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The model of self-generated seismo-electromagnetic oscillations of the LAI system

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Abstract. Very low frequency (VLF) electromagnetic radiation (in diapason 1 kHz–1 MHz) in the atmosphere, generated during an earthquake preparation period, may be connected with the linear size characterising the expected earthquake focus. In order to argue this hypothesis, a very simple quasi-electrostatic model is used: the local VLF radiation may represent the self-generated (own) electromagnetic oscillations of interactive seismoactive segments of the lithosphere-atmosphere system. This model qualitatively explains the well-known precursor effects of earthquakes. In addition, using this model after diagnosing existing data makes it principally possible to forecast an expected earthquake with certain precision.

As a physical basis of the working hypothesis is the atmospheric effect of polarization charges occurring in the surface layer of the Earth, it is possible to test the following constructed model in the Earth's crust, where the reason for polarization charge generation may be different from piezoelectric mechanism, e.g., some other mechanism.

1 Introduction

In a solid medium, some considerable accumulation of polarization charge may take place in such an environment where heterogeneity having definite scale lines, is already formed or is being formed. Geological medium is not homogeneous. The progressive increase of tectonic stress is accompanied by the formation of inhomogeneous structural sources or by qualitative changes of the medium. It is known that at the final stage of an earthquake preparation, some chaotically moving microfractures may be formed as a one-direction main fault. It is possible that a maximum electropolarization effect which manifests itself at various times prior to the earthquake, due to structural peculiarities of geological medium, corresponds to this very moment. Polarization effect is often accompanied by electromagnetic radiation. It formally means that besides the electrostatic effect, which forms capacity, polarization is also accompanied by the induction effect. But, while analysing the possibility of induction interaction in the lithosphere-atmosphere system, it should be taken into account that there are many possibilities of induction effect development. Supposedly, the source of this effect is always the lithosphere in connection with seismic phenomena. It is schematically possible that there is certain type of electromagnetic circuit (contour), elements of which are connected with the lithosphere, as well as atmosphere. In particular, the fact that the upper limit of VLF (recorded before an earthquake) is of MHz order, it may indicate the minimum size of the Earth heterogeneity cluster which is able to cause an electric induction effect in the atmosphere (Yoshino, 1991; Molchanov et al., 1993; Hayakawa et al., 2002). As to ULF diapason, it seems that it is caused by magnetic field perturbations, the reason of which may be inside the Earth, as well as current processes in the conductive atmosphere (Bleier et al., 2009). Though there exists another version according to which the electric oscillations frequency variation in the ionosphere is not necessarily connected with seismic phenomena only. It means that the induction source may be in the atmosphere, but the impact – in the lithosphere. The original example of this version is the model of inductive prolongation of the ionosphere SQ current system in the upper lithosphere (Duma et al., 2003).

As we consider, below, electromagnetic oscillations generated in separate segments of the lithosphere-atmosphere system in quasi-electrostatic approximation, it is possible to operate only with atmospheric electric field without taking into account the atmospheric current. This makes it

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easier to solve the problem of mathematical modelling as it is simple in electrostatic approximation to connect polarization charges with the atmospheric electric field that is broken at the atmosphere-lithosphere boundary. Therefore, the quasi-electrostatic model does not require presentation of the mechanism of electric conduction change in the atmosphere, in particular, the assumption of radon emission from the lithosphere to the atmosphere. It is noteworthy that from the point-of-view of determining the atmospheric current variation mechanism in seismoactive regions, the consideration of this effect does not lead to any universal result which would be equally true for regions with a different geological structure. In particular, the modification of so called "Frenkel's model" (Liperovsky et al., 2008) of the atmospheric capacitor (based on radon emission), in opinion of the authors, may be effective only for the Far East region and partially for the Middle Asia region. Though, according to the works of Mikhailov et al. (2004) and Smirnov (2005, 2008), the mechanism of electric conduction variation of the atmosphere is vague even for the Kamchatka region where volcanic earthquakes are especially frequent and the emanation effect of radon is much more probable here than in regions with geological structures different from the Far East, e.g., the Caucasus. Consequently, it is logical to assume that (except special cases) the change of vertical electric current intensity in the atmosphere is chiefly connected with the change of electric field stress. Therefore, a sharp change of electric conduction of the lithospheric medium prior to an earthquake and its subsequent atmospheric effect caused by the emanation of charged particles or ionization of the medium may be considered as a special case (Freund, 2006). It seems that such phenomenon is very rare. Otherwise, there would have been some considerable materials quantitatively strengthening, e.g., a qualitative model of VLF radiation constructed on the principle of the sharp break of electric conduction of medium (Yoshino, 1991).

2 Model description

It is known that during the earthquake preparation period the piezo-electric effect caused by mechanical stresses is observed in rocks (Mognaschi, 2002; Triantis et al., 2008). Generally, the polarization charge is to be distributed on a certain surface that is either limited by a fault or formed along faults (Yoshino, 1991). As the Earth's surface has conditionally negative potential with respect to the atmosphere, the segment of the lithosphere where an earthquake is prepared may be considered as negatively charged before the piezo-effect. In ordinary conditions, as a rule, it is accepted that the Earth is charged negatively and the atmosphere – positively. Polarity change takes place during the period of earthquake preparation, i.e., it means that the Earth surface/atmosphere boundary is very positively charged just before earthquakes, which has been proven by experiments (Bleier et al., 2009). This very effect is considered in our model.

As the result of tectonic stress increase, some heterogeneity will originate in this segment, or positive charge areas which, like "Frenkel's generator", will cause inductive polarization at a certain height of the atmosphere. According to the model, in the focal area of the expected earthquake, at the final stage of its preparation, against the background of numerous fractures, a main fault of definite linear size is being formed. Thus, it may be represented as a linear wire the length of which considerably exceeds the characteristic size of its section. A conductor of the same size, but with the opposite polarity will occur in the atmosphere by induction. It is obvious that such a model is inverse, or it may be assumed that the initial conductor is in the atmosphere and the secondary i.e., the induced one – in the lithosphere. The operation of the linear conductors is noticeable enough as the atmospheric discharges (lightning) are linear phenomena and not areal. Formally, in case of two distant from each other horizontal conductors with opposite polarities in the lithosphere and the atmosphere, a structure resembling a capacitor is to be formed and possibly locked by a vertical atmospheric electric field. As electromagnetic induction is the reason for the generation of such spatial formation, i.e., it has certain inertia like usual oscillatory circuit, there must exist the characteristic frequency of self-generated electromagnetic oscillation of this system. Tompson's formula obtains the main frequency. The existence of its overtones which takes place, in practice, must not be excluded. The spectrum of overtones depends on the linear sizes of the resonance area.

Thus, the use of physical analogy with linear conductors while explaining the mechanism of VLF atmospheric electromagnetic radiation connected with seismic activity is quite logical. Such analogy does not considerably distort quantitative results, e.g., due to disregarding areal effect in model condenser capacity. In addition, the general picture is not to qualitatively change even when a system formed by several electromagnetic circuits instead of one, is considered in a seismically active region.

Usually, the system capacity C is concentrated in the capacitor and the inductance L, in the coil in the electromagnetic oscillatory circuit. In such a circuit, the capacity and inductance of the connecting wires, as well as the coil capacity, are disregarded. When electromagnetic dissipation is disregarded, the main self-generated oscillation frequency of the circuit is defined by the well-known Tompson's formula

$$\omega^2 = \frac{1}{L \cdot C} \tag{1}$$

which is more precise when the capacity outside the condenser and inductance outside the coil are less. It is obvious that the self-generated (characterising) frequency of the oscillatory circuit increases when capacity and inductance decrease. In this case, the capacity and inductance of connecting wires become considerable. Therefore, at very high

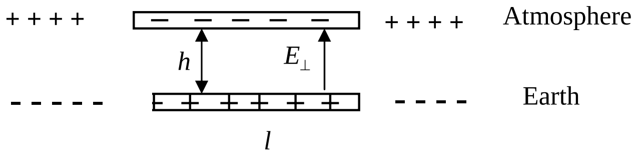

Fig. 1. Analog contour.

frequencies there is no necessity of a condenser and a coil as the inter-self-generated capacity and the inductance of the connected wires (linear conductor) is absolutely sufficient for the generation of oscillations (Fig. 1). At the same time, it is not necessary that virtual wires were tied strictly to the circuit frame. It means, the circuit is transformable and may be presented in an open state. The main thing is the existence of the locking mechanism of wires, the function of which is performed by the components of the atmospheric electric field in the given model. From the viewpoint of physical analogy, this means that if we charge two conductors with similar charges but opposite signs and then lock them, some current and connected with it a magnetic field will appear in the system. As conductors have inductance, the electromotive force of induction will also occur, i.e., a circuit with all parameters is formed in which electromagnetic oscillations are generated.

Thus, the presented model qualitatively explains the generation mechanism of very low frequency electromagnetic waves in previous periods of an earthquake and indicates to the source of the disturbance of the atmospheric vertical electric field. As this field has the function of circuit locking, we should envisage that it is disturbed by the oscillation frequency of the circuit as well as according to characterising time of ohmic damping. As for ULF, the oscillations in this diapason are the pulsations of the magnetic field and the most probable reason of their generation is the sharp changing of the electric conductivity of the upper atmosphere the cause of which may be, for instance, radon emanation (Bleier, 2009).

Thus, the disturbance of the atmospheric electric field must have high and low frequency components. At the same time, in spite of the disregard of ohmic resistance effect in the circuit, due to electromagnetic radiation, there undoubtedly is some energy loss in the intensity and propagation direction of which depends on the form and spatial size of the circuit.

3 Theoretical basis of the model

Let us admit that the length of the horizontal, opposite polarity conductors is l, the characteristic quantity of the conductor section is a, the distance between the conductors is h. It is known that when $h \gg a$ the inter-capacity of conductors is:

$$C \approx \frac{\pi \varepsilon_0}{\ln\left(\frac{h}{a}\right)} l$$

and mutual induction of conductors $L \approx \frac{\mu_0}{\pi} \ln\left(\frac{h}{a}\right) l$ (it is assumed that relative electric and magnetic constants $\varepsilon' = \mu' = 1$).

Postulation of the very same section is not a strict limitation because if the wires have different a and b sections, we receive (Landau et al., 1957):

$$L \sim \ln \frac{h^2}{ab}$$

Thus, because the product of absolute dielectric and magnetic constants is $\varepsilon_0 \mu_0 = \frac{1}{c^2}$, according to formula (1) of the self-generated electromagnetic oscillations of the circuit, we have

$$\omega = \left(\varepsilon_0 \mu_0 l^2\right)^{-\frac{1}{2}} = \frac{c}{l} \quad (2)$$

where c is the light velocity, and the product of the absolute dielectric and magnetic constants

$$\varepsilon_0 \mu_0 = \frac{1}{c^2} \quad (3)$$

Let us assume that l changes in (1–100) km interval that corresponds to the characteristic size of the fault length in the earthquake focus.

According to formula (1), the diapason of the self-generated electromagnetic oscillation frequency change of the analogous circuit is $\omega = 3\ (10^3 - 10^5)$ Hz. It is obvious that there is the quantitative agreement with the frequently recorded very low frequency atmospheric electromagnetic radiation spectrum during the earthquake preparation period (Kachakhidze et al., 2010).

As for the atmospheric electric field which is the lock of polarized lines, certain freedom of circuit form exists here: if the locking is vertical, then according to our result, the height does not matter (Fig. 1). In case of an open circuit, the locking mechanism is presented by the horizontal component of the atmospheric field, and the conductor length may exceed the considerable linear sizes of the polarization area depending on the inhomogeneity scale of the atmosphere. In case of a horizontal circuit the positively polarized conductor may be coupled with the opposite sign conductor having any length. Such topology of the circuit is quite handy if we take into consideration that electromagnetic precursors of earthquakes often appear quite far from the epicentres of main shocks (Tramutoli et al., 2001, 2005; Kachakhidze et al., 2003; Dunajecka et al., 2005; Pulinets et al., 2006, 2007; Liperovsky et al., 2008).

Thus, under the assumption, polarization of deep fault density and changing of free charges caused by polarization is the reason for the creation of the linear-wire-like charged structure near the Earth surface.

For qualitative modelling of this effect, we use the approximation of the plane electromagnetic layer. For this goal, we profile the Earth by a vertical XOZ positive semi-plane. Z axis is directed vertically upwards, X – horizontally along the fault. $z=0$ corresponds to the accumulation level of the polarization charges and $z=h_0$ – the level of the linear wire. We have a general equation

$$\text{div } \boldsymbol{j} = -\frac{\partial \rho}{\partial t} \tag{4}$$

where $\boldsymbol{j}$ is the density of the current, ρ – the density of the free charges corrected by permittivity. Equation (4) is true everywhere, including the points of the current source. It is known that if not taken into account the polarization effect and the vector-potential changing of the magnetic field, a homogeneous equation relevant to Eq. (4) is true, and it is transformed into the equation of electric potential by Ohm's law

$$\boldsymbol{j} = \sigma \boldsymbol{E} = -\sigma \text{ grad } \varphi \tag{5}$$

where φ is the electric potential, $\boldsymbol{E}$ – the tension of the electric field, σ – the specific electric conductivity. Thus, from Eq. (4) by using Eq. (5), we receive

$$\text{div}(\sigma \text{ grad } \varphi) = \frac{\partial \rho}{\partial t} \tag{6}$$

Modelling of the character of electric conductivity changing is necessary in order to analytically solve Eq. (6). For this purpose, $\sigma = \sigma_0 e^{-kz}$ is a handy relation (where k and σ_0 are constants). For instance, in order to present a geo-electric effect caused by a deep thermal source, a solution of homogeneous equation relevant to Eq. (6) is received by using this model type (Wait, 1982). Thus, according to Eq. (6) we have the following equation:

$$\frac{\partial^2 \varphi}{\partial x^2} + \frac{\partial^2 \varphi}{\partial z^2} - k\frac{\partial \varphi}{\partial z} = \sigma_0^{-1} e^{kz} \frac{\partial \rho}{\partial t} \tag{7}$$

From Eq. (7) the modelling picture of the electric potential distribution in the vertical electropermeance layer may be determined by the method which was used for the vertical profile of the Earth's atmosphere (Khantadze, 1973). For this purpose, we use a simple profile which is equipotential by horizontal direction

$$\varphi(z) = \varphi_\infty \left(1 - e^{-nz}\right) \tag{8}$$

where φ_∞ is the atmosphere potential far away from the vertical electropermeance layer, n – the unknown number. According to Eq. (8), $\varphi(0)=0$ and there is only one component of electric field tension

$$E_Z = -\frac{\partial \varphi}{\partial z} = -E_{0z} e^{-nz} \tag{9}$$

where $E_{0z} = n\varphi_\infty$ is a characteristic value of the electric field tension.

The character of the free charge density changing depended on the polarization effect is presented by the following model:

$$\rho = \rho_0 e^{-\frac{t}{t_0}} e^{-(k+n)z} \tag{10}$$

here ρ_0 is the characteristic value, t_0 – the characteristic time of the charge change.

By using the (8) and (10) expressions, from Eq. (7) we receive a characteristic equation for n

$$n^2 + kn - a = 0, \tag{11}$$

where

$$a = -\rho_0 t_0^{-1} e^{-\frac{t}{t_0}} \sigma_0^{-1} \varphi_\infty^{-1} \tag{12}$$

In order to simplify the (12) expression, we assume that $t=0$ and use Eq. (4) to which the below cited characteristic equation corresponds

$$\frac{j_{oz}}{h_0} = \frac{\sigma_0 E_{oz}}{h_0} = -\frac{\rho_0}{t_0} \tag{13}$$

where j_{oz} is the characteristic value of the electric current density. As $\varphi_\infty = n^{-1} E_{oz}$ by using Eq. (13), we receive $a = h_0^{-1} n$ (the sign of E_{oz} has no principal meaning for qualitative estimation).

Thus, if we assume that $n = h_0^{-1}$ and put the sign "+" (according to physical viewpoints) before the discriminant of Eq. (11), we will have

$$n = -\frac{k}{2} + \sqrt{\frac{k^2}{4} + h_0^{-2}} \tag{14}$$

In particular, in case $k = h_0^{-1}$ the characteristic parameter of vertical changing of the electric potential $n \approx 0,6 \cdot h_0^{-1}$. When $t \neq 0$ the second member under the root in Eq. (14) is corrected by the numerical factor $e^{-\frac{t}{t_0}}$ which causes the decrease of n. By the above description, it is possible to model such a vertical layer, the quasi equipotentiality of which, different from the relevant layer of Eq. (8) profile, is destructed in all directions. For instance, we may use the following expressions:

$$\varphi = E_0 \left(x - l_0 e^{-nz} \cos mx\right) \tag{15}$$

$$\rho = \rho_0 e^{-\frac{t}{t_0}} e^{-(k+n)z} \cos mx \tag{16}$$

where E_0 is the characteristic value of the electric field tension.

As a result of Eq. (16), we have two components of the electric field tension

$$E_x = -\frac{\partial \varphi}{\partial x} = -E_0 \left(m l_0 e^{-nz} \sin mx + 1\right) \tag{17}$$

$$E_z = -\frac{\partial \varphi}{\partial z} = -E_0 l_0 n e^{-nz} \cos mx \tag{18}$$

where l_0 is the linear scale of horizontal heterogeneity of charge density, m – a wave number.

According to Eqs. (17) and (18), it seems that if $m = l_0^{-1}$ and $n < m$, the maximal value of the first member of E_x always exceeds the maximal meaning of E_z. Taking into account this fact, in case of $t=0$ and in addition to it if we assume that the fault length $l \approx h_0$, like the characteristic Eq. (13) we will have

$$\frac{\sigma_0 E_0}{l} \approx \frac{\rho_0}{t_0} \cos \frac{x}{l_0} \tag{19}$$

Taking into account Eq. (19), putting the (15) and (16) expressions in Eq. (4) and solving the characteristic equation we receive:

$$n = -\frac{k}{2} + \sqrt{\frac{k^2}{4} + l_0^{-2} + l_0^{-1} h_0^{-1}} \tag{20}$$

Thus, we may conclude that in the limit of the vertical electromagnetic layer model, in the proximity of exponential changing of electric conductivity, the change of the electric parameters of the virtual linear conductor supposed near the Earth surface, depends only on the linear parameters of the polarized layer and its generation level.

Thus, the (14) and (20) expressions are relevant to the arising moment of the polarization. But, according to Eq. (10), for the completeness of the presented model, it is necessary to take into consideration the factor $e^{-\frac{t}{t_0}}$ which consists of the characteristic time t_0. For example, the same parameter figures in the model expression of the density change of the surface polarization charge generated as a result of the piezoelectric effect in an earthquake focus. This equation is given in the work (Ikeya et al., 1997):

$$q(t) = \alpha \Delta \Sigma \left[\left(\frac{\varepsilon \eta}{\tau - \varepsilon \eta} \right) \left(e^{-\frac{t}{\tau}} - e^{-\frac{t}{\varepsilon \eta}} \right) \right] \tag{21}$$

where α is the piezo-electric coefficient, $\Delta \Sigma$ – the stress drop in the earthquake focus caused by displacement, η – the specific resistance of the medium, τ – the characteristic time of displacement, – $\varepsilon \eta$ the characteristic time of the charge density pulsation, $\varepsilon = \varepsilon' \varepsilon_0$.

Theoretically, any characteristic time in Eq. (21) is relevant to the (10) expression. It is obvious, that due to the solid and electric features of the medium, in case $\varepsilon \eta$ and τ are incommensurable parameters, then it is correct to use the larger one out of the two.

4 Discussion

The considered model and Eq. (2) allow us to discuss the process of earthquake preparation, its occurrence time and phenomena related with it not only qualitatively, but quantitatively with certain accuracy. We have the possibility to reliably answer the following questions:

4.1 What does the certain sequences of MHz and KHz frequencies mean in the spectrum of emission?

We created a pretty simple electrodynamic model of VLF emission. By this model, the electric dipoles originated on the cracks surfaces finally set on the main fault during the process when the cracks join and form a fault. By the time some separate cracks may act as termoionized canals with different electric conductivity.

It is possible that the total length of the canal with high electric conductivity (the fault length by geological point-of-view), is related to the VLF electromagnetic emission according to Eq. (2). It may lead to purposeful monitoring in order to keep an eye on the origination of the main fault and process of its length change.

Particularly, in case of having electromagnetic emission to the extent of 1 MHz the characteristic length of the fault is not more than 300 m (according to linear relation in Eq. (2); as electromagnetic emission appears in KHz – the length of the fault begins to increase, e.g., in case of 10^5 Hz – the length l is already equal to 3 km.

Thus, it is obvious what causes the so often observed sequences of the MHz and KHz frequencies in the electromagnetic emission spectrum. It may mean that during earthquakes preparing period, before origination of the main fault there are plenty of cracks to which electromagnetic emission with characteristic MHz frequencies correspond, and as the cracks begin to join in the main fault, a range of KHz frequencies appear in the electromagnetic spectrum. It is natural that such an opinion is not unique as the source of generation of the same diapason of VLF may be another electromagnetic phenomena which develop in the upper atmosphere and ionosphere. Their distinction is possible only by means of reliable morphological analyses of data.

4.2 Estimation of the fault length in the focus and the intensity of the expected earthquake

Equation (2) supposes a one-digit relation between ω and l. It is clear that a linear relation (idealized by model imagination) between these values must be distorted in the real medium.

The changing of the distortion coefficient must be estimated by means of analysis of the experimental data. It is expected that the distortion coefficient has a different meaning for the fixed value of ω (in the limits of certain errors) in different regions, i.e., in different geological media.

Thus, in a real medium, Eq. (2) is expressed as follows:

$$\omega = \beta \frac{c}{l} \tag{22}$$

as $\beta(\omega)$ is the coefficient dependent on the frequency and geological characteristics of the medium, it must be determined independently for any seismoactive region or local segment.

By means of Eq. (22), for a concrete ω or for the central frequency (in case of having a bunch of frequencies), we may estimate the intensity of the expected earthquake with certain accuracy. In such a case, it is obligatory to know the empiric relations between earthquake magnitude and fault length for separate regions.

4.3 The change in the atmospheric electric field as an earthquake precursor

According to the model, some locking mechanism of virtual wires must exist. The components of the atmospheric electric field may function as such a mechanism.

According to the experimental data, in many cases, change in the atmospheric electric field obtains anomalous character for several days or hours prior to an earthquake occurrence. Particularly, the character of changes in the atmospheric electric field potential gradients that had appeared before the $M \geq 4.5$ earthquakes of the Caucasus (132 events) was studied. In order to reveal the precursor effect, a strict method of "filtration" was carried out which excludes all possible influences capable of changing this parameter. Anomalous changing of a potential gradient of the atmospheric electric field takes place during a period of 10 days to several hours prior to an earthquake occurrence (Kachakhidze, 2000; Kachakhidze et al., 2009).

These changes were expressed in the form of outbursts. It is possible that the perturbation of atmospheric electric field reaching its maximal value, appears like a reason of "vertical locking" of schematic electromagnetic contour in the consequence of which the vertical components of the atmospheric electric field return to their background meanings.

The phenomenon of electromagnetic induction between the Earth and the atmosphere may reoccur as the source of perturbation like polarized fault may exist for a certain period.

There is another version as well as it is possible to imagine the contour in an open form in which the horizontal component of the atmospheric electric field functions like a "locking mechanism". In such a case, the length of the wire may significantly exceed the linear sizes of the polarization area because in case of horizontal locking the positively polarized wire may tie to a wire with any length and the opposite sign. Such a contour typology schematically coincides with the fact that the atmospheric electric precursors of earthquakes often appear quite far away from epicentres (Kachakhidze et al., 2003; Dunajecka et al., 2005; Pulinets et al., 2006; Liperovsky et al., 2008).

4.4 Possibility of estimation of earthquake occurrence time

The formation of approximately the same type faults with the same linear scales is expected in different seismoactive regions with similar geological structure under the same tectonic stress. Supposedly, in such cases, almost a similar spectrum of electromagnetic emission must be generated.

Consequently, if the change character of the frequency spectrum before earthquakes occurrence is known for any region, the model let us determine the assumed time of an earthquake occurrence for a concrete event with certain accuracy. It is obvious that the precision of the β coefficient has the main significance for determining the fault length and relatively the magnitude of the expected earthquake.

Thus, the diagnostic task is created: in case of the existence of retrospective data of electromagnetic emission for some geological medium, there is a possibility to recheck the accuracy of earthquake occurrence time by observing the changes in electromagnetic spectrum.

4.5 Foreshocks

Earthquakes with certain intensities correspond to VLF electromagnetic emission with certain frequencies. It means that foreshocks are also characterised by self-generated frequency spectrum of electromagnetic emission (mainly, in the diapason of MHz).

Thus, we may conclude that in the limit of the electromagnetic circuit (contour) scheme constructed with virtual linear wires, it is principally possible to control the process of earthquake preparation and occurrence by means of monitoring the changes in the electromagnetic emission frequency spectrum.

5 Summary

This work offers the original model of the self-generated electromagnetic oscillation of the local segment of the lithosphere-atmosphere system. In the authors' opinion, the model simplifies the physical analyses of the nonlinear effect. The results of this effect are admittedly reflected in the electromagnetic picture which expresses the relation of the lithosphere-atmosphere-ionosphere system.

The model, in a qualitative sense, explains the mechanism of VLF electromagnetic emission revealed in periods prior to earthquake occurrence and reasons of anomalous changes in the atmospheric electric field potential gradient. Besides, it corroborates the possibility of monitoring the main shock expectation by observing foreshocks. Correspondingly, the model makes it principally possible to determine the intensity of an expected earthquake, the time of its occurrence, location and linear sizes of the focus with a certain accuracy.

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References

Bleier, T., Dunson, C., Maniscalco, M., Bryant, N., Bambery, R., and Freund, F.: Investigation of ULF magnetic pulsations, air conductivity changes, and infra red signatures associated with the 30 October Alum Rock M5.4 earthquake, Nat. Hazards Earth Syst. Sci., 9, 585–603, doi:10.5194/nhess-9-585-2009, 2009.

Duma, G. and Ruzhin, Y.: Diurnal changes of earthquake activity and geomagnetic Sq-variations, Nat. Hazards Earth Syst. Sci., 3, 171–177, doi:10.5194/nhess-3-171-2003, 2003.

Dunajecka, M. A. and Pulinets, S. A.: Atmospheric and thermal anomalies observed around the time of strong Earthquakes in Mexico, Atmosfera, 18(4), 235–247, 2005.

Freund, F. T., Takeuchi, A., and Lau, B. W. S.: Electric currents streaming out of stressed igneous rocks – A step towards understanding pre-earthquake low frequency EM emissions, Phys. Chem. Earth, 31, 389–396, 2006.

Hayakawa, M. and Molchanov, O. A.: Seismo-Electromagnetics: Lithosphere-Atmosphere-Ionosphere Coupling, TERRAPUB, Tokyo, 1–477, 2002.

Ikeya, M., Takaki, S., Matsumoto, H., Tani, A., and Komatsu, T.: Pulsed charge model of a fault behavior producing seismic electric signal, J. Circuit. Syst. Comp., 7(3), 153–164, 1997.

Kachakhidze, M., Kachakhidze, N., Kiladze, R., Kukhianidze, V., and Ramishvili, G.: Relatively small earthquakes of Javakheti Highland as the precursors of large earthquakes occuring in the Caucasus, Nat. Hazards Earth Syst. Sci., 3, 165–170, doi:10.5194/nhess-3-165-2003, 2003.

Kachakhidze, M., Kereselidze, Z., and Kachakhidze, N.: The Model of Own Seismoelectromagnetic Oscillations of LAI System, Geophys. Res. Abstr., Vol. 12, EGU2010-4427-2, EGU General Assembly, 2010.

Kachakhidze, N.: Electric Field Potential Gradient of Atmosphere as a Possible Precursor of Earthquakes, Bulletin of The Georgian Academy of Sciences, 161, N3, 2000.

Kachakhidze, N., Kachakhidze, M., Kereselidze, Z., and Ramishvili, G.: Specific variations of the atmospheric electric field potential gradient as a possible precursor of Caucasus earthquakes, Nat. Hazards Earth Syst. Sci., 9, 1221–1226, doi:10.5194/nhess-9-1221-2009, 2009.

Khantadze, A. F.: Some issues of the conductive atmosphere dynamics, Publish House “Metsniereba”, Tbilisi, p. 279, 1973.

Landau, L. D. and Lifshic, E. M.: Electrodynamics of continuum, M. Tech.-Teor. Lit., p. 532, 1957.

Liperovsky, V. A., Meister, C.-V., Liperovskaya, E. V., and Bogdanov, V. V.: On the generation of electric field and infrared radiation in aerosol clouds due to radon emanation in the atmosphere before earthquakes, Nat. Hazards Earth Syst. Sci., 8, 1199–1205, doi:10.5194/nhess-8-1199-2008, 2008.

Mikhailov, Y. M., Mikhailova, G. A., Kapustina, O. V., Buzevich,, A. V., and Smirnov, S. E.: Power spectrum features of near-Earth atmospheric electric field in Kamchatka, Ann. Geophys., 47(1), 237–245, 2004.

Mognaschi, E. R.: IW2GOO. On The Possible Origin, Propagation And Detectebility Of Electromagnetic Precursors of Eaerthquakes, Atti Ticinensi di Scienze della Terra, 43, 111–118, 2002.

Molchanov, O. A., Mazhaeva, O. A., Golyavin, A. N., and Hayakawa, M.: Observation by the Intercosmos-24 Satellite of ELF-VLF electromagnetic emissions associated with earthquakes, Ann. Geophys., Atmos. Hydrospheres Space Sci., 11, 5,431–440, 1993.

Pulinets, S. A., Ouzounov, D., Karelin, A. V., Boyarchuk, K. A., and Pokhmelnykh, L. A.: The physical nature of thermal anomalies observed before strong earthquakes, Phys. Chem. Earth, Parts A/B/C, 31(4–9), 143–153, 2006.

Pulinets, S. A., Biagi, P., Tramutoli, V., Legen’ka, A. D., and Depuev, V. K.: Irpinia earthquake 23 November 1980 – Lesson from Nature reviled by joint data analysis, Ann. Geophys., 50(1), 61–78, 2007.

Smirnov, S.: Association of the negative anomalies of the quasistatic electric field in atmosphere with Kamchatka seismicity, Nat. Hazards Earth Syst. Sci., 8, 745–749, doi:10.5194/nhess-8-745-2008, 2008.

Smirnov, S. E.: Peculiarities of negative anomalies of the quasistatic electric field in the near-Earth atmosphere on Kamchatka, Geomagn. Aeron., 45(2), 282–287, 2005.

Tramutoli, V., Di Bello, G., Pergola, N., and Piscitelli, S.: Robust satellite techniques for remote sensing of seismically active areas, Ann. Geophys., 44(2), 295–312, 2001.

Tramutoli, V., Cuomo, V., Filizzola, C., Pergola, N., and Pietrapertosa, C. Assessing the potential of thermal infrared satellite surveys for monitoring seismically active areas: The case of Kocaeli (Ýzmit) earthquake, August 17, 1999, Remote Sens. Environ., 96, 409–426, 2005.

Triantis, D., Anastasiadis, C., and Stavrakas, I.: The correlation of electrical charge with strain on stressed rock samples, Nat. Hazards Earth Syst. Sci., 8, 1243–1248, doi:10.5194/nhess-8-1243-2008, 2008.

Wait, R. J.: Geoelectromagnetizm, Academic Pr., New York, London, p. 235, 1982.

Yoshino, T.: Low-Frequency Seismogenic Electromagnetic Emissions as Precursors to Earthquakes and Volcanic Eruptions in Japan, Journal of Scientific Exploration, 5(I), 121–144, 1991.