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Possible mechanism of ionospheric anomalies to trigger earthquakes − Electrostatic coupling between the ionosphere and the crust and the resulting electric forces acting within the crust −

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Abstract

This study proposes a capacitive coupling model between the Earth's crust and the ionosphere to explain ionospheric anomalies observed prior to major earthquakes and to explore their potential role in triggering seismic events. In this model, a fractured zone within the crust acts as a capacitor, accumulating electric charge through the infiltration of high-temperature, high-pressure water containing dissolved ions. The precipitation of ultrafine charged particles within the fracture zone generates an electric field that interacts with the ionosphere, leading to anomalies such as increased total electron content (TEC), lowered ionospheric altitude, and reduced propagation velocity of medium-scale traveling ionospheric disturbances (MSTIDs). The model further suggests that the ionosphere can exert electrostatic forces on the crust via capacitive coupling. Specifically, negative space charges formed in the lower ionosphere—often enhanced by solar flares—can induce electric fields within crustal voids, generating electrostatic pressure sufficient to promote void collapse and large-scale fracturing. Quantitative estimates indicate that ionospheric disturbances with TEC increases of 10–90 units can produce pressures up to several MPa within crustal voids, comparable to gravitational and tidal forces.
The coincidence of strong solar flare activity with the 2024 Noto Peninsula earthquake supports the hypothesis that ionospheric charge variations may contribute to earthquake initiation. This mechanism provides a novel perspective on the interaction between atmospheric and lithospheric systems and suggests that monitoring ionospheric conditions could enhance earthquake forecasting capabilities. By integrating geophysical, atmospheric, and electrostatic principles, this work highlights the significance of ionosphere–crust coupling and its implications for seismic hazard assessment. The findings underscore the need for further interdisciplinary research to validate the proposed mechanism and to refine predictive models for earthquake precursors.

Keywords: Capacitive coupling model, solar flare-induced TEC variations, triggering an earthquake, electrostatic forces, ionospheric anomalies.

1. Introduction

We have proposed a capacitive coupling model between the Earth's crust and the ionosphere to explain ionospheric anomalies that have been reported in association with large earthquakes [1]. In this model, a fractured zone within the crust acts as a capacitor that establishes an electric field between the crust and the ionosphere, thereby allowing mutual interaction.

When high-temperature, high-pressure water (subcritical or supercritical) containing dissolved ions infiltrates crustal fractures, the pressure reduction causes the ions to precipitate as ultrafine charged particles[2, 3] . The resulting accumulation of electric charge within the fracture zone can, according to our model, account for the ionospheric anomalies observed prior to major earthquakes such as the 2011 Tohoku [4−6], 2016 Kumamoto [7], and the 2024 Noto earthquakes [8]—specifically, the increase in total electron content, the decrease in the propagation velocity of medium-scale traveling ionospheric disturbances (MSTIDs) [4, 7] and the lowering of the ionospheric height.

Furthermore, the capacitive coupling model suggests that the ionosphere can reciprocally exert an electrostatic force on the crust, potentially triggering large-scale fracturing. The following sections discuss this possibility.

2. Capacitive coupling model

As illustrated in Fig. 1, the fracture zone within the crust, the ground surface, and the lower ionosphere are capacitively coupled [1].

Supercritical water under high temperature and pressure infiltrates the fracture zone, forming a dielectric layer that acts as a capacitor. Ultrafine charged particles generated from dissolved ions could create an electric potential difference across the fracture zone, leading to an increase in the surface potential [9]. Through capacitive coupling, high-mobility electrons in the upper atmosphere attach to atmospheric molecules to form a negative space-charge layer in the lower ionosphere. This process causes a lowering of the ionospheric altitude and an increase in electron density.

We assume characteristics of the fractured zone before major breakdown as: Average thickness of the fractured layer is 10^{-5} m, Relative permittivity ε_s of 5 and a capacitance of 5×10^{-6} F/m^2, breakdown voltage of the zone 300 V. Then the stored charge is 1.4×10^{-3} C/m^2.

The electric field lines generated by this charge can induce the observed ionospheric anomalies. For instance, ionosphere lowered with distance of 20 km prior to Noto peninsula earthquake [8]. The charge associated with the lowered region forms a negative space charge at the base of the ionosphere by attaching to neutral gas molecules. This space charge effectively terminates the electric field originating from the fracture zone. The magnitude of this charge is comparable to that stored within the fractured crustal region.

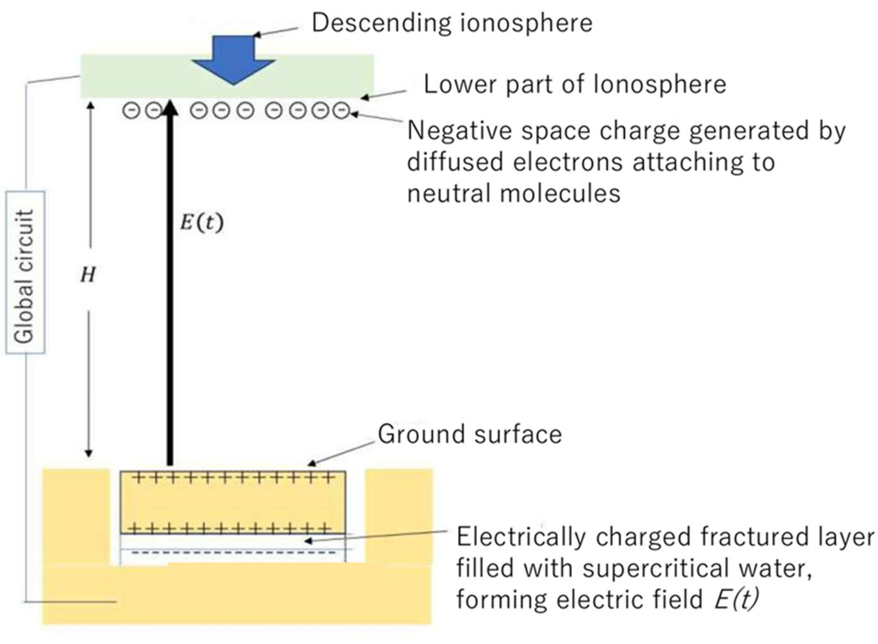

Fig. 1. Capacitive coupling between the fractured layer, ground surface, and ionosphere.

3. Electrostatic forces acting on crustal voids induced by lower-ionospheric charges

It has been suggested that microscopic voids (pores) generated within the crust grow and connect, eventually leading to macroscopic rupture [10]. These voids typically have dimensions on the order of several hundred nanometers, and large-scale failure is known to occur when the void fraction exceeds approximately 7%.

Ionospheric disturbances caused by solar flares are well known to produce communication disruptions. When a solar flare enhances ionization in the ionosphere, the diffusing electrons in the lower ionosphere can form a negative space charge. Through capacitive coupling, this space charge induces an electric field within the crustal voids, generating electrostatic pressure, as depicted in Fig. 2.

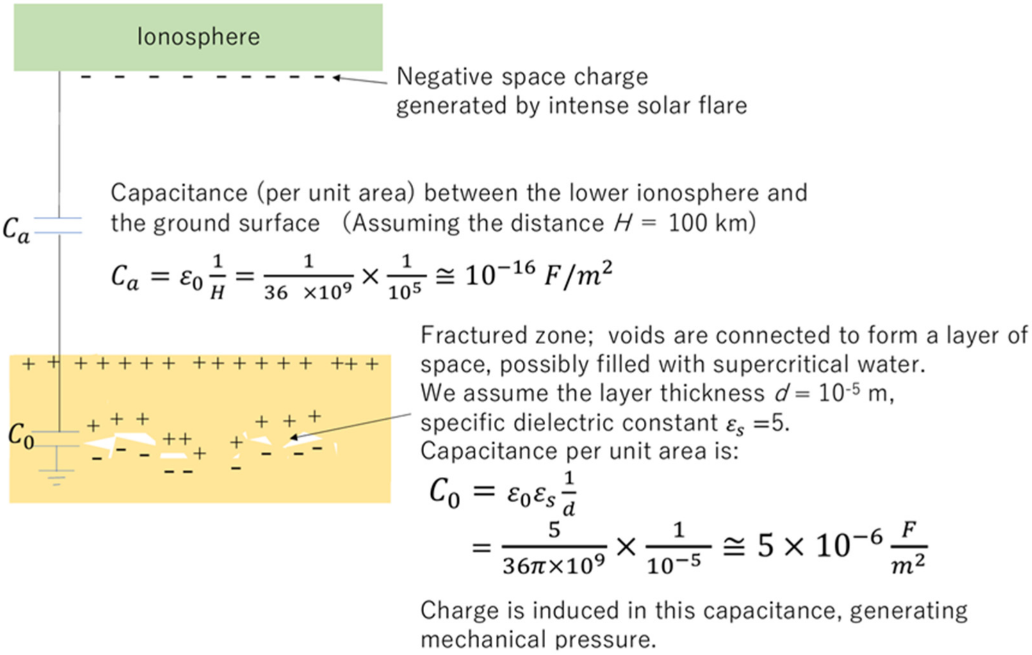

Fig. 2. Mechanical pressure is exerted in the capacitance of the fractured layer by the negative space charge in lower ionosphere caused by solar flare.

To estimate this effect, consider that a charge of Q TECU (Total Electron Content Units, 1 TECU = 10^{16} electrons m^{-2}) descends to form a negatively charged cloud in the lower ionosphere. A portion of the descending charge could produce negative space charge, however, the rate is not known, and here, we assume that the density σ_n of the negative space charge is Q.

Assuming an average thickness of the network of the connected voids in the crust is d meter, then, the capacitance per unit area is

$$C_B = \varepsilon_s \varepsilon_0 \frac{1}{d} \cong 5 \times 10^{-11} \frac{1}{d} \quad \mathrm{F/m^2} \tag{1}$$

If the negative space charge of density σ_n is formed, the induced surface charge density on the ground will have an equal magnitude due to capacitive coupling.

$$\sigma_n = Q \times 1.6 \times 10^{-3} \quad \frac{\mathrm{C}}{\mathrm{m^2}} \tag{2}$$

Setting the potential of the lower crust to zero, the resulting potential difference in the connected voids is

$$V_B = \frac{\sigma_n}{C_B} \cong 3Q \times 10^7\, d \qquad \mathrm{V} \tag{3}$$

The electric field, E_B, and the pressure caused by the charge, P_B, within the void are given as:

$$E_B = V_B \frac{1}{d} \cong 3Q \times 10^7 \quad \frac{\mathrm{V}}{\mathrm{m}} \tag{4}$$

$$P_B = \sigma_n E_B \cong 5\, Q^2 \times 10^4 \quad \frac{\mathrm{N}}{\mathrm{m^2}} \tag{5}$$

At a latitude of approximately 35°N, solar flares with a recurrence period of about once per year can increase the total electron content by more than 90 TECU. During the X9.3-class solar flare in September 2017, for example, the TECU increased from 17 to 27, corresponding to a +10 TECU rise [11]. If a negative space charge in the lower ionosphere is 10 TECU, the resulting pressure within crustal voids can reach $5 \times 10^6 \frac{N}{m^2}$. For rarer and stronger solar flares, the induced pressure would be even greater.

This result suggests that the electric field produced by the lower-ionospheric space charge can, through capacitive coupling, apply an electrostatic force sufficient to promote the collapse of voids in the crust, thereby triggering a large earthquake [12].

4. Conclusion

The capacitive coupling between the ionosphere and the Earth's crust implies that variations in ionospheric charge density can exert electrostatic forces within crustal voids. Our estimates show that, in addition to the pressure by tide and gravitational force, the magnitude of the electrical force may be sufficient to initiate large-scale fracturing, potentially triggering major earthquakes. During the 2024 Noto Peninsula earthquake, for instance, a strong solar flare occurred in the early morning [13]. This coincidence suggests that the electrostatic forces acting on pre-existing, expanded voids in the crust could have accelerated fracture processes, leading to the main seismic event.

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