Telecommunications and Radio Engineering, 74 (9):841-849 (2015)

INVESTIGATION OF MIDDLE LATITUDE LOWER IONOSPERE RESPONSE TO METEOR SHOWERS

A. M. Gokov

S. Kuznets Kharkiv National University of Economics
of the Ministry of Education and Sciences of Ukraine
9a, Lenin Ave., Kharkiv 61166, Ukraine
E-mail: amg_1955@mail.ru

It is experimentally determined that during the periods of maximal inflow of dust particles associated with meteors into the ionospheric plasma quasi-periodic variations of amplitudes Ao and Ax of partially reflected signals and radio noise are observed during several dozens of minutes that is apparently stipulated by the infrasonic waves generation. It is detected that during the above periods in the night middle latitude ionospheric D-region at the altitude z > 80 km it is observed an episodic growth of electron concentration values with the duration from several to dozens of minutes by more than 50…100% as compared to the test days that can be explained by the effects of charge and dynamics of dust particles.

KEY WORDS: *lower ionosphere disturbances, time and altitude variations of amplitudes of partially reflected signals and radio noise, electron concentration, infrasonic waves, mid-latitude ionospheric D-region, meteor showers*

1. INTRODUCTION

Natural lower ionosphere disturbances associated, for example, with powerful earthquakes, solar terminator, volcanoes, heavy rainstorms, powerful atmospheric phenomena (passage of atmospheric fronts, cyclones and anticyclones etc.), and solar eclipses, have not been investigated sufficiently by now.

They often exert a substantial influence upon the Earth atmosphere and ionosphere and, therefore, represent a large interest for understanding the physics of ionosphere and solving a number of applications in telecommunication, radio navigation etc.

The partial reflection (PR) technique (see, for example, [1–9]) is most often used for studying the events occurring in the above cases in lower ionosphere. It is explained by an acceptable accuracy while obtaining data about time and altitude variations of basic parameters of lower ionosphere and radio noises and the possibility of performing continuous long-lasting (dozens of hours to several days) observations with the time resolution from several seconds to several minutes and the resolution upon the altitude of 1.5–3 km. The latter characteristic is a very advantageous difference between the PR technique and other methods used for investigation of the Earth lower ionosphere, for example, the rocket ones, which are of episodic nature.

Investigation of the Earth's lower ionosphere (within the altitude range from 80 to 120 km) represents a large interest because this is the least investigated region of the atmosphere. Difficulties of performing investigations at the altitudes concerned are related to the fact that they are inaccessible for high-altitude balloons. At the same time, the air density at such altitudes is still high that hampers motion of the Earth artificial satellites. Therefore, the range of techniques used for investigation and diagnostics of this altitude region is rather limited. Direct experiments at the altitudes concerned are performed with the help of transit rockets only.

It is known that natural disturbances possess a broad range of duration – from several seconds to several dozens of hours.

During recently there are performed intensive research works both in the sphere of physics of dust-and-gas clouds in the atmosphere, as well as in the sphere of physics of silver clouds and polar mesosphere radio reflections representing by themselves clouds of ice particles with nano- and microscale dimensions in the ionospheric plasma at the altitudes of 80–95 km. In that conditions, various processes are running on the surface of dust particles, of which the electron and ion recombination can be separated. Uncompensated electron and ion fluxes as well as the influence exerted by the photo effect may result in negative or positive charging of the dust particles.

In the event when the ionospheric plasma contains charged particles of dust, it goes about the dusty plasma of the ionosphere. Meteor showers serve as one of the sources of dust in the ionosphere at the altitudes of 80–120 km.

The altitudes of meteors appearing usually lie within the limits of 80-130 km, they are systematically increasing with the increase of the meteor shower velocities.

The altitudes of meteors disappearing usually lie within the limits of 60 to 100 km and they are also increasing with the increase of the meteor shower velocities and with transition from more bright to less bright meteors. Very bright bolides can disappear at the altitudes from 20 to 40 km.

The meteor substance inflow exerts a substantial influence upon impurity gas, ion and aerosol composition of the upper atmosphere as well as upon a number of processes in the upper atmosphere: formation of silver clouds, sporadic layers E_s of the ionosphere etc.

Maximal concentration of the dust particles associated with meteor showers is observed at the altitudes of 80–90 km and amounts to more than 10^4 cm^{-3} [10,11].

Convective transfer of volcanic origin particles and the particles of soot associated with great fires [12] cannot be excluded. Dust particles can also be formed due to water vapor condensation.

Availability of charged dust particles in the lower ionosphere is essentially influencing upon its ionization properties [13] as well as upon the wave processes undergoing in the dusty plasma of the ionosphere.

The possibility of existence of the low-frequency dust acoustic disturbances associated with movement of charged fine-dispersed dust particles is one of the most important manifestations of the properties of the dusty plasma of the ionosphere. The frequency bandwidth of dust acoustic waves existing in the dusty ionosphere is overlapped with the infrasonic frequency domain.

In [14,15] it is shown that high-velocity motion of charged fine-dispersed dust particles during the periods of intensive meteor showers (typical size of particles is of the order of several nanometers) results in the possibility of occurrence of low-frequency dust acoustic disturbances at the lower ionosphere altitudes. Typical amplitude of electrostatic oscillations in the dust acoustic waves can essentially exceed the value of 10 V that provides for the possibility of generation of intensive infrasonic waves within the frequency bandwidth from several decimal fractions to several dozen Hertz with the oscillation amplitude comparable with the values of non-disturbed atmospheric pressure at the altitudes of 70–130 km [15].

Therefore, studying the possibility of generation of infrasonic waves with the help of dust acoustic perturbations in dusty plasma of the ionosphere and their observation near the Earth surface remains the problem of current importance. Dust acoustic perturbations can also serve as a source of the acoustic gravity waves (AGW) having the wavelengths larger or of the order of 1 km and the frequencies lying within the infrasonic domain.

Consideration of main manifestations of AGW excited by dust acoustic disturbances during the meteor showers, which can be recorded by surface-based observers, also represents an undoubted interest. Investigation of wave properties of dusty plasma of the ionosphere can also be useful from the point of view of its diagnostics.

The present paper considers the results of experimental investigation of a possible mid-altitude lower ionosphere response during the periods of meteor showers and also variations of characteristics of partially reflected SW-signals and radio noises during the above periods. The results are obtained with the help of the PR technique using the equipment owned by V. Karazin Kharkiv National University [16] near Kharkiv, Ukraine in the territory of the Radio Physical Observatory during 2000–2012.

2. BASIC RESULTS AND DISCUSSION

Time variations of the electron concentration $N(z,t)$ at various altitude levels in the mid-latitude lower ionosphere and variations of characteristics of PR-signals and radio noises at the frequencies of 2.2 and 2.31 MHz were studied during the periods of the Geminids meteor showers (one of the brightest meteor showers) in December 2006 and 2009 and the Leonids (famous for their powerful meteor storms) in November 2000 and 2001.

Observation periods:

The Geminids:

in December 2006: 5, 6, 7, 8, 9, 10, 14, 15, 16, 17, 18, 20, 21, 22 and 25;
in December 2009: 9, 14, 15, 16, 17;

The Leonids:

in November 2000: 1, 8, 9, 15, 16, 17, 18, 19, 20, 21, 22, 23 and 29;
in November 2001: 7, 14, 15, 16, 17, 18, 19, 21, 26, 28, 29, and 30.

Sounding of the ionosphere was performed with the sounding pulse propagation frequency of 1 Hz and of 10 Hz in a number of experiments.

As a rule, measurements of characteristics of PR-signals and radio noises were performed in continuous day-and-night cycles.

Basic parameters of the meteor showers are provided in Table 1.

TABLE 1: Meteor shower parameters

	The Geminids	**The Leonids**
Active between	7–17.12	13–21.11
Peak of shower	14.12	17–18.11
Zenithal hourly rate	120	480–3500
Observed velocity	35 kmps	71 kmps
Shower peak time, LT	~ 02.00 am	12.00 am – 03.00 am

There were analyzed time and altitude recordings of amplitudes of PR-signals and radio noises obtained at night time along with variations of electron concentrations N in the lower ionosphere. The values of N were calculated with the error not exceeding 30% under the technique of [17].

It was also performed visual observation of meteor showers during the unclouded days.

Analysis of the experimental data showed that basic particularities of time and altitude variations of amplitudes of partially reflected SW signals $A_{o,x}(z\ t)$, noises $A_{nox}(t)$ and electron concentration $N(z,\ t)$ for all of the above mentioned experiments can be summarized as follows:

1) during the periods of maximal inflow of dust particles associated with the meteors into the plasma of the ionosphere non-stationary mode of PR-signals and radio noises is essentially more apparent than during the periods before and after the process;

2) certain differences in behavior of $A_{o,x}(z,\ t)$ and $A_{nox}\ (t)$ during the highest peaks of the meteor showers as compared to the periods before and after them and during the test days (when there were no meteor showers) are revealed in the experiments performed:

quasi-periodical variations of $A_{o,x}(z,\ t)$ and $A_{nox}\ (t)$ are observed during dozens of minutes. In this case, there occurred a shift of the above process by altitude. Figure 1 provides an example of time-altitude profiles $< A_0^2 >$, each obtained in the experiment of 18.11.2001 (12:10 a.m. LT) during the highest peak of the Leonids meteor shower using averaging upon 50 realizations (for 5 s).

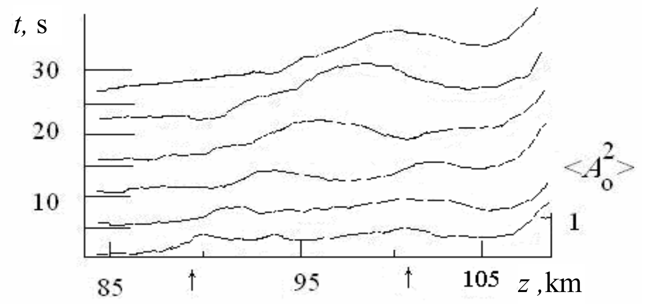

FIG. 1: An example of time and altitude profiles $< A_0^2 >$ obtained during the experiment of 18.11.2001 (12:10 a.m. LT) in the period of the highest peak of the Leonids meteor shower

There were determined the particularities that had not been observed during the undisturbed periods and on test days. A shift of the maximal value of $< A_0^2 >$ upon altitude (by 12–14 km) with time (during 30 s) can be clearly seen. A similar procedure is also occurring for $< A_x^2(z, t) >$. Estimate of the apparent vertical shift velocity of the disturbance is 350 mps. We admit that similar variations were also observed during the periods of heavy rainstorms and passage of powerful atmospheric fronts (see, for example, [4,8,18,19]).

At performing spectral processing of the dependences $A_{so,x}(z, t)$ (performed for the altitudes z = 85–105 km) during the experiment concerned, it is determined a significant increase of the spectral component energy at the frequency of 0.5 Hz that corresponds to the infrasonic band. As an example, Fig. 2 provides variations of spectral density of the PR-signal and noise mixture at different altitude levels in the mid-latitude D-region during the period of the Leonids meteor shower on 17–18.11.2001 (1– for the altitude of 95 km; 2 – for 85 km).

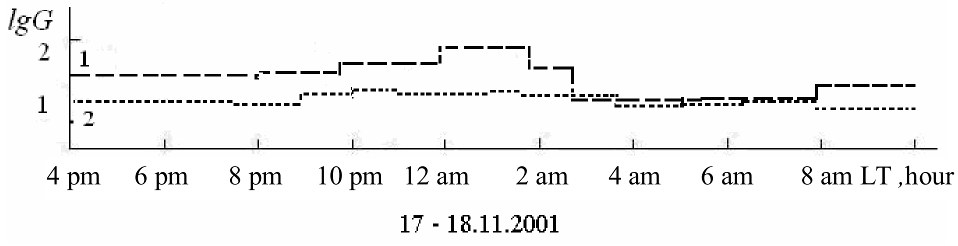

FIG. 2: Spectral density variations of the PR signal and noise mixture at various altitude levels in the mid-latitude D-region during the Leonids meteor shower on 17-18.11.2001

It is already well-known that at high-frequency sounding of the ionosphere (for example, within the 2–10 MHz frequency bandwidth) the radio waves would be subject to diffraction at infrasonic waves that results in shifting of the sounding frequency (satisfying the Bragg condition) for the value equal to the frequency of the infrasonic waves $f_d = f_{\text{in frasound}}$ (the Doppler frequency shift).

Observations using the method of the vertical Doppler sounding were performed during our investigations simultaneously with application of the PR technique.

Figure 3 shows an example of the Doppler spectra obtained in the above experiment (17-18.11.2001).

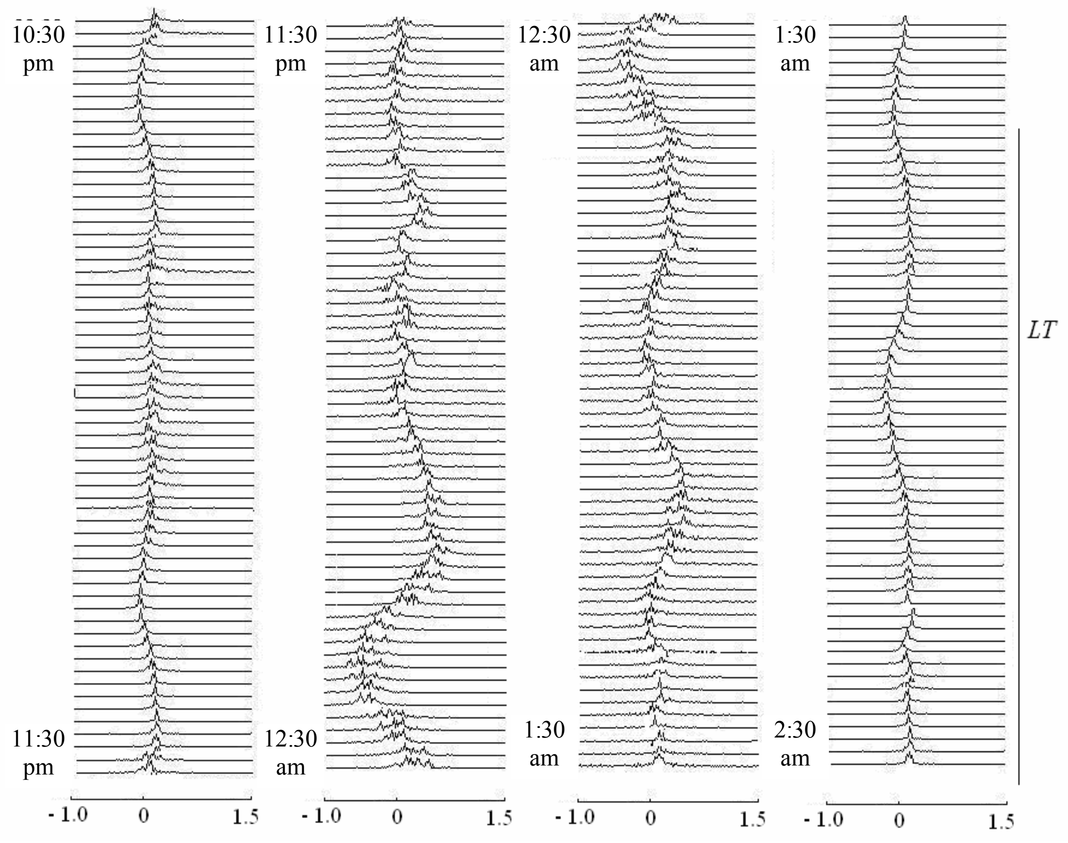

FIG. 3: Example of the Doppler spectra obtained in the experiment of 17-18.11.2001

From Fig. 3 it is evident that first it is clearly seen the growth to 0.3 Hz (maximal value) with subsequent decreasing of approximately to -0.4 Hz during 15 minutes and further increasing and decreasing of the values within the limits of several Hz. Later on during about 60 minutes $f_d \sim 0$–0.1 as before. This variation of f_d is, apparently, associated with generation of infrasonic waves during meteor showers because, as it is noted above, at spectral processing of the recordings of $A_{so,x}$ (z, t) obtained with the help of the PR technique it is determined an increase of the spectral component G intensity at the frequency of 0.5 Hz within the altitude range.

It should be noted that similar variations were not detected while performing the background measurements on the test day (like in a number of other experiments under the undisturbed conditions).

Analysis of initial recordings of PR-signals showed that the process passage velocity was ~ 330–350 mps.

Similar behavior of the amplitudes of PR-signals and noises mixture turned out to be, in general, typical for the experiments concerned during the periods of the highest peaks of meteor showers.

Spectral processing of the experimental results detected a substantial power increase at the frequencies of 2 and 5 Hz in other experiments that also corresponded to the infrasonic band. It should be also noted that similar variations were not detected while performing the background measurements on the test day.

The obtained data confirm the results of theoretical and experimental investigations [20] indicating that excitation of dust acoustic perturbations during the periods of intensive meteor showers could result in generation of infrasonic waves, which might prevail over infrasonic waves from other sources near the Earth surface within the frequency bandwidth from several decimal fractions to several dozen Hertz;

3) an episodic increase of the electron concentration values by more than 50–100 % as compared to test days with the duration from several minutes to dozens of minutes was observed at the altitudes of $z > 85$ km in the night mid-latitude D-region of the ionosphere during the periods of the meteor shower peak. It can be confirmed by one of the examples of electron concentration variations obtained during the periods under investigation. Figure 4 provides time variations of the electron concentration at the altitude of 90 km during the periods before (12.11.2001), at the highest `peak of the Leonids meteor shower (17.11.2001) and after it (22.11.2001);

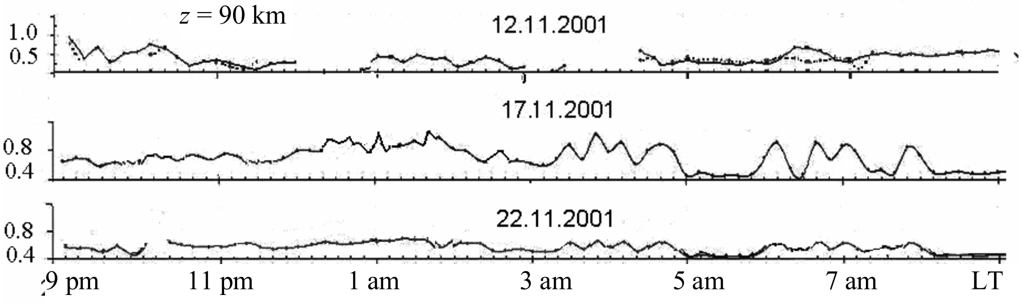

FIG. 4: Time variations of electron concentration at the altitude of 90 km during the periods before (12.11.2001), at the highest `peak of the Leonids meteor shower (17.11.2001) and after it (22.11.2001)

4) there were not detected any significant differences in the behavior of $A_{o,x}(z, t)$, noises $A_{nox}(t)$ and $N(z, t)$ as compared with the test periods in the lower mid-latitude D-region of the ionosphere (z < 85 km).

3. CONCLUSIONS

There were experimentally studied particularities of time and altitude variations of the amplitudes of partially reflected SW signals $A_{o,x}(z, t)$, radio noises $A_{no,x}(z, t)$ and the electron concentration $N(z)$ in the night mid-latitude D-region of the ionosphere during the Geminids meteor shower in December 2006 and 2009 and the Leonids meteor shower in November 2000 and 2001. It is determined that quasi-periodic variations of $A_{o,x}(z, t)$ and $A_{no,x}(z, t)$ are observed during several dozens of minutes in the periods of maximal inflow of associated with meteors dust particles into the plasma of the ionosphere. Apparently, it is stipulated by motion of charged fine-dispersed dust particles and generation of infrasonic waves associated with the above motion. It is also determined that an episodic increase of the electron concentration values by more than 50–100 % as compared to test days with the duration from several minutes to dozens of minutes is observed at the altitudes of $z > 80$ km in the night mid-latitude D-region of the ionosphere during the above periods. The nature of the said behavior of $N(z, t)$ is explained by the influence exerted by the dust particles associated with meteors on the ionospheric plasma and stipulated by the effects of charge and dynamics of dust particles.

REFERENCES

1. Belikovich, V.V., Benediktov, Ye.A., Vyakhirev, V.G., and Ivanov, V.A., (1980), Night ionization of the D-region and of the mid-latitude ionosphere in the period of a magnetic storm, *Geomagnetism and aeronomy*. **20**(3):547–554 (in Russian).
2. Belikovich, V.V., Vyakhirev, V.D., Kalinina, Ye.Ye., Tereshchenko, V.D. et al., (2008), Ionospheric response to a partial solar eclipse on 29.03.2006 according to the observations at Nizhni Novgorod and Murmansk, *Geomagnetism and aeronomy*. **48**(1):103–108 (in Russian).
3. Belikovich, V.V., Vyakhirev, V.D., Kalinina, Ye.Ye., Tereshchenko, V.D. et al., (2006), Studying of the ionospheric D-region using partial reflections in spring 2004 at middle and high latitudes, *Geomagnetism and aeronomy*. **46**(2):229–233 (in Russian).
4. Gokov, O.M., (2010), *Disturbances in low-temperature plasma of middle latitude lower ionosphere associated with natural effects*, KhNUE Publ., Kharkiv: 176 p. (in Russian).
5. Gokov, O.M., (2013), *Investigations of peculiarities of the non-disturbed middle latitude D-region of ionosphere*, KhNUE Publ., Kharkiv: 156 p. (in Russian).
6. Gokov, A.M. and Tyrnov, O.F., (2003), Middle Latitude Ionospheric D-Region Responses to Solar Events as Investigated by Partial Reflection Technique, *Telecommunications and Radio Engineering*. **59**(3-4):114–134.
7. Gokov, A.M., Gritchin, A.I., and Tyrnov, O.F., (2008), Experimental study of the response of the mid-latitude ionospheric D region to the solar eclipse of March 29, 2006, *Geomagnetism and aeronomy*. **48**(2):241–249 (in Russian).
8. Gokov, A.M. and Tyrnov, O.F., (2012), Investigations of the response of mid-latitude ionospheric D-region to power atmospheric front passage, *Trans. 22nd International Crimean Conference CriMiCo-2012 "Microwave & Telecommunication Technology"*. Sevastopol, pp. 1047–1048.
9. Gokov, A.M. and Tyrnov, O.F., (2013), Investigations of the response of the mid-latitude lower ionosphere to meteor showers, *Trans. 23rd International Crimean Conference CriMiCo-2013 "Microwave & Telecommunication Technology"*. Sevastopol, pp. 1122–1123.

10. Musatenko, S.I., Musatenko, Yu.S., Kurochka, Ye.V., Lastochkin, A.V. et al., (2006), Dusty plasma in the mid-latitude ionosphere during meteor showers, *Geomagnetism and aeronomy*. **46**(2):182-192 (in Russian).
11. Kopnin, S.I., Kosarev, I.N., Popel, S.I., and Yu, M.Y., (2004), Localized Structures of Nanosize Charged Dust Grains in Earth's Middle Atmosphere, *Planetary and Space Science*. **52**:1187-1194.
12. Kopnin, S.I., Kosarev, I.N., Popel, S.I., and Yu, M., (2005), Dust acoustic solitons in the dusty plasma of the Earth's ionosphere, *Physics of plasma*. **31**(2):224-232 (in Russian).
13. Kalashnikova, O., Horanyi, M., Thomas, G.E., and Toon, O.B., (2000), Meteoric Smoke Production in the Atmosphere, *Geophysical Research Letters*. **27**(20):3293-3296.
14. Kopnin, S.I., Popel, S.I., and Ming, Yu., (2007), Modulational excitation of low-frequency dust acoustic waves in the Earth's lower ionosphere, *Physics of plasma*. **33**(4):323–336 (in Russian).
15. Kopnin, S.I. and Popel, S.I., (2008), Generation of infrasonic waves by low-frequency dust acoustic perturbations in the Earth's lower ionosphere, *Physics of plasma*. **34**(6):517–526 (in Russian).
16. Tyrnov, O.F., Garmash, K.P., Gokov, A.M., Gritchin, A.I. et al., (1994), The Radiophysical Observatory for remote sounding of the ionosphere, *Turkish J. Phys*. **18**(11):1260–1265.
17. Garmash, K.P. and Cherhogor, L.F., (1996), Profiles of electron concentration of D-layer of the ionosphere at calm and perturbed conditions using data of partial reflections, *Geomagnetism and aeronomy*. **36**(2):75–81 (in Russian).
18. Gokov, A.M. and Tyrnov, O.F., (1998), Experimental investigations of the effects of strong thunderstorms on the parameters of the mid-latitude ionospheric D region, *Geomagnetism and aeronomy*. **38**(1):184–188 (in Russian).
19. Gokov, A.M. and Tyrnov, O.F., (2011), On the possibility of generating low frequency whistlers in the lower ionosphere during the disturbances of different nature, *Trans. 21st International Crimean Conference CriMiCo-2011 "Microwave & Telecommunication Technology"*. Sevastopol, pp. 1083–1084.
20. Kopnin, S.I., (2008), *Dust acoustic mode manifestations in Earth's dusty ionosphere*, Theses for Assoc. Prof. of Physics and Mathematics, Moscow: 119 p. (in Russian).