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Lightning induced heating of the ionosphere

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RESUMEN

Se estudiaron las anomalías de temperatura iónicas y eléctricas inducidas por los duendes (*sprites*) asociados con las tormentas en la región F_2 de la ionosfera. Para esta investigación los datos se obtuvieron del Analizador de Potencial Retardado (RPA por sus siglas en inglés) del vuelo experimental a bordo del satélite hindú SROSS-C2 durante el año solar mínimo 1995-96. Los datos de la actividad de las tormentas se obtuvieron del Departamento Meteorológico de la India (IMD). El análisis de los datos y la comparación con los días de temperatura normal demostró un aumento consistente de ésta en asociación con la actividad de los duendes durante las tormentas. La región física de este aumento de temperatura puede estar relacionada con la generación de frecuencias, desde UHF hasta rayos gama, debido a la actividad de los duendes de los rayos que se propagan hacia arriba hasta la altitud del satélite (Taranenko y Roussel-Dupre, 1996; Lehtimen *et al*., 1996) y calientan el plasma local en la ionosfera.

ABSTRACT

The ion and electron temperature anomalies induced by the sprites associated with active thunderstorms in the ionosphere F_2 region have been studied. For this study the data was obtained by the Retarded Potential Analyzer (RPA) payload experiment flown aboard the Indian SROSS-C2 satellite for the solar minimum year 1995-96. The data on thunderstorm activity has been obtained from the India Meteorological Department (IMD). The data analysis and comparison with the normal day's temperature demonstrate the consistent enhancement during the sprites associated with active thunderstorms. The physical region for this temperature enhancement may be related to the generation of UHF to gamma ray frequencies due to lightning sprite activity, which propagate still upward at the satellite altitude (Taranenko and Roussel-Dupre, 1996; Lehtimen *et al*., 1996) and heat the local plasma in the ionosphere.

Key words: Ionospheric temperature, thunderstorms, sprites

1. Introduction

In recent years sprites have been observed as an atmospheric phenomena and are formed by massive but weak luminous flashes that appear directly above an active thunderstorm system (Sentman and Wescott, 1993; Sentman *et al*., 1995). They are coincident with cloud-to-ground or intracloud lightning strokes, and their spatial structures range from small single or multiple vertically elongated spots to bright groupings that extend from the cloud tops up to about 95 km. Sprites are predominantly red. The brightest region lies in the altitude range from 65-75 km, above which there is often a faint red glow or wispy structure that extends 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. Some of the very large events, such as shown in Figure 1, seem to be tightly packed clusters of many individual sprites. Other events are more loosely packed and may extend across horizontal distances of 50 km or more and occupy atmospheric volumes in excess of 10,000 km^3. Blue jets are a second high altitude optical phenomenon distinct from sprites that are observed above thunderstorms. As their name implies, blue jets are optical ejections from the top of the electrically active core regions of thunderstorms. Following their emergence from the top of the thundercloud, they typically propagate upward in narrow cones of about 15 degrees full width at vertical speeds of roughly 100 km/s, fanning out and disappearing at heights of about 40-50 km (Wescott *et al*., 1995).

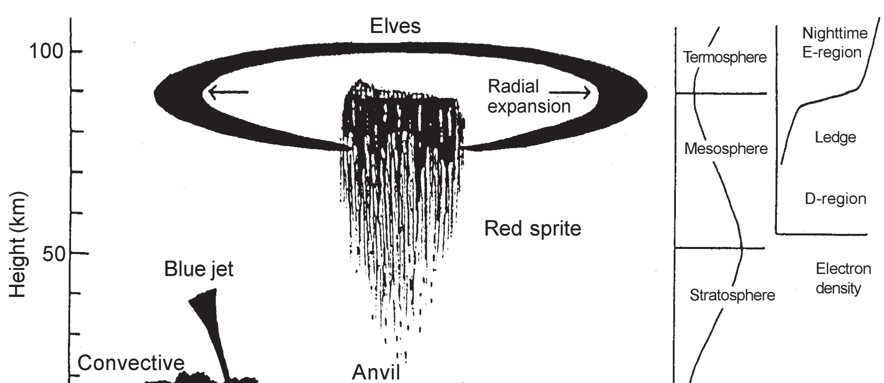

Fig.1. Upper atmospheric optical emissions excited by thunderstorms.

The plasma temperature at low and mid latitudes is mainly sensitive to three physical processes, namely the electron heating by photoelectrons, electron cooling by heat transfer to the colder ion and neutrals, and heat transport due to thermal conduction. The sprites associated with active thunderstorms may affect the electric field, conductivity and the temperature of the stratosphere, mesosphere and ionospheric regions (Gupta, 1997; Otsuyama, 1999) may play a significant role. Many researchers (Taranenko, 1992; Pasko *et al*., 1995; Wiscott *et al*., 1996; Yukhimuk *et al*., 1998; Eack *et al*., 2000; Singh *et al*., 2001 and others) have extensively studied the effect of sprites on the ionosphere.

In the present study the effect of sprites associated with active thunderstorms and in coincidence with the lightning on the ionospheric temperature has been studied. The study has been conducted for the low latitude region in the altitude range of 425-625 km over Bhopal (23.16° N, 77.36° E) and Trivandrum (08.29° N, 76.59° E) in India using the electron and ion temperature data recorded by the Retarded Potential Analyzer (RPA) aboard Stretched Rohini Series Satellite (SROSS-C2). The thunderstorms data were obtained from the India Meteorological Department (IMD) for the above locations.

2. Experimental data and analysis

The electron and ion temperature data were recorded using the Retarded Potential Analyzer (RPA) aboard the SROSS-C2 satellite, which was launched by ISRO on May 4, 1994 to study the ionospheric temperature anomalies. The RPA payload consists of two sensors, viz. electron and ion sensors and associated electronics (Garg and Das, 1995). The electron and ion RPAs are used for in situ measurements of ionospheric electron and ion temperatures. 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, which gives the value of electron and ion temperature.

For the present study it is essential to match the active thunderstorm's duration with the location and time the satellite passes. The satellite passes rarely match with the time and location of the active thunderstorm. In the present analysis, we have used the electron and ion temperatures data for solar minimum year 1995-96. The time and location matching have resulted only four events at two different locations corresponding to Bhopal and Trivandrum. Care has also been taken to select the satellite data, which is free from diurnal, seasonal, latitudinal, longitudinal and altitudinal effects. This has been done statistically by taking an average of electron and and ion temperature data on 15 normal days before and after the active thunderstorm. To remove the latitudinal and longitudinal effects, a satellite data window of 5° in latitude and longitude with respect to thunderstorm location has been chosen in the altitude range from 425-625 km.

To see the effect of solar flare activity, the data on solar flares were obtained from the National Geophysical Data Center (NGDC), Boulder, Colorado (USA). Only those thunderstorm days that are free from solar flares have been considered. Thus, any temperature anomalies recorded during the active thunderstorm events selected may be considered as the temperature effect induced by the sprite associated with the active thunderstorm.

3. Results and discussion

The electron and ion temperature anomalies recorded during the sprites associated with the active thunderstorms at two locations for the four different events are shown in Figures 2 and 3.

Two events of the active thunderstorm were recorded in Bhopal. On January 11, 1995 an active thunderstorm was recorded. During the normal days the average electron temperature was up to 1457° K and enhanced up to 1940° K (Fig. 2a) during the sprites associated with the active thunderstorm. The average ion temperature on normal days was up to 960° K and went up to 1151° K

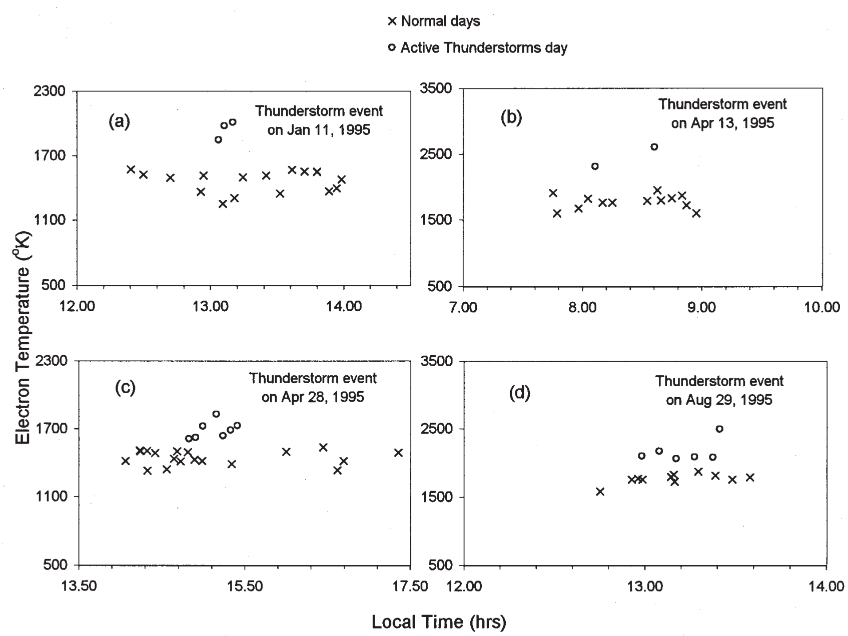

Fig. 2. Variation of electron temperature during thunderstorm and normal days for the events recorded in Bhopal (a, d) and Trivandrum (b, c) in 1995.

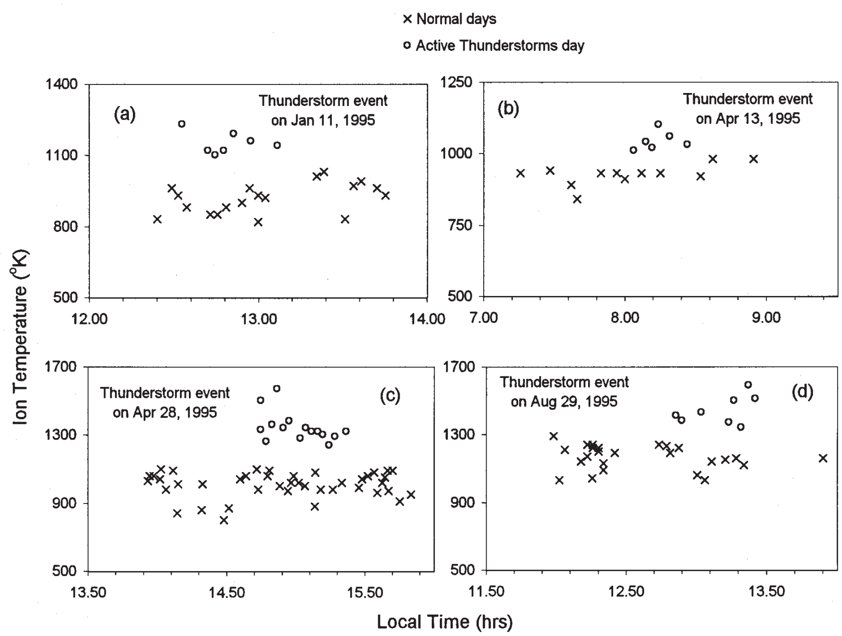

Fig. 3. Variation of ion temperature during thunderstorm and normal days for the events recorded in Bhopal (a, d) and Trivandrum (b, c) in 1995.

(Fig. 3a) during the sprites associated with the active thunderstorm. Thunderstorm activity was also recorded on August 29, 1995. During this event the average electron temperature was enhanced up to 2160° K over the normal day's average temperature 1762° K (Fig. 2d). The average ion temperature on normal days was up to 1167° K and enhanced up to 1441° K (Fig. 3d) during the sprites associated with the active thunderstorm.

Two events of the active thunderstorm were recorded in Trivandrum. On April 13, 1995 an active thunderstorm was recorded. During the normal days the average electron temperature was up to 1769° K and enhanced up to 2451° K (Fig. 2b) during the sprites associated with the active thunderstorm. The average ion temperature in normal days was up to 925° K and went up to 1045° K (Fig. 3b) during the sprites associated with the active thunderstorm. Thunderstorm activity was also recorded on April 28, 1995. During this event the average electron temperature was enhanced up to 1684° K over the normal days' average temperature of 1449° K (Fig. 2c). The average ion temperature on normal days was up to 900° K and enhanced up to 1343° K (Fig. 3d) during the sprites associated with the active thunderstorm.

The average electron and ion temperatures during thunderstorm and normal days for all four events have been shown in Table 1. The table also shows the time, duration and location of thunderstorm activity.

Table 1. Comparison of average of electron and ion temperatures during sprites associated with active thunderstorm and normal days

S. No.	Date of event	Time and duration of thunderstorm	Location of thunderstorms	Electron temperature (°K) Average during normal days	Electron temperature (°K) Average during thunderstorm day	Ion temperature (°K) Average during normal days	Ion temperature (°K) Average during thunderstorm day
1.	Jan 11, 95	1201-1500 IST (0259 hrs)	23.16°N, 77.36°E	1457	1940	960	1151
2.	Apr 13, 95	0601-0900 IST (0259 hrs)	08.29°N, 76.59°E	1769	2451	925	1045
3.	Apr 28, 95	1501-1800 IST (0259 hrs)	08.29°N, 76.59°E	1449	1684	900	1343
4.	Aug 29, 95	1201-1500 IST (0259 hrs)	23.16°N, 77.36°E	1762	2160	1167	1441

The above analysis shows that there is a consistent enhancement of ionospheric electron and ion temperature recorded due to sprites activity associated with active thunderstorms. This enhancement was for the average electron temperature ranging from 1.2 to 1.4 times that of an average normal day's temperature. However, for ion temperature this enhancement was from 1.1 to 1.5 times that of an average normal day's temperature.

The present study supports recent observation of optical phenomena such as sprites, blue jets, blue starters, elves and associated phenomena (Otsuyama *et al*., 1999; Pasko *et al*., 1995, 1996, 1997; Sentman *et al*., 1995; Inan *et al*., 1991, 1996; Taranenko 1992; Lehtimen *et al*., 1996, 2000; Bell *et al*., 1995; Gupta, 1997) propagating from the top of the active thunderstorms may generate radiations from UHF to gamma rays frequencies (Rai *et al*., 1972; Inan, 1991; Eack *et al*., 2000; Singh *et al*., 2001), which in turn may propagate still upward at the satellite altitude (Taranenko and Roussel-Dupre, 1996; Lehtimen *et al*., 1996) and heat the local plasma in the ionosphere.

4. Conclusions

In the present study we examined the effect of sprites and related phenomena on the ionospheric temperature at the low latitude region in the altitude range of 425-625. The SROSS-C2 satellite data for electron and ion temperatures during solar minimum year (1995-96) has been used for the present study. To reveal the effect of sprites associated with active thunderstorm, the thunderstorm data obtained from the Indian Meteorological Department (IMD) and solar flare data also obtained from the National Geophysical Data Center (NGDC), Colorado, USA, have been used. The study reveals that the electron and ion temperature shows a consistent enhancement during the sprites associated with active thunderstorm activity.

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