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Review Article

Advanced Techniques for Pre-Earthquake Prediction

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Abstract

Earthquakes are among the hidden forces that threaten human life and the future of civilization. Earthquakes can result in landslides, ground shaking, fires, fissures, structural damage to buildings, tsunamis and damage to highways and bridges. The extent of destruction and suffering caused by an earthquake depends on: duration, magnitude, and intensity. And with the technological progress and studies in space sciences, the Earth did not receive the attention of studies and researches, especially that related to pre-earthquakes prediction. This paper presents a brief study of some modern methods for pre-earthquakes prediction through study of physical changes in the Earth's atmosphere, especially in the ionosphere.
Keywords: Lithosphere- Ionosphere Coupling, Seismic- Ionospheric Perturbation, Air Ionization, Radon Anomalies**,** Earthquakes Negative Impacts on Economic Grounds, Pre-Earthquake Signals.

1. INTRODUCTION

The lithosphere-atmosphere-ionosphere coupling phenomenon consists of the coupling of three geo-levels of the Earth, the lithosphere, the atmosphere and the ionosphere, so that phenomena occurring in the lithosphere can propagate into the atmosphere and affect higher layers reaching the ionosphere [1]. From physics point of view, understanding the underlying physical interactions between these three geo-levels, which take place during the seismic preparation phase of high-energy release events, such as, earthquakes, volcanic activity, hurricanes, and tsunami can develop ways and techniques for providing predictions (information), before such events occurrence [1].

Three main coupling mechanisms have been proposed by [1]. The first is related to the presence of p-holes (positive vacancies) that are generated during the preparation phase of an earthquake by stresses along the fault. These charged particles could alter the electrical circuit in the atmosphere, ionizing it and creating instabilities in the mesosphere, eventually reaching the ionosphere [1]. Another hypothesis is related to the migration of fluids along the fault and the release of radon gas that seems to be detected during the preparation phase of the most energetic seismic events. This release would affect the atmosphere, which would eventually propagate and generate disturbances in the ionosphere [1]. The third mechanism is based on electromagnetic effects, the seismo-electromagnetic phenomena which are based on monitoring the ionosphere electron density with the application of electromagnetic waves. However, in recent years, with the launch of satellite missions, electromagnetic anomalies associated with seismic activity have been detected from space. This is a major step forward in the understanding of the preparation phase of the most energetic seismic events by combining not only seismological but also atmospheric and ionospheric information [1].

Unlike the previous conventional measurements of crustal movements (i.e., mechanical measurement), a new wave of electromagnetic measurements has appeared as a new science field and there has been achieved an extensive amount of achievements in the study of electromagnetic earthquake precursors during the last two decades [2]. Seismic preparation phase of high-energy release events prediction, such as, earthquake prediction is one of the most urgent subjects for human beings. If short-term earthquake is realized, casualty and economical loses are greatly reduced [2].

The recent sequence of highly destructive earthquakes around the world has heightened awareness of earthquake hazards and the inability of seismology as a discipline to derive information of increasing earthquakes hazards in the weeks and days before major seismic events [2]. Therefore, increasing awareness about the lithosphere-atmosphere-ionosphere coupling phenomenon is the main objective of this study.

Interactions in the lithosphere, atmosphere and ionosphere are important to creatures living on the Earth. Variations in one sphere of lithosphere, atmosphere and ionosphere can dominate changes in the other two spheres. Phenomena of the lithosphere, atmosphere and ionosphere coupling generated by distinct types of events (e.g., pre-earthquake anomalies– co-seismic responses, tsunami, volcano eruptions and so on) near the Earth's surface have been widely studied in recent decades [3].

2. Physics of Air Ionization at the Earth Surface and Pre-Earthquake Signals

Air ionization is one of the main processes in the whole near-Earth environment because, from most distant areas of the magnetosphere up to the lower boundary of the atmosphere, at which ions are detected as a result of the ionization. It can be stated that, the sources of ionization of the atmosphere are divided into three groups: solar electromagnetic radiation and solar wind energetic particle fluxes, galactic cosmic rays, and natural Earth radioactivity. Different altitude levels of the atmosphere are subjected to the action of such different sources [4]. Figure 1, shows the distributions of ionization and their sources.

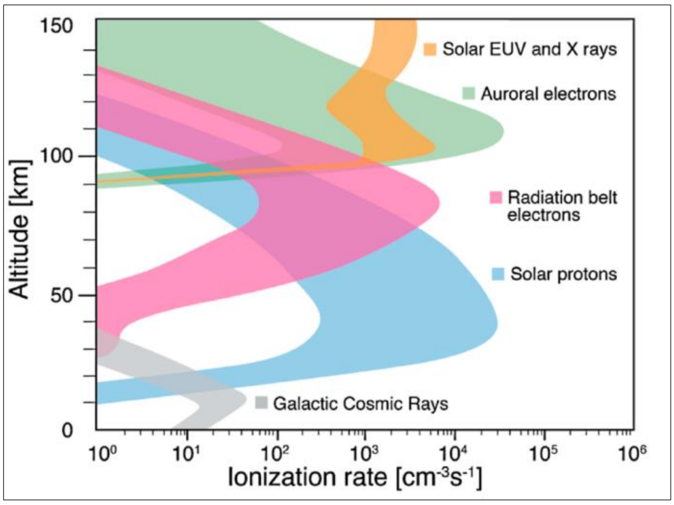

Figure 1: Vertical profiles of ionization of the atmosphere by solar electromagnetic radiation, energetic particle fluxes, and galactic cosmic rays [4]

Recent ionospheric observations indicate that the total electron content (TEC) may anomalously decrease or increase up to 5–20% before the occurrence of big earthquakes [5]. Pre-earthquake signals have been widely reported, including perturbations in the ionosphere. These precursory signals may be caused by one underlying physical process: activation of highly mobile electronic charge carriers (holes) in rocks that are subjected to ever increasing levels of stress [6]. Figure2 shows the electrical property of rocks subjected to stress force.

When rocks are subjected to stress force in the earthquake preparation region, the deformation of lattice structure in rocks can produce electronic charge carriers (positive holes, h*) and electric currents (J_{rock}).

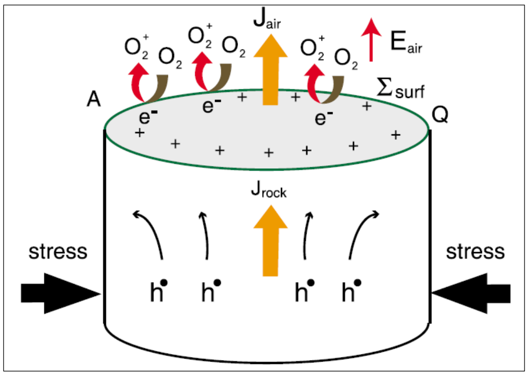

Figure 2: Rocks subjected to stress force in the earthquake preparation region [5]

The positive holes diffuse from the highly stressed region into the unstressed region, repel each other electrostatically, and push toward the rock surface [5]. The field ionization ($O2 \rightarrow O_2^+ + e-$) occurring at the surface, produces the $O2^{+}$ ions. The number density of electrons and holes inside the stressed rock volume increases. The h* charge carriers can flow out of the stressed rock and into an adjacent unstressed rock, while the electrons, e^{-}, stay behind. The reason for the electrons staying behind is that there are no energy levels in the unstressed rock, which they could access [7]. The activated hole (h*) charge carriers generate electric currents along stress gradient, causing the accumulation of positive charges (O_2^{+} and positive holes, h*) at the earth surface [5]. The activated hole (h*) charge carriers generate electric currents along stress gradient, causing the accumulation of positive charges at the earth surface. The upward electric field E_{rock} associated with the positive surface charges will drive the upward current J_{air} [5]. This J_{air} will eventually propagate upward and generate disturbances in the ionosphere, decrease the electron density in the ionosphere.

However, on the basis of the experiments presented by [7] a more likely explanation is that electric discharges at the Earth's surface are caused by h* charge carriers arriving at the ground–air interface, building up sufficiently strong electric fields to cause field-ionization of air molecules and corona discharges (A corona discharge is an electrical discharge caused by the ionization of air surrounding a conductor carrying a high voltage) [7].

Such ionization events are expected to occur over areas as large as h* charge carriers are able to spread after they have been stress-activated at depth. Pervasive corona discharges may cause luminous phenomena and may also be the cause for increased noise in the radiofrequency range [7]. Local outbursts of light from the ground may be due to a condition in the Earth's crust that is theoretically predicted to occur when the number density of h* in the rocks increases to a point where the electronic wave functions of the h* charge carriers begin to overlap, creating a solid state plasma [7]. Such plasmas are expected to be inherently unstable, leading to a cloud of h* charge carriers traveling outward at speeds around $200ms^{-1}$. When the wave front breaks through the Earth's surface, it will ionize the air and produce flashes of light. Depending on conditions yet to be fully understood, such process could also lead to ''flames'' coming out of the ground or to outbursts of light [7].

3. Radon Anomalies and Pre-Earthquake Signals

Radon (222Rn) is an odorless, colorless, inert, and radioactive noble gas (with half-life T1/2 = 3.8 days). Radon gas, is produced in the decay series of U-238. The total uranium content of the earth crust is about 3-4 ppm (parts per million) which is significant in terms of total mass and its radiological contribution to our atmosphere [8]. Radon and its daughters have been found to be mainly responsible for lung cancer not only among the uranium miners but also among the general public [8]. In addition to the serious health hazards related to radon, it can be used to predict the arrival of an earthquake, to locate uranium deposits and oil. This is because radon is a radioactive gas and it can be traced by detecting alpha particles emitted during the decay of radon and its daughters [8].

Japan is the primary source of studies on earthquake forecasting using atmospheric radon. Such studies reported that anomalies in the atmospheric radon concentration were linked to the moment releases of large earthquakes based on ten years of continuous observation of the concentration over north-eastern Japan and Hokkaido [9]. Japanese studies have revealed that the unusually high radon concentration (about 10 Bq m−3) before large earthquake increased air conductivity and was sufficient to produce ionospheric disturbances [9].

In the build-up to a strong earthquake, crushing process in the Earth's crust produce numerous micro cracks at the surface. In this context, Radon diffuses from the Earth's crust to the atmosphere through the micro cracks and then undergoes alpha decay, beta decay, and gamma decay in the air, as shown in figure 3 [4].

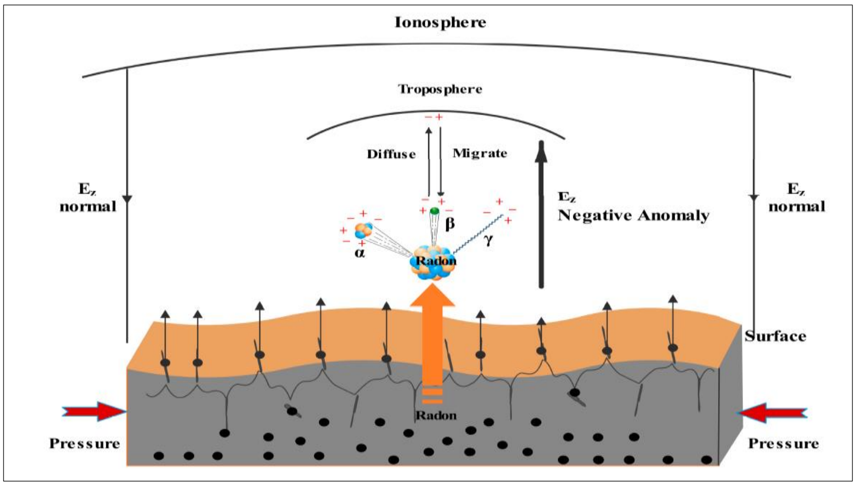

Figure 3: Schematic diagram of atmosphere ionization by radon [4]

A high amount of positive and negative ion pairs are produced by ionizing alpha particles, electrons, and gamma-rays in the air. The positive and negative ion pairs diffuse and migrate in the air. Then eventually, the distribution of positive and negative particles reverses the normal downward positive atmospheric vertical electric field in fair weather.

4. Seismo-Electromagnetic Phenomena and Pre-Earthquake Signals

The central concept of the Seismo-electromagnetic phenomena method is based on monitoring the ionosphere electron density with the application of electromagnetic waves. Earthquake prediction can be classified into the following three types depending on its time scale: Long-term earthquake prediction has the time scale of hundreds or thousands of years based on anecdotal records, and medium-term earthquake prediction, the time scale of a few tens of years based on the past data of seismicity [2]. The medium-term predictions assume that the occurrence probability of sever earthquake during the next 30 years is 70%. These medium-term predictions are almost useless to save human lives [2]. Therefore, It is important, necessary and urgent request to develop an effective short-term prediction method that leads to knowing the time (when) and place (where), and magnitude (how big) with an allowed accuracy before an earthquake occurs [2].

However, this short-term prediction method has been developed by Japanese scholars [2]. This method is non-seismological method but a new direction using electromagnetic effects. The new method or the short-term prediction method was under study for about 30 years and an extensive amount of progress has been achieved in the field of seismo-electromagnetics during the last two decades [2].

The Seismo-electromagnetic phenomena method uses Very Low Frequency (VLF/LF) signals as a tool to predict earthquake. VLF/LF band (3 - 30 kHz) falls under radio spectrum and is widely known for its application in navigation and communication [10]. Due to low attenuation and long wavelength, VLF/LF signals—transmitted from different VLF/LF transmitters can travel long distance by undergoing consecutive reflections between lower ionosphere and surface of the Earth [2]. Many research works present that perturbations in VLF/LF amplitudes or phases have been observed prior to earthquake day. However, the results are often controversial for there are many other factors that might influence the VLF/LF waves. For instance, the ionospheric layer is highly influenced by geomagnetic winds, solar flares, cosmic rays and gamma-rays from the space, coronal mass ejection, and so on, which can also bring about variations in VLF/LF wave propagation [10]. On the other hand, studies during the last two decades enabled researchers to distinguish the earthquake effect from others through changes that take place in the properties of sky waves (the reflected waves from the ionosphere to the earth) [2]. Figure4 shows the measurement set-up for the ionospheric perturbation during the pre- earthquake period and an anomaly in VLF/LF propagation.

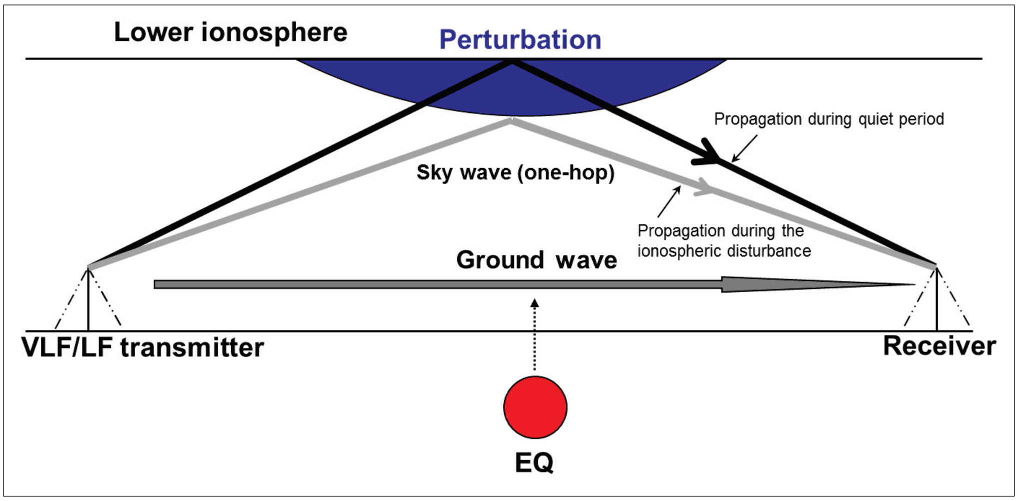

Figure 4: Method of measurements Ionospheric perturbation during the pre- earthquake (EQ) period [2]

As can be seen from figure4, that ionospheric VLF signals for the detection of ionospheric perturbations have two parts: one part of signals from a VLF transmitter takes the propagation mode of ground wave, whose amplitude is constant day and night. The other part takes the propagation mode of sky wave(s) going upward and reflected from the ionosphere, so that, the propagation characteristics of the sky wave depend entirely on the properties of the ionosphere [2].

For the detection of ionospheric perturbations two methods of analysis are used: (i) Terminator time (TT) method; and (ii) Night time Fluctuation (NF) method [10]. The terminator time method takes into account two parameters: Sunrise terminator time (SRT) and Sunset terminator time (SST). SRT is defined as the first minimum which occurs after the sharp weakening of signals around sunrise and SST is defined as the last weakening of the signal before its sharp rise around sunset [10]. The terminator is determined as the time when the VLF amplitude (and/or phase) of sky waves exhibit a minimum. Results of analysis are shown in figure 5.

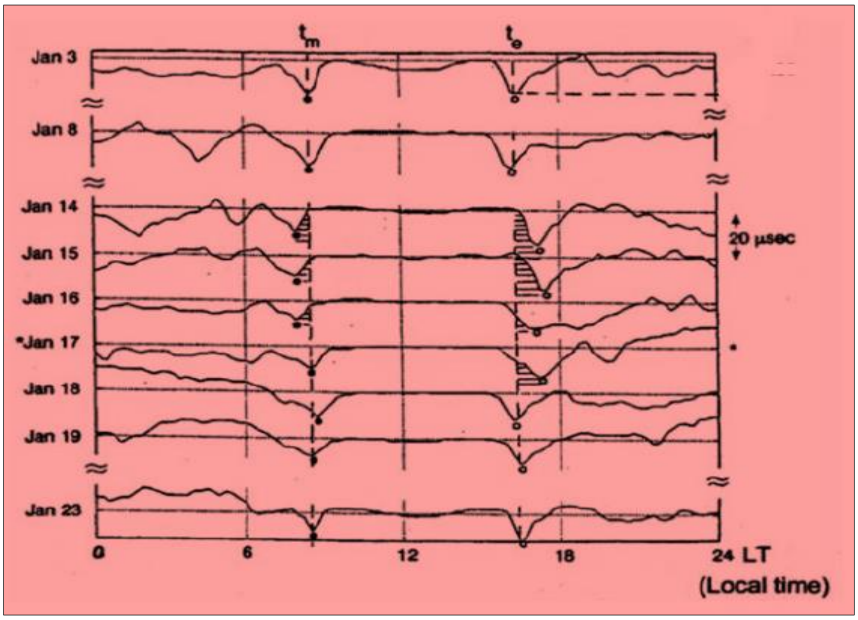

Figure 5: The first evidence of seismo-ionospheric perturbation for the 1995 Kobe earthquake on January 17. The plot of diurnal variations of propagation characteristics (in this case phase), in which the terminator times (t_m and t_e) show significant changes pre- earthquake period [2]

More evidences have been presented that the ionosphere could be unexpectedly sensitive to seismic activities and seismo-ionospheric influence has been presented as a most prospective candidate for earthquake forecasting and energy transmitting among lithosphere, atmosphere, and ionosphere [11]. Monitoring the electron density (Ne) (plasma density) in the ionosphere is the key parameters to characterize the status of ionospheric plasma, to reconstruct the ionosphere configuration and testify the reliability of measuring data from different instruments [11]. In nature, plasma is by far the most abundant state of matter in the visible universe and makes up for the majority of star and interstellar medium [12]. On Earth system, however, the only known natural plasma phenomenon is lightning and the largest, though far less known, abundance of plasma in the Earth system is the ionosphere [12]. The ionosphere is plasma embedded in the Earth’s atmosphere and ionospheric disturbances can be caused by seismic activities, as well as solar radiation, solar flares, lightning, and geomagnetic storm [12, 13].

5. DISCUSSION AND CONCLUSION

Statistical studies that were related to earthquake events have shown that an average of 60,000 lives was killed each year, (80,000 victims from 1994 to 2004), and (780,000 victims from 2001 to 2010) [14]. Such devastated earthquakes have also great negative impacts on economic grounds, causing massive possessions and industrial sector damage [14] gave some figures about the losses of earthquake events: as the 1989 Loma Prieta earthquake in California estimated at $6 billion, the 1995 Kobe earthquake in Japan estimated at $200 billion, the 2011 Tohoku earthquake in Japan followed by its great tsunami were estimated at $220 billion. Moreover, additional costs such as: lost productivity, lost income, lost tax revenue, as well as the cost of rebuilding all infrastructures must be taken into account [14]. However, the economic impact of a magnitude 7 or larger earthquake is expected to exceed €100 billion. The situation can only become more severe with the on-going growth and concentration of human populations in urban centers often found in seismic regions [14].

However, recent sequence of highly destructive earthquakes around the world has heightened awareness of earthquake hazards and the inability of seismology as a discipline to derive information of increasing earthquake hazards in the weeks and days before major seismic events [2]. It can be stated that earthquake short-term prediction is one of the most urgent and challenging subjects for human beings. If short-term earthquake is figure out, many lives would have been saved and additional costs such as: lost productivity, lost income, lost tax revenue, as well as the cost of rebuilding all infrastructures avoided if an early warning system had been in place [14].

As a new science, earthquake prediction is completely different from seismology. Seismologists are only interested in studying earthquakes after they occur, but human life and the future of civilization are only concerned with knowing the occurrence of future earthquakes in order to mitigate their devastating effects on the lives and future of humanity. Earthquake prediction is not only a very accurate and true science, but it is also a practical matter for saving humanity.

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