American-Eurasian J. Agric. & Environ. Sci., 16 (5): 874-881, 2016
ISSN 1818-6769

DOI: 10.5829/idosi.aejaes.2016.16.5.10441

Variability of Galactic Cosmic Rays Flux and Solar Activities in the Earth's Atmospheric Environment

A.E. Umahi

Department of Industrial Physics (Astrophysics unit),
Faculty of Science, Ebonyi State University, Abakaliki, Nigeria

Abstract: A brief review of the variability of galactic cosmic ray's flux and solar activities in the earth's atmospheric environment is presented. The data from observatory stations are arranged in excel spread sheet and statistically analyzed. The results of the characterizations of the major two events (i.e. GCRs and GSF) against time (measured in hour) shows significant variations. The GCRs showed a continuous variation with time (measured in hour) while the GSF showed some slight block variations with time (measured in hour) in all the 8, 808 hourly events in the year, 2000. The inability to observe GCR counts in some hours in the month may be attributed to the instrumental cut off rigidity (GV). The anti-correlation coefficient, r between GCRs and GSRs, ranging from -0.001 to -0.500, also interprets that the events originates from different sources. The low level of r in these results indicates that other solar activities such as sunspot, coronal mass ejection, solar wind and directly enters the Earth's atmosphere.

Key words: Cosmic Rays · Solar Flare · Ionization And Solar Activity

INTRODUCTION

The scientific reports on the variability of galactic cosmic ray's flux and solar activities in the earth's atmospheric environment which generates and enhances ionization, nuclear-electromagnetic cascade, chemical and biological effects, climatic changes and depletion of the ozone layer. These atmospheric occurrences have been an interesting issue for global discussion. This issue has led to the investigation of cycles of solar modulations on galactic cosmic rays and the debate have not be exhausted. The hazard to astronauts, communication, human DNA and cells cannot be over emphasized. These confusions are given National Aeronautics and Space Administration (NASA) serious challenges.

The galactic cosmic rays (GCRs) and galactic solar rays (GSRs) are high energetic protons from outside and within our solar system respectively. In particular, the GCRs are both high energetic protons and heavy ions and the GSRs are high energetic protons buildups. The composition of primaries of GCRs and GSRs are ~ 10% of proton and ~1% electrons [1]. The GSRs are rays from our solar system which is driven mainly by the sun during sporadic activities and the release of high energetic particles into space such as solar flares, solar wind and others which are propagated directly toward earth's atmosphere. The contributions of these GCRs and GSRs are to generate ionizing radiation loses due to ionization and nuclear-electromagnetic cascade in the atmospheric particle interaction. The increasing rate of ionization processes that takes place in the earth's atmosphere is the most dangerous emissions from the event radiations, including protons, x- Rays and ultraviolent radiations (UV). Due of these uncontrollable natural events, they continuous monitoring of the Earth's atmospheric becomes an important and interesting activity for astronomers, astrophysics and space scientist globally [2]. They are other sources of radiations into the earth's atmosphere such as supernova explosions, supernova remnants, radio galactic quasars, Seyfert galaxies, gamma-ray burst, etc, which are determined within the heliosphere by their interaction with magnetic field [2].

The curiosity to explore the events in the earth's atmosphere led the construction of early Balloon experiments used in the past to measure the induced ionization at different locations and during solar cycles [3-7], rockets [8], Spacecraft's [9, 10], Muon telescope [11] and ground base observatory centers/networks are

Corresponding Author: A.E. Umahi, Department of Industrial Physics (Astrophysics unit), Faculty of Science, Ebonyi State University, Abakaliki, Nigeria.

initially used in observing the ionization rates and level in the Earth's atmosphere at different latitude. For easy observation, less hazard and observation continuity, the ground base observatory networks remains the best means of monitoring the atmospheric mechanism and ionization process. The sites of some observatories for cosmic rays measurement are as follows: Mirny, Antarctica (66°33'S; 93°00'); Tixie (71°33' N; 128°54'); Murmansk Region (68°59' N; 33°05'); Norilsk (69°00' N; 88°00'); Moscow Region (55°28' N; 37°19'); Alma-Ata (43°12' N; 76°56'); Erevan (40°10' N; 44°30'), Forschungszentrum Karlsruhe, Germany (49°N, 8°E) and Sea Expeditions (60° N-60^{0}S). The main site for solar flare measurements are National Aeronautics and Space Administration (NASA), Bonner Ball Neutron Detector (BBND), Charged Particle Directional Spectrometers (CPDS), Dosimetric Mapping (DOSMAP), Radiation Doses Experienced by Astronauts in EVA (EVARM), Passive Dosimetry (PD), Phantom Torso (PT) and Tissue Equivalent Proportional Counter (TEPC).

The most interesting area in the clear understanding of the earth's atmosphere is that great scientist designed, constructed and developed models, codes and packages for atmospheric ionization and nucleonic-electromagnetic cascade. The Earth's atmosphere model for nucleonic-electromagnetic cascade using the Monte Carlo CORSIKA (COsmic Ray SImulations for KAscade) simulation [12, 13]. Models of the numerical cosmic ray (CR) ionization using the works of COST-724 action (2003–2007) [14]. This last work was extended and used for analytical approximation of the direct ionization of primary cosmic rays (CRs) above 30 km by Sofia model [15, 16]. The FLUKA package simulated the low-energy nuclear interactions below 30km by extending the CORSIKA Monte-Carlo [17, 18]. The Oulu CRAC (Cosmic Ray Atmospheric Cascade) model conceived the concept of CORSIKA/FLUKA Monte-Carlo Simulations for direct ionization by primary CR particles [19, 20]. The Bern model (ATMOCOSMICS/PLANETOCOSMICS code) extracted the principles of GEANT-4 Monte-Carlo simulation package for cascade evolution [21]. Thereafter, the results of this Bern package were obtained in detailed [22, 23]. The CORSIKA and GEANT-4 code combined investigations for the cascade evolution in the atmosphere and also simulated the interactions and decays of various nuclei, hadrons, muons, electrons and photons [14].

The observatory and experimental measurements led to the study of the origin of the cosmic rays and propagation in the atmosphere [24, 25], Cosmic ray induced ion production, Ion balance and mobility in the atmosphere [26-29], Ionospheric electron production rate by cosmic rays [30 and 31], cosmic ray spectrum [32], cosmic ray proton, solar proton events and helium spectra [33-35], Rigidity dependence of cosmic ray proton measured by the Ulysses spacecraft [10], enhanced ionization production by solar protons [36], Cosmic Ray and Solar cosmic ray ion and ionization speed on different altitudes [17 , 37], theory of Cosmic ray and high energy solar particles transport in the atmosphere [38, 39 and 30], global atmospheric electrical circuit [40- 43], varying atmospheric profiles on extensive air shower observation, ionization and energetic particles in the atmosphere [5, 15, 39], production of atomic nitrogen and oxygen by relativistic proton impact in air [45 46], galactic cosmic rays on human health and earth's climate [47], Solar and galactic cosmic rays in the earth's atmosphere [48]. This work will focus on the variability of galactic cosmic rays flux and solar activities in the earth's atmospheric environment where the particles are cosmic rays and solar flare are considered. The main procedure of this work is to statistically analysis study the hourly variations of cosmic rays and solar flare in the earth's atmosphere using excel programs.

Ionization of Induced Galactic Cosmic Rays: The ionization due to galactic cosmic rays (GCRs) is reported to be present always in the atmosphere and it changes with the 11-year solar cycle due to the solar modulation. Primary cosmic rays initiate a nucleonic-electromagnetic cascade in the atmosphere, with the main energy losses at altitudes below 30 km which results in ionization, dissociation and excitation of molecules [2]. The expression for the numerical models of cosmic rays induced ionization (CRII) has been presented in detailed [29]. In the expression, the cosmic rays

(CR) consist of protons, α-particles and heavier species. The ionization yield function which indicates the number of ion pairs produced at a particular altitude in the atmosphere by each CR particle with kinetic energy was considered. The differential energy spectrum for each CR in space near Earth depends on solar activity and parameterized the expression by the modulation potential [19]. These numerical models are based on the computations using the Monte-Carlo simulations of the nucleonic-electromagnetic cascade initiated by CRs in the atmosphere. The Bern model [22], was based on the GEANT-4 Monte-Carlo simulation package. The Oulu model, based on the CORSIKA Monte-Carlo package extended by FLUKA package to simulate the low-energy

nuclear interactions and accounting for direct ionization by primary CR particles. Detailed tables of this numerical expression are shown [20]. The Sofia model includes an analytical approximation of the direct ionization by primary CR [31], as well as CORSIKA/FLUKA simulations [17]. Considering different locations and dates of individual measurements and calculated values, the agreement was excellent [49, 20]. The results of the CORSIKA-based Sofia model are very close to those of the Oulu model. The analytical approximation model reasonably agrees with the numerical models [38].

On the lower atmosphere, the ionization of the middle and upper atmosphere, where the cascade is not completely developed, simple analytical solution were applied. The atmospheric depth at the altitude of 30 km, which was much less than the nuclear free path of protons and particles were considered. Therefore, they neglected nuclear interactions in the middle atmosphere above 30 km (upper stratosphere and ionosphere) and consider only ionization losses of the primary CR particles [50, 51]. Furthermore, for the altitude above 50 km, they also neglect changes of the energy of energetic particles, thus reducing the computation of CR ionization to an analytical thin target model [30].

In the altitude range from 25-30 to 50 km, an intermediate model were used which accounts for the particle's deceleration due to ionization losses [30 , 52]. This model was applied for calculation of electron density and atmospheric electrical conductivities in the middle atmosphere for different particles: Galactic Comic Rays (GCRs), Anomalous Cosmic Rays (ACRs) and Solar Energetic Particles (SEPs). The intermediate ionization model was developed by considering the Chapman function values for the inclined penetrating particles in the spherical atmosphere [17, 30]. The program CORIMIA (COsmic Ray Ionization Model for Ionosphere and Atmosphere) was developed for the calculation of the electron and ion production rate due to cosmic rays using ionization losses (Bohr-Bethe-Bloch function) approximation in six characteristic energy intervals, including the charge decrease interval for electron capturing [53]. Results of the model for calculation of CR ionization rates (number of electron-ion pairs in cm^{-3} per second at given altitude, km) in the ionosphere and middle atmosphere are presented [52]. The mathematical expression of the fully operational program CORIMIA is also detailed [30, 52]. Where the CR differential spectrum (cm^{-2} s^{-1} st^{-1} MeV^{-}), ionization losses [47], of each particle, azimuth angle, θ which is the angle towards the vertical. The gradient of space angle, $\Delta\theta$ accounts for the penetration at a given height in the space angle (0°, θ_{max} = 90° + $\Delta\theta$), which is greater than the upper hemisphere angle (0°, 90°) for flat model. The energy cut-off rigidity was also considered. The summary of the ionization integral was made on the groups of nuclei (i = 1, … 6) and given by protons, p; Helium (α particles); Light, L (3 < Z < 5); Medium, M (6 < Z < 9); Heavy, H (Z >10) and Very Heavy VH (Z > 20) nuclei in the composition of cosmic rays. The value Z is the charge of the nuclei; Q = 35 eV is the energy which is necessary for formation of one electron-ion pair [52].

Ionization of Induced Solar Rays: The solar rays which are high energetic particle radiations driven from the surface of the sun as strong fluxes of the energetic particles such as solar flares or sunspots or solar winds or coronal mass ejections (CMEs). The high solar energetic particle radiations (HSEPRs) are mostly protons which interact with the Earth's atmosphere and can produce an important increase of the atmosphere ionization [44]. These HSEPRs are accelerated up to hundreds of MeV and increase ionization was observed at high altitude in the polar atmosphere. During strong activities, HSEPRs can also be accelerated up to a few GeV. Ionization effects due to HSEPRs can be extended down to the lower altitude. One of the strongest HSEPRs events of solar activities ever observed was in January 20, 2005. The quantitative effect of the HSEPRs event in the earth's atmosphere on the ionization was investigated and reported [14]. The peak of the event of HSEPR on the ionization of the Earth's atmosphere was computation using the spectrum and the angular distribution of solar protons outside the magnetosphere from the neutron monitor network data.

The high energetic particles from galactic cosmic and galactic solar radiations are the two major charged particles and their interactions were considered with the particles in the Earth's atmosphere. These particles influence the physical-chemical processes in the Earth's Atmosphere. The effects include cloudiness density charges, atmosphere cloud coverage and control the variability of atmosphere transparency and therefore, the affect high radiation flux reaching the lower atmosphere. The morphological effects of these particles on induced ionization for the upper troposphere of the earth atmosphere are displayed in detailed [14].

In comparison, high energetic particles from galactic cosmic radiations which impinge on Earth atmosphere are nearly isotropic while radiations from galactic solar activities have an anisotropic spatial distribution,

especially during the maximum event. The illustration for the anisotropic propagation are discussed and shown in detail [14]. The asymptotic directions, which are the particle arrival directions outside the magnetosphere, depend on the particle's rigidity and are also computed using the backward trajectory technique [54].

Materials, Methods and Result Analysis: The materials used in this work are from observatories of Mexico for cosmic ray data and Space Physics Interactive Data Resources (SPIDR) for solar flare data for the year 2000 respectively. These data were collected in hourly intervals per month. The data are also available for scientific disposal. These data of about 720hrs per month for 12- months events were arranged in four different sets in an excel spread sheets were they are statistically analyzed and used in this paper. In each of the sets, a chosen cut off rigidity of 7000 counts for cosmic rays and 100 counts for solar flare were taken. The computations of galactic cosmic rays (GCRs) and galactic solar flare (GSFs) data were considered in each of the set. The sets were characterized as number of counts of GCR and GSF against time (measured in hour) and they are shown in a graphical form in Fig. 1-2. The first set covers the events from January, February and March of maximum of 0.744 $\times 10^2$hr are shown in Fig. 1; the second set covers the events from April, May and June of maximum of 0.744 $\times 10^2$hr as shown in Fig. 2; the third set covers the events from July, August and September of maximum of maximum of 0.768 $\times 10^2$hr as shown in Fig. 3; and the fourth set covers the events from October, November and December of maximum of 0.768 $\times 10^2$hr as shown in Fig. 4.

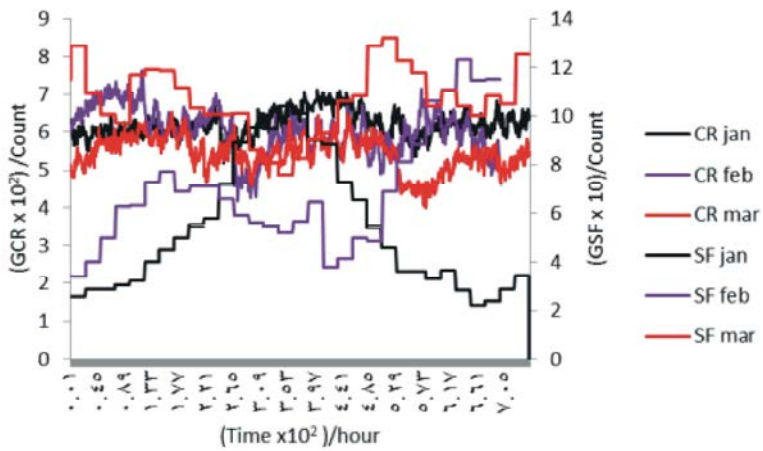

Fig. 1: Variations of Galactic Cosmic Rays (GCRs) and Galactic Solar Flares (GSFs) against Time/hour. The legend colour for GCRs (CR) and GSFs (SF): the month of January is black; the month of February is blue and the month of March red

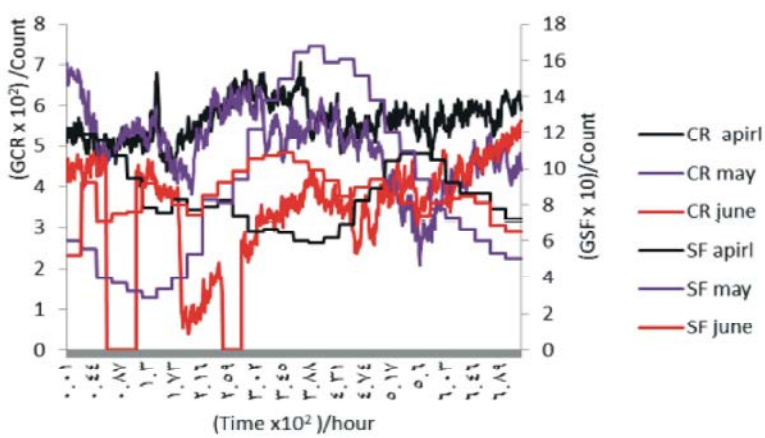

Fig. 2: Variations of Galactic Cosmic Rays (GCRs) and Galactic Solar Flares (GSFs) against Time/hour. The legend colour for GCRs (CR) and GSFs (SF): the month of April is black; the month of May is blue and the month of June is red

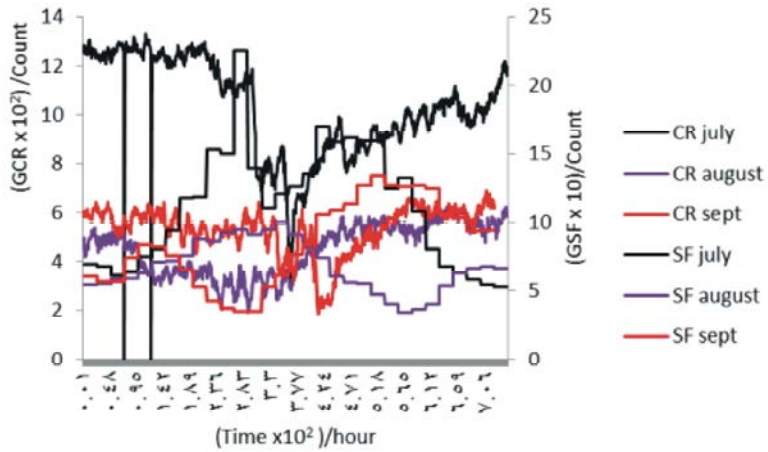

Fig. 3: Variations of Galactic Cosmic Rays (GCRs) and Galactic Solar Flares (GSFs) against Time/hour. The legend colour for GCRs (CR) and GSFs (SF): the month of July is black; the month of August is blue and the month of September is red

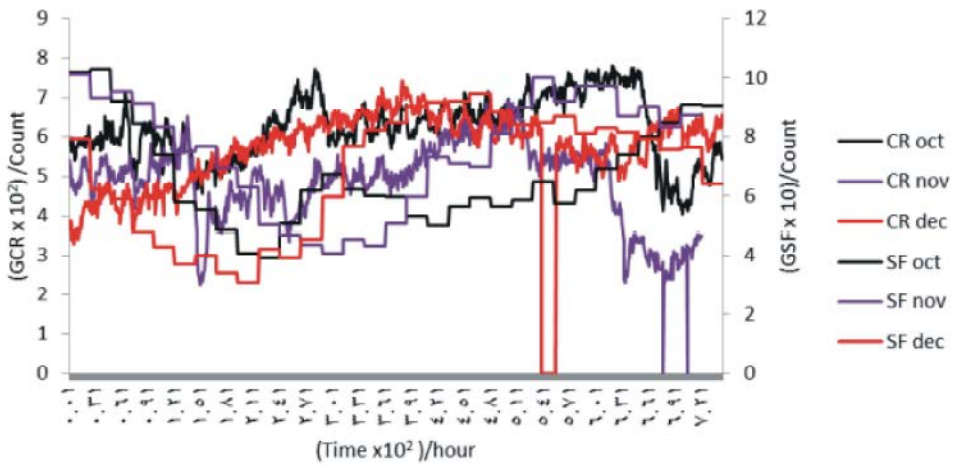

Fig. 4: Variations of Galactic Cosmic Rays (GCRs) and Galactic Solar Flares (GSFs) against Time/hour. The legend colour for GCRs (CR) and GSFs (SF): the month of October is black; the month of November is blue and the month of December is red.

In addition to the above characterizations, a correlation analysis of excel program were carried out in order to ascertain the level of relationship between GCRs and SCRs. The results of the correlation coefficient, r, ranges from -0.001 to -0.500.

DISCUSSION

The data shown in the characterization from Figures 1 to 4, indicates that the Galactic Cosmic Rays (GCRs) intensity during a given month is not uniquely related to the Galactic Solar Flare (GSF) activity occurring during any one particular month but to that occurring over a period of months. This is precisely what would be expected in this work if the modulation of GCRs by GSFs are produced in the earth's atmospheric interactions. The level of modulation will affect GCRs not only while they are in the vicinity of the atmosphere but throughout the motion through the atmosphere. Though the magnitude of their effect may vary with atmospheric regions. The GCRs intensity observed on the earth's atmosphere are therefore dependent on the distribution of interactions in the earth's atmosphere and hence the GSFs over a long scale of time. The results of the statistical study in this work, the two events (i.e. GCRs and GSF) showed significant characterization with respect to hourly sample variations. The GCRs showed a continuous variation with time (measured in hour) while the GSF

showed some slight block variations with time (measured in hour) in all the 8, 808 hourly events in 2000. This variation is in agreement with some authors [14, 52, 1 and 55]. In the result no GCRs detection was observed in some hours of the months such as June (ranging from 0.46 to 1.05×10^2hr and 2.28 to 2.71×10^2hr), July (at 0.55 and 1.06×10^2hr) and November (at 6.83 and 7.14×10^2hr). On the other side of the events, GSF showed high significant variations in all the months and then all the events in months were detected.

In comparison on the variations between GCRs and GSF: Fig. 1 showed that the event of GCRs in January and February are high while March is low. The reverse is the case in the corresponding events of GSF in January, February and March; Fig. 2 showed that the GCRs is low in May and June while April is high. The reverse is the case in the corresponding GSFs in the month May, April and June; Fig.3 showed high variations in July and September for GCRs and partial high variation in August within 4.01 to 7.01×10^2hr, in the contrary GSF showed relatively high variations in July between 2.51 to 3.01×10^2hr and 4.01 to 5.01×10^2hr while other part of the variation are low; Fig.4 showed high variation of GCRs in October, November and December while the GSFs are all low in the same months.

The most interesting part of these characterization, is that the variations met in June (ranging from 3.90 to 5.46×10^2hr), August (at 1.01 and 4.01×10^2hr), October (at 0.75 and 6.52×10^2hr), November (at 1.25, 1.87 and 4.97×10^2hr) and December (at 0.63, 4.04 and 6.52×10^2hr). The variations in August showed greater relationship between the events, i.e. conspicuous oscillation.

The correlation coefficients, r between GCRs and GSFs are anti-correlation, ranging from -0.001 to -0.500. The anti-correlation coefficient is in agreement with other authors [14, 52, 1, 55]. In conclusion, the observatory stations exploring the earth's atmosphere records measurements of GCRs and GSF on hourly events for the year, 2000. The measurements are interpreted on an excel spread sheet statistically. The graphical analysis showed that they are presents of GCRs and SCRs in the earth's atmosphere. The hourly variation of GCRs indicates a continuous arrival of events with variation in amplitude, except when arrivals are not recorded. The non-records of the events may be attributed to the instrumental rigidity (GV) which varies with observatory instrumental design. But, the hourly variation of GSF is constantly continuous for some seconds, their amplitude also varies. Finally, the anti-correlation coefficient found in these results shows that the events originate from different sources.

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