Comment on "A capacitive coupling model between the ionosphere and a fault layer in the crust with supercritical water" by Mizuno *et al.*

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Abstract

Mizuno *et al*. recently published a paper in this journal describing a new hypothesis that accounts for pre-earthquake ionospheric disturbances that have been reported in earlier studies, although the reliability of these reports is debated. According to their hypothesis, the origin of the ionospheric disturbances is frictional heating along the fault by pre-earthquake slip. Due to this heating, the water in the fracture layer becomes supercritical, and electrical charge is stored inside the layers. The stored charge generates a difference in the electric potential (voltage) across the upper and lower sides of the layer, which in turn induces changes in the electric field between the Earth's surface and the ionosphere. Based on simple calculations and experiments, they propose that this scenario is realistic; however, their analysis includes fundamental flaws. Their estimate of the temperature increase is erroneous, as they ignore the thermal diffusion; consequently, they overestimate the temperature increase by a large margin. Moreover, Mizuno et al.'s explanation for the generation of the electrical field is unrealistic. They assume that the charge inside the fracture layer generates a voltage across the layer; however, this claim ignores basic electromagnetic theory. In summary, the scenario described in Mizuno *et al.*'s paper is implausible, although their experimental results are valid.

Keywords: Earthquake, electrical charge, charge separation, thermal diffusion.

1. Introduction

Mizuno, Kao, and Umeno recently published a paper in this journal ([1]; herein referred to as MKU24) in which they presented a new hypothesis that might account for the downward drift of the ionosphere before earthquakes. Pre-earthquake electromagnetic phenomena, including ionospheric disturbances, have been reported previously [e.g., 2–6], although the reliability of the reports of these precursory phenomena is debated and opposing views have also been published [e.g., 7, 8]. If these precursory phenomena really exist, a major problem is understanding the mechanisms that generate them. To date, no mechanisms for precursory electromagnetic phenomena have been accepted widely.

- MKU24 assumes that the pre-seismic downward drift of the ionosphere is caused by the following mechanisms:
- The electrification in the supercritical state generates a difference in electrical potential across the fracture layer, which changes the electrical field and causes the downward drift of the ionosphere (sections 2.2–2.4 of MKU24).

To support this scenario, MKU24 performed a preliminary experiment to demonstrate that electrification occurs in a clay–water mixture at high temperatures and pressures (section 3 of MKU24). In conclusion, MKU24 state in the second paragraph of section 4 that "Using several assumptions, we have estimated the charge and energy stored in the fractured layer are sufficient to cause the downward drift of the ionosphere for 20 km".

However, this conclusion is based on major errors. Even if their experimental result is correct, 60 their theory cannot account for the downward drift of the ionosphere. Below, I list the two main 61 problems with their hypothesis.
Frictional heating due to fault slip generates high temperatures in the fracture zone on 49 a fault plane (fracture layer), resulting in supercritical water in the layer (section 2.1 of 50 MKU24).

2. Major issues

2.1 Incorrect estimate of the temperature rise inside a fracture layer

MKU24's theory begins with the hypothesis that frictional heating due to pre-slip (i.e., slow, subtle slip on a fault before large earthquakes) causes a marked rise in temperature, which transforms the water in the fracture layer into a supercritical state. To confirm their hypothesis, they use the example of a segment with area, S, of 1 m^2 that slips 1×10^{-2} m. The width of the fracture layer, d, was assumed to be 1×10^{-5} m. Using these values, they estimated that the corresponding frictional heat per unit area, Q, is $\sim 4 \times 10^5$ J m^{-2}. They further estimated that the temperature increase in a volume $S \times d$ (1×10^{-5} m^3) due to this heat energy is >1000 °C, which is sufficient to produce supercritical water.

Although not explicitly described in their paper, MKU24 appear to estimate the temperature increase (T_{mku}) as follows:

$$T_{\text{mku}} = \frac{QS}{C\rho Sd} \tag{1}$$

where C is the specific heat capacity and ρ is the mass density. The values of C and ρ are needed to estimate the temperature increase when the heat is specified. If we assume that C is 4×10^3 J kg^{-1} K^{-1} and ρ is 1×10^3 kg m^{-3}, which correspond to liquid water, and assume the other parameters are the same to those used by MKU24, Tmku is $\sim$10,000 K (10,000 °C), which is sufficient to produce supercritical water, as described by MKU24.

However, the above calculation does not give the correct temperature increase because it ignores the thermal diffusion. A more realistic estimate of the increase in temperature (T_{correct}), considering the thermal diffusion, is as follows:

$$T_{\text{correct}} \cong \frac{Q}{\sqrt{kC\rho t_0 \pi}} \tag{2}$$

where k is the thermal conductivity coefficient and t_0 is the duration over which the heating occurs. The derivation of this equation is presented in the Appendix. Eq. (2) yields a much smaller estimate of the temperature increase than Eq. (1), which shows that the temperature increase calculated by MKU24 is greatly overestimated. For example, assume that t_0 is 0.5 s and k is 0.6 J s^{-1} m^{-1} K^{-1}, although not very accurate. Then the ratio is approximately

$$\frac{T_{\text{correct}}}{T_{\text{mku}}} = \frac{d\sqrt{C\rho}}{\sqrt{kt_0 \pi}} \sim 2 \times 10^{-2} \tag{3}$$

Note that the actual value of the thermal conductivity k would be much larger [e.g., 9], giving a smaller value of the ratio. This demonstrates that the actual temperature increase is two orders of magnitude smaller than that suggested by MKU24. If we assume a larger value of d, this ratio becomes larger; however, T_{mku} becomes smaller. In any case, Tcorrect rarely reaches 1000 K, and the parameters assumed by MKU24 do not give rise to supercritical water as a result of pre-slip.

MKU24 and the discussion above assume the fault parameters corresponding to pre-slip. If we assume fault parameters that correspond to the main shock, the estimated temperature increase is much larger than that obtained in the calculation above and can possibly account for a supercritical state; however, the conclusions of MKU24 were related to pre-earthquake phenomena.

2.2 Implausible mechanism for generating a voltage across a fracture layer

MKU24 assumed that positively charged particles are generated in the supercritical fluid in the fracture layer. The situation assumed by MKU24 is illustrated in Fig. 1 (a). MKU24 stated that "Existence of charged particles inside the fractured layer causes a voltage across the layer" (first sentence of the last paragraph of section 2.2 of MKU24; see also the first sentence of their section 2.3).

However, MKU24's explanation for the generation of potential difference due to the positive charges is not plausible. Charges *inside* a fracture layer cannot cause a voltage *across* that layer (Fig. 1 (a)). Likewise, positive charges inside a fracture layer and negative charges outside the layer do not cause a potential difference across the layer (Fig. 1 (b)), only between the inside and outside of the layer. A voltage across the layer is only generated by a separation of charges on either side of the layer; i.e., positive charges on one side and negative charges on the other (Fig. 1 (c)).

MKU24 assumed positive charges on the upper side of the fracture layer and negative charges on the lower side (Fig. 1 (c); Fig. 1 of MKU24), without any explanation of how or why the positive and negative charges are separated this way; they only describe how the charged particles are generated *inside* the layer. An experiment described in section 3.1 of MKU24 demonstrates that supercritical fluids can generate positive charges *inside* the fracture layer (and negative charges. *outside* the layer); however, this experiment only demonstrates the possibility of the situations shown in Fig. 1 (a) or (b), not that shown in Fig. 1 (c). Therefore, MKU24's discussion in their sections 2.2 and 2.3, which is based on charge separation as illustrated in Fig. 1c, is not supported by evidence.

In addition, MKU24's theory is flawed even if charge separation occurs. Because of the conductivity of the Earth's crust (typically 10^{-1} to 10^{-4} S m^{-1}), separated charges should dissipate very quickly. Johnston estimated that the relaxation time of charge in the Earth's crust with an electrical conductivity of 10^{-3} S m^{-1} is 10^{-6} seconds [10]. MKU24 suggests that high resistivity due to the supercritical fluid would make it possible for the charge to persist for a sufficient duration (second paragraph in their section 4); however, even if we assume that the fracture layer becomes a perfect insulator in the supercritical state, discharge should occur through the margin of the fracture layer because the area of the fault is finite. Indeed, MKU24 state that "The generated charge is discharged directly within the fractured layer and through the surrounding quasiconductive crust" (last paragraph of their section 2.3). This means that, even if an electrical field is generated as MKU24 describe, the field should disappear rapidly and therefore would not result in a downward drift of the ionosphere.
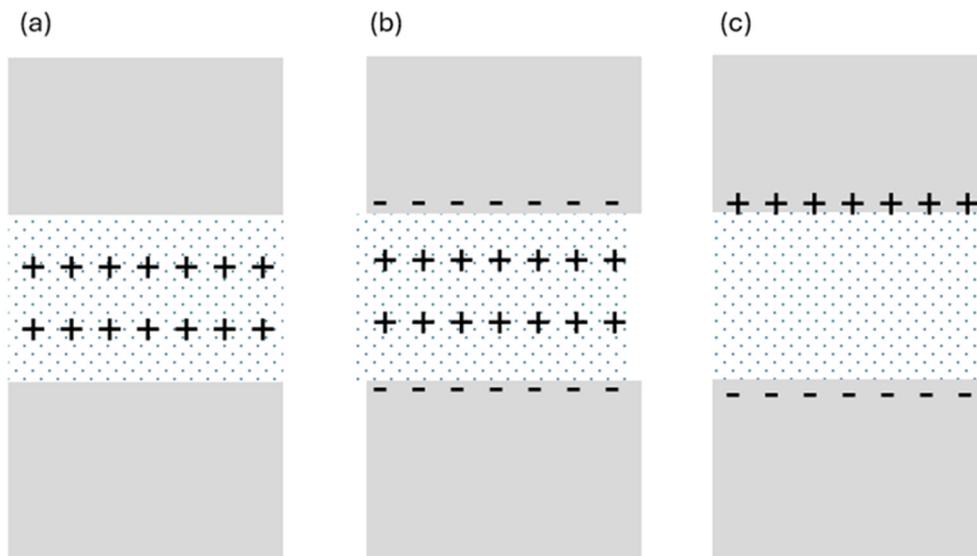

Fig. 1. Three possible distributions of electrical charge. The "+" and "−" symbols represent positive and negative charges, respectively, and the dotted area represents the fracture layer around a fault. (a) Positive charges inside the fracture layer. (b) Positive and negative charges inside and outside the fracture layer, respectively. (c) Positive and negative charges on the upper and lower sides of the fracture layer, respectively.

3. Conclusion

Key components of MKU24's scenario are implausible. Frictional heating cannot generate the high temperatures required to generate supercritical water. Even if a supercritical state is reached and the supercritical fluid generates a charge in the fracture layer, it cannot generate an electric field that would drive a downward drift of the ionosphere.

In summary, MKU24's conclusions about the mechanism that generates pre-earthquake ionospheric anomalies are unsupported, although their experimental results on charge generation under supercritical conditions may be valuable. Theories based upon their conclusions should be corrected based on an appropriate understanding of seismology and electromagnetic theory.

Acknowledgments

References

[1] Mizuno A., Kao M., and Umeno K., A capacitive coupling model between the ionosphere and a fault layer in the crust with supercritical water, *Int. J. Plasma Environ. Sci. Technol.*, Vol. 18 (1), e01003, 2024.

[2] Hayakawa M., Hattori K., and Ohta K., Monitoring of ULF (ultra-low-frequency) geomagnetic variations associated with earthquakes, *Sensors,* Vol. 7, pp. 1108−1122, 2007.

[3] Uyeda S., Nagao T., and Kamogawa M., Short-term earthquake prediction: Current status of seismoelectromagnetics, *Tectonophysics,* Vol. 470, pp. 205−213, 2009.

[4] Hayakawa M., and Schekotov A., On the ionospheric perturbation for the 1995 Kobe earthquake: Revisited, *Geomat. Nat. Haz. Risk,* Vol. 7, pp. 278−286, 2016.

[5] Iwata T., and Umeno K., Preseismic ionospheric anomalies detected before the 2016 Kumamoto earthquake, *J. Geophys. Res.–Space,* Vol. 122, pp. 3602−3616, 2017.

[6] Umeno K., Nakabayashi R., Iwata T., and Kao M., Capability of TEC correlation analysis and deceleration at propagation velocities of medium-scale traveling ionospheric disturbances: Preseismic anomalies before the large earthquakes, *Open J. Earthquake Res.,* Vol. 10, pp. 105−137, 2021.

[7] Eisenbeis, J., and Occhipinti, G., The TEC enhancement before seismic events is an artifact, *J. Geophys. Res.–Space*, Vol. 126 (4), e2020JA028733, 2021.

[8] Ikuta, R., and Oba, R., How credible are earthquake predictions based on TEC variations? *J. Geophys. Res.–Space*, Vol. 127 (3), e2021JA030151, 2022.

[9] Kano, Y., Mori, J., Fujio, R., Ito, H., Yanagidani, T., Nakao, S., and Ma, K.F., Heat signature on the Chelungpu fault associated with the 1999 Chi-Chi, Taiwan earthquake, *Geophys. Res. Lett.*, Vol. 33 (14), L14306, 2006.

[10] Johnston, M.J.S., Review of electric and magnetic fields accompanying seismic and volcanic activity, *Surv. Geophys.*, Vol. 18, pp. 441–475, 1997.

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International Journal of
Plasma Environmental Science and Technology

Supporting Information

Appendix: Estimate of the temperature rise

Consider a uniform medium in which a time-varying heat source, $q(t)$, exists on a plane expressed by $x = 0$ that illuminates a fault in the Earth's crust. The temperature, T, is a function of location, x, and time, t, and obeys the one-dimensional thermal conduction equation:

$$\frac{\partial}{\partial T} T(x,t) = a \frac{\partial^2}{\partial x^2} T(x,t) \tag{A1}$$

with the following boundary conditions:

$$k \frac{\partial}{\partial x} T(x = \pm 0, t) \rightarrow \mp q(t) \text{ and} \tag{A2}$$

$$T(x = \pm\infty, t) = 0 \tag{A3}$$

where $a = k/C\rho$, k is the thermal conductivity coefficient, C is the specific heat capacity, and ρ is the mass density. We wish to know the heat generated by the frictional force during slip on a fault. If the slip occurs during $0 \leq t < t_0$ with a constant speed, and if the frictional force is also constant during the slip, the heat, q, is given by

$$q(t) = \begin{cases} Q/t_0, & 0 \leq t < t_0 \\ 0. & t_0 \leq t \end{cases} \tag{A4}$$

Note that Q is the heat per unit area, whereas q is the heat per unit area per unit time; therefore, Q corresponds to that in Eqs. 1–2 in the main text. The solution of Eq. (A1) under these conditions [Eqs. (A2)–(A4)] is given by

$$T(x,t) = \frac{Q}{C\rho t_0} \times \begin{cases} F(x,t) & 0 \leq t < t_0 \\ F(x,t) - F(x, t - t_0) & t_0 \leq t \end{cases} \tag{A5}$$

where the function F is defined as

$$F(x,\tau) = \frac{\sqrt{\tau}}{\sqrt{\pi a}} \exp\left(-\frac{x^2}{4a\tau}\right) + \frac{x}{2a} \operatorname{erf}\left(\frac{x}{2\sqrt{a\tau}}\right) - \frac{x}{2a} \operatorname{sgn}(x) \tag{A6}$$

and sgn is the sign function. It is straightforward to confirm that this function satisfies the governing equation and the boundary conditions.

Near the fault plane, $T(x,t)$ reaches a maximum at $t = t_0$, which is the time that slip ends. The maximum value is

$$T(x = 0, t = t_0) = \frac{Q}{\sqrt{kC\rho t_0 \pi}} \tag{A7}$$

This is the same as Eq. (2). Note that the thermal diffusion in a three-dimensional case is faster than that in one dimension; therefore, this estimate is an upper bound on the temperature increase.