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Remote Earthquake-Induced Large-Scale Ionospheric Disturbances and Strong Mesospheric Electric Fields*

A.M. Gokov, S.I.Martynenko, V.T. Rozumenko, and O.F. Tyrnov

V. Karazin National University of Kharkov, 4, Svoboda Sq., Kharkov, 61077, Ukraine

The results of MF radar remote sensing of plasma disturbances at mesospheric heights caused by severe distant earthquakes are presented. The mechanism underlying the similar effects of these disturbances is closely associated with the large-scale electric-potential redistribution owing to an increase in the atmospheric conductivity over a seismic region is described.

The process of simultaneous development of large-scale ionospheric disturbances was originally ascertained by experiment in terms of the radio radiation data recorded at 18 MHz through the network of radiometric stations in North America, which are spaced thousands of kilometers apart. These disturbances were triggered by the powerful seismic activity that persisted throughout several days prior to the onset of the nascent tremors and later in the course of the full-force devastating earthquake that badly hit the territory of Chile, May 22, 1960 [1]. Specifically recording were made of the seismic disturbance-correlated signal amplitude increase that exceeded the background radiation by a factor of ~ 2. This particular effect was likewise observed prior to and during the powerful earthquakes (of magnitude $M = 7.2$) near the town of Kobe (Japan), January 17, 1995 [2]. In that area two series of radio radiation "bursts" were registered on a frequency of 22.2 MHz at a distance of 77 km from the epicenter. These types of seismoionospheric phenomena which exert a substantial influence on the HF radio signal characteristics have mot been adequately explored to date.

Below are given some results of radiophysical studies into the disturbances in the lower ionosphere, which are induced by high-power remote earthquakes. Consideration is also given to some conceivable mechanisms of developing these disturbances.

Experimental results

To diagnose the disturbances in the lower ionosphere at considerable distances (up to several thousands of kilometers and more) from the areas that are thought to be the hardest hit by the earthquakes, we have resorted to the measurement data on the characteristics of partially reflected (PR) radio signals from the heights $z \approx 60$ to 85 km and the noise effects at 2 to 3.5 MHz with 25 μsec sounding pulse duration.

To illustrate this we present an example of the time-varying magnitudes $R = A_-^2 / A_+^2$ for PR signals at different altitudes and for noise effects. Here A_+^2, A_-^2 are the intensities of ordinary and extraordinary components of PR signals. These intensities are averaged over 1 min sequential intervals. The data were gleaned at the Radiophysical Observatory of Kharkov National University during the earthquake which occurred in the western part of New Gwinea at a distance of nearly 11 000 km, 12.48.54 LT (local time) (3.37^{0}S, 135.18^{0}E, magnitude $M = 5.7$; depth 33 km; the instant at which the earthquake occurred is shown by an arrow).

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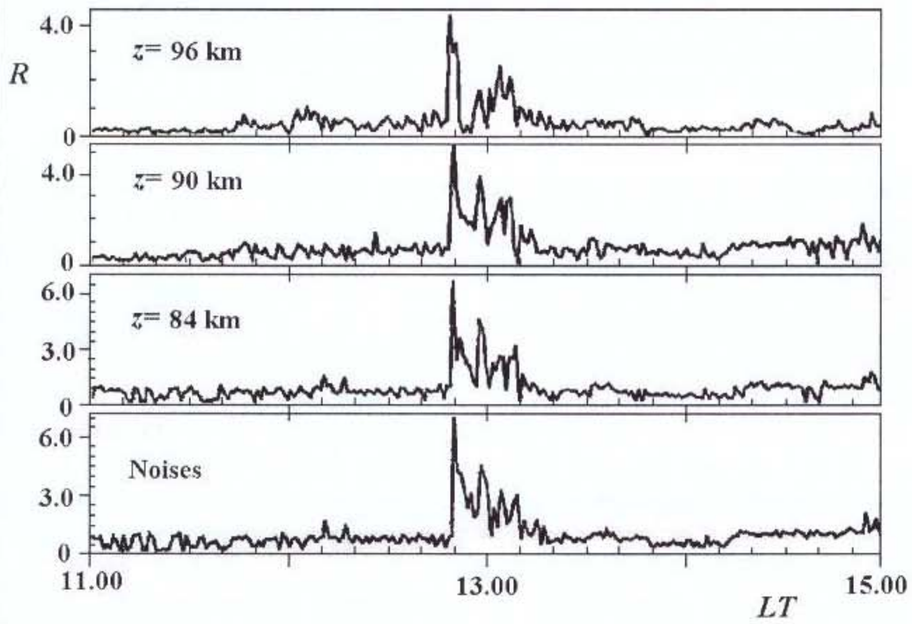
The minor typical time taken for the disturbances to develop (within less than a few seconds) may suggest that the variations in the PR signals characteristics are due to the appropriate changes in temperature and electron collision frequency in the D-region of the ionosphere. Similarity of height-time dependence R indicates that the major ionospheric disturbances was localized below $z = 84$ km. Unfortunately considering the conditions under which the given experiment was being conducted an attempt to ensure that the PR signals are reliably extracted from the heights below 84 km has failed because the intensity of the above signals were less significant than that of noise. In general, however, one can easily observe that the remote earthquake has given rise to the violent burst R, which may result from a decrease in the integral absorption of signals and noise at heights below 84 km.



Tropospheric-mesopheric electric circuit

In the 70-s the intrinsic strong mesospheric electric fields were detected at mesospheric heights [3-5]. This has opened up new areas for researchers to provide an additional insight into the mechanisms for electrodynamic interaction between the troposphere, mesosphere and ionosphere. These mechanisms are based on the concept of the mesosphere as an active element of the global electric circuit. The electrodynamic tropospheric-ionospheric connections have been analyzed by means of a special model of the tropospheric-ionospheric electric circuit incorporating the following elements; 1) a local (or large-scale) high-power source of the mesospheric current with the current density $j_m \approx 10^{-9}...10^{-8}$ A/m^2 [6,7]. This source is capable of increasing the electron temperature and the effective electron collision frequency up to the magnitude which is one order higher-then-normal accepted background values [6,7]; 2) the local near-Earth (or tropospheric-stratospheric) resistance R_t; 3) the local mesospheric load resistance R_m for the mesospheric source; 4) the external resistance of global atmospheric layer between the Earth's surface and the lower ionospheric boundary R_a is equal to of 200 ohm. In the undisturbed conditions the electric current density of the global capacitor discharge (i.e. the "fair" weather current density [10] is expressed as $j_a \approx 10^{-12}$ A/m^2 and $j_m >> j_a$. Therefore, given j_m, the magnitude j_a can be neglected. Taking the undisturbed conditions we have $R_t >> R_m >> R_a$ and, consequently, the total load resistance of the mesospheric current source is given as $R_i = R_t R_t / (R_m + R_t) \approx R_m$, i.e. the electric tropospheric-mesospheric couplings do not appear to reveal themselves.

As far as disturbed conditions are concerned, the resistance R_t may be decreased by an order of magnitude or under. For instance, it is likely to occur owing to an increase of the surface radiation level in the areas badly damaged by the severe earthquakes as well as due to the accidents at nuclear power stations when radioactive substances are ejected into the atmosphere [5,6]. As a result, the relationship between R_t and R_m tends to vary, thereby making a certain impact upon the level of R_i as well. In particular, a decrease of R_t by two orders of magnitude results in the near-Earth resistance becoming considerably reduced as compared to the mesospheric resistance ($R_t << R_m$ and $R_i \approx R_t$). Then the potential difference U in the mesosphere, which determines the strength E of the high mesospheric electric field, become dependent upon R_t. A decrease of R and R_t, in its turn, leads to a respective decrease in E and, as a consequence, to a drop in electron temperate T_e in the mesosphere under the effect of the enhanced tropospheric conductivity (namely, to reduction down to the conventional magnitudes of tropospheric conductivity in the undistorbed conditions). Thus, the presence of high-power mesospheric electric fields brings about the formation of new additional electric dynamic tropospheric-mesospheric couplings under the disturbed conditions.

The parameter disturbance of lower ionosphere

In order to assess the influence of decreasing the intensity E of the mesospheric electric field upon the lower ionosphere parameter we have made use of the well-known set of the balance equations pertinent to the electron temperature T_e, electron density N and the concentration of positive ions N^+ in a layered-inhomogeneous, weakly ionized plasma. This particular set of equation is complemented by the quasi-neutrality condition [9]. The initial values of T_e for the mesosphere in the presence of high electric fields and with no tropospheric disturbances of the conductivity were calculated in terms of solving the above system of equations with regard to the quasi-stationary case ($E = 1...10$ V/m, height $z \approx 60$ to 75 km in the daytime). The results obtained from the numerical calculations pertaining to the strongly disturbed tropospheric conditions (i.e. $R_t << R_m$) indicated that, say, close to the height $z \approx 60$ km, when the intensities of the mesospheric electric field are lowered by $\Delta E_1 = 1$ V/m and $\Delta E_2 = 10$ V/m the values of T_e tend to decrease by a factor of 2.3 and 12 respectively. All this brings about the 2- and 8-fold decrease of the effective electron collision frequency; in addition, the electron density N tends to grow by a factor of 1.1 (at $\Delta E_1 = 1$ V/m) and N is found to get reduced by two times (at $\Delta E_2 = 10$ V/m). As a result, the low-frequency electronic conductivity of the mesospheric plasma increases, thereby causing the heights of fixed levels of the ionospheric LF conductivity to be lowered by approximately $\Delta z_1 \leq 5$ km and $\Delta z_2 \leq 10$ km respectively the numerical calculations suggest that under these circumstances the crucial role is actually played by the resultant decrease of effective election collision frequency ν_e. A similar effect of "scaling down" the lower boundary of the ionosphere was experimentally recorded in terms of, among other, through the measurement data on the characteristics of the VLF signals propagating above the nuclear power station areas during the accidents involving the emission of radioactive substances into the atmosphere [11,12].

Conclusions

The detection of high-power electric fields [3-7] at mesospheric heights enables one to add a new dimension to the electrodynamic tropo-, meso- and ionospheric connections and to gain a deeper insight into their mechanisms. For example, if these particular fields do persist over the regions affected by elevated seismic activity the following mechanisms can conceivably be implemented. A dramatic rise (say, by one or two orders of magnitude) in the tropospheric conductivity over the seismoactive areas through the tropo-mesospheric electric connections will produce a drop in the intensity of the powerful mesospheric electric field. This is certain to entail a relaxation decrease in T_e and ν_e (over an accompanying time interval of less than 1 ms). It is precisely the latter effect that is bound to facilitate the rapid change in the conditions under which the radio waves are propagating in the lower ionosphere over the seismoactive region.

Note that, as the electric potential in the mesosphere over the remote earthquake area undergoes appreciable changes, it may well be that they will initiate the variations of the difference in the mesospheric potentials between the earthquake-stricken and observation areas. These variable processes are taken to be equivalent to the change of the mesospheric electric field intensity over the area under observation. Therefore it would see only too natural that it is precisely over the area to be observed that the mesospheric plasma disturbances can be expected to develop.

Given the phenomena as illustrated in the above Figure, the large-scale difference in mesospheric potentials will show a certain decrease under the action of the distant disturbance and this will give rise to a decrease in T_e, ν_e and the integral PR signals absorption at heights below 84 km.

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