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Research Paper

Observation of intensity of cosmic rays and daily magnetic shifts near meridian 70° in the South America

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ABSTRACT

In analysis of experiments carried during September 2008 using secondary cosmic ray detectors located in Chacaltaya (Bolivia) and Niteroi (Brazil), Augusto et al. (2010) showed an increase in the intensity of charged particles which takes place 3 h after sunrise and lasts until 1 h after sunset, furthermore they said that during this period the solar magnetic field lines overtake the Earth's surface. These stations are located within the South Atlantic Magnetic Anomaly (SAMA), having both different magnetic rigidities. To reproduce data from the Niteroi and Chacaltaya stations, we record data during the same hours and days using our neutron monitors, muon telescopes and magnetometers within the stations Putre and Los Cerrillos. Our observation stations in Putre and Cerrillos are located at 18°11′47.8″S, 69°33′10.9″W at an altitude of 3600 m and 33°29′42.3″S, 70°42′59.81″W with 570 m height above sea level, respectively. These stations are located within the South Atlantic Anomaly (SAMA) and are separated approximately 1700 km from each other and 1700 km from the center of the anomaly. Our network is composed furthermore by two auxiliary Cosmic Ray and/or Geomagnetic stations located at different latitudes along 70°W meridian, LARC and O'Higgins stations, which are located within Antarctic territory, covering a broad part of the Southern Hemisphere.

Our magnetometer data shows that for each of the components, shifts in the magnetic field intensity for every station (even for those out of the SAMA) lasted between 3 and 4 h after sunrise and 1 and 2 h past sunset, which are the periods when the geomagnetic field is modulated by the transit of the dayside to nightside and nightside to dayside. We believe that, although the magnetometric data indicates the magnetic reconnection for the Chilean region, there is no direct influence from the SAMA other than the lower rigidity cut-off that leads to an increased count rate. Other details about the magnetic field components such as muon and neutron count rate, diurnal variation and"sunset enhancement' are reported in this work.

1. Introduction

It has been theorized by Augusto et al. (2010), that The South Atlantic Magnetic Anomaly (SAMA), now located over South America, would be responsible for a specific rise in the secondary particle production that occurs during the period between 3 h after sunrise until 1 h after sunset. This increase in the secondary particle production shows that the SAMA region promotes the precipitation of high-energy particles, with energies above the pion production threshold, which generate an air shower of particles from the Earth's atmosphere. The hard components of this shower (Muons) are able to reach sea level. This can be translated into an intense but narrowed variation of the muon and neutron count rate, as well as magnetic field intensity.

The aim of this work is to reproduce the results of the specific raise in the secondary particle production generated by the South Atlantic Magnetic Anomaly (SAMA) that occurs 3 h after sunrise until 1 h after sunset. These results have been obtained in different experiments done in Niteroi (Brazil), which is located at sea level, and Lago-Chacaltalla (Bolivia) at 5200 m.a.s.l. These two stations are separated by 2700 km and lie within SAMA region.

In order to examine the diurnal variation rate during the same period of time, we have used our cosmic ray and geo-magnetic observatories in the Chilean Network, as described in Section 2 and in full extent in Cordaro et al. (2012). The main experiments are done in the High Mountain Observatory Putre-INCAS (PUTRE), at 3598 m.a.s.l. and at Los Cerrillos Observatory (OLC) at 570 m.a.s.l. These stations are located inside of the SAMA and form an

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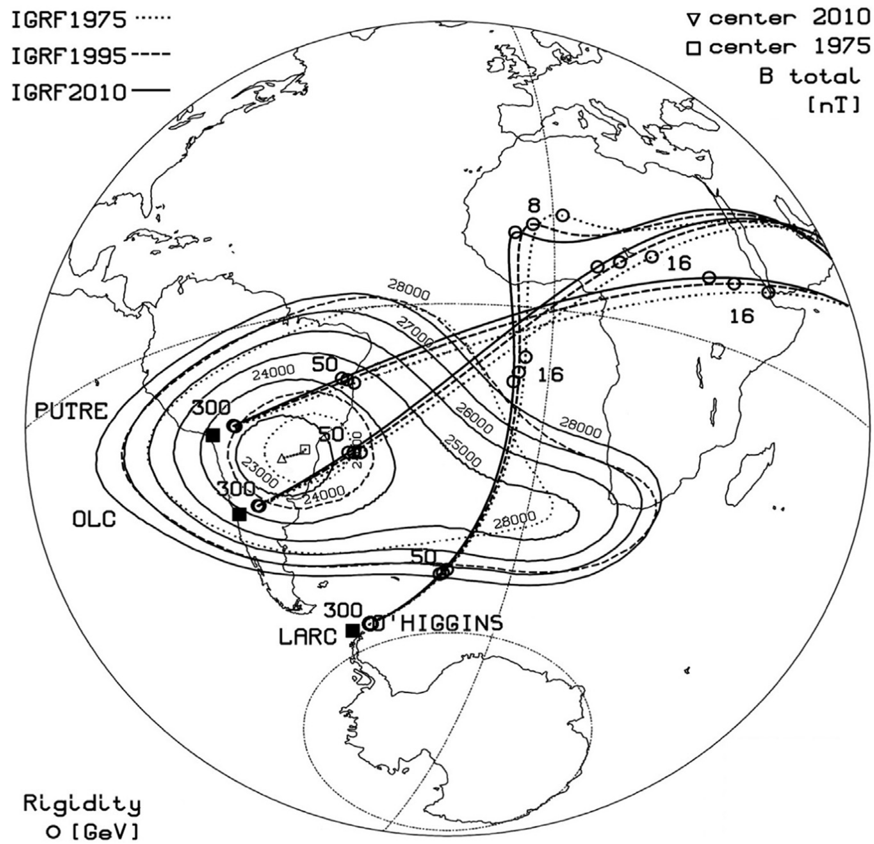

Fig. 1. Geomagnetic B total field intensity map with the variability of the South Atlantic magnetic anomaly and the particle asymptotic directions arrivals map for Putre, Los Cerrillos, LARC and O'Higgins stations (both nearly identical directions of arrivals). The SAMA center and its extension towards the Chilean coast are clearly shown. Image drawing from IGRF model and programs for asymptotic direction calculation, which means the path through a charged particle to reach its zenith point (Pomerantz, 1971).

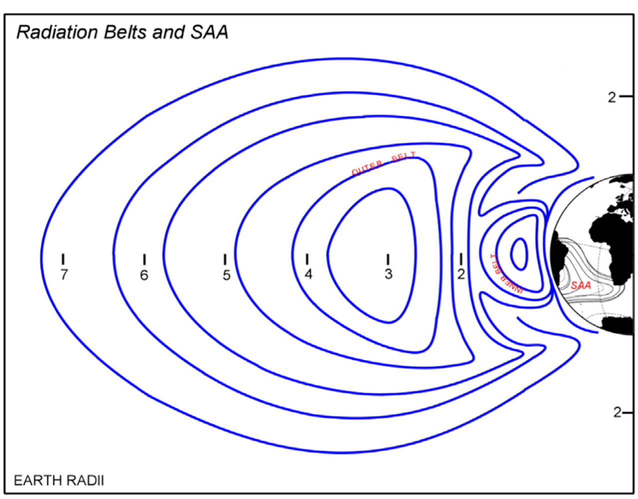

Fig. 2. South Atlantic Anomaly forming the anisotropy on the inner Van Allen belt. Image sketched from IGRF/AP8M models and NASA/ESA sources.

almost perfect equilateral triangle with the center of the anomaly at approximately 1700 km (1636 Km average), see Fig. 1. Furthermore, our two observatories have different magnetic cut-off rigidities, like the observatories in Brazil and Bolivia. The experiments were performed in September 2008 (Augusto et al., 2010).

There are some factors that should be taken into account such as: The changes in the barometric pressure that indicates how the mass of atmosphere above the instruments varies and the effects of the earth's magnetic field on the motion of the particles of cosmic rays from a height of 20 km to the ground. In the first case we have eliminated the pressure dependence of the counting rate and we have determined the primary cosmic variations at all observatories, calculating an attenuation coefficient of 0.8289 ± 0.0026%/hPa, at an average pressure level of 664 hPa, for the Neutron counter He 3 at Putre-Incas. At OLC, the BF3 neutron counter gives an attenuation factor of $0.684 \pm 0{:}014$%/hPa, at an average pressure level of 958 hPa. At the Antarctic Observatory Cosmic Rays and Geomagnetism (LARC), the calculated attenuation coefficient was $0.750 \pm 0{:}016$%/hPa at an average pressure level of 989 hPa. (Cordaro et al., 2012; Cordaro and Storini 1995, 2001). In the second case we have obtained the value of magnetic rigidity cut off and geomagnetic field (Priest and Forbes, 2000).

The South Atlantic Magnetic Anomaly (SAMA) is an area located over South America, drifting from the South Atlantic region into the Andes mountain range, where the field intensity at the Earth's surface has a weak minimum, less than 22,600 nT. This is mainly due to the additional contribution of the quadrupole component of the main field, which creates a local dip on its total magnetic field. Because of the Earth's inner Van Allen radiation belt follows the shape imposed by the magnetic field, this comes closest to the Earth's surface, a few hundred kilometers away as it is shown in Fig. 2. This leads to an increased flux of energetic particles in this region where the instruments and electronics of satellites can be severely damaged from radiation.

According to the IGRF-11/2010 data (IAGA, 2010), the magnetic field strength in the center of the SAMA region (26.5°S, 56.5°W) has an approximate value of 22,552 nT. The anomaly is considered to extend a region up to field strength of 28,000 nT, covering a wide area between the South Atlantic to the Chilean coasts and its slow variations (see Fig. 1) have not significant impact during our measurements (September 2008). Currently, close the 24.000 nT ring of anomalies that expanding latitudes between Arica (18°28′43″S, 70°18′19″W) to Santiago (33°29′42.3″S, 70°42′59.81″W). As a result, the Inner Van Allen belt exposes highly energetic particles (mostly protons) deeper into the atmosphere that (due to the low field intensity over the SAMA) can interact with the dense atmosphere, resulting in ionization production and increasing the electric conductivity (Vernov et al., 1967).

Since the geographical location and altitude differences between the observatories are taken into consideration for the measurements, the weather conditions can be easily compensated for this specific experiment. Both of our observatories register similar variations in their cosmic rays data, showing no particular enhancements or daily variations on the monitor values. While being compared with the LARC station (outside the SAMA), there are no significant differences measured between the two other stations. However, there is an interesting result from analyzing the *Y*-axis (East–West direction), indicating an Earth–Sun reconnection process.

We think that in the SAMA region, and for the conditions of our experiments, there are no special count rate variations compared to other stations located outside of this region. Therefore, besides the lower average magnetic field intensity values of these observatories owed to the fact of being inside the SAMA, we observe no other differences with those which are not inside the anomaly. Details of these results are presented in this paper. This conclusion is reinforced by the magnetic field intensity measurements that show no specific enhancement in any of the stations, even for the high mountain Putre observatory.

2. Experimental setup

The Chilean Cosmic Ray and SAMBA magneto-metric networks are our basic tools for the study of geomagnetic fields and particle detection. Our network is composed by four Cosmic Ray and/or Geomagnetic stations located at different latitudes along 70°W meridian, which are located within Chilean Continental territory and the Antarctic territory, covering a wide range of latitudes in the Southern Hemisphere. Two of our stations are currently under the influence of the SAMA, hence it is of interest to compare these stations with the other stations outside SAMA.

The northernmost station is a High Mountain observatory, called ''Putre-Incas'' (PUTRE). This station began its operations in November 2003 and is located in the Altiplanic Andean region over Tropic of Capricorn. The geographic coordinates of the Putre-Incas station are 18.197 °S, 69.55 °W and its altitude is 3598 m.a.s.l. The geo magnetic rigidity cutoff of this station is 11.73 GeV. The main instrumentals within Putre-Incas are a 3-IGYNM (International Geophysics Year Neutron Monitor) and a MMU (M-unidirectional Muon telescope). The 3-IGYNM was originally installed with a BP9D-BF3 proportional neutron counter and, since August 2007, has been upgraded with LND25384-3He proportional neutron counters. The unidirectional muon telescope is a classical muon telescope formed by two layers of scintillator plastics of $1\ \mathrm{m} \times 1\ \mathrm{m} \times 0.14\ \mathrm{m}$, which are disposed at a distance of 1 m of each other. The scintillator plastic is a solid compound made from aromatic hydrocarbons with the following composition: Polystyrene: 98.95%, Paraterphenyl 1%, POPOV 0.05%. Each detector is made from a scintillator plastic block, a phototube and a sealed metallic container which holds them. As shown in Fig. 3, between both detectors there's a 0.05 m thick Pb sheet, that Works as an absorber of soft radiation and they work in coincidence generating data in three channels: a High channel with an average of 497,550 counts/h, a Low channel with an average of 463,930 counts/h and a High/low coincidence channel with an average of 121,812 counts/h (Buldrini et al., 1983). This

Fig. 3. Instruments details in PUTRE Observatory. Muon telescope 2-MMU. (1) Digital data systems for acquisition and data storage of Muon telescope and Neutron detectors. (2) Detector up in muon telescope constituted for phototube and plastic block in sealed pyramid metallic container, (3) Moderator, 0.05 m thick of Lead. (4) Distribution System of high and low voltage. (5) Detector down in muon telescope, constituted for plastic block in sealed pyramid metallic container and phototube (6) Neutron monitor 3IGYNM-3He Detectors, Lead and Polystyrene, (7) distribution System of high and low voltage. Collaboration UCH-UTA.

unidirectional muon monitor allowed to design and build a multidirectional muon monitor with a detection Surface of 8 m2 and seven channels, which has been working continuously since 1980 in the Los Cerrillos Observatory (Cordaro et al., 2001). The unidirectional muon monitor operates along a 3He Neutron monitor (Cordaro et al., 2012), both located in Putre since 2003. The mean atmospheric pressure on site is 666.6 HPa. The barometric coefficient calculated for muons on the Putre Observatory is 0.19%/HPa, which allows us to correct the counts by pressure (Fig. 4 Table 1).

The Cosmic Rays Los Cerrillos Observatory (OLC) is located in Santiago de Chile since 1948. Its geographic coordinates are at 33.50°S, 70.72°W and has geomagnetic rigidity cutoff of 9.53 [GeV]. During the first half of the 1980s, a Multidirectional Muon Telescope with eight photo-multiplier tubes and seven channels of data were added and made fully operational within this station. Between the years 1989n and 1990 a 6NM64 neutron monitor with BP28-BF3 proportional counters was reconstructed, modernized and operated. This neutron monitor was later relocated to the Antarctic territory in 1991 (E. Frei Base, Chilean Air Force-King George Island). In the year 2001, a 6NM64 neutron monitor in the same configuration of the LARC Antarctic 6NM64 neutron monitor was built. This instrument and the OLC Observatory is called ''mirror station'' to the LARC Observatory because the temporal and spatial coincidences of same variables are registered and the

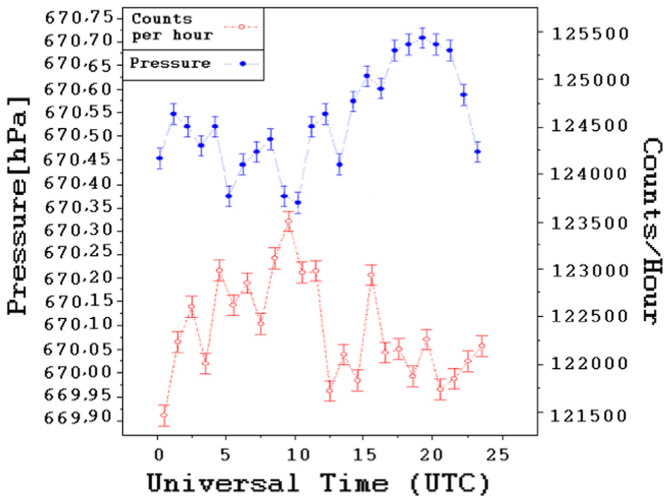

Fig. 4. Anti-correlation: up level atmospheric pressure and error bars in hPa. Dawn level Average daily variation and error bars in the count/h. During September 1, 2008.

Table 1
Geomagnetic rigidity cutoff values and the mean values for the vertical (high-low coincidence) channel for the partial periods of December 2006, September 2007 and September 2008.

Period 6–20 December 2006	PUTRE Station (PUT)
Initial level	B total: 24,326 nT
Hourly values	3IGY: 118,126
	MMU vertical: 122,359
Geomagnetic cutoff	Days 12–16
IGRF2006+TSY2001	11.69 GeV σ: 0.04
Period 1–30 September 2007	
Initial level	B total: 22,326 nT
Hourly values	3IGY-^{3}He: 215,036
	MMU vertical: 121,869
Geomagnetic cutoff	Days 1–30
IGRF2007+TSY2001	11.71 GeV σ: 0.01
Period 1–30 September 2008	
Initial level	B total: 22,244 nT
Hourly values	3IGY-^{3}He: 218,408
	MMU vertical: 121,517
Geomagnetic cutoff	Days 1–30
IGRF2008+TSY2001	11.69 GeV σ: 0.01

instrumental configuration is very similar.

In all Chilean cosmic rays observatories there is SAMBA (South American Magnetometer B-field Array) equipment installed. The purpose of SAMBA is to operate and analyze data from a low-latitude meridional array of magnetometers along the coast of Chile and Antarctica (Zesta et al., 2004). The array includes 11 magnetometer sites approximately along the 0° geomagnetic longitude and spanning geomagnetic latitude from −5° to −48°. The design of the sensor used in the ground-based magnetometers for the SAMBA network is based on the design for the earlier.

UCLA Sino Magnetic Array at Low Latitudes (SMALL) terrestrial vector fluxgate magnetometer (Gao et al., 2000). The complete sensor designed as the magnetometer is buried 1 m underground (to minimize temperature variations) at a distance from the electronics. The installation of the instrument is checked reading the East–West component, which must have a value initially close to zero. A brief description of the four stations is shown in Table 2, and it is fully detailed in Cordaro et al. (2012).

Table 2
Main characteristics and instrumental of the Chilean cosmic rays observatories. Both PUTRE and OLC stations being inside the SAMA. (1) The center of the SAMA for 2010 is located at 26.5 °S, 56.5 °W. The PUTRE-OLC distance is 1706 km. (2) The suffix CL indicate a Chilean build, the suffix IT indicate an Italian build. (3) The acronym of the SAMBA magnetic station on each site.

Station Name	PUTRE	OLC	LARC	O'HIGGINS
Geographical	18°11′ 47.8″S	33°29′ 42.3″S	62°12′9″S	63°19′15.6″S
coordinates	69°33′ 10.9″W	70°42′ 59.81″W	58°57′42″W	57°54′0.36″W
Distance to SAA center, km	1629	1574	3978	4100
Station height above sea level, m	3589	570	40	13
Geomagnetic latitude	8.17 S	23.40 S	52.32 S	53.42 S
Rigidity cutoff GeV	11.73	9.53	2.71	2.45
Instrumental setup				
Neutron monitor	3IGY-3He-CL	6NM64-BF3	6NM64-BF3-CL	NM-3He
			3NM64-3He-CL	Install in study
			3NM64-3He-IT	
Rigidity cutoff GeV	11.73	9.53	2.71	2.45
Instrumental setup				
Neutron monitor	3IGY-3He-CL	6NM64-BF3	6NM64-BF3-CL	NM-3He
			3NM64-3He-CL	Install in study
			3NM64-3He-IT	
Muon telescope	2-MMU	8-SMU	Not installed	Not installed
Magnetometer	PUT	CER	LARC	OHI
Station	UCLA-Fluxgate	UCLA-Fluxgate	UCLA-Fluxgate	UCLA-Fluxgate

Table 3
The sunrise, solar noon and sunset for September 01, 15 and 30 of 2008 at PUTRE, OLC and LARC observatories.

Station name	PUTRE (PUT)	OLC (CER)	LARC
Day 01 Sunrise UTC	10:45	11:00	10:51
Day 01 Solar noon UTC	16:38	16:42	15:55
Day 01 Sunset UTC	22:31	22:26	21:02
Day 15 Sunrise UTC	10:33	10:41	10:05
Day 15 Solar noon UTC	16:33	16:37	15:50
Day 15 Sunset UTC	22:33	22:35	21:38
Day 30 Sunrise	10:21	10:21	9:16
UTC Day 30 Sunset UTC	22:36	22:45	15:45
Day 30 Solar noon UTC	16:28	16:32	22:17

3. Results

3.1. The diurnal variation

In order to proceed with the analysis, we first take the raw data of the muon telescopes in PUTRE and OLC, then we continue with the neutron count rate in both stations, to finish analyzing the magnetometer's intensity data using data sorted by their daily standard error and deviation, and using those with higher values attempting to improve any special variation in particle count rate (and magnetic field intensity as well) that could appear, meaning the days 26, 15, 6 and 1 of September of 2008. If the South Atlantic Anomaly influences the production of secondary particle

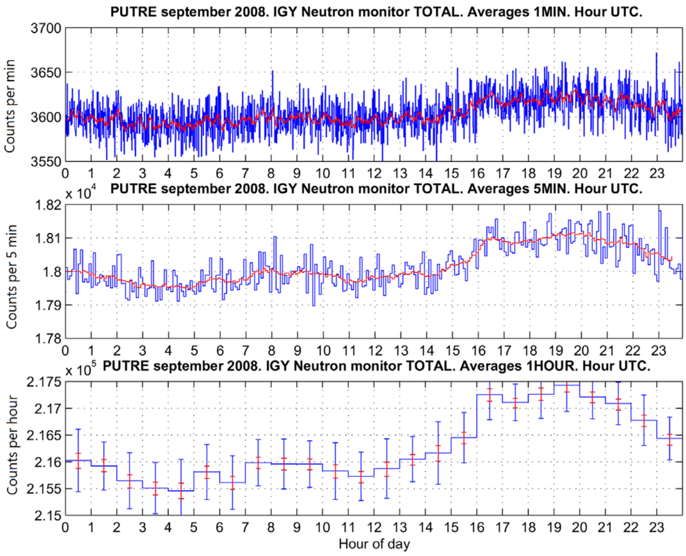

FIGURE 5 LEFT

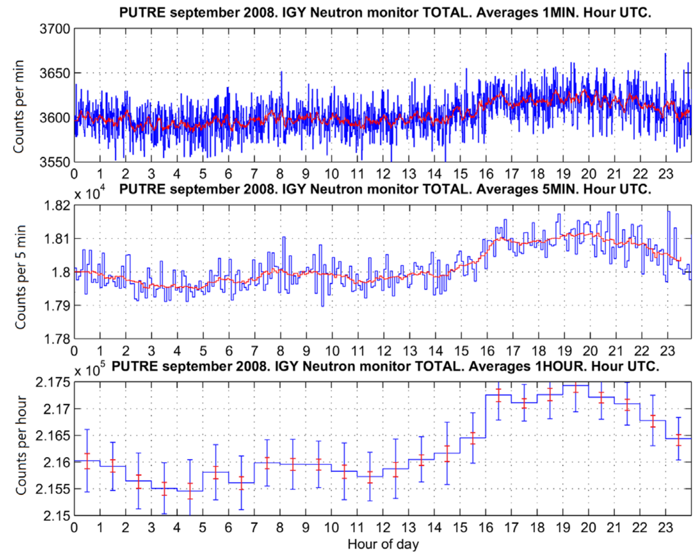

FIGURE 5 RIGHT

Fig. 5. Corrected average count rate for neutron and muon monitors for September 2008 Putre station with timesteps of (a,b) 1 min, (c,d) 5 min and (e,f) 1 h respectively. The red line is the moving average on the data of 1 and 5 min. In the hourly average the standard deviation and standard error for each sample is showed in blue and red respectively. Sunrise occurs between 10:21 UTC and 10:45 UTC and sunset occurs between 22:31 UTC and 22:36 UTC. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

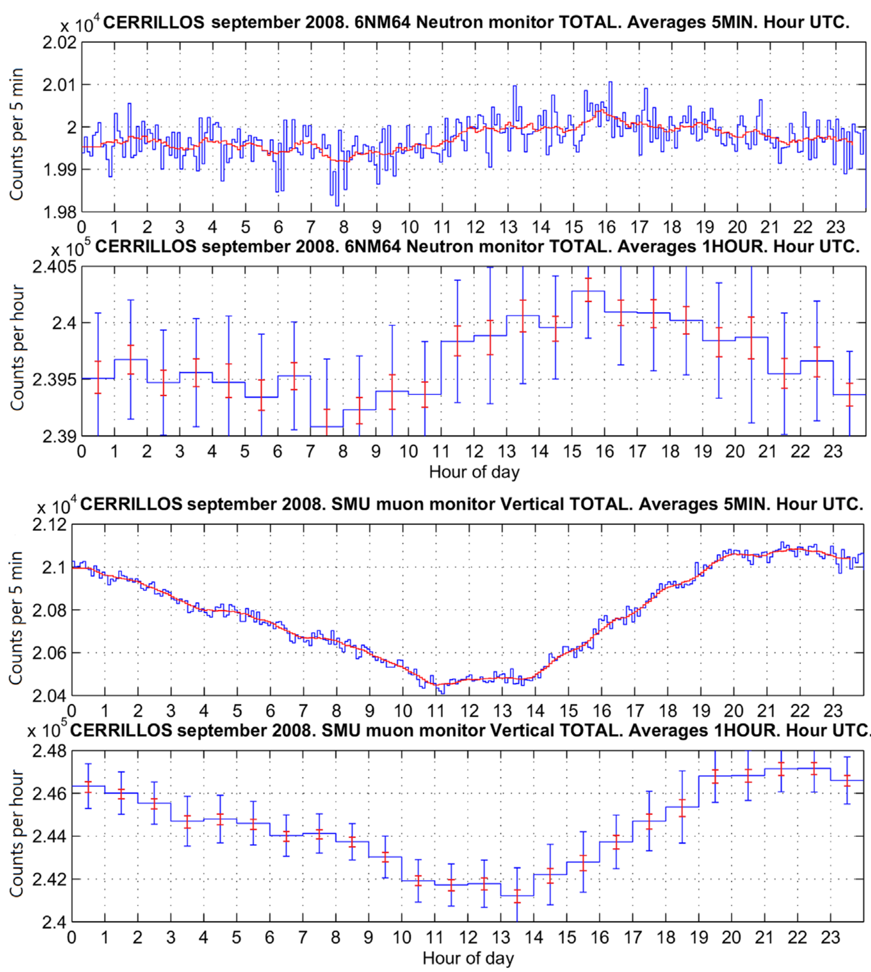

Fig. 6. Corrected daily average count rate for (a,b) neutron and (c,d) muon monitors for OLC station with timesteps of 5 min and 1 hour respectively during September 2008. The red line is the moving average on the data of 1 and 5 min. In the hourly average the standard deviation and standard error for each sample is showed in blue and red respectively. Sunrise occurs between 10:21 UTC and 11:00 UTC and sunset occurs between 22:26 UTC and 22:45 UTC. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

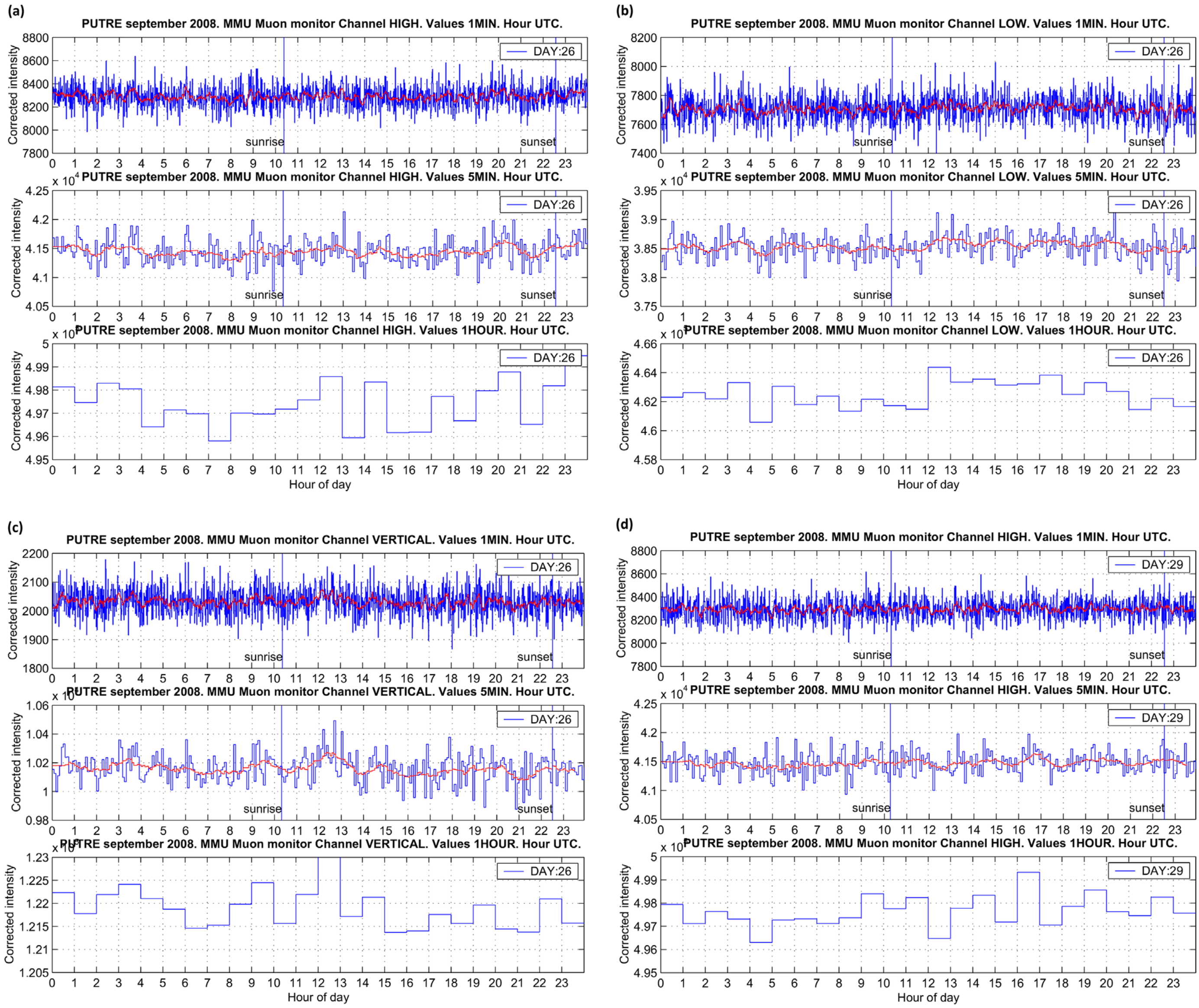

Fig. 7. Corrected muon count rate for PUTRE station with timesteps of 1 min, 5 min and 1 h of (a) High channel, (b) Low channel and (c) Vertical channel for September 26th, 2008. The High channel count rate (d) is also provided for September 29th. The red line is the moving average on the data of 1 and 5 min. The times of sunrise and sunset are indicated. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

precipitation, an increased muon count rate, a higher neutron count rate and a higher magnetic field intensity variation should be observed.

For this purpose, we analyze the raw data over one month (September 2008) at the Putre-Incas observatory to check for global daily variations in the count rate, and specific variations around the sunrise and sunset. To obtain the sunrise and sunset hours in the observatories, we have used the web and on-line resources from ESRL-GMD-NOAA (Earth System Research Laboratory Global Monitoring Division). These resources are based on equations from Meeus (1998). A summary of sunrise, solar noon and sunset at the three observatories is shown in Table 3.

As it is shown in Fig. 5, the diurnal variation can be detected at the PUTRE station within this period. The asymmetry appears in our neutron count rate data, which shows an increase during a range of approximately 14 h, starting between 10:00 and 12:00 UTC (with sunrise between 10:21 and 10:45 UTC) and finishing between 22:00 and 24:00 h UTC (with sunset between 22:31 and 22:36 UTC). We also observe a slight increase in data for averaged muons and neutrons during sunset (22:31 to 22:36), which is not seen during sunrise beyond statistical variations for the data in this sampling rate. For hourly averaged neutrons data, increases in counts are not seen during sunrise or sunset hours.

With the same goal, the raw muon and neutron monitor data sets from the OLC observatory were also analyzed. We looked for the signatures of daily count rate variations and the so-called 'sunset-enhancement' (Fig. 6). According to Augusto et al. (2010), there should be an increase or enhancement of muon counts approximately one hour after sunset. The muon increase would be related to the sudden reconnection of magnetic field lines and should be detectable using our muon monitors given that they are the hard component of the shower (Montgomery, 1949). We analyzed the daily average count rate for muons between September 26th and 29th, 2008, as it is shown in Fig. 7.

These results show no special enhancement after sunset. To corroborate these findings, we have also analyzed the neutron count rate for other significantly relevant dates (showing a count rate standard deviation of 0.0015 and standard error of 0.00043) and three different time steps in the search of this sunset phenomenon, as it can be seen in Fig. 8. Once again, there is no clear

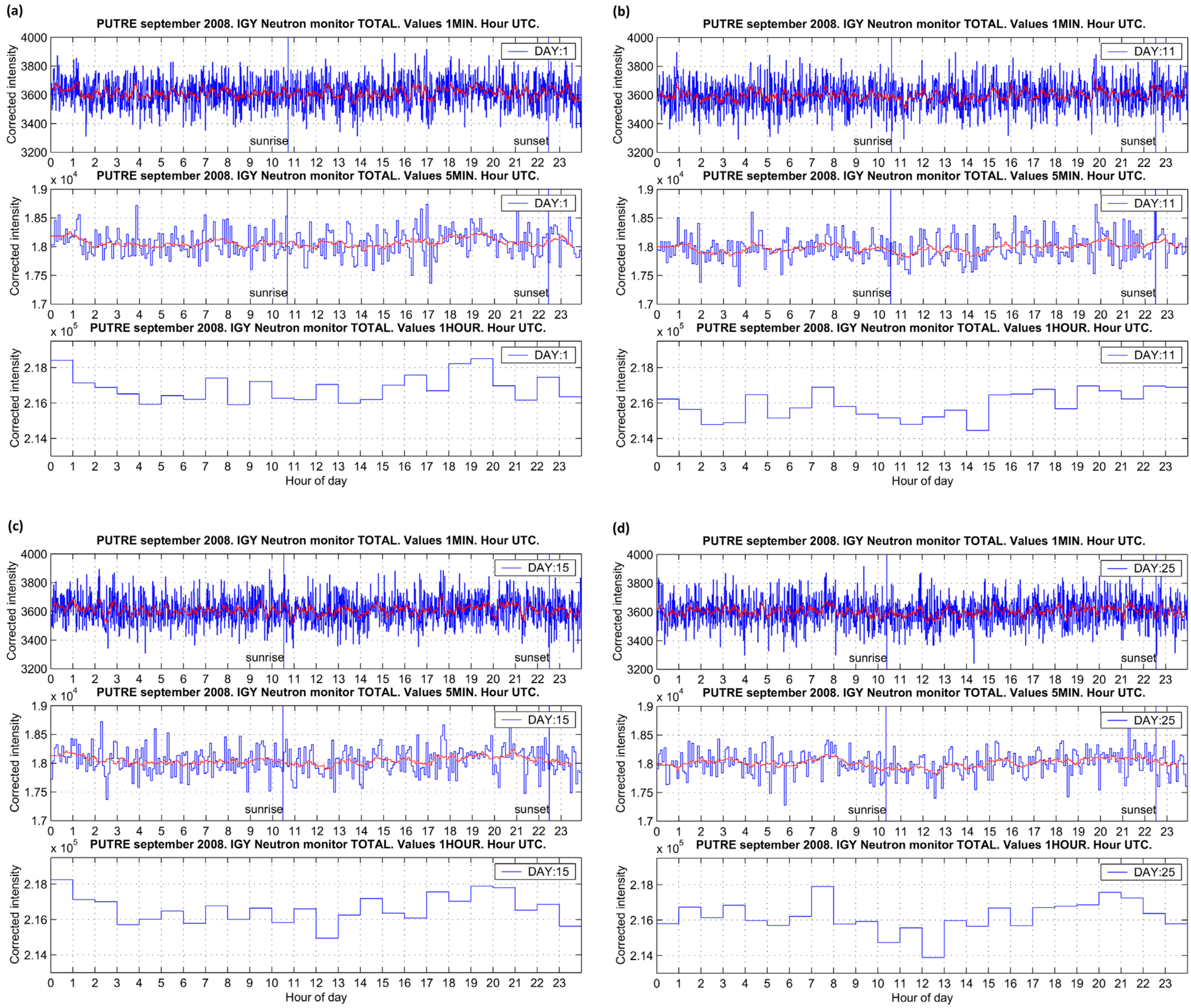

Fig. 8. Corrected neutron count rate for Putre station with timesteps of 1 min, 5 min and 1 h for (a) September 1st, (b) September 11st, (c) September 15th and (d) September 25th, 2008. The red line is the moving average on the data of 1 and 5 min. The times of sunrise and sunset are indicated.

sign of a sunset enhancement for muon counts that we can detect out of the marginal error, other than the small increase that was measured using the neutron monitor (Figs. 3 and 5), an hour after sunset, according to Augusto et al. (2010).

3.2. *The magnetic field intensity*

To complete our diurnal variation analysis we present the mean magnetic field intensity for our stations at PUT and OLC, plus data from the Antarctic station, during the same dates on September 2008 where the component x, y and z represent North, East and Down direction. The daily data from the magnetometers, sampled every minute for the entire month of September, were converted to a representative daily value plot. For this purpose, the first minute of the representative day is calculated as the average of all first minutes, every day in the month. Similarly the calculation proceeds, with all minutes, up to the sixtieth minute. Fig. 9 shows a daily variation plot of the magneto metric data from our stations. As seen in Fig. 9, PUT and OLC coincide, while the LARC stations show a displacement from the maximum value. It is also seen from Fig. 9, that there is a common daily variation in the stations, which are under the influence of the SAMA, that starts with sunrise and it declines 1 h past sunset.

The inclination of the earth's axis of rotation and its relation to the plane of the orbit due to the motion of the Earth around the Sun is responsible of the regularity of the seasons. With the same idea in the case of the magnetic field we have chosen a period from 1st to 30th September, 2008, because it includes the equinox. The length of day is equal to the length of night (22–23 September) that's why the earth receives the same amount of solar wind in each point of the meridians. Similarly for the Tropic of Capricorn we find the Winter Solstice from 21 to 22 December in the south hemisphere. Our interest lies in the magnetic field strength from the poles, on average about 57,000 nT (2010) to Ecuador, on average about 30,000 nT (2010), related to its secular variations in our defined geographical positions, around the meridian 70° West in the South hemisphere.

As the Earth's magnetic field exerts a very strong influence on charged particles moving through the Interplanetary Magnetic Field (IMF) until the ground level for particles with specific

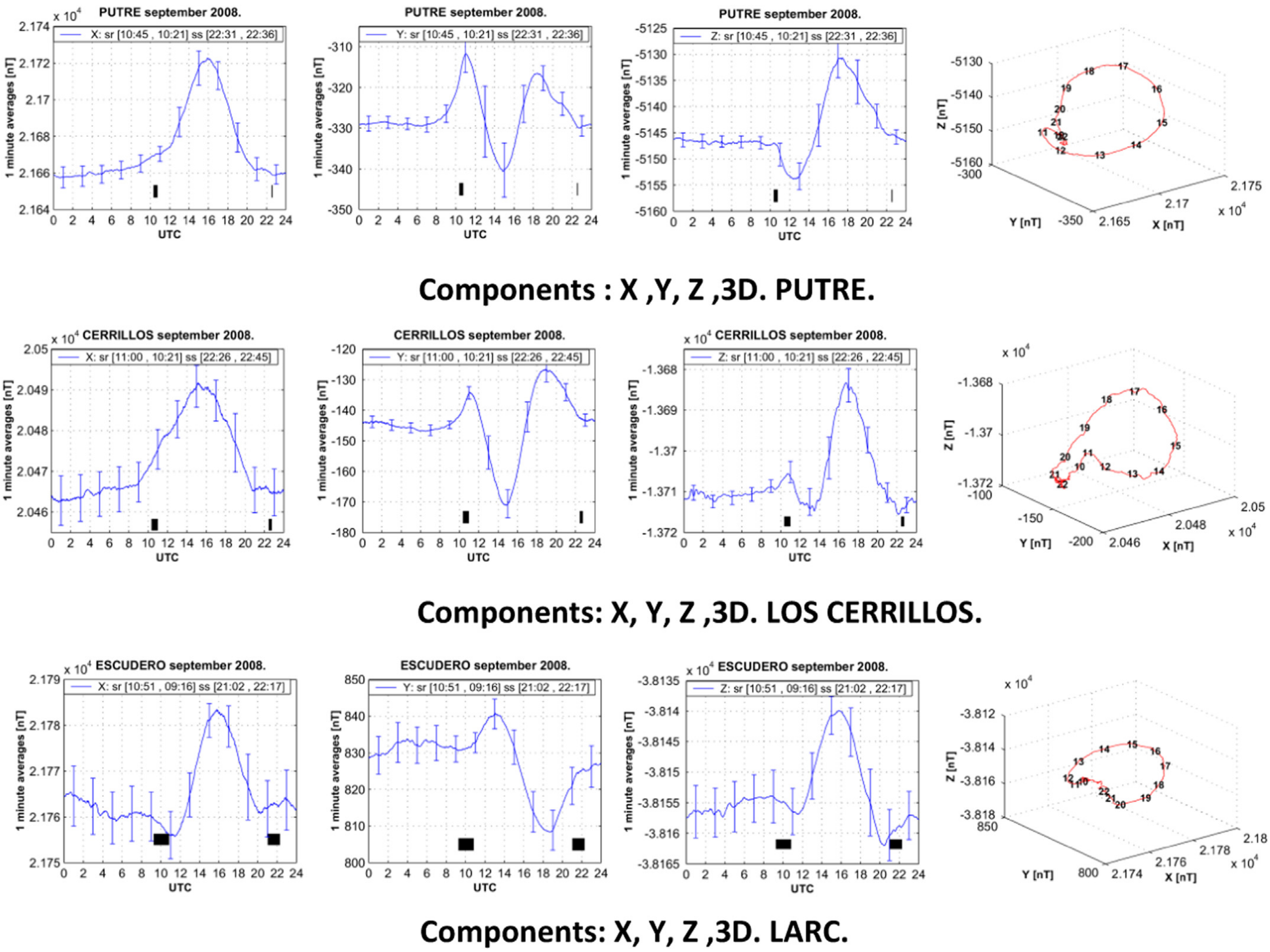

Fig. 9. Mean daily magnetic field intensity of the *X* (north–south), *Y* (east–west), *Z* (down) components for PUT/PUTRE, CER/OLC and ESC/LARC stations with a 1 min timestep. It shows the statistics of the dispersion of monthly data as error bars, every two hours. The images also show a 3D image for the intensities components for the different daily hours, highlighting the sunrise and the sunset. The range of times for sunrise and sunset are indicated.

directions of arrivals, for example, for the asymptotic directions of arrivals of particles in the observatories we can observe the origin of them as shown Fig. 1. It is particularly important to know in detail the movement of the particles because this field reflects the connection, reconnection or disconnection with the solar magnetic field and magnetic field of the Earth. The curvature of the particles depends on the intensity of magnetic field resulting variations on the energy (Cordaro et al., 2012). The magnetic field of the earth shifting is represented by the so-called dynamo effect (internal).

We input timescales in the order of 105 years and speeds of 104 cm/s. In the terrestrial dynamo model we believe that the spatial and temporal behavior of the components North (*X*), East (*Y*) and depth (*Z*) of terrestrial magnetism and field measurements of daily temporal variations reflect changes in Earth's magnetic field. These components are directly affected by the action of the solar magnetic field or otherwise indicate that the daily cycle generated by the Earth's rotation generates a continuous and eternal cycle of reconnection, maintenance and disconnection between the terrestrial and solar magnetic lines at the times indicated by sunrise, solar noon and sunset. But even this mechanism is related to the determination of the geomagnetic cutoff rigidity for the entry of the particles in extended periods of time and broad geographic regions.

In order to study the daily variation of magnetic field at the stations, we determine the times of sunrise, noon and sunset for September 2008, with reference to the day 1, day 15 and day 30. For these specific dates and times, the hourly averages of their adding's of the magnetometers in each of its components are calculated, as shown in Table 4. These calculations will be the basis for the determination of the values that will measure the day–night difference.

In order to calculate the percentage difference of the geomagnetic measurements obtained at the times of sunrise and sunset, geomagnetic variations of each component in units of nT, are converted in percent variation (0–100%) in where the value of 0% corresponds to the minimum value of the geomagnetic component, and the value 100% corresponds to the maximum of the geomagnetic component. The magnetic component Sunrise–Sunset difference % is maximum in East direction for the tree observatories along meridian 70° West, i.e. the variation in the time of the component *Y* East gives us the account of the magnetic field drift in each terrestrial rotation. The details are shown in Tables 5 and 6. As one can see in Table 6, the difference between sunrise-sunset is presented with two values. The first value is calculated considering the sunrise-sunset hours of the first day of the month, the second value is calculated considering the sunrise-sunset hours of the last day of the month.

Table 4
The magnetic component values (*X* North, Y East, Z Down) at PUTRE, OLC and LARC observatories UTC hours for sunrise, solar-noon and sunset for September 1th, 15th and 30th 2008.

Station name	PUTRE (PUT)	OLC (CER)	LARC
01Sr UTC	10:45	11:00	10:51
(X,Y,Z) nT	(21670.4, 313.0, 5147.7)	(20475.5, 134.4, 13706.5)	(21756.1, 832.7, 38156.3)
01Sn UTC	16:38	16:42	15:55
(X,Y,Z) nT	(21717.6,327.3, 5132.2)	(20488.9, 147.0, 13683.3)	(21782.7, 822.6, 38140.1)
01Ss UT	22:31	22:26	21:02
(X,Y,Z) nT	(21659.1, 329.8, 5145.3)	(20465.4, 142.5, 13714.4)	(21762.0, 821.4, 38160.3)
15Sr UTC	10:33	10:41	10:05
(X,Y,Z) nT	(21670.2, 315.1, 5147.2)	(20473.7, 136.8, 13705.6)	(21758.0, 831.2, 38154.9)
15Sn UTC	16:33	16:37	15:50
(X,Y,Z) nT	(21718.5, 328.4, 5132.5)	(20489.0, 148.5, 13683.6)	(21783.3, 823.4, 38140.0)
15Ss UTC	22:33	22:35	21:38
(X,Y,Z) nT	21659.0 −329.8 −5145.3	20464.8 −143.0 −13714.2	21763.1 824.5 −38159.5
30Sr UTC	10:21	10:21	9:16
(X,Y,Z) nT	(21669.3, 317.8, 5147.0)	(20472.1, 139.6, 13706.6)	(21759.5, 830.7, 38154.5)
30Sn UTC	16:28	16:32	15:45
(X,Y,Z) nT	(21719.1, 329.3, 5132.7)	(20488.9, 150.2, 13684.1)	(21783.4, 824.2, 38139.9)
30Ss UTC	22:36	22:45	22:17
(X,Y,Z) nT	(21658.9, 329.9, 5145.3)	(20464.6, 143.1, 13714.2)	(21762.7, 825.2, 38158.9)

Table 6
Magnetometers average reading on night-side for September 2008. These are compared with reference values provided by the IGRF-11 model. The values of Sunrise–Sunset difference in percent are showed. The value of the 'East' component is the difference between zero initial calibration setup and the current value of the geomagnetic-field.

Station Name	PUTRE (PUT)	OLC (CER)	LARC
North comp. average, night-side, nT	21660	20465	21765
North comp. X IGRF-11 nT	20043	20286	19990
Difference, nT	1617	179	1775
Sunrise–Sunset difference, %	17.2–15.9	34.6–25.5	−21.2 to −11.6
East comp. average, night-side, nT	−329	−145	830
East comp. X IGRF-11 nT	−1490	1135	3974
Difference, nT	1161	1280	3144
Sunrise–Sunset difference %	58.2–42.0	18.3–7.8	34.9–17.0
Vertical comp. average, night-side, nT	−5146	−13715	−38166
Vertical comp. X IGRF-11 nT	−4169	−13467	−29594
Difference, nT	977	248	8572
Sunrise–Sunset difference %	−10.3 to −7.3	24.5–23.4	18.0–19.7

4. Discussion

It is known that the magnetic field rate as well as the particle count rate are different instances of regular and irregular phenomenon from the nearby space weather, where the most predominant for the regular case is the so called diurnal variation (Gunnarsdóttir, 2012), which can be seen in almost all our stations (Figs. 5–9 and Table 6). Some irregular variations happen when a sudden increase in the incoming particles is recorded, which induces a decrease from 10% to 20% in the magnetic field intensity due to the change of pressure that the particles apply to the magnetosphere, effect that may last between a couple of hours to several days (Priest and Forbes, 2000; Russel et al., 1999; Kulsrud, 2005; Jankowski and Sucksdorff, 1996). A way to explain how those particles arrive to the detectors is following the magnetic field lines, in the magnetic reconnection, also present in the diurnal variation (Russel et al., 1999; Kulsrud, 2005; McPherron, 2012; Mullan, 2010), where they establish that the flux of particles between two different plasma regimes occurs through the union of parallel and antiparallel magnetic fields between terrestrial and interplanetary magnetic fields (IMF) (Priest and Forbes, 2000; Kulsrud, 2005; McPherron, 2012; Lanza and Meloni, 2006; Steigerwald, 2012). The irregular magnetic field variations are also related to strong magnetic fields and to auroral events in high latitudes which may produce electric currents in the ionosphere, called "*auroral electrojet*", that could greatly impact the magnetic field, producing "Magnetic Bays" on the range up to hundreds of nT (Merrill and McElhinny, 1983), (and we have studied in past papers (Diego et al., 2005)) and which in this period were not detected in our stations, and thus we did not consider for this paper.

Table 5
The magnetic component average values (*X* North, *Y* East, *Z* Down) at PUTRE, OLC and LARC observatories UTC hours for sunrise and sunset for September 2008, expressed as percentages.

Station name	**Magnetic component**	**Sunrise UTC**	**Sunset UTC**	**Magnetic component at Sunrise %**	**Magnetic component at Sunset %**	**Mag. comp. Sunrise–Sunset Difference %**
PUTRE/PUT	North	10:45	22:31	19.91	2.70	17.22
PUTRE/PUT	North	10:21	22:36	18.19	2.34	15.86
PUTRE/PUT	East	10:45	22:31	95.40	37.19	58.21
PUTRE/PUT	East	10:21	22:36	78.77	36.76	42.02
PUTRE/PUT	Down	10:45	22:31	26.56	36.82	−10.25
PUTRE/PUT	Down	10:21	22:36	29.55	36.85	−7.30
OLC/CER	North	11:00	22:26	44.64	10.07	34.57
OLC/CER	North	10:21	22:45	32.98	7.50	25.49
OLC/CER	East	11:00	22:26	82.57	64.25	18.32
OLC/CER	East	10:21	22:45	70.72	62.90	7.83
OLC/CER	Down	11:00	22:26	28.28	3.80	24.48
OLC/CER	Down	10:21	22:45	27.86	4.42	23.44
LARC	North	10:51	21:02	1.30	22.48	21.18
LARC	North	09:16	22:17	13.57	25.13	−11.56
LARC	East	10:51	21:02	75.08	40.16	34.92
LARC	East	09:16	22:17	68.89	51.93	16.96
LARC	Down	10:51	21:02	25.66	7.69	17.98
LARC	Down	09:16	22:17	33.68	13.99	19.70

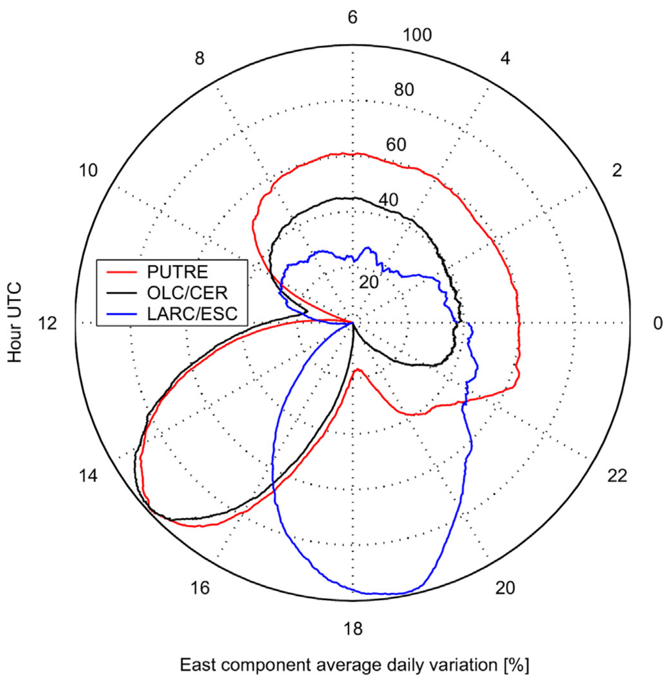

Fig. 10. Anisotropy on East component of the PUTRE, OLC and LARC geomagnetic field for September 2008. The variation of full range on each component is showed as variation from 0% to 100%.

The co-rotational anisotropies views at ground level observatory corresponding to the interaction of particles with the interplanetary magnetic field (Pomerantz, 1971), where a dependent simulation (neutrons and muons) of magnetic rigidity can provide a significant physical measurements of the event without the need to go into details about the physics of the phenomenon (Cordaro et al., 2012; Pomerantz, 1971). Furthermore, currently studies show that the relationship between galactic cosmic rays (GCR) and corotating interaction regions (CIR) is not clear at all and needs more investigation (Guo, Florinski).

The energy of galactic cosmic rays are above of geomagnetic cutoff rigidity. The intensities variations are less than 1%. Furthermore we have recorded the *Time of flight* (ToF) of particles using the delayed time among incoming signals between two photomultiplier tubes with a multichannel analyzer (Cordaro et al., 2012) that was first carried out to neutrons detector in Putre station with their barometric coefficients and standard errors. Thus, for this time recording, we considered that their error is not significative to a Gaussian model (Gross, 2011). The data correspond to a Gaussian model, if there was a significant increase would be out of the critical zone, its asymmetry coefficient would be positive. The registration is zero. The polar graph shown in Fig. 10 strengthens the reconnection model presented by Biskamp (1993) and posteriorly by Priest and Forbes (2000). It can be seen that, between 14 and 16 h UTC (10–12 h local time), there is a maximum intensity of the magnetic field. This phenomenon can be explained through models for magnetopause (Biskamp, 1993; Russel et al., 1999).

5. Conclusions

1. The *diurnal variation* can be detected in any of the stations of the Cosmic Rays Chilean Network and SAMBA magnetometric stations. We show that the diurnal variation can be detected in stations outside of the South Atlantic Anomaly, and thus considered a natural phenomenon.
2. There is no particular variation or enhancement in meson and neutron count rates measured in stations within the SAMA region. Only lower rigidity cut-off value were measured, which yield a higher mean count rate than average. An increased hard mesonic particle production is not detected in our stations.
3. The reconnection process has no sudden increase or enhancement towards the night. In contrast, measured reconnections processes show a smooth decrease towards the night and a smooth increase into the night time mean value, as opposed to the hypothesis made by Augusto et al.. The east-west direction for magnetic field intensity shows this process properly, showing a special daily behavior that accounts for the whole reconnection system.
4. The estimated error for counts of particles recorded is less than 1% to specifics days, as well as to a complete month, where the indicated variations to sunset are not seen. Therefore the results of the Tupi-Niteroi experiment were non-reproducible.

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