REMOTE SENSING AS A TOOL OF SEISMIC HAZARDS MONITORING*

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ABSTRACT

The possibility of the detection of the seismic hazards precursors in the ionosphere is continuously discussed by the scientific community. Some experimental facts give realistic evidence of the ionospheric-lithospheric interaction existence provoked by the seismic activity.

The effects which have been detected in the ionosphere in the case of "powerful" earthquake are discussed.

A new experimental study which will improve our knowledge of these phenomena is planned to execute onboard the remote sensing satellite SICH-1M which has to be launched at the end of the year 2002 in frames of Ukrainian National Space Program. It will carry onboard the international scientific experiment VARIANT. The instrumentation of this satellite will allow to extend the scientific goals of the mission on the study of seismogenic phenomena in the ionosphere.

Also correlated measurements in frames of the other space mission – French microsatellite DEMETER (launch in 2002) - are planned, as well as synchronous onground observations of radiated by VLF transmitters waves over the seismoactive regions in Japan (AIRUS project).

The details of these experiments and the discussion of the possible mechanisms of the lithospheric-ionospheric interrelations are given in the report.

1. INTRODUCTION

It is rather evident now that seismic activity can be reflected in ionosphere by electromagnetic emissions which can not only accompany but also precede natural hazards. An analysis of probability of such phenomena was made in (Henderson *et al*, 1993) and it was shown that this probability is very poor. It seems that such conclusion is rather trustworhy only because the data of satellites designed for another purposes were processed. The estimation of expected levels of electromagneticfluctuations in the ionosphere provoked by seismic activity shows (Parrot, 1995) that only specially designed electromagnetically clean satellite has opportunity to measure such signals.

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The idea of the study of electromagnetic phenomena in ionosphere related with earthquakes was born in former Soviet Union after first occasional successfull observations of corresponding magnetic fluctuations onboard the “Interkosmos” satellite. In late eighties the scientific proposal was already prepared but only now such an experiment is close to the realizastion.

2. THEORETICAL BACKGROUND

Observations of seismogenic perturbations of the ionospheric plasma density are the purpose of a new experiment proposed to execute onboard of SICH-1M satellite. These observations are interesting because the generation of plasma inhomogeneities is the most common signature of seismic impact upon the ionosphere. Moreover, some scientists even assume that the generation of electromagnetic earthquake precursors is the secondary effect that accompanies the ionosphere density variations. For example, following this approach the generation of "VLF-belts" over earthquake epicenter is explained as a guiding of whistlers by seismogenic plasma ducts. There was no possibility before to check experimentally these hypotheses because the electromagnetic phenomena have been detected by satellites separately from the ground-based observations of the ionospheric irregularities.

Accordingly to a large set of observations the variations of plasma density appear a few days before the earthquake in the lower and middle altitude ionosphere (in D, E and F_1 layers). These perturbations usually don't penetrate into upper ionosphere and that is why they can't be detected *in situ* from a high altitude satellite. The experiment onboard SICH-1M satellite is aimed at the supplementing of the electromagnetic measurements in the upper ionosphere by the simultaneous observations of corresponding variations in the lower ionosphere.

Some mechanisms of seismogenic effect upon the ionospheric density profile are proposed. The main part of corresponding data has been established by means of radiophysical sounding (Liperovsky *et al*, 1992). The following effects have been detected in the case of "powerful" earthquake:

- compression of the ionosphere F layer density in a wide “belt” over the earthquake epicenter (extended about thousand kilometers in the latitudinal direction and in a few thousands kilometers in longitudinal direction);
- increasing of the frequency of sudden and quick E_s layers spreading (in time interval < 15 minutes),
- generation of the drifting ionospheric inhomogeneities (slow MHD waves with periods T~2÷3 hours),
- turbulent motion of plasma layers and the generation of small-scale plasma inhomogeneities (with inhomogeneity scale about tens meters and more and plasma density variations $\delta n_p / n_p \sim 0.01$).

In the case of "weak" earthquake the most noticeable feature is the ionosphere heating which causes the plasma flowing out of the region of increased pressure. As a result the F layer density decreases around the epicenter in a zone with radius of a few hundreds kilometers. All mentioned phenomena have been detected in about one-three days before shocks. The notions “powerful” and “weak” earthquake here are conditional because it is clear that ionospheric response depends on many factors, not only on the magnitude of future shocks. The conditional threshold accepted in the literature has been chosen at the magnitude $M=5$: $M>5$ means powerful earthquake, $M<5$ – weak earthquake.

There are few reasonable hypotheses suggested in the literature in order to explain these data. An “acoustic” hypothesis is that the ionosphere experiences the influence of acoustic gravity waves propagated in the neutral atmosphere. There are no reliable experimental facts about the acoustic gravity waves generation before earthquake. Nevertheless the estimations show that a number of physical processes foregoing to earthquake must generate these waves, for instance, the emanation of greenhouse gases (CO_2 and others) from the crust. The dissipation of acoustic gravity waves in the upper atmosphere disturbs the energetic balance of the ionosphere and may stimulate large-scale plasma motion (drift, convection).

The hypothesis about electrostatic nature of lithosphere-ionosphere coupling considers seismogenic variations of electric field in the capacity “Earth-ionosphere” (Martinenko *et al*, 1994 , Kim *et al*, 1995). The idea is that the pre-earthquake situation is characterized by the emanation of radon (and a number of other gases and metallic aerosols) which strongly affects the air conductivity. Local variations of the Earth electrostatic field may reach some kV/m near the ground penetrating into the ionosphere with attenuation $\sim 10^{-8} \ldots 10^{-6}$; probably it is enough to give rise to ionospheric plasma drift motions and instabilities. For the first time this hypothesis has been suggested in order to explain the effect of Chernobyl accident upon the radio wave propagation in waveguide “Earth-ionosphere” (Martinenko *et al*, 1994).

3. VARIANT EXPERIMENT

VARIANT is an international space experiment which will execute electromagnetic measurements in ionospheric plasmas. This experiment will be performed onboard the Ukrainian remote sensing satellite SICH-1M, which will be launched in 2000 at the polar circular orbit with the inclination of around 83 ° and altitude 670±30 km. The scientific payload includes three instruments for registration of space current density: a split Langmuir probe, a Rogovski coil and a Faraday cup. The first two of these instruments are dedicated to measure current density variations and the last the particles’ fluxes. The scientific equipment also includes sensors for measurements of the electric and magnetic field fluctuations in the frequency range from DC to 40 kHz. Main objectives of the VARIANT mission are as follows:

- direct comparison of the spectral characteristics of the electric and magnetic fields with the characteristics of the field aligned currents in the polar regions; mapping of the field aligned current distribution;
- the field aligned current structures comparative study with the characteristics of the ionospheric convection observed by the system of radars SuperDARN;
- comparative study of technological problems associated with different techniques of current density measurements;

and the secondary objectives are:

- active experiments with the onboard radar;
- registration of the signatures of the seismo-active and volcanic phenomena; investigation of the man-made impact upon the ionosphere (anthropogenic hazards, pollution, etc).

Following the major project goal – the study of the ionospheric plasma response on the influence of the magnetosphere and solar wind from the top side, and the atmosphere and the Earth, from the botom side, – a corresponding set of electromagnetic experiments onboard the SICH-1M satellite is planned.

As it was mentioned, onboard satellite instrumentation includes three instruments for the registration of electric current density as the main signature of ionosphere-magnetosphere coupling. These particular instruments should allow in future the separation of the spatial and temporal variations onboard single satellite. This possibility is based on the idea to carry out the direct measurements of the current layers by crossing them (Vaisberg *et al,* 1989). This gives rise to the possibility to determine the current density of the plane wave, that really allows the independent evaluation of curl **B**. If the magnetic field fluctuations are measured simultaneously one can get the distribution of the **k**-vectors, and then calculate the real wave frequency (Krasnossel'skikh *et al,* 1991). The scientific equipment devoted to this task includes split Langmuir probe (WZ) (Vaisberg *et al,* 1989), Rogovsky coil (ZF) (Krasnossel'skikh et al, 1996) and Faraday cup (FC) (Safrankova *et al*, 1995). The simultaneous measurements of electric and magnetic field fluctuations in the ELF/VLF frequency band will be performed making use of the electric and magnetic fields sensors (instruments EZ, FZM and WZ). The waves in this frequency range are supposed to be associated with different types of the ionospheric disturbances. They are also assumed to be the most typical signatures of the seismogenic effects. Taking all this into account, the proposed payload includes 4 types of sensors (table 1).

The spectral noise density of all sensors is given there for the frequency 100 Hz. The spatial density of electric current measurements represent a special and very important task of the experiment which procures the unique possibility to justify, validate and compare three existing methodologies of the ionospheric current registration in space experiment as well as to perform the inter-calibration of the instruments. The proposed scientific payload also includes a VLF analyser (CBK, Poland, J.Juchniewicz) which allows the fulfilment of SICH-1M experiment objectives.

Table 1. Scientific Payload Proposed for SICH-1M Mission

№	Device	Measurement	Designed by
1.	Wave probe WZ	Electric current density **J**: Frequency range 0.1 Hz … 40 kHz Noise 10^{-12} A/cm^{2}Hz$^{1/2}$ Magnetic field vector **B**: Frequency range 0.1 Hz … 40 kHz Noise 10^{-13} T/Hz$^{1/2}$ Electric potential φ: Frequency range 0.1 Hz … 40 kHz Noise 10^{-6} V/Hz$^{1/2}$	LC ISR, Ukraine (V. Korepanov) IKI, Russia, (S. Klimov)
2.	Rogovsky coil ZF	Electric current density **J**: Frequency range 0.1 Hz … 400 Hz Noise 10^{-12} A/cm^{2}Hz$^{1/2}$	LPCE/CNRS, France (F.Lefeuvre, V. Krasnosselskikh)
3.	Electric probe EZ	Electric field vector **E**: Frequency range 0.1 Hz … 200 kHz Noise 10^{-6} V/Hz$^{1/2}$	LC ISR, Ukraine (V. Korepanov)
4.	Faraday cup FC	Electric current density **J**: Frequency range 0.1 Hz ... 1 kHz, Noise 10^{-10} A/cm^{2}Hz$^{1/2}$	Sheffield University, United Kingdom (H. Alleyne, M. Balikhin)
5.	DC magnetometer FZM	Magnetic field vector **B** Frequency range DC - 1 Hz	LC ISR, Ukraine (R. Berkman, S.Belyayev)

As it was said, small variations of the ionospheric plasma parameters can carry indications of the Earth’s seismic activity. In a few hours or days before earthquakes the variations of spectra and intensity of air glow, ULF-VLF electromagnetic fields, various ionospheric plasma phenomena are supposed to detect both by the satellite and ground based facilities, available in the vicinity of the epicentre of the earthquake. Today the understanding of the nature of these phenomena is far from being complete. Its investigation is related to such problems of ionospheric plasma physics as energetic balance of the ionosphere and its properties as the electromagnetic medium.

Now it is accepted that the typical signatures of seismogenic effects in the ionosphere are electromagnetic emissions (Parrot, 1995). Most of the observations onboard satellites that have detected such emissions found them in the VLF range (as whistler mode) and more seldom in the ULF range (as Alfven mode). A great amount of data have been obtained by INTERCOSMOS-18,19 and 24, OGO-6, NIMBUS, AUREOL-3, GEOS-2, INTERCOSMOS-BULGARIA-1300, DE-2, COSMOS-1809 missions. Specific noise-like VLF electrostatic emissions have been detected in the range of few tens kHz over the earthquake epicentre within 200 to 300 km in the latitudinal direction and over a greater distance in the longitudinal direction. These emissions originated about 10 to 20 hours before the main shock and continue over about the same time after it. They reached their intensity peak at the instant of the main shock. ULF(~1 Hz) oscillations have been recorded several hours before the main shock in a narrow magnetic field tube (40...100 km along the satellite trajectory) originating in the epicentre of the earthquake. In the case of weak earthquake the magnetic field disturbances had spectral density of the order of 0.2...0.5 $nT/Hz^{1/2}$ at altitudes of 800 to 900 km and frequency about 8 Hz. To improve the reliability of such data is also one of the goals of the planned experiment.

For the verification of the hypothesis that the ionosphere experiences the influence of atmospheric acoustic gravity waves emitted by seismic oscillations of the Earth surface, since the frequencies of seismic waves range in the band 0.001…1 Hz, it is natural to speak in terms of the infrasonic channel of lithosphere-ionosphere coupling. It is also supposed that the dissipation of acoustic gravity waves may trigger the instability of the magnetospheric convection and give rise to the development of perturbations, that can in their turn propagate from the ionosphere upwards in the form of the Alfven waves. It can be assumed that the crossing of the ionospheric dynamo region (at height 80…150 km) by the infrasonic waves can generate electromagnetic Alfven waves with the same frequency. Such waves may be registered onboard the satellite using its scientific payload.

LCISR operates also powerful ground based source of acoustic radiation, which will be used as test equipment to check the possibility of the ionosphere excitation by acoustic channel. Preliminary experiments demonstrate the effect of acoustic waves on the ionosphere including the generation of ELF magnetic field perturbations caused, probably, by Alfven waves generation. The SICH-1M mission provides a good opportunity to carry out the combined experiments with the ground based emission of acoustic waves and the detection of ionospheric plasma response by the satellite.

4. CONCLUSION

The remote detection of seismic hazard precursors is so vital problem that any progress in this direction has to be welcome. The described experiments are still one attempt to get more experimental data allowing to go further in this study. It is supposed that there is enough high level of probability proven by the precedent theoretical research to detect in the ionosphere the changes which could be attributed to the forthcoming earthquakes. There is a big hope to reveal the relation existence between seismic activity and corresponding ionospheric perturbations on the basis of such multi-points experiment. The seismogenic anomalies of the ionospheric parameters attributed as earthquake precursors and/or accompaniments could be established.

We emphasize that in spite of a great number of publications and increasing practical interest to the works in the branch of earthquake forecast the results obtained in this field till now are rather poor: separate experimental facts, some attempts of data systematization and some theoretical hypotheses. Existing experimental background does not permit to outline the more or less reliable picture of the seismogenic phenomena occurring in the ionosphere. We have to realize what is already established and what is necessary to ascertain first of all in the proposed satellite experiments. For this purpose some tentative patterns of the ionospheric earthquake precursors have been constructed. These patterns are mostly working hypotheses that must be examined in the future.

To verify the basic ideas about the nature of lithosphere-ionosphere coupling we propose to combine the local satellite and remote sensing ground-based measurements ("Variant" mission onboard SICH-1M satellite, DEMETER microsatellite and AIRUS radiophysical subionospheric sounding with Japanese network of VLF receivers). The proposed project will be also helpful for the study of non-seismogenic types of the ionospheric perturbations.

During two years of the planned active phase of this multi-points experiment the “survey” of 400 earthquakes with a magnitude ≥5, between 0 and 5 hours before the shock, and with $\Delta_{lat} < 10°$ and $\Delta_{long} < 10°$ is expected.

5. REFERENCES

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