Proceedings of Tenth Workshop "Solar Influences on the Magnetosphere, Ionosphere and Atmosphere", *Primorsko, Bulgaria, June 4 - 8, 2018*

SEVAN particle detector at Zagreb Astronomical Observatory: 10 years of operation

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Abstract.

At the "Regional IHY (International Heliophysical Year) Planning Meeting for the Balkan and Black Sea Region", organized by Solar Terrestrial Influences Laboratory in Bulgaria 2005, the possibilities of new network of the Space Weather particle detectors designed by Armenian scientists were presented. Network is known today as SEVAN (Space Environment Viewing and Analysis Network). In December 2008 the installation of the SEVAN particle detector at Zagreb Astronomical Observatory was finished. It is the first instrument for detecting cosmic rays in Croatia and its installation greatly promotes solar physics research in our country. Here we present some results obtained from data collected by SEVAN particle detector at Zagreb Astronomical Observatory during first 10 years of operation. We calculated the barometric coefficients using two statistical methods (least square method and least absolute deviation method. Pressure corrected data is available on web page of the Zagreb observatory. Examples of solar modulation effects (Forbush decrease) and first evidence of registration of TGEs (Thunderstorm Ground Enhancements) are also given.

Introduction

In December of 2008th Zagreb Astronomical Observatory was included in the SEVAN network (Space Environmental Viewing and Analysis Network) and SEVAN CRO unit it is the first cosmic ray particle detector that was installed in Croatia thanks to the cooperation with Aragat's Space Environmental Centre (ASEC) of the Alikhanyan Physics Institute (Armenia) who provided all the logistics. The SEVAN network is a ground based worldwide network of instruments on different geographic locations and altitudes. The main scientific goal is to improve research in solar and atmospheric physics, space weather conditions, and thunder forming events. SEVAN measures the flux intensity of secondary cosmic rays formed in cascades in the Earth's atmosphere from the primary cosmic rays. The basic SEVAN unit consists of two identical plastic scintillator slab sizes (4 standard slabs) of $50 \cdot 50 \cdot 5\ cm^3$ in the upper layer and lower layer and 5 thick scintillator slabs sizes of $50 \cdot 50 \cdot 25\ cm^3$ in the middle of the instrument. The upper and lower layers are separated by two lead absorbers which are the size of $100 \cdot 100 \cdot 5\ cm^3$. All scintillator layers are light protected in iron shielding with a photomultiplier tube. This construction allows the detection of low energy particles, neutral particles and high energy muons fluxes, depending on the registration of signal or the absence of a signal (*Roša et.al.*, 2010, *Chilingarian et.al.*, 2018). In this paper we present the most important data and research during the 10 year operational period of SEVAN CRO cosmic ray detector.

Topic: Instrumentation for Space Weather Monitoring

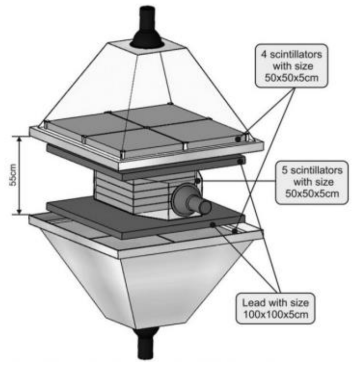


Fig. 1 SEVAN particle detector module schematic. The corresponding signals: 100 – traversal of the low energy charged particle. 010 – traversal of the neutral particles, 111 , 101 – traversal of the high energy muons (> 250 MeV). SEVAN CRO is located on latitude 45.82 N; longitude 15.97 E; altitude 170 m; vertical cut-off rigidity ≈ 4.9 GV

Data & Analysis

The count rate intensity of the incoming cosmic ray particle flux on ground based instruments is affected by local atmospheric pressure. The barometric coefficient has to be calculated for the correction of the data because the barometric effect affects the variations of the measured count rate (*Dorman*, 1974). The measurements at SEVAN CRO were performed during the solar minimum at the end of the 24th Solar cycle, with no disturbances of the IMF (interplanetary magnetic field) and magnetosphere and in the period of significant atmospheric pressure variations. The dataset of a four day minute count rate from SEVAN CRO particle detector during 25. – 28. December 2017 was used for calculating the barometric coefficient during the biggest oscillations pressure period (~30 mbar difference between the lowest and the highest pressure rates) and during a period with no geomagnetic storms where the Dst Index was < -30 nT (*Loewe and Prolss*, 1997), Dst values were obtained from Kyoto University given at http://wdc.kugi.kyoto-u.ac.jp/dstdir/index.html.. Real pressure data was taken from DHMZ (Croatian Meteorological and Hydrological Service) which was calibrated with the SEVAN CRO pressure data using linear regression, with the correlation coefficient being 0.9986.

When the incoming flux of secondary cosmic rays is constant, the measured intensity I depends on the local atmospheric pressure which is shown in the following equation (*Dorman*, 1974, *Chilingarian et.al*., 2009):

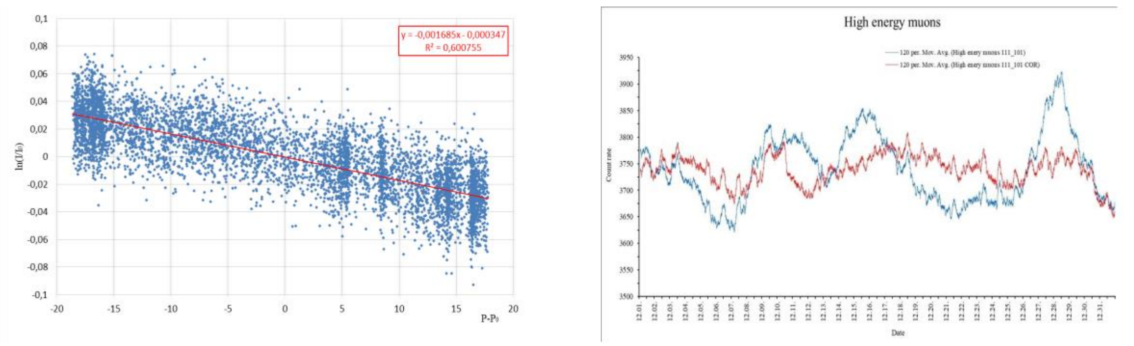
$$dI = -\beta dP \tag{1}$$

Where dI is the change in intensity because of the change in pressure dP and β is the barometric coefficient. If β is constant the expression (1) gives:

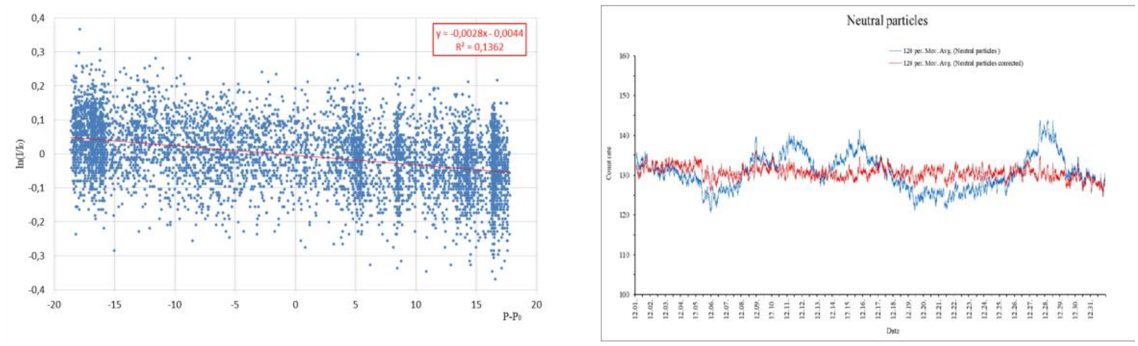
$$I = I_0 e^{-\beta(P-P_0)} \tag{2}$$

Where I are the counting rates at pressure P and I_0 and P_0 are the average counting rate and pressure for the measuring interval. By performing the transformation, we can apply the expression for linear regression:

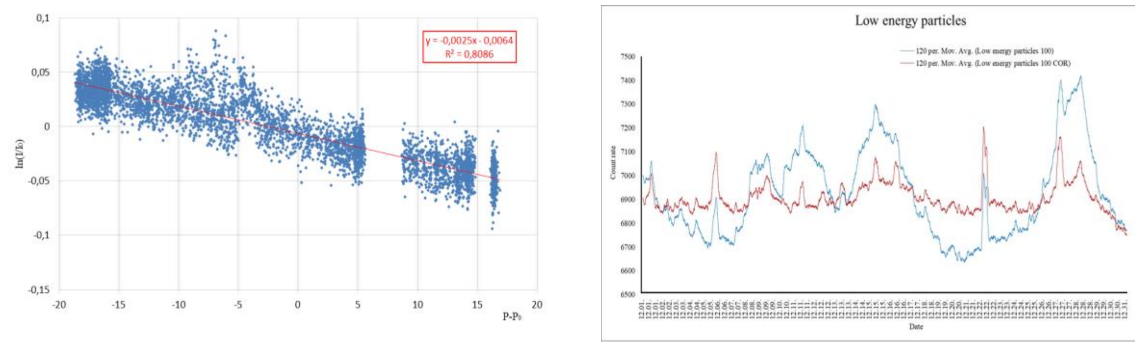
$$ln\,(I\,/\,I_0) \;=\; -\beta(P-P_0) \tag{3}$$



a)



b)



c)

Fig. 2 Graphs for barometric coefficient are on the left side, from top to bottom; a) high energy muons, b) neural particles and c) lower energy particles (with excluded data, see Tab. 1.). On the right side are the monthly smoothed graphs with moving average which show corrected data using the barometric coefficient.

In figure 2 the left side of the graphs show the relation between intensity and atmospheric pressure. We calculated the barometric coefficient during the period of 25 – 28 December 2017 for high energy muons, neutral particles and low energy particles. The corresponding barometric coefficients are -0.169 %/mbar for muons with largest correlation coefficient of analyzed dana -0.775; -0.282 %/mbar for neutrons with a relative lower correlation coefficient of -0.368 and -0.254 %/mbar for low energy particles with a correlation coefficient of -0.765. Absolute values of barometric coefficients are lower in total because of the location of detector is on a lower altitude, also the barometric coefficient for neutral particles and low energy particles are higher then for muons, which is expected as lower altitudes are less sensitive to lower energies, register less cascade particles showers and are less sensitive to primary lower energies beacuse of lower cut off rigidity (*Chilingarian*, 2009). For lower energy particles some data had to be excluded because of an appearant consistant fault in instruments during some periods. These events need to be investigated further. Excluded events are shown on *Tab. 1*. We also calculated the barometric ceofficent with another statistical analysis, the least absolute deviaton method (LAD). LAD method is similiar to least square method LSM, it minimizes the sum of absolute errors and is more robust which extends its application to studies where outliers dont need to be emphasized. We developed a special algorithm for this method. In figure 2 on the right side a 30 day minute count for December 2017 is shown with a moving average. The curves show measuring (uncorrected) counting rate (blue line) and pressure corrected data (red line).

Monitor	β(%/mbar) LSM	β(%/mbar) LAD	r	σ LSM	σ LAD	N
High Energy Muons	-0.169±0.0018	-0.169±0.00022	-0.775	0.01693	0.01693	5760
Neutrons	-0.282±0.0093	-0.274±0.00115	-0.368	0.08747	0.0875	5760
Low Energy Charged Particles	-0.202±0.0022	-0.224±0.00028	-0.765	0.02091	0.02137	5760
Upper Detector	-0.190±0.0018	-0.202±0.00020	-0.838	0.01521	0.01543	5760
Middle Detector	-0.147±0.0026	-0.144±0.00033	-0.584	0.02519	0.02521	5760
Lower Detector	-0.179±0.0016	-0.188±0.00021	-0.817	0.01559	0.01572	5760
Low Energy Charged Particles*	-0.251		-0.894			4799*
Lower Detector*	-0.209		-0.888			4799*

* shows the excluded data for lower energy particles and the lower detector.

Tab. 1 Compiled data for all the channels where β is the barometric coefficient using LSM and LAD with their appropriate error; r is the correlation coefficient, σ is the standard deviation and N is the number of events.

The database for uncorrected and corrected pressure on SEVAN CRO unit can be accessed on a online tool on the web page of Zagreb Astronomical Observatory https://zvjezdarnica.hr/obrazovni/znanost/sevan-podaci/.

Forbush decreases are rapid short decreases in the galactic cosmic ray intensity which are induced by short term changes in solar wind and the interplanetary magnetic field which are related to interplanetary coronal mass ejections and corotating interaction regions (*Maričić et.al*., 2013). We present an example of a Forbush decrease which was registered with our SEVAN CRO instrument. In the period of 17 - 18 February 2011 there is a rapid decrease in secondary cosmic ray particle count rate. The data shows modulation of the flux for low energy particles, high energy muons and neutral particles.

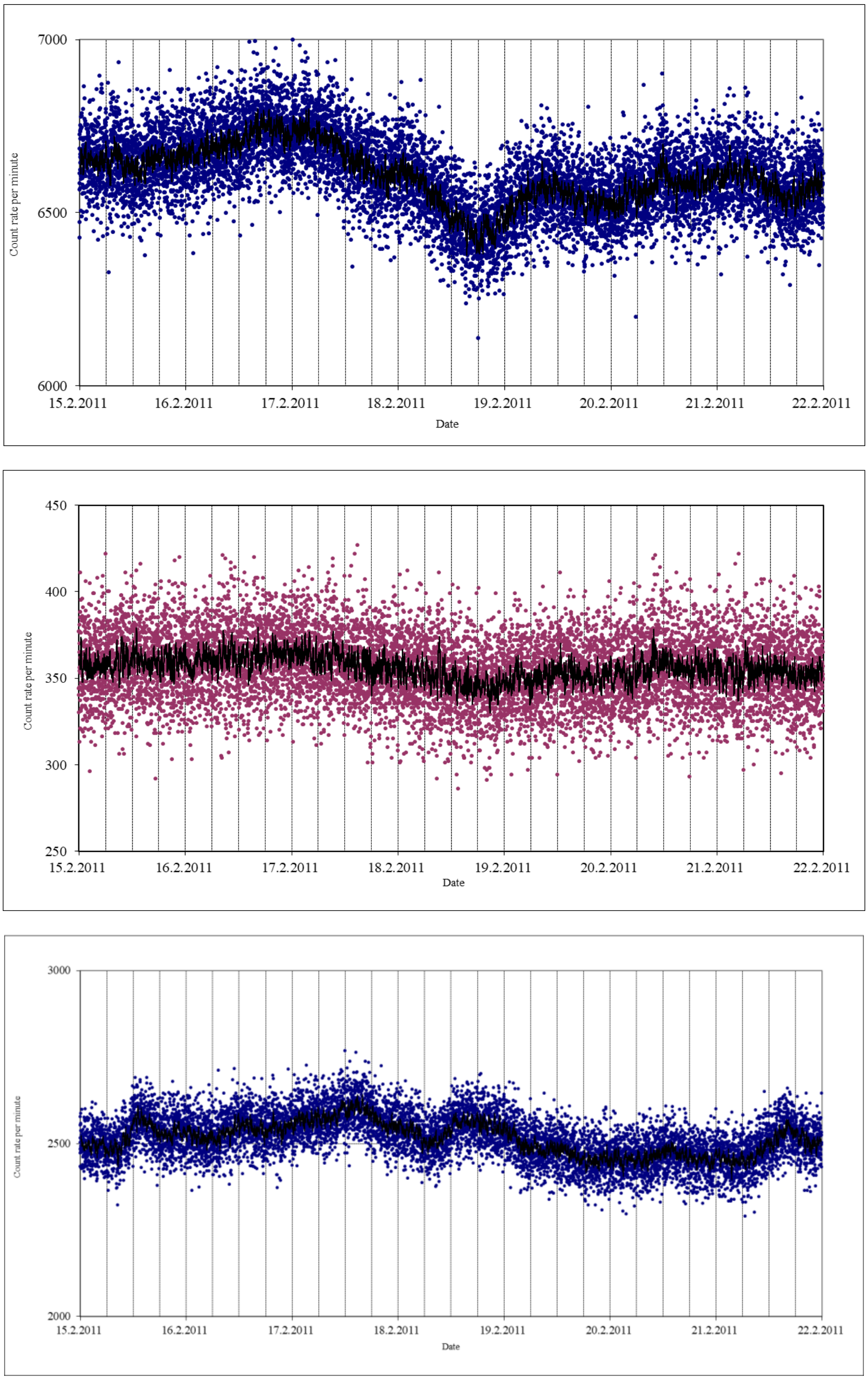


Fig. 3 Forbush decrease detected on SEVAN CRO instrument showing from top to bottom: low energy particles, neural particles, high energy muons

Diurnal cosmic ray variations depend on the geographic location of the cosmic ray detector, magnetospheric and heliospheric magnetic field conditions. Diurnal variations are characterized by phase and amplitude and are important data for measuring and research of the Sun – Earth interaction and the analysis of the cosmic ray fluxes (*Mailyan and Chilingarian*, 2010). For the period of 1 - 20 November 2010, we calculated the average values of count rate for the same minute of each day. The data is smoothed with the moving average of two hours. For high energy muons the peak is ~ 13:00 UT, low energy particles have two peaks ~ 6:30 UT and ~ 10:00 UT and neutral particles also show two peaks at ~ 9:00 UT and ~ 11:00 UT.

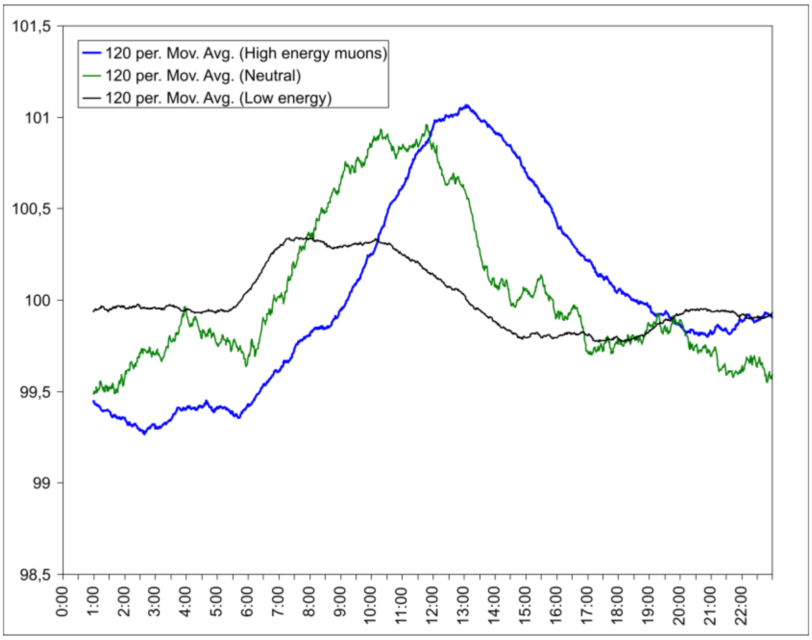


Fig. 4 Diurnal cosmic ray variation of 20 days from 1st to 20th November 2010

Thunderstorm Ground Enhancements (TGE) are sudden changes of secondary cosmic ray particle fluxes (enhancing fluxes of electrons, gamma rays and neutrons) during thunderstorms which are connected to high energy events in Earth's atmosphere. They consist of a few minutes high-energy emission (up to 30 - 40 MeV) and a few hours duration of low energy emission (< 3 MeV). TGEs occur mainly during deep negative electric field periods. The flux enhancement is well correlated with the electric field disturbances (*Chilingarian et.al.*, 2015). Here we present the first evidence of TGEs at Zagreb Observatory by SEVAN detector. We show the disturbances of the electric field measured on a station located 1.5 km from the Zagreb Astronomical Observatory on 14 May 2017 during lightning activity .

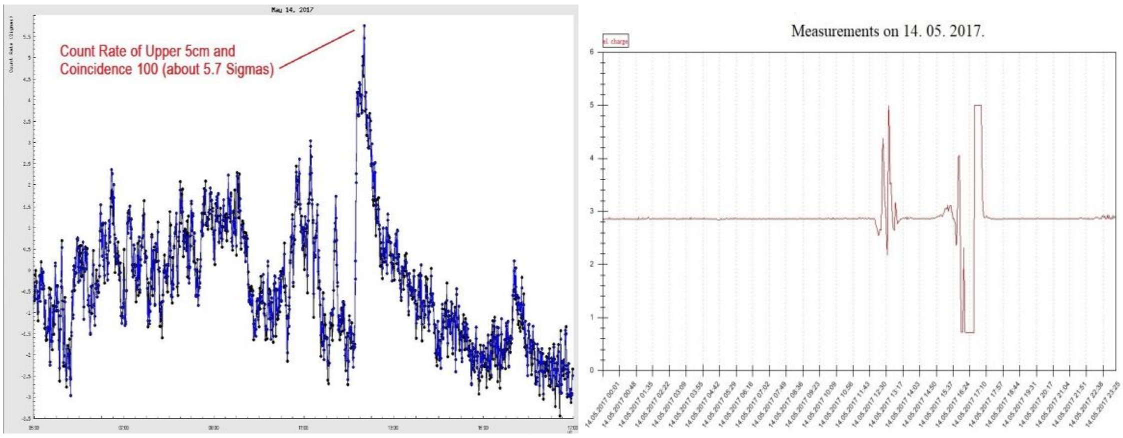


Fig. 5 On the right side is the measurement of disturbance in electric field, the measurements are relative and the instrument is not calibrated during the lightning event. On the left side is the TGE enhancement in upper 5cm plastic scintillator and coincidence of “100” (mostly low energy electrons and gamma rays) where we can see an increase in count rate during a lightning.

Conclusions

In this paper we presented some results obtained by SEVAN CRO detector during its 10 operational years, such as the values of barometric coefficients, diurnal variation, example of a Forbush decrease and the flux enhancements related to TGE events. The ability of detection of different particle fluxes (e.g. neutrons, high and low energy muons) is suitable for monitoring space weather conditions, especially solar modulation of cosmic ray flux. But also SEVAN data can be very useful for analysis of high energy phenomena in Earths atmosphere, such as the physics of the thunderstorms which still remain unsolved.

Acknowledgment

We would like to thank DHMZ (Croatian Meteorological and Hydrological Service) for the atmospheric pressure data, Kyoto university teams for they open policy and database regarding Dst index and colleagues from Ruđer Bošković Institute led by Ivan Kontušić regarding the atmospheric electric field data.

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