Mitigation of Earthquake Hazards using Satellite Measurements

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Abstract

Earthquake is one of the natural hazard threatening life, property and human being in many nations. In last few decades scientists have made substantial progress in developing the methods to analysis the earthquake hazards. Many researchers discuss the possibility of seismic hazards in the ionosphere. The seismic activity can be reflected in the ionosphere by electromagnetic waves and which not only accompany seismic activity but also precede it. Satellites and ground-based observations can detect earthquake precursors in the ionosphere a few hours or days before the main shock that will helpful in mitigating this hazard. Satellites observations can register specific density variations, electromagnetic emissions ranging from ULF to HF frequencies as well as fluxes of precipitating energetic particles in the ionosphere. The micro satellite DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) is the first micro satellite dedicated for seismo-ionospheric studies developed by CNES (French National Space Agency). The prime objective of DEMETER is to study the disturbances in the ionosphere due to seismic activity and due to the anthropogenic activities. The scientific payload of DEMETER is composed of several sensors, which allows to measures waves in broad frequency range (DC to 4 MHz) and also measures the local plasma parameters including temperature and density of electrons. This paper presents the examples of ionospheric precursors observed during earthquakes by DEMETER satellite over the seismically active regions of the world.

INTRODUCTION

Earthquakes are among the most destructive forces of nature, causing innumerable loss of lives and financial damages. Strong earthquakes take place frequently every year in the world. Mitigation of seismic hazards requires integration of science and human action, namely science of earthquake, anti-seismic engineering and socio-political measures. When structure damage is reduced, most other seismic hazards will also be reduced. On the top if short-term prediction could be made, casualities would be further reduced dramatically. We review the state of art in short-term prediction, in particular recent progress in approaches using electromagnetic phenomenon. Thus the reinforcement of existing structures and enhancement of short-term prediction are the two keys for seismic hazard mitigation. Substantial efforts have been made towards the development of earthquake hazards analysis on a time scale basis in last few decades, but it seems very much essential to encourage a detail study on the earthquake processes, using space and ground based technologies. However, by this time it is established fact that the development of seismic activity is accompanied by changes of different parameters of ionospheric plasma above the areas of occurring of earthquakes.

According to the available publications, the first publication on the ionospheric local plasma density and temperature variations measured on board AE-C and ISIS-2 satellites was given by [1]. Later it was demonstrated the existence of large-scale plasma irregularities over the areas of earthquake preparation zone [2] . Increases as well as decreases of the critical frequencies are observed in the D, E and F regions before earthquakes. Although this phenomenon is not well understood, it could be related to a redistribution of the electric charges at the surface of the Earth and then in the Earth's atmospheric system, [3], [4], and [5]. Increases as well as decreases of the critical frequencies are observed in the D, E and F regions before earthquakes. Ionospheric effects of aerosols and metallic ions emitted in the atmosphere above seismic regions have also been considered in [6].

The Electro-Magnetic (EM) disturbances associated with earthquakes have been a subject of study for the past many years however not all earthquakes produces such emissions [5]. Several mechanisms have been proposed for the generation of electromagnetic emissions in the ULF/ELF/VLF range before and after earthquakes. These EM emissions can propagate up to the ionosphere and observations made with different satellites have shown variations of these EM emissions above seismic regions. These EM emissions significantly modify the ionospheric parameters. The generation mechanism of the electromagnetic emissions is not yet entirely understood. There are many hypotheses to explain the generation mechanism of these phenomenons. The first hypothesis concerns direct production of compression of rocks close to the focal point. There are many hypotheses to explain the generation mechanism of these phenomenons. An earthquake can generate electric charges in different ways during rock compression: first it can be due to piezo-electric and tribo-electric effects, second due to diffusion of water inside ground. Injection of gases (including the radioactive elements like radon) from the lithosphere into the atmosphere is considered as a primary cause of the following chain of process: increase of air conductivity, increase of vertical currents between the earth and ionosphere, heating of ionosphere and enhancement of electric field in it. These phenomena, leads to dissipative instability and conductivity irregularities in the lower ionosphere through radiating ELF/VLF electromagnetic fields. Heating of the lower ionosphere leads to vertical plasma motion and deformation of the F2 layer.

The study of various ionospheric parameters and the analysis of EM waves may give a tool to study the EM disturbances associated with earthquakes. This paper presents the examples of ionospheric precursors observed from various experiments onboard DEMETER satellite during earthquakes.

Micro-Satellite DEMETER

The DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) is the first micro satellite developed by CNES (French National Space Agency) for seismo-ionospheric studies. It is a low-altitude satellite (h = 710 km) with a nearly polar orbit. The scientific objective of DEMETER is to study emissions of electromagnetic waves observed during earthquakes and volcanic eruptions, disturbances in the ionosphere and the upper atmosphere. The second scientific objective is the global monitoring of electromagnetic environment around the earth. There are two modes of operation:

Survey mode: To record low bit rate data all around the earth in which acquisition of data is continuous and which gathers the spectra of low time and frequency at 25 kbits/s.

Burst mode: To record high bit rate data above the seismic regions. In this mode the acquisition is targeted on zones of seismic activity and which gathers high rate waveforms at 1.8 M bits/s. Data and plots for all experiments are available through a web server (http://demeter.cnrs-orleans.fr).

Technical Details of DEMETER

- **Magnetometer Search Coil Instrument (IMSC)**: It is designed to measure three field magnetic components in a wide frequency range (10Hz to 17.4kHz). The value of magnetic field is given by the current flowing through a coil of turns around a μ metal. The three antennas used to measure these three field components are mounted along three orthogonal axes at the end of an arm 1.9 meter long.[10]

- **Electrical Field Instrument (ICE):** The main objective of the ICE experiment is to detect and characterize the electromagnetic perturbations in the ionosphere that are associated with seismic activity. It measures the three component of electrical field in a frequency range from DC to 3MHz. The ICE experiment consists of 4 spherical sensors with embedded pre-amplifier electronics mounted on the ends of 4 booms or antenna of 4m long. The difference in potential measured for each of the three components is due to difference between the voltages of the sensors taken in pairs. The value of electric field is determined by dividing the difference in potential by the effective wavelength of the antenna. [7]

- **Plasma Analysis Instrument (IAP):** This instrument is designed to measure the main plasma parameters in the ionosphere variations of which reflect disturbances in the ionosphere. They are the density and ionic composition, temperature (range 1000K – 5000K) and velocity of dominant ions H+, He+ and O+ less than 2km/s. The measurement is taken by two analysers that measure respectively the energy distribution of the ions along the line of sight of the instrument in parallel with orbital velocity [8].

- **Langmuir Probe Instrument (ISL):** This instrument measures the electron density of plasma (range 10^2 to 5.10^6), electron temperature (range 500K to 3000K) and the potential of the satellite (range +/-5V). The ISL is made up of two Langmuir probes: a cylindrical probe and a segmented spherical probe of 4cm in diameter. The fundamental parameters of thermal plasma are determined mainly from the current-voltage response curve of the Main Langmuir probe i.e. the cylindrical probe.[9]

- **Plasma Detector Instrument (IDP)** :This instrument is designed to measure the energy spectrum of electrons perpendicular to magnetic field (30keV to 2MeV) to measure disturbances in the radiation belts induced by earthquakes.

RESULTS

The seismic events of magnitude greater that 5.5 have been chosen from the seismically active regions of the world For the case study of a particular seismic event seismic associated recorded variations in the electron density, and ion density (O+, H+, He+ ions) have been checked. Also the spectrogram of electric field is checked, which is ranging from ULF to VLF. All the orbits ten days before the main shock were checked and the orbits in which significant variations observed are shown. In all the four cases, we have observed the variation in electron and ion density above the epicentre region the earthquake. The electrostatic turbulence is also observed along with the density variation, which is in the ULF to ELF ranges. The events covered are shown below:

Case I: - Soloman Islands (M=6.8; 08/10/2004)

An earthquake of magnitude 6.8 occurred at 08:27:53 UT near the Soloman islands on 4th October 2004, Figure 1 shows the orbit of DEMETER, four days before the main shock. The top three panels show the plasma density variations observed by ISL and IAP experiment. The next panel shows the spectrogram of Very Low Frequency (VLF) in frequency range of 500Hz. The obtained results clearly shows that variations in electron and O^+ ion density have been observed from 11:33UT to 11:35:30 UT near the epicentre. The last panel clearly indicates that the ionospheric turbulence is observed near epicentre region near 11:34 UT which is in the ULF ranges. Figure 2 shows the orbit track of DEMETER on 4th October 2004. The epicentre of this event is in low latitude region of the ionosphere.

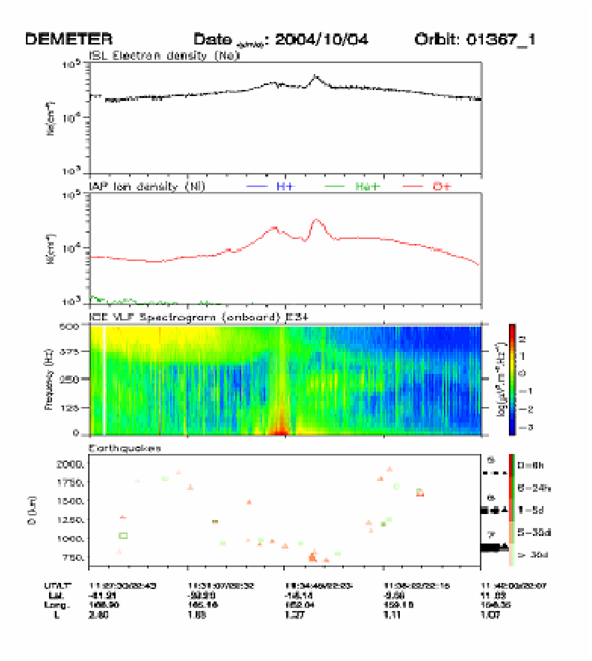

Figure1: Shows the data of DEMETER on 4th October 2004.

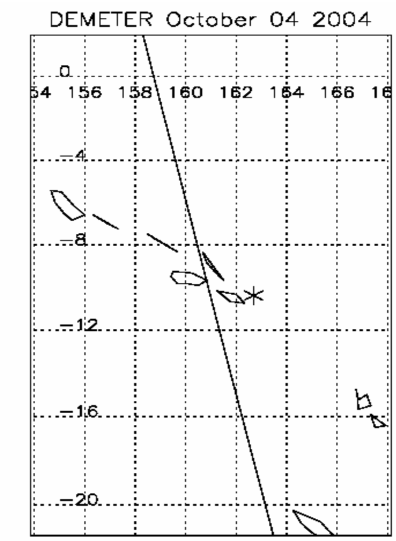

Figure 2: Shows the orbit track of DEMETER on 4th October 2004. '*' indicates the position of epicenter.

Case II: Papua Region (M=7.0; 26/11/2004)

A devastating earthquake of magnitude 7.0 occurs in the Papua region of Indonesia (3.88°S, 135.3°E) on 26th November 2004. The data corresponding to this event is shown in Figure3. The parameters shown in this figure are same as taken in first case. This data is six days before the main shock at a distance of ~15degree (latitude) from the epicentre. In this Figure we observed variations in electron and ion density just above the epicentre region. Significant variations in electron and ion density were observed near the epicentre region. Similar variations have been also observed in ULF/ELF range. This enhancement in parameters might be attributed to the large magnitude of the earthquake and epicentre. The orbit corresponding to this event is shown in Figure 4. The epicentre of this earthquake is in equatorial region.

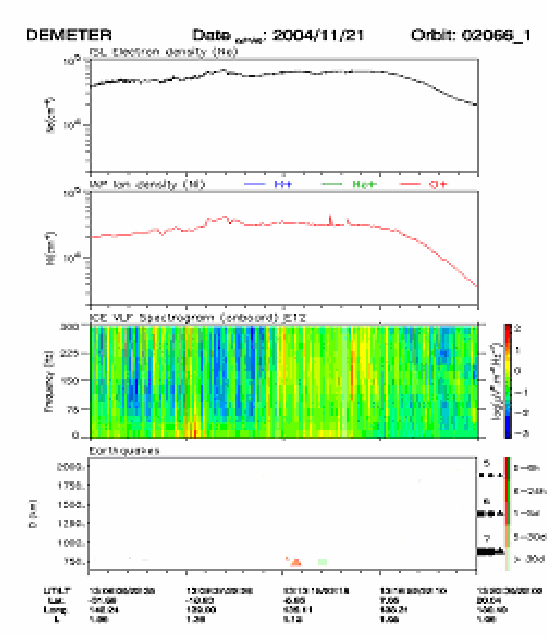

Figure 3. Shows the data of DEMETER on 26th November 2004.

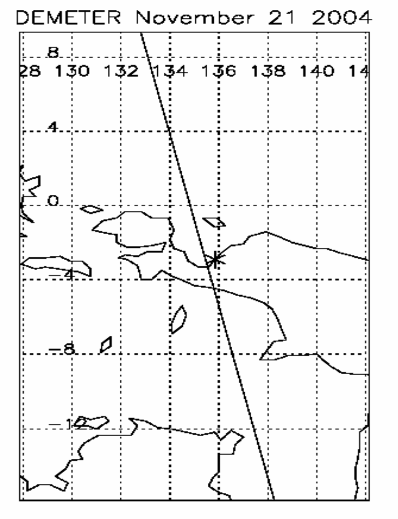

Figure 4. Shows the orbit track of DEMETER on 26th November 2004. '*' indicates the position of epicenter.

DISCUSSION

The events that we have shown in this paper are from low ionosphere. The low latitude ionosphere is highly complex and dynamic due to various phenomenon-taking place here. The equatorial anomaly is a specific belt of electron concentration irregularity in the shape of crest appearing on both sides of the geomagnetic equator electro- dynamically driven by crossed geomagnetic and electric fields. The eastward directed electric field responsible for its formation appears in ionosphere during the afternoon hours, which causes the equatorial anomaly development. If the earthquake preparation area lies close to the equator as in the anomalous electric field will interact with the eastward electric field, which will result in the equatorial anomaly shape distortions as described by [6]. The statistical analyses of the data from IK-24 satellite over the equatorial latitudes and concluded that the equatorial anomaly is sensitive to the earthquakes. [11],[12].

CONCLUSION

The ionospheric perturbations over the epicentre of large earthquakes have been studied. It is shown that they include the variations of plasma parameters and electrostatic turbulence. The spatial and temporal variations of ionospheric parameters are very close to the epicentre of the earthquake. The epicentre of the seismic events lies in the low latitude region of the ionosphere. Also the observed variations are close in time and space of the epicentre so it is possible that these variations were caused by earthquakes. The ionsphere is very complex and mainly controlled by solar acticity. The study of larger data set will helpful in understanding the lithosphere-ionosphere mechanism and thus mitigating the earthquake hazard.

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