The Model of Own Seismoelectromagnetic Oscillations of LAI System

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Abstract

Very low frequency (VLF) electromagnetic radiation (in diapason 1 kHz – 1MHz) in atmosphere, generated during earthquake preparation period, may be connected with linear size, characterizing incoming earthquake source. In order to argue this hypothesis very simple quasi-electrostatic model is used: local VLF radiation may be the manifestation of own electromagnetic oscillations of ~~concrete~~ seismoactive segments of lithosphere-atmosphere system. This model explains qualitatively well-known precursor effects of earthquakes. At the same time, it will be principally possible to forecast expected earthquake with certain precision if we use this model after diagnosing existed data.
As physical basis of working hypothesis is atmospheric effect of polarization charges occurred in surface layer of the Earth, it is possible to test the below constructed model in mediu here reasons of polarization charge generation may be different from piezoelectric mechanism, for example, due to electrolytic hydration.

I. Introduction

In solid medium considerable accumulation of polarization charge may take place in such a place where heterogeneity, having definite scale lines, is already formed or is in the process of forming. Geological medium is more, or less equally stressed before earthquake preparation. Progressive

increase of tectonic stress is accompanied by formation of inhomogeneous structural sources, or by qualitative change of medium. It is known that at final stage of earthquake preparation chaotically occurred microfractures may be formed as one – direction main fault. It is possible that maximum electropolarization effect which manifests itself at various times before earthquake occurrence due to structural peculiarities of geological medium corresponds to this very moment. Polarization effect is often accompanied by electromagnetic radiation. Formally this means that besides electrostatic effect, which forms capacity, polarization is also accompanied by induction effect. But while analyzing possibility of induction interaction in lithosphere-atmosphere system it should be taken into account that there are many possibilities of induction effect development. We can suppose that the source of this effect is always lithosphere in connection with seismic phenomena. So we can think that schematically we have to do with certain type electromagnetic circuit (contour), elements of which should be connected with lithosphere, as well as atmosphere. In particular, the fact that upper limit of VLF (recorded before an earthquake) is of MHz order, may indicate at that minimum size of the Earth heterogeneity cluster which can call forth electric induction effect in atmosphere (TakeoYoshino, 1991; Molchanov et al., 1993; Hayakawa et al., 2002). Though there exists alternative version according to which it is not at all necessary that electric oscillations frequency variation in ionosphere is connected with seismic phenomena only. This means that induction source may be in the atmosphere, but the response to it - in the lithosphere. Especially original example of such alternative is the model of inductive prolongation of ionosphere SQ current system in the upper lithosphere (Duma et al., 2003).

As we consider below electromagnetic oscillations, generated in separate segments of lithosphere-atmosphere system in quasi-electrostatic approximation, we can operate only with atmospheric electric field, without taking into account atmospheric current. This makes easier the problem of mathematical modeling because it is simple in electrostatic approximation to connect polarization charges with atmospheric electric field which is broken at atmosphere-lithosphere boundary. That's why quasi-electrostatic model does not need presentation of the mechanism of electric conduction change in the atmosphere, in particular, assumption of radon emission from the lithosphere to the atmosphere. It should be noted that from the point of view of establishment of atmospheric current variation mechanism in seismoactive regions the foresight of this effect does not yield any universal result which would be equally true for regions with different geological structure. In particular, modification of so called "Frenkel's" model of atmospheric capacitor (based on radon emission) in opinion of the authors, may be effective only for the Far East region and partially, for Middle Asia region (Liperovsky et al., 2008). Though, according to the work (Mikhailov et al., 2004; Smirnov, 2005; Smirnov, 2008) the mechanism of electric conduction variation of the atmosphere is vague even for Kamchatka region

where volcanic earthquakes occur especially often and emanation effect of radon is much more probable than in regions which have geological structures different from Far East, for example in the Caucasus. That's why it is logical to assume that (except special cases) change of vertical electric current intensity in the atmosphere is chiefly connected with change of electric field stress. We can consider as special case, for example, sharp change of electric conduction of lithospheric medium before earthquake and its subsequent atmospheric effect caused by emanation of charged particles or ionization of medium. It seems that such phenomenon is very rare. Otherwise there would be considerable materials which would strengthen quantitatively, for example, qualitative model of VLF radiation, constructed on the principle of sharp break of electric conduction of the medium (TakeoYoshino 1991).

2. Model description

It is known that in the period of earthquake preparation piezo-electric effect, caused by mechanical stresses, is observed in rocks (Mognaschi, 2002; Triantis et al., 2008). Generally, polarization charge should be distributed on a surface, which should be either limited by fault or formed along faults (TakeoYoshino 1991). As the Earth surface has conditionally negative potential with respect to the atmosphere, that segment of the lithosphere where an earthquake is prepared can be considered as negatively charged before piezo-effect. As the result of tectonic stress increase heterogeneity will originate in this segment, or positive charge areas, which, like "Frenkel's generator", will call forth inductive polarization at certain height of the atmosphere. According to the model, in source area of incoming earthquake, at final stage of its preparation, against a background of numerous fractures, definite, linear size main fault is being formed. So it can be represented as linear wire, the length of which considerably exceeds characteristic size of its section. Conductor of the same size but with opposite polarity should occur in the atmosphere by induction. It is obvious that such model is inverse or it can be assumed that initial conductor is in the atmosphere and secondary or induced one is in the lithosphere. Operation with linear conductors is noticeable enough because atmospheric discharges (lightning) are linear phenomena and not areal. Formally, if two, moved away from each other horizontal conductor with opposite polarity exist in the lithosphere and the atmosphere then a structure, resembling a capacitor should be formed which may be locked by vertical atmospheric electric field (Fig. 1). As electromagnetic induction is the reason of generation of such spatial formation, or it has certain inertia like usual oscillatory circuit, there should exist its own characteristic frequency of electromagnetic oscillation.

Thus using physical analogy with linear conductors while explaining the mechanism of VLF atmospheric electromagnetic radiation connected with seismic activity is quite logical. Such analogy will not distort considerably quantitative results, for example, because of disregarding areal effect in model condenser capacity. Also, general picture should not change qualitatively even when in seismically active region the system is considered which is formed not by one, but several electromagnetic circuits.

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

$$\omega^2 = \frac{1}{L \cdot C} \qquad (1)$$

which is more precise when capacity outside the condenser and inductance outside the coil are the lesser. It is obvious that oscillatory circuit's own (characterizing) frequency increases when capacity and inductance decrease. But now capacity and inductance of connecting wires become considerable. That's why within very high frequencies there is no necessity of condenser and coil because inter own capacity and inductance of connected wires (linear conductor) will be absolutely enough for oscillation generation. At the same time, it is not necessary that virtual wires were tied strictly in circuit frame. It means, the circuit will transform and can be presented in open state. The main thing is the existence of locking mechanism of wires, function of which perform components of atmospheric electric field in the given model. From the point of view of physical analogy, this means that if we charge two conductors with similar charge which have opposite signs, and then lock them, current and connected with it magnetic field will appear in the system. As conductors have inductance, electromotive force of induction will also occur or by all parameters circuit will be established in which electromagnetic oscillations will be generated.

Thus, presented model explains qualitatively generation mechanism of very low frequency electromagnetic waves in previous periods of an earthquake and indicates at the source of disturbance of atmospheric vertical electric field. As this field has the function of circuit locking, we should envisage that it is disturbed by oscillation frequency of the circuit, as well as according to characterizing time of ohmic damping.

Thus, disturbance of atmospheric electric field should have high and low frequency components. At the same time, in spite of disregard of ohmic resistance effect in the circuit, there sure will be energy loss

due to electromagnetic radiation, intensity and propagation direction of which will depend on the form and spatial size of the circuit.

3. Theoretical basis of the model

Let's say that the length of horizontal, opposite polarity conductors is l, characteristic quantity conductor's section is a, distance between conductors is h. It is known that inter capacity of conductors, when $h >> a,$ 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 strict limitation as if the wares have different a and b sections, we have (Landau, et al., 1957):

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

Thus, because the product of absolute dielectric and magnetic constants is $\varepsilon_0\mu_0 = \frac{1}{c^2}$, from (1) formula of circuit's own electromagnetic oscillations we'll have

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

where c is velocity of light, but the result of multiplying of absolute dielectric and magnetic constants

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

Let's assume that l changes in (1-100) km interval, which corresponds to change diapason characteristic scale of earthquake source. From Eq. (1) we'll receive that change diapason of analogous circuit's own electromagnetic oscillation frequency is ω=3 (10^3 - 10^5) Hz. So it is obvious quantitative agreement with often recorded very low frequency atmospheric electromagnetic radiation spectrum in earthquake preparation period (Kachakhidze et.al., 2010).

As for atmospheric electric field, which is the locking of polarized lines, certain freedom of circuit form exists here: if there is vertical locking, then according to our result the height does not mean anything (Fig.1). If we consider second variant of open circuit, then occurred horizontal component of atmospheric field plays the role of locking mechanism, and conductor length may exceed considerable linear sizes of polarization area, depending on inhomogeneous scale of the atmosphere. In case of horizontal circuit, positively polarized conductor may be coupled with opposite sign conductor having any length. Such topology of the circuit is quite handy if we take into consideration at electromagnetic precursors of earthquakes often manifest themselves quite far from the epicenter of main shock (Tramutoli et al., 2001; Kachakhidze et al., 2003; Dunajecka et al., 2005; Tramutoli et al., 2005; Pulinets et al., 2006; Pulinets et al., 2007; Liperovsky et al., 2008).

So, by an assumption, polarization of the deep fault and changing of the free charges density caused by polarization, is the reason of creation of the structure like linear wire near earth surface. In order to qualitative modeling of this effect we use approximation of the plane electromagnetic layer. For this goal we profile earth by vertical XOZ positive half-space. Z axis is directed up to vertical, X – to horizontal, along the fault. z=0 corresponds to level of accumulation of polarization charges and $z=h_0$ – level of the linear wire. We have general equation

$$div\ \vec{j} = -\frac{\partial}{\partial t}\rho \qquad (4)$$

where $\vec{j}$ is the density of current, ρ - density of the free charges corrected by permittivity. Equation (4) is true everywhere, including of points of current source. It is known that if we do not take into account effect of polarization and changing of vector-potential of magnetic field it will be true monotonous equation relevant to (4), which will be transformed into equation of electric potential by Omm's law

$$\vec{j} = \sigma\vec{E} = -\sigma grad\,\varphi \qquad (5)$$

where φ is electric potential, $\vec{E}$ - tension of electric field, σ - specific electric conductivity. So from Eq. (4) by using Eq. (5) we get

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

Modeling of character of electric conductivity changing is necessary for the analytic solving of Eq. (6). For this goal $\sigma = \sigma_0 e^{-kz}$ is handy relation (where k and σ_0 are constants). For instance in

order to present of geoelectric effect caused by deep thermal source the solving of monotonous equation relevant to (6) is gotten by using of this type model [Wait, 1982]. So, from Eq. (6) we will have equation

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

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

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

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

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

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

Character of changing of free charge density depended on polarization effect is presented by following model

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

where ρ_0 is the characteristic value, t_0 – the characteristic time of charge changing.

By using of (8) and (10) expressions, from Eq. (7) we get characteristic equation for n

$$n^2+kn-a=0, \qquad (11)$$

where

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

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

$$\frac{j_{oz}}{h_0}=\frac{\sigma_0 E_{oz}}{h_0}=-\frac{\rho_0}{t_0} \qquad (13)$$

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

So, if we assume that $n=h_0^{-1}$ and set the sign "+" (for the physical opinion) in front of

discriminant of Eq. (11) we will have

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

In particular, in case $k = h_0^{-1}$, characteristic parameter of vertical changing of electric potential $n \approx 0{,}6 \cdot h_0^{-1}$, when $t \neq 0$ the second member under the root in the Eq. (14) corrects by the numerical factor $e^{-\frac{t}{t_0}}$ which causes decreasing of n. By above described way it is possible to model such vertical layer, quasi equipotentiality of which, different from Eq. (8) profile's relevant layer, will be destroyed in all directions. For instance, we may use the following expressions:

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

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

where E_0 is the characteristic value of electric field tension.

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

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

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

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

From Eq. (17) and Eq. (18) it seems that if $m = l_0^{-1}$ and $n < m$, the maximal significance of the first member of E_x always is more than 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 characteristic Eq. (13) we will have

$$\frac{\sigma_0 E_0}{l} \approx \frac{\rho_0}{t_0}\cos\frac{x}{l_0} \qquad (19)$$

After taking into account Eq. (19), putting (15) and (16) expressions into Eq. (4) and solving characteristic equation we will get:

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

So we may make up conclusion that in the frame of model of vertical electromagnetic layer, in the proximity of exponential changing of electric conductivity, changing of electric parameters of virtual

linear conductor, which has in mind near of earth surface, depends only on the linear parameters of polarized layer and its level of generation.

So, (14) and (20) expressions are relevant to the moment of arising of polarization. But, according to (10), in order to perfect imagination of presented model, it is necessary to take account a factor $e^{-\frac{t}{t_0}}$, which consists of characteristic time t_0. For example, the same parameter figures in the model expression of density changing of surface polarization charge generated by piezoelectric effect in the earthquake focus. This is gotten by [Ikey et.al., 1997]:

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

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

Theoretical, any characteristics of time in Eq. (21) are relevant to (10) expression. It is obvious, that because of solid and electric features of medium, in case if $\varepsilon\ \eta$ and τ are incommensurable parameters, using of large one is correct.

4. Discussion

Considered model and formula (2) let us discuss the process of earthquake preparing, time of its occurring and phenomenon related with it not only qualitatively but quantitatively with certain accuracy. We have possibility reliable to answer the following questions:

I. What does it mean the certain sequences of MHz and KHz frequencies in the spectrum of emission?

We created pretty simple electrodynamic model of VLF emission. By this model electric dipoles originated on the cracks surfaces finally set on the main fault during the process of cracks joining up into fault. By this time perhaps the separate cracks represent termoionized canals with different electric conductivity.

It is possible that very summary length of the canal with high electric conductivity (the length of fault by geological point of view), is related with VLF electromagnetic emission by (2) formula. It must be the reason of purposeful monitoring in order to keep an eye on origination of main fault and process of changing of its length.

Particularly, in case of having electromagnetic emission to the extent that 1 MHz, the characteristic length of fault will not be more than 300 m (according to linear relation in formula (2); As it appears electromagnetic emission in KHz – the length of fault begins to increase. For instance: in case of 10^5 Hz – the length l is already equal to 3 km.

So, it is obvious what does it cause so often observed sequences of MHz and KHz frequencies in electromagnetic emission spectrum. Perhaps it means that during earthquakes preparing period, before origination of main fault, there are plenty of cracks to which correspond electromagnetic emission with characteristic MHz frequencies but as the cracks begin to join up into main fault – range of KHz frequencies are appeared in the electromagnetic spectrum.

II. Estimation of incoming earthquake length of focus fault and intensity.

The formula (2) supposes one-digit relation between ω and l. It is clear that linear relation (idealized by model imagination) between these values must be distorted in the real medium. Changing of coefficient of distortion must be estimated by analysis of experimental data. It is expected that coefficient of distortion has different meaning for the fixed value of ω (in the limits of certain errors of course) in the different region i.e. different geological medium.

So, formula (2) will get the following expression in the real medium:

$$\omega = \beta \frac{c}{l} \qquad (22)$$

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

By the formula (21), for the concrete ω or for the central frequency (in case of having parcel of frequencies) we may estimate intensity of incoming earthquake with certain accuracy. In such case it is obligatory to know empiric relations between earthquake magnitude and length of fault for separate regions.

III. Changing of atmospheric electric field as earthquake precursor.

According to the model it must be trailing mechanism of virtual wires. The components of atmospheric electric field perhaps function as such mechanism.

By experimental data, in many cases, changing of atmospheric electric field has anomalous character for several days or hours before earthquakes occurring. Particularly, it was studied character of changing of atmospheric electric field potential gradient before Caucasus $M \geq 4.5$ earthquakes occurring (132 events). In order to reveal precursor effect it was carried out strict method of

"filtration" which exclude all possible influences capable of changing of this parameter. Anomalous changing of potential gradient of atmospheric electric field appears since10 days up to several hours before earthquakes occurring (Kachakhidze, 2000; Kachakhidze et all., 2009).

These changing were expressed by outbursts. Perhaps the very perturbation of atmospheric electric field, reaching its maximal value, appears like a reason of "vertical trailing" of schematic electromagnetic contour in consequence of which vertical components of atmospheric electric field come back to their background meaning.

The phenomenon of electromagnetic induction between earth and atmosphere may be repeated because the source of perturbation like polarized fault may exist for a certain period.

There is alternative variant as it is possible to imagine contour in the opening appearance in which horizontal component of atmospheric electric field functions like "trailing mechanism". In such case the length of wire may significantly exceed linear sizes of polarization area because in case of horizontal trailing positive polarized wire may be tied with any length wire with opposite sign. Such typology of contour schematic coincide with the fact that atmospheric electric precursors of earthquakes often appear plenty far away from epicenter (Kachakhidze et al., 2003; Dunajecka et al., 2005; Pulinets et al., 2006; Liperovsky et al., 2008).

IV. Possibility of estimation of earthquakes occurring time

Existence of approximately same type fault with the same linear scales are expected in the different seismoactive regions with similar geological structure under the same tectonic stress. It is foreseen that in such cases almost similar spectrum of electromagnetic emission must be generated.

So, if character of changing of frequency spectrum is known for any region before earthquake occurring the model will let determine the assumed time of earthquake occurring for the concrete event with the certain accuracy. It is obvious that precision of very β coefficient has main meaning for determination of fault length and accordingly of magnitude of incoming earthquake.

Thus, diagnostic task is created: if there are retrospective data of electromagnetic emission for the some geological medium we will have possibility to recheck accuracy of time of earthquake occurring by changing in electromagnetic spectrum.

V. Foreshocks. The certain intensity earthquake must correspond to VLF electromagnetic emission with certain frequencies. It means that foreshocks must be characterized by own frequency spectrum of electromagnetic emission (mainly, in the diapason of MHz).

So, we may make conclusion that in the frame of scheme of electromagnetic circuit (contour), created by virtual linear wires, it is in principle possible to control earthquake preparing and its occurring process by monitoring of changing of electromagnetic emission frequency spectrum.

5. Summary

It is offered the original model of the own electromagnetic oscillation of the local segment of the lithosphere - atmosphere system. By the view of authors model simplifies physical analyses of the nonlinear effect the results of which is admittedly reflected in the electromagnetic picture which expresses relation of the lithosphere-atmosphere-ionosphere system.

The model in a qualitative sense explains mechanism of VLF electromagnetic emission revealed in the periods before earthquakes occurring and reasons of anomalous changing of atmospheric electric field potential gradient. Besides it confirms possibility of monitoring of main shock expectation by foreshocks observation. Correspondingly the model in principle gives us possibility to determine intensity of incoming earthquake, the time of its occurring, location and linear sizes of the focus with certain accuracy.

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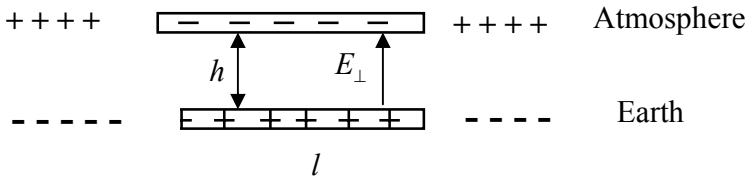

Figure 1. Analog contour