LARGE-SCALE DISTURBANCES ORIGINATING FROM REMOTE EARTHQUAKES AND STRONG MESOSPHERIC ELECTRIC FIELDS

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ABSTRACT

The results are discussed of MF radar remote sensing of disturbances caused by strong earthquakes at great distances in the plasma at mesospheric heights, and a mechanism is advanced for the development of such large-scale disturbances in ionospheric plasma parameters, which is a large-scale mesospheric electric potential redistribution due to an increase in the atmospheric conductivity over a seismic region.

INTRODUCTION

The authors of [1] were the first to observe the development of large-scale ionospheric disturbances caused by strong seismic activity persisted for a few days and during the Chile May 22, 1960, earthquake with magnitude 9.6; the measurements were taken using a net of 18 MHz riometers in North America and spaced by thousands kilometers from each other. Among other things, increases in the signal amplitude by a factor of up to 2 over a background noise were observed to correlate with the seismic disturbances. Similar effects were observed before and during the January 17, 1995, Kobe earthquake with 7.2 magnitude [2]. In the latter case, two sequences of 22 MHz radio bursts were observed at a distance of 77 km from the epicenter. Such seismic phenomena have not found satisfactory explanation yet.

In this paper, we present some National Kharkiv V. Karazin University observations of disturbances caused by remote earthquakes in the lower ionosphere, and discuss possible mechanisms for their development.

EXPERIMENTAL RESULTS

The lower ionosphere disturbance diagnostics at distances of up to a few thousand kilometers off strong earthquakes included records of f=2–3.5 MHz noise and 25 μs MF radar pulses scattered from the z~60 – 80km altitude region.

Fig. 1 represents time dependences of $R = A_-^2 / A_+^2$ obtained for different altitudes at the National Kharkiv V. Karazin University Radiophysical Observatory approximately 11,000 km away from 5.7 magnitude earthquake which occurred at the 33 km depth near Western New Guinea, 3.37 S latitude and 135.1 E longitude, at 12:48:54 LT on March 20, 1995; the arrow marks the time of the earthquake. Here A_+^2 and A_-^2 are the ordinary and extraordinary, respectively, MF radar signal intensities averaged over successive 1-min intervals. The small characteristic time scale of the disturbance development (less than a few seconds) can suggest that the changes in MF radar signals were caused by the corresponding changes in the electron temperature T_e and the effective collision frequency ν_e in the ionospheric D region. The similarity between the dependences of R on time and height suggests that the main ionospheric disturbance was localized below the 84-km altitude where the signal-to-noise ratio was low and prevented the detection of MF radar signals. As a whole, it is clearly seen that the remote earthquake caused the sharp increase in the value of R, which could result from a decrease in the total absorption of signals and noise below the 84-km altitude.

THE TROPOSPHERE-MESOSPHERE ELECTRIC CIRCUIT

The detection of strong mesospheric electric fields at mesospheric heights (see, for example, [3–7]) provides a new opportunity to explain electrodynamic interactions between the troposphere, the mesosphere, and the ionosphere. The electrodynamic troposphere-ionosphere coupling is treated using the following model of a troposphere-mesosphere

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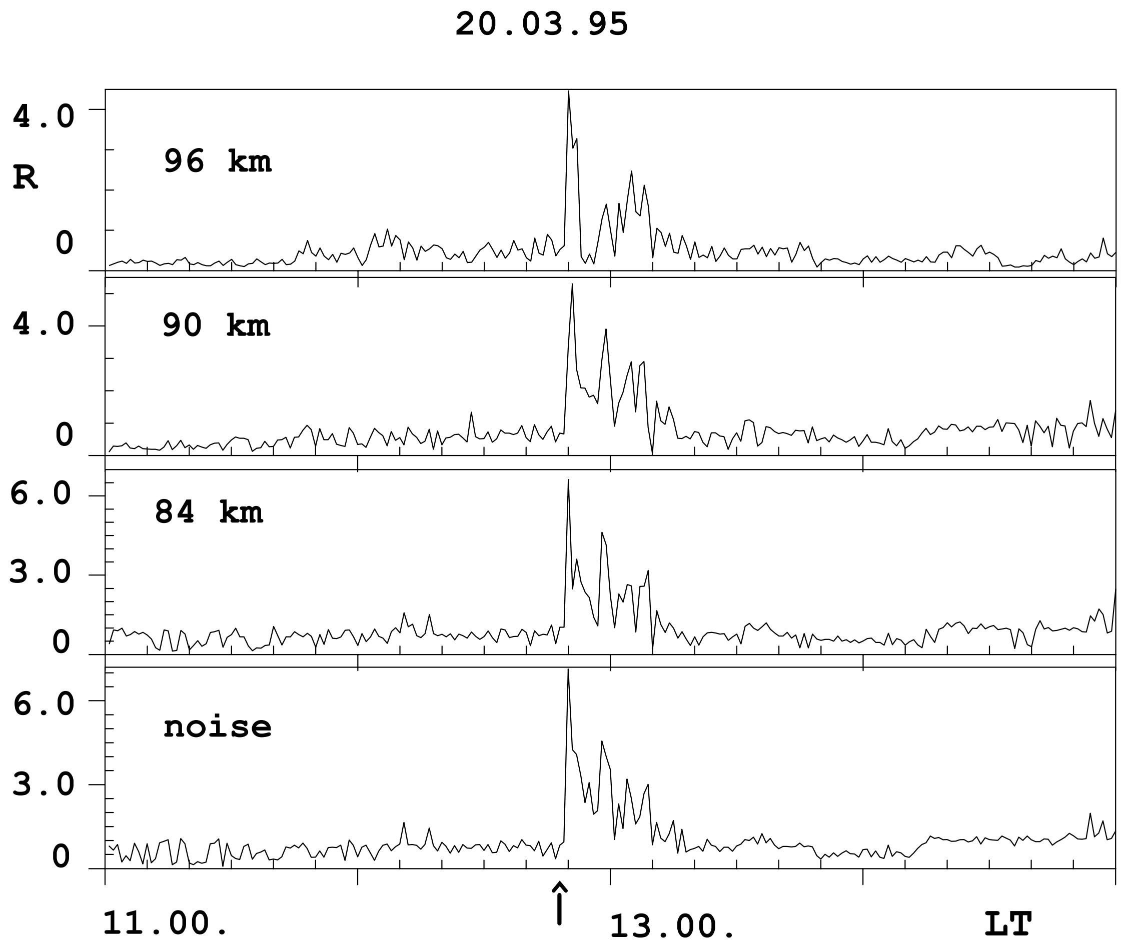

Fig. 1. Time dependences of R for 2.3 MHz signals scattered from 84 km, 90 km, 96 km altitudes at Kharkiv during the March 20, 1995, West New Guinea earthquake; the time of earthquake is marked by the arrow.

electric circuit which includes (i) a localized or global-scale powerful source of the mesospheric current $j_m \sim 10^{-8} - 10^{-9}$ A/m^2 [6] that should sustain electron temperatures and collision frequencies elevated by an order of magnitude over commonly accepted level [3–7], (ii) a local near-ground (or troposphere-stratosphere) resistance R_t, (iii) a local mesospheric load resistance R_m for the mesospheric source, and (iv) the resistance of the global atmospheric layer between the ground and the lower boundary of the ionosphere $R_a \approx 200$ Ohm. Since the electric current discharge density in the global capacitor $j_a \sim 10^{-12}$ A/m^2 under undisturbed conditions (fair-weather current, see, for example, [8]), and $j_m >> j_a$, the j_a may be neglected. Also during undisturbed conditions, $R_t >> R_m >> R_a$. Then during undisturbed conditions, the integral mesospheric source loading $R_i = R_m R_t / (R_m + R_t) \approx R_m$, i.e., the electrical troposphere-mesosphere coupling does not appear.

During disturbed conditions, the resistance R_t could decreases by an order of magnitude and more due to, for example, an increase in the level of near-earth radiation in the vicinity of strong earthquakes or during accidents at nuclear plants with the discharge of radioactive materials (see, for example, [9, 10]). Consequently, the ratio between R_t and R_m changes, and this leads to a change in R_i. For example, a decrease in R_t of up to two orders of magnitude results in the inequality $R_t << R_m$, and in $R_i \approx R_t$. Then the potential difference U in the mesosphere, which depends on the strong electric field intensity E, becomes dependable on R_t. Because of an increase in the tropospheric conductivity, the decrease in R_i and R_t, in turn, results in a corresponding decrease in E and the electron temperature T_e (up to commonly excepted undisturbed levels) in the mesosphere: the ionospheric electron cooling "law" under the influence of disturbances in tropospheric conductivity when strong mesospheric electric fields occur. Thus, strong mesospheric electric fields result in a new additional electrodynamic troposphere-mesosphere coupling during disturbed conditions.

DISTURBANCES IN LOWER IONOSPHERE PARAMETERS

To estimate the effect of the decrease in the mesospheric electric field intensity E on changes in lower ionosphere parameters, we have used the well known system of equations, the energy balance equation (in terms of the electron temperature T_e), the two continuity equations for the electron density N and the positive-ion density N^+ in the stratified inhomogeneous weakly-ionized plasma, and the condition of quasi-neutrality (see, for example [6, 7]):

$$\frac{\partial N}{\partial t} = q_i + \beta_d \lambda N - \beta_a N - \alpha_r N^2(1+\lambda) + \frac{\partial}{\partial z}\left\{(D_t + D_a)\frac{\partial N}{\partial z}\right\}, \tag{1}$$

$$\frac{\partial N^+}{\partial t} = q_i - \alpha_r N^2(1+\lambda) - \alpha_i N^2 \lambda (1+\lambda) + \frac{\partial}{\partial z}\left\{(D_t + D_a)\frac{\partial N^+}{\partial z}\right\}, \tag{2}$$

$$\frac{\partial T_e}{\partial t} = \frac{2Q_e}{3kN} - \delta \nu_e (T_e - T_n), \tag{3}$$

$$N^+ = N + N^- \tag{4}$$

where:

D_t	=	coefficient of eddy diffusion,
D_a	=	coefficient of ambipolar diffusion,
k	=	Boltzmann's constant,
N^-	=	negative ion number density,
q_i	=	total production rate per unit volume of positive ions resulting from the ionization of neutral atmospheric constituents,
Q_e / N	=	average energy acquired by the electron from an external source of heating (e.g., from external electric field),
t	=	time,
z	=	altitude,
α_r	=	effective ion-electron recombination coefficient for the positive ions,
α_i	=	effective ion-ion recombination coefficient,
δ	=	fractional loss of energy per electron collision,
λ	=	N^- / N is negative ion to electron ratio,
β_a	=	effective rate at which the negative ions are formed by attachment of electrons to neutral constituents,
β_d	=	effective rate at which negative ions are destroyed by electron detachment.

In the ionospheric D region, the disturbances in the ion temperature are neglected because they are a factor of M/m lower than those in T_e (M is the average ion mass, and m is the electron rest mass). The kinetic coefficient K_σ ($|\omega_1 - \omega_H| / \nu_e$) $\approx K_\sigma(0) \approx 1.4$, and $\sigma \approx 1.4\, e^2 N / m\nu_e$ where e is the electron charge.

The initial values of T_e were taken as the solutions to the above equations in quasi-steady state (E=1–10 V/m, z=60–75 km, daytime conditions) when there occur strong electric fields in the mesosphere, and when conductivity disturbances are absent in the troposphere.

Numerical simulations for highly disturbed tropospheric conditions, $R_t << R_m$, show that, for example, at z=60 km decreases of $\Delta E_1 = 1$ V/m and $\Delta E_2 = 10$ V/m in mesospheric electric field intensity result in decreases of a factor of 2.3 and 12, respectively, in T_e. Also, this cause the corresponding decrease in the effective electron collision frequency ν_e by a factor of 2 and 8, as well as in an increase the electron number density N by a factor of 1.1 for $\Delta E_1 = 1$ V/m and in a decrease by a factor of 2 for $\Delta E_2 = 10$ V/m; as a result, the low-frequency electron conductivity at the mesospheric heights increases, which results in a decrease in the low-frequency electron conductivity contours by approximately $\Delta z_1 \le 5$ km and $\Delta z_2 \le 10$ km, respectively. Hence, numerical simulations show that the resulting decrease in the effective electron collision frequency ν_e plays a key role.

DISCUSSION

The detection of strong mesospheric electric fields at mesospheric heights (see, for example, [3–7]) provides a new opportunity to explain electrodynamic interactions between the troposphere, the mesosphere, and the ionosphere. Thus, for example, the existence of such fields over a seismically active area makes possible the following mechanism. A big increase (by one or two orders of magnitude) in the tropospheric conductivity over the seismic area can result in a decrease in strong mesospheric electric field intensities due to troposphere-mesosphere electrical coupling (see, for example, [9, 10]). This causes a rapid decrease in T_e and ν_e as well as the corresponding changes in mesospheric conductivity. The last effect results in rapid changes in radio propagation conditions in the lower ionosphere over the seismic area.

It should be remarked that large changes in the mesospheric electric potential over a remote earthquake could result in a change in the difference in electric potential voltage between mesospheric potentials over the remote earthquake and over the observation site, which is equivalent to changes in mesospheric electric field intensities over the observation site. Therefore the development could also be expected of disturbances in the plasma at mesospheric heights. For the experiment depicted in Fig. 1, the remote earthquake should have decreased the large-scale difference in the electric potential voltage, which has resulted in a decrease of T_e, ν_e, and the total absorption of the signals and noise below the 84-km altitude.

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