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Electric field penetration into the ionosphere in the presence of anomalous radon emanation

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Abstract

The scientists came to consensus that electric field driven mechanism is more probable to explain ionospheric anomalies before earthquakes than the acoustic-driven mechanism (Pulients and Davidenko, 2014), and it is essential to understand how a vertical electric field from the ground penetrates into the ionosphere. Anomalous radon emanation in the epicentral area is believed to change the atmospheric electrical conditions. Considering the effect of radon emanation on atmospheric conductivity, the electric potential equation is established and solved numerically in the presence of a vertical electric field of 1 kV/m on the ground. The results show that radon emanation can strengthen atmospheric conductivity, as a consequence, the resulting electric field is increased by about 60% in the daytime ionosphere. However, the resulting electric field in the ionosphere is very weak (only about 0.3 μV/m), which implies that the penetration of vertical electric field of 1 kV/m in the seismic area is unlikely to produce daytime ionospheric anomalies before earthquakes.

Keywords: Ionospheric disturbances; Electric field; Radon emanation; Earthquakes

1. Introduction

Numerous reports have shown that ionospheric disturbances before equatorial and low-latitude earthquakes have high occurrence in daytime, especially in the afternoon sector (Liu et al., 2000; 2006; Zhao et al., 2008; Sharma et al., 2010; Xu et al., 2010). Ionospheric anomalies in foF2/TEC before earthquakes are interpreted in terms of an external eastward (westward) electric field which raises (reduces) the ionosphere to high (low) altitudes of reduced (increased) chemical loss through $\boldsymbol{E} \times \boldsymbol{B}$ plasma drift, and produces positive (negative) disturbances. Simultaneously, the external electric field in one hemisphere can map through the geomagnetic field lines into the conjugated areas of the opposite hemisphere, resulting in conjugated effect (Pulinets and Boyarchuk, 2004).

Modeling studies have demonstrated that the required zonal electric field is up to ∼mV/m (Namgaladze et al., 2009; Xu, 2009; Klimenko et al., 2011; Liu et al., 2011; Le et al., 2013). On the other hand, using the data recorded by ground-based ionosondes, Xu et al. (2011) derived an enhanced eastward electric field of 1–2 mV/m close to the epicenter of Wenchuan 2008 earthquake with the help of the expression relating the daytime F2-layer maximum parameters NmF2 and hmF2. It is thought that the external electric field that produces ionospheric disturbances originates from the ground. Ground observations have demonstrated the existence of an anomalous increase of vertical electric field of ∼kV/m on the ground of seismic region (Kondo, 1968; Hao, 2000, etc.). However, the processes of generation and penetration of the vertical electric field into the ionosphere are not yet very clear. Kim et al.

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(1994) firstly calculated the penetration of electric field based on a simple model with an upper boundary of 90 km and showed that the electric field in the ionospheric is about 1 mV/m, for a given external vertical electric field of 1 kV/m on the ground. However, the electric field might be overestimated. Ampfere et al. (2010) obtained a rather weak electric field of ~μV/m in the daytime ionosphere due to low atmospheric conductivity, which is too weak to contribute to ionospheric disturbances. Due to the importance of Pedersen conductivity above 90 km, Kim et al. (2012) replaced the upper boundary of 90 km by 170 km, and obtained an electric field of ~μV/m in the daytime ionosphere. Recently, Denisenko et al. (2013) claimed that the resulting electric field in the ionosphere is negligible based on the results from a three dimensional model with a more reasonable upper boundary of 500 km.

It is generally accepted that the enhanced vertical electric field on the ground is generated by the emission of radioactive particles (radon) into the atmosphere within the area of preparation zones (Pulinets and Boyarchuk, 2004). Abnormal increases in radon concentration before earthquakes have been reported by several researchers (Yasuoka and Shinogi, 1997; Walia et al., 2006; Omori et al., 2007). Radon concentration has significant influence on the atmospheric electric conductivity, and might alter the atmospheric electrical structure. In this paper, considering the horizontal gradient of atmospheric conductivity due to differential abnormal radon emanation, we establish a model of the penetration of electric field from the lithosphere into the ionosphere, and estimate the amplitude of the resulting electric field in the daytime ionosphere in the presence of abnormal radon emanation.

2. Model of electric field penetration from ground into the ionosphere

The electrostatic coupling between ground and ionosphere was firstly comprehensively discussed by Park (1976). Following the approach, the basic equations to be solved are

$$\nabla \cdot \boldsymbol{J} = 0 \tag{1}$$

$$\boldsymbol{J} = \boldsymbol{\sigma} \cdot \boldsymbol{E} \tag{2}$$

$$\boldsymbol{E} = -\nabla \boldsymbol{\Phi} \tag{3}$$

where $\boldsymbol{J}$ is the current density, $\boldsymbol{\sigma}$ is the conductivity tensor and approximately isotropic in the atmosphere, and Φ is the electric potential. For a tow-dimensional problem in a Cartesian coordinate system, the electric potential Φ can be expressed as

$$\sigma\frac{\partial^2\Phi}{\partial x^2} + \sigma\frac{\partial^2\Phi}{\partial z^2} + \frac{\partial\sigma}{\partial x}\frac{\partial\Phi}{\partial x} + \frac{\partial\sigma}{\partial z}\frac{\partial\Phi}{\partial z} = 0 \tag{4}$$

where σ is the atmospheric conductivity. The x and z axes point to the east and upward, respectively. If distribution of atmospheric conductivity is assumed to vary with altitude only, the left third term is to be omitted.

As for the lower boundary condition, the vertical component of the enhanced electric field near the ground in the seismic region is given as

$$-\partial\Phi/\partial z|_{z=0} = E_0 \exp(-x^2/d^2) \tag{5}$$

where E_0 is the maximum value of the vertical electric field near the ground, and is assumed to be 1 kV/m, d is the characteristic size of the electric field and is assumed to be 200 km.

It has been a general practice to assume an equipotential ionosphere, resulting in $\partial\Phi/\partial z = 0$ (only zonal component in the ionosphere). Denisenko et al. (2008) proposed an upper boundary condition at an altitude of 80 km, which is proved applicable compared with a more reasonable upper boundary of 500 km (Denisenko et al., 2013). Furthermore, with the higher upper boundary of 500 km, there will be a vertical component of electric field (i.e., $E_z = -\partial\Phi/\partial z \neq 0$) in E and F region. Nevertheless, E_z is unable to contribute to ionospheric disturbances in F region due to unchanged altitude of plasma. The upper boundary condition has the form

$$-\frac{\partial}{\partial x}\left(\sum\nolimits_p \frac{\partial\Phi}{\partial x}\right) + \sigma_{up}\frac{\partial\Phi}{\partial z}\bigg|_{z=up} = 0 \tag{6}$$

where Σ_p is integrated Pedersen conductivity and is assumed to be 10 S in daytime. σ_{up} is the Pedersen conductivity at upper boundary of 80 km. With the conditions of upper, lower, periodic boundaries, and distribution of σ, the Eq. (4) can be numerically solved through difference method. In simulation, the altitude range of the simulation space is from 0 km to 80 km, and the altitude spacing is 500 m. The horizontal range is −400 km to 400 km, and the spacing is 2 km. The contribution of radon emanation to atmospheric conductivity σ will be considered in the next section.

3. Atmospheric electric conductivity due to radon anomaly

3.1. Distribution of atmospheric conductivity

The atmospheric conductivity results from the concentration of small ions which it contains. Empirical distributions of atmospheric conductivity are extensively used in electrostatic coupling between ground and ionosphere. Although some comprehensive theoretical models of atmospheric conductivity have been established (Rycroft et al., 2008), here we adopt a simple theoretical model which will give a basic result for a response of the atmospheric conductivity for radon emanation.

The ion number density n is presented by

$$\frac{\partial n}{\partial t} = q - \alpha n^2 - \beta N n \tag{7}$$

where q is the ionization rate, α and β are the recombination and attachment rates, respectively, and N is the aerosol number density. β has a value of $(3.0 - 4.0) \times 10^{-12}$ m^3/s (Pierce, 1976), and N is 10^{-10}/m^3