LIGHTNING INDUCED HARD X-RAY FLUX ENHANCEMENTS: CORONAS-F OBSERVATIONS

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ABSTRACT

Preliminary examination of October-December 2002 SONG/CORONAS-F low-altitude data revealed a many X-ray enhanced emissions (30-500 keV) in the slot region between the Earth's radiation belts. In one case, CORONAS-F data were analyzed when the most intense emissions were seen westward of the South Atlantic Anomaly in rather wide L shell range from 1.7 to 2.6. Enhanced fluxes observed on day 316 were most likely associated with Major Severe Weather Outbreak in Eastern USA, producing extensive lightning flashes as was documented by LIS on board TRMM satellite.

INTRODUCTION

Satellite and balloon-borne X-ray observations of electron precipitations are well known for a long time, however, observations of hard X-rays associated with electron precipitation due to lightning flashes are rare. One-to-one correspondence between balloon X-ray data and ground VLF emissions triggered by lightning whistlers have been for the first time presented by Rosenberg et al. [1]. In rocket experiment, Goldberg et al. [2] observed X-ray bursts that were coincident with lightning detected by nearby ground stations. Geographic overview of hard X-rays from low-Earth orbit over mid-latitudes and their possible originating in lightning due to electron precipitation and/or acceleration has been discussed by Feldman et al. [3].

In the present paper we report new observations of hard X-rays transient events seen outside of the stable trapping with large effective area scintillator on board of CORONAS-F satellite.

INSTRUMENTATION

The SOlar Neutron and Gamma rays (SONG) experiment on the three-axis stabilized CORONAS-F spacecraft contains large area CsI(Tl) scintillator (20x10 cm) to measure energetic neutral radiation from the Sun [4, 5]. The whole scintillator is entirely surrounded by a 2-cm thick plastic anticoincidence shield for charged particles. The CORONAS-F is in a sun synchronous polar orbit (inclination = 83°) at 500-km nominal altitude. The omni-directional detector provides high time resolution measurements (1 sec in burst and 4 sec in monitoring mode) of X/gamma rays in range from 30 keV to 200 MeV in twelve differential channels, plus one integral channel above 200 MeV. For the present analysis we select four lowest energy channels (30-60, 60-150, 150-500, and 500-1500 keV). The SONG device is mounted on the platform at a distance of one meter from the satellite. Note that a fraction (as yet undetermined) of the detected hard X rays is generated by interactions between primary cosmic rays and radiation belt particles with the CORONAS spacecraft and SONG device itself.

OBSERVATIONS

Preliminary examination of the October-December, 2002 SONG/CORONAS-F X-ray data reveals several enhanced emissions in the slot region for which we have good conjunctions with TRMM satellite documenting lightning activity by Lightning Imaging Sensor (LIS). The optical imager LIS locates lightning within its 600x600 km field of view with 2-ms timing resolution on altitude of 350 km [6].

One of the most intense enhancements, seen also in the inner zone, was found on November 12, 2002 (day 316) at 1253 UT (~ 0800 LT) westward from the South Atlantic Anomaly (SAA) in longitudes from -75° to -65°. It is displayed in Fig.1 (rightmost panel) where intense X-ray emissions (about 50 times the background value) in the energy channel of 60-150 keV cover rather wide L shell ranger from 1.7 to 2.6. Fig.2 (left) shows that observed enhancement is characterized by double-peak profile between 30 and 500 keV. Emissions at L=2-2.6 which gradually increase towards the SAA have a pattern of the atmospheric drift loss cone (DLC) electron precipitation in course of electron eastward drift. Fig. 1 shows (right and middle panels) that enhancements below L=2 are likely localized in longitude; we have no enhanced flux westward on longitudes (-100°,-90°) in 1.5 h latter at 1420 UT on day 316 (see also Fig. 2, right).

L-shell profile of X-ray counts in Fig.2 (left) shows a relatively narrow peak in inner zone centering on L ~ 1.8, and broad maximum in the inner part of the slot region. Similar observations with double-peak feature in connection with lightning induced electron precipitation have been recently reported by Blake et al. [7]. The

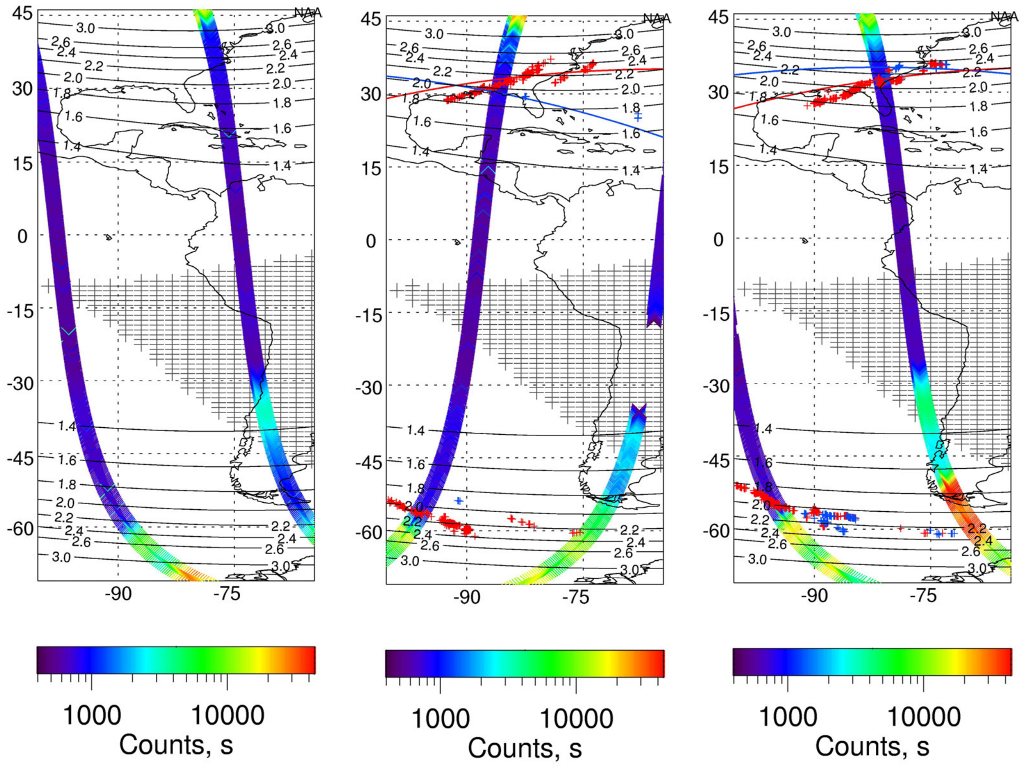

Fig.1 Geographic locations of X ray counts (60-150 keV) during two consecutive CORONAS-F orbits in each panel on November 9 (left), November 10-11 (middle), and November 12 (right). Colored scale matches the log of the counts. Lightning discharges detected by the LIS are shown as a red/blue crosses together with respective TRMM trajectories indicated by solid red/blue curves. The crosses on south indicate magnetically conjugate points of the northern lightning flashes. Footprints of the several L shells and stable trapped region (shaded) at 500 km are shown for reference along with the location of the NAA VLF transmitter.

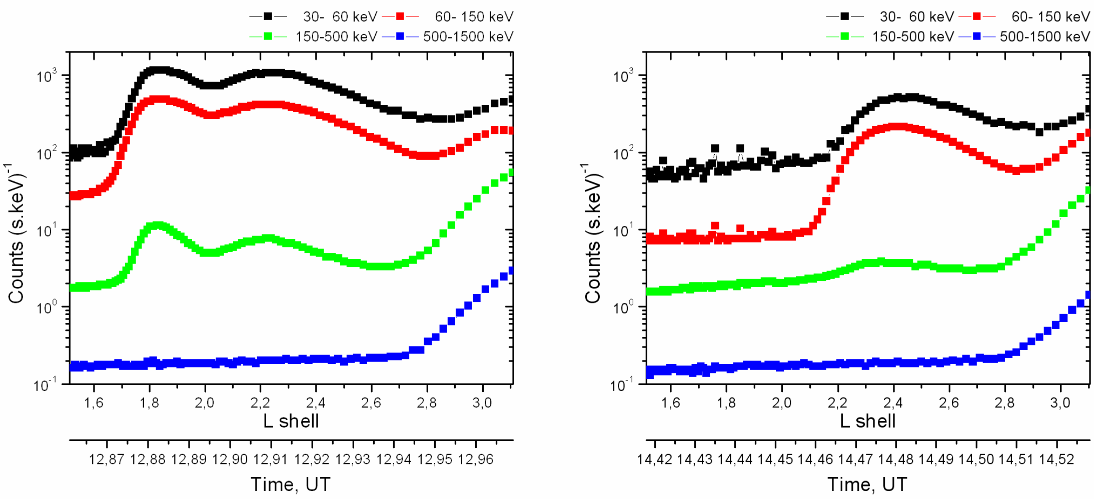

Fig.2 X-ray counting rates versus L shell/time in four energy channels measuring by SONG during two consecutive passes of the CORONAS-F satellite in the rightmost panel of Fig. 1..

narrow low L peak is attributed to resonant scattering at first equatorial crossing at low L due to focusing of lightning-generated whistler waves by particular ionospheric electron density gradients; high L shell broad structure is caused by whistlers undergoing multiple magnetospheric reflections [8].

TRMM data shows that extensive thunderstorm chain on Nov 12, 2002 (Fig. 1, rightmost panel), located in longitude range of -90° to -70° in Northern Hemisphere within L shell range of 1.8-2.4, was alive at least within 1100-1244 UT interval (blue crosses are for 1100-1106 UT and red ones for 1241-1244 UT). Note lightning discharges had been seen in this area up to middle of next day. The presence of the conjugate positions of the lightning flashes westward of the X-ray peak location suggests precipitation into the DLC, although localized in longitudes. Electrons precipitated from DLC at ~ -70° and at L=1.8 must be scattered from stable trapping (< 0.25 G) somewhere westward to the mirror points with B > 0.32 G. Illustration is in Fig. 3, right. In the lightning region on north, the satellite was in the bounce loss cone, and no enhancements of the X-ray count rate was noted at L ~ 1.7-2.6.

Fig. 1 (leftmost) demonstrates that there is no (significant) enhancement at the same L-shell and longitude positions, three days ago (on November 9, 2002, day 313, ~1300 UT) in the energy range of 60-150 keV. The same was observed for other energy channels (Fig.3, left). On day 313, the TRMM satellite passed through the region of interest on north around ~ 1215 UT without indicating any lightning activity (not shown).

The SONG instrument indicated enhanced X-ray counts in the end of the Nov 10, 2002, at around 2345 UT. This is shown in middle panel in Fig. 1. The closest time when TRMM passed through the area of interest was on Nov 10 (blue curve in middle panel) at 1610 UT without observing any significant lightning activity. However, on 11 Nov, 2002 a large thunderstorm area (red crosses) has already been build up between 1156 and 1202 UT, covering (-92°,-73°) long. interval as was detected by LIS instrument.

In the southern hemisphere TRMM passes over the investigated longitude interval at rather low L shells (< 1.4). On day 316 and up to ~ 1100 UT, LIS indicated very sporadic and rare lightning flashes only near the equatorial region during the crosses of the longitudes of interest.

SUMMARY AND DISSCUSION

The shown lightning flashes on 11-12 November, 2002 were associated with Major Severe Weather Outbreak in Eastern USA, one of the largest severe weather events of the past 25 years, occurred across much of the eastern United States on November 10-11, 2002, and accompanied by many tornadoes, damage thunderstorms, resulting in 36 deaths in 13 states (http://lwf.ncdc.noaa.gov). Infrared GOES image (http://cdo.ncdc.noaa.gov) on November 12, 2002 at 0015 UT documents the cloud covers over the location of the lightning flashes (not shown).

Before the severe weather event, the X-ray flux enhancement has been observed only in the outer part of the slot region (L ~ 2.5-3) and was rising gradually in eastward direction (not visible in leftmost panel of Fig. 1). After appearing thunderstorm clouds, producing lightning, demonstrated by GOES and TRMM, new X-ray emissions arise close to the magnetic conjugate of lightning under the inner belt region and in the inner part of the slot zone. These X rays enhanced emissions was detected in three energy channels over 30 and 500 keV span. The whistler waves launched by lightning on north propagate to south and can resonate with energetic

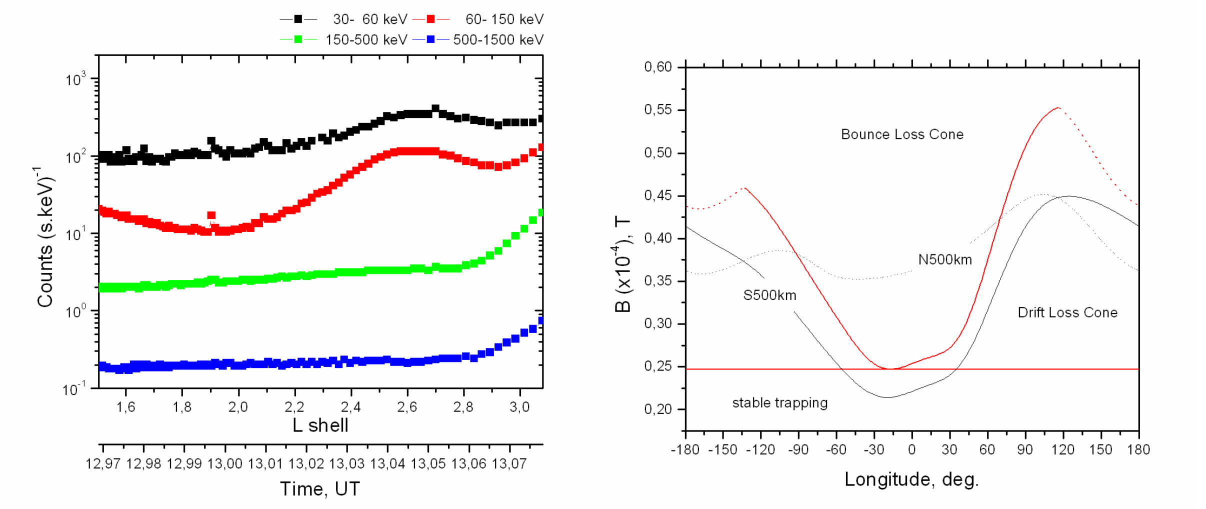

Fig.3 Left: X-ray counting rates versus L shell/time in four energy channels measuring by SONG during CORONAS-F satellite pass on day 313. Right: Illustration of the 100-km atmospheric loss cones for L=1.8. Electrons scattered into DLC are destined into the atmosphere on longitudes between -135° and -20° on the south (solid red curve), and on 120° and -170° on north (dotted red curve). Approximate satellite locations at 500-km on south (north) are indicated solid (dotted) black curve.

trapped electrons of different energy and pitch angles which are moving northward. This interaction lowers mirror points to the Earths atmosphere in the Southern Hemisphere where X-rays can be produced through the bremsstrahlung process and subsequently backward radiated on low altitude orbit. For the observed X-ray energy range, the average electron energy lies between 60 and 1000 keV.

From satellite observations, Datlowe and Imhof [9] reported that most intense peaks of electron precipitation cluster at longitudes of major VLF transmitters. In the observed longitude range there is one communication transmitter (currently in operation) with power > 110 kW, namely, NAA (Maine, USA) located at longitude of -67° and radiated at 24.0 kHz frequency with power ~ 1000 kW. Transmitter signal can contribute by resonance interactions with inner belt electrons to the detected X-ray emissions. Calculations of Abel and Thorne [10] indicate that 22.3 kHz VLF transmitter frequencies can resonate with 100-1500 keV electrons below L=2.2. Note, VLF data from Palmer Station, Antartica (L ~ 2.6, 65°S, 296°E) documented an activity at NAA transmitter (http://www-star.stanford.edu/~palmer/) during times of the observed X-ray enhancements. Discussions on a possible amplitude and phase perturbations of the sub-ionospheric signal associated with lightning is out of the scope of this paper.

Enhanced X ray count rates, observed in the inner edge of the slot region may also suggest an injection of new particle population. However the mechanisms of the injection should be different from those operated during magnetic storms and sub-storms. No significant geomagnetic activity was observed during and several days before the event as indicates Dst index. Recently proposed runaway avalanche acceleration [11] producing energetic electron beams in intense electric fields above thunderstorms and their subsequent trapping by geomagnetic field can lead to the precipitation in the hemisphere conjugate to lightning [12]. Feldman et al. [3] has speculated that hard X ray enhancements observed near the geomagnetic equator, where is not present a significant population of permanently trapped electrons, could be due to newly injected electrons into to DLC of the inner radiation belt by upward lightning.

The detected increases on November 12, 2002 at ~ 1300 UT when CORONAS-F was located in local dawn (~ 0800 LT) are probably not associated with solar X-ray flares. GOES data does not report any class type of X ray flare [13] around the time of X ray counts peaks detection.

In summary, good coincidence of the location of the lightning flashes with conjugate X-ray enhancements and their good timing suggests that CORONAS-F observed X-ray counts are most likely connected to the underlying long-lived lightning documented by TRMM. Further work is needed to clarify this point by comparison with coordinated VLF measurements.

ACKNOWLEDGEMENTS

This work was supported by VEGA grant 2/4064. The locations of lightning flashes were obtained from the NASA Web site http://thunder.nsstc.nasa.gov/.

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