Ionospheric ion density variation in the low and mid latitude ionosphere: Possible connection with earthquake

N Maheshwari1,5,*, D K Sharma1,4, M S Khurana1,58 & Jagdish Rai2
1Department of Applied Sciences & Humanities, Manav Rachna College of Engineering, Faridabad 121 001, Haryana, India
2Department of Physics, Indian Institute of Technology, Roorkee 247 667, Uttaranchal, India
E-mail: 5mah.nishi@gmail.com, 4dksphdes@rediffmail.com, 58anan1301@gmail.com

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The problem of earthquake prediction has revealed correlation between seismic activity and ionospheric ion temperature and density anomalies. This paper presents observations of the ion density measured with the help of Retarding Potential Analyzer (RPA) payload aboard Indian SROSS-C2 satellite in the altitude ~500 km. The satellite data was analyzed from January 1995 to December 1996 to see the fluctuations in ion density over the seismic region. The emphasis of this paper is on the anomalies in the low and mid latitude ionosphere. The results obtained confirm the earlier results of ion temperature anomalies over the same region.

Keywords: Ionospheric anomaly, Seismic activity, Ion density anomaly

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1 Introduction

Since last few decades, a connection between earthquake and ionosphere has been proposed. Many hypotheses have been suggested but could not succeed because of the earthquake precursory to reduce the hazard to life and property. The thermal fluctuations in the ionosphere related to the prediction of earthquakes and volcanic eruptions remain largely an unsolved problem. A large number of earthquakes occur on the Earth each year and ~100-120 of them have a magnitude ≥4 (on Richter scale). These are extremely hazardous for the inhabitants of the Earth. The ionospheric anomalies appearing few hours or few days before the seismic activity have been studied and reported by a number of researchers1-12.

There are a number of papers on satellite recordings of ionospheric disturbances possibly associated with earthquakes. While signature of seismic and non-seismic phenomena related to earthquake on the ground is doubtless, a possibility of observations of seismo-associated effects in the atmosphere and ionosphere claimed is sometimes questionable. This situation has been discussed in recent papers13-18 paying attention to different criteria of data selection. However, the main problem is that these studies were not statistical in a grid sense due to multi-parametric dependence of expected events on natural conditions and principal impossibility to separate time and space variations from one satellite observations, because one needs to have data set either continuous in space at a fixed time or continuous in time at a fixed place to use the conventional statistical methods. In addition to the ambiguity of observational conclusions, the mechanism underlying the seismo-ionospheric or seismo-atmospheric effects are also unclear18. On the other hand, study of the seismicity and underlying processes can be essentially improved by using the satellite methods as it happened with climate and weather studies when the proper satellite information became available. To prove the direct relationship between quasi-static electric field and plasma density anomalies and seismic activity is difficult but actual task of the modern ionosphere physics. An anomalous increase of 3-7 mV m⁻¹ in the vertical component of the quasi-static electric field has been first observed onboard InterCosmos-Bulgaria-1300 satellite in the near-equatorial ionosphere over the earthquake region, ~15 min before an earthquake with magnitude of 4.8 (on Richter scale) (ref. 19). A reliable correlation between the global distribution of seismic activity and ion density variations in the ionosphere has been proposed by Hayakawa et al.20. The possible generation of the seismically related electric field in
the atmosphere and the mechanism of penetrations of atmospheric field into the ionosphere have been studied by Pierce\textsuperscript{21}.

Pulinets & Boyarchuk\textsuperscript{22} have explained the variations of near-Earth plasma density observed over seismically active areas several days / hours before strong seismic shocks. It demonstrates that the seismo-ionospheric coupling is part of the global electric circuit and the anomalous electric field appearing in active seismic areas is the main carrier of information from the earth into the ionosphere. The discussion of physical mechanisms is based on experimental data. It proceeds to describe existing complex systems of space-born and ground-based monitoring for electromagnetic and ionospheric precursors of earthquakes, as well as those still under construction.

Koshevaya et al.\textsuperscript{3} have studied the connection mechanism between the lithosphere and the ionosphere. They have found macroscopic changes of the ionospheric parameters prior to the occurrence of the earthquake above the epicenter at altitude in the range 400 - 1000 km in the ionosphere. Zaslavski et al.\textsuperscript{3} concluded that in some cases the electron density in the F-region increases in the localized epicenter zone; whereas in other cases it has decreased. These effects are generally small in size and nearly masked by other ionospheric disturbances. Their small magnitude diminishes their capability to become a real seismic precursor. A review of electromagnetic phenomena associated with earthquake in terrestrial electromagnetic noise environment was also presented by Hayakawa\textsuperscript{16}. Molchanov & Hayakawa\textsuperscript{15-16} analyzed the 10 major earthquakes related electromagnetic signals. They found that the ionospheric effect was a transient oscillation with 5 - 10 day period, which is initiated a few days before a large earthquake and decays over a few days to weeks after it. They concluded that this phenomenon could be understood in terms of long period gravity waves generated during the earthquakes and their intensification in the ionosphere as they propagate upward. Rikitake\textsuperscript{23} also concluded that the low period gravity waves generated at the epicenter may propagate to ionospheric height. Emission and propagation of electromagnetic radiations, ULF, ELF and VLF from earthquake epicenter were also reported\textsuperscript{14,24-28}. These waves may create localized joule heating in the ionosphere.

\section*{2 Data selection and Analysis}

The Retarding Potential Analyzer (RPA) aeronomy experiment designed and developed at National Physical Laboratory (NPL), New Delhi was sent in space onboard Indian satellite SROSS-C2 on 4 May 1994 to study the ionospheric composition and temperature anomalies. The SROSS-C2 satellite was launched with the help of ASLV-D4 rocket from Sri Harikota Range (SHAR) in the orbit at 930×430 km altitude having 46° inclination to the equatorial plane. After two months of its operation, the satellite orbit was bought down to 630×430 km altitude. It was successfully operated continuously for seven years and on 12 July 2001, re-entered the atmosphere. The SROSS-C2 satellite was the fourth satellite of Stretched Rohini Series Satellite programme of ISRO and it was designed, developed, fabricated and tested at the ISRO Satellite Center (ISAC), Bangalore.

The RPA experiment onboard the SROSS-C2 consists of an electron RPA, ion RPA and a potential probe for making simultaneous measurements of ionospheric parameters was used by Garg & Das\textsuperscript{29} and Sharma et al.\textsuperscript{30} The electron RPA makes measurements of the total electron concentration, irregularities in electron concentration and the temperature of the electrons. The ion RPA makes measurements of the total ion density, irregularities in ion density, temperature of the ions and densities of the various ions (H\textsuperscript{+}, He\textsuperscript{+}, O\textsuperscript{+}, O\textsuperscript{2+} and NO\textsuperscript{+}) present in the ionosphere. The variations in the satellite potential with respect to plasma potential during spin and motion of the satellite are measured with the help of potential probe. The temperature data are obtained by analyzing one complete electron and ion I-V plots through linear and non-linear curve fitting technique, respectively. Each I-V plot is constructed by current collected by the sensors with 64 steps of retarding grid voltage applied to the sensor, which takes 1.408 sec. During this time, satellite travels a distance of 10-11 km. Only those I-V curves that fall within the specified limits were analyzed for deriving electron and ion temperatures. The data are sampled at every 22 ms which when translated into distance is ~176 m taking the satellite velocity to be 8 km s\textsuperscript{-1}. The RPA experiment is switched on only during the satellite visibility over the ground station at Bangalore (12.6°N, 77.3°E geographic).
The data collected by SROSS-C2 satellite using RPA payload during the period January 1995 - December 1996 were used to analyze the anomalous variations in the ion density due to earthquake events in the altitude range 430-630 km. The earthquake events related details for the same period were downloaded from United State Geological Survey (USGS) website. It is a difficult task to study the ionospheric anomalies using the satellite data in respect of earthquake events because passes of satellite very rarely match the epicenter zone of seismic event. The first task is to select the satellite data corresponding to the seismic events recorded during the above mentioned period. The recorded average ion density during seismic activity has been compared with average normal day’s ion density for the same time interval. The ions density data were analyzed in such a way that the perturbation due to diurnal, seasonal, latitudinal, longitudinal and altitude effects are negligible. The average of normal time ion density was calculated for a month, which includes pre and post earthquake days. One season data has been included for each event, therefore, the possibility of seasonal effect has been ruled out. A 10° window has been selected around the epicenter zone to avoid the latitudinal and longitudinal effects. To calculate the normal day ion density, event time interval data have been used to avoid any perturbation due to diurnal effect. All data correspond to the altitude range 430 - 630 km only, thus, making it independent of the altitude.

In order to avoid the masking of ion density perturbation due to solar flares, the solar flares data were obtained from National Geophysical Data Center (NGDC), Boulder, Colorado (USA). Only those earthquake events have been considered in this study, which are free from the solar flares. Similarly, it has also been verified from the thunderstorms/ lightning activity data obtained from India Meteorological Department (IMD), Pune that the earthquake events are free from any effect due to thunderstorms.

3 Results and Discussion

To study the ionospheric ion density variation during the occurrence of earthquake, a total six events have been identified from January 1995 to December 1996 over the Indian region. The details of all six events of geographical location, time of occurrence and other related parameters are given in the Table 1. The number of orbits of each point has been shown in Figs 1 and 2, respectively. The total number of orbits have been used to calculate the average plasma density, which varies from 5 to 8. The effect of seismic activity on the ionospheric ion temperature for the above mentioned events has been studied earlier and presented. In the present paper, the effect of the seismic activity on the ionospheric ion density in the F2 region ionosphere has been studied. The daily variation of magnetospheric activity parameters such as \( K_p \), \( A_p \) and \( F10.7 \) indices has been shown in the Table 1. A time window of ± 5 h has been selected for the normal day’s average temperature. The time difference of the observations and the earthquake occurrence has been considered within the same hour window. In the figures, the observed points have been plotted on logarithmic scale.

The standard deviation and its comparison with the normal density has been taken and presented. However, a few points have been observed during the seismic activity. In most of the events single point were found at a particular time. Therefore, it is not possible to take the standard deviation of each point. Figures 3(a-c) and 4(a-c) show variations in ion density during seismic activity and normal days during 1995 and 1996, respectively. During the event on 12 March 1995, the total ion density was \( 2.35 \times 10^{10} \) m\(^{-3} \) over the normal day’s ion density \( 2.17 \times 10^{10} \) m\(^{-3} \). Similarly, on 21 October 1995, the ion

<table>
<thead>
<tr>
<th>S No</th>
<th>Date of the seismic event</th>
<th>Origin time of seismic events, hrs LT</th>
<th>Location of seismic events</th>
<th>Magnitude, on Richter Scale</th>
<th>Depth, km</th>
<th>( K_p ) index</th>
<th>( A_p ) index</th>
<th>( F10.7 ) index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>12 Mar 1995</td>
<td>08:22:54</td>
<td>17.74°N, 73.77°E</td>
<td>4.7</td>
<td>10</td>
<td>60</td>
<td>080</td>
<td>76.2</td>
</tr>
<tr>
<td>2.</td>
<td>21 Oct 1995</td>
<td>19:39:39</td>
<td>31.43°N, 78.96°E</td>
<td>4.9</td>
<td>33</td>
<td>33</td>
<td>007</td>
<td>81.0</td>
</tr>
<tr>
<td>3.</td>
<td>09 Dec 1995</td>
<td>10:04:44</td>
<td>15.44°N, 88.43°E</td>
<td>4.8</td>
<td>10</td>
<td>17</td>
<td>006</td>
<td>73.9</td>
</tr>
<tr>
<td>4.</td>
<td>12 Feb 1996</td>
<td>20:39:54</td>
<td>22.62°N, 82.89°E</td>
<td>4.3</td>
<td>33</td>
<td>20</td>
<td>007</td>
<td>69.1</td>
</tr>
<tr>
<td>5.</td>
<td>25 Sep 1996</td>
<td>17:41:17</td>
<td>27.43°N, 88.55°E</td>
<td>5.0</td>
<td>33</td>
<td>23</td>
<td>009</td>
<td>70.8</td>
</tr>
<tr>
<td>6.</td>
<td>10 Nov 1996</td>
<td>09:00:04</td>
<td>18.30°N, 76.69°E</td>
<td>4.1</td>
<td>33</td>
<td>17</td>
<td>006</td>
<td>71.0</td>
</tr>
</tbody>
</table>
Fig. 1 — Number of orbits of each point for three different events recorded in 1995

Fig. 2 — Number of orbits of each point for three different events recorded in 1996

Fig. 3 — Ion density variation during earthquake (x) and normal days (o) along with the standard deviation for three different events recorded in 1995

Fig. 4 — Ion density variation during earthquake (x) and normal days (o) along with the standard deviation for three different events recorded in 1996
density was $7.07 \times 10^3$ m$^{-3}$ over the normal day ion density $8.71 \times 10^3$ m$^{-3}$. During the events on 09 December 1995, very few points were found in the satellite observation and it was observed that there was no significant change in the ion density. However, it has been found that the ion temperature enhancement in the ionosphere was observed during the corresponding seismic events by Sharma et al.\textsuperscript{31} This enhancement was found 1.2 times to the normal day’s average ion temperature.

In 1996, three seismic events were found. During the event on 12 February, the total ion density was $8.20 \times 10^3$ m$^{-3}$ over the normal day’s ion density $5.40 \times 10^3$ m$^{-3}$. Similarly, on 25 September, the ion density was $5.38 \times 10^3$ m$^{-3}$ over the normal day ion density $4.72 \times 10^3$ m$^{-3}$. During the events on 10 November, the ion density was $2.76 \times 10^3$ m$^{-3}$ over the normal day ion density $3.09 \times 10^3$ m$^{-3}$. Thus, during the three events in 1996, there is no significant change in the ion density. The decrease was observed also in the magnetic field data and in electric field data, but it is much weaker and its statistical significance is questionable. No similar effects were observed during the day and for deep earthquakes.\textsuperscript{32} However, the ion temperature enhancement in the ionosphere was observed during the corresponding seismic events.\textsuperscript{31} This enhancement was also found 1.2 times to the normal day’s average ion temperature.

4 Conclusions

The SROSS-C2 data has been analyzed to study the ionospheric ion density variation in F$_2$ region due to seismic events. In the present study, all the six events had nearly almost the same magnitude. It has been found that the average ion density was not significantly affected during the occurrence of earthquakes in the low and mid latitude region. The variation of the ion density, fall within the error limit of the observation. In this paper, a very few events of the earthquake has been studied to draw the definite conclusion. To correlate these density variations with magnitude of earthquakes, a large number of events are required. The present study further broadens the scope of earthquake signature studies using ionospheric ion density variation.

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References