Geographical and moon phase relationship of the UV and Red-IR luminous events detected by the Tatiana 2 satellite

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Abstract: We present preliminary results of the analysis of data taken by the Tatiana 2 satellite over the period from October 20, 2009, to January 27, 2010.
The geographical distribution of transient discharges with energies larger than 1 kJ in the ultraviolet (UV), Red-Infrared (R-IR) wavelength ranges for the Full and New Moon phases and the correlation of these discharges with the fluxes of Charged Particles (CP) were investigated for first time using Tatiana 2 data. We found that UV events at New Moon phase are mainly distributed in the equatorial zone, while for Full Moon phase the events show a homogeneous distribution.
UV and R-IR detections differ in duration and can show a variety of time profiles: from single short time flashes of ~ 1 milliseconds (ms) to flashes with a complex profile of more than 100 ms duration. Measurements of the charged particle fluxes (with a threshold energy for electrons of 1 MeV) provide no evidence of synchronous occurrence with UV events.
The CP fluxes show high values at the South Atlantic Anomaly (SAA). Remarkably, the CP fluxes distribution over the SAA is outlined by the magnetic field lines over this region.

Keywords: UV flashes, Charged Particles distribution

1 Introduction

At the Earth atmosphere, Ultraviolet (UV) transient events, can occur as a result of a number of phenomena [1].

Fluorescence by incoming charged particles when they pass through the atmosphere is one of them. Other atmospheric phenomena as Aurorae and thunderstorms also generate UV light, commonly named Transient Luminous Events (TLEs). However, UV emission as Aurorae is restricted to high latitudes while TLEs have a tendency to occur over the oceans [2] with seasonal variations in their distribution [3].

The intensity of the emission by fluorescence depends on: 1. The amount of particle energy that goes to ionization and 2. The atmosphere density.

At altitudes higher than 100 km the density is low and then the loss of energy of the excited molecules, down to the basic level, takes place mainly by radiation. At these altitudes the output of UV and Red radiation per unit of energy consumed for ionization is approximately the same.

At low altitudes the density is higher, then the energy loss of excited molecules can occur also due to collisions, competing with radiative losses. For this reason, the fluorescence output drops. At these altitudes the UV glow is prevalent and it is about five photons per one meter of relativistic particle path [4].

On the other hand, the Sun is a source of charged particles, mainly during Flares and Coronal Mass Ejections (CME). Also the geomagnetic disturbances accelerate particles in the Earth atmosphere leading to particle fluxes whose times are not so short as for transient events but that also increase the UV radiation at the atmosphere. The study of the UV, R-IR and CP distributions has become an important task in order to further study of transient phenomena.

2 Instrument

The Tatiana 2 satellite was built to detect UV and R-IR emission as well as Charged Particles (CP) with the aim to study transient phenomena at the upper Earth atmosphere. Tatiana 2 was launched on September 17, 2009. It is at a low altitude polar orbit at 98.8° inclination and altitude of $815-850$ km, equipped with two Photo Multiplier Tubes (PMT), a Charged Particles Scintillation Plate (CPSP) of 5 mm thickness, with an area of 350 cm^2 and threshold energy for electrons of 1 MeV, and a telescope based on microelectromechanical silicon technology (MTEL) [5].

The working bandwidths of the PMTs are $240-400$ nm (UV) and $610-800$ nm (R-IR) with a field of view of 16° which, pointing towards the nadir, covers an area of the Earth atmosphere of 230 km diameter.

The light signal produced in the CPSP is recorded with a PMT of the same type as that in the UV and R-IR detectors.

A Tatiana 2 record consists of 128 samples of 1 millisecond (ms) time interval each using a 10 bit Digital to Analogic Converter (DAC). The regime of data acquisition can make one record per minute. To detect short flashes of radiation and bursts of charged particles, all three sweeps of the digital oscilloscope are triggered by the flash signal in the UV detector.

3 Estimation of the energy released as UV and R-IR emissions in the atmosphere

The dependence of the PMT gain $G(M)$ on the DAC code M is experimentally estimated and can be approximated by [6, 7].

$$G(M) = 3 \times 10^6 (M/255)^{8.5} \qquad (1)$$

where 3×10^6 is the maximal gain and 8.5 is the tilt of the volt-ampere logarithmic characteristic (they were measured experimentally in the course of the PMT calibration).

Provided the PMT gain factor is known and using values of the second code, the Analogic to Digital Code N, one can determine the number of photoelectrons generated on the PMT cathode for each ms (t_{st}) of the total record (128 ms).

$$n_e(N,M) = \frac{N \cdot 3 \cdot 10^{-3} C t_{st}}{G(M) \cdot \tau \cdot 1.6 \cdot 10^{-19}} \qquad (2)$$

where C is the effective capacitance of the PMT anode (16 pF), $\tau \equiv rc$ is the time constant of the anode circuit (30 μs), $1.6 \cdot 10^{-19}$ is the electron charge (in Coulombs), $3 \cdot 10^{-3}$ is the sampling interval of the ADC (in Volts). The amount of photons passing through the PMT cathode in the same time interval is equal to

$$i(N,M) = \frac{n_e(N,M)}{P} \qquad (3)$$

where P is the quantum efficiency of the PMT cathode, 0.20 for a chosen PMT in the wavelength range $300-400$ nm and 0.02 in the wavelength range $600-800$ nm.

The sum of all signals (each ms) of the pulse determines the total amount of photons in the record. The total amount of photons of the source is calculated under the assumption that the radiation of the source within the viewing aperture is isotropic and the distance to it is equal to the height of the orbit, H. For this purpose, we consider the effective surface of the photocathode S (for the UV detector $S = 0.4$ cm^2 and for the R-IR detector the cathode area was restricted to $S = 0.2$ cm^2, in order to the expected signal in the R-IR range be within the range of analog to digital converter, ADC, measurements), so the estimated number of photons in the signal is multiplied by the factor $4\pi H^2/S$. For $r \sim 800$ km the factor $4\pi H^2/S = 2.2 \cdot 10^{17}$ for the UV detector and $4.4 \cdot 10^{17}$ for the R-IR). The radiant energy in the ultraviolet region is obtained by the multiplication of this result by an average photon energy of 3.5 eV. In the red-infrarred region an average photon energy of 1.75 eV is considered for the same purpose.

4 Geographical distributions of UV, R-IR and CP events

Fast flashes of electromagnetic radiation are known to occur in the upper atmosphere [8]. The flashes are of short duration (milliseconds), and their large size implies that they expand in space with high velocity. These events in the UV range were previously studied by the Tatiana 1 satellite [9, 10]. It was found that these flashes can be caused by electric discharges, in regions of storm clouds that form a separated belt, mainly, in the equatorial region. However, some of this type of events do not have been detected over clouds [5].

UV events at New Moon and Full Moon phases were detected at the dark side of the Earth by the Tatiana 2 satellite. The main features of the measured events are as follows:

1. Most of them are detected in the tropical region of the Earth (at latitudes from 23.5° N to 23.5° S)
2. They have M code above 130 units.
3. They have UV energies larger than 1 kJ.
4. At least during two milliseconds, of the 128 ms of a record, the N code reaches values larger than 100 units.

Figures 1 and 2 show the overall UV events distribution at New Moon and Full Moon phase nights, respectively, in geographical coordinates obtained over the entire operation period of the satellite.

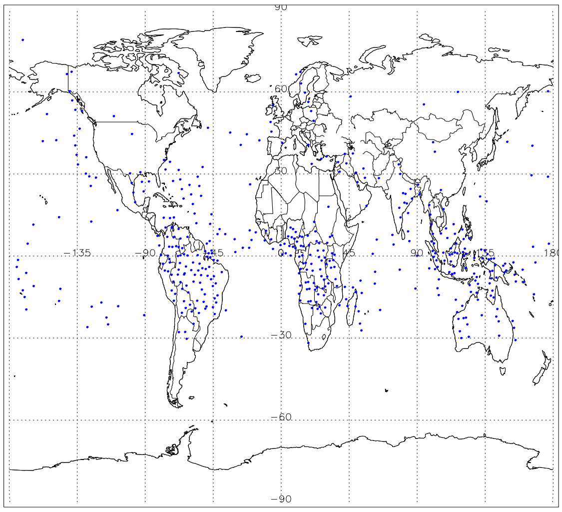

Figure 1: Global distribution of the Ultraviolet events with energies larger than 1 kJ detected at New Moon phase nights (less than 10 percent illumination).

We observed that UV events larger than 1 kJ in New Moon nights are concentrated near the Equator and above the continents. On the other hand, UV events detected at Full Moon nights are homogenously distributed on the Earth just as R-IR events detected in the same moon phase (Figures 2 and 4). Those distributions are different to R-IR events recorded at New Moon phase which are mainly concentrated over the Equatorial zone (Figure 3).

Most of UV detected events show R-IR synchronized emissions. Temporal profiles of such events are shown in Figure 5.

Note that the time profile of the R-IR record is lower than the UV one along the entire time interval, because the quantum efficiency of the PMT cathode in this range is an order of magnitude lower than in the UV one.

The monitoring of the geographical distribution of the CP fluxes in the atmosphere is important for several reasons. For example, they represent a serious threat to the normal

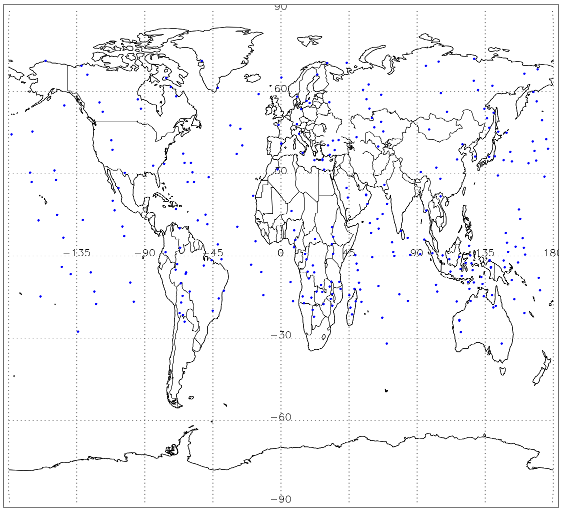

Figure 2: Global distribution of the Ultraviolet events with energies larger than 1 kJ detected at Full Moon phase nights (above 90 percent illumination).

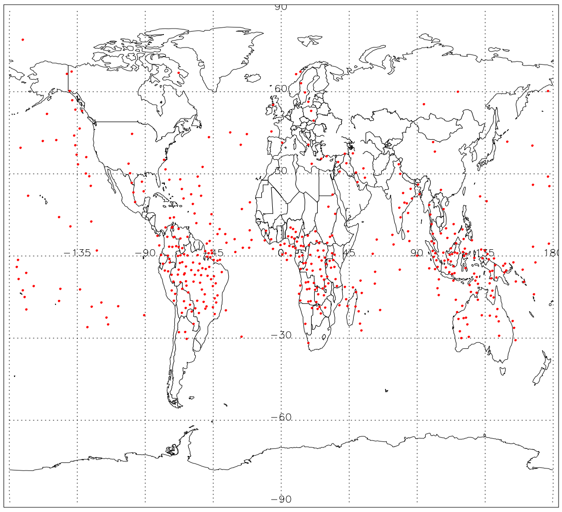

Figure 3: Global distribution of the Red-Infrared events detected by the Tatiana 2 satellite larger than 1 kJ at New Moon nights. Note that emissions are mainly concentrated over Equatorial region and that all of these events are correlated with UV emissions.

functioning of space instruments, as well as for the health of cosmonauts on manned flights. Other reasons are of physical interest, because it is known that CP fluxes produce interesting phenomena in the atmosphere and is through the study of these fluxes that we can to understand these phenomena.

The Tatiana 2 satellite made measurements of electron fluxes with energies > 1 MeV. Figure 6 shows the global distribution of that fluxes on the Earth. We can see that the major zone with the highest fluxes is the SAA, with electron fluxes increasing toward its center. Table 1 describes the colour - flux code of Figure 6.

Colour	Flux ($photoelectrons/sr \cdot s \cdot cm^2$)
Purple	$0 - 1 \cdot 10^{17}$
Blue	$1 \cdot 10^{17} - 1 \cdot 10^{18}$
Blue Sky	$1 \cdot 10^{18} - 1 \cdot 10^{19}$
Green	$1 \cdot 10^{19} - 1 \cdot 10^{20}$
Yellow	$1 \cdot 10^{20} - 1 \cdot 10^{21}$
Red	$1 \cdot 10^{21} - 1 \cdot 10^{22}$
Orange	$1 \cdot 10^{21} - 1 \cdot 10^{23}$
Black	$1 \cdot 10^{23} - 1 \cdot 10^{24}$

Table 1: Color-flux code of the electron fluxes detected by the CP detector. Events with weak fluxes are the most frequently detected.

The Polar regions show a lot of detected events with weak electron fluxes, that can be explained if we consider that at high latitudes, corresponding to the coordinates of the "return" of outer and inner radiation belt particles, the charged particles move in a plane perpendicular to the magnetic field direction as well as the CPSP.

As it is known, the SAA is the region with the weakest geomagnetic field magnitude, reason whereby the charged particles are trapped in. A superposition of the map of geomagnetic field lines obtained from the IGRF11 model for the year 2010 at 600 km over the sea level (the highest altitude allowed by this model) and the geographical distribution of the charged particles detected by Tatiana 2 is shown in Figure 6. We can clearly distinguish the correspondence between the magnetic iso-contours and the charged particles distribution. Also, it is seen that, where the geomagnetic field is weaker, higher fluxes are detected.

Among the UV and R-IR flashes recorded, there was no a clear correlation with the electron fluxes detected (Figure 6). The absence of synchronous flashes of electron flux, however, does not necessarily exclude the possibility that there may exist a considerable electron flux captured by the magnetic field and carried off outside the location of the orbital detector. Estimates indicate that at low magnetic latitudes $\sim 0° - 30°$, with the inclination of magnetic field being $50° - 90°$, the magnetic field deflects the high energy electrons (tens of MeV) from the vertical so that an electron beam may deviate aside from the point of observation of UV radiation to a distance of several hundred kilometers [5].

5 Discussion and conclusions

Differences with Moon phase are found for the distributions of UV and IR-R flashes.

The Tatiana 2 data give a new insight into the difference observed for flash distributions (do not considering the cloud covering).

At New Moon, the UV flashes seem to have the tendency to occur at the Equatorial region, over the continents. On the other hand, at Full Moon they are more homogeneously distributed. We recall that the observed period included only Autumn and Winter months at the North hemisphere.

The UV flashes are commonly accompanied by R-IR flashes at both moon phases, but mainly at moonless nights.

The CP distribution does not seem to be correlated with the UV and R-IR detections. It clearly shows a large amount of detections at the SAA in agreement with early results [11]. For the first time the Tatiana 2 data shows the early found result that the flux of CP increases towards the SAA central parts. Also, we have found that the CP distribution very well correlates with the Earth magnetic field lines at 600 km over the sea level.

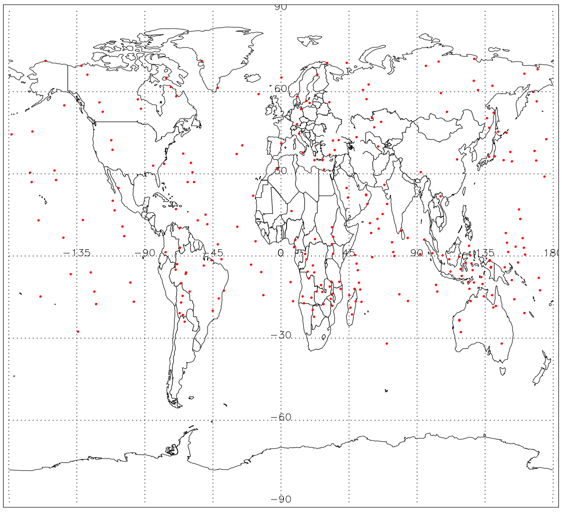

Figure 4: Distribution of the Red-Infrared events detected by the Tatiana 2 satellite larger than 1 kJ at Full Moon nights. Events are more homogeneously distributed over the Earth.

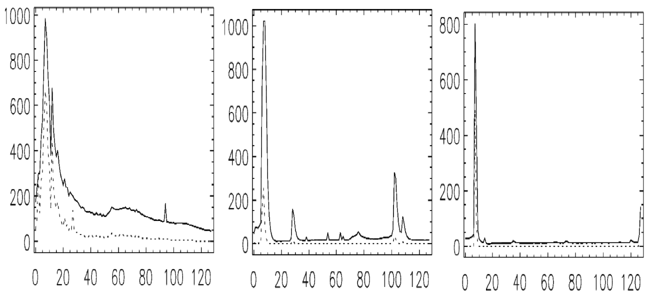

Figure 5: Temporal profiles of detected events by the Tatiana 2 satellite. Dotted line is for R-IR emissions and solid line is for UV radiation. X-axis indicates time in ms and Y-axis indicates intensity in arbitrary units. As may be seen from the temporal profiles, both emissions seem to be synchronized.

A further study, primarily measuring the spatial size of the flashes, is required to elucidate their nature.

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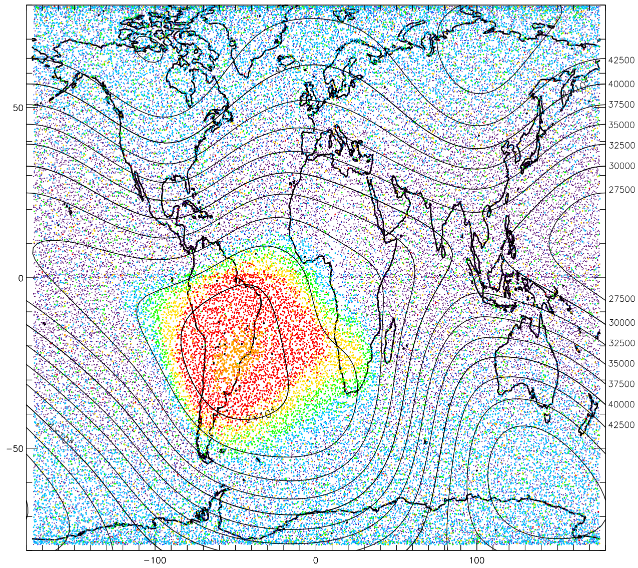

Figure 6: Superposition of the geographical distribution of charged particles to the geomagnetic field lines contours (at 600 km of altitude) and Earth map. The values of the iso-contours of the magnetic field are expressed in nT (right side). The SAA is the region with the weakest magnetic field magnitude. Geographical coordinates are indicated in the left side and in the bottom of the figure. X-axis indicates longitude, Y-axis indicates latitude.

References

[1] Pasko Victor, Yoav Yair & Cheng-Ling Kuo (2011), Lightning Related Transient Luminous Events at High Altitude in the Earth's Atmosphere: Phenomenology, Mechanisms and Effects, *Space Science Reviews*, 164.

[2] Chen A.B et al., (2008), Global distributions and occurrence rates of transient luminous events, *Journal of Geophysical Research*, *113*, *A*08306.

[3] Lee Li-Jou et al., (2010), Controlling synoptic scale factors for the distribution of transient luminous events, *Journal of Geophysical Research*, 115, *A*00*E*54.

[4] Vedenkin N.N et al.,(2009), Atmospheric ultraviolet light and comparison of its intensity with the variation of electron flux with energies higher than 70 keV in satellite orbit (according to Universitetskii-Tatiana satellite data), *Moscow University Physics Bulletin*, 64, *No.*4, 450 – 454.

[5] Sadovnichy V. A. et al., (2011), Investigations of the Space Environment Aboard the Universitetsky-Tat'yana and Universitetsky-Tat'yana 2 Microsatellites, *Solar System Research*, 45, 3 – 29.

[6] Garipov G.K. et al.,(2006), Ultraviolet Radiation Detector of the MSU Research Educational Microsatellite Universitetskii-Tat'yana, *Physical Instruments and Experimental Techniques*, 49, 126 – 131.

[7] Garipov G.K. et al., (2011), Time and Energy Characteristics of UV Flashes in the Atmosphere: Data of the Universitetsky Tatiana Satellite, *Cosmic Research*, 49*, No.*5, 391 – 398.

[8] Khrenov B. A. et al., (2008), Transient flashes of electromagnetic radiation in the upper atmosphere, *Cosmic Research*, 46*, No.*1, 25 – 34.

[9] Garipov G.K. et al., (2005), UV radiation from the atmosphere: Results of the MSU Tatiana satellite measurements, *Astroparticle Physics*, 24, 400 – 408.

[10] Garipov G.K. et al., (2005), Ultraviolet Flashes in the Equatorial Region of the Earth, *JETP Letters*, 82*, No.*4, 185 – 187.

[11] Casadio S. and Arino O. (2011), Monitoring the South Atlantic Anomaly using ATSR instrument series, *Advances in Space Research*, 48, 1056 – 1066.