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LITHOSPHERE – ATMOSPHERE – IONOSPHERE CIRCUIT MODEL

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Abstract

By helping of model of analogous circuit, created with virtual linear conductors, it is possible to implement monitoring of earth electromagnetic emission of earthquake preparing process by frequency spectrum control. By model it is also possible to connect telluric by nature geoelectric and geomagnetic perturbations caused by rocks polarization with self-generated electromagnetic oscillations of lithosphere-atmosphere-ionosphere system. In case of quite reliable results of observed data diagnostic analyse, it is supposed that the analogous model will be useful by point of earthquake prediction problem.

Keywords: *lithosphere, earthquake, rock, precursor, telluric*

Introduction

There is created theoretical model in the work [13] according to which very low frequency (VLF) electromagnetic emission in /1-1000/ kHz diapason, generated in earthquake focus, may be the manifestation of self-generated electromagnetic oscillations of concrete seismoactive segments of lithosphere-atmosphere-ionosphere system. Such imagination is quite handy although its justice needs empirically to confirm theoretical relation forecasted by model. In order to it is obligatory multilateral diagnostic analyse of VLF emission fixed before earthquake. First of all existence of morphological relation between characteristic linear size of earthquake focus (main fault length) and main (lowest) frequency of VLF emission must be proved. In case of existence of such relation, it must be real perspective of using of VLF emission towards prediction problem of magnitude and time of incoming earthquake occurring.

Physical mechanism of earth VLF electromagnetic emission

Because of practical goals, first of all the task of physical mechanism of VLF emission must be realized, the problem of unambiguity of which is actual up to these days. The noted theoretical model is based on electric polarization effect of tense rocks. It is considered that piezo-electric effect, caused by mechanical tension, takes place in rocks in the period of earthquake preparing [21].

In general, charge of polarization must be distributed on some surface which must be enclosed by fault or formed along fractures [28].

It is accepted that geological medium is more or less uniformly tense and homogeneous. Origination and multiplication of heterogeneous structures take place with dynamic process intensification. The one result of this process is joining of micro-cracks, originated chaotic, into main fault with certain direction in the last stage of earthquake preparing. It is believable that effect of polarization reveals maximally during main fault formation. We must note that it is necessary to check the mechanism of VLF emission in such natural conditions where gathering of charge of polarization is caused by the reason different from the mechanical action on the rocks. Local geomagnetic anomaly at the Black seaside resort Ureki territory may be unique one for this task. By preliminary geophysical data, gathering of polarization charges takes place in the central area of this

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anomaly. This phenomenon may be connected with magneto-hydrodynamic effect developed in the process of water diffusion at the seaside zone.

Electric polarization belongs to the category of electrostatic phenomena. But if polarization charge is accompanied by electromagnetic emission, we may say that besides electrostatic effect, which creates capacity in the certain space, electromagnetic induction may be existed. It is obvious that such phenomena must be taken into account during analyse of electromagnetic relations inside lithosphere-atmosphere-ionosphere system. Formally, there are various variants of developing of induction effect however towards seismic phenomena we may accept that lithosphere always is the source of induction effect. Because of it, taking into account physical analogy from the theory of electromagnetic oscillations, we may imagine that we touch with natural electromagnetic circuit, component elements of which are connected with lithosphere as atmosphere (ionosphere) as well [9, 10, 22, 23].

The fact that the upper limit of VLF frequency detected before earthquake is in MHz bounds, may point out minimal size of cluster of earth heterogeneity which may cause notable effect of induction in the atmosphere [9, 10, 22].

It is considerable that there is alternative variant according to which VLF emission's connection with seismic phenomena is not obligatory one. Primary source of electromagnetic induction may be in magnetosphere or in ionosphere, but secondary or response, in lithosphere. For example, such alternative is base of prolongation model of ionospheric SQ-current system in the upper layer of inductive lithosphere [5].

Besides, it is known that cosmic VLF electromagnetic emission is continuously observed in the high latitudes of magnetosphere. In the auroral oval it is conditioned by direct invasion of charged particles of solar wind into polar ionosphere which is implemented from polar cusps with vortex form. VLF emission is observed pretty seldom in the middle and low latitudes in ionosphere level as in earth surface as well in comparison with high latitudes. In spite of it is obvious that earth VLF electromagnetic emission must be reliable separated from the same frequency diapason emission of magnetospheric origination but caused by another mechanism in the middle and low latitudes or especially seismically active latitudinal belt. Such separation is especially simple during disturbed solar wind when the sharp changing of energetic spectrum of captured plasma takes place in the inner structures of magnetosphere. Precondition of generation of megnetospheric VLF electromagnetic emission in the middle latitudes is, in inner magnetic plasma energetic spectrum, increasing of energetic (with $E \approx 10-30$ kev) electron density in the main plasma reservoir of magnetosphere, in plasmosphere and its interfacial main radioactive belt, ionosphere. Such electrons with notable quantity appear here only during powerful geomagnetic perturbations, global magnetic storms.

Scheme of analogous circuit model

Symbolically earth surface has negative potential towards atmosphere because of it the very segment of lithosphere where the earthquake is preparing, may be accepted as negatively charged one until piezo-effect. In result of tectonic stress increasing, heterogeneity will appear in this segment or places with positive charges, which like "Frenkels generator," will cause inductive polarization at the some altitude in atmosphere.

In quasi-electrostatic approximation, which is in agreement with lithosphere-atmosphere-ionosphere circuit model (with analogous conductors), it is possible to operate with large-scale atmospheric electric field as circuit closer. Such imagination especially makes easier mathematical modeling of inductive interaction inside lithosphere-atmosphere-ionosphere system. In quasi-electrostatic approximation it is natural to connect polarization charges with atmospheric electric field. Because of it is not necessary to take into account factor of atmospheric electric conductivity and to imagine its mechanism of changing, for instance, to accept radon emission from lithosphere to atmosphere. It makes easier the picture in seismoactive regions where radon atmospheric effect is

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not accompanied by one-valued result which would be equally just for regions with different geological structures.

Exactly this is the essential demerit of atmospheric condenser which is based on radon emission or the substantial demerit of "Frenkel models" last modification [19].

So, we accept that in the incoming earthquake focus, with multitude cracks background, at the last stage, the main fault creates which may be identified with linear conductors. The conductor, with the same length but with opposite polarity, must be created by induction in the atmosphere. It is obvious that this model is universal because formally it is acceptable that primary conductor is created in the atmosphere but secondary – in lithosphere. To operate with linear conductors is pretty obvious because if there are two distant horizontal conductors with inter opposite polarity in lithosphere and in atmosphere, the electric interaction is possible between them. Namely, it may be created the structure like condenser which will be locked by vertical atmospheric field (fig.1a). Like ordinary circuit of oscillation, atmospheric circuit will have certain inertia which is the pre-condition of generation of self-generated electromagnetic oscillations. By physical point inertia means that if we charge two conductors with opposite but the same charges and lock it, the current and magnetic field connected with it will appear in this system. Because the conductors have inductance the electromotive force of induction will be appeared also or will be created circuit and generation of electromagnetic oscillations will occur. The qualitative changing of this picture must not be happened even in case when the system comprised by several electromagnetic circuits may be created in the seismic active area. For instance, we may imagine that the line of polarization of generator rocks of primary circuit, directed along deep faults, is the one of them conductor. The conductor along the earth surface is parallel to it but the circuit is locked by orthogonal electric field. By this imagination secondary circuit is inductive response in the atmosphere of primary circuit. In any cases it is possible to generate of self-generated electromagnetic oscillations the mechanism of which is just for any quantity of circuits. For justice, it is pretty enough to remember that 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 conductors, as well as capacity of the coil, are disregarded. When electromagnetic dissipation is disregarded, circuit's self-generated oscillations frequency is defined by well-known Tompson's formula:

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

where L - is coil inductance, C - condenser capacity. Formula (1) is more precise as capacity outside the condenser and inductance outside the coil are the lesser. Besides, the oscillatory circuit's own (characterizing) frequency increases with capacity and inductance decreasing. But in this case capacity and inductance of connecting conductors become considerable. Formula (1) is correct also in case when circuit is not isolated and is close to other conductors. In such case it is possible changing of circuit inductance as capacity as well. It means that influenced polarization will be created but self induction effect caused by neighbouring current circuit (circuits) may be added to inter- induction effect. .Such influence will be especially well revealed in case when the first circuit is electrical neutral (condenser is not charged) but current flows in second one. Inter induction may be notable in isolated circuit but in the limits of high frequencies. In such case obligation for being of condenser and coil in order for arising of electromagnetic oscillations in circuit will not be at all because inter capacity and inductance of connected conductors (linear conductors) will be enough for generation of oscillations. In case of induction it is not necessary that connected conductors were tied in circuit frame. It means that the circuit may be presented in open state which factual will create atmospheric (ionospheric) electromagnetic antenna (fig.1 b).

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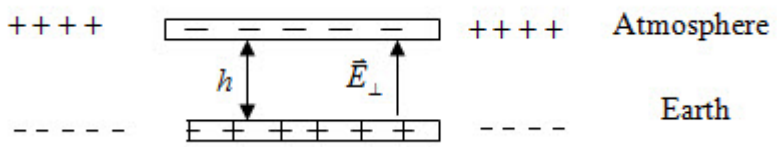

Fig 1 a. The first variant of analogous circuit

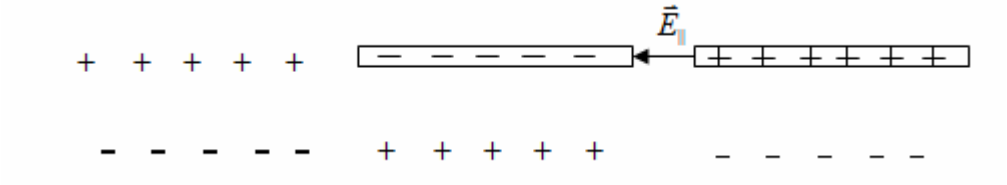

Fig 1 b. The second variant of analogous circuit

The main thing is existence of locking mechanism of circuit with virtual conductors in any cases. Such function in atmosphere will be presented by atmospheric electric field but in depth of earth – telluric electric field.

So, presented model quantitatively explains mechanism of generation of very low frequency electromagnetic waves in the periods before earthquakes and points out the source of perturbation of atmospheric vertical electric field. Because this field carries out circuit locking function, we must take into account that its perturbation must be occurred by circuit oscillation frequency as by characteristic time of ohmic attenuation as well. At the same time, in spite of neglecting of ohmic resistance effect directly in circuit, no doubt that it will be losing of energy because of electromagnetic emission, intensity and direction of spreading of which will be depended on circuit geometry and linear sizes.

Analytic shape of the model

Let's say that the length of parallel, opposite polarity conductors is l, characteristic size of section is a, distance between conductors is h. It is assumed that relative electric and magnetic constants for air $\varepsilon = \mu = 1$ (we use SI – system). It is known that inter capacity of conductors, when $h >> a$, is:

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

but inter induction of conductors:

$$L \approx \frac{\mu_0}{\pi} ln\left(\frac{h}{a}\right) l .$$

So, we will have expression for self-generated oscillations frequency of electromagnetic circuit from formula (1):

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

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

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$$\varepsilon_0 \mu_0 = \frac{1}{c^2}$$

Let's assume that interval of changing of main fault length l in the earthquake focus is (1-100) km. From formula (2) we'll receive that change diapason of analogous circuit's self-generated electromagnetic oscillation frequency is ω=3 (10^3 - 10^5) Hz. As a rule, frequency of generated electromagnetic VLF emission in earthquake focus changes in diapason 1kHz – 1MHz. So it is obvious quantitative agreement with characteristic values of lowest (main) frequency of very low frequency atmospheric electromagnetic emission fixed before earthquake.

By the model there is certain freeness in circuit geometry: if the circuit is locked its chain will be tied by vertical component of atmospheric electric field. In case of open circuit it will be induced additional conductor conditioned by horizontal component of atmospheric electric field.

In this case the length of additional conductor may significantly outnumber the length of the main conductor and this one will be depended on linear scale of atmosphere heterogeneity (fig. 1 b).

Like our model the work [18] is based on the effect of inverse of lithosphere segment polarity, caused by increasing of tectonic stress in the focus of incoming earthquake in accord with 1a scheme. There is considered phenomenon of electromagnetic induction too in the ionosphere which causes perturbation of total content of electrons (TEC). But the reason of it, unlike our model, is increasing of electrons concentration in the plasma babbles besed on epicentral area.

Such geometry of analogous circuit may be handy in case when VLF emission reveals in earthquake focus as in distances far away from epicenter as well [12, 19, 21, 26].

In order to manifest adequacy of analogous circuit model with experimental data let's consider some examples (L'Aquila, China, Haiti earthquakes).

Formula (2) is for ideal case. In reality must be nonlinear connection:

$$l = \beta \frac{c}{\omega} \quad (3)$$

β is caused by geological behaviors of region and electric properties of medium.

It is considerable that the fall-unstable model (fig.2) of fracture origination, well-known in

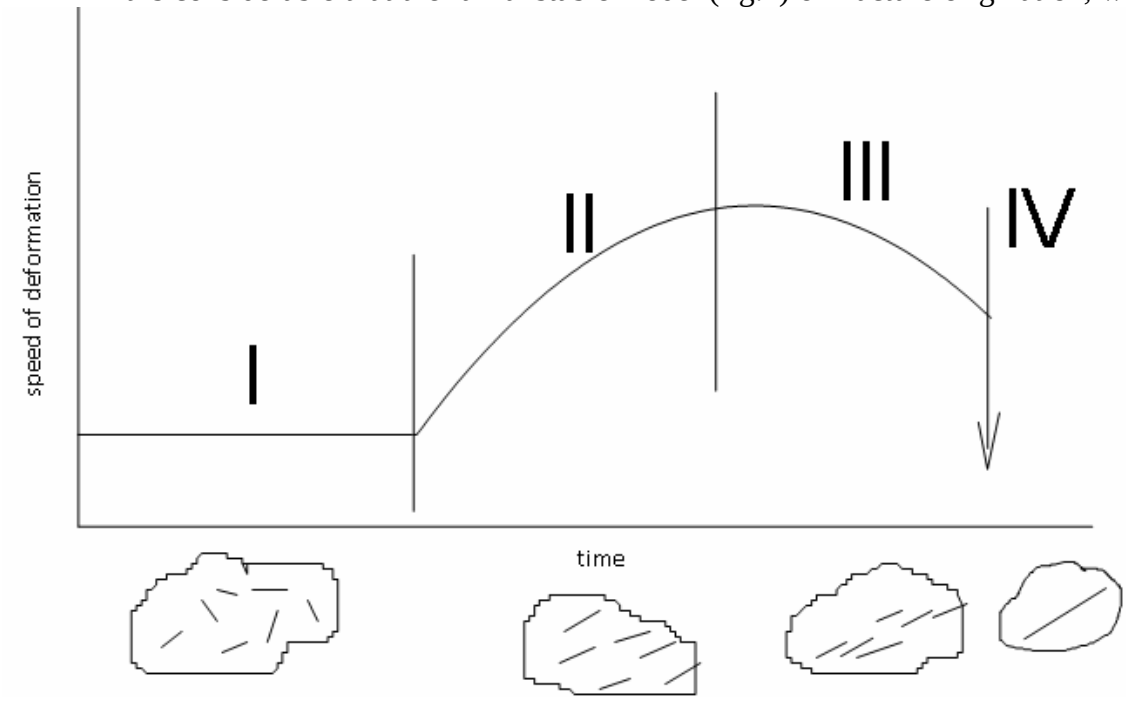

Fig.2. Scheme of fall-unstable model of fracture origination (Mjachkin, et al., 1975)

seismology [20], is relevant to model presented by us and explains very well the following sequence

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of EM emission observed before earthquakes: MHz, kHz and EM quiescence just before the earthquake occurrence [11, 7].

It is known that the fall-unstable model of fracture origination is divided into three stages: the first stage, which may last for tens of months in case of large earthquakes, is not considered as so-called "precursory" stage because microfractures (several tens or thousand meters long) originate chaotically without any orientation during this period.

This stage of microfractures origination is reversible process – it is possible to originate not only microfractures at this stage but their "locking" too. Because of it, the first stage must be expreesed by discontinuous spectrum in MHz range frequency diapason of electromagnetic emission.

The second stage of fall-unstable model of fracture origination is already the continuous process of origination of definitely oriented microfracture, in which earlier "locked" parts are involveed. We must suppose that the second stage will be expressed by continuous spectrum in MHz range frequency diapason. They suppose that this process takes place for 10-14 days before earthquakes. Observed material confirms this suggestion – continuous emission in MHz diapason frequency spectrum of EM appears for 10-14 days before earthquakes [25].

In accord with the fall-unstable model of fracture origination, at the same stage, it becomes the process of fracture length increasing (in range of kilometers) at the expense of their joining which, relevant to our model and (3) formula, means transition of MHz to kHz in the frequency spectrum of electromagnetic emission.

At the following third stage of the fall-unstable model, joining of relatively large size fault into one main fault takes place which, in case of monitoring of EM emission spectrum, must cause gradual dropping of frequency meanings in kHz which, for its part, by the formula (3), correspond to increasing of fault length in the incoming earthquake focus.

Based on Ulomov formula [31], which gives the relation between earthquake magnitude and fault length in earthquake focus:

$$\lg l = 0.6M - 2.5 \quad (4)$$

increasing of fault length in incoming earthquake focis indicates increasing of magnitude.

Final setting of relevant unstable zone, that is the main fault, is accompanied by general dropping of average "macro" stress in the most part of the volume because by this time new fractures do not originate at this stage. This effect in accord with our model must be expressed in EM emission disappearing which takes place for several hours before earthquakes and which is confirmed by observed material [11, 7]. The last, IV stage in fall-unstable model, corresponds to earthquake occurring moment.

It is considerable the fact that monitoring of frequency spectrum of EM emission gives us possibility to separate pretty easily foreshock and aftershock series from the main shock.

EM emission was considered as only earthquake indicator in the thoretical model presented by us [12] in which the possible mechanism of EM emission in the period before earthquake was explained. Besed on above mentioned analysis it is clear precursory character of EM emission because it seems that it "brings" especially valuable information for incoming earthquake prognostic diagnosis.

Telluric effects of rocks deep polarization

Low virtual conductor is located on the earth surface by formalism of analogous circuit. But main fault in the earthquake focus along which polarized surface (conductor) creates, is always depth. Due to it, there is the problem of an outing of earth VLF electromagnetic emission from earth depth connected with skin-effect. In paper [12] the scheme of prolongation of depth polarized conductor in direct to earth surface is given by model, which gives vertical electrical profile of earth section. In order to plot down relevant analytic electrodynamic picture it is enough to postulate only

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electric conductivity of medium and changing of character of polarization charge density. Let's assume that electric conductivity σ from the fault plane to earth surface decreases, ρ density of polarization charge attenuates in time and these both processes occurs by exponential law:

$$\sigma = \sigma_0 e^{-kz}; \qquad \rho(t) = \rho_0 e^{-\frac{t}{t_0}} \qquad (5)$$

where $\rho(t)$ is the density of polarization charge on the fault level, ρ_0 - characteristic value, Z - vertical ccordinate, σ_0 - characteristic value of electric conductivity, k - logarithmic decrement of attenuation, t_0 - characteristic value (logarithmic decrement).

The such simple analyse shows that virtual conductor in the earth surface qualitively is electrodynamical reflection of polarization line created on the fault. Because of it this model, for concrete meanings of fault and medium parameters, with certain accuracy, may be used for estimation of geomagnetic characteristics (telluric) connected with electric current and characteristics of geomagnetic variations (pulsations). Principally, it is possible to determine density of polarization charge which is obligatory one for energy estimation of earth VLF emission.

So, according to [12] the mechanism of generation of electromagnetic emission must be directly connected with the effect of depth rocks polariozation in the epicentral area of incoming earthquake which must be accompanied by perturbations of telluric current and its accompanying electric and magnetic fields. Similar phenomana are fixed many times in the period before earthquakes. It is found that geoelectric variations (pulsations) caused by seismic activity are accompanied by geomagnetic variations [30].

The last ones are fixed by certain backwardness of phase which is connected with electric conductivity of medium. In general, we may say that the effect of medium magnetic viscosity appears active in earth, like space. Its value, mostly, may define frequency spectrum of geomagnetic pulsations of ionospheric origination [16].

Sequentially, in spite of not having possibility to use telluric electromagnetic parametre data as earthquake indicator yet, morphological analyse of their changing may be pretty enough for seismic prediction problem.

Magnetospheric VLF electromagnetic emission

It is clear that earth VLF electromagnetic emission in the especially seismo-active latitude belt must be reliably separated from the same frequency diapason emission of magnetospheric origination, caused by another mechanism.

It is known that this effect practically always accompanies increasing of gas-dynamic pressure of solar wind and recconection between interplanetary magnetic field and geomagnetic field on the boundary of magnetosphere day side as well. This process in many cases ends with global geomagnetic storm and intensification of VLF electromagnetic emission over the earth especially in the middle latitudes.

As a rull, frequency spectrum of this emission is not significantly different from the frequency spectrum of VLF emission generetad in the focus of incoming earthquake. Because of it is natural that main problem is to detect single-valued the source of VLF emission i.e. excluding of magnetospheric VLF emission in the seismo-active area in the period of earthquake preparing.

It is obvious that without solving of this task using of earth VLF emission as earthquake electromagnetic indicator, purposely for prognostic goal, will not be perspective. During geomagnetic storm it is natural that earth VLF emission, if it exists, will be overlaped by more intensive magnetospheric emission. Because of it single-valued seperation of VLF emission from

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the spectrum of total VLF emission is practically impossible during high geomagnetic activity [1]. Although during earth VLF emission analysis it is not considered yet the fact that generation of magnetospheric VLF electromagnetic emission may have place in quiet or less perturbated geomagnetic conditions too (Kereselidze et all, 1993). The goal of this diagnostic model is showing of possibility and activity of VLF electromagnetic emission generation in quiet and less perturbated geomagnetic conditions in middle latitudes in the very belt where plasmosphere is projected.

Fundamental base of diagnostic model of VLF magnetospheric emission is the classical analytic solving by S. Chapligin gotten in approximation of jet of ideal incompressible liquid stream. By this solving it may be modeling of wide scale hydrodynamic picture of flowing of magnetosphere by solar wind in which so-called zone of stagnation is separated. Particularly, it is possible to determine velocity of solar wind plasma at the border of stagnation zone the size of which depends on in advance postulated accuracy [15]. The main axis of this diagnostic model is hypothesis according to which wide scale laminar flowing of plasma stream of solar wind close to border of magnetosphere day side, in certain conditions, pass into turbulent. At this time the indicator of changing of dynamic regime of flowing is stability of stagnation zone. Destruction of it is capable of changing the wide scale hydrodynamic picture of flowing.

In such case the probability of hitting of solar wind energetic electrons within magnetosphere bottom of stagnation zone must increase. It will help to swich the mechanism of electron cyclotron unstability of VLF electromagnetic emission, in plasmosphere and ionosphere.

At the concrete moment, the stability of stagnation zone is determined by MHD criterion:

$$M = 1 - v_1 / 2v_a \geq 0 \qquad (6)$$

where v_1 - is velocity of plasma of solar wind on the border of stagnation zone, v_a - Alphen velocity on the border of stagnation zone. The method of their calculation is pretty simple and is given in work [16].

In due time diagnostic model was checked with enough completeness. It was found that it exists reliable morphological relation between MHD regime of solar wind flowing and VLF electromagnetic emission fixed in upper ionosphere in quiet and less perturbated geomagnetic conditions.

In the process of morphological analysis it was used data of VLF emission of middle latitudes and indicator indices of level of geomagnetic activity. Particularly, global middle latitude geomagnetic index satisfied condition $D_{st} \geq -15$ nT but global index of magnetic activity - $K_p \leq 2$, which corresponds to quiet or less perturbated magnetosphere with pretty enough reserve, criterion (4) showed sufficient reliability. Particularly, in case when $M \geq 0$ i.e. when, according to diagnostic model, wide scale structure of solar wind, flowing close to magnetosphere border might be laminar VLF emission, without rare exception, was not fixed.

Instead of it, VLF was practically always fixed in case when $M < 0$ i.e.during turbulent regime of solar wind flowing. Joint diagnostic accuracy of these results is pretty high ($\approx 85\%$). It was found that together with increasing of latitude interval, diagnostic possibilities of the model decrease which clearly expresses magnetospheric VLF electromagnetic emission dependence on the source of plasmosphere [23].

So, we think that estimation of activity of magnetosphere by only Kp and D_{st} indices [1] can not exclude possibility of VLF/LV emission generation. The additional M criterion (index), above offered by us, makes stricter these requirements. Illustration of it is presented on fig. 3-5, where are done pictures of changing of Kp, D_{st} indices and M criterion. We note that the first two pictures are practical identical to pictures given in [1]. Although in case of D_{st} index, we use stricter limitation M≥ -15 nT (in all figures the moment of earthquake occurring is plotted by black point).

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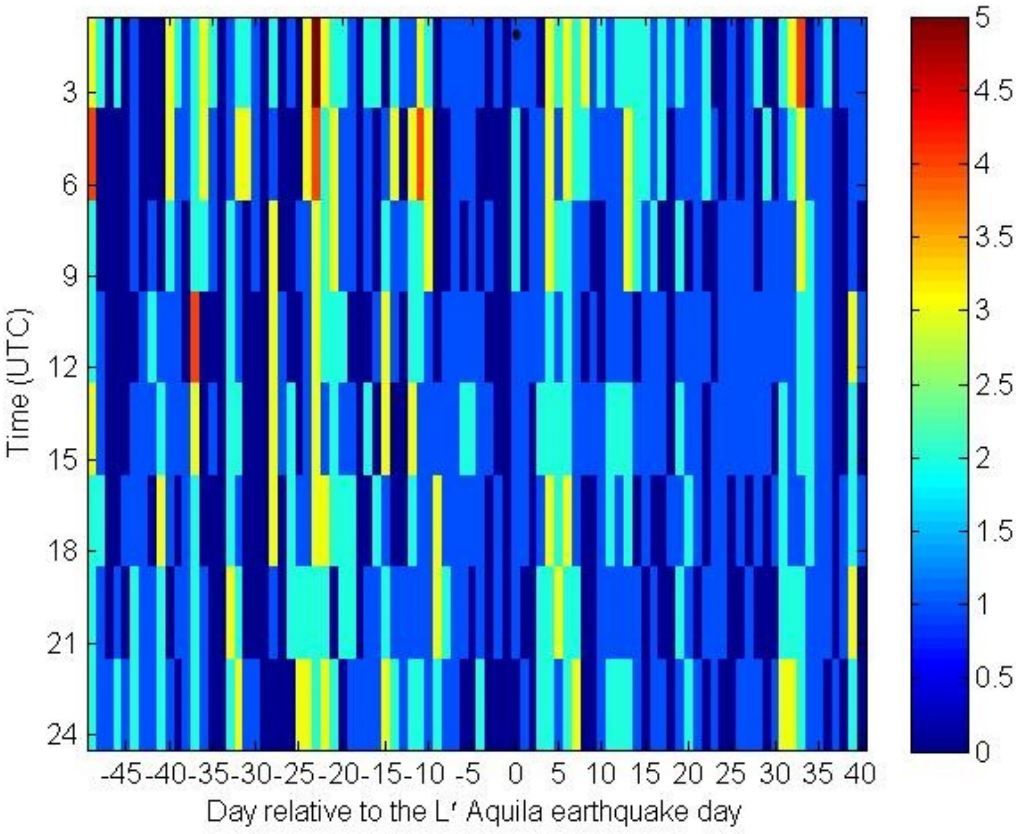

Fig. 3. Changing of Kp index during L'Aquila earthquake

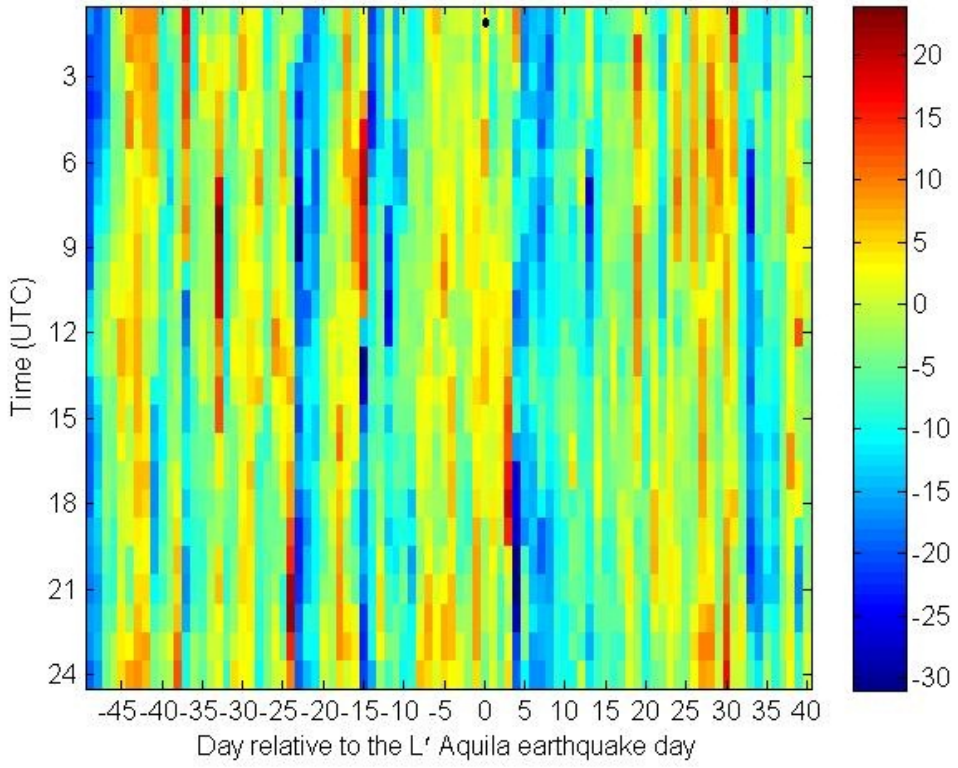

Fig. 4. Changing of D_{st} index during L'Aquila earthquake

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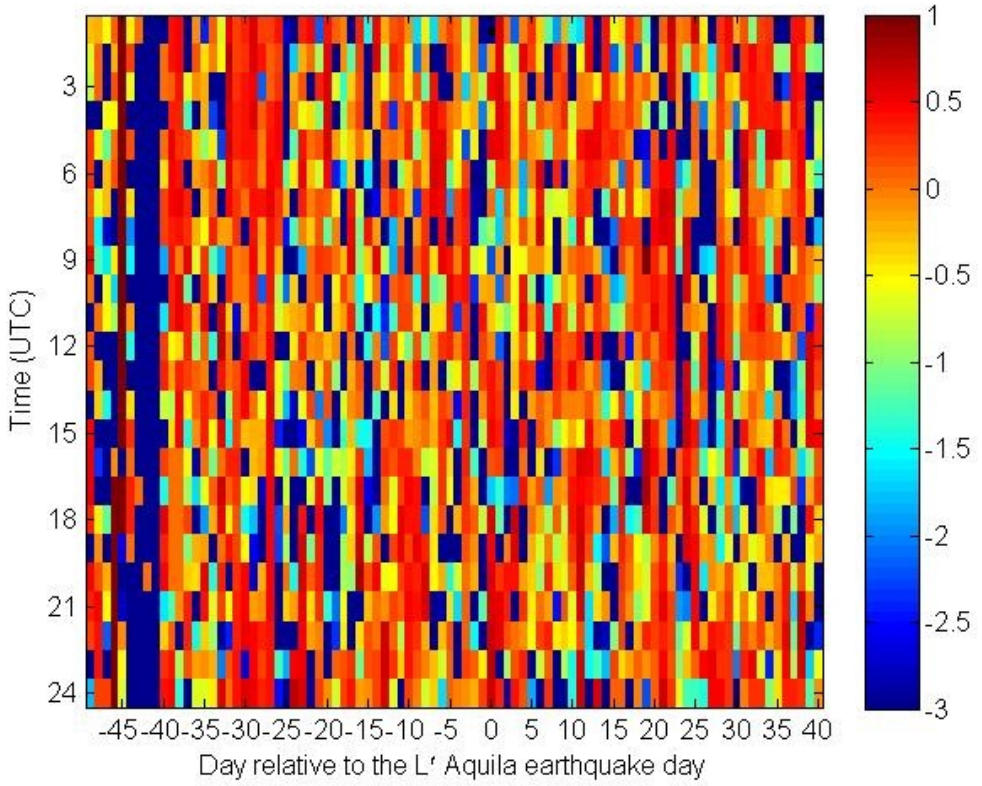

Fig. 5. Changing of M index during L'Aquila earthquake

Simple analysis shows that in many cases, when magnetosphere is in quiet or less perturbated condition by Kp, D_{st} indices, M criterion is less than zero, what means that magnetospheric VLF/LV emission may exist on middle and low latitudes.

Conclusion

Formalism of virtual conductors makes partly easier consideration of various problems in connection with earthquakes. Namely, model of analogous circuit may be used for following tasks:

1. Accumulation of surface polarization charges in near ground layer will influence on atmospheric electric potential gradient changing of which may be taken like one electromagnetic indicator of seismic activity (Kachakhidze et al, 2009).

2. It is possible to connect short-periodic geomagnetic pulsations accompaning ionospheric perturbations with earth VLF emission by analogous circuit. Relaxation of polarization charges in this segment of lithosphere-atmosphere-ionosphere system in earth surface layer must cause intensification of telluric curent and generation of geomagnetic and geoelectric fields pulsations.

3. The magnitude of incoming earthquake may be deternined by empiric formula of relation between earthquake magnitude and linear sizes of focus. It is obvious that as exact will be formula of connection between length of fault in focus and magnitude, as exact will be determined magnitude of incoming earthquake.

4. After diagnostic, in case if it will be found that the main frequance of VLF electromagnetic emission is more or less the same, the model of analogous circuit let us fix the time of earthquake occurring with certain accuracy.

5. It is possible to arise several analogous circuits connected with each other in atmosphere (ionosphere) by induction and to join them with one system which may be the reason of spreading

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of VLF emission in the distances quite far away from earthquake epicenter, which is observed pretty often.

6. It is possible to connect short-periodic geomagnetic pulsations, accompaning ionospheric perturbations, with earth VLF emission by analogous circuit.

7. It is not excluded arising of several analogous circuits connected with each other in atmosphere (ionosphere) by induction and their joining with one system which may be the reason of the fact observed pretty often - spreading of VLF emission in the distances quite far away from earthquake epicenter.

8. EM emission, considered earlier as a earthquake indicator, gives prognostic diagnosis possibility.

References:

1. Akhoondzadeh, M., Parrot, M. and Saradjian M. R. Investigation of VLF and HF waves showing seismo-ionospheric anomalies induced by the 29 September 2009 Samoa earthquake (Mw=8.1). Nat. Hazards Earth Syst. Sci., 2010, 10, 1061–1067. www.nat-hazards-earth-syst-sci.net/10/1061/2010/;

2. Athanasiou1, M. A. , Anagnostopoulos, G. C. , Iliopoulos, A. C. , Pavlos, G. P. and David C. N. Enhanced ULF radiation observed by DEMETER two months around the strong 2010 Haiti earthquake. Nat. Hazards Earth Syst. Sci., 2011, 11, 1091–1098. www.nat-hazards-earth-syst-sci.net/11/1091/2011/;

3. Biagi P. F., Maggipinto T., Righetti F., Loiacono D., Schiavulli L., Ligonzo T., Ermini A., Moldovan I. A., Moldovan A. S., Buyuksarac A., Silva H. G., Bezzeghoud M., and Contadakis M. E. The European VLF/LF radio network to search for earthquake precursors: setting up and natural/man-made disturbances. Nat. Hazards Earth Syst. Sci., 2011, 11, 333–341. www.nat-hazards-earth-syst-sci.net/11/333/2011/;

4. Cirella S., Piatanesi A., Cocco M., Tinti E., Seognamiglio L., Michelini A., Lomax A. And Boschi E. Rupture history of the 2009 L'Aquila (Italy) earthquake from non-linear joint inversion of strong motion and GPS data. Geophys. Res. Lett., 2009, 36, L19304, doi:10.1029/2009GL039795;

5. Duma G., Ruzhin Y. Diurnal changes of earthquake activity and geomagnetic Sq-variations. Natural Hazards and Earth System Sciences, 2003, 3,171-177;

6. Dunajecka M., Pulinets. Atmospheric and thermal anomalies observed around the time of strong Earthquakes in Mexico. Atmosfera, 2003, 18 (4), 235-247;

7. Eftaxias K., Athanasopoulou L., Balasis G., Kalimeri M., Nikolopoulos S., Contoyiannis Y., Kopanas J., Antonopoulos G., and Nomicos C. Unfolding the procedure of characterizing recorded ultra low frequency, kHZ and MHz electromagetic anomalies prior to the L'Aquila earthquake as pre-seismic ones – Part 1. Nat. Hazards Earth Syst. Sci., 2009, 9, 1953–1971. www.nat-hazards-earth-syst-sci.net/9/1953/2009/;

8. Guangmeng. Guo. Studying Thermal Anomaly Before Earthquake With NCEP Data.The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. 2008,vol. XXXVII. Part B8, Beijing, 295-298;

ISSN 1512-1461

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

10. Hayakawa M,. VLF/LF Radio Sounding of Ionospheric Perturbations Associated with Earthquakes.2007, Sensors, 7, 1141-1158, www.mdpi.org/sensors;

11. Johnston, M.: Review of electric and magnetic fields accompanying seismic and volcanic activity, Surveys in Geophysics, 1997, 18, 441- 475;

12. Kachakhidze M., Kachakhidze N., Kiladze R., Kukhianidze V., Ramishvili G. Relatively small Earthquakes of Javakheti Highland as the precursors of large earthquakes occurring in the Caucasus, Natural Hazards and Earth System Sciences, 2003, 3, 165–170;

13. Kachakhidze N., Kereselidze Z., Kachakhidze M., Ramishvili G. Specific variations of the atmospheric electric field potential gradient as a possible precursor of Caucasus earthquakes. Nat. Hazards Earth Syst. Sci., 2009, 9, 1221–1226. www.nat-hazards-earth-syst-sci.net/9/1221/2009/;

14. Kachakhidze, M. K., Kereselidze, Z. A., and. Kachakhidze, N. K. The model of self generated seismo-electromagnetic oscillations of the LAI system. Solid Earth, 2011, 2, 17–23, www.solid-earth.net/2/17/2011/;

15. Kereselidze Z.A., MHD effects of finite electric conductivity of solar wind near the earth's magnetosphere. TSU, Tbilisi, 1986, p. 122;

16. Kereselidze Z.A. and Orvelashvili V.Sh. Relation of the Solar Wind MHD Flow in the Transition Region to VLF Radiation in the Earth Magnetosphere. Geomagnetism and Aeronomy, , 1993, 33,4, pp.165-167;

17. Kereselidze, Z., Kachakhidze M., Kachakhidze N., and Kirtskhalia V. Model of Geomagnetic Field Pulsations before Earthquakes Occurring. Nova Science Publishers Georgian International Journal of Sciences and Technology., 2010, Vol. 2, Issue 2, p. 167-178;

18. Kuo, C. L., Huba, J. D., Joyce, G., Lee, L. C. Ionosphere plasma bubbles and density variations induced by pre-earthquake rock currents and associated surface charges. Journal of Geophysical Research, Vol. 116, A10317, 10 PP., 2011. doi:10.1029/2011JA016628

19. Liperovsky, V., Meister, C., Liperovskaya, E., Bogdanov, 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., 2008, 8, 1199–1205;

20. Mjachkin V.I., Brace W.F., Sobolev G.a., Dieterich J.H. Two models for earthquake forerunners, Pageoph., 1975, vol. 113. Basel;

21. Mognaschi E.. On The Possible Origin, Propagation and Detectebility Of Electromagnetic Precursors Of Eaerthquakes. IW2GOO, Atti Ticinensi di Scienze della Terra, 2002, vol. **43**,111-118;

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

ISSN 1512-1461

23. Nishida, A. Geomagnetic Diagnosis of the Magnetosphere. Springer-Verlag. New yark-Heidelberg-Berlin, 1978;

24. Ouzounov D., Defu L., Chunli K., Cervone G., Kafatos M., Taylor P. Outgoing long wave radiation variability from IR satellite data prior to major earthquakes. Tectonophysics, 2007, 431, 211–220;

25. Papadopoulos G. A., Charalampakis M., Fokaefs A., and Minadakis G. Strong foreshock signal preceding the L'Aquila (Italy) earthquake (Mw 6.3) of 6 April 2009. Nat. Hazards Earth Syst. Sci., 2010, 10, 19–24.. www.nat-hazards-earth-syst-sci.net/10/19/2010/;

26. Pulinets S., Boyarchuk K. Ionospheric Precursors of Earthquakes.Springer. 2003. 315 p.;

27. Pulinets S.,Ouzounov D., Karelin A., Boyarchuk, K., Pokhmelnykh· L. The physical nature of thermal anomalies observed before strong earthquakes. Physics and Chemistry of the Earth, 2006, parts A/B/C,v. 31, Issues 4-9, 143-153;

28. TakeoYoshino. Low-Frequency Seismogenic Electromagnetic Emissions as Precursors to Earthquakes and Volcanic Eruptions in Japan. Journal of Scientific Exploration.,1991, vol. *5*, № I , 121 – 144;

29. Triantis D., Anastasiadis C., Stavrakas I.. The correlation of electrical charge with strain on stressed rock samples. Nat. Hazards Earth Syst. Sci., 2008, 8, 1243-1248, www.nat-hazards-earth-syst-sci.net/8/1243/2008/;

30. Varotsos, P. A. , Sarlis, N. V. and Skordas, E. S. Detrended fluctuation analysis of the magnetic and electric field variations that precede rupture. Chaos 19, 023114. 2009. DOI: 10.1063/1.3130931;

31. Ulomov V.I. Ordering of geostructure and seismicity in seismoactive regions. Seismisity and seismic zoning of Northern Eurasia.Volume 1, Moscow, 1993, p.27-31;

32. Xuemin Zhang, Xuhui Shen, Jing Liu, Xinyan Ouyang. Ionospheric perturbations of electron density before the Wenchuan Earthquake. International Journal of Remote Sensing Vol. 31, No. 13, 10 July 2010, 3559–3569;.

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