launched: COMPASS-1, (Russia, December 2001), QuakeSat, (USA, June 2003), and DEMETER, (France, June 2004). Several space projects are now under development: COMPASS-2 (Russia, to be launched in July, 2005), Vulkan satellite constellation (Russia, the launch of the first satellite from constellation is scheduled on 2006), ESPERIA (Italy, the launch terms are not determined), Sich-1M (Ukrainian remote sensing satellite carrying the electromagnetic complex of international "Variant" project for registration of seismo-electromagnetic emissions, launched on 24 December 2004). The foundation of decision making on the dedicated satellite project consists from two parts: from one side – it is results from earlier non dedicated space missions where precursors were registered (Larkina et al., 1983; Gokhberg et al., 1983; Galper et al., 1983; Parrot and Lefeuvre, 1985; Chmyrev et al., 1989; Bošková et al.,

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1994; Pulinets, 1998a,b; Pulinets et al., 2003), from the other side – the appearance of the physical background in the form of models of seismo-ionospheric coupling (Pulinets et al., 2000; Sorokin et al., 2001; Hayakawa and Molchanov, 2002; Pulinets and Boyarchuk, 2004). But it is a long way from the case registration of some precursor to the real monitoring and even prediction, and it consists from the synergy problems mainly, for instance, how to configure the satellite payload, what kind of orbit to select, how to organize the data assimilation and processing, what is the algorithm of decision making in prediction, etc. Looking from the perspective of the results of already launched satellites, as well as estimating the efforts on the creation of the new dedicated satellites, it seems, the time came to discuss the problems of the creation of the dedicated space mission for the short-term earthquake warning, what is the purpose of the present paper.

2. Precursors ranging

The mission starts from the decision what we intend to measure onboard the satellite to configure the scientific payload. Up to now there were identified several parameters of the near-earth plasma, which variations may be interpreted as the short-term earthquake precursors. One can try to use them all (as it is intended to do in the Russian Vulcan space constellation), or to select only one (as it is decided to do in the American QuakeSat mission), or to select several (as it is made in French DEMETER satellite). But what should be criteria of the selection?

One should regard at least two factors: first, the precursor substantiation, and second – the prediction capability of the precursor. Under substantiation we mean the following factors: the number of space missions where such kind of precursors were registered, number of cases registered and existence of statistical studies, existence of the physical mechanism explaining the observed precursors. The important factors are also the number of publications on the given precursors, number of different scientific groups studying this type of precursors. It seems that important factor is also the historical continuation of studies. Sometimes it happens that we can find in the literature publications about the precursor, but suddenly they stop, and afterwards these precursors are never mentioned in the literature.

The prediction capability means the ability to answer at three main question of the short-term prediction: WHEN?, WHERE?, and HOW STRONG? It means that using the given type of the precursors the algorithm should be developed permitting to determine the time of the expected shock, its coordinates and magnitude.

Let us look at the different types of space precursors from indicated points of view. But before to start this discussion it should be noted that regardless the other types of precursors, the ionospheric ones in the form of variations of the critical frequency of the ionosphere f_oF2 [MHz] (which is the measure of the peak electron density $NmF2$ [el/m^3] = $(f_o\mathrm{F2})^2/80.3$) are equivalent with respect to the type of the ionospheric sounding. Vertical sounding from the ground surface and correspondent measurements of the critical frequency are equal to the sounding from the board of the satellite (Ondoh and Marubashi, 2001). It means that statistical studies or other measurements of the critical frequency made from the ground surface are applicable to the estimations of the space measurements of the critical frequency.

If we consider the chronological order of the precursor's discovery and identification, we can put them in the following order:

- Ionospheric precursors (critical frequency variations and vertical distribution of electron concentration).
- Optical emissions.
- VLF emissions.
- Particle precipitation.
- ELF emissions.
- Small-scale irregularities.
- Mean ion mass changes.
- Thermal precursors.

Let us put the same list of precursors but using the number of publications as a criterion:

- Ionospheric precursors (critical frequency variations) >100.
- VLF emissions ~50.
- Thermal precursors ~30.
- Particle precipitation ~15.
- Optical emissions ~10.
- Mean ion mass changes ~10.
- ELF emissions ~10.
- Small-scale irregularities ~5.

Here should be mentioned that if for some type of precursors like thermal or mean ion mass changes the number of publications grows recently, the other precursors such as optical ones were mentioned for the last time in the literature yet at the end of 90th.

It is interesting to look at how many scientific groups in how many countries are involved in the studies of the different types of precursors. Such approach clearly demonstrates the acknowledgement of different types of precursors in the scientific community as well as the level of their studies development. Taking into account that we try to select the precursors for the satellite measurements, in this consideration we include only precursors which can be registered by satellites. Table 1 depicts the scientific groups and authors having

Table 1
The list of precursors in terms of scientific groups having the original publications on them

Precursor type	Groups
Ionospheric precursors	Russia (10 groups), Kazakhstan, Uzbekistan, Georgia, Turkmenia, Armenia, France, Italy, Taiwan, China, India, Japan, Greece, Mexico, Indonesia, Chile, United Kingdom,Ukraine, Belarus, Argentina
Thermal precursors	Russia, Italy, United States, India
VLF emissions	Russia (2 groups), France, Japan
Optical emissions	Russia (3 groups), Georgia, Turkmenia
Particle precipitation	Russia (3 groups), Poland
ELF emissions	Russia, France, Japan
Ion mass changes	Czech Republic, Russia
Small-scale irregularities	Russia, Uzbekistan

original publications with the original results and does not take into account the papers where the original results are discussed by others.

Looking at the two lists and Table 1 one can to conclude that the ionospheric precursors are at the first place by all criteria without any doubts.

2.1. Statistical studies

Up to now the real statistical studies were carried out only for VLF emissions (Larkina et al., 1989; Parrot, 1994), ground based measurements of the ionospheric precursors of earthquakes (Chen et al., 1999; Pulinets et al., 2002; Liu et al., 2004a,b), and for the local plasma parameters measurements (local electron concentration and temperature) (Afonin et al., 1999). Regardless the ionospheric precursors statistics was made using the ground based measurements, the most definite and informative conclusions were obtained:

1. Ionospheric variations reveal the local time dependence (in the form of the sign of the critical frequency deviation from undisturbed level), as well as “day before shock” dependence.
2. There exist an earthquake magnitude threshold $M = 5$ from which ionosphere starts to “feel” the earthquake preparation process.
3. The anomalous variations in the ionosphere appear in average (with high level of confidence) within the time interval from 5 to 1 days before the seismic shock.
4. The size of the modified area in the ionosphere increases with the earthquake magnitude.

All these factors show the way to the practical application and to estimation of the prediction capability of the precursors. As is concerned with the VLF emissions statistical results, they are different in the latitude-longitude distribution of the observed phenomena in the paper of (Larkina et al., 1989), and (Parrot, 1994). Larkina et al. (1989) report on the emissions prolixity in longitudinal direction, while Parrot (1994) reports spread in the meridional direction. This contradiction in VLF statistics again puts the ionospheric precursors at the first place relative to the statistical parameters confidence.

2.2. The physical explanation of the space precursory phenomena

Up to now the most complete and developed model is created for the observed variations of the electron density in the ionosphere which are associated with the earthquake preparation process. Its concise and updated description can be found in (Pulinets, 2004), and complete version – in (Pulinets and Boyarchuk, 2004). Regardless the main purpose of the model was to explain the ionospheric variations, it is able to clarify the other effects observed in the space plasma as one can see from Fig. 1. The most interesting recent achievement of the model is its ability to explain the surface thermal anomalies registered by the remote sensing satellites (Tramutoli et al., 2001; Tronin et al., 2002; Ouzounov and Freund, 2004). The set of plasma-chemical reactions starting as a result of the ionization by radon, involves the changes of the water vapor content in the near ground layer of atmosphere leading to the changes of the relative humidity and the surface air temperature (Pulinets et al., 2004). The spatial and temporal scales of the thermal precursors are very similar to the ionospheric ones which prove once more their interrelation.

2.3. Precursors identification

Due to high variability of the space plasma parameters and their dependence on many factors, many of solar and magnetospheric origin, it is not a simple task to identify the registered variations as a consequence of the earthquake preparatory process. It is not enough to find the geographic or temporal coincidence with the area of seismic activity. It may be just coincidence. Therefore the multidimentional/multiparameter portrait of the precursor should be created, which permits us to identify

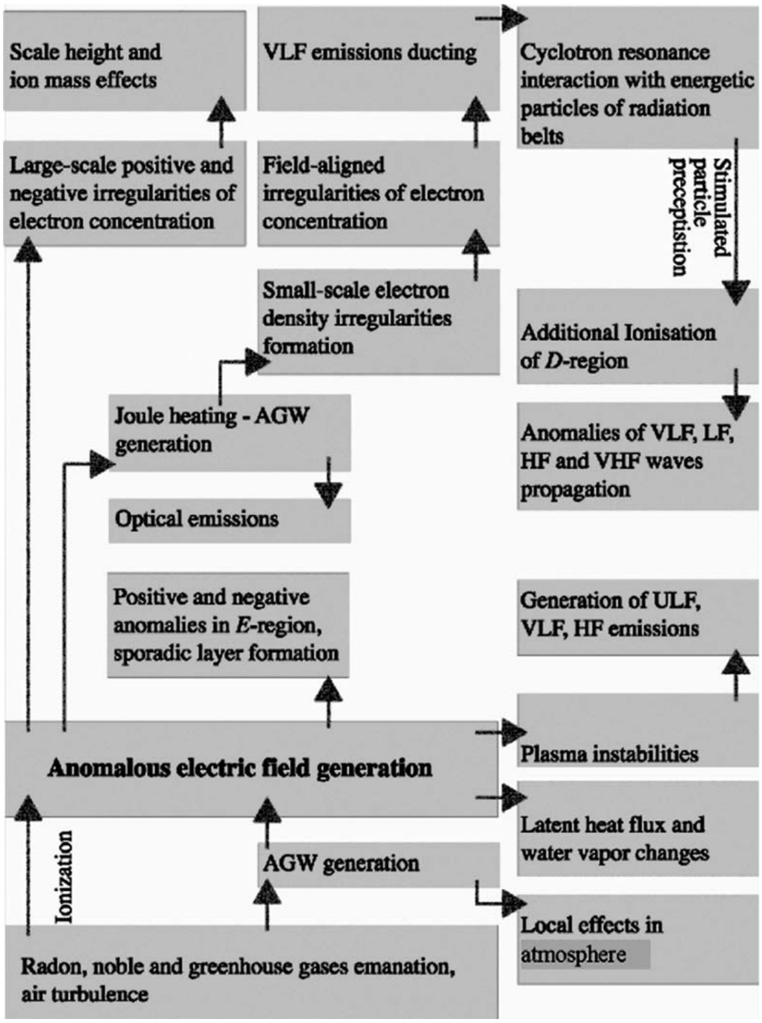

Fig. 1. Schematic presentation of the physical model of seismo-ionospheric coupling (after Pulinets and Boyarchuk, 2004).

the precursory variations unambiguously. It is the reason why the registration of only one parameter is absolutely not enough. At least some combination of parameters should be used which within the frame of the physical model permits to identify the precursor. As an example we can propose the combination of the topside sounder and the mass-spectrometer. It is well known that the electron concentration in the ionosphere can significantly change during the magnetic storms what can mask the precursory variations because, in general, the variations during the magnetic storms are more pronounced. But it is also known (Szuszczewicz et al., 1998) that during the magnetic storm the mean ion mass in the ionosphere increases. Contrary, before the earthquake the mean ion mass in the ionosphere decreases (Bošková et al., 1994; Pulinets et al., 2003). So comparing the data of topside sounder and mass-spectrometer, one can unambiguously distinguish between the storm-time and seismo-ionospheric variations of the electron density in the ionosphere. The special technique was elaborated also to detect the variations of the mean ion mass using the topside electron density profile scale height (Pulinets et al., 2003).

2.4. Prediction capability

As it was mentioned earlier, if one wants to speak on the short-term prediction, the special procedure should be fulfilled which determines the three main parameters of the approaching earthquake: place, time and the magnitude. Not all of the precursors mentioned above are able to give such information. For example, the particle precipitation is expected only from the radiation belts which are limited in L-shells, i.e. in latitude. So not at all latitudes this precursor will be registered. Due to the particle longitudinal drift the precipitation pattern will be stretched in longitude, which will also embarrass the epicenter position determination. It means that regardless the particle precipitation is involved in the chain of the processes within the ionosphere and magnetosphere connected with the earthquake preparation, its prediction capability is rather low.

Very solid and interesting results are demonstrated by the thermal measurements recently (Tramutoli et al., 2001). But from some records (Fig. 2) one can see that the whole tectonic fault or even larger linear geological structures are activated which also makes difficulties in the determination of the epicenter position.

From the analysis of all types of precursors known up to now the large scale ionospheric irregularities were recognized as the most appropriate from the point of view their prediction capability (Pulinets, 2004). Not to repeat the discussion and figures from the cited paper, we only take the conclusive remarks.

1. The position of the impending earthquake epicenter can be determined as the projection of the center of modified area in the ionosphere on the ground surface along the geomagnetic field line. The error is estimated as 100–200 km.
2. The time of the approaching earthquake has the expectation period 5 days after warning.
3. The magnitude of the approaching earthquake can be estimated using the Dobrovolsky formula (Dobrovolsky et al., 1979).

2.5. Final ranging

Because of the paper limitations we are not able to discuss here every precursor. The discussion above demonstrates only the approach which should be used to make a proper selection. After the detailed analysis the final order of the precursors looks in the following way:

- Ionospheric precursors.
- Thermal precursors.
- Mean ion mass changes.
- VLF emissions.
- Particle precipitation.
- ELF emissions and quasi-DC fields.
- Small-scale irregularities.
- Optical emissions.

Though the thermal precursor is quite a new phenomenon, it have got the second in our list place due to rapid development of the technique during last 3 years and relatively rich statistics gained (Cervone, 2004).

2.6. Coordination with the ground based measurements

It is natural that the satellite system is not a standing alone project, and will work in the close cooperation with the ground based segments of the seismic monitoring. They include both the traditional seismological techniques (seismometers, strain meters, inclinometers, geochemical measurements, etc.) and developed recently methods of registering of the seismoelectromagnetic emissions (Ismaguilov et al., 2001) and anomalous radiowave propagation technique (Hayakawa et al., 1996; Kushida and Kushida, 2002). Anticipation time of 5 days warning given by the satellite will permit to activate the ground based segment for the possible detection of the earthquake epicenter position with the higher precisions than it is given by the satellite.

3. Ionospheric measurements discussion

Taking into account that the measurements of the electron concentration distribution have the highest priority in our list of precursors, it is necessary to select the

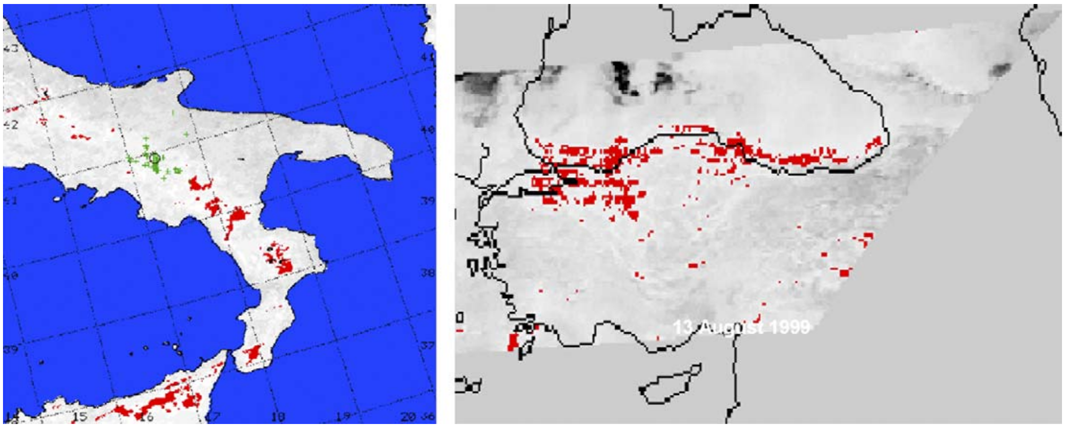

Fig. 2. Left panel – Anomalous surface temperature increase one day before the Irpinia earthquake in Italy (Tramutoli et al., 2001) registered by NOOA/AVHRR radiometer. Right panel – anomalous temperature increase registered4 days before the Imit earthquake in Turkey by Meteosat-TIR instrument (Tramutoli et al., 2003).

most appropriate technique for application onboard the satellite. There are three techniques known up to now which are able to retrieve the vertical profiles of the electron concentration: topside sounding (Pulinets and Benson, 1999), ionospheric tomography (Kunitsyn and Tereshchenko, 2003), and radio occultation technology (Hajj and Romans, 1998). Let us compare their advantages and disadvantages.

From the point of view of the refinement and precision of the ionosphere vertical structure reconstruction the ionospheric tomography technique is the most advanced technology. It permits to reconstruct the whole profile of the electron concentration, i.e. below and over the peak. But at the same time it has several disadvantages which are impossible to avoid. The most serious one is that this technique requires having the meridional chain of ground based receivers. Immediately we obtain the serious limitation in global coverage. Up to now there are only three or four actively working chains in the world which cover less than 1% of the ground surface. Not every of countries suffering from the earthquake damages, is able to organize the continuous tomography monitoring at their territories. The other disadvantage is following. Even you have the desired chain, you are able to reconstruct the ionosphere structure only in one vertical plane corresponding to the meridian where your receivers are installed, and no chance to have the longitudinal distribution of the ionospheric parameters what is extremely important in the ionospheric precursors monitoring.

The radio occultation technique is able to retrieve the whole vertical profile of the electron concentration also. These profiles are obtained when the LEO satellite "observes" the occultation of one of the GPS satellites. The distribution of such occultation is sparse, and with the help of only one satellite you are not able to track the day-to-day changes of the ionosphere structure at the same place (having in mind the seismically active area) in the same geometric configuration of occultation and at the same local time. This makes the obtained occultation profiles useless in the precursors monitoring, even with high quality of the obtained profiles. Concerning the quality of the profiles, there are also some doubts if we speak on the equatorial and low latitude ionosphere. The ray path geometry during occultation can be very different, and in some cases the ray can pass through the middle latitude ionosphere at some heights, and through the equatorial anomaly at other heights, and what a kind of profile is reconstructed in such configuration, is a great question. Probably, the satellite constellation like COSMIC can improve the solution of this problem but it is the matter of future.

The topside sounding technique is relieved from disadvantages mentioned above. It gives the global regular grid of measurements and has no limitations nor in global coverage (land/ocean), nor in longitude. Regardless it is able to retrieve only the topside part of the vertical profile, the results of the previous studies of the ionospheric precursors by this technique show that it is quite enough (Pulinets and Legen'ka, 2003). The main effect, important to the precursor's identification (the scale height/mean ion mass changes) is observed in the topside ionosphere. And the last, but probably not the least is that up to now there is no one publication on the ionospheric precursor registered by ionospheric tomography or radio occultation techniques while there are plenty of results obtained with the help of topside sounding. It means that for the present moment the topside sounder is the only device which can be recommended as the principal instrument for the satellite ionospheric precursors monitoring.

4. The satellite payload configuration

Of course, the main limitation in the satellite system creation is the budget. One should to conform his desires to his abilities. But even the smallest budget it seems cannot justify the launch of the satellite with only one device from the perspective of the precursor identification. The possible minimal (from one side) and optimal (from the other side) configuration of the mini-satellite was described in (Jason et al., 2003). One can find in the cited paper well-grounded recommendation to install onboard the mini-satellite the three instruments: topside sounder, mass-spectrometer and magnetometer. The magnetometer is used in two-fold purposes – to control the satellite attitude and possibly to measure the ELF seismogenic emissions.

4.1. The comprehensive payload configuration

Here we will present the satellite configuration as it was proposed within the frame of "Preduprezhdenie" scientific project of the Russian Academy of Sciences, and then was implemented in the Russian "Vulkan" satellite constellation which is the part of the Russian Space Program for 2006–2010, Table 2.

During the project discussions the problem of electromagnetic compatibility of sensitive ELF/VLF measurements and topside sounder transmitter raised. The author's opinion is that the compatibility can be provided within the frame of one satellite as it was done at Intercosmos-19 and Cosmos 1809 satellites but decision was made for the "Vulkan" project to make the two level configuration putting the sensitive electromagnetic measurements at low orbit (500 km circular) satellites, and the topside sounding and local plasma measurements at higher orbit (1000 km circular) satellites.

One can wonder why the thermal IR sensors are not provided at the proposed satellite payload. The answer

Table 2
The recommended payload for the dedicated satellite of short-term earthquake precursors monitoring

No.	Instrument	Measured parameters
1	Topside sounder	Vertical profiles of electron concentration (topside)
2	Mass-spectrometer	Ion composition at the satellite orbit altitude
3	Local plasma spectrometer	$T_{e\perp}$, $T_{e//}$, $T_{i\perp}$, $T_{i//}$, N_e, N_i
4	ELF/VLF wave complex	Multi-component measurements of the electromagnetic emissions and fields in ELF/VLF frequency bands
5	Particle spectrometer	Measurements of energy spectrum and pitch angle distribution of energetic particles
6	Drift meter	Local DC electric field measurements
7	Optical spectro-photometer (optional)	Measurements of optical emissions in oxygen lines 5577 and 6300
8	Radio beacon (optional)	Emitting coherent signals at two frequencies for ionospheric tomography
9	GPS receiver (optional)	Radio occultation measurements

is very simple. The number if remote sensing satellites at present moment is quite sufficient (and it is still growing) to provide the necessary thermal measurements using the data of already existing satellites.

5. The satellite constellation

As it was mentioned earlier, there exist very large distance between the scientific studies of the space plasma precursors of earthquakes with the help of satellites and their real time monitoring including the possible short-term prediction. In the second case the very important factor is not to miss the target, i.e. to register precursors for ALL impending earthquakes starting from the magnitude 5 as the threshold value. The probability of the precursors registration is based on their main morphological and statistical properties (Pulinets et al., 1998, 2002, 2003; Chen et al., 2004). From the analysis of the precursors characteristics it was determined that it is not possible to provide the complete global coverage for all earthquakes with one satellite and it is necessary the satellite constellation.

5.1. Determination of the number of satellites in constellation

From the statistical studies it was determined that the ionospheric precursors start to appear in average within the interval 5 days before the seismic shock with magnitude higher than 5 (Liu et al., 2004a). The existence of magnitude threshold equal to 5 is explained within the frame of the physical model of seismo-ionospheric coupling (Pulinets and Boyarchuk, 2004). Anomalous electric field from the ground surface starts to penetrate into the ionosphere when its spatial scale exceeds 200 km what approximately corresponds to the size of the earthquake preparation area for magnitude 5. The ionospheric variations associated with the earthquakes with magnitude less than 5 are practically undetectable.

Within the 5-day interval before the seismic shock the precursors can appear every day or (in the worst case) only once. As it was shown by Pulinets et al. (1998) the precursor duration (in the form of deviation of the critical frequency from undisturbed level) lasts nearly 4 h. It means that the number of satellites should cover the whole 24 h of LT with span no more than 4 h. This task can be fulfilled (taking into account the ascending and descending parts of the satellite orbit) by 12 h/4 h = 3 satellites. To increase the probability of the satellite position coincidence with the precursor development it worth to narrow the local time sectors covered by satellite by means of increasing the number of satellites in constellation. It is proposed to have the 4-sun-synchronized orbit satellite constellation with orbits distributed equally in longitude (or in local time). In this equidistant in longitude distribution the sun-synchronization of the orbit is not the severe requirement. In principle it is enough to have the high inclination orbit (~83°).

5.2. Satellite orbit inclination and altitude

The problem of the orbit inclination is connected with the ionospheric precursor's dependence on the local time (Pulinets et al., 1998). In these circumstances the most appropriate identification of the precursors can be accomplished in the form of creation of the LT maps for the critical frequency distribution together with vertical profiles (and correspondent scale height calculation), (Pulinets and Legen'ka, 2003; Pulinets et al., 2003). To produce the LT maps the satellite should appear over the region under control every day at the same local time during the time interval equal at least to 5 days. Such conditions can be provided by the orbit which inclination is sufficiently high or is sun-synchronous. If the satellite constellation is created, and contains three or four satellites, the sun-synchronous orbit is not a problem. But for the single dedicated satellite it can be a problem which is explained as follows. Every region due to its unique tectonic and geological structure has its own dependence of the precursor on the local time. For example, Liu et al. (2000) report the negative deviation of the critical frequency is usually observed at 12–18 LT, and it is the main ionospheric precursor for

Taiwan. So, if you have only one satellite at sun-synchronized orbit in the sector, say 10 LT, you would be never able to register the precursors over Taiwan due to the local time problem. But the high inclination satellite will drift in local time by several minutes every day, and finally it will reach the wishful sector of the local time. That is why, we do not insist to have the sun-synchronized orbit for satellites registering ionospheric precursors of earthquakes.

At the same time the low inclination orbit cannot be recommended as well. Strong longitudinal effect observed in low latitude and equatorial ionosphere (Deminova, 2003), rapidly changing local time along the satellite orbit plus local time dependence of the precursors itself will extremely complicate the precursor identification.

The altitude of the satellite orbit is determined by the topside ionosphere structure and conditions of the vertical topside sounding. It is known that during high solar activity and increased geomagnetic activity the peak altitude in the area of equatorial anomaly can reach extremely high values, up to 700 km. To have the satellite always above the peak, it is necessary to launch the satellite at the higher orbit. Another very important factor – is the transition height (the height where the prevailing in the F2 layer O^+ ion is replaced by the light ions of He^+ and H^+). At this altitude the ionosphere scale height is changing, and from the Intercosmos-19 data we know that the transitions height is close to 750 km. Taking into account that the scale height variations are very important in the process of the precursors identification, we need to have the satellite well above the transitions height. In these circumstances the recommended altitude with the topside sounder onboard as the main instrument, will be of order of 1000 km.

5.3. Data collection and satellite schedule

In satellite data managing always the compromise should be achieved between the volume of onboard memory and the bandwidth of the download link. The number of ground based receiving telemetry stations and their longitude distribution determines also at how many orbits per day you are able to download your data. Existence of the satellite constellation complicates the task. The other complication is necessity to have almost continuous and real-time data processing if one starts to speak on the short-term prediction. One of the possible solutions is presented in Fig. 3 (Pulinets, 1989). Using the geostationary satellite-retranslator facilitates the data transmission from the all satellites almost continuously. Every satellite at least at the part of every its orbit is in line of site of the geostationary satellite. Such system layout permits to have the global map of the ionosphere in the real-time and make operative decisions.

In some satellite projects the so called ‘‘burst regime’’ is used for data recording, what means the increased data sampling during passing the satellite over specified territories (in our case – seismo-active areas of the globe). It seems that such approach in the case of the earthquakes precursors monitoring is not well substantiated due to the following reasons. First, for the severe earthquake the modified area within the ionosphere can reach 40° in longitude (and even more), some effects can be observed in magnetically conjugated areas. The

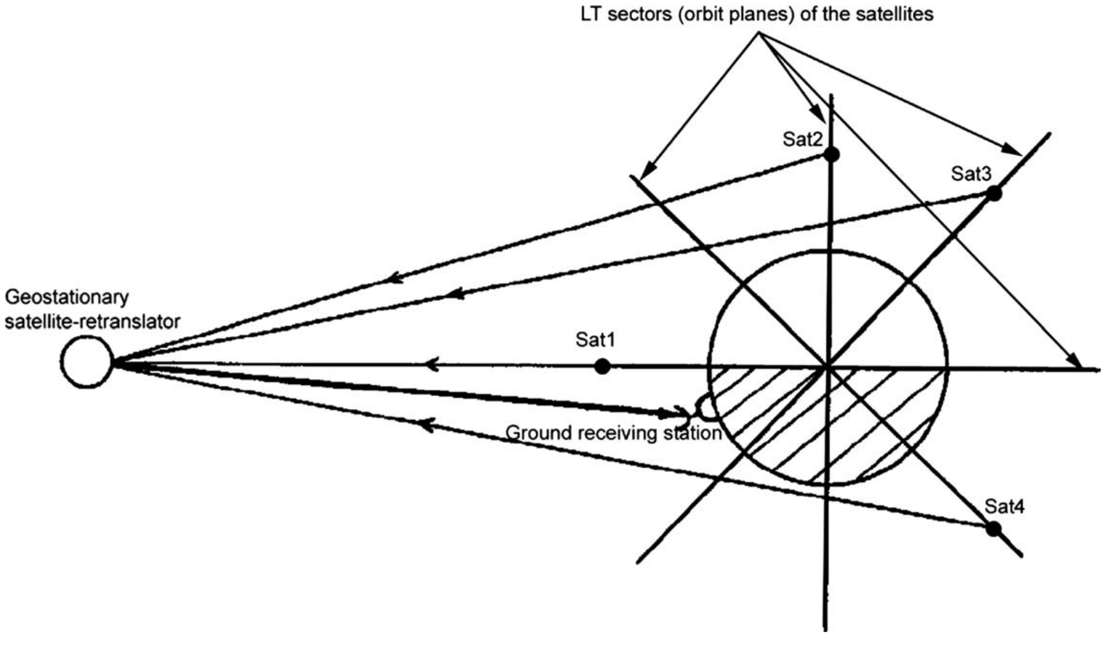

Fig. 3. Proposed satellite constellation layout for operative data download.

limitation of data sampling by narrow bands of longitude can lead to missing of some important information. Second, the ionospheric precursors – are anomalies from the point of view of undisturbed ionosphere. The anomalies can be detected only if the background conditions are well known. And it is very important to have the data of equal quality as for background, so for anomalies. In other case one can create the artificial anomalies by changing the data sampling rate. So our recommendation is to have the same data sampling rate for all passes of all satellites.

6. Conclusion

In the present paper some recommendations were developed for the creation of the satellite system of the short-term earthquake precursors monitoring. The most attention is devoted to the ionospheric precursors as the most promising from the point of view of their prediction capabilities demonstrated in the paper. The main conclusion is that the global monitoring of the short-term earthquake precursors from space is possible, but the satellite constellation is necessary if one wants to use this information in practical purposes of short-term earthquake prediction. The Vulkan constellation (if properly configured) can be the possible candidate of such system.

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