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Variation of Electromagnetic Waves, Electric Field and Magnetic Field in F region due to Earthquake*

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Abstract: Reliable, repeatable earthquake forecast is a subject surrounded by controversy and skepticism. What is clear is that reliable forecast would be a critical tool for effective earthquake disaster management. It is proposed that satellites and ground-based facilities may detect earthquake precursors in the F region of Ionosphere a few hours or days before the main shock. It is proposed that, due to the anisotropy of atmospheric conductivity at heights greater than 60 km, the large-scale, high-intensity (ca. 1000 V m^{-1}) vertical electric field appearing at seismically active regions a few days before strong earthquakes can penetrate into the ionosphere and create specific irregularities of electron concentration in this region (Pulinets et al. 1998). This anomalous quasistatic electric field generated on the ground in a seismo-active zone is detected through the seismogenic variations in the near-Earth plasma due to the high conductivity along the geomagnetic field lines. Several observations were made of Very Low Frequency (VLF) emissions apparently associated with earthquakes, which were recorded independently at ground-based stations and on satellites. Data were analyzed for those cases when both intense (Ms> 5) earthquakes occurred in the region close to the satellite longitude and the satellite was operating in the VLF mode. A statistical analysis, based on the enhancement of wave intensity at the time of earthquakes and using GEOS-2 data, seems to indicate that there is a (possibly indirect) association between seismic activity and some of the VLF emissions observed at the satellite. Ionospheric measurements made from the ground also showed an increase of the critical frequencyf0Esof the sporadic layer Eswhen earthquakes occurred nearby. As, there is a change of electromagnetic waves & electric field due to earthquake in F region so, change of magnetic field should be there due to earthquake. Magnetic Field Change can be detected by satellite and the human lives and the properties can be defending from earthquake.

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1. Introduction

Earthquake is a phenomenon of earth's lithospheric plate movement. As the result of the earthquake earth's crust is destroying. Due to the earthquake we have detect some changes in characteristics of earth's magnetic field, electric field and as well as in ionosphere (F region) magnetic field, electric field and electromagnetic waves' variation.

Characteristics of Earth's Magnetic Field, Electric Field

Earth's Magnetic Field:

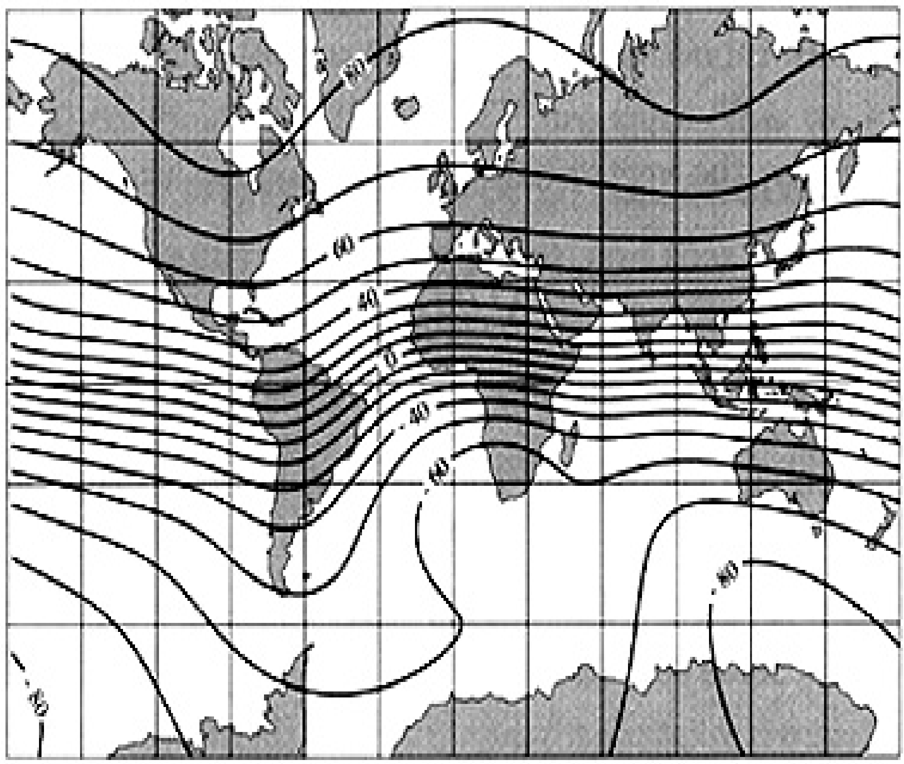

Fig 1: Earth's Magnetic Field

From Fig 1 we can understand about the direction, characteristics of Earth's Magnetic Field. If we draw a vector diagram of this then it will be like the Fig 2.

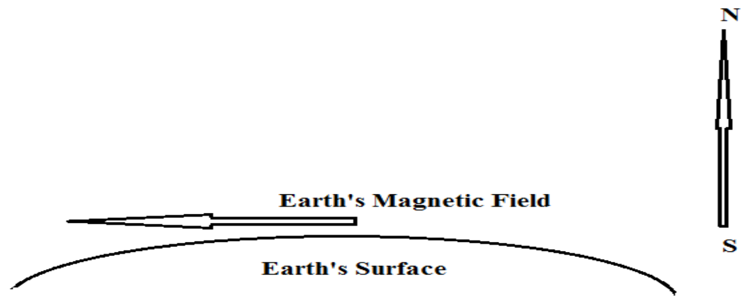

Fig 2: Vector Diagram of Earth's Magnetic Field

Earth's Electric Field

From Earth's surface to the bottom layer of the Ionosphere the nature of the electric field is normal. In earth's atmosphere here and there electric field is acting. In the earth's atmosphere electric field is creating due to some charged particles and aerosols. Aerosols are most responsible for the earth's electric field. Earth's Electric Field is acting at the right angle of the Earth's Magnetic Field. It is observed.

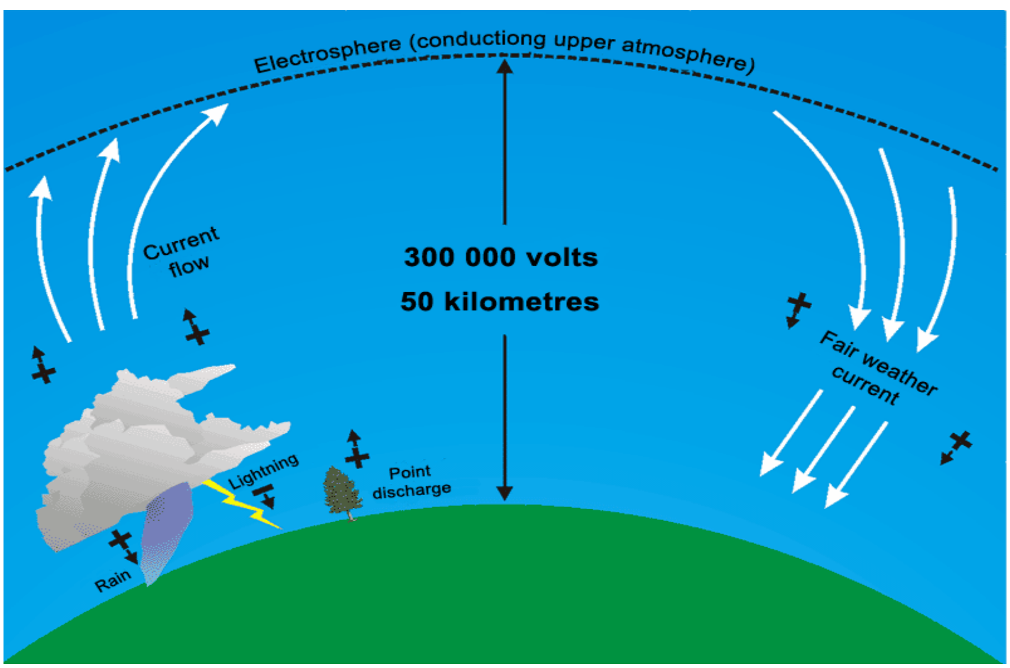

Fig 3: Earth's Electric Field Characteristics of Electric Field, Magnetic Field and Electromagnetic Waves in F region

Magnetic Field in F region

Earth's Magnetic Field in F region is lying at an angle with the Earth's Magnetic Field which is from earth's surface to bottom layer of the Ionosphere.

In ionosphere various types of ions are ionizing with each other. Solar wind, Cosmic Rays and others solar system's activities are affecting on the F region. Due to these causes the magnetic field direction is changing in F region.

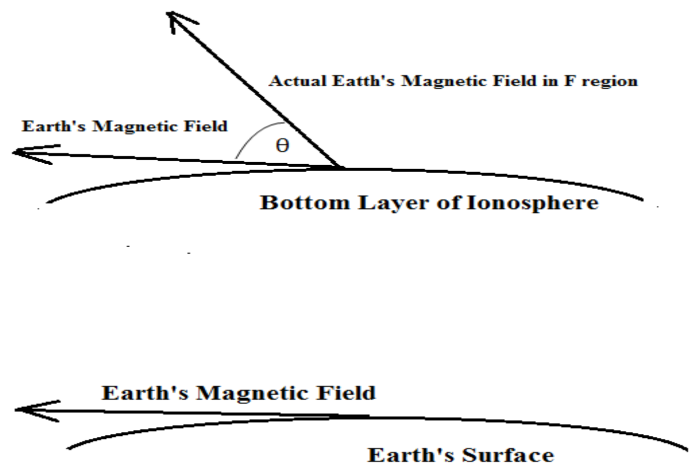

Fig 4: Magnetic Field in F region

Electric Field in F Region

In F region there is an external DC electric field is present. And it is having Vertical and Horizontal component. This external DC electric field has a net electric field due to its' two component. The vertical electric field is acting to the earth's surface and the horizontal component is acting to the ionosphere.

In F region the net magnetic field is acting at the right angle of the net electric field due to the electro-magnetic induction as electro-magnetic waves.

Electromagnetic Waves in F Region

Due to the ionization of the ions we can detect easily the electromagnetic waves in F region. Here the electro-magnetic induction is going every time and it is going very rapidly.

Due to earthquake there will be a change in electromagnetic waves in F region. Intensity of the electromagnetic waves is depending on the density of the electron and other charged particles. Changing in the intensity of the electromagnetic waves is the main responsible reason for changing the electric and magnetic field in F region.

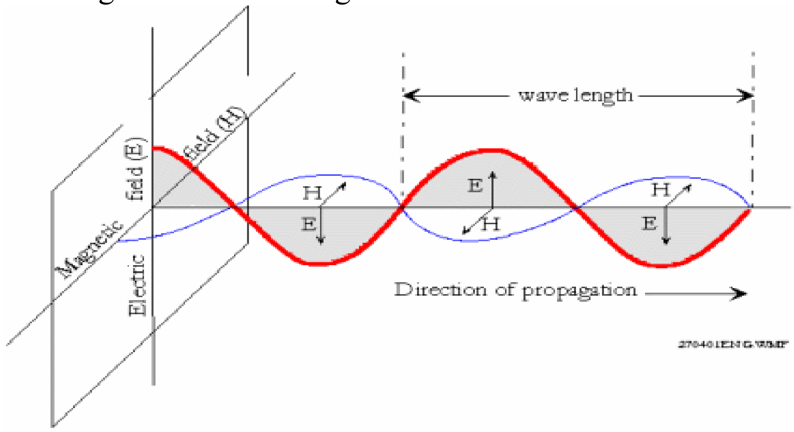

Fig 5: Electromagnetic Waves in F region

2. Variation of Electromagnetic Waves in F region due to Earthquake

The first report on an ionospheric anomaly occurring before an earthquake was made by Nestorov (1979) and, as a sounder was functioning in the Kerguelen Islands, the ionospheric data were checked. It was shown (Parrotet al., 1985) that the critical frequency of the $\boldsymbol{E_s}$ layer increases at the time of the shocks, indicating that the ionosphere was disturbed at this time.The same quantitative measurement was made at the station of Djibouti when earthquakes occurred close by (Parrot &Mogilevsky, 1989), where the results also indicated a disturbed ionosphere just prior to the earthquakes. But, there are many other reasons to increase the electron density, and very commonly the curves show other peaks, in particular during the daytime. Thus, the results are more convincing when the earthquake occurs during the night.

Concerning the upper ionosphere, examples of ELF emissions observed with a low-orbiting satellite above the epicentre of an earthquake about tohappen, are given by Larkina, Nalivayko, Gershenzon, Gokhberg, Liperovskiy,and Shalimov (1983) and by Parrot and Mogilevsky (1989). But, the search for correlations between seismic activity and electromagnetic emissions is also restricted by the natural noise. The maximum intensity of the low-altitude ELF hiss occurs when the invariant latitude is larger than 50°, and then only in the region between 40" N and S of the equator is used, where on average no natural emission occurs.

Another example of such observations made by the low-orbiting satellite AUREOL-3 (apogee 2012 km, perigee 408 km, inclination 82"5', period

Electromagnetic disturbances associated with earthquakes 205109.5 minutes) is given. It concerns an earthquake of magnitude5.5 that occurred on March 19, 1982 at 00.17.52 UT, whose epicentre was in West Irian at latitude 02.80°S, longitude 138.8 1 "E. The focal depth was 48km. A signal increase is seen around 20.50 UT when the satellite passed over the same latitude as the epicentre. The increase is also observed on another component in the 140 Hz filter and on the same component E_H in the 150 and 325 Hz filters, but the amplitude of the peak decreases as the frequency increases. No signal is seenat frequencies > 800 Hz in this case.

As was explained before, the level increase observed after 21.00 UT is not related to the seismic activity, as it can be observed each time the satellite enters in the mid latitude zone. The case studies have shown increases of the signal at the time of earthquakes, but ELF emissions are very common and can result from many other phenomena. Thus, the only way to know if those increases are coincidental or not, are by using statistics. A statistical study was carried out with the data recorded by the geo stationary satellite GEOS-2 (Parrot &Lefeuvre, 1985). Using a geostationary satellite made it possible to prevent the effects due to the time-space doubt. Earthquakes with magnitudes greater than 4.7 (the magnitude of the earthquake sin the Kerguelen Islands) and with epicentres located near the magnetic field line of the satellite were selected. With a rough signature of an earthquake based on an ELF increase a quarter of an hour before or after the earthquake, a positive correlation of 44% was obtained. The same analysis performed on a random data set taken during the life of GEOS-2 gave a percentage of 41%, which is very similar. However, the important point is that, when we decrease the distance between the longitudes of the epicentre and the longitude of the satellite to less than 20°, the percentage goes up to 51%. When only low-magnetic-activity periods are considered, the percentage of positive correlation is 46% against 3 1% for the random data set.

Another interesting point is the relation with the frequencies. Parrot and Lefeuvre(1985) showed that for the random data set, the maximum of positive correlations occurred around 1 kHz, which is the frequency where most of the natural noise was usually observed on GEOS-2, whereas, for the earthquake data set, this maximum moved to lower frequencies. The first report on an ionospheric anomaly occurring before an earthquake was made by Nestorov (1979) and, as a sounder was functioning in the Kerguelen Islands, the ionospheric data were checked. It was shown (Parrot et al., 1985) that the critical frequency of the E_s layer increases at the time of the shocks, indicating that the ionosphere was disturbed at this time The same quantitative measurement was made at the station of Djibouti when

earthquakes occurred close by (Parrot &Mogilevsky, 1989), where the results also indicated a disturbed ionosphere just prior to the earthquakes.
But, there are many other reasons to increase the electron density, and very commonly the curves show other peaks, in particular during the daytime. Thus, the results are more convincing when the earthquake occurs during the night. Concerning the upper ionosphere, examples of ELF emissions observed with a low-orbiting satellite above the epicentre of an earthquake about to happen, are given by Larkina, Nalivayko, Gershenzon, Gokhberg, Liperovskiy, and Shalimov (1983) and by Parrot and Mogilevsky (1989). But, the search for correlations between seismic activity and electromagnetic emissions is also restricted by the natural noise. The maximum intensity of the low-altitude ELF hiss occurs when the invariant latitude is larger than 50°, and then only in the region between 40" N and S of the equator is used, where on average no natural emission occurs.

Another example of such observations made by the low-orbiting satellite AUREOL-3 (apogee 2012 km, perigee 408 km, inclination 82"5', period Electromagnetic disturbances associated with earthquakes 205 109.5 minutes) is given in Figure 1. It concerns an earthquake of magnitude5.5 that occurred on March 19, 1982 at 00.17.52 UT, whose epicentre was in West Irian at latitude 02.80°S, longitude 138.8 1 "E. The focal depth was 48km. The signals of the electric component $\boldsymbol{E_H}$ in the 72 Hz filter are plotted in Figure1B as a function of the time. Regular blanks are a result of the on-board calibrations, which were removed from the data. A signal increase is seen around 20.50 UT when the satellite passed over the same latitude as the epicentre. The increase is also observed on the another component in the 140 Hz filter, and on the same component $\boldsymbol{E_H}$ in the 150 and 325 Hz filters, but the amplitude of the peak decreases as the frequency increases. No signal is seen at frequencies > 800 Hz in this case. As was explained before, the level increase observed after 21.OO UT is not related to the seismic activity, as it can be observed each time the satellite enters in the mid latitude zone.
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3. Variation of Electric Field in F region due to Earthquake

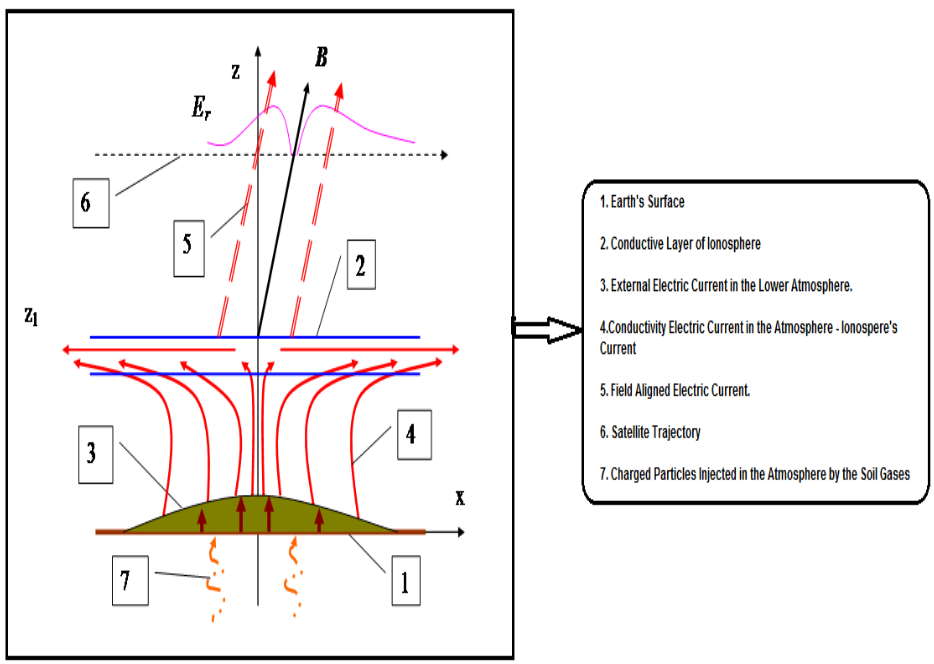


Fig 6: The Model Used for Calculations of Current and Field in the Atmosphere – Ionosphere (F Region) Electric Circuit above Seismic Zone

Equation for spatial distribution of DC electric field potential over seismic region

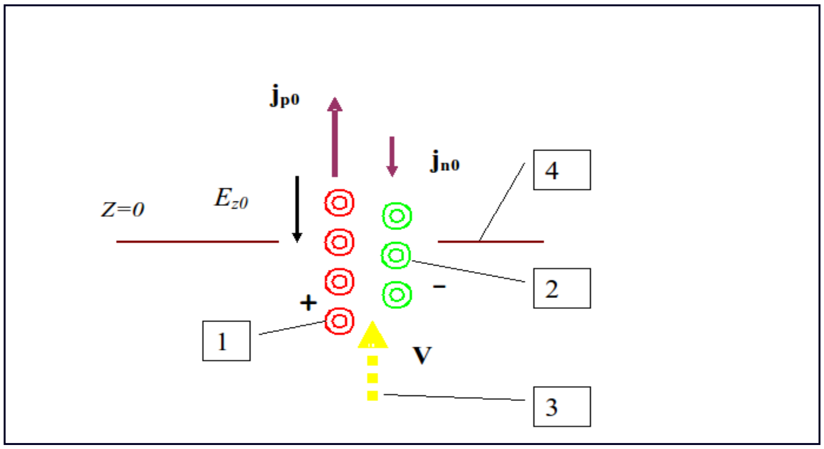


Fig 7: Scheme of the Feedback Formation between External Current and Vertical Electric Field on the Earth Surface

The external current is excited in a process of vertical atmospheric convection of charged aerosols. Aerosols are injected into the atmosphere due to intensifying soil gas elevation during the enhancement of seismic activity. Its inclusion into the atmosphere – ionosphere electric circuit leads to such redistribution of the conductivity current that DC electric field increases up to 10 mV/m in the ionosphere.
The equation for DC electric field potential has a form:

(4.1) $$\frac{d}{dz}\left[\sigma(z)\frac{d\varphi}{dz} - j_e(x,y,z)\right] = 0 \qquad \varphi_1 = \varphi(x,y,z=z_1)$$

The boundary conditions are as follows:

Atmospheric electric field variations with time scale exceeding 1 day at the distances within tens to hundreds kilometers from earthquake center during seismically active period never exceed the background magnitudes ~ 10 - 100 V/m. The mechanism of feedback between disturbances of vertical electric field and the causal external currents near the Earth surface can explain such limitation.

$$\varphi\Big|_{z=0} = 0; \quad \sigma_1 \frac{d\varphi}{dz}\bigg|_{z=z_1-0} = 2\Sigma_P\left(\frac{1}{\sin^2\alpha}\frac{\partial^2\varphi_1}{\partial x^2} + \frac{\partial^2\varphi_1}{\partial y^2}\right) - \frac{\varphi_1}{\rho}; \quad \rho = \int_0^{z_1}\frac{dz}{\sigma(z)}$$

Scheme of the Feedback Formation between External Current and Vertical Electric Field on the Earth Surface

1 - Positive charged aerosols.
2 - Negative charged aerosols.
3 - Elevated soil gases.
4 - The Earth surface.

Intensified soil gas elevation during the enhancement of seismic activity increases aerosols injection into the atmosphere. The field limitation on the Earth surface is caused by feedback mechanism between excited electric field and the causal external current. This feedback is produced by the potential barrier for charged particle at its transfer from ground to the atmosphere.

Dependence of External Currents on the Vertical Electric Field on the Earth's Surface

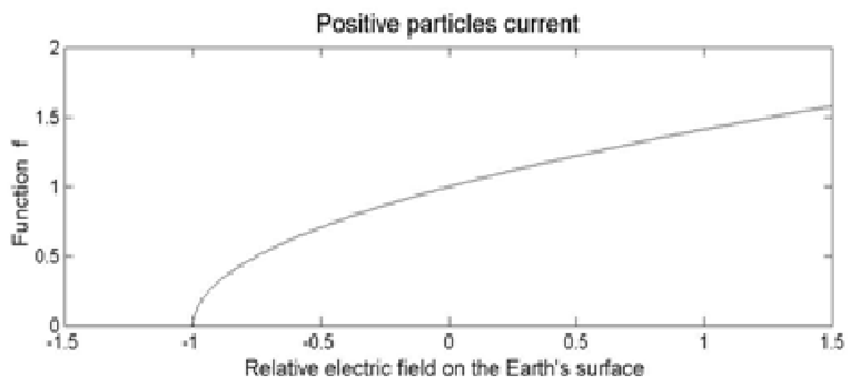


Fig 8: Upper Panel: The Positive Particles Current

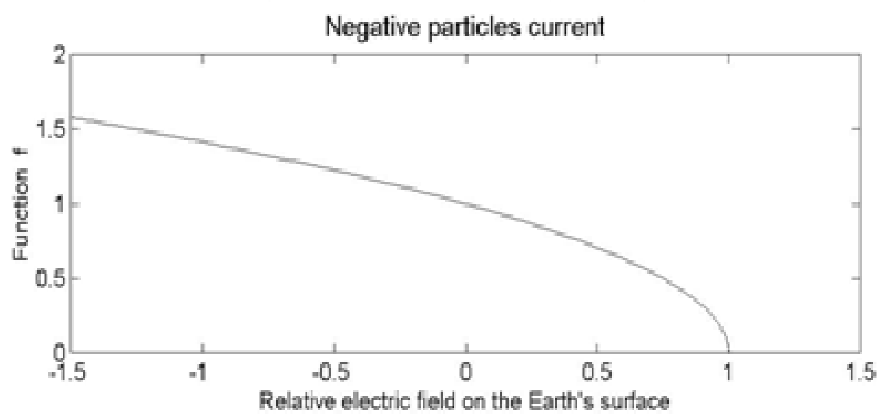


Fig 9: Lower Panel: The Negative Particles Current

Dependence of Vertical Electric Field on the Earth Surface on the Magnitude of External Current

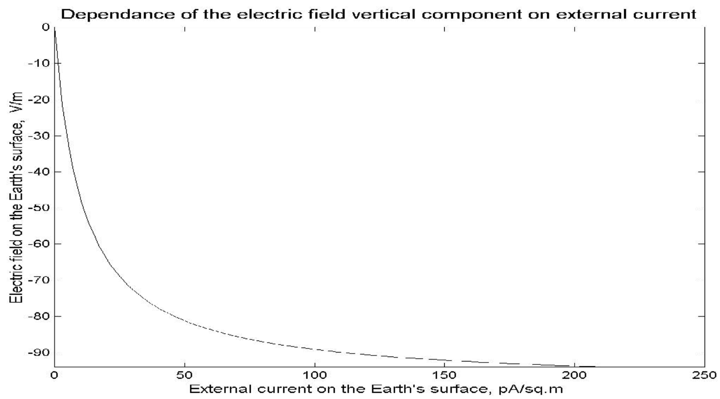
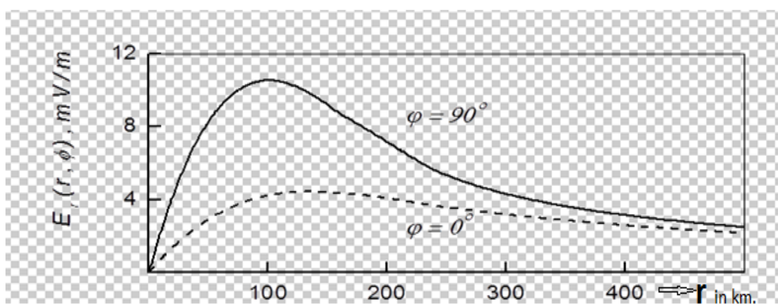


Fig 10: Dependence of Vertical Electric Field on the Earth Surface on the Magnitude of External Current

DC Electric Field Calculated for Axially Symmetric Distribution of the External Electric Current:

$\boxed{\alpha = 20^{\circ}}$

Angel of Field Inclination is



$\boxed{\alpha = 20^{\circ}}$

Fig 11: Upper Panel: Horizontal DC Electric Field in the Ionosphere along and Across the Plane of Magnetic Meridian. Angle of Magnetic Field Inclination is

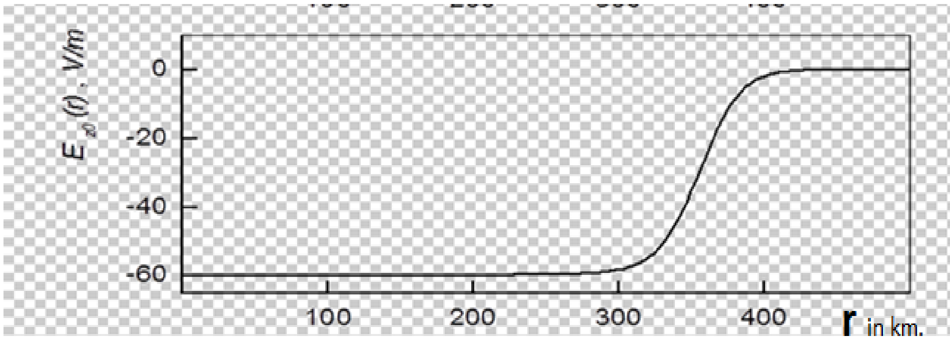


Fig 12: Middle Panel: Vertical Component of DC Electric Field on Earth's Surface

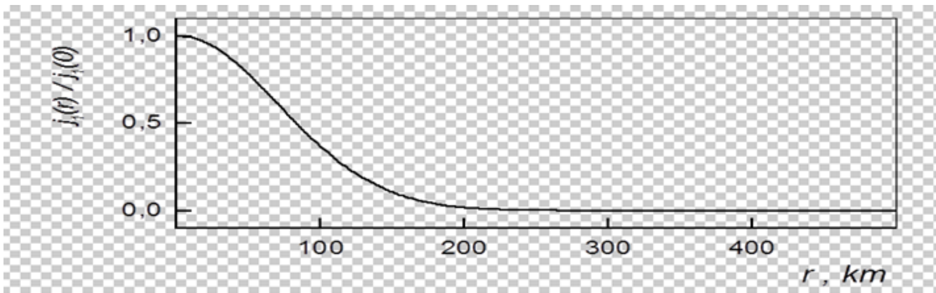


Fig 13: Lower Panel: Normalized Vertical Component of External Current on the Earth Surface

Spatial Distributions of DC Electric Field Calculated for Axially Symmetric Distribution of the External Electric Current

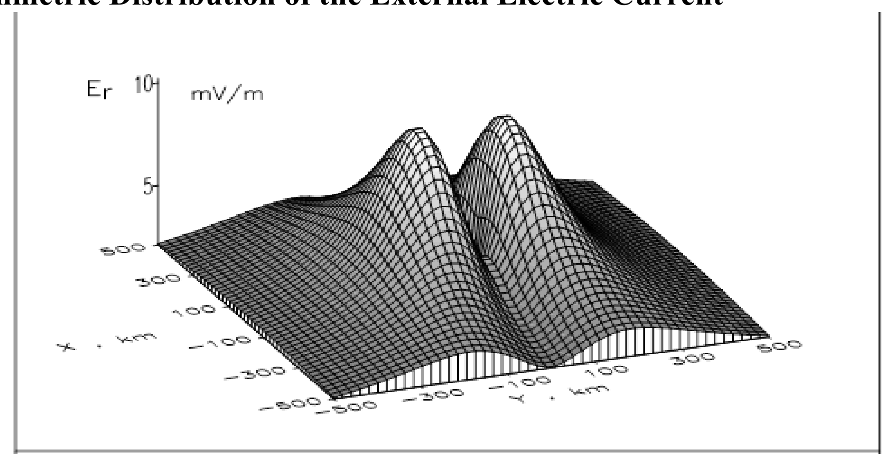


Fig 14: Upper Panel: Horizontal Component of DC Electric Field in the Ionosphere. Angle of Magnetic Field Inclination is $A=20^0$

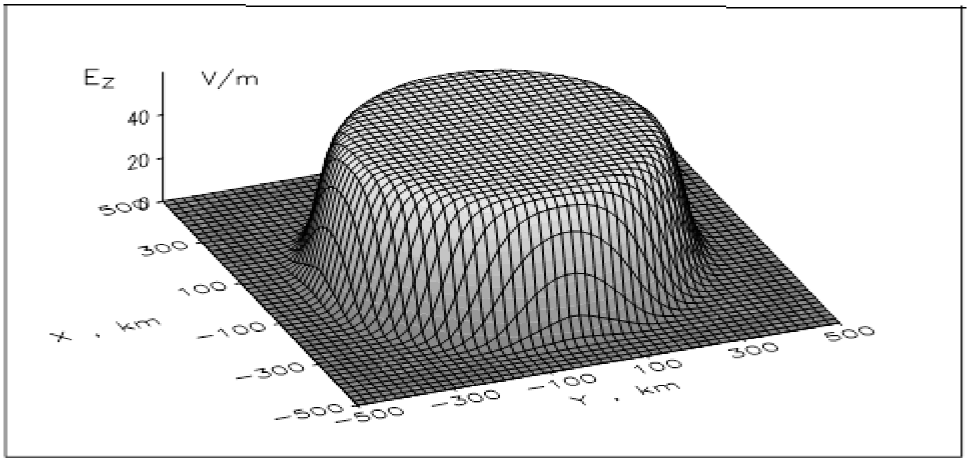


Fig 15: Lower Panel: Vertical Component of DC Electric Field on the Ground Surface

Spatial Distribution of DC Electric Field in the Ionosphere Calculated for the Different Angles of Magnetic Field Inclination:

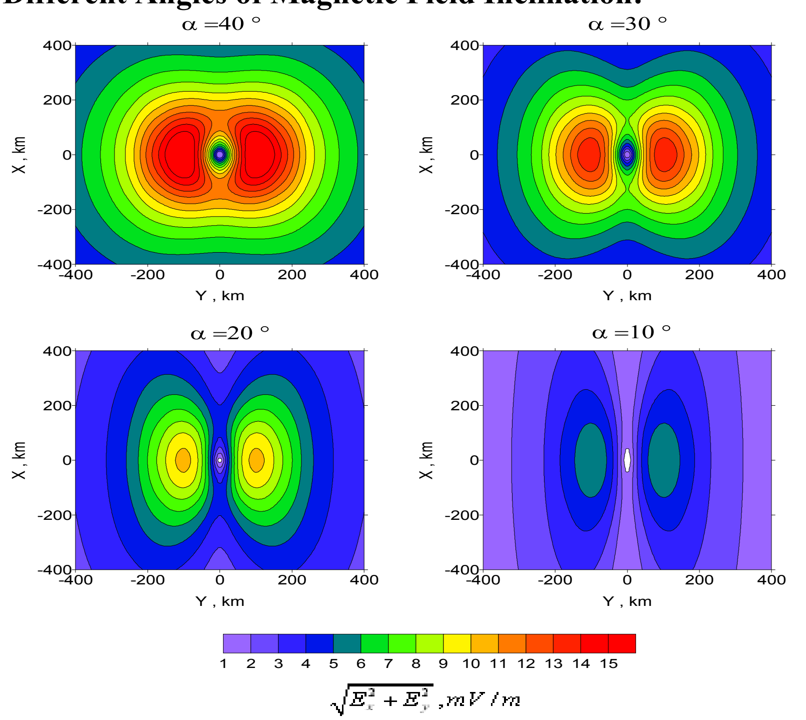


Fig 16: Spatial Distribution of DC Electric Field in the Ionosphere Calculated for the Different Angles of Magnetic Field Inclination

Spatial Distribution of Horizontal DC Electric Field in the Ionosphere at the Different Altitudes of Aerosols Elevation

1. $h_p = 20km,$	$h_n = 15km$
2. $h_p = 10km,$	$h_n = 5km$

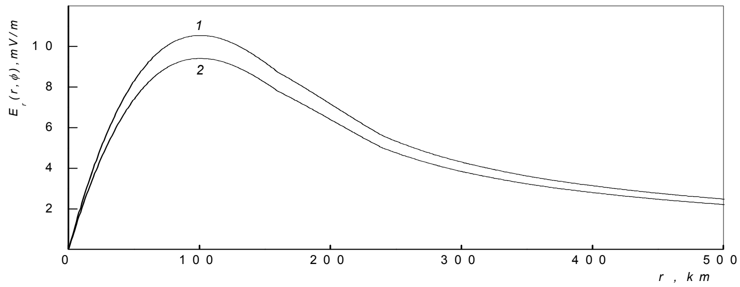


Fig 17: Spatial Distribution of Horizontal DC Electric Field in the Ionosphere at the Different Altitudes of Aerosols Elevation

Examples of Satellite Observations of DC Electric Field

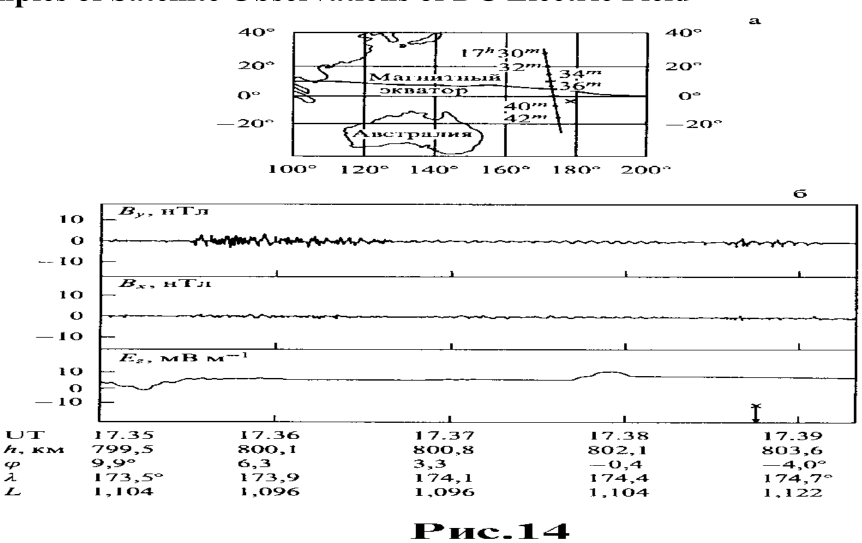


Fig 18: DC Electric Field Observed by the *"ICB -1300"* Satellite within 15-Min Interval before the Earthquake Occurred on January 12, 1982 At 17.50.26 UT

4. Variation of Magnetic Field in F Region Due to Earthquake

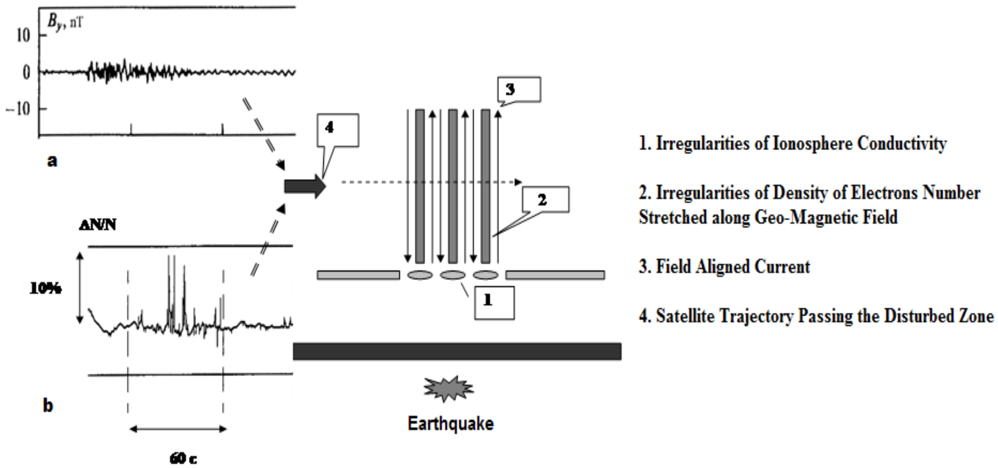


Fig 18: Examples of Satellite Observations of ULF Magnetic Field Oscillations and Electron Number Density Fluctuations

a) ULF magnetic field oscillations observed onboard the *"ICB -1300"* satellite within the 15-min interval before the Earthquake occurred on January 12, 1982 at 17.50.26 UT.

b) Electron number density fluctuations observed onboard the "COSMOS-1809" satellite within the 3.4 hour interval before aftershock of the Spitak Earthquake on January 20, 1989 at 00.04.06 UT.

Prediction of direction of the magnetic field in F region due to earthquake from the above observations would be like the figure no. 19.

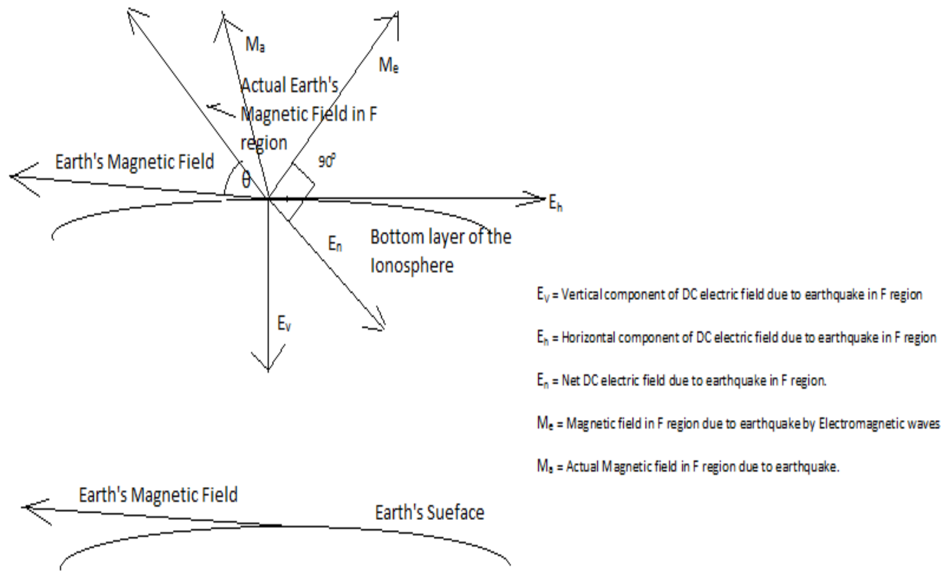


Fig 19: Direction of Magnetic Field in F region due to Earthquake

Description of the Above Diagram

The actual earth's magnetic field acts at an angle of θ with the earth's magnetic field in F region. We know that there are two component of DC electric field in F region due to earthquake which are given in diagram marked as E_h and E_v. Due to these two components of DC electric field one net electric field due to earthquake would be like E_n. As, in F region electromagnetic waves are present then, we can predict a direction of magnetic field due to earthquake by electromagnetic waves in F region (in diagram M_e).Due to M_e and the actual magnetic earth's magnetic field in F region one net magnetic field can be act like as M_a..

5. Conclusion

1. Convective transport of charged aerosols in the lower atmosphere at different stages of typhoon and earthquake development leads to formation of external electric current. Its inclusion in the atmosphere – ionosphere electric circuit is accompanied by amplification of conductivity current that flows into the ionosphere. The current flowing within the conducted layer of the ionosphere is closed in the conjugate ionosphere through the magnetic field-aligned current.

2. The computation method presented in this report allows calculating spatial distribution of the conductivity current and related electric field for arbitrary altitude dependence of atmospheric conductivity and horizontal distribution of external electric current at oblique geomagnetic field. The calculations show that DC electric field in the ionosphere can reach the magnitudes 10 to 20 mV/m.
3. An analysis of satellite data has revealed the electric field disturbances up to 20 mV/m in the ionosphere over typhoon and earthquake preparation zones. The ground-based observations did not reveal any significant long-term (1 to 10 days) electric field disturbances within earthquake area at the distances of tens to hundreds km from epicenter.
4. The field limitation on the Earth surface is caused by feedback mechanism between excited electric field and the causal external current. This feedback is produced by the potential barrier for charged particle at its transfer from ground to the atmosphere.
5. The effect of limitation of the vertical electric field magnitude on the ground creates significant advantage for satellite monitoring of seismic related electric field disturbances as compared to ground-based observations. Thus the ionosphere can be more efficient indicator of definite class of earthquake precursors than the ground-based observations.

Acknowledgement

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