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Unusual cosmic ray increases observed during several solar flares in 2011-2013

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We present and discuss the cosmic ray increases detected with the CARPET cosmic ray instrument during several solar flares in 2011-2013. The CARPET cosmic ray detector was installed at El Leoncito Astronomical Complex (CASLEO; Argentina) in 2006. We compare the CARPET data with the X-ray and proton data from GOES and FERMI measurements as well as with the RHESSI observations. The neutron monitor network cosmic ray measurements are also included in the analysis. We summarize the common features of the recorded events and discuss their association with solar flare activity and near-Earth conditions.

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1. Introduction

The CARPET ground-based cosmic ray detector was installed in 2006 at the El Leoncito astronomical complex (CASLEO) in the Argentine Andes at altitude of 2550 m (31.8^{o}S, 69.3^{o}W; geomagnetic cutoff rigidity R_c=9.65 GV) [1-6]. Since 2009, in Geneva, the CARPET device prototype - GCR (Galactic Cosmic Ray) instrument - operates during scientific experiments carried out in the scope of the International CLOUD project at CERN [7]. Cosmic ray measurements performed by the CARPET detector were used in the past to analyze long- and short term particle flux variations and study their origin. Among significant number of cosmic ray increase events two classes of events were recognized: (1) the CARPET count rate increases with duration from few tens of minutes up to few hours, associated with variations of the atmospheric electric field and rain precipitations, and (2) the cosmic ray increases observed during solar flare activity. In this paper we present new experimental data related to the second class of events, e.g. the CARPET(GCR) count rate increases recorded in 2013 during enlarged solar activity level on October 15 and November 19, 2013. Solar flare activity was analyzed using the results of solar observations including X-ray and gamma emission performed on board spacecraft (e.g., GOES, FERMI and RHESSI [8-10]). Data from cosmic ray measurements performed by the worldwide neutron monitor network were also analyzed [11]. We summarize main observational characteristics of these unusual cosmic ray increases recorded during 2011-2013.

2. Instrumentation

The CARPET cosmic ray detector consists of 240 STS-6 Geiger-Muller counters arranged in 24 blocks [1]. In each block, a layer of five upper counters is separated from five lower counters by an aluminum absorber (filter) of 7 mm thick. Data are sampled automatically every 500 ms in three data channels. The first two channels correspond to the integral count of the charged particles crossing separately the upper layer of 120 counters (N1-channel) and the lower layer of 120 counters (N2-channel). Particles passing through the upper counter, filter and lower counter are simultaneously registered in the coincidence third channel (N12-channel). The design of the CARPET(GCR) detector allows the detection of particles with different energies: electrons and positrons with energies E>200 keV, protons with E>5 MeV and muons with E>0.5 MeV in channels N1 and N2. Photons at energies E>20 keV are also registered by counters but with $\ll$1% efficiency. More energetic particles are registered in the coincidence channel (N12): electrons with energies >5 MeV, protons with E>30 MeV, and muons with E>15.5 MeV. Figure 1 (left panel) shows the count rates of the CARPET device (at CERN in Geneva) recoded in all three data channels (N1, N2 and N12) on October 15, 2013. Integration time of the data is 5 minutes. There are "background" charge particles count rate variations from 0 UT up to $\sim$15 UT and clear simultaneous count rate increase in three channels of the device during $\sim$15-20 UT. We will discuss the main characteristics of such events.

Thus the CARPET (GCR) detector is sensitive to the low energy secondary cascade component of cosmic rays produced by primary galactic and solar cosmic rays in the Earth′s atmosphere and/or other processes in the surface atmosphere. We note, the correction coefficients for pressure and

temperature effects in the CARPET measurements were estimated as β=-(0.44±0.01)%/hPa and α=(-0.09±0.02)%/deg., respectively [5].

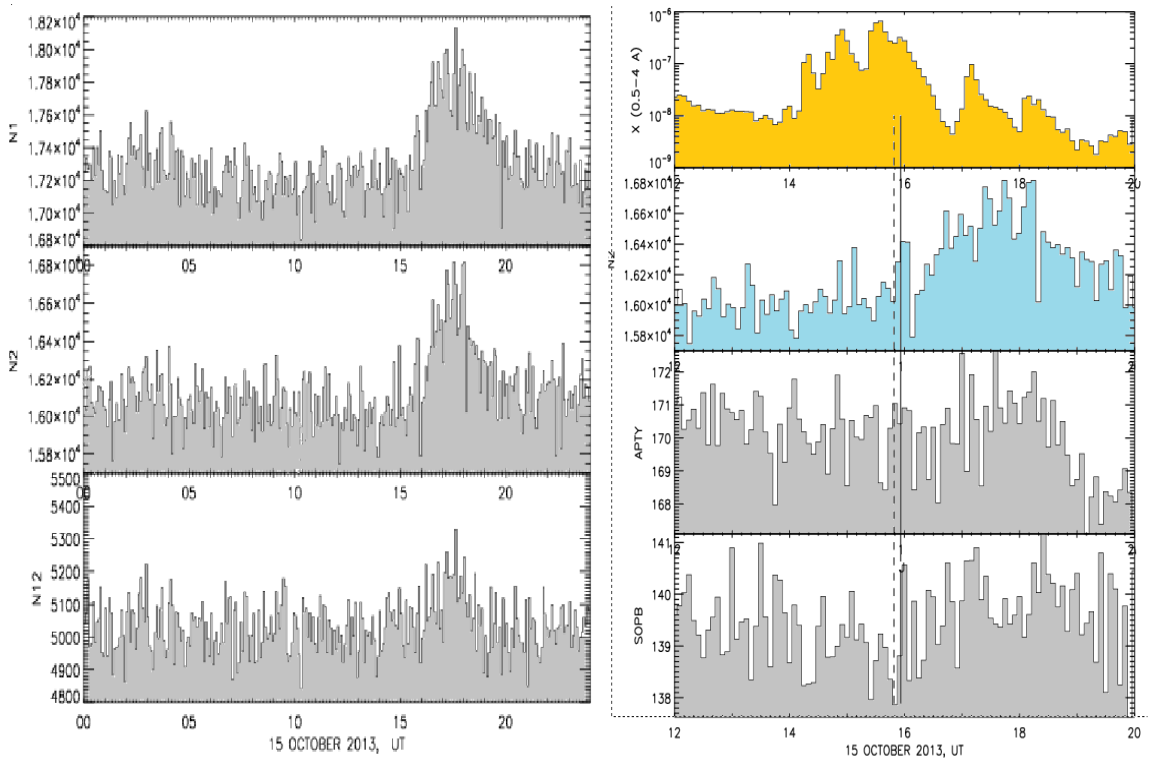

Figure 1: Left (from top to bottom): Count rate of the CARPET(GCR) instrument at CERN in three data channels (N1, N2 and N12) on October 15, 2013. Data integration time is 5 min. Right (from top to bottom): time variation of solar X-ray emission measured on board GOES geostationary satellite on October 15, 2013 (0.5-4 $\AA$; 5-minute data in W·m^{-2}) [8]. Then, a 5-minute averaged count rate in channel N2 of the CARPET(GCR) device. The temporal variations of 5-minute count rates of the neutron monitor Apatity (APTY) and South Pole (SOPB) are shown at bottom last two panels [11]. Vertical dashed and solid lines show the initial time of the selected solar X-ray bursts (E>12-25 keV) registered on board the RHESSI and FERMI spacecrafts, respectively [9,10]

3. Observational data on October 15, 2013

This event was recorded by the CARPET (GCR) device at CERN and was not seen in the CARPET measurements at CASLEO. Figure 1 shows the count rates of the CARPET(GCR) device (at Geneva, CERN) recoded in three data channels (N1, N2 and N12) on October 15, 2013. Integration time of the data is 5 minutes. There is a clear simultaneous count rate increase in three channels of the device in the period ∼15-20 UT. The amplitude of increase was ∼5% in each channel. This is a typical example of the CARPET count rate increases (events) recorded since 2006 with only one difference i.e. there is an increase in the third N12 channel in addition to the effect (increase) detected simultaneously in the first two channels (N1 and N2). The increase in the channel N12 of the detector suggests the appearance of additional flux of energetic protons (>30 MeV) and electrons (>5 MeV) during this time interval.

Analysis of the data on solar activity and cosmic rays (measurements made by ground-based neutron monitors and on board the GOES satellite) on October 15, 2013 [8] leads to the following conclusions:

(a) a series of H-α solar flares (including a C6.5 flare) occurred on the Sun in the NOAA active regions (ARs) 1865 (S20 E52) and 1861 (S12W14) during time interval ∼14-17 UT.

(b) during this interval 6 solar X-ray bursts (E≥12-25 keV) were detected onboard RHESSI and FERMI satelites [8,9]. Vertical lines on Figure 1 (right panel) mark start time only of two X-ray bursts observed in the eastern solar AR 1865, right before of the beginning of the CARPET increase event.

(c) there is no charge particle flux increase measured onboard GOES-13 on October 15, 2013

(d) analysis of the ground-based neutron monitors data base NMDB [11]) shows the absence of clear increase in the cosmic ray flux (counts) during this period. As example we present the time profile of 5-minute count rate of neutron monitors Apatity (APTY) and South Pole (SOPB) in Figure 1 (right). There are pressure and efficiency corrected data in relative units [11].

4. Observational data on November 19, 2013

In contrast to the October 15, 2013 the solar flare activity on November 19, 2013 was higher. The long-lived AR 1893 (S70W14) produced a set of C-class flares and one powerful X1-class event which started at ∼10:26 UT. No one geomagnetic disturbance (Kp<2) as well as cosmic ray ground-level enhancements (GLE event) were reported during the day. Perhaps, this is because of active regions (and solar flares) relative position and interplanetary magnetic field lines were not "connected" directly to Earth this time.

We found two new events on November 19, 2013 which could be added to this specific class of the CARPET event (increases). First event was recorded by the CARPET device at CERN in ∼12-20 UT time interval and second increase observed at CASLEO (Argentina) in ∼16-20 UT.

4.1 First event on November 19, 2013

Experimental details of this event are given in Figure 2.

Upper panel shows a variation of solar X-ray emission (0.5-4 $\AA$) measured on board GOES-13 satellite [8]. Increased solar X-ray flux level over 3 hours was observed till ∼ 15 UT. There is a X1-class solar flare, which started in ∼10:26 UT in AR1893 (S70W14). A set of intense X-ray bursts (E≥12-25 keV) was recorded on board the RHESSI (vertical dashed lines in Figure 2) and FERMI satellites (solid lines) from the same active region.

This increased solar activity was occurred before the CARPET event observed in ∼11:30-21:00 UT at CERN. The time profile of the 5-minute count rate in channel N2 of the CARPET (GCR) shown on panel (b) of the Figure 2. A similar time extended increase of >50 MeV solar proton flux was observed on board GOES-13 satellite (panel c). We have analyzes the NMDB data of the neutron monitors observations on November 19, 2013. It is worth to note that a long-time increase of the NMs particle counts could also be determined. The time profiles of the Nain (NAIN) and Thule (THUL) neutron monitor records illustrate this fact (panels (d) and (e) in Figure 2).

We point out that this event is not seen in the CARPET detector records at CASLEO (Argentina) on November 19, 2013.

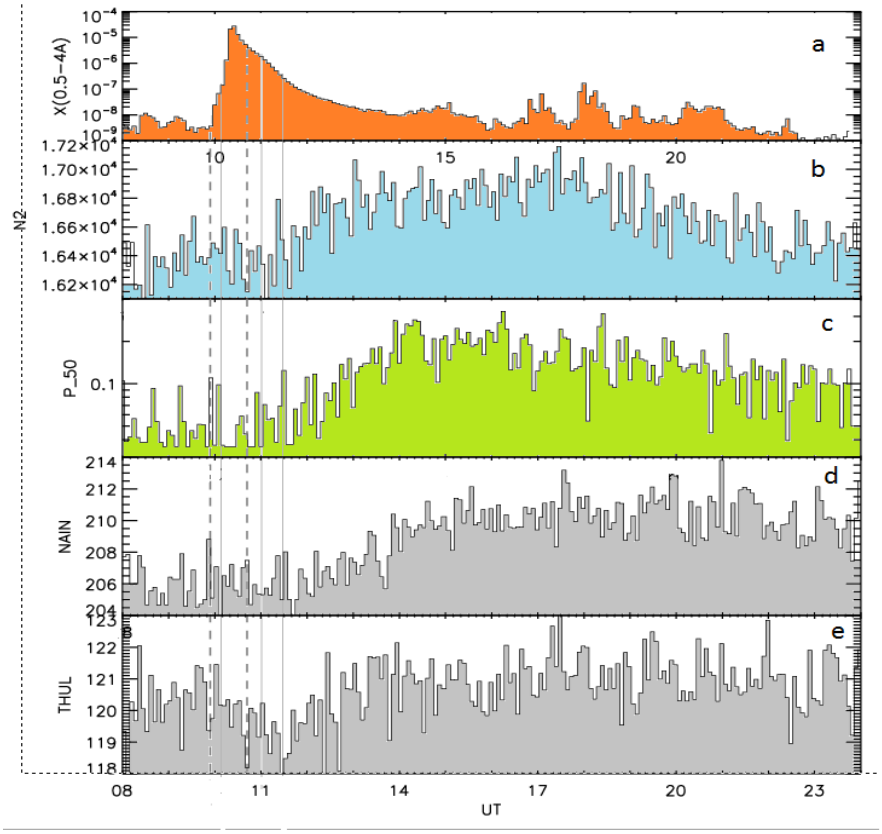

Figure 2: From top to bottom: (a) variation of solar X-ray emission (0.5-4 $\AA$; 5-minute data in W·m^{-2}) measured on board GOES-13 satellite on November 19, 2013 from 08:00 to 24:00 UT [8]. (b) time profile of 5-minute count rate in channel N2 of the CARPET (GCR) detector in Geneva (CERN). (c) variation of >50 MeV proton flux measured on board GOES-13 (5-minute data; P_50, cm^{-2}·s^{-1}·sr^{-1}; [8]). (d) and (e) time profiles of count rate of neutron monitor Nain (NAIN) and Thule (THUL). There are pressure and efficiency corrected 5-minute NMs data. Vertical dashed and solid lines indicate the start time of the solar X-ray bursts (E>12-25 keV) recorded on board the RHESSI and FERMI, respectively [9,10]

4.2 Second event on November 19, 2013

In contract to the previous event, second increase was observed by the CARPET device installed at CASLEO (Argentina) and not recognizable in the CARPET records at CERN (see panel (b) in Figure 2).

A few C-class solar flares were recorded at the Sun during 14-20 UT (see left panel (a) in Figure 3). Also solar X-ray bursts were detected on board the RHESSI and FERMI in this time interval. We mark just one X-ray burst (vertical dashed line on the left of Figure 3) detected on board RHESSI in the C-class flare right before the beginning of the CARPET increase event.

The count rate variation in channel N1 of the CARPET instrument (at CASLEO, Argentina) on November 19, 2013 is presented at left panel (b) in the Figure 3. There is a clear count rate increase observed between 16 and 20 UT. The amplitude of count rate increase is $\sim$14%. To compare this result we present several neutron monitor records during November 19, 2013 chosen from NMDB data base namely, panels (c,d and e) show the time profiles of the 5-min count rates of the NM Forth

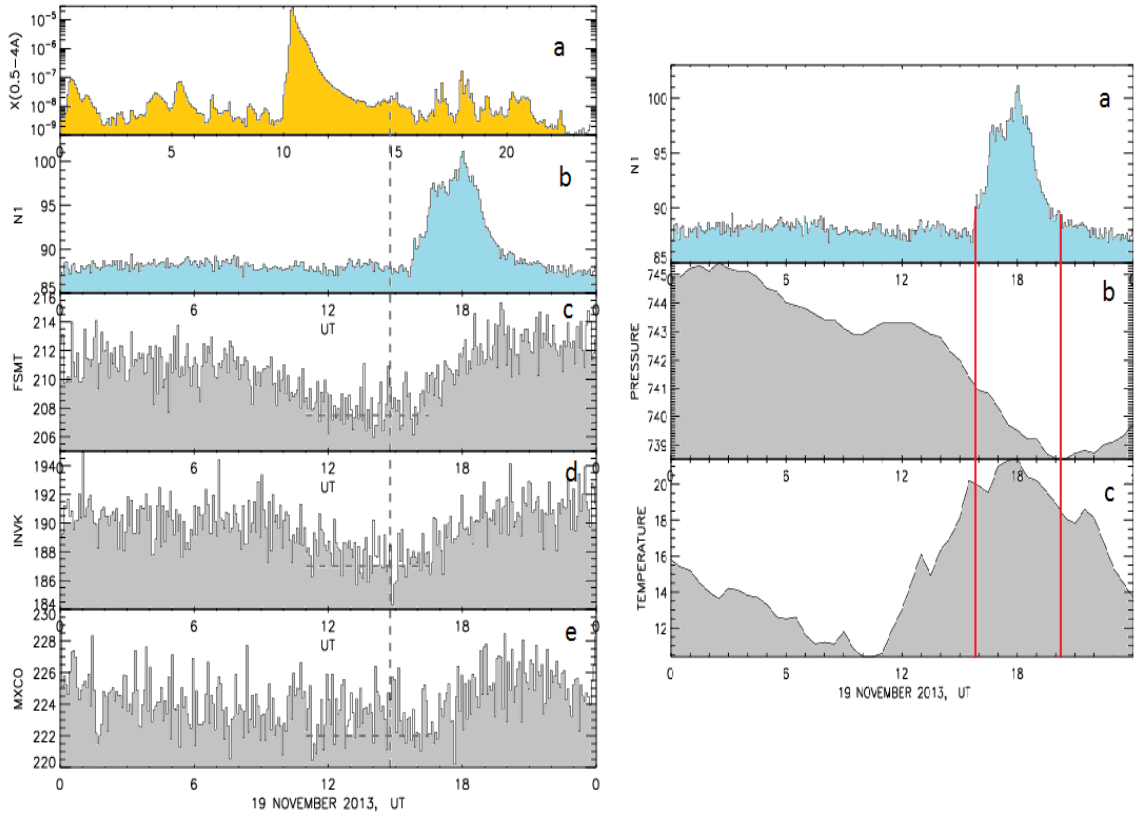

Figure 3: Left (from top to bottom): (a) variation of solar X-ray emission measured on board GOES geostationary satellite on November 19, 2013 (0.5-4 $\AA$; 5-minute data in W·m^{-2}) [8]. (b) count rate in first data channel (N1) of the CARPET detector (at CASLEO, Argentina). Data integration time is 5 min. (c-e) the temporal variations of 5-minute count rates of the neutron monitor Fort Smith (FSMT), Inuvik (INVK) and Mexico (MXCO) [11]. There are pressure and efficiency corrected 5-minute data. Vertical dashed line marks the start time of the solar X-ray burst (E>6-12 keV) registered on board the RHESSI [9]. Right (from top to bottom): (a). the CARPET count rate variation in channel N1. Data integration time is 5 min. (b) and (c) panel show the time variation of the surface atmospheric pressure and temperature at CASLEO (Argentina).

Smith (FSMT), Inuvik (INVK) and Mexico (MXCO). We note presence of the diurnal variations in these NMs records as well as the NMs count rate increases after ∼15-16 UT.

The observed increase in the CARPET records during 16:00 and 19:00 UT on November 19, 2013 was not governed by changes in atmospheric pressure and temperature. We show pressure and temperature time profiles on panel b and c at right side of the Figure 3. We apply the data correction coefficients for pressure and temperature as β=-(0.44±0.01)%/hPa and α=(-0.09±0.02)%/deg., respectively for CARPET records presented on right panel of the Figure 3. We obtain an expected amplitude of the CARPET count rate increase of ∼2% which is in disagreement with the observed ∼14% amplitude event. It allows to suggest the presence of additional charge particle fluxes recorded by the CARPET detector during this event.

5. Summary

The new increases of charged particle fluxes registered on October 15, 2013, and November 19, 2013, and described above enlarge the number of the similar events observed by the CARPET (GCR) detector in 2011-2013 [4]. Table below summarize main experimental features of recorded events.

Table 1: Cosmic ray increases recorded by the CARPET (GCR) detector in 2011-2013

N	Date of event, obs. time (UT)	Amplitude of increase	Solar Flare (start (UT), imp., NOAA AR, coord.)	Fermi event	Rhessi event
1	7 March 2011 ∼20:00-21:40	∼4.5	∼19:30; M3.7, 1164, N23W50	+	+
2	8 March 2011 ∼14:40-19:50	∼3	∼14:20; SF, 1165, S16W90 ∼18:08; M4.4, 1165, S16W90	+	+
3	23 January 2012 ∼03:40-08:00	∼5	∼03:30; M8.7, 1402, N28W20	+	
4	27 January 2012 ∼16:40-21:00	∼2	∼17:37; X1.7, 1402, N31W74	+	
5	15 October 2013 ∼16-19	∼5	∼15:20; C6.5, 1865, S20E52 and 1861, S12W14	+	+
6	19 November 2013 ∼ 12-20	∼5	∼10:26; 1X, 1893, S70W14	+	+
7	19 November 2013 ∼ 16-20	∼14	∼11:30; 1893, S70W14	+	+

The most interesting features of these events are as follow, (a) the occurrence of prolonged flaring activity accompanied by C-, M-, and X-class solar flares and by intense X-ray bursts before (during) the events. We note also, flux of solar neutrons was recorded during 7 March 2011 event [4], (b) the absence of clear sharp increases of count rate of the ground-based neutron monitors, i.e. there is no one classical *GLE*-event, and (c) however, a time extended increase of the flux of low-energy solar protons (>10-100 MeV) was observed in many described events.

At present, we cannot determine the exact origin of these events (increases) recorded by the CARPET (GCR) detectors at CASLEO (Argentina) and at CERN (Geneva). To determine the possible atmospheric effects in these events, we continue analysis of the meteorologic data and available atmospheric electric field measurements. First results obtained in this direction were presented in [3-5]. Future observations by the new Neutron Detector and Gamma-Ray Spectrometer installed in 2015 at CASLEO (Argentina) close to the CARPET device location will help to understand the origin of such unusual and interesting cosmic ray events.

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