Satellite Monitoring of Ionospheric Disturbances Associated With Volcanic Eruption

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Abstract

Seismo-electromagnetic phenomena can reflect to the electric and magnetic field perturbations during the course of seismic events. The ground based studies show that electromagnetic signals may precede and accompany volcanic eruption. Satellite based technique is the most promising diagnostic tools for studying this electromagnetic anomalies. Some important electric and magnetic field variation observed prior to two individual volcanic eruption are discussed in this paper over Indonesian region; the first Volcano of VEI=3 erupted on 6th August 2010 in Karangetang (2.78°N,125.40°E) and the second Volcano event of VEI=4 erupted on 26th October 2010 at Merapi (7.542°S, 110.442°E). The observations have been detected prior to both the events using the low altitude satellite DEMETER, which is aimed at studying the ionospheric perturbation related to volcanic eruption. The variability of various electromagnetic signals observed by DEMETER during volcanic eruption is presented and the anomalies are observed before the eruptions for the period 30 days before the eruption and 15 days after the eruption. Although the database is still limited, the study shows that volcanic activity may be precede by EM perturbations of the ionosphere.

1. Introduction

Earthquakes and Volcanoes are among the most destructive forces of nature, causing innumerable loss of lives and financial damages. Strong Volcano eruptions take place frequently every year in the world. However, only some of them volcanoes in the world are monitored by complex geophysical equipments, whereas hundreds of volcanoes remain without any adequate observations and real time monitoring systems. If short term prediction could be made, causalities would be further reduced significantly. For volcanoes, observations on the ground of pre-eruptive signals appear more reliable. Most of volcanic eruptions can be predicted by the integration of continuous real time observations. In the electromagnetic field (EM), a long history of ground observations shows that electric, magnetic and electromagnetic signals may precede and accompany volcanic eruptions. A number of observations show unambiguous electromagnetic signals before volcanic eruptions as resistivity changes, long time evolution of the magnetic field, transient magnetic and electric signals [1][2][3][4][5][6].Therefore, multiplatform satellites could partly contribute to the mitigation of volcanic hazards and trap some of the pre-eruptive signals. We have tried to explain the state of art in short-term prediction by using electromagnetic phenomenon. The study of various ionospheric parameters and the analysis of EM waves may give a tool to study the EM disturbances associated with Volcanic Eruptions. This paper presents the examples of ionospheric precursors observed from various experiments onboard DEMETER satellite during volcanic eruption. Anomalous variations were observed in plasma parameters above the region before the eruption. It includes the variation of electron density, electron temperature, ion density and ion temperatures. Electromagnetic emissions of Very Low Frequency (VLF) ranges were also noticed during this period.

- Characteristics of Volcano

We have considered two strong volcanic eruptions in Indonesian region with VEI ≥ 3 occurred during 2010. This region covers the most seismically active regions of the world. The first Volcano of VEI = 3 erupted on 6th August 2010 in Karangetang (2.78°N,125.40°E) and the second one of VEI = 4 erupted on 26th October 2010 at Merapi (7.542°S, 110.442°E). The geography of Indonesia is dominated by volcanoes that are formed due to subduction zones between the Eurasian plate and the Indo-American plate. Volcanoes in Indonesia are part of the Pacific ring of Fire.

- DEMETER

The DEMETER is the first micro satellite developed by CNES (French National Space Agency) for Seismo-ionospheric studies. The orbit of DEMETER is polar and circular with an altitude of 710 km. The scientific payload of DEMETER is composed of several instruments which provide a nearly continuous survey of the plasma, waves and energetic particles. ICE, the electric field experiment, uses four electric probes to measure the three components of the electric field in a frequency range from DC up to 3.5 MHz IMSC, a search-coil magnetometer, measures the three components of the magnetic field in a frequency range from a few Hz up to 20 kHz. ISL, the Langmuir probe gives access to the electron density and temperature. IAP, the thermal ion spectrometer measures the ion density, composition, flow velocity and temperature. A solid state energetic particle detector, IDP, measures high energy electrons and protons. There are two modes of operation: (i) a survey mode to record low bit rate data all around the Earth at invariant latitudes less than ≈ 65, and (ii) a burst mode to record high bit rate data above seismic regions. The data are stored in a large onboard memory which is downloaded two times per day when the satellite is above Toulouse, the location of the Operation Centre. Data and plots are available through a web server (http://demeter.cnrs-orleans.fr). The quick-look plots are in public access. The seismic information is routinely merged with the orbitography of DEMETER and introduced in a data base in order to facilitate selection of events following various requirements (magnitude, depth, distance between the satellite and the epicentre, time interval between the time of the quake and the time of the data). Experimenters and guest investigators have access to these facilities in order to download or to display online selected data. All data files and plots are organized by half-orbit.

2. Data and Methodology

The objective of the study is to observe DEMETER data around the time of volcanic eruptions and their respective EM signals related to volcanic activities .For this purpose we have taken only volcanoes located between latitudes −50◦N and +50◦N are taken into account. Because beyond these latitudes, auroral phenomena prevail in DEMETER records and could hide small EM anomalies associated with ground phenomena [4]. Volcanoes characterized by a Volcanic Explosivity Index (VEI) ≥ 3 are considered, to show independently of their location and eruptive behaviour. The database is produced by observations from downward (north to south) and upward (south to north) orbits. Downward orbits correspond to daytime whereas upward orbits correspond to night time. In this study a time window beginning 30 day before the eruption and 15 day after the eruption has been chosen, because most of the transient EM signals recorded on the ground occur during this time lapse only. In this study the data collection is used for observing the different types of anomalies encountered in the vicinity of volcanoes. We had taken two strong volcanic eruptions in the year 2010. The first Volcano of VEI=3 occurred on 6th August 2010 in Karangetang (2.78°N,125.40°E) and the second Volcano event of VEI=4 occurs on 26th October 2010 at Merapi (7.542°S, 110.442°E) Indonesia. The local geomagnetic activity was found to be moderate during the days of observation as there were no solar flare and no geomagnetic storms observed during that period. Therefore the ionospheric perturbations observed were independent of the solar terrestrial disturbance and the observed variation might be attributed to the seismic activity.

3. Result and Discussion

Magnetic and electric signals may precede volcanic eruptions on land. Transient signals are mostly observed during pre eruptive periods which can be roughly on the order of weeks depending on the dynamism of the volcano. By using satellite observations we may analyse the perturbations of the ionosphere induced by the volcanic eruption. Satellites monitoring is beneficial to track anomalies in large areas of the Earth where ionospheric disturbances are not too large because non geostationary satellite like DEMETER, the drift in longitude between two consecutive orbits is generally too large (few thousand kilometres) for continuously evaluating the persistence of anomalies with time [4]. Figure-1 shows the half orbit (32539_1) of DEMETER on 31st July 2010 for a volcano Karangetang (2.78°N, 125.40°E) erupted on 6th August 2010. This orbit is 6 days before volcano eruption. The data corresponding to this event is shown in Figure-1. From top to bottom the first panel highlights the spectrogram of electric component up to 2 kHz recorded by ICE experiment on board DEMETER satellite. The intensity of the emissions is colour coded according to the scale on the right and second panel shows the spectrogram of magnetic component up to 4 kHz recorded by IMSC experiment. The third and fourth panel shows the variation of electron density and electron temperature observed by ISL instrument, the fifth and sixth panel represents the density variation of H+, He+ and O+ ions and ion temperature observed from IAP experiment. The last panel represent the seismic events lies in the path of orbit.

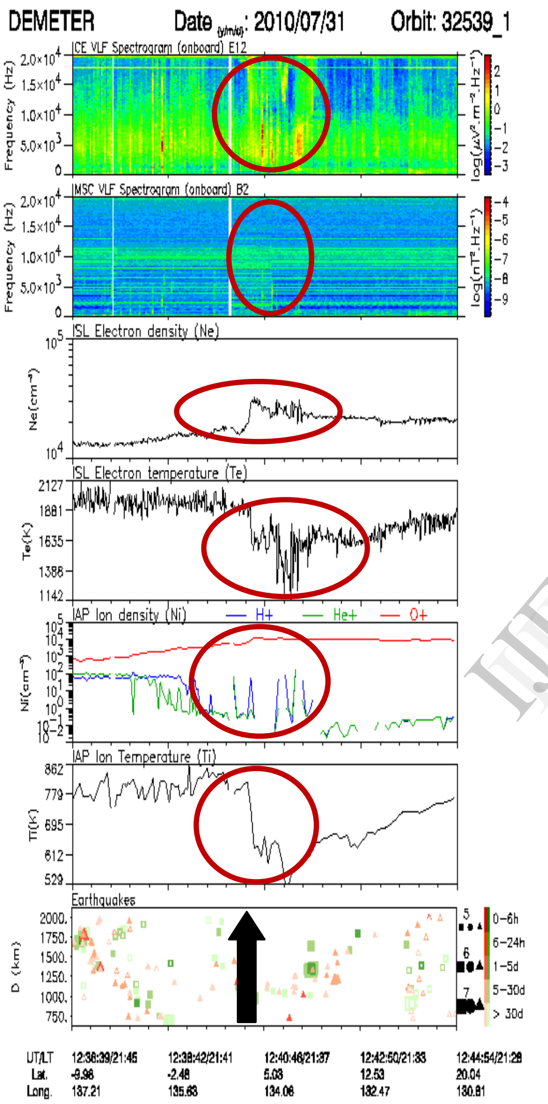

Figure 1 Karangetang Volcano (2.78^{0}N, 125.40^{0}E) Indonesia on 06/08/2010.

The data is presented as a function of the Universal time (UT), the Local time (LT), the geographic latitude and longitude and the L values are also given. The black arrow in each panel shows the position of volcano. Figure-1 clearly shows that there is an increase VLF emission from latitude 2 °N to 8°N that is very near to the volcano eruption region (shown by red colour). The second panel shows the minute changes in magnetic value near volcanic eruption. The fourth and third panel shows the increase in the electron density and decrease of ion temperature up to nearly1600K respectively. The third and second panel shows the increase ion-density of O+ ions increases up to $10^4 cm^{-3}$ and regarding the ion temperature there is a clear variation in ion temperature. In last panel shows that there is no major seismic earthquake activity happen which will contradict our result? These ionospheric variations can be explained in terms of anomalous electric field generated near the Volcano eruption region of future eruption as the data may be taken up to 2000km away from the epicentre [7].Also the observations were taken on the day where geomagnetic indices (Kp, Dst, ap) values are normal, so these so variations might be caused due to the eruption activity.

Figure-2 shows the half orbit (33539_1) of DEMETER on 7th October 2010 for a volcano Merapi (7.542°S, 110.442°E) Indonesia erupted on 26th October 2010.

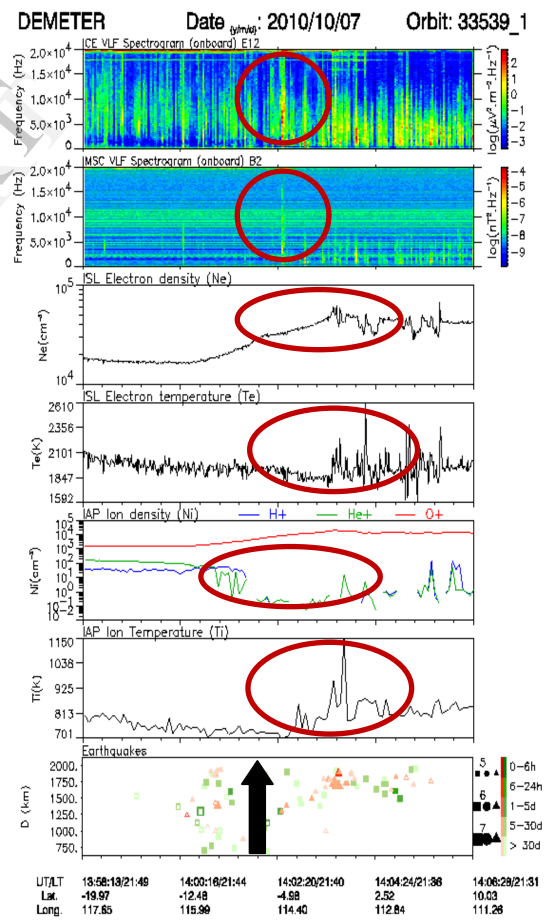

Figure 2 Merapi Volcano (7.542^{0}S, 110.442^{0}E) Indonesia on 26/10/2010.

This orbit is 19 days before volcano eruption. The data corresponding to this event is shown in Figure-2. From top to bottom the first panel highlights the spectrogram of electric component recorded by ICE experiment on board DEMETER satellite. The second panel shows the spectrogram of magnetic component recorded by IMSC experiment. The third and fourth panel shows the variation of electron density and electron temperature observed by ISL instrument, the fifth and sixth panel represents the density variation of density O+ ions from its initial value and ion temperature variation observed from IAP experiment. The last panel represents the seismic events lies in the path of orbit. The data is presented in the same way as in the previous case. The black arrow in each panel shows the position of volcano. Figure-2 clearly shows that there is an increase VLF emission from latitude 7°S to 6°N that is very near to the volcano eruption region (shown by red colour) spectrogram of electric component up to 2 kHz. The second panel shows the changes in magnetic value near volcanic eruption. In this case also the anomalous electric field generated near Volcano eruption region of future eruption is responsible for these observed ionospheric variations where the observation were taken at the geomagnetic indices(Kp, dst, ap) are shows normal behaviour. So these variations were independent of the solar terrestrial disturbance and might be attributed to the volcanic activity. The fourth and third panel shows the increase in the electron density and variation of ion temperature respectively at near the volcano position. The third and second panel shows the variation in ion density of O+ and the increase in ion temperature near the position of volcano eruption.

4. Conclusion

The ionospheric perturbations over the volcano of future eruption has been discussed which includes the variations of plasma parameters and increase in the intensity of VLF emissions and variation in electron density above the volcano region of future eruption. The spatial and temporal variations of ionospheric parameters are very close to the future eruption. The origin of such type of anomalies is to be electrostatic turbulences and whistlers phenomena. These types of anomalies are also observed in the vicinity of impending earthquakes [8] [9] [10].

There is a hypothesis that anomalous electric field penetrating into the E-region of the ionosphere creates irregularities [11]. And due to the equipotentiality of geomagnetic lines the electric field without any decay penetrates at the higher levels of the ionosphere. This effect is seen in the F region of ionosphere and in the area of maximal conductivity due to joule heating, acoustic gravity waves will be generated giving rise to small-scale density irregularities within the ionosphere [12]. The plasma density variations that we have observed are due to this effect. These irregularities spread along the geomagnetic field lines creating field-aligned ducts where VLF emissions of different origin (seismic origin) will be scattered. This will lead to increased level of VLF emissions within the magnetic tubes along the areas of anomalous electric field generation. Geomagnetic indices (Kp, Dst, ap) values are normal at the time of observation. So the perturbations observed were independent of the solar terrestrial disturbance and these phenomena might be attributed to seismic activity.

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