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The effect of geomagnetic field on radio signal patterns from cosmic ray air showers

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Different type of mechanisms are involved in creation and propagation of radio signals from cosmic ray air showers. The geomagnetic origin is one of such procedures which is very important especially in low frequency band radio studies. Based on CORSIKA and CoREAS code, we investigate the influence of the Earth magnetic field parameter on filtered peak radio amplitude patterns in 32-64 MHz frequency band using a specially developed computer code. Simulated air showers are from Proton and Iron primary particles with 10^{17} eV initial energy. We investigate vertical (θ= 0^0) and inclined (θ= 60^0) cosmic rays with ϕ= 0^0 . It is found that radio signal patterns from inclined cosmic rays are heavily dependent on the Earth magnetic field values and as a result of that some radio patterns change fundamentally as we move from a location in the Southern to a new place in the Northern hemisphere. We have chosen Pierre Auger Observatory and a location where we hope to have a new radio array in near future. Analyzing these patterns can clearly confirm the importance and influence of the Earth magnetic field parameter on the radio signal patterns from cosmic ray air showers.

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1. Introduction

There is a long history in investigation and detection of cosmic ray air showers [1]. The origin and mechanisms involved in creation and propagation of this phenomena have always been a matter of discussions [2]. To answer these unsolved questions many different approaches have been used to determine key parameters of a cosmic ray.

In experimental side, surface particle and fluorescence light detectors are the most established approaches for such a purpose. Although they have some notable features, searching for a new approach which could complement current techniques has always been an ongoing project.

Radio detection of cosmic ray air showers has experienced a great progress in the last decade. This new method is the most suitable for ultra high energy cosmic rays [3]. Since these ultra high energy cosmic rays deflect less in galactic and extragalactic magnetic fields [2],[4], it is even possible to determine some source candidates of cosmic rays beside obtaining key parameters like the type and initial energy of the primary particle by studying radio measurement only [5].

In recent years radio detection of cosmic ray air showers has shown its privileges over the current approaches and this has lead to a resonance in this field of science [6]. In addition to its nearly 100% duty cycle which makes it an ideal option for detecting cosmic rays in different weather conditions, the complementary features makes it a good option to be used simultaneously with other techniques to provide even more accurate results. This type of work is already implemented in Pierre auger observatory under project AREA [7].

Many different mechanisms are involved in creation and propagation of radio pulses from cosmic ray air showers [8]. It is believed that for studies in low frequencies (<100 Mhz) the Earth magnetic field does have a major role in emerging radio pulses. Moreover, we encounter coherent radio signals in these frequencies [8].

It is for this reason that we are going to investigate the importance of the Earth magnetic field parameter on radio signal patterns in 32-64 MHz frequency band. According to earlier analyses the geomagnetic and charge excess mechanisms are two major sources for radio signals from cosmic ray air showers especially in low frequencies [9].

2. Methodology

In order to investigate the effect of the Earth magnetic field, we performed a series of simulations with CORSIKA [10] and CoREAS [11] software. These codes are well established and their results show good agreement with many real experiments [12].

We used CORSIKA 7.4 and CoREAS 1.0 for this study. QGSJETII-04 [13] and Gheisha 2002d has been selected as hadronic interaction models for high and low energies with thinning set to 10^{-6}. Since we want to investigate the effect of the Earth magnetic field, different values have been used for the MAGNET parameter in CORSIKA steering file. Specifically, we have chosen two places, one in the Northern and the other in the Southern hemisphere. The location of our expected Semna Radio Array (SRA) and the Pierre Auger Observatory (PAO) site in Argentina are the chosen locations. The observation level of all simulations is set to 1400m above sea level.

The details about the MAGNET parameter values and other specifications are provided in Table 1. It should be noted that we have chosen 4 arbitrary cases among many simulated cosmic

rays for this study. In order to do a fine investigation, we use a radio array consist of 74 virtual radio antennas. This array covers a detection area from center to 100m from shower core in 15 degree intervals. We focused on areas around shower core since as we go further from that area radio pulses get weak and because of interferences with environmental noises, they may not include very useful information in far distances for cosmic rays with this specific initial energy [8].

To calculate peak radio amplitude values in 32-64 MHz frequency band, a unique computer code is developed to measure filtered peak radio amplitudes for different electric field components with which we obtain radio signal patterns.

Table 1: Specific values used for simulations and some information about air showers.

Shower No.	1	2	3	4
Shower Zenith Angle (degree)	0	60	0	60
Depth of Shower Maximum (gr/cm^2)	592.0498518	592.0498518	647.3076594	643.3711955
Magnetic Field Strength (Gauss)	0.4758	0.4758	0.2428	0.2428
Magnetic Field Inclination Angle (degree)	53.8044	53.8044	-35.7324	-35.7324
Magnetic Field Inclination Angle (degree)	36.1955	23.8044	125.7324	65.7324

3. Ground footprints at SRA

There are two main parameters in the CORSIKA and CoREAS input files which represent the Earth magnetic field values. The first one determines the horizontal component of the Earth magnetic field to the North while the second one is the vertical component of the Earth magnetic field downwards. It is possible to obtain these values for any desired location from different sources including the Geomag [14] website. In this step, we investigate simulated cosmic rays with MAGNET parameter set to correspond with the Pierre Auger Observatory in Argentina.

The left panel of Fig.1 shows the ground footprint of the North-South (E_x) component for a vertical cosmic ray. This pattern is almost symmetric around both North-South and East-West axis. The right panel of Fig.1 is the ground footprint of the Vertical (E_z) component. This pattern shows how the highest values have been measured by the radio antennas located at the core of the air shower.

The (E_y) component does have an orientation to the East. This slight asymmetry arises from contributions of different emission mechanisms especially the charge excess. Fig.2 Clearly shows the high impact of the (E_y) component on the (E_{total}) radio pattern as they all almost identical for a vertical cosmic ray. The values of the peak radio amplitudes decrease rapidly as we move from the shower core to further distances. These two type of figures are almost identical four all kind of cosmic rays regardless of their initial energy and type of primary particle as we discussed in [3]. These patterns also contain some valuable information about the arrival direction of a cosmic ray [15].

One important element of any cosmic ray is the type of primary particle. Fig.3 and 4 show the radio signal patterns for the North-South, East-West, Vertical and Total components dedicated to a

vertical Iron cosmic ray with 10^{17} eV energy. It is clear that these shapes are almost identical to the ones showcased in Fig.1 and 2.

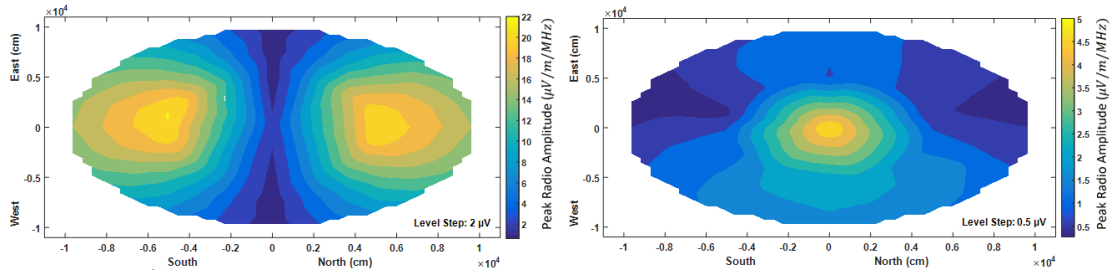

Figure 1: From left to right: Ground footprints of E_x and E_z components of a vertical proton cosmic ray with 10^{17} eV initial energy.

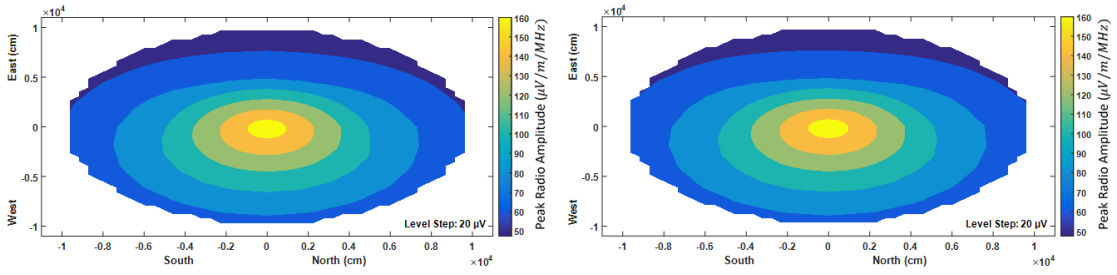

Figure 2: From left to right: Contour plot of E_y and E_{total} components of a vertical proton cosmic ray with 10^{17} eV initial energy

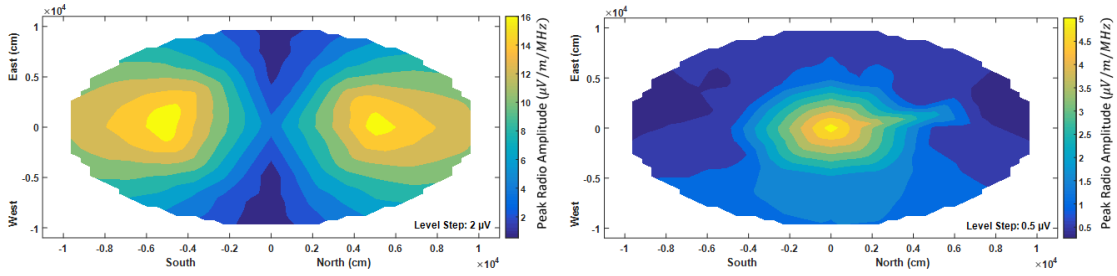

Figure 3: From left to right: Ground footprint of E_x and E_z components of a vertical Iron induced cosmic ray with 10^{17} eV initial energy.

As the cosmic ray becomes inclined the zenith angle shows its impact on all radio signal patterns especially on the North and Vertical components. Fig.5 and 6 Show radio signal patterns for all electric field components denote to an inclined proton cosmic ray with $\theta = 60^0.\phi = 0^0$. It should be noted that these patterns are very much the same for any cosmic ray initiating from a different type of primary particles.

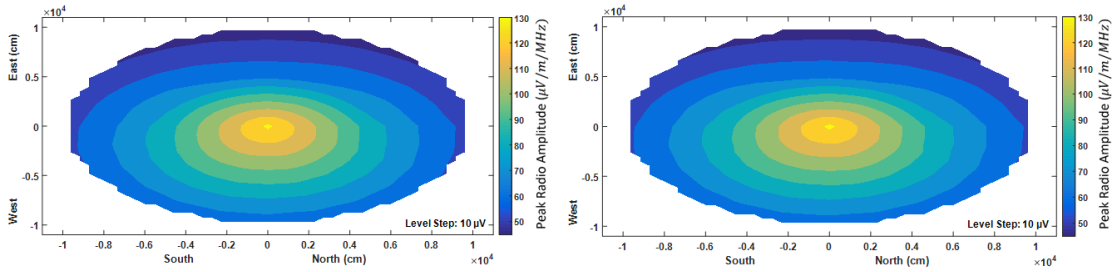

Figure 4: From left to right: Ground footprint of E_y and E_{total} components of a vertical Iron induced cosmic ray with 10^{17} eV initial energy.

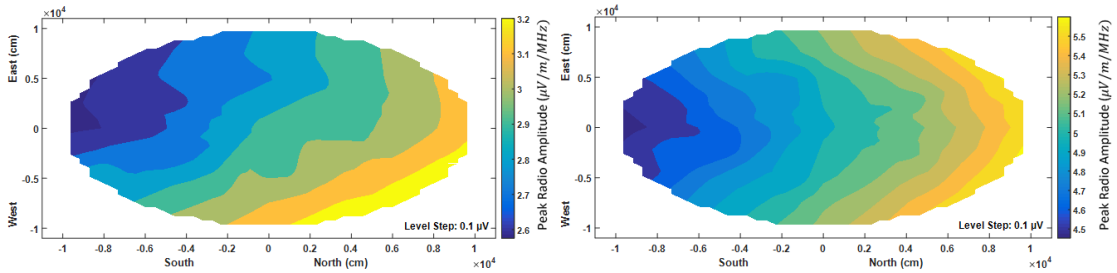

Figure 5: From left to right: Ground footprint of E_x and E_z components for an inclined proton induced cosmic ray with θ= 60^0,ϕ= 0^0 with 10^{17} eV initial energy.

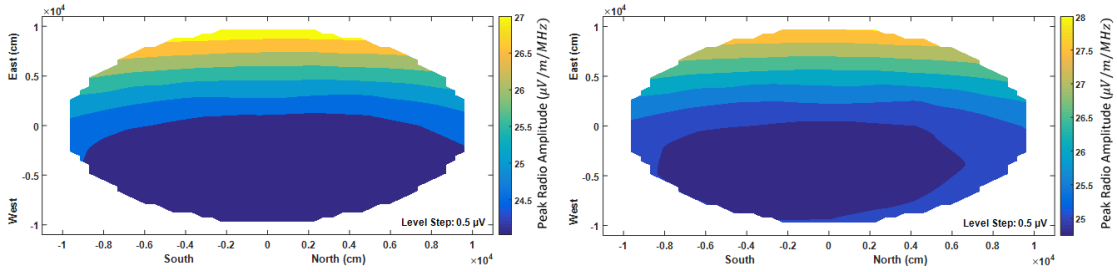

Figure 6: From left to right: Ground footprint of E_y and E_{total} components for an inclined proton induced cosmic ray with θ= 60^0,ϕ= 0^0 with 10^{17} eV initial energy.

As it is obvious from Fig.6, although the level steps of the patterns are very small, the highest values have been calculated on the West side of the shower core. The North-South and Vertical pattern, however, have direction aligned with the orientation where the cosmic ray is propagating.

4. Ground footprints at PAO

As we move our virtual antennas from SRA to PAO, we expect to see some changes in radio patterns. Fig.7 shows these patterns for a vertical proton induced air shower with 10^{17} eV initial energy in the location of PAO.

As we expect, the ground footprints of electric field components remain almost unchanged under new circumstances for vertical cosmic rays. The important point is a decrease in the average values of the total field component in the new location. This shows the effect of the earth magnetic field parameter on the radio signals from cosmic ray air showers.

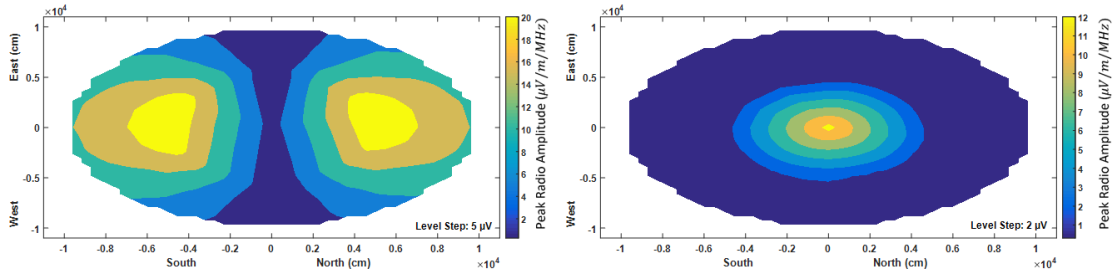

Figure 7: From left to right: Ground footprint of E_x and E_z components for a vertical proton induced cosmic ray with 10^{17} eV initial energy at the location of PAO.

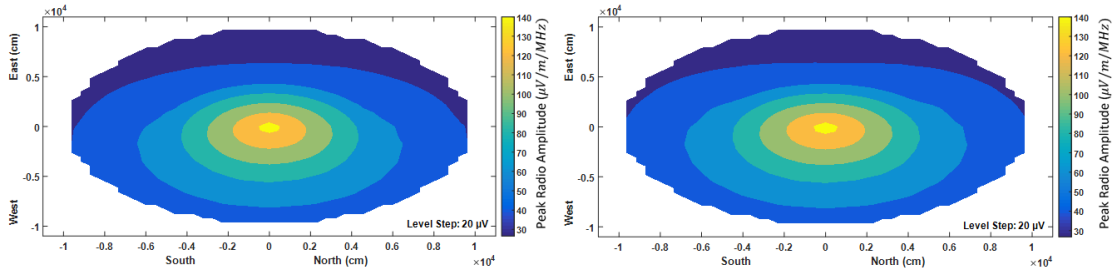

Figure 8: From left to right: Ground footprint of E_y and E_{total} components for a vertical proton induced cosmic ray with 10^{17} eV initial energy at the location of PAO.

The situation is different for an inclined air shower with $\theta = 60^0$propagating to the North. Fig.9 shows the similarity of the E_x and E_z patterns as they still shape toward the shower propagation direction.

On the other hand, the E_y and E_{total} patterns shifted nearly 180^0 as the highest values have been recorded in the West direction under the new magnetic field values (Fig.10).

These patterns clearly show the importance of the Earth magnetic field parameter on radio signals from cosmic ray air showers. It is for this reason that in every radio measurement, it should be a special attention to the effect of the Earth magnetic field.

5. Conclusion

Based on CORSIKA and CoREAS simulations, we did an investigation on radio signal patterns obtained from peak radio amplitudes using a specifically developed computer code. These values correspond to all electric field components including The North-South, East-West, Vertical and Total. Fitting these values to the detection area, yields radio signal patterns. Studying these patterns reveals great information about cosmic rays including energy and the arrival direction.

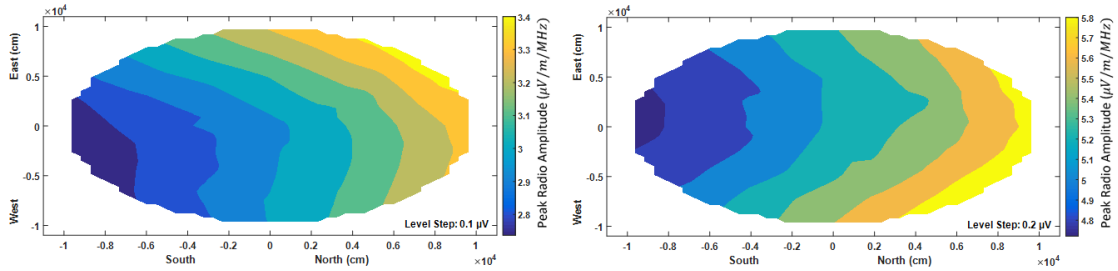

Figure 9: From left to right: Ground footprint of E_x and E_z components for an inclined proton induced cosmic ray with θ= 60^0,ϕ= 0^0 with 10^{17} eV initial energy at the location of PAO.

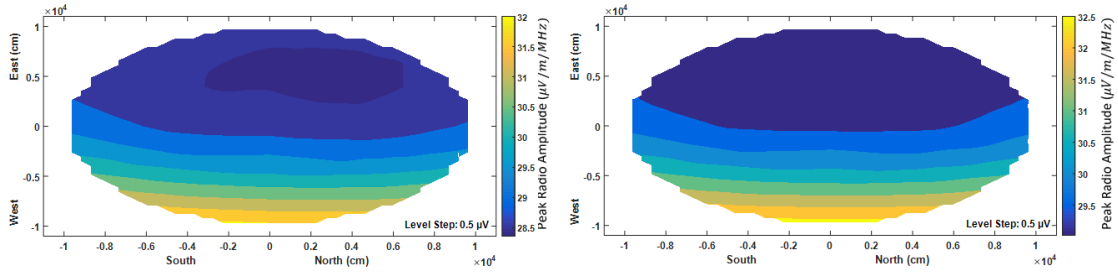

Figure 10: From left to right: Ground footprint of E_y and E_{total} components for an inclined proton induced cosmic ray with θ= 60^0,ϕ= 0^0 with 10^{17} eV initial energy at the location of PAO.

Since the geomagnetic effect is believed to play a major role in creation and propagation of radio signals from cosmic ray air showers especially in low frequencies, it is mandatory to pay a special attention to this parameter during radio signal analyses.

In this study, we chose two different locations in the Southern and Norhtern hemisphere for comparison purposes. The first site in the North hemisphere is a location that we expect to have a new radio array (SRA) in near future and the second one in the location of Pierre Auger Observatory. Calculated radio signal patterns for vertical cosmic rays show strong similarity for all radio patterns in both locations.

For inclined air showers propagation to the north with θ= 60^0 the E_x and E_z patterns remain almost unchanged but even with small level steps, the overall orientation of both E_y and E_{total} patterns shift nearly 180 degrees if we move from SRA to PAO.

These patterns, the changes in their directions and their overall shapes clearly shows the importance of the Earth magnetic field parameter which should be under serious consideration in any radio measurement studies.

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