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Conception and model of seismo-ionosphere-magnetosphere coupling

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Seismo-ionospheric coupling was extensively studied during the last decade. As a result the physical mechanism is developed explaining the variations observed within the ionosphere by action of anomalous electric field, penetrating into the ionosphere from the Earth's surface in seismically active regions, several days/hours before the strong earthquakes. The present paper fills some gaps existing in the previously published model. We introduce the concept of atmospheric plasma appearing in the near ground layer of atmosphere under the action of radon radioactivity in seismically active areas. Such plasma could be unstable to different kinds of electromagnetic emissions observed experimentally before the strong earthquakes. One kind of such emission, namely HF meter band emission, is explained in the paper as a result of rotational instability of ion clusters. The effects within the ionosphere and magnetosphere are also regarded. As a possible source of sporadic *E*-layers the metallic aerosols are considered which are transported from the lower layers of atmosphere by anomalous electric field. The paper describes also the seismogenic variations on the higher altitudes—upper ionosphere and magnetosphere—small-scale and large-scale irregularities formation within the *F*-layer of the ionosphere and magnetospheric duct formation. Our concept implies that VLF noise intensification observed by satellites at longitudinal belts above the future epicenter latitude location are due to irregularities formation mapped from the ionosphere and VLF noises scattering into the modified magnetospheric tube.

1. Introduction

The paper summarizes recent advances reached in creation of the physical model of seismo-ionosphere-magnetosphere coupling. During development of the model the conception of atmospheric plasma was developed by Pulinets *et al.* (2000a) including:

- *the source of ionization in the form of radon release from the crust*;
- *hydration process*—attachment of water molecules to the newly formed ions and ion clusters what prevents them from the recombination and makes them quasi-stable at the ground level;
- *metallic aerosols emanation from the crust* that facilitates the generation of strong electric field in the area of emanation. Ion-molecular reactions in the area of emanation together with the turbulent diffusion lead to generation of strong vertical electric field (Boyarchuk *et al.*, 1998).

The second step in the model development is the calculation of atmospheric electric field penetration at ionosphere levels (Kim *et al.*, 1994). The main role in this process plays the anisotropy of air conductivity, appearing at levels higher than 60 km. The very important also is *the size of the area occupied by anomalous electric field*.

Next part of the model demonstrates the effects of electron concentration modification over the vertical electric field source. The model is supported by a plenty of experimental measurements. Ionospheric effects from volcano eruptions, thunderstorm fronts, large tectonic faults, Chernobyl and Three-Mile Island atomic power plants disasters are demonstrated by Pulinets *et al.* (1998a). The most striking is appearance of variations within the ionosphere several days before the strong earthquakes. These results are statistically confirmed with high confidence. The similarity of ionosphere variability stimulated by different sources of anomalous electric field indicates the universality of the proposed physical mechanism.

Ionospheric and plasmaspheric large-scale irregularities calculated within the frame of model up to heights 2000 km let us to find the new approach to the VLF noise registered onboard the satellites over the seismically active regions (Pulinets *et al.*, 1999). The VLF noises in a magnetic-force tube above the area of earthquakes are secondary in relation to ionospheric variations. Most likely, they are not outcome of radiation from seismoactive area, but VLF noises of various origins entrapped in a magnetic tube are simply modified by the large plasma irregularities formed under action of anomalous electric field.

The latest version of the proposed model is published in Pulinets *et al.* (2000b). In the present paper we demonstrate how our model conception is able to explain the existing experimental results on the registration of electromagnetic and plasma short-term precursors of strong earthquakes.

2. Near Ground Processes

We limit our consideration only to the processes starting from the ground surface leaving out of scope of our paper the underground changes in the Earth's crust.

Many authors report different electromagnetic anomalies observed in near ground atmospheric layer in the vicinity of forthcoming earthquake epicenter area, starting from the DC vertical atmospheric electric field (Vershinin *et al.*, 1999; Kamogawa, 1998), ULF emissions 0.001–

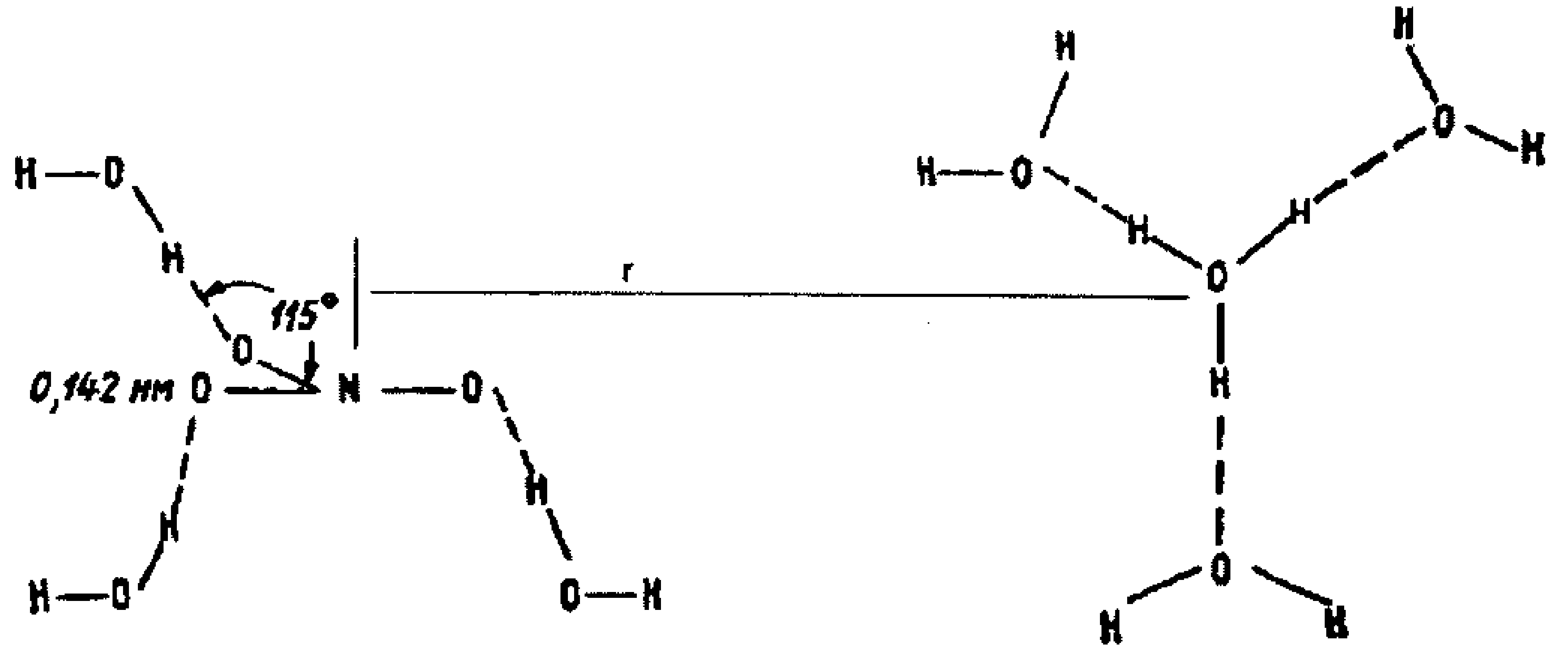

Fig. 1. Schematic presentation of ion cluster with Coulomb interactions.

0.12 Hz (Yepez *et al.*, 1999), VLF emissions (Fujinawa *et al.*, 1999) up to LF, MF (Yamada and Oike, 1999) and HF (Maeda, 1999; Vallianatos and Nomicos, 1998) emissions.

All these phenomena could be regarded within the frame of proposed conception of atmospheric plasma (Pulinets *et al.*, 2000a). Concept <<plasma>> usually is not applied to a troposphere. At the same time looking from the point of encyclopedic definition, i.e. "ionized gas with equal concentration of positive and negative charges (quasi-neutrality)", an inconsistency will not be. Moreover, for troposphere quite natural is concept of a characteristic radius of ionic atmosphere, or Debye radius of shielding:

$$r_d = \left(\frac{\varepsilon_0 kT}{e^2 n_\pm}\right)^{1/2}. \qquad (1)$$

In a near-ground layer of an air under normal atmospheric conditions the concentration of light ions is close to $n_\pm = 10^2 \sim 10^3$ cm^{-3}, their thermal temperature $kT \cong 0.025$ eV; ions are single-charged, therefore $r_d \cong 10 \sim 30$ cm. The atmospheric plasma is strongly collisional: the collision frequency of thermalized electron with molecules of an air exceeds 10^{10} Hz. It is also multicomponent—alongside with electrons, the molecular and complex ions, there are present neutral and charged aerosol particles, cloud drops and precipitation drops, ice crystals aerosols and other impurities distorting a classical structure of plasma. The troposphere, as a rule, is only partially ionized, i.e. the condition $kT << \varepsilon_i$, is fulfilled where ε_i - effective potential of ionization of an air. At the same time during thunderstorms, presence of clouds and sources of artificial ionization the conditions could appear, when the atmospheric plasma will be essentially non-equilibrium locally, i.e. will have charged particles essentially distinguishing as by electric mobility, so by magnitude and sign of electric charge. For example, such situation is realized in seismoactive zones due to radon and various metal aerosols emanation from the Earth's crust, as well as under conditions of radioactive contamination near enterprises of a nuclear industry in the case of emergencies. In these circumstances the near-ground layer of approximately 3 m thickness subjected to the effect of radioactivity becomes the reservoir of atmospheric plasma. Under action of an ionizing radiation in atmosphere at an initial stage the large amount of O_2^+ ions is formed both as a result of direct ionization, and as a result of charge exchange between an initial ion N_2^+ and electrons, which fast adhere to atoms of oxygen, since the oxygen has a significant energy of an affinity to electrons, forming the negative ions O^- and O_2^-. As a result of fast ion-molecular reactions during the interval of order 10^{-7} s the main elementary tropospheric ions will be formed: O^-, O_2^-, NO_2^-, NO_3^-, CO_3^-, O_2^+, NO^+, H_3O^+. The concentration of electrons is so insignificant that they can be neglected. The large amount of water vapor molecules contained in the troposphere ($\sim 10^{17}$ cm^{-3}), having a noticeable dipole moment $p = 1.87D$, leads to hydration of elementary ions and formation of ion complexes of a type $NO_2^-\cdot(H_2O)_n$ and $NO_3^-\cdot(H_2O)_n$, $NO_3^-\cdot(HNO_3)_n(H_2O)_m$ and $O_2^+\cdot(H_2O)_n$, $NO^+\cdot(H_2O)_n$, $H^+\cdot(H_2O)_m$ and $H_3O^+\cdot(H_2O)_n$ that happens rather fast. The ions $NO_3^-\cdot(H_2O)_n$, $NO_3^-\cdot(HNO_3)_n(H_2O)_m$ and $H_3O^+\cdot(H_2O)_m$ could be regarded as main ions of troposphere with high level of probability. The average time of life of these ions reaches 30–40 min. and more in usual conditions (Smirnov, 1992). In hydrated ions the cluster shell consisting from 3 up to 5 molecules of water, has an energy of connection near 4 eV, and it should not fail from impacts at the temperature of below 1000 K. Naturally we assume that such a shell can hinder a recombination. It was shown recently that recombination of hydrated ions slows down in the lower troposphere (0–35 km) and ion balance equation is linear, not quadratic one (Stozhkov *et al.*, 1997). We considered the process of near-ground electric field generation earlier (Boyarchuk *et al.*, 1998; Pulinets *et al.*, 2000b). Here we will concentrate on the problem of sharp variations of electric field and their possible origins.

As a result of association of such hydrated ions—radicals irrespective of an amount of water molecules in an envelope, a neutral cluster will be formed, for example, such as one $NO_3^-\cdot(H_2O)_n\cdot H_3O^+$. Its stability is provided by both ionic and covalent connections (Smirnov, 1992) (see Fig. 1).

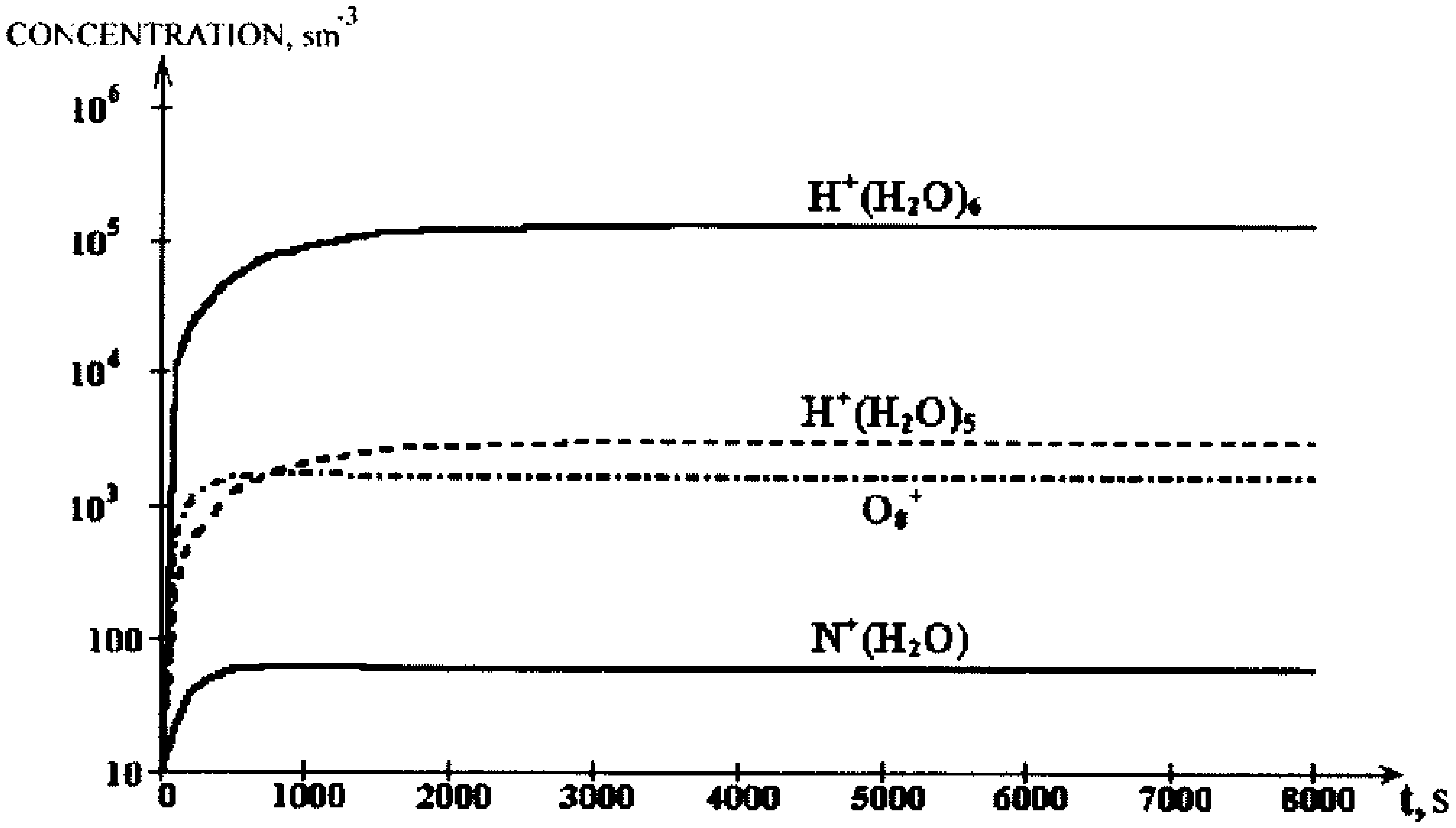

Fig. 2. Different ions formation dynamics under the action of ionizing radiation and ion molecular reactions.

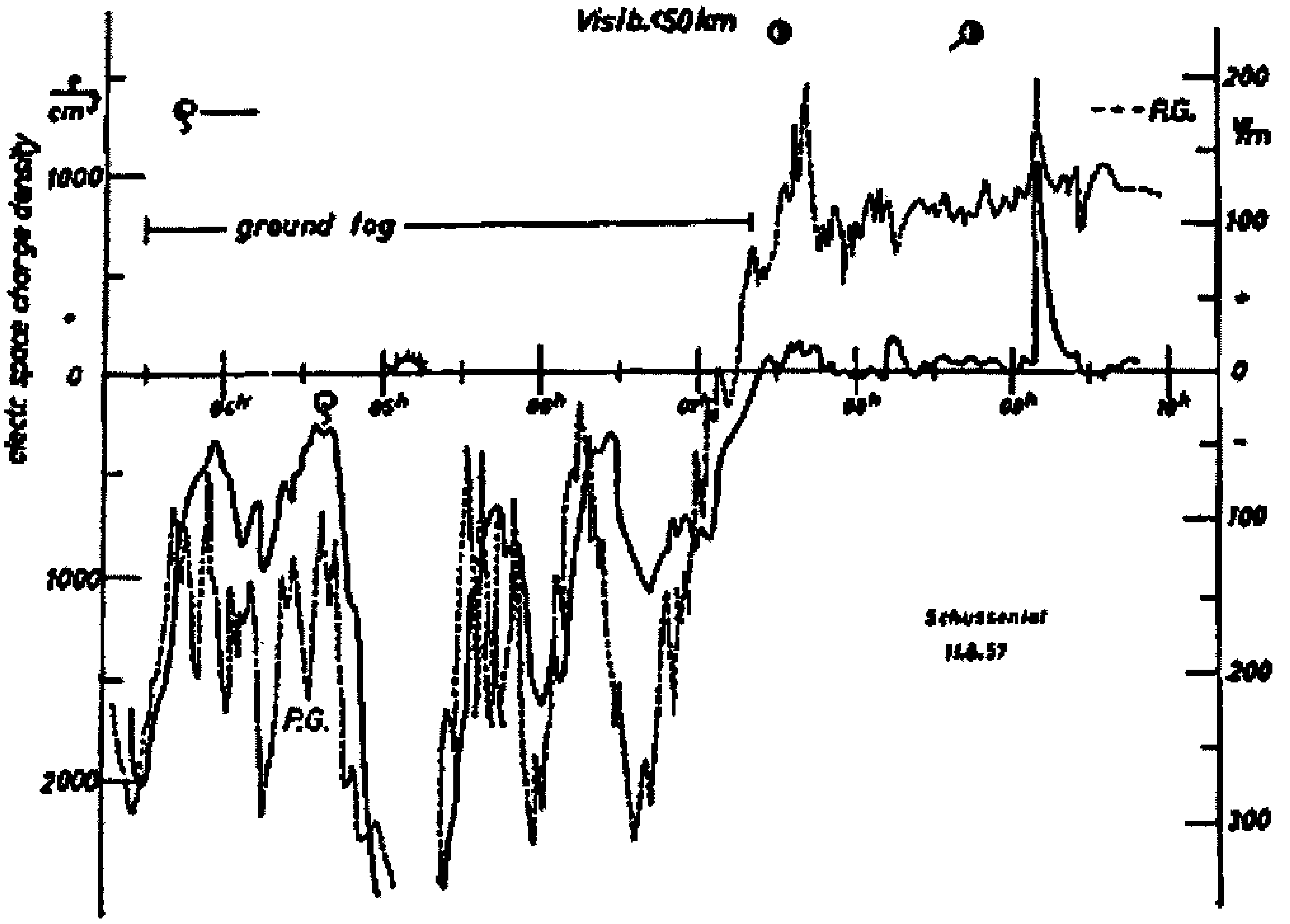

Fig. 3. Atmospheric electric field dynamics in fog conditions.

The numerical modeling of classic Coulomb plasma (Mayorov *et al.*, 1994; Yakovlenko, 1995; Stakhanov, 1979) by multiple particle approximation have shown essential (up to 12 orders of magnitude) delay of a recombination time of a system composed from heavy particles of identical mass, and the conditions are regarded at which the plasma of ions with envelopes from water molecules can be sustained in the supercooled state on the degree of ionization, anomalously long time. The neutral clusters become the ion accumulators while the atmosphere as a whole continues to be neutral. But any external impact on the system whose energy exceeds the cluster connection energy could lead to their decay and the volume suddenly becomes ionized. Such an idea was expressed also in Arnold (1982) and Larin (1991). We model such low temperature plasma of atmosphere with the presence of cluster ions under the impact of hard ionizing radiation. Calculations show that ion concentration is weakly dependent on the water molecules concentration (only 15% in the interval of humidity from 100% up to 5%). The estimated recombination velocity was 3 orders of magnitude lower than the ordinary Langevin recombination velocity and was of order $5 \cdot 10^{-9}$ sm^{3}s^{-1}. The time of stationary condition development is no more than 1–2 hours. The dynamics of different ions concentration is shown in Fig. 2.

The neutral cluster concentration will be of order of 10^5 sm^{-3}, the electron concentration in these conditions is neglectable and does not affect the recombination velocity. Under external forcing we obtain the ionized atmosphere with characteristic ion concentration. The well-known mechanisms of charge concentration could lead to the sharp jumps of the atmospheric electric field as it happens, for example in the fog conditions (see Fig. 3 (Mühleisen, 1958)).

It is shown that if the ion-ion recombination velocity of the cluster ions $H^+(H_2O)_5$, $H^+(H_2O)_6$, $N^+(H_2O)$, O_8^+, $CO_3^-(H_2O)$, $NO_2^-(H_2O)$ is by 3–4 order magnitude lower than the standard Langevin ion-ion recombination constant which is $2\cdot10^{-6}$ sm^3/s in the conditions of ionization velocity in wet air (mist) of order 10 $\text{sm}^{-3}\text{s}^{-1}$ it is possible to provide the charge separation up to vertical electric field values of order of several kV/m.

Such values of the electric field could lead to effects of coronal discharge as it was registered by (Kamogawa, 1998) and give the origin to the electromagnetic emission. In principle, the atmospheric plasma described here with the presence of metallic aerosols emanated from the Earth's crust in the seismically active areas is the typical dusty plasma with the characteristic plasma instabilities which can give rise also to the electromagnetic emission of different frequencies. The dusty plasma instabilities in the near-ground layer will be regarded in the future paper, as well as the effect of critical ionization velocity. Here we consider the HF frequency band. As it was mentioned earlier the HF electromagnetic emission of 22.2 MHz frequency was observed before and after the Kobe earthquake (17.01.95) at the astronomical observatory Nishiharima 77 km to North-East from the epicenter (Maeda, 1999). The experimental measurements at Apennines archipelago at frequencies 40 and 50 MHz determined the source of the electromagnetic emission is at the atmospheric heights of order of 100 m–8 km over the area of future epicenter (Vallianatos and Nomicos, 1998). The ion clusters described higher, free ions and aerosols could form the large dipole quasi molecule which possess as a rule the rotation-rotation transitions of correspondent dipoles emitting in the meter wavelength band. Let us estimate the dipole characteristics in the rigid rotator regime. We consider the specific case of symmetrical top with main electron and zero order oscillation state. In this case the rotational constant of the molecule B_e (sm^{-1}) does not depend on the rotational quantum constant J and the emission frequency of the rotational quantum transition ν (sm^{-1}) from the rotational quantum level J will look like:

$$\nu_J = 2\cdot B_e \cdot (J+1). \tag{2}$$

The rotational constant B_e could be presented as:

$$B_e = \frac{h}{8\cdot\pi^2\cdot c\cdot\mu\cdot r_e^2}, \tag{3}$$

where $h = 6.62\cdot10^{-27}$ erg·s - Planck constant; $c = 3\cdot10^{10}$ cm/s - light velocity; μ - reduced molecule mass (g); r_e - equilibrium internuclear distance (cm).

The spectrum line emission intensity could be expressed as (Popova and Ravodina, 1984):

$$I_J = N_J \cdot \frac{64\cdot\pi^4}{3\cdot c^3}\cdot\nu_J^4\cdot R^2, \tag{4}$$

where R - element of the matrix of the electric dipole moment of the transition (weakly dependent on J), and N_J - population of J-th state, which could be expressed as:

$$N_J = N_0\cdot(2\cdot J+1)\cdot\exp\left(-\frac{h\cdot c\cdot B_e\cdot J\cdot(J+1)}{k\cdot T}\right). \tag{5}$$

Here N_0 is population of zero rotational state, $k = 1.38\cdot10^{-16}$ erg/K - Boltzman constant, T - air temperature (K). In Eq. (5) we also take into account that the relation of the statistical weights of the J-th and zero states is equal to $(2\cdot J + 1)$.

The N_J function has maximum on J under (Boyarchuk *et al.*, 2000)

$$J_{\max} = \sqrt{\frac{k\cdot T}{2\cdot B_e\cdot h\cdot c}} - \frac{1}{2}. \tag{6}$$

It should be mentioned that the emission intensity (4) has the maximum also. But the intensity maximum does not coincide with the maximum of population because the frequency of emission is in the expression (4) in the forth degree (in other words the energy of quantum of emission also depends on J). Substituting Eqs. (2) and (5) in Eq. (4) and taking derivative by J we receive the analytical expression for the electromagnetic emission maximum, which also depends only on rotational molecule constant B_e and the surrounding temperature T:

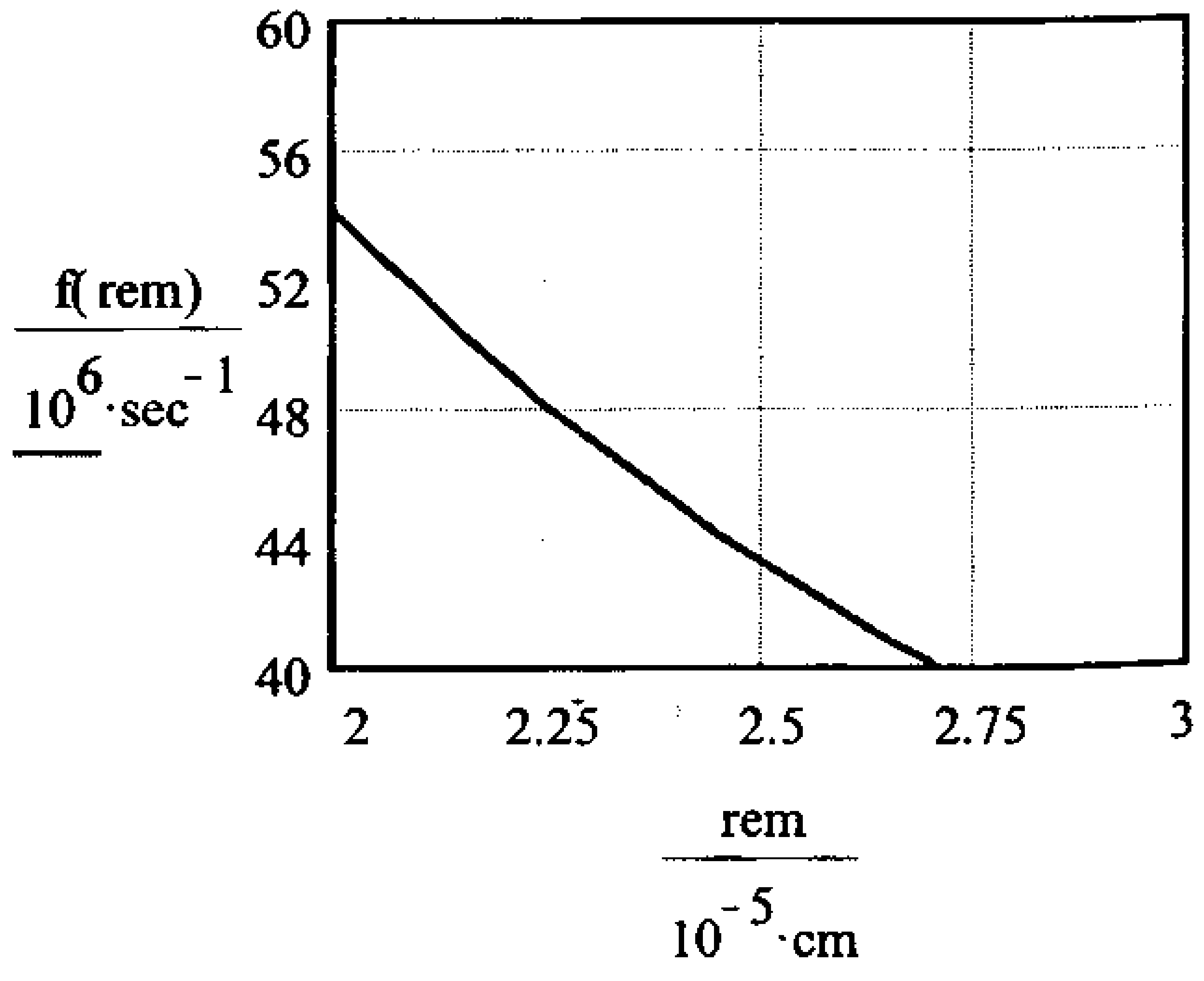

Fig. 4. Dependence of the maximum of HF emission frequency at rotational-rotational transitions of the molecule with reduced mass μ = 73 a.u. on the internuclear distance under the temperature T = 270 K.

$$J(r_e)=\left[\frac{18\cdot k\cdot T+h\cdot c\cdot B_e(r_e)}{216\cdot h\cdot c\cdot B_e(r_e)}+\frac{\sqrt{-6\cdot k\cdot T\cdot\left(500\cdot k^2\cdot T^2+44\cdot k\cdot T\cdot h\cdot c\cdot B_e(r_e)+h^2\cdot c^2\cdot B_e^2\right)}}{72\cdot\left(h\cdot c\cdot B_e(r_e)\right)^{2/3}}\right]^{1/3}$$

$$-\frac{\left[\frac{h\cdot c\cdot B_e(r_e)-10\cdot k\cdot T}{12\cdot h\cdot c\cdot B_e(r_e)}-\frac{1}{9}\right]}{\left[\frac{18\cdot k\cdot T+h\cdot c\cdot B_e(r_e)}{216\cdot h\cdot c\cdot B_e(r_e)}+\frac{\sqrt{-6\cdot k\cdot T\cdot\left(500\cdot k^2\cdot T^2+44\cdot k\cdot T\cdot h\cdot c\cdot B_e(r_e)+h^2\cdot c^2\cdot B_e(r_e)^2\right)}}{72\cdot\left(h\cdot c\cdot B_e(r_e)\right)^{3/2}}\right]}. \qquad (7)$$

Taking into account Eqs. (3) and (7) we obtain the following expression for the maximum of HF emission in Hz:

$$f(r_e)=\frac{h}{8\cdot\pi^3\cdot\mu\cdot r_e^2}\cdot\left(J(r_e)+1\right). \qquad (8)$$

Figure 4 demonstrates the dependence of the maximum emission frequency on the internuclear distance under the temperature $T = 270$ K generated on the rotation-rotation transitions of the molecule with the reduced mass equal to μ = 73 a.u., which corresponds, for example, to the quasi-molecule composed from the positively and negatively charged clusters $NO_3^-\cdot(H_2O)_6$ and $NO_3^+\cdot(H_2O)_6$.

One can see that emission frequency 40–50 MHz corresponds to the internuclear distance of 0.21–0.25 μm. The energy of the Coulomb interaction between the single charged nucleus $E_q = e^2/r_e$ does not exceeds 0.007 eV, which is more than 3 times lower than the surrounding temperature. In such conditions it is difficult to expect the stability of such a molecular complex. Therefore it could be that emission is not from the quasimolecule but from the dipole aerosol with much higher mass or that the registered emission does not correspond to the maximum of the quasimolecule emission. In the latter case the effect should be expressed more sharply under the higher frequencies of emission near 200 MHz.

In order to have the energy of interaction of positively and negatively charged clusters equal to the surrounding temperature, the frequency maximum of rotational emission would be within the band measured experimentally, and the reduced mass of the quasimolecule should be no less than 1100 a.u. (Fig. 5).

The horizontal lines in the picture correspond to the experimentally measured frequencies. Let us try to estimate the maximum frequency for the maximal intensity emission for the given molecular structure. One can see from Fig. 6 that the intensity maximum of emission is close to the frequency 155 MHz but the population maximum corresponds to the emission with the frequency 69 MHz. The emission intensity from the rotational levels with $J \approx 9000$ is only 2% from the maximum one.

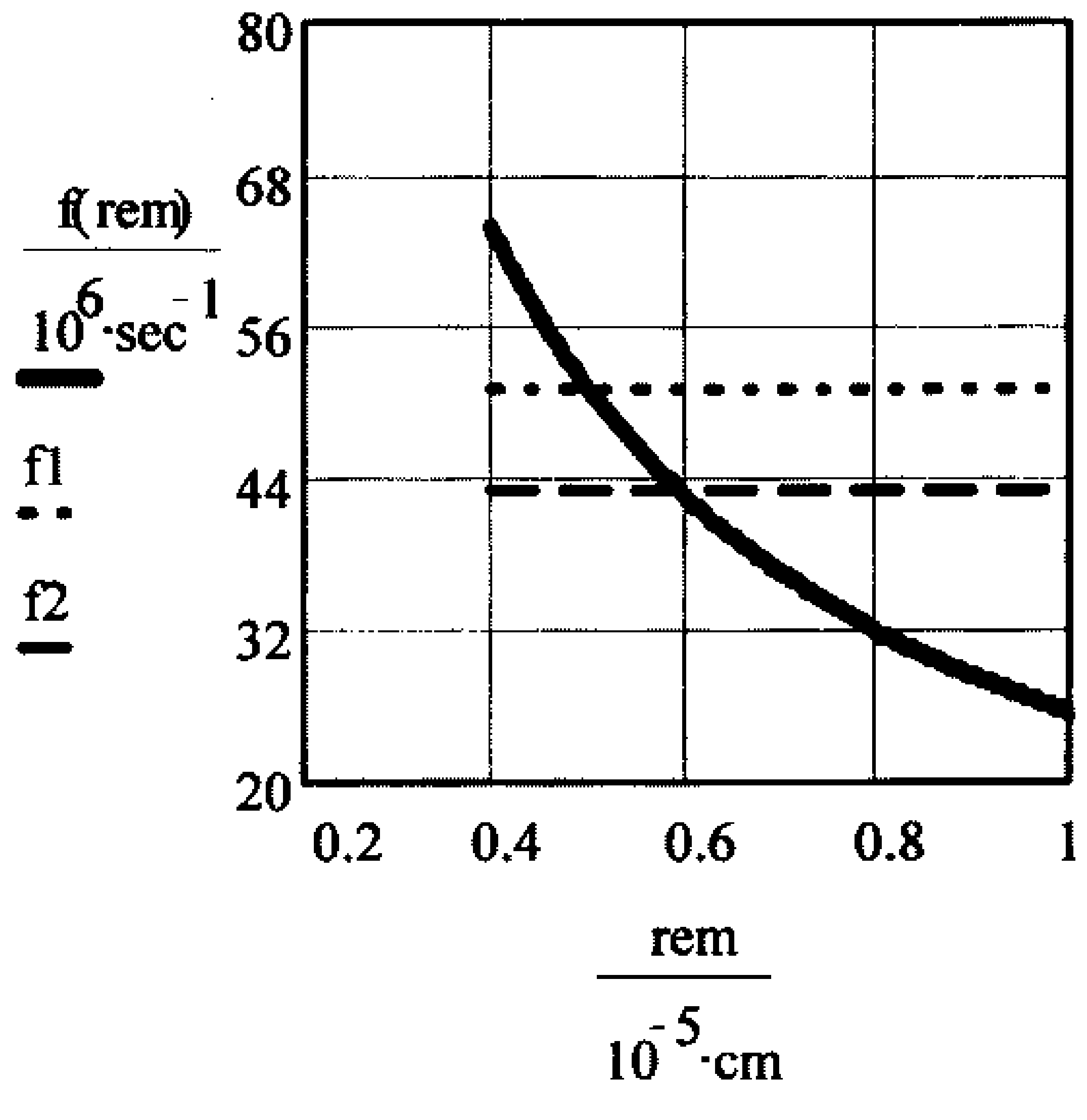

Fig. 5. Dependence of the maximum emitted frequency on rotational-rotational transitions of the molecule with the reduced mass equal to 1100 a.u. on the internuclear distance under the temperature T = 270 K.

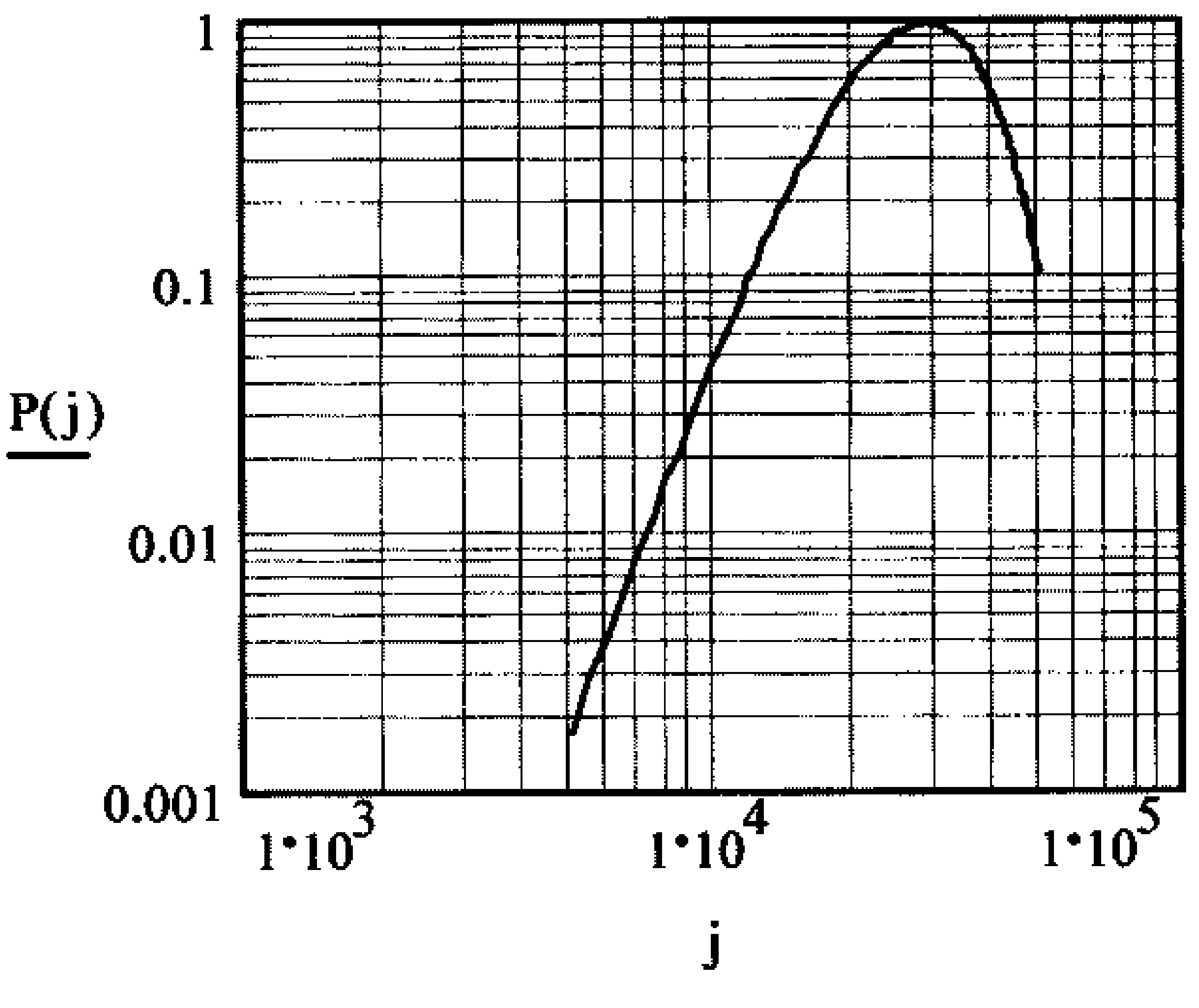

Fig. 6. Line intensity dependence in molecular emission spectrum (relative units) on the rotational quantum number.

The proposed model give a possibility to explain the observed seismo-electromagnetic emission at the meter band and the determined frequency maximum open the way to increase the registration sensitivity.

3. Troposphere as an Additional Source of Metallic Ions within the Ionosphere

Next level where the seismogenic effects would be registered, is troposphere and lower ionosphere. The anomalies of VLF radio waves propagation (Gufeld *et al.*, 1992; Hayakawa *et al.*, 1996) and formation of additional layers of ionization in the form of sporadic layers (Ondoh and Hayakawa, 1999) were detected. It is well known and accepted that the metallic ions play an essential role in the formation of sporadic layers irrespective of physical mechanism used for explanation. The VLF wave propagation anomalies could also be interpreted in terms of additional ionization layer but formed on the lower heights of order 60–80 km. This hypothesis is supported by the recent results of Japanese scientists (Fukumoto *et al.*, 2000) on the registration of overhorizon propagation of the FM broadcasting signals before the strong earthquake when the radio beam passes over the epicenter of anticipated earthquake. The generally accepted source of the metallic ions within the ionosphere is regarded as the meteors burning in the Earth's atmosphere (MacLeod *et al.*, 1975). But under specific conditions the metallic ions transport from the lower troposphere into the ionosphere is possible. Such a hypothesis was proposed for the first time in Pulinets *et al.* (1993, 1994). Let us try to estimate the transport time in supposition that due to the low recombination ions will not be loosed during the transport time.

Volcano eruptions, seismoactive zones and tectonic faults, anthropogenic activity, dust storms enrich the tropospheric layer (0–15 km) by metallic ions. The diffusion cannot provide the vertical transport to the level of order (60–90 km) for time intervals of order of days. Moreover, the inverse temperature height intervals where the temperature lowers with the height make such transport even more problematic. But quasistatic electric fields of the thunderstorm clouds or seismogenic electric field described in the previous section can make such transport of metallic ions essentially more effective.

It was shown by Park and Dejnakarintra (1973) that the vertical electric field of the thunderstorm cloud which at the heights of 15 km is of order 100 kV/m could provide the electric field on the height of 90 km of order of 1 mV/m. To simplify calculations we will mean that the troposphere height $h = 15$ km corresponds to $z = z_{tr} = 0$ km. In such conditions the ionosphere height $h = 90$ km will correspond to $z = z_i = 75$ km. Taking at $z = 0$ the electric field value $E_0 = 10^5$ V/m we will describe its exponential drop with height as:

$$E_z(z) = E_0 \cdot \exp\{-z/H_E\}, \tag{9}$$

where $H_E = 3$ km - characteristic scale of electric field change in the giant thunderstorm cloud providing electric field of 1 μV/m at z_i according to Park and Dejnakarintra (1973).

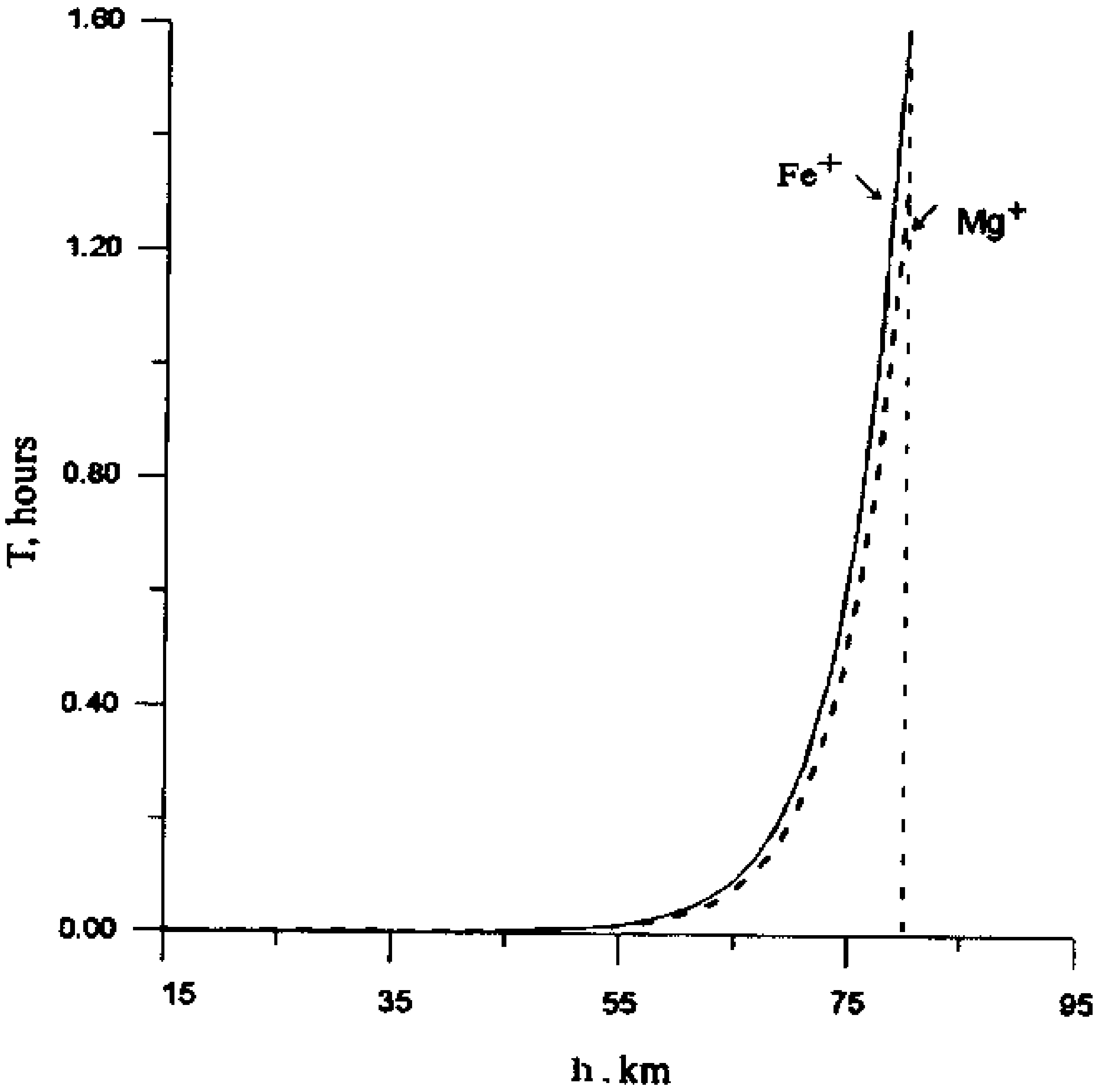

Fig. 7. Metallic ions rise time dependence on height.

The ions velocity V under the action of electric field E could be expressed as

$$V = \mu E, \tag{10}$$

where $\mu = q/(m_i \nu_i)$ - correspondent ion mobility, q - ion charge, m_i - ion mass, and ν_i - ion-neutral collision frequency which could be well approximated by exponential dependence:

$$\nu_i = \nu_0 \cdot \exp\{-z/H_\nu\}. \tag{11}$$

In the given case the rising time T from $z_{tr} = 0$ to z_i could be expressed by the integral:

$$T = \int_0^{z_i} \frac{dz}{V_z} = \frac{m_i \nu_0}{qE_0} \int_0^{z_i} \exp\{z / H_E - z / H_\nu\} dz, \tag{12}$$

or after integration

$$T = \frac{m_i \nu_0}{qE_0} \cdot \frac{H_\nu H_E}{H_\nu - H_E} \cdot \left\{ \exp\left(\frac{H_\nu - H_E}{H_\nu H_E} \cdot z_i \right) - 1 \right\}. \tag{13}$$

When $H_E = H_\nu$, we obtain:

$$T = \frac{m_i \nu_0}{qE_0} \cdot z_i. \tag{14}$$

It is obvious that the transport time is proportional to the ion mass and collision frequency and inversely proportional to the ion charge and electric field intensity. Let us calculate the T for Fe^+ and Mg^+ ions. Our calculations show that the collision frequencies for Fe^+ and Mg^+ could

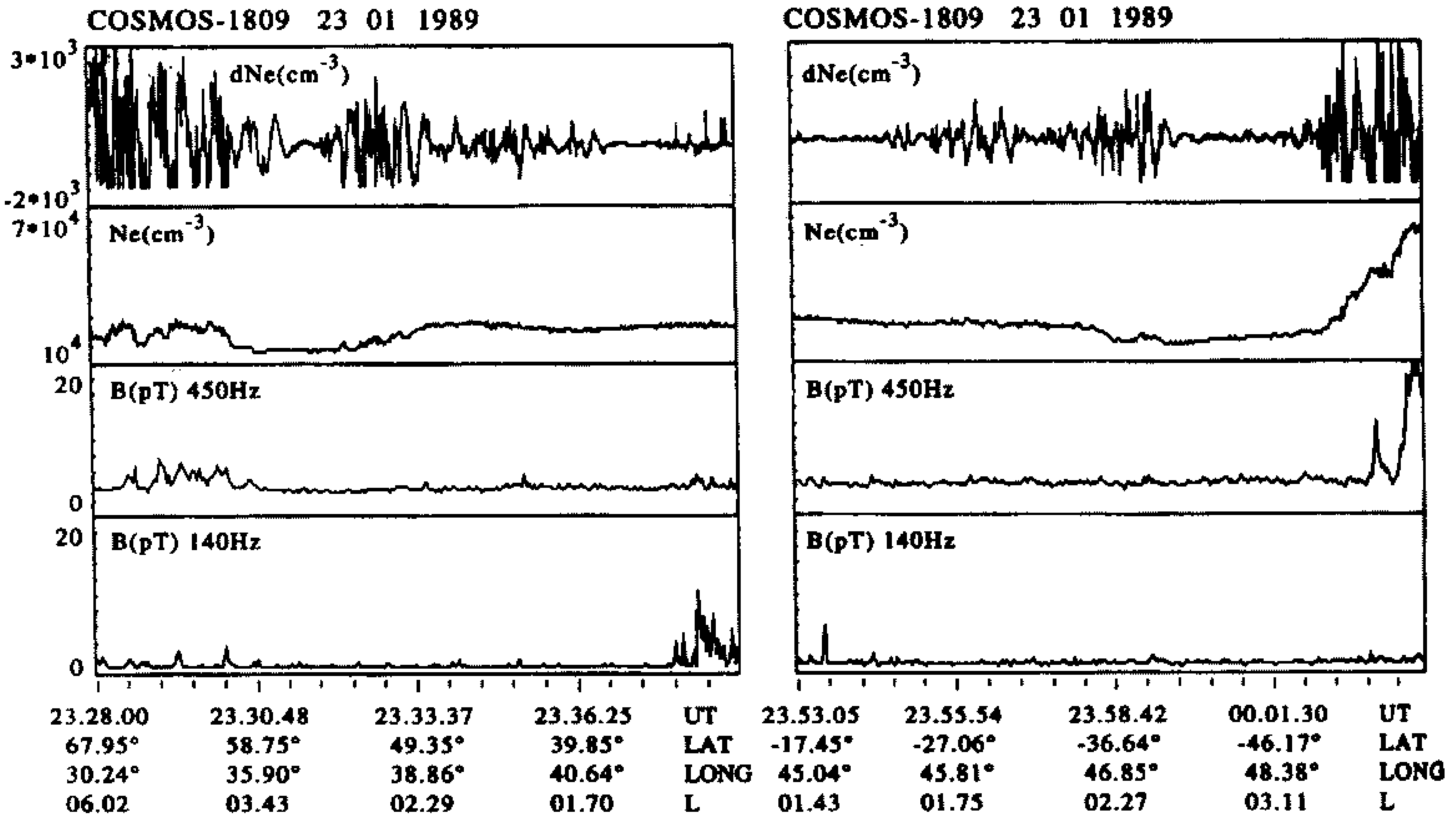

Fig. 8. Example of small-scale irregularities registered by Cosmos 1809 10 min. hours before the earthquake on 23.01.1989.

be expressed in the heights interval 15–90 km as:

$$\nu(\mathrm{Fe}^+) = \nu_0(\mathrm{Fe}^+)\cdot\exp(-z/H_\nu),$$

$$\nu(\mathrm{Mg}^+) = \nu_0(\mathrm{Mg}^+)\cdot\exp(-z/H_\nu), \qquad (15)$$

where $\nu_0(\mathrm{Fe}^+) = 7.91\cdot10^8\ \mathrm{s}^{-1}$, $\nu_0(\mathrm{Mg}^+) = 1.53\cdot10^9\ \mathrm{s}^{-1}$, and $H_\nu = 7$ km. Substituting the correspondent values in Eq. (9), we will obtain for the rising time:

$$T(\mathrm{Fe}^+)_{[\mathrm{hours}]} = 6.69\cdot10^{-6}\cdot(\exp\{4z/21\} - 1),$$

$$T(\mathrm{Mg}^+)_{[\mathrm{hours}]} = 5.54\cdot10^{-6}\cdot(\exp\{4z/21\} - 1),$$

if z is expressed in km. These dependencies are shown in Fig. 7. One can see that for the living time of the giant thunderstorm cloud which is of order of 2 hours, the effective rising height for both kinds of ions is more than 75 km. We can claim therefore that the thunderstorm cloud can transport the metallic ions into the ionosphere. We can argue also that if we will diminish the value of the electric field by an order of magnitude which corresponds to the electric field of usual thunderstorm cloud, the rising time up to level of 65 km will be near 1 hour, which does not exceed the living time of ordinary thunderstorm cloud. The same conclusion could be attributed to the seismogenic electric field. So we can conclude in general that troposphere could be an effective source of the metallic ions for the ionosphere.

4. Effects within the Ionosphere

The effects within the ionosphere as a result of seismogenic electric field penetration were modeled in Pulinets *et al.*, (1998a, 2000b), Hegai *et al.* (1997) and Kim and Hegai (1997). If we will speak about the *F*-layer of the ionosphere and higher one could expect the following effects observed before the strong earthquakes over the anticipated epicenter area:

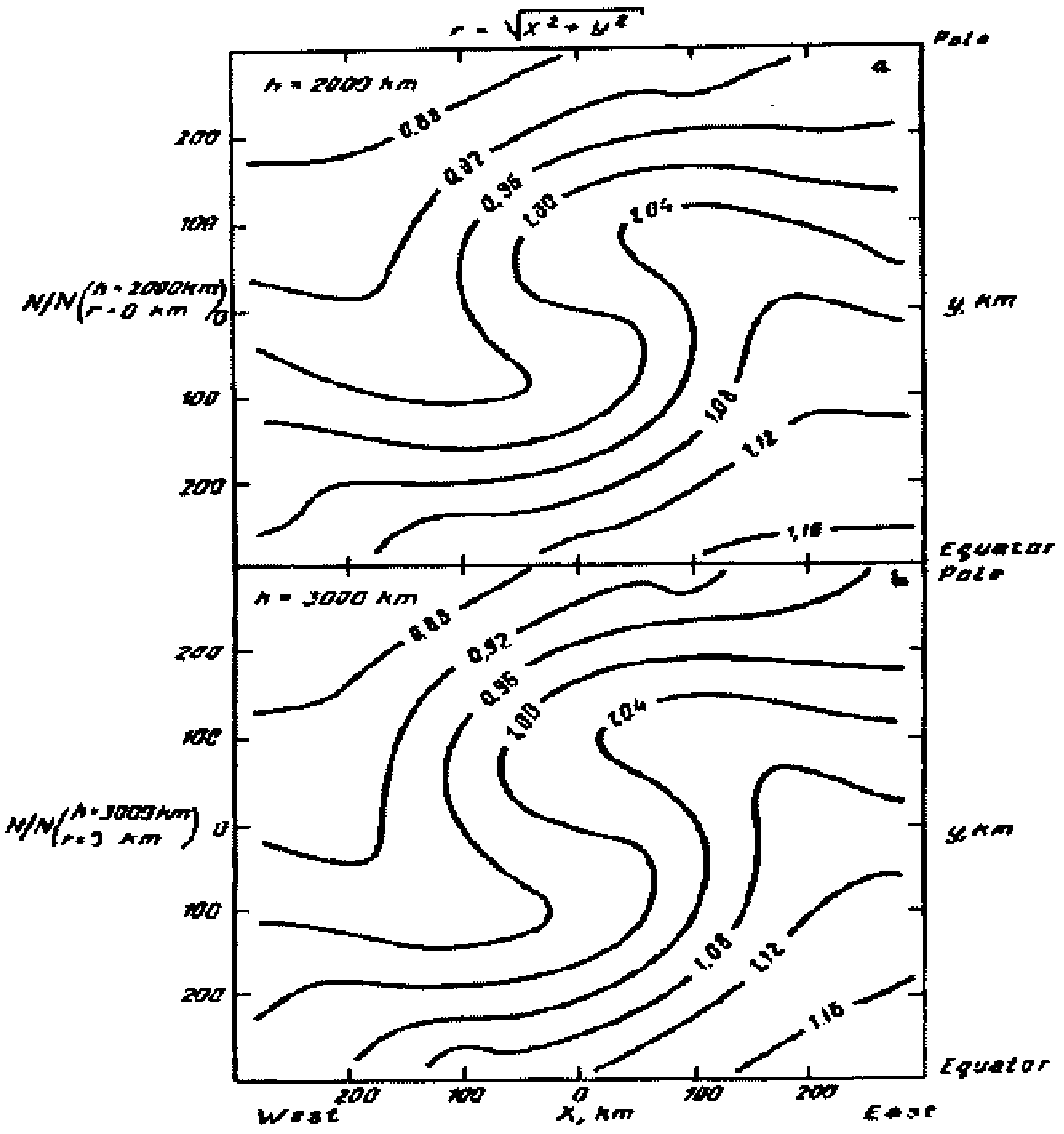

Fig. 9. Isolines of normalized electron concentration in the plane perpendicular to the geomagnetic field line. Magnetic tube cross-sections at the heights 2000 km (top panel) and 3000 km (bottom panel) 3 hours after seismogenic electric field appearance.

- small-scale irregularities generation due to acoustic-gravity waves effect (Hegai *et al.*, 1997);
- large-scale irregularities formation due to anomalous electric field of seismic origin penetration into the ionosphere (Pulinets *et al.*, 2000b);
- modification of geomagnetic flux tube above the

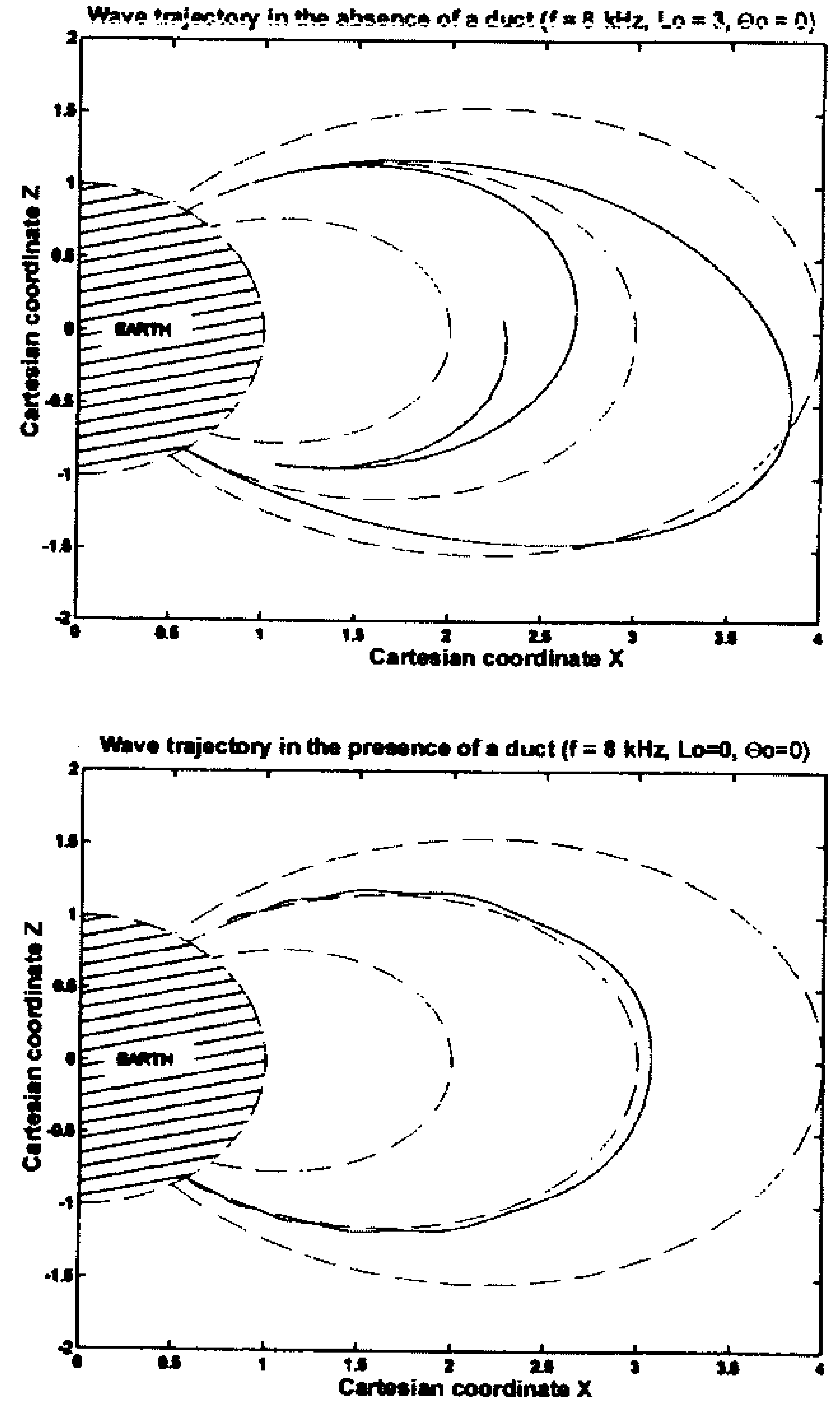

Fig. 10. Whistler propagation in undisturbed conditions (upper panel) and in the presence of field-aligned irregularities.

seismoactive area associated with VLF noises trapping into the modified tube and ionospheric effects in magnetically conjugate areas (Kim and Hegai, 1997; Pulinets *et al.*, 1999; Pulinets *et al.*, 2000b).

Figure 8 demonstrates the formation of small-scale irregularities within the ionosphere registered by Cosmos 1809 satellite at the height 960 km (Chmyrev *et al.*, 1997). Such irregularities could develop as a result of action of acoustic gravity waves described by Hegai *et al.* (1997).

Figure 9 demonstrates results of calculation of large-scale irregularities formation within the plasmasphere on the heights 2000 and 3000 km in the plane perpendicular to geomagnetic field line direction (Kim and Hegai, 1997). As it was shown in Pulinets *et al.* (1999), such a situation should lead to the VLF noises trapping into the modified geomagnetic field tube (Fig. 10, bottom panel) in comparison with ordinary whistler waves propagation within the magnetosphere (Fig. 10 upper panel). One can expect that in conditions when both the hemispheres are not sunlit (which depends on the solar terminator declination), the large scale plasma irregularities might be observed in both magnetically conjugate hemispheres (Heelis, 2000). Such a case was registered by Intercosmos-19 satellite before the Irpinia earthquake in Central Italy (Pulinets and Legen'ka, 1997) and 2-D distribution of the F-layer critical frequency deviation is presented in Fig. 11.

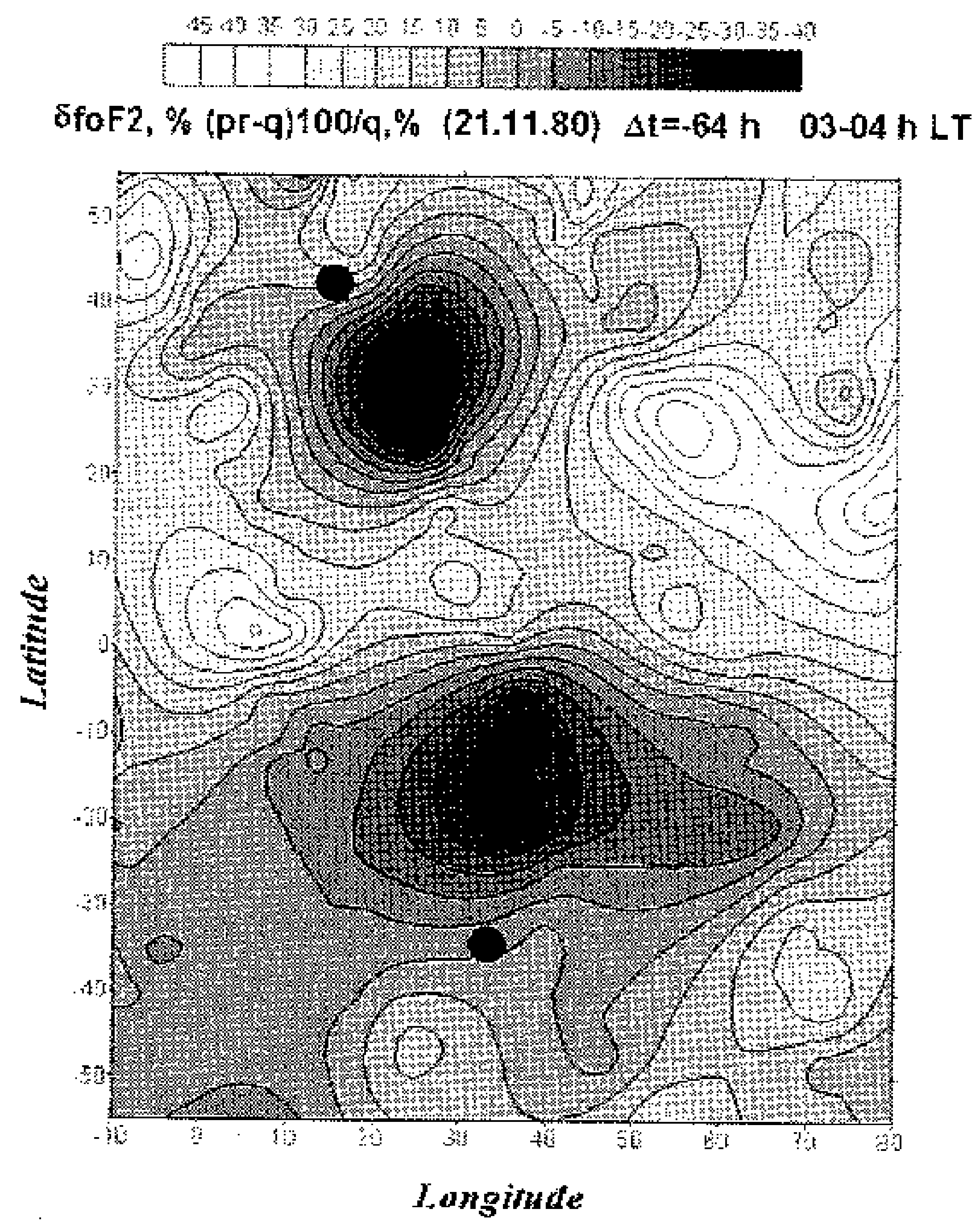

Fig. 11. Critical frequency deviation 2-D distribution from Intercosmos-19 topside sounding data registered one day before the Irpinia earthquake in Central Italy on 23.11.1980.

5. Conclusions

We can conclude that seismo-ionospheric effects observed at all heights of the atmosphere-thermosphere-ionosphere-magnetosphere chain is a kind of electromagnetic coupling due to large-scale anomalous electric field appearing over the seismoactive area several days before the strong earthquakes. It is similar to the red spite event coupling but the seismo effect is not transient but is quasi-stationary, has lower values of the electric field but larger spatial scale. Several models of such field generation exist up to now, including underground loading and electric charge generation on the earth surface. We propose another model connected with plasmachemistry processes and ion-molecular reactions over the ground surface. Regardless the physical mechanism of the large scale electric field, it produces any effects within the ionosphere. It should be underlined that the large scale is very important to the electric field penetration effectiveness. As our calculations show (Pulinets *et al.*, 1998b) even small additional electric field near 60 V/m is enough to create the sufficient effect within the ionosphere in the case of large scale of the field. The proposed conception of electromagnetic coupling gives a possibility to explain the most of experimental results of electromagnetic and plasma precursors of strong earthquakes observed over the ground surface and in the ionosphere and magnetosphere. It demonstrates that all kinds of electromagnetic emissions observed on different heights are secondary in relation to the near-Earth plasma modification. This fact could be used in putting priority to different kinds of measurements used in seismic prediction monitoring. The proposed conception permits also the "open eyes" approach to organization of ground-space system of earthquakes precursors monitoring.

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