Atmospheric Electric and Electromagnetic Field Rapid Changes as Possible Precursors of Earthquakes and Volcano Eruption: a Brief Review

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The paper is focused on a brief review of reports about anomalous perturbations in the atmospheric electric and electromagnetic fields registered before earthquakes. The possible response of these parameters to corresponding lithosphere earthquake and volcano events involves complicated relations between various phenomena which comprise the regions from the upper layer of the solid earth to ionosphere and top of the atmosphere. Recently the observations in the ionosphere bring important information in this respect. However, they can not replace ground-based measurements which have still the basic value. Atmospheric electricity stations in seismic areas might bring important contribution in this respect. Broader international co-operation is needed. Taking into account great importance of such studies, any input in this respect is very advisable. There is still a lack of continuously working atmospheric electricity stations in seismic regions, especially in the regions where the good or fair weather conditions would dominate during a year. Seismic regions of Turkey are adequate for such observations.

Introduction

The Global Seismic Hazard Assessment Program (GSHAP) was launched in 1992 by the International Lithosphere Program with the support of the International Council of Scientific Unions and terminated in 1999. The hazard, expressing Peak Ground Acceleration expected at 10% probability of occurrence in 50 years, is obtained by combining the results of 16 independent regional and national projects which covered among others whole Mediterranean region with Turkey, Iran and Carpathian area included. The results have been collected in [1] and presented on GSHAP Web site [2]. The risky area in Turkey consists of two belts dispersed from eastern boundary of the country to the west and south. On the western part of Turkey dangerous area surrounds practically whole coast of the Mediterranean Sea (Fig. 1).

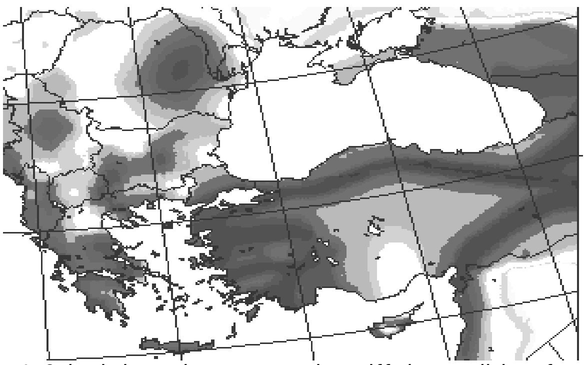

Fig.1. Seismic hazard map presenting stiff site conditions for occurrence rate of 10% within 50 years for the Mediterranean region. Dark colors: the most dangerous areas (www.seismo.ethz.ch/GSHP).

This estimation has been confirmed by hitherto observed strong earthquakes (Fig 2).

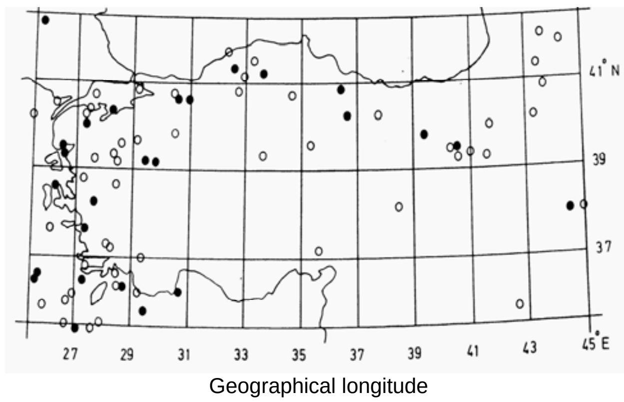

Fig.2. Map of Turkey with epicenters of the largest earthquakes with the magnitudes M $\geq$ 7.0 (black filled circles) and M =6.0 $\div$ 6.9 (empty circles), which occurred in the time interval 1913-1970 [3].

As such natural disasters cause tremendous fatalities in human life and heavily economic losses a prediction of them would be very desirable especially in countries localized at regions of the high seismic hazard level as Turkey. No proven method is currently available for short-term (hours to weeks) and intermediate-term (1 month to 10 years) prediction of earthquakes as defined time scale of events by Sykes et al [4]. The possibility of earthquake prediction is still very difficult to be achieved due to a great complexity of the problems involved in this task. Till nowadays the knowledge of the physical processes before and during earthquakes is incomplete which is in conjunction with difficulties in making detailed measurements of various parameters of the crustal mantle medium, their deformation, stress accumulation and release phenomena. Some characteristic features of earthquakes point to deterministic behavior of the processes, some others are taken to be evident for the classical chaotic behavior of seismicity [5]. However, there are authors who argued that chaotic behavior does not preclude the probabilistic forecasting of these events [4].

Numerous attempts have been undertaken to identify and study possible precursors of earthquakes and as well as volcano eruptions which occur in much smaller length scale. As “precursors” one can mean some anomalous phenomena which occur before earthquakes. The main problem with using them as the source of successful predictors is that they are detected sporadically. Other important difficulty in collecting data is usually the lack of instruments, observatories and qualified observers very close to the epicenters of large earthquakes. However, up to now collected data, programs of complex geophysical registrations carried out and prepared in different countries, efforts of many groups of investigators which develop multi-disciplinary interactions within various sub-disciplines of geophysics allow us to expect the progress in understanding of the phenomena associated with earthquakes. We hope they will give a possibility of the short-term prediction such danger events.

To the local precursory phenomena one can include followings: increase or decrease in seismic activity in the area of strong future earthquake [5-6]; precursory tilt or displacements of the ground surface; electric or electromagnetic signals from the Earth’s crust; changes in characteristic features of the soil as e.g. soil humidity [7] and temperature of the ground surface [8-10]; chemical emissions from the underground [11-14]; atmospheric electric and electromagnetic field changes; optical [15-17] and acoustic [18] emissions near the ground; changes in animal behavior. The paper is focused mainly in a brief review of reports about perturbations in the atmospheric electric and electromagnetic fields registered before and during earthquakes.

Atmospheric electric field coupling to the ionosphere

The lower level atmospheric electric field (AEF) is coupled with the ionosphere by the global electric current circuit (GECC), the idea based on the classic paradigm of Wilson [19]. General properties of this circuit were discussed in [20-25]. A simplified outline of meridional section of the GECC is presented in Fig. 3. According to the Ohm’s law the vertical electric current density is $j_z = \sigma E_z$, where σ is the air conductivity determined by ionizing radiation factors. The ionosphere-Earth vertical current density j_z of 1 ÷ 4 $pA\ m^{-2}$ is driven by the ionosphere-Earth potential difference φ_i of about 250 kV acting across the vertical column resistance $R_T + R_S$ at each location, where

$$R_{T,S} = \int_L^H \sigma(z)^{-1} dz$$

is integrated from the altitude of lower boundary L to upper boundary H of the troposphere (T) or stratosphere (S), z is altitude. Usually R_S is small compared to R_T, but sometimes, after volcanic eruption they could become comparable. At any altitude $j_z = \varphi_i/(R_T+R_S)$. Measurements support the theoretical expectation that the total upward source current I_1 is equal to the integral of j_z over the globe.

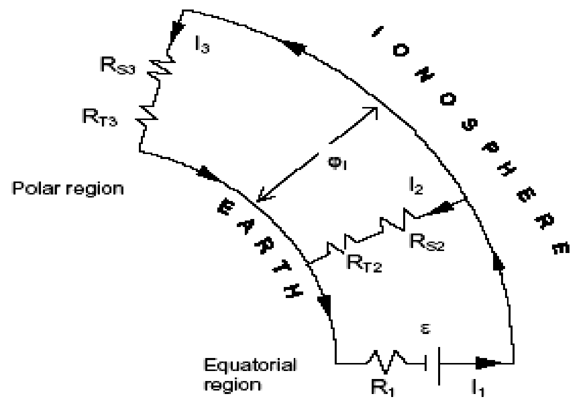

Fig.3. Meridional section of the global electric circuit accordingly to [25]; φ_i – potential difference between ionosphere and Earth, ε - the source of I_1 - current produced by low-latitude thunderstorms, I_2, I_3 – vertical currents from highly conducting ionosphere to highly conducting earth, R_S, R_T – vertical column resistances in stratosphere and troposphere.

The tropical thunderstorms are thought to generate on average an upward charging current I_1 averaging about 1000-1500 A. It is estimated that about 1500-2000 thunderstorms occur around the globe at any time. This current is responsible for maintaining the ionosphere - Earth potential difference. The ionosphere-Earth return current can be divided in the low-latitude branch I_2 and the high-latitude branch I_3 [25]. Both, the ionosphere and Earth surfaces are highly conducting with respect to the lower atmosphere and can be considered as almost equipotential except the polar cap regions where ionosphere potential is strongly affected by intensive magnetosphere plasma convection produced by solar wind and geomagnetic field interaction. Two most important parameters of the GECC are enumerated in Table 1. On the higher altitudes σ much grows due to the ionization of the air provoked by facilitated penetration of cosmic rays and the ultraviolet (UV) radiation of the Sun.

The near-ground atmospheric electric field is extremely sensitive to meteorological parameters. For the studies of the lithospheric effects on variations of E_z the measurements can be taken into account only during so called “fair weather conditions”, i.e. conditions with the lack of rain and wind storms, fog and low level clouds, when the local wind velocity is less than 6 m/sec, the sight distance is bigger than 4 km, upper clouds do not cover more than 0.3 part of the sky. Usually, during the fair weather the mean AEF strength E_z near the ground level is directed down and equals 100-250 V/m, which value depends on the geographic latitude and orography of the observation place.

TABLE 1

The Fair Weather Atmosphere: Electric Parameters at Different Altitudes

Altitude (km)	~ 50-80	~ 18	0.01	Land surface	Refe-rences
electric field E_z (V/m)	~ 10^{-2}	~ 1	~ $(1\div2)\cdot10^{2}$	-	[26]
conductivity σ (Ω^{-1} m^{-1})	~ $10^{-6}\div10^{-7}$	~ 10^{-11}	~$10^{-13}\div10^{-14}$	5×10^{-2}	[26,27]

The atmosphere, ionosphere and magnetosphere coupling generate a complex pattern of electric field which can be modeled mathematically only in cases of very simple assumptions. The quasi-electrostatic approach is based on the assumption that the penetration of AEF $E = -\nabla\varphi$ from the near ground level atmosphere to ionosphere can be described by the second order differential equation obtained from the Maxwell equations ignoring induction effects ($\partial B/\partial t = 0$): $\nabla(\sigma_{lm}\nabla\varphi) = 0$ and Ohm's law $j = \sigma\cdot(E + v\times B)$, where j is the electric current density, v is the velocity of the gas or plasma, B is the magnetic field of the Earth modulated by solar wind, φ is scalar potential, σ_{lm} is the conductivity tensor. These equations ought to be supplemented by the hydrodynamic and thermodynamic equations of the plasma which is coupled with electric forces or by system of equations describing kinetic processes in atmosphere that govern ion densities and the electric field, as diffusion and mobility of all particles, their drift, recombination, interaction between particles, rate of ion production [24, 27-28].

Ground-based electric field precursors

History of the observation of atmospheric electric field associated with earthquakes is long. As may be, the first who published observations of electric and magnetic perturbations before such events made by different observers at Imperial Meteorological Observatory in Tokyo over a year was Milne [29]. He found that in 9 of 10 cases of the strong earthquakes at distances of about 100 *km* from the point of observation, there were anomalous variations of AEF. According to [30] reductions of AEF were observed at the distance not more than 150 *km* from epicentres of earthquakes several hours before the events at Kyrgyzstan in 1924, Chatkal in 1949, Dushanbe and Obi-Garm in 1949. During the events the maximal amplitude of electric field strength, E_z, reached about 1000 *V/m* and the field changed the sign. Bonchkovskiy [31] also noted such range of amplitudes before strong earthquakes. Kondo [32] observed decreases of the E_z before Japan earthquakes. Similar effects in AEF were observed in seismic region in Kamchatka Peninsula [33].

Several earthquakes with magnitudes $M \geq 7$ occurred in the Carpathians in the period from 1960s to 1990s. During only one (August 30, 1986, 21^h28^m UT) at the AEF ground level station at Swider (geographical coordinates 52.1^0 N, 21.25^0 E), Poland, situated at the distance of about 700 *km* from the epicentre, the fair weather and quiet geomagnetic field conditions were observed. As it was reported in [34] before the earthquake, during the time period 2^h - 8^h UT on August 30 the big anomaly in the AEF was observed. The amplitude of changes reached 1000 *V/m* (- 250 *V/m* $\div$ + 750 *V/m*).

Numerous cases of the negative anomalies of the E_z component have been reported during the period 1977-1996 in China [35]. This anomalies were observed usually at night in the fair weather conditions and were appearing even several times during the period 2 $\div$ 30 days before the earthquake if the events had the magnitude of $M \geq 3.5$ and the epicentres were not carried away more than 550 *km*. Their amplitudes were reached even 1000 *V/m* and the time duration from several hours to more than ten hours.

From all observed anomalies in AEF records characterised by occurring of the negative values of E_z on not rainy days at the magnetic station Paratunka in Kamchatka during the period 1997-2002 only the 36% were connected with later following earthquakes [36]. Other cases had no any relation to seismic activity.

There are relations in literature about weak lighting in volcano clouds. It is a convincing proof of changes in electric potential in the atmospheric area above the volcano but the released energy is even three orders less than the estimated energy in lighting discharges in thunderstorms [37]. Clear abnormal variations in vertical AEF was observed about 3 days prior to Mt. Mihara volcanic eruption on October 4, 1990, and these variations dominated about a month following the event [38].

We should emphasize that above mentioned and many others reported experimental cases referred to pre-effects of earthquakes and volcano eruptions measured at different atmospheric electric stations are not uniform. Physical features of definite earthquakes are different; data have been registered in various atmospheric conditions, elaborated with different methods and interpreted by various investigators. The most of the AEF measurements have been episodic and the recordings were often not complemented with meteorological background data. Thus, up to now there are no scientifically described detailed rules which let to determine what kind of the amplitude and phase changes in the AEF strength would be a sure precursor of a strong earthquake or eruption.

Some explanation of the distant reaction of AEF onto changes of conditions in crust before earthquake would be based on conception of "preparation zone" [39] or "precursory activation zone" [40] of the earthquake which size determined by the formula R=100.43 M, where R is radius, M is the earthquake magnitude.

Radon emanations

Direct reason of AEF rapid change could be the radon enhanced emanation from the crust. Radon (^{222}Rn) is well known as one of the main ionisation sources of the near-ground atmosphere. As the resistivity of the air is controlled by the background level of radiation, a higher concentration of radon leads to an increase of the lower atmosphere conductivity [41], and formation of the negative space charge, which affects on AEF. Exhalation of radon increases the current between the Earth and ionosphere which effect could be observed as at ground level as in ionosphere [13, 42]. Nine days before the Kobe tragic earthquake on January 17, 1995, radon concentration reached the peak of more than 10 times that it was observed in stable conditions characterised by the radon radiation level of 20 *Bq* per litre at those area [14].

Electromagnetic emissions related to earthquakes

Electromagnetic emissions (EM) contain the waves from a wide range frequencies beginning at a few hundreds of *Hertz* (ULF) through VLF up to HF range (several *mega-Hertz*). Many papers in literature are dedicated to this topic, we shall only relate about several results associated with earthquakes. EM can be emitted either on the ground level or generated in the ionosphere. Many observations of EM in the ionosphere were made from satellites. The extensive reviews of both can be found in [43, 44] together with the reviews of theories which try to explain these phenomena.

We should cite here only several experimental examples of Gokhberg et al [45] related the growing of the intensity of EM at frequencies of 27 *kHz* and 1.63 *MHz* received half an hour before the Iranian earthquake with M=7.4 on September 16, 1978, at the station located in Caucasus, 1200 *km* from the epicenter. The epicenter was located in central Iran at the distance of 1200 *km* from ionospheric observatory. They reported also about another event when approximately one-half hour before the main shock of the earthquake with $M = 7$ occurred in Kyoto prefecture on March 31, 1980, at the Sugadaira Space Radiowave Observatory, Japan, the anomalous amplitude of signal was registered at frequency 81 *kHz*. The distance between the observatory and epicenter was about 250 *km*.

There is some analogy between EM observations before volcano eruptions and before earthquakes, e.g. before eruption of Mt. Mihara in November 1986 the impulsive EM noise was observed [46] as well as several days ahead of another eruption on October 4, 1990, enhanced variations in the ULF and VLF bands were registered [47].

Generally the mechanisms proposed by different authors to explain causes of precursory effects, reflect complicated relationships between different geophysical parameters that comprises regions from the lithosphere to the top of the atmosphere. These relationships would be considered as seismo-ionospheric coupling [44, 48, 49].

Recently, GPS permanent network have provided a very good chance to study these seismo-ionospheric effects. GPS executes regular monitoring of the ionosphere in global scale measuring the total electron content (TEC) which is sensitive to changes in critical frequency foF2 and could be useful for identifying ionospheric precursors of earthquakes [44]. Analysis of GPS data have shown anomaly with positive sign in TEC, i.e. enhancement of about 20-25% relative to normal state, before Baltic Sea earthquake on 21 September 2004 [50].

Attempts of elucidation of seismo-ionosphere effects

In theoretical modelling there are two principal approaches: one uses atmospheric gravity waves and the second one considers the AEF changes. In this paper we have only noticed a possible role of AEF. It is based on the assumptions that the variable physicochemical conditions in the earth's crust before earthquakes due to rapid strain, rock dilatation or compression, rock dislocation and ground displacement, changeable water permeability through ground layers, water flows and disturbed thermal equilibrium could cause changes in the electric resistivity of the ground and could generate electric fields and electric potential anomalies in near earth's surface ground layer which would influence onto global AEF.

Conclusions

The problem of the forecast of earthquakes on time-scale of few hours or few days demands subsequent studies and establishment of network of complex geophysical observatories equipped with AEF apparatuses in seismic active regions, as e.g. organised at Mexico complex observatories [51], using GPS data, ionospheric stations data and co-operating apparatuses on micro-satellites. Broader international co-operation is needed.

Acknowledgments

One of the authors (Z.K.) acknowledges the Bogazici University, Kandilli Observatory and Earthquake Research Institute, Istanbul, Turkey, for the financial support which has enabled to participate at the Annual Meeting of the Balkan, Black Sea and Caspian Sea Regional Network on Space Weather Studies in Manavgat, Antalya, where the paper was presented.

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