Effect of solar activity on ionospheric temperatures in F2 region

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Ionospheric F-region is very dynamic and highly depends on the solar cycle. In the present study almost half of the solar cycle from January 1995 to December 2000 (from solar minimum to solar maximum) satellite data were used. The data were recorded with the help of Retarding Potential Analyzer (RPA) payload aboard Indian SROSS-C2 satellite at an average altitude of 500 km over the Indian region. The data analysis shows that the nighttime average ionospheric electron and ion temperatures show a positive correlation with solar activity. However, the sunrise peak values show anti-correlation with solar activity. Further the ratio of sunrise average peak value and nighttime average show a negative correlation with the solar activity, both for electron and ion temperatures. A sudden enhancement at sunrise has been observed during all seasons, in both electron and ion temperatures. Comparison of the measured ionospheric electron and ion temperatures with the predicted values from the international reference ionosphere (IRI) reveals that the peak during sunrise hours is slightly underestimated by the IRI model.

Keywords: F2 region, Ionospheric, temperature, Solar activity, RPA payload
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1 Introduction

The main energy source responsible for space and time variations of meteorological parameters is the visible / infrared solar radiation intercepted by the earth. Also the upper atmosphere (ionosphere) arises from ionization of different constituent gaseous molecules by the atmospheric absorption of solar radiations of the wavelength less than 1026 Å. It should be expected that the change in solar energy or in its distribution would produce changes in climate and also in the ionosphere. It is well known that solar activity is not constant. It has a periodicity of approximately 11 years, whose most obvious aspect is the sunspot number. There have been many attempts to correlate solar activity variation with climate. The first convincing statistical results which enabled a relationship to be established between climate and solar activity were given by Labitzke and Van.

The electron temperature variations at the F2 layer peak height during the month of September 1999 have been studied by Gulyaeva et al. They found that the magnetic activity does not influence the electron temperature at low and equatorial latitudes, while at mid-latitudes a high degree of correlation with the F2 peak plasma heating exists. They also found the effects at sunrise and sunset.

The temporal and spatial variations of the electron density and temperature in the topside ionosphere have been studied at an altitude of 600 km with the help of Japanese satellite Hinotori. But the Hinotori data are limited to a period of medium and high solar activity. Hanson et al. observed the variation in electron and ion temperatures with the OGO-6 satellite near the magnetic equator above 500 km altitude. They showed that equatorial troughs of electron and ion temperatures occur in the topside ionosphere during nighttime. The plasma cooling was also measured by ISS-b satellite at ~ 1100 km altitude.

The aim of the present study is to investigate the effect of solar activity variation on the ionospheric electron and ion temperatures over the F2 region ionosphere using the data recorded by SROSS-C2 satellite launched by Indian Space Research Organization (ISRO).

2 Data selection and analysis

The ionospheric electron and ion temperatures were measured by the Retarding Potential Analyzer (RPA) payload aboard the Indian SROSS-C2 satellite, which was launched by Indian Space Research Organization (ISRO) 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 in the orbit 630 × 430 km altitude with an inclination of 46° to the equatorial plane. It was successfully operated continuously for seven years and on 12 July 2001 re-entered the earth’s atmosphere. It covered geographic latitude belt of 31°S to 34°N and the longitude range from 40°E to 100°E. A detailed description of RPA payload design and its fabrication have been given by Garg and Das. The satellite was moving with the velocity of 7.8 km/s.

The satellite data have been selected over Indian region from 5°N to 34°N latitude and 65°E to 95°E longitudes, which covers the maximum passes of the SROSS-C2 satellite over Indian region. The measured electron and ion RPA data have been analyzed to see the variations in the electron and ion temperatures during low to high solar activity and also for studying the seasonal variations in the effect of solar activity on electron and ion temperatures. The observations are also used to assess the predictability of the IRI-95 in estimating electron and ion temperatures over the Indian region covered by the SROSS-C2 satellite.

3 Results and discussion

To study the effect of solar activity on ionospheric electron and ion temperatures, data measured by RPA have been analyzed for half of the solar cycle. Both the measured electron temperature and ion temperature variations have been obtained by computing hourly average and the same are presented in Figs 1 and 2, respectively for the years 1995-2000. Figure 1 shows the clear peak during the sunrise hours and also a diffused peak corresponding to the secondary enhancement in electron temperature during evening hours. However, for ion temperature the sunrise peak

![Figure 1: Diurnal variation of electron temperature for different years.](image-url)
and evening temperature enhancement is smaller than electron temperature, which is shown in Fig. 2.

It has been observed that the electron temperature sharply rises during the sunrise hours (0530-0630 hrs LT) and a secondary enhancement has also been observed during the sunset hours (1630-1730 hrs LT) throughout the half solar cycle. However, the sunrise peak enhancement in the ion temperature has been observed almost 1 h delayed to the peak enhancement of the electron temperature throughout the half solar cycle. For the ion temperature the peak values have been observed at about 0700 hrs LT (hourly average 0630-0730 hrs LT) while the evening enhancement time was similar to the enhancement time of electron temperature.

In the year 1995, the nighttime average electron temperature was around 800 K and sharply rises during the sunrise hours to about 3800 K. In 1996, the nighttime average electron temperature was about 750 K and sharply rises to about 3400 K during sunrise. After a fall the nighttime average electron temperature continuously increased from the year 1997 towards the high solar activity year (2000), while the sunrise peak values show an opposite trend. Similar trends for the nighttime as well as sunrise enhancements in the average ion temperature have been observed.

The pre-sunrise ion temperature enhancement in the low- and mid-latitude ionosphere at 600 km has also been reported recently by Chao et al. The spatial and temporal variations of the electron temperature at equatorial anomaly latitudes have also been studied by Su et al. using the Hinotori satellite at about 600 km. They have observed similar morning rise in electron temperature. Thus the results obtained from SROSS-C2 satellite data are consistent to that from the Japanese satellite ‘Hinotori’.

Fig. 2—Diurnal variation of ion temperature for the years (a) 1995, (b) 1996, (c) 1997, (d) 1998, (e) 1999 and (f) 2000, measured by SROSS-C2 satellite.
To study the seasonal behaviour of electron and ion temperatures, the RPA data have been analyzed for three different seasons: summer (May, June, July and August), winter (November, December, January and February) and equinoxes (March, April, September and October) from the solar minimum year to solar maximum year. However, one year figures (1995) have only been presented to reduce the number of figures and improve the presentation quality. Smoothing of the measured temperature variations have been done by computing hourly averages and calculating their standard deviations; these are presented in Figs 3 and 4 for the electron and ion temperatures, respectively. In Figs 3 and 4 the measured temperature data are also compared with the values from the IRI-95 model for the same time and location.

It has been observed that the electron temperature rises sharply during the sunrise hours (0530-0630 hrs LT), and a secondary enhancement has also been observed during the sunset hours (1630-1730 hrs LT) for all seasons. The seasonal average values of electron and ion temperatures during sunrise, sunset, daytime and nighttime for three seasons (summer, winter and equinox) have been presented in Table 1.

<table>
<thead>
<tr>
<th>Seasons</th>
<th>Electron Temperature, K</th>
<th>Ion Temperature, K</th>
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</thead>
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<td></td>
<td>Maximum at sunrise</td>
<td>Maximum at sunset</td>
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<tr>
<td>Summer</td>
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</tr>
<tr>
<td>Winter</td>
<td>3500</td>
<td>1900</td>
</tr>
<tr>
<td>Equinox</td>
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Table 1—Seasonal average values of ionospheric electron and ion temperatures at an altitude ~ 500 km measured by SROSS-C2 satellite.
The IRI-95 model-estimated values show a good agreement with the measured values of electron temperature during the night hours. The sunrise enhancements are also evident in the IRI predicted values. However, the values are under-estimated in comparison with the measured values. The IRI model-predicted values do not show the secondary enhancements in electron temperature. Ion temperature enhancements during sunrise and sunset hours (Fig. 4) have also been observed. However, their magnitudes are smaller than the corresponding enhancements of electron temperatures (Fig. 3). The IRI-95 model predicted values show a general increase in daytime ion temperature, but there are no specific peaks in ion temperature at sunrise or sunset in the IRI model values.

The ratio of sunrise peak value and nighttime average electron temperature is shown in Fig. 5(a) for half of the solar cycle. It has been found that the electron temperature is much enhanced to about 4.6 times over the nighttime average temperature. It linearly decreased with increasing solar activity. The sunset peak value and nighttime average electron temperature ratio also linearly decreased, which is shown in Fig. 5(b). This shows that the ratio of sunrise and sunset peak value and nighttime average electron temperature are highly correlated to the solar activity. The correlation coefficient value is almost unity (greater than 0.9) for both conditions (sunrise and sunset). A similar trend has been shown [Figs 6(a) and (b)] by the ion temperature ratio during solar minima towards solar maxima. Annual average values of ionospheric electron and ion temperatures during sunrise, sunset, daytime and nighttime from solar minimum to solar maximum year have been shown in Table 2.

The solar EUV flux affects the ionospheric temperatures through several mechanisms. An enhanced flux gives rise to more photoelectrons, which in turn elevate plasma temperatures by heating processes. Meanwhile, the increased electron density
leads to an enhanced electron cooling rate, which may lead to lower electron temperature. The actual response of ionospheric temperatures to a change in solar EUV is a result of two competing processes. In summer when the level of electron density is low, a larger EUV flux results in a lower electron temperature, because the heating rate increases more significantly than the cooling rate; in winter when electron density is high, a larger EUV flux results in a higher electron temperature. An evening enhancement has also been observed in both temperatures. It was 1.5-2.6 times for the electron temperature and for ion temperature 1.3-1.8 times over the average nighttime temperatures.

4 Conclusions

The effect of solar activity variation on the ionospheric electron and ion temperatures over the F2 region ionosphere has been studied from solar minimum year to solar maximum year using the data recorded by SROSS-C2 satellite. This study reveals that the electron and ion temperatures are lowest during night and show at least two peak values with different magnitudes. This sunrise enhancement was 2.8-4.6 times for electron temperature and for ion temperature it was 1.2-2.2 times over the nighttime average temperature during high solar activity to low solar activity. An evening enhancement has also been observed in both temperatures. It was 1.5-2.6 times for the electron temperature and for ion temperature 1.3-1.8 times over the average nighttime temperatures.

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References

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Table 2—Annual average values of ionospheric electron and ion temperatures from solar minimum year to solar maximum year

<table>
<thead>
<tr>
<th>Year</th>
<th>Electron Temperature, K</th>
<th>Ion Temperature, K</th>
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<tr>
<td></td>
<td>Maximum at sunrise</td>
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