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Effect of lightning on ionospheric temperature determined by SROSS-C2 satellite

D K Sharma & Jagdish Rai

Department of Physics, Indian Institute of Technology, Roorkee 247 667

and

M Israil

Department of Earth Sciences, Indian Institute of Technology, Roorkee 247 667

and

P Subrahmanyam, P Chopra & S C Garg

Radio & Atmospheric Sciences Division, National Physical Laboratory, New Delhi 110 012

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The ionospheric temperature in relation with the thunderstorm activity has been studied. The data were obtained by the RPA payload aboard Indian SROSS-C2 satellite, which has yielded valuable information on electron and ion temperatures (T_e and T_i) over low latitude locations in the altitude range 425-625 km. The data collected during solar minimum period from 1995 to 1996 have been analyzed for anomalous variations in topside plasma temperature (electron and ion temperature). The data on thunderstorm have been obtained from IMD. The T_e is found to increase by 1.2-2.7 times during the thunderstorm activity when compared with the normal days, while T_i increases by about 1.2-2.4 times for the same period. The enhancements in T_e and T_i have been attributed to the production of UHF-gamma radiations during a lightning sprite which propagates upward to the height of interest.

1 Introduction

The ionospheric weather has become an important phenomenon in nature. The ion and electron temperature fluctuations are associated with the ionospheric structure and tropospheric disturbances. In the fluctuation of ionospheric temperature the lightning sprites may play a significant role. Sprites are the huge but weakly luminous flashes that appear directly above an active thunderstorm system and are coincident with cloud-to-ground or intra-cloud lightning discharges. Their spatial structures range from small, single or multiple and vertically elongated spots and the spots with faint extrusions above and below, to bright groupings extending from the cloud tops to altitudes up to about 95 km. The brightest region lies in the altitude range 65-75 km, above which there is often a faint red glow or wispy structure that extends[1,2] to about 90 km. Below the bright red region, blue tendril-like filamentary structures often extend downward to as low as 40 km. Sprites rarely appear singly, usually occurring in clusters of two, three or more. Following their emergence from the top of the thundercloud, they propagate upward at a vertical speed of roughly 100 km/s, disappearing in the height range 40-95 km. In the fluctuations of mesospheric electric field, in the variation of the electrical conductivity of the atmosphere from cloud top to the ionosphere and in the changes of the ionospheric temperature, the lightning sprites[3-6] may play the significant roles.

During last four decades the ionosphere has been studied extensively. These studies include[7-9] experiments as well as theoretical simulations. The experimental study can be done by using balloons, rockets, satellite, coherent and incoherent scatter radar, magnetometers and a number of ground-based instruments. No satellite-based clear study of the F2 region of the ionosphere has been made during the thunderstorm activity. Therefore, in the present work, we have studied the effect of thunderstorms on ionospheric temperatures (T_e and T_i). For this purpose, the data from RPA payload aboard Stretched Rohini Series Satellite (SROSS-C2) have been used. The SROSS-C2 was launched by ISRO on 4 May 1994 to study the ionospheric composition and temperature anomalies. The simultaneous data of thunderstorms were obtained from India Meteorological Department (IMD).

2 Experimental data and analysis

It is a difficult task to study the ionospheric temperature during thunderstorms activity using the satellite data, because very rarely the passes of the satellite match the thunderstorm activity at the given meteorological data stations. The data for ten stations during the solar minimum year (1995-1996) over India have been analyzed. However, only four events have been found which correspond to thunderstorm activity over Bhopal (23.16°N, 77.36°E) and Trivandrum (08.29°N, 76.59°E). The data for electron and ion temperatures were obtained by RPA payload aboard SROSS-C2 satellite.

The RPA payload consists of two sensors, viz. electron and ion sensors and associated electronics. The electron and ion RPAs are used for *in situ* measurements of ionospheric electron and ion parameters. In addition, a spherical Langmuir probe is included and is used as a potential probe for estimating the variation of spacecraft potential during spinning of the satellite. The electron and ion sensors both have planar geometry and consist of multi-grid Faraday cups with a collector electrode. The different grids in the sensor are designated as the entrance grid, the retarding grid, the suppressor grid and the screen grid. These grids are made of gold-plated tungsten wire mesh having 90-95% optical transparency. The two sensors are mechanically identical but have different grid voltages suitable for the collection of electrons and ions, respectively. The charged particles whose energies are greater than the applied voltage on the retarding grid pass through various grids and finally reach the collector electrode to cause the sensor current. This current is measured by a linear auto-gain ranging electrometer.

The analysis was done for the aforesaid two locations in India for the altitude range 425-625 km. The vertical profile of electron and ion temperatures has been obtained at fixed locations with ±1° variation in longitude and latitude. The IRI-90 model[10] data for the same period were downloaded from the Internet. The IRI-90 is an empirical model containing representative vertical profile of the main parameters, characterizing the ionospheric plasma, namely, the electron density, electron temperature, ion temperature and ion composition.

3 Results

The variations of electron and ion temperatures at two locations Bhopal and Trivandrum along with IRI model have been shown in Figs 1 and 2. The variations in T_e at Bhopal are shown in Fig. 1[(a) and (b)] and for Trivandrum in Fig. 1[(c) and (d)]. The T_i is shown in Fig. 2[(a) and (b)] and Fig. 2[(c) and (d)] for Bhopal and Trivandrum, respectively. Each figure is divided into three parts, representing preceding day, succeeding day (date mentioned) and active thunderstorm day (mid part). These are the dates of passes of satellite above Bhopal and Trivandrum. These stations were chosen for the maximum number of passes of the satellite SROSS-C2 and meteorological data centre to provide the data for the same period on thunderstorm. The passes in the range

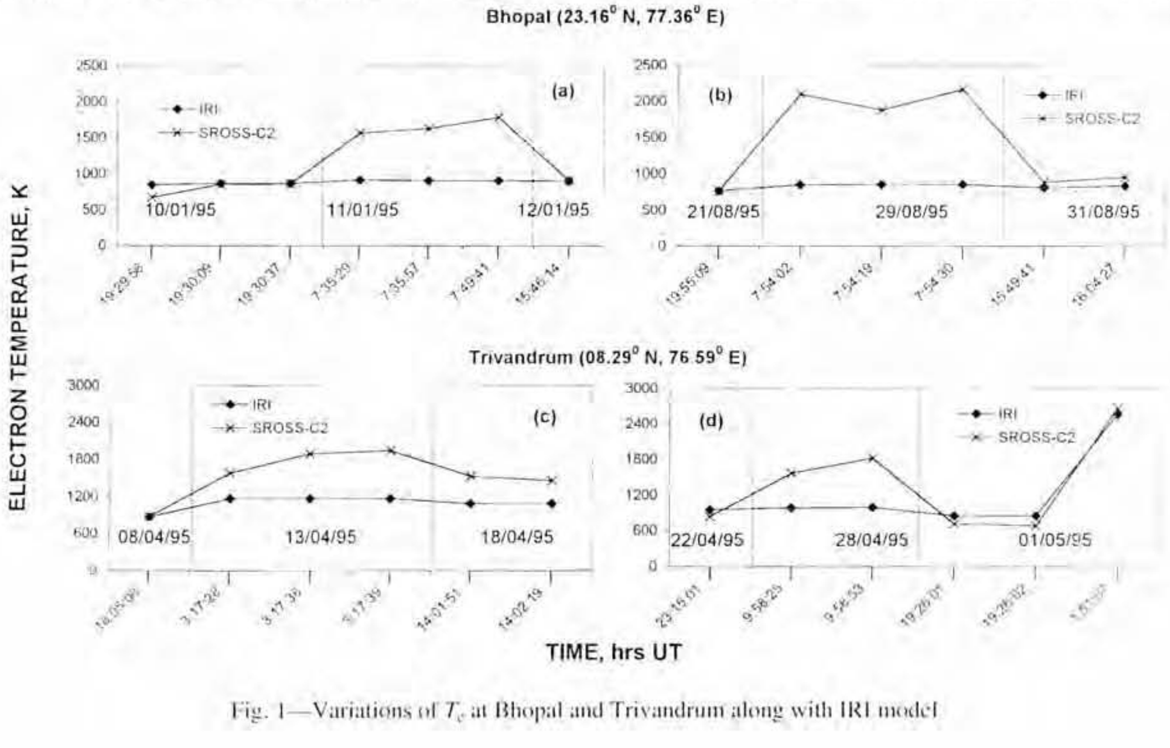

Fig. 1—Variations of T_e at Bhopal and Trivandrum along with IRI model

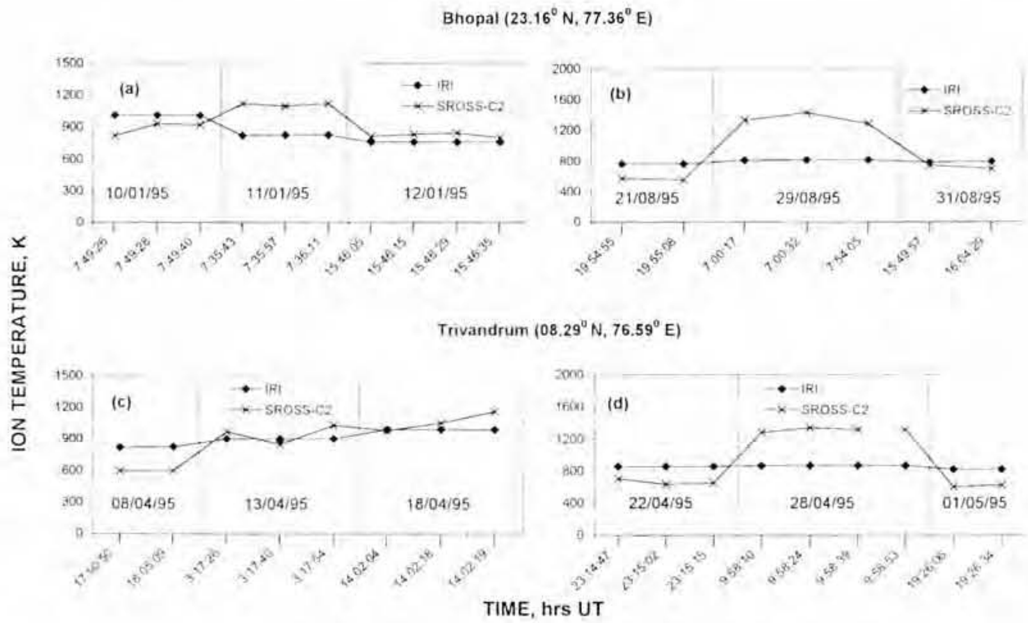

Fig. 2—Variations of T_i at Bhopal and Trivandrum along with IRI model

Table 1—SROSS-C2 satellite data along with IRI values of electron temperature (T_e) during 1995

Date	Time hrs	Time min	Time sec	Long. deg.	Lat. deg.	Alt. km	$(T_e)_{sat}$	$(T_e)_{iri}$	
				Bhopal (23.16°N, 77.36°E)					
January									
10	19	29	58	75.9	23.6	595.1	674	855	
10	19	30	10	76.4	23.1	595.9	861	868	
10	19	30	38	77.7	22.0	597.7	862	873	
11	7	35	30	75.9	22.5	434.8	1569	915	
11	7	35	58	77.3	23.7	434.2	1629	906	Lightning
11	7	49	41	78.3	22.3	432.9	1785	907	Activity
12	15	46	14	77.2	23.2	526.4	911	903	
August									
21	19	55	9	76.7	22.4	430.9	759	766	
29	7	54	3	76.3	22.1	610.6	2094	848	
29	7	54	20	77.1	22.8	610.1	1881	849	Lightning
29	7	54	31	77.6	23.2	609.7	2166	850	Activity
31	15	49	42	76.0	23.0	472.6	884	806	
31	16	4	27	77.6	23.7	467.2	949	836	
				Trivandrum (8.29°N, 76.59°E)					
April									
8	18	5	8	77.1	7.4	597.8	871	862	
13	3	17	28	76.1	8.7	431.1	1575	1162	
13	3	17	39	76.6	8.2	430.9	1892	1164	Lightning
13	3	17	40	76.6	8.2	430.9	1941	1163	Activity
18	14	1	52	76.8	7.5	613.0	1525	1082	
18	14	2	20	77.9	8.8	613.7	1453	1083	
22	23	15	1	76.4	7.7	475.7	828	947	
28	9	58	25	76.6	7.8	557.7	1564	978	Lightning
28	9	58	54	77.7	9.0	560.4	1821	984	Activity
May									
1	19	26	1	77.9	8.3	550.6	701	839	
1	19	26	2	77.4	8.8	551.7	677	839	
1	1	51	7	76.8	9.0	431.0	2657	2562	

Table 2—SROSS-C2 satellite data along with IRI values of ion temperature (T_i) during 1995

Date	Time hrs	Time min	Time sec	Long. deg.	Lat. deg.	Alt. km	$(T_i)_{sat}$	$(T_i)_{iri}$	
				Bhopal (23.16°N, 77.36°E)					
January									
10	7	49	27	77.6	21.6	433.2	820	1010	
10	7	49	28	77.6	21.7	433.1	930	1011	
10	7	49	41	78.2	22.3	432.9	920	1011	
11	7	35	43	76.6	23.1	434.5	1120	823	Lightning Activity
11	7	35	57	77.2	23.7	434.2	1100	824	
11	7	36	11	77.9	24.3	433.9	1120	825	
12	15	45	46	75.9	24.3	523.7	810	759	
12	15	46	0	76.6	23.7	525.0	830	759	
12	15	46	15	77.2	23.1	526.4	840	759	
12	15	46	29	77.9	22.6	527.8	800	759	
August									
21	19	54	54	76.0	23.0	431.1	570	762	
21	19	55	8	76.6	22.4	430.9	550	762	
29	7	54	4	76.4	22.2	610.5	1330	811	Lightning Activity
29	7	0	18	77.0	22.7	610.1	1430	812	
29	7	0	32	77.7	23.3	609.7	1280	814	
31	15	49	57	76.7	22.3	471.2	740	780	
31	16	4	29	77.7	23.6	467.1	700	793	
				Trivandrum (8.29°N, 76.59°E)					
April									
8	17	50	50	75.9	8.7	600.9	600	822	
8	18	5	9	77.2	7.4	597.7	600	825	
13	3	17	26	76.1	8.8	431.1	970	900	Lightning Activity
13	3	17	41	76.7	8.1	430.9	850	900	
13	3	17	55	77.2	7.5	430.7	1030	901	
18	14	2	4	77.3	8.1	613.3	980	989	
18	14	2	18	77.8	8.7	613.6	1050	989	
18	14	2	19	77.9	8.8	613.7	1160	989	
22	23	14	47	75.9	8.3	476.9	700	854	
22	23	15	1	76.4	7.7	475.7	630	855	
22	23	15	16	77.0	7.0	474.4	650	855	
28	9	58	11	76.0	7.1	556.4	1280	868	Lightning Activity
28	9	58	25	76.5	7.8	557.7	1340	865	
28	9	58	39	77.1	8.4	559.0	1320	867	
28	9	58	53	77.7	9.0	560.3	1320	866	
May									
1	19	26	6	77.3	8.9	551.0	600	820	
1	19	26	34	78.4	7.6	549.0	620	820	

±1° in longitude and latitude (Tables 1 and 2) were taken for the present study.

At Bhopal, the T_e [Fig. 1{(a) and (b)}] in the preceding day goes up to 850 K and up to 950 K in the succeeding day, but during the lightning activity the temperature shows a significant change and increases up to 2200 K in both the events. The T_e at Trivandrum [Fig. 1{(c) and (d)}] in the preceding day is the same as that at Bhopal and during the lightning activity goes up to 2000 K. On the succeeding day, the T_e has decreased [Fig. 1(d)], but the temperature after 19:26:02 hrs UT becomes too high. However, a glance at Table 1 shows that by that time the satellite had come to an altitude of 431 km from 551.7 km.

The T_i shows [Fig. 2{(a) and (b)}] significant changes during the lightning activity. The T_i at Bhopal on the preceding day goes up to 930 K and on succeeding day up to 850 K, but it is higher during the lightning activity and goes up to 1500 K. The behaviour of T_i at Bhopal is the same as that for Trivandrum [Fig. 2{(c) and (d)}]. These variations of T_e and T_i show good agreements with IRI on preceding and succeeding days.

The enhancement of the ionospheric temperatures can be attributed to the effect of lightning discharges[11-14]. The lightning sprites propagating from cloud top to the ionosphere may generate radiations from UHF to gamma ray frequencies[15], which, in turn, may propagate still upwards to the height of interest to heat the local plasma. Even the cloud-to-ground and intra-cloud lightning discharges are known to produce the runaway electrons[16,17] which generate UHF emissions, X-rays and gamma rays due to Bremsstrahlung[18] propagating upwards to the ionosphere. However, to come to any conclusion, one needs theoretical calculations, which is beyond the scope of this paper.

4 Conclusions

The present study reveals the fact that the electron and ion temperatures are highly affected by the lightning activity. During the lightning activity, T_e in the ionosphere is increased by 1.2-2.7 times, while T_i is increased by 1.2-2.4 times.

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