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THEORETICAL MODEL OF POSSIBLE DISTURBANCES IN THE NIGHTTIME MID-LATITUDE IONOSPHERIC *D* REGION OVER AN AREA OF STRONG-EARTHQUAKE PREPARATION

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We present a theoretical model of possible electron-density disturbances in the nighttime mid-latitude ionospheric D region, preceding strong earthquakes. It is found that the electron density in the nighttime D region over an earthquake epicentral zone can considerably increase before severe earthquakes. The horizontal size of the area of disturbed electron density is about 300 *km. The disturbance effect is expected to be more pronounced if a powerful VLF transmitter operates in the vicinity of an imminent earthquake epicentral zone. In this case, a very dense ionization layer of daytime D-layer type can be formed at the altitudes of the upper nighttime mesosphere and can give rise to the effect of strong absorption of HF radio waves propagating over the earthquake preparation area.*

1. INTRODUCTION

Based on measurements of the propagation characteristics of VLF radio waves of the "Omega" phase navigation system along paths crossing seismo-active areas, bay-shaped phase perturbations of the radio signals, not related to solar–magnetospheric activity, were discovered in [1]. The statistical analysis of 1300 earthquakes with magnitudes $M = 4.0-7.0$ showed that such phase perturbations began to appear in the nighttime $10-20$ days before earthquakes. The confidence probability of the relationship between the observed signal-phase perturbations and the earthquakes was about 90%. Phase perturbations of the radio signals of the "Omega" system were most prominent before very severe earthquakes in Spitak (Armenia, $M = 7.1$, 1988) [2], Rudbar (Iran, $M = 7.5$, 1990) [3], and Kobe (Japan, $M = 7.1$, 1995) [4]. Such signal-phase perturbations can be caused by a noticeable increase in the electron number density at the altitudes of the nighttime ionospheric D region above earthquake-preparation areas.

In this respect, it is interesting to clarify how the processes in the source of an imminent earthquake at the final stage of its preparation can influence the electron density in the nighttime ionospheric D region. The authors of [4] suggested that such an influence can probably be explained by the generation of long-period gravity waves similar to planetary Rossby waves as a result of resonance interaction between the seismic processes and the neutral atmosphere. However, such an explanation seems unreal, since no significant changes in the near-surface atmospheric layer above the epicentral zone of an imminent earthquake have been observed so far. Meanwhile, excitation of planetary Rossby waves, even by various resonance mechanisms, requires significant amounts of energy and momentum to be transferred to the atmosphere. Moreover, since Rossby waves have planetary scales, phase perturbations of the "Omega" signals should also be observed on paths passing thousands of kilometers away from the earthquake epicenter.

Evolution of charged components in the ionospheric D region is determined quite strictly by the conditions of ionization-recombination equilibrium, so that the observed disturbances of the electron density

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N_e can hardly be explained by a simple redistribution of the plasma due to the drift of charged particles induced by an electric field unless such a field is extremely strong. In this respect, a hybrid mechanism was proposed in [5] to explain the seismic nature of the electron-density disturbances in the D region. According to this mechanism, the above-mentioned disturbances of the number density N_e are caused by the vertical transport of charged particles into the D region from the upper sporadic E_s layer and variation in the density of nitric oxide under the combined effect of electric fields and infrasonic waves generated in the earthquake-preparation source and propagated up to ionospheric altitudes. However, such a hypothesis was not corroborated in [5] by any quantitative calculations of variations in N_e.

In this paper, we present a theoretical model that explains and allows for calculating the possible electron-density disturbances in the nighttime ionospheric D region over epicentral zones of earthquakes under preparation. Our model is a natural development of our multi-year theoretical studies of the possible ionospheric precursors of strong earthquakes, which were performed within the framework of a unified approach based on the assumption that the primary source of ionospheric disturbances preceding severe earthquakes is a disturbance of the vertical electric field on the ground initiated by physico-chemical processes in an earthquake source. Indeed, such disturbances of the vertical electric field were observed repeatedly in epicentral zones before earthquakes [6–8]. Penetration of an electrostatic field of seismogenic origin into the ionosphere was calculated quantitatively in [9], in which the electric field in the ionosphere was shown to be fairly strong. Using the results of [9] and allowing for the recent level of theoretical modelling of the ionosphere, we elaborated step-by-step quantitative models of strong-earthquake precursors at the altitudes of the E and F regions [10, 11] and also in the upper ionosphere [12]. Note that the immediate factor determining the ionospheric disturbances in these models was the drift of charged particles of the ionospheric plasma under the action of the electric field of a seismic source. However, as was pointed out above, the electric drift of charged particles in the ionospheric D region does not have a significant effect on their number-density distribution. Hence, in this case, the electron-density disturbance before an earthquake is determined by a physical mechanism of a different origin, which is considered in detail below.

2. THE PHYSICAL MECHANISM

It was shown in [12] that a plasma irregularity extending from one hemisphere to another along the geomagnetic field is formed in the plasmasphere before a strong earthquake under the action of the electric field of a seismic source in the vicinity of the geomagnetic field line passing through the epicenter of an imminent earthquake. The typical size of the irregularity across the geomagnetic field is about 300 km at altitudes about 2000 km. Such a plasma irregularity is a duct for low-frequency electromagnetic waves of natural and artificial origin. We should note that similar plasma irregularities elongated along the geomagnetic field lines can also occur under the action of the electric fields of large thunderclouds [13]. Coherent VLF radio waves emitted by powerful ground-based radio stations, including the transmitters of the “Omega” navigation system, should be efficiently channeled in such ducts and should propagate along them in the plasmasphere penetrating in the region of trapped high-energy particles of the Earth’s radiation belt. The resonance cyclotron interaction of the propagating VLF wave and the energetic-electron population can take place in the radiation belt, which leads to the pitch-angle scattering of the trapped particles. As a result, some energetic electrons will be scattered into the loss cone and precipitate in the lower atmosphere. The resonance cyclotron interaction of VLF waves with energetic charged particles is the subject of many publications (see, e.g., the reviews [14, 15]).

Natural incoherent wideband VLF radiation trapped in a duct should lead to chaotic variations in the pitch angles of energetic electrons. Mathematically, such a pitch-angle scattering can be described as diffusion in the pitch-angle space [15]. In this case, natural VLF waves can be efficiently amplified in a duct, which, in turn, should result in intense pitch-angle scattering of the energetic electrons and in their enhanced precipitation [16–18]. Coherent VLF radio waves have a much stronger effect on the pitch-angle distribution of energetic charged particles and on their precipitation from the radiation belt since, in this case, variations in the pitch-angle during the bounce period are no longer chaotic, but regular. The pitch-angle scattering