IL NUOVO CIMENTO VOL. 22 C, N. 3-4 Maggio-Agosto 1999

Radon and ionosphere monitoring as a means for strong earthquakes forecast (*)

S. A. PULINETS (1), V. A. ALEKSEEV (2), K. A. BOYARCHUK (3)
V. V. HEGAI (1) and V. KH. DEPUEV (1)

(1) *Institute of Terrestrial Magnetism*
Ionosphere and Radiowave Propagation of the Russian Academy of Sciences
IZMIRAN - Troitsk, Moscow Region, 142092, Russia
(2) *Troitsk Institute for Innovation in Thermonuclear Investigations*
TRINITI - Troitsk, Moscow Region, 142092, Russia
(3) *General Physics Institute of the Russian Academy of Sciences*
IOFAN - 38 Vavilov Str., 117942, Moscow, Russia

(ricevuto il 9 Giugno 1998; approvato il 18 Dicembre 1998)

Summary. — The relation between radon emanation in seismically active regions and variations of the ionosphere parameters is considered. The quasistationary anomalous electric field generated in the near-ground layer of the atmosphere due to radon and metallic aerosols emanation is proposed as the main agent of the seismo-ionospheric coupling mechanism. The effects of the quasistationary electric field penetrated into the ionosphere are considered theoretically and compared with the experimental results. The comparison confirms the proposed conception of the seismo-ionospheric coupling.

PACS 91.30.Px – Phenomena related to earthquake prediction.
PACS 94.20 – Physics of the ionosphere.
PACS 92.60.Pw – Atmospheric electricity.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

The relation between the radon emanation in seismically active regions and variations of the ionosphere parameters will be considered. The quasistationary anomalous electric field generated in the near-ground layer of the atmosphere due to radon and metallic aerosols emanation is proposed as the main agent of the seismo-ionospheric coupling mechanism.

2. – Initial experimental data

The first direct comparison of the radon variations in a well near-future epicenter and the critical frequency f_0F2 of the ionosphere scaled for specific instants of local

---

(*) Paper presented at the "Fourth International Conference on Rare Gas Geochemistry", Rome, October 8-10, 1997.

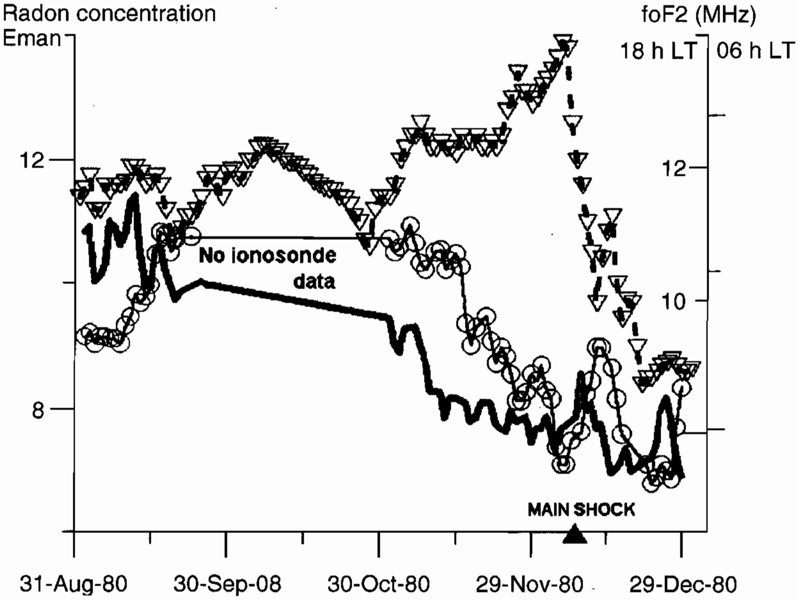

Fig. 1. – Radon concentration and critical frequency of the ionosphere variations comparison. Measurements were made not far from the epicenter of an anticipated earthquake.

time was reported in [1]. The results of observation are presented in fig. 1. These data were collected before the earthquake which happened on December 13, 1980 near Tashkent (the earthquake moment is shown on the X-axis by a bold triangle). Two other curves demonstrate smoothed (running average) variations of the critical frequency f_0F2 scaled during several months for two selected local time moments (06 h LT (thick line) and 18 h LT (thin line with circles)). The anticorrelation of the two processes is evident: when the radon concentration grows (with sharp maximum few days before the shock), the concentration in the morning as well as during the afternoon hours gradually falls with sharp oscillations (minimum before the shock and maximum after it) in the vicinity of the earthquake moment. In [1] only a supposition on the possible role of the atmospheric electric field was expressed.

3. – Anomalous-electric-field generation mechanism

The model of the anomalous-electric-field generation due to radon and metallic aerosols emanation from the Earth's crust was developed in [2]. Radon is the main source of α-particles which produce intensive ionization of the near-ground layer of the atmosphere. Each α-particle emitted by ^{222}Rn with average energy $E_\alpha = 6$ MeV can produce theoretically about $2 \cdot 10^5$ electron-ion pairs. The output of radon can reach 12 eman before an earthquake, which corresponds to an ionization rate of about $7.6 \cdot 10^3\,\mathrm{cm}^{-3}\,\mathrm{s}^{-1}$ [3]. Different ion-molecular reactions take place, which are typical for this layer. The action of these reactions during about 10^{-5} s results in the formation of stable ion's content of the atmosphere near the Earth's surface [4]: O^-, O_2^-, O_2^+, NO^+, CO_3^-, NO_2^-, NO_3^-, NH_4^+ and H_3O^+. The content of other types of ions is negligible. A huge quantity of molecules of water vapor ($\sim 10^{17}\,\mathrm{sm}^{-3}$), having an appreciable dipole moment $p = 1.87\,D$, are contained in the troposphere. Then rather quickly hydration of elementary ions and formation of ions' complexes of the type $NO_3^- \cdot (H_2O)_n$ and $H_3O^+ \cdot (H_2O)_m$, with characteristic significances $n = 2$–3 and $m = 3$–6, occur. Metallic aerosols can present themselves as central ions of water clusters too $M^- \cdot (H_2O)_n$ (here M^- is the ionized atom of the metal), as they frequently have energy affinity to electrons exceeding that for nitrogen oxides and therefore can replace them in the molecular nucleus. The mobility of the negative ions on the average is 1.3–1.4 times higher than that of the positive ions. Apparently, this difference of mobility can be attributed to the asymmetry of the arrangement of ions with charges of different signs with respect to the oxygen atom in the water molecule. Consequently, negative ions are characterized by lower energy, *i.e.*, by a smaller number of attached water molecules, than positive ions. We can assign the considered ion to the class of small or intermediate ions with mobilities of 0.05–$5\,\mathrm{cm}^2\mathrm{V}^{-1}\mathrm{s}^{-1}$. Thus, due to the difference in the mobilities of ions with charges of different signs, the atmospheric electric field E under certain conditions may induce a non-compensated spatial charge near the surface. Let us consider a simplified model of this effect in the case of weak turbulent diffusion, *e.g.*, in early-morning hours, when a cloud of a radioactive gas spreads within a thin near-ground layer where ions are produced. Under the effect of the natural field of the Earth E a spatial distribution of charges can form at the surface: positive ions will be directed to the Earth surface where they will recombine, but as their mobility is low, a spatial layer of positive ions forms at the surface. The negative ions will move vertically upwards (we do not consider electrons in this model since their concentration at the Earth surface is small). An "electrode layer" with a local field E_{L} will form near-ground. The local field E_{L} compensates the natural field E and the resulting electric field will be $E - E_{\mathrm{L}}$. The field in the area of formation of this layer will decrease and under certain conditions it can even change its sign. The field in the area higher than this layer will be amplified due to the presence of a non-compensated negative charge. Figure 2 (a, b) presents the results of simulations performed within the framework of the model described above. This figure shows the concentrations of positive and negative ions and the amplitude of the electrostatic field as functions of the altitude in the near-surface layer 50 s after the onset of ionization. The presented plots clearly demonstrate the formation of a near-surface electrode layer. The electric field decreases in this layer and noticeably increases above this layer. This effect is

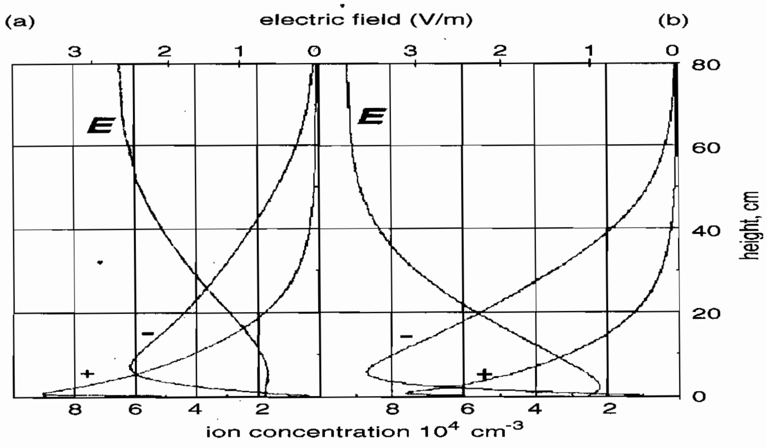

Fig. 2. – Calculated ion concentration and electric field as a result of radon ionization (a) without additional flux, (b) in the presence of metallic aerosols flux.

enhanced due to the increase in the mobilities and diffusion of ions. The presence of the metallic aerosols' flux can appreciably increase the concentration of negative ions. This noticeable negative spatial charge enhances the electric field above this layer. However, the electric field inside the electrode layer decreases to a lesser degree. This effect is shown in fig. 2(b).

4. – Penetration of the electric field into the ionosphere and ionosphere modification

In [5] with the help of the existing model of the vertical distribution of atmosphere conductivity, calculations of the electric-field penetration into the ionosphere were made. The model explains the horizontal electric field $\sim 1\,\text{mV/m}$ at the ionospheric heights as a result of the original vertical electric field $\sim 1\,\text{kV/m}$ at the ground surface. The horizontal electric field within the ionosphere can create positive as well as negative variations of electron concentration. For example, in the F layer due to complex ion drift trajectories a complex two-focal electron concentration distribution will form over the source of the anomalous electric field [6]. The results of the calculation for a height 500 km are shown in fig. 3. One can see from the figure that the effect within the ionosphere does not coincide with the position of the electric-field source on the Earth's surface (it is shown by the black dot in the figure). It is due to the inclination of the geomagnetic field lines through which the electric field is mapped from the heights of the E-region of the ionosphere into the upper heights. The configuration of the foci will change with the atmospheric-electric-field direction (up or down) and with height. As was shown by model calculations, the positive and negative focuses will exchange their places while passing over the F-layer maximum. The magnitude of the quasi-static electric-field effect within the ionosphere is determined by two parameters: by the electric-field magnitude, and by the size of the electric-field source. It means that the effectiveness of the electric-field penetration into the

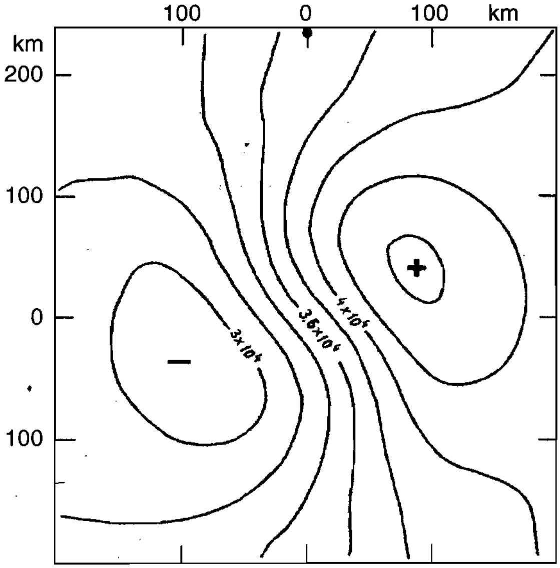

Fig. 3. – Model distribution of electron concentration at the 500 km height as a result of the seismogenic electric-field effect.

ionosphere will increase, if a larger area is occupied by radon emanation. It also will depend on the effectiveness of the space charge formation process over this area. The turbulent diffusion processes are very important too.

5. – The model verification by the experiment

The spatial distribution of the electron concentration could be obtained with the help of satellite measurements [7], which is the main advantage of the satellite technique in comparison with one-point ground-based measurements. The topside sounding from onboard the Intercosmos-19 satellite gave a possibility to test the theory and find within the ionosphere two-focal distributions of the electron concentration predicted by the theoretical calculations [6]. The same result was obtained with the

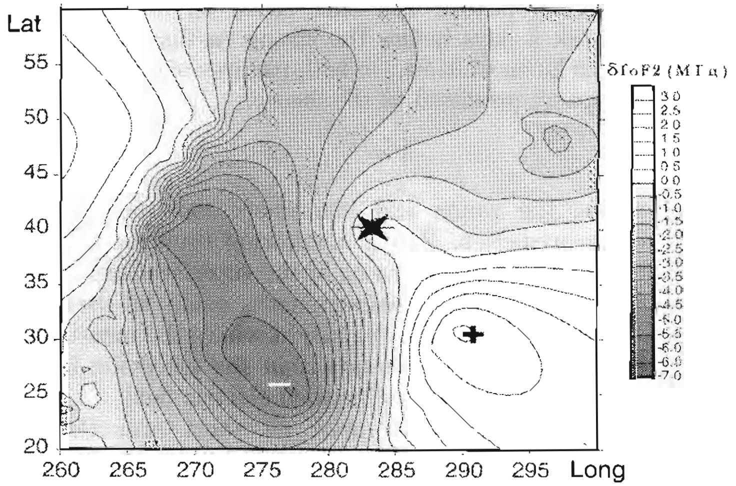

Fig. 4. – Latitude-longitude distribution of the critical frequency deviation $\Delta f_0 F2$ after the Three-Mile Island accident obtained by topside sounder.

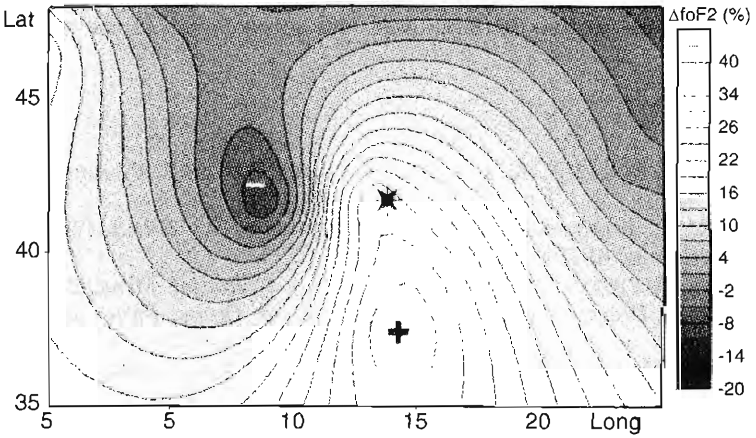

Fig. 5. – Latitude-longitude distribution of the critical frequency deviation $\Delta f_0 F2$ before the strong earthquake in Central Italy, by the data of the European network of ionosondes.

help of a relatively dense network of ground-based ionospheric stations in Europe. Interpolation between the measurement points permitted to produce the map of the spatial distribution of electron density within the ionosphere. Both results support the idea that radiactive substances within the troposphere (as a source of ionization), and submicron aerosols could create a strong vertical electric field within the troposphere affecting onto the ionosphere.

In fig. 4 and 5 two distributions of deviation of the ionospheric critical frequency from an undisturbed level are presented (the critical frequency is proportional to the square root of the electron concentration). The first one was obtained with the help of a topside sounder installed onboard the Intercosmos-19 satellite. The measurements were made the day after the accident at the US atomic power station in Three-Mile Island on March 28, 1979. This event led eventually to the most serious commercial nuclear accident in US history and to fundamental changes in the way nuclear power plants were operated and regulated. The accident itself progressed to the point where over 90% of the reactor core was damaged [8]. The second picture was built based on the data of the European ionospheric stations network 5 days before the strong earthquake ($M = 5.8$) in Central Italy (Abruzzo, 41.8 N, 13.9 E) on 07.05.84. On both pictures one can observe the two-focal structure within the ionosphere predicted by the theory.

6. – Conclusion

As was shown above, the radon and ionosphere monitoring could serve as a powerful tool for seismic prediction. Radon monitoring could be used as middle-term precursor (several months) as well as a tracer of the submicron aerosols emanation [1]. The vertical atmospheric electric-field measurements could be used also for seismic prediction but attention should be paid to the height where the measurement probe will be installed. The electric field will decrease within the electrode layer and increase outside it in comparison with a natural undisturbed electric field.

Ionospheric measurements could be used as short-term (less than 5 days) precursor. They do not give exact information about the epicenter position of the anticipated earthquake, but they are one of the most reliable time precursors.

Ionospheric measurements could be used also for monitoring the radioactive pollution of the atmosphere and the ground surface, as well as for other phenomena (volcano eruptions, sand storms, large air pollution etc.) where a large atmospheric electric field could be generated due to fine disperse dust and aerosols within the atmosphere.

REFERENCES

[1] Pulinets S. A., Alekseev V. A., Legen'ka A. D. and Khegai V. V., *Adv. Space Res.*, **20**, **11** (1997) 2173-2176.

[2] Boyarchuk K. A., Lomonosov A. M. and Pulinets S. A., *BRAS Physics, Supplement, Physics of Vibrations*, **61** (1997) 175-179.

[3] Alekseev V. A., Alekseeva N. G. and Jchankuliev J., *Radiat. Meas.*, **25** (1995) 637-639.

[4] Boyarchuk K. A., *Proceed. of Russ. Acad. Sci., Atmos. Ocean. Phys.*, **33** (1997) 236-240 (in Russian).

[5] Kim V. P., Hegai V. V. and Illich-Svitych P. V., *Fizika Zemli* (1994) 37-40.

[6] Boyarchuk K. A., Pulinets S. A., Hegai V. V. and Lomonosov A. M., to be published in *Uspekhi RAS* (1998).

[7] Pulinets S. A., to be published in *Adv. Space Res.* (1998).

[8] http://www/libraries.psu.edu/crweb/tmi/alldata.htm.