Effect of solar flares on electron and ion temperatures as measured by SROSS-C2 satellite

D K Sharma & Jagdish Rai
Department of Physics, Indian Institute of Technology, Roorkee 247 667, India
and
M Israil
Department of Earth Sciences, Indian Institute of Technology, Roorkee 247 667, India
and
P Subrahmanyam, P Chopra & S C Garg
Radio & Atmospheric Science Division, National Physical Laboratory, New Delhi 110 012, India

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The ionospheric electron and ion temperatures \((T_e\) and \(T_i\)) measured by RPA payload aboard SROSS-C2 satellite are found to be enhanced during the solar flares. The electron temperature \((T_e)\) is enhanced by \(-32.05\text{--}45.31\%\) and the ion temperature \((T_i)\) enhanced by \(-4.12\text{--}21.95\%\) over quiet days. This enhancement has been obtained in the daytime ionosphere. The solar flare does not have any significant effect on the nightside ionosphere.

Keywords: Solar flares, Electron temperature, Ion temperature, SROSS-C2

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1 Introduction

Many atmospheric agencies may play important role in changing\(^1\text{--}^6\) the plasma temperature in F2-region of the ionosphere. One of them is the solar flare, which directly affects the ionosphere and radio communication on earth and also releases energetic particles into the space. These energetic particles accelerated in space are dangerous to astronomers and interfere with the electronic systems in satellite and spacecrafts. So, the effect of solar flare on the earth’s ionosphere has become the most important study of the day.

A flare is defined as a sudden, rapid and intense variation in brightness. A flare occurs when magnetic energy that has built up in the solar atmosphere is suddenly released\(^7\). Radiation is emitted across virtually the entire electromagnetic spectrum, from radio waves at long wavelengths through the optical emissions and X-rays to \(\gamma\)-ray at short wavelengths. The amount of energy released is equivalent to millions of 100-megaton hydrogen bombs exploding at the same time. As the magnetic energy is being released, particles, including electrons, protons and heavy nuclei, are heated and accelerated\(^8\text{--}^9\) in the solar atmosphere. The energy released during a flare is typically of the order of \(10^{27}\) erg/s. These radiations can travel a long distance in the planetary atmosphere and influence the plasma temperature and ion density.

Many researchers\(^7\text{,}^8\text{,}^10\text{--}13\) have studied the effect of solar flares using GPS and other satellite data\(^14\). Afraimovich et al.\(^10\) have studied the ionospheric effects of the solar flares of 23 Sep. 1998 and 29 July 1999 with the help of GPS network. They found that the fluctuation of total electron content (TEC) and its time derivative by removing the linear trend of TEC with a time window at about 5 min are coherent for all stations on the dayside earth and no such effect of solar flares was detected on the nightside of the earth. The effect of solar flares on the ionospheric F-region has also been studied\(^13\text{,}14\) by VHF radio beacon experiment on geo-stationary satellite and the TEC enhancement was noticed. Global observation of the outstanding flares of 7 Aug. 1972 using 17 stations in North America, Europe and Africa\(^14\) revealed that the TEC was increased by 15-30\% during the solar flares. The low latitudes showed a larger increase of TEC compared with the high latitude. Some events of solar flares have also been studied\(^13\text{,}15\) to see the effect on E- and F-region ionosphere and it has been found that the electron density was enhanced at these heights. Thome and Wagner\(^16\) theoretically studied the effect of solar flares on electron density and found that the
2 Experimental data and analysis

The SROSS-C2 satellite was launched by Indian Space Research Organization (ISRO) on 4 May 1994 to study the plasma composition and temperature anomalies. It has yielded valuable data on electron and ion temperatures ($T_e$ and $T_i$) and ion density over low latitude locations in the altitude range 425-625 km. It was successfully operating continuously for seven years and on 12 July 2001 returned to earth. The SROSS-C2 is the fourth satellite of the Stretched Rohini Series Satellite Programme of ISRO and it was designed, developed, fabricated and tested in ISRO Satellite Center (ISAC), Bangalore. The weight of this satellite was 114 kg, which carried 6 kg hydrazine fuel and generated 50 watt onboard power. The velocity of satellite was 7.8 km/s. It covered the geographic latitude belt of -31° to 34° and the longitude range 40-100°. The orbital inclination of the satellite was 46° with the equatorial plane. This is a spin-stabilized satellite with its spin axis perpendicular to its longitudinal axis and the rate of spin was 5 revolutions per minute (rpm). The satellite moved in the orbit keeping the spin axis perpendicular to the orbital plane. In this kind of orbital motion RPA sensors face the velocity vector once in each spin cycle of satellite. The angle between the sensor normal and satellite velocity vector keeps on changing from 0 to 360° at the rate of 30°/s.

The data collected during the period 1995-1998 have been analyzed for anomalous variation in the electron and ion temperatures. The data on solar flare have been obtained from National Geophysical Data Center (NGDC), Boulder, Colorado, USA. The International Reference Ionosphere (IRI) model data for the same period were downloaded from the Internet and these are used for the purpose of comparison.

The IRI is an international project sponsored by the Committee on Space Research (COSPAR) and the International Union on Radio Science (URSI). The IRI describes the median or average value of electron density, plasma temperatures (electron, ion and neutrals temperatures) and ion composition as a function of height, location, local time and sunspot number for magnetically quiet conditions. It is an empirical model based on the data from the worldwide network of ionosonde stations, incoherent scatter radar, the ISIS and Alouette topside sounders and in situ measurements by several satellites and rockets. The IRI-95 model data have been used in this paper to figure out the continuous variation of plasma temperature during quiet days. The SROSS-C2 measurements tally fairly well with the IRI model predictions for quiet conditions. We have used the IRI model to find out the extent of enhancement in plasma temperatures during disturbed conditions (solar flares) from quiet geomagnetic conditions taking it as pre-storm reference level.

It is a difficult task to study the plasma temperature using the satellite data during solar flares, because very rarely passes of satellite match the occurrence of solar flares at the meteorological data stations. Therefore, we have analyzed the data for ten stations during the period 1995-1998 over India. However, only three events have been found for electron temperature and three events for ion temperature, which correspond to solar flare activity over Bhopal (23.16° N, 77.36° E), Panji (15.30° N, 73.55° E) and Pune (18.31° N, 73.55° E). Data for electron and ion temperatures were obtained and the analysis was done for these locations for the altitude range of 425-625 km. Care has been taken to select the satellite data, which are free form diurnal, seasonal, latitudinal, longitudinal and altitude effects by selecting the appropriate data window at fixed locations with ±1° variation in longitude and latitude. A window of ±1° in latitude and longitude for the satellite observations at the meteorological data centre has enabled the latitudinal and longitudinal effects to be ineffective. The electron and ion temperatures data for preceding and succeeding days were selected as nearly at the same time of the days as that of the solar flare, which has made it free from the diurnal effect. During a satellite pass many data points were recorded at regular intervals, but on many occasions the RPA sensors could not record the electron and ion temperature data.

The plasma temperatures are influenced by various tropospheric disturbances as well as solar phenomena. Those solar flare events were chosen for present study.
which are free from other activities like sprites, blue jets, blue starters, elves and associated phenomena propagating from top of the active thunderstorm. These phenomena may play an important role in changing the plasma temperature and density. The selected satellite data are also free from thunderstorms activities, which have been verified by using the data of thunderstorms obtained from India Meteorological Department (IMD), Pune. The plasma temperature and density may also be influenced due to earthquakes. Care has been taken so that these six events are also free from earthquakes. All temperature data recorded by SROSS-C2 satellite are within the error limit of ± 50 K for the temperature range 500-5000 K.

3 Results and discussion

During 1995-1998, a total of six events of solar flares on the dayside of earth were found corresponding to the locations of Bhopal, Panaji and Pune. These stations were chosen on the basis of maximum passes of SROSS-C2 satellite to correspond the solar flare activity and also for having their IMD data, which provided the information of tropospheric disturbances at the above locations. It was ascertained that the events chosen are free from the thunderstorm and seismic activities. These events were also chosen during geo-magnetically quiet period.

Figure 1(a) shows $T_e$ during the solar flare activity at Bhopal. There was a solar flare from 0536 to 0610 hrs LT on 9 Nov. 1998. The SROSS-C2 satellite also passed during this time over Bhopal and almost similar passes (in latitude, longitude and altitude) of satellite were found in the preceding day (8 Nov. 1998) and on succeeding day (7 June 1995). The average $T_e$ on preceding day went up to 2174 K and on succeeding day up to 1820 K. During the solar flare activity it was enhanced up to 3328 K. This enhancement was 34.67% over preceding day and 45.31% over succeeding day. The IRI model for quiet conditions has also been plotted in the same figure.

Only one event was found to correspond at Panaji. On 10 July 1996 there was a solar flare from 1040 to 1116 hrs LT. The average $T_e$ was enhanced [Fig. 1(b)] up to 37.00% over succeeding day (11 July 1996). However, the data on preceding day of this event was not available. Figure 1(c) shows the enhancement in $T_e$ at Pune during the solar flare of 5 June 1995 (0854-1002 hrs LT). The average $T_e$ was enhanced up to 38.67% from the preceding day and 32.05% from the succeeding day (7 June 1995).

The ion temperature is also enhanced during the solar flare activity. The enhancement in $T_i$ has been found to be less than that in $T_e$. Figure 2(a) shows $T_i$ during solar flare at Bhopal. There was a solar flare from 0536 to 0610 hrs LT on 9 Nov. 1998. The SROSS-C2 satellite also passed during this time over Bhopal and almost similar passes of satellite were found in preceding day (8 Nov. 1998) and the succeeding day (10 Nov. 1998). The average $T_i$ on preceding day went up to 1093 K and up to 1020 K on the succeeding day. During solar flare it was enhanced up to 1140 K. This enhancement of average $T_i$ was 4.12% over the preceding day and 10.52% over the succeeding day.

One event was found to correspond at Panaji. On 19 May 1995, there was a solar flare from 1640 to 1702 hrs LT. The average $T_i$ was enhanced [Fig. 2(b)] up to 20.97% over the preceding day and 16.78% over the succeeding day (20 May 1995). Figure 2(c) shows the enhancement in $T_i$ at Pune during the solar flare. On 28 Dec. 1998, there was a solar flare from 0902 to 0950 hrs LT. The average $T_i$ was enhanced up to 21.95% over the preceding day (25 Dec. 1998) and up to 10.97% over the succeeding day (30 Dec. 1998).

The average electron and ion temperatures during solar flares and preceding and succeeding quiet days (free from other activities) have been shown in Table 1.

These enhancements have been found in the dayside of the earth’s ionosphere due to solar flares. To see the effect of solar flares on nightside on the ionosphere we have found two events above Chennai (13.04° N, 80.17° E) and Panaji. At Chennai the SROSS-C2 data were available for the solar flare event of 2 Feb. 1997 (1904-2118 hrs LT) and for Panaji on 4 May 1998 (2212-2300 hrs LT). Both the solar flares were after the sunset over India. No significant changes were found in $T_e$ and $T_i$ over the aforesaid locations during the solar flares. Thus, it may be concluded that the solar flares do not affect the nightside ionosphere. A similar investigation has been done during flares events on 23 Sep. 1998 and 29 July 1999 by Afraimovich et al., with the help of GPS network data. Some events of solar flares have also been studied to see the effect on E- and F-region ionosphere and it has been found that the electron density was enhanced at the height of 300 km (F2) region. The present studies are almost at similar
Fig. 1—Variations of $T_e$ at (a) Bhopal (M P), (b) Panaji (Goa) and (c) Pune (Maharashtra) along with IRI-95.
Fig. 2—Variations of $T_i$ at (a) Bhopal (M P), (b) Panaji (Goa) and (c) Pune (Maharashtra) along with IRI-95
height (F2-region) and reveal an enhancement in $T_e$ and $T_i$.

For the present study only those satellite passes have been considered which were free from thunderstorm activity, because lightning and sprites are also known to increase the plasma temperature\(^6\). The thunderstorms data are available only for fixed locations. Therefore, the satellite passes at those fixed locations where thunderstorms are available, have been considered.

The enhancement in ion production and plasma temperature is mainly due to production of X-rays during a solar flare\(^2\). These X-rays reach the earth’s ionosphere about 8 min after the occurrence of the solar flare\(^18\). Therefore, the time difference between the occurrence of solar flare and the ionospheric heating is not very large.

The geomagnetic storm is markedly temporary disturbances of the earth’s magnetic field. It is thought that the geomagnetic storms are produced by the influx of a greater than the normal amount of solar particles released from the sun during a flare. The solar particles reach the ionosphere after about 100 h with its normal velocity 400 km/s. Thus, the present correlations are not due to the geomagnetic disturbances caused by the solar flares.

4 Conclusions

This study brings out the fact that the solar flare is an important factor in changing the plasma temperature. The average electron temperature enhancement has been found to be 32.05-45.31% during the solar flare. However, the average ion temperature is enhanced from 4.12% to 21.95% only. The enhancement in ion temperature has been found to be less than that in electron temperature. The effect of solar flare on the nightside plasma temperatures has not been detected in the altitude range 425-625 km.

<table>
<thead>
<tr>
<th>Locations (in India)</th>
<th>Preceding day</th>
<th>During solar flare</th>
<th>Succeeding day</th>
<th>Preceding day</th>
<th>During solar flare</th>
<th>Succeeding day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhopal, Madhya Pradesh (23.16° N, 77.30° E)</td>
<td>2174</td>
<td>3328</td>
<td>1820</td>
<td>1093</td>
<td>1140</td>
<td>1020</td>
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<tr>
<td>Panaji, Goa (15.30° N, 73.55° E)</td>
<td>*</td>
<td>2059</td>
<td>1297</td>
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<tr>
<td>Pune, Maharashtra (18.31° N, 73.55° E)</td>
<td>1538</td>
<td>2508</td>
<td>1704</td>
<td>1280</td>
<td>1640</td>
<td>1460</td>
</tr>
</tbody>
</table>

*SROSS-C2 data were not available.

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References