Influence of the Magnetic and Electric Fields on the (SEPs) at Solar Corona Region

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Abstract

The objective of this research investigates the influence of the electric and magnetic fields at the corona region of the sun on the solar energetic particles. The result show that the azimuthal magnetic field component has higher values for the slow than the fast solar wind for the same distance and angles, besides that the azimuthal B_φ at constant distance $5\times R_\odot$ is higher at the equator than the pole region and the values of slow solar wind higher than the fast solar wind. Similarly the colatitude electric field E_θ will have higher values at the equator than the pole region. It is seen that the equator region will be more advantage and effect on the movement of the solar energetic particles that contribute to the solar wind.

Keywords: solar wind, corona, solar energetic particles, magnetic field, electric field.

تأثير الحقول المغناطيسية والكهربائية على (الجسيمات الطاقية الشمسية) في منطقة الهالة الشمسية

علياء زياد حازم و ماجدة حمدان الكبيسي

الخلاصة

الهدف من هذا البحث هو دراسة تأثير الحقول الكهربائية والمغناطيسية في منطقة الهالة من الشمس على الجسيمات الطاقية الشمسية. ولوحظ أن مركبة المجال المغناطيسي السمتي لديه قيم اعلى للرياح الشمسية البطيئة من الرياح الشمسية السريعه لنفس المسافة و الزوايا. و بالاضافه الى ان B_φ السمتي لمسافه محدده تكون اعلى عند منطقه الاستواء منه عند منطقه الاقطاب وقيم الرياح الشمسية البطيئه اعلى من قيم الرياح الشمسية السريعه. بصوره مشابهه المجال الكهربائي العرضي E_θ لديه قيم اعلى عند منطقة الاستواء منه عند منطقة الاقطاب. واشارت النتائج الى ان منطقه الاستواء سوف تكون اكثر ميزه وتأثير على حركه الجسيمات الطاقيه الشمسية التي تساهم في الرياح الشمسية.

كلمات البحث: الرياح الشمسية، الهالة، الجسيمات الطاقية الشمسية، الحقل المغناطيسي، الحقل الكهربائي.

١-١ Introduction

The sun was born in an interstellar gas cloud, which contain mostly hydrogen but also heavier elements, at the center of the solar disk, the increase in the mass led to an increase in the pressure and temperature (Cohan 2008), there is a large dissimilarity of temperature from about 5700 Kelvin at the surface to upwards of 15 million degrees at the center (Anatia et. al 2003).

Our star is near enough to observe details on its surface such as sunspots, prominences, coronal holes, flare, etc., which all brief as solar activity (Hanslmeier 2007) ,the sun powered by nuclear reaction in its core, (Milone, Wilson 2014), and it is compose of core, radiation zone, convection zone, the atmosphere which is divided into four regions as follow; the photosphere, chromosphere, transition region, and corona, the innermost region reaching out to above the top of the convection zone is the photosphere, and then there is chromosphere and outside this the corona region (Brekke 2012).

Can see with our eyes from our sun or from the billions of stars in our galaxy is the optical radiation that is radiated at the surface of the sun, in the so called photosphere. The optical emission produced by Thomson scattering in the much more tenuous atmosphere or corona (Aschwanden 2004). The corona is forth region of the atmosphere above the chromosphere a pearly white halo and it is the layer with temperature 1-2 million (Goossens 2012) extends tens of millions of kilometers in the space, the corona is continually expanding into the interplanetary space and in this form called “solar wind” (Narayanan 2012).

The solar wind is the high speediness particles flow continuously blowing out from the solar corona into interplanetary space, it is flowing at active time (Kivelson, Russell 1995), extending further than the orbit of the earth. It corresponds to an about 4- days particles journey from the sun to the earth, the strength of the magnetic field of the corona is not well known, but its bottom it might be of the order of 10^{-2} tesla, decomposing away with increasing distance.

1-2 The Solar energetic Particles (SEPs)

The solar energetic particles (SEPs) are an important Phenomenon in the study of space science, where the birthplace of energetic particles is a sun. The SEPs usually follow eruptive phenomena in the solar corona, such as flares and Coronal Mass Ejections (CMEs) (Dinku 2014). Energetic charged particles (such as electrons and protons) traveling much faster than ambient particles in the space plasma, at a fraction of the speed of light (relativistic!). They can go from the Sun to the Earth in one hour or less! The term SEPs usually refers to protons (Zheng & Evans 2014).

1-3 The Magnetic and Electric Field in the Parker Spiral

The coronal magnetic field (CMF) in the outer corona is dragged outward by the radially expanding solar wind to the external regions of the heliosphere (Kruger 2005). The first model proposed by parker 1958, which is called the parker model that is explain the nature of this regions, the hot coronal plasma making up the solar wind possesses an extremely high electrical conductivity. In such plasma, it expects the concept of “frozen-in” magnetic field-lines, which is the field is coupled to the plasma motion (or the flow velocity), referred to as the frozen-in magnetic field (Narita 2012).

Consider a spherical polar coordinate system (r, θ, φ) which co-rotates with the sun, of course, the symmetry axis of the coordinate system is assumed to coincide with the axis of the sun’s rotation. In the rotating coordinate system, the assumption of a spherically symmetric magnetic field easily yields the following expressions for the components of the interplanetary magnetic field (Spohn et. al 2014), (Pei 2007):

$$B_r = \frac{B_\circ r_\circ^2}{r^2} \tag{1}$$

$$B_{\theta = 0} \tag{2}$$

$$B_\varphi = -\frac{B_\circ r_\circ^2 \Omega}{u_s} \frac{\sin_\theta}{r} \tag{3}$$

Where (r, θ, φ) are heliocentric spherical coordinates, here r is the radial distance ranging from 1 to 15 $R_\odot$ ($R_\odot$ is the radius of the sun Levy et. al 1987), θ is the colatitude and φ the longitude. B_o is the magnitude of the magnetic field at a reference distance r_o: which is the radial distance from the sun 1$R_\odot$ and its equal to 6.69×10^8 m, B_o can be compute from the equation below (Tautz et.al 2010):

$$B_\circ = 1830\ \text{nT}\ \left(\frac{r_\circ}{r}\right)^2 \sqrt{1+\left(\frac{r}{\zeta}\right)^2} \tag{4}$$

Where $\zeta = \frac{u_s}{\omega_\circ} \approx 1AU$ (5)

$\omega_\circ$ is the angular velocity of the sun, Ω is the solar rotation rate taken as constant which is equal to 2.86×10^{-6} rad sec^{-1}. (Dalla et. al 2010), the distance is conversion from AU to m; finally B_o is the surface solar magnetic field which is equal to 1830 $\times 10^{-9}$ Tesla (Tautz et. al 2010).

The speed of the solar wind u_s which have two types of velocity (Owens 2013): first the fast solar winds equals to 400 Km sec^{-1} and second the slow solar wind which is equal to 800 Km sec^{-1} (Encyclopedia of Astronomy and Astrophysics 2001). Assumed that the solar wind flow that is radial, uniform and time independent.

The magnetic field-lines of the sun are drawn into spirals (Archimedean spirals, to be more exact) by the solar rotation. Transformations to a stationary frame of reference give the same magnetic field configuration, with the addition of an electric field (Fitzpatrick 2008):-

$$\boldsymbol{E} = -\boldsymbol{u} \times \boldsymbol{B} = -u_s \, B_\varphi \, \hat{\theta} \qquad (6)$$

Due to the motion of the solar wind, in the inertial (non-rotating) reference frame an electric field **E** = −$\mathbf{u}_s$/c × **B** is present, which, using equations (1) to (3) then the electric field equation could be as follow (Dalla et. Al 2013):-

$$E_r = 0 \qquad (7)$$

$$E_\theta = \frac{\Omega \, B_\circ \, r_\circ^2}{c} \, \frac{\sin_\theta}{r} \qquad (8)$$

$$E_\varphi = 0 \qquad (9)$$

1-4 The Results and Discussion

The calculations of solar energetic particles at corona region of the sun are made in the distance. Obtained the results by the equations that describe the (SEPs) has been programed by using Matlab version 2014, these calculations are made in (SI) unit system by using spherical coordinates (r, θ, φ) to analyze and computes the values and results for the influences of the magnetic and electric fields in spherical coordinates that act on the movement of the particles at this region.

1-4-1 The Magnetic Field Results

The magnetic field in the direction of φ is found by using the equation (3), with different values of the angle θ for the fast and slow solar wind velocity u_s, the component of azimuthal magnetic field at the equator region is much stronger than the polar region (at θ equal to 360°) as shown in figures (1) to (3) for the fast solar wind and the figures from (4) to (6) for the slow solar wind, it can be seen from these figures the azimuthal magnetic field component has higher values for the slow than the fast solar wind for the same distance and angles. It is also shown that the B_φ component at constant distance $5\times R_\Theta$ with different values of θ component from 180˚ to 360˚ is higher at the equator region than the pole region and the values of slow solar wind higher than the fast at the same values of θ angles as illustrated in figure (7).

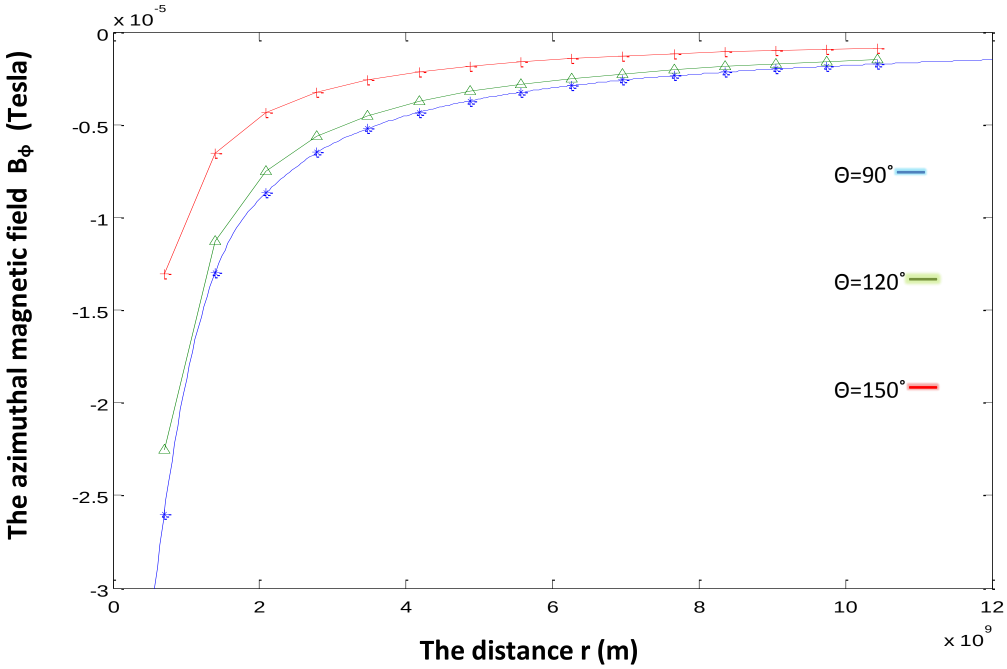

Figure (1) The variation of azimuthal magnetic field $\mathbf{B}_\varphi$ with corona distance **r** for fast solar wind

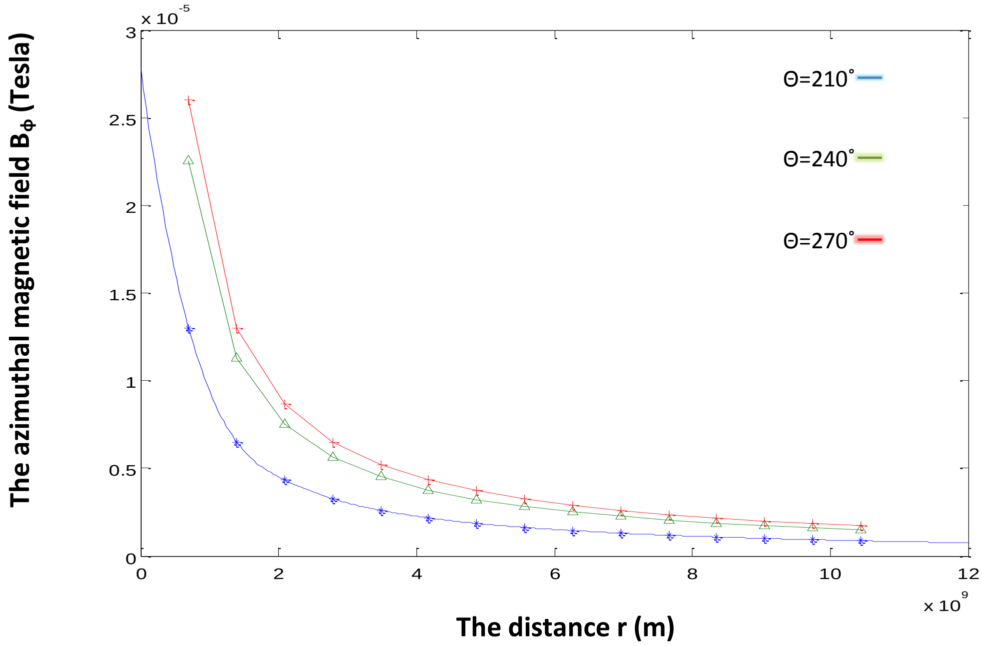

Figure (2) The variation of the azimuthal magnetic field $\mathbf{B}_{\varphi}$ with corona distance **r** for fast solar wind

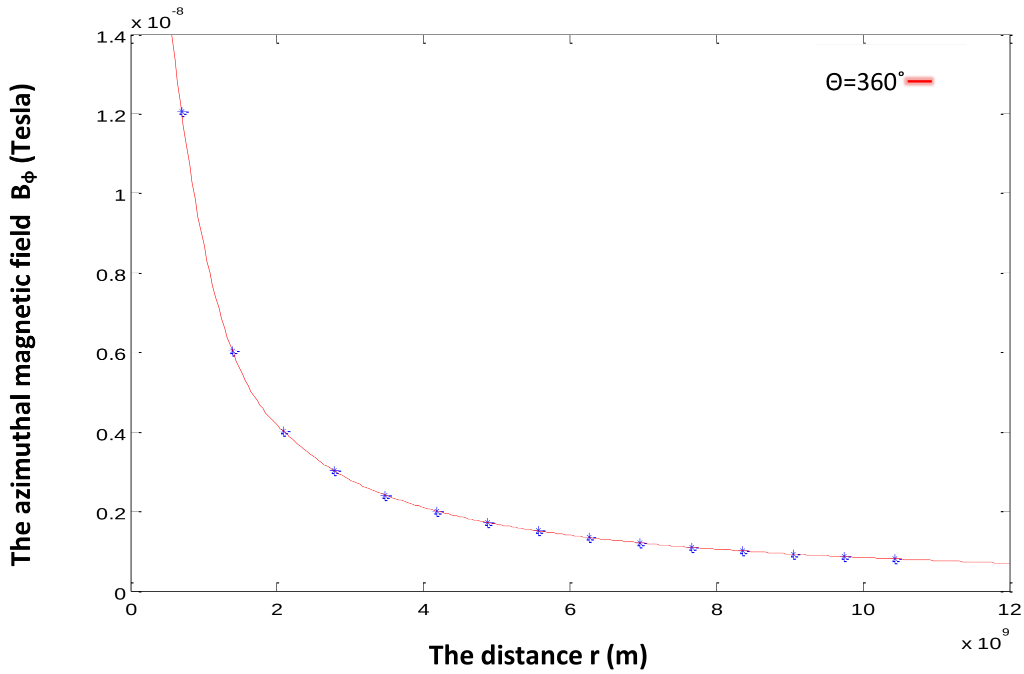

Figure (3) The variation of azimuthal magnetic field $\mathbf{B}_{\varphi}$ with corona distance **r** for fast solar wind

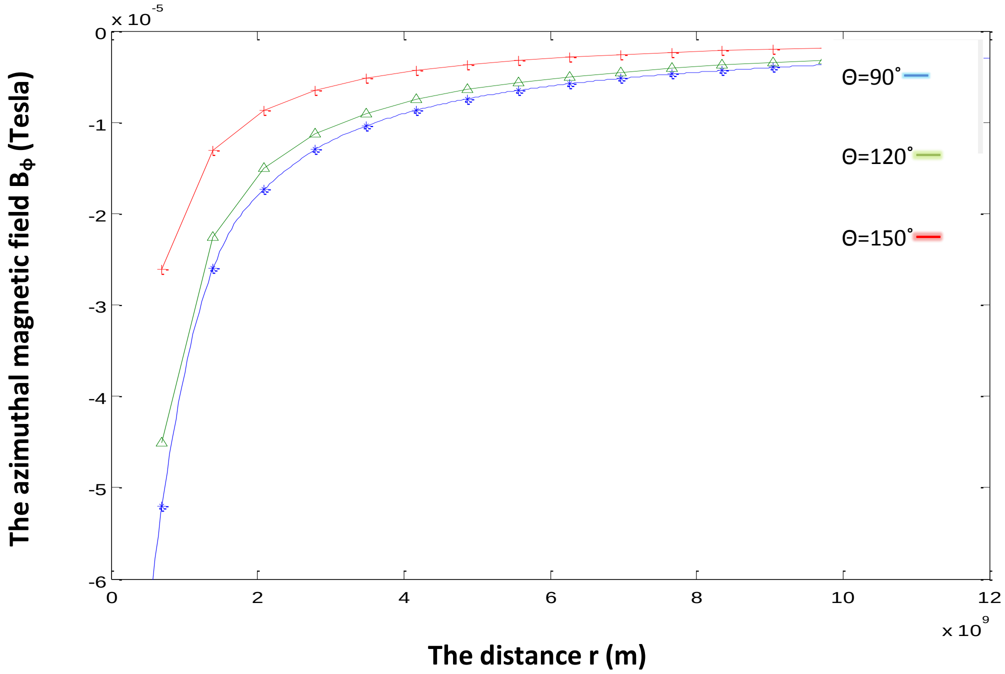

Figure (4) The variation of azimuthal magnetic field $\mathbf{B}_{\varphi}$ with distance **r** for slow solar wind

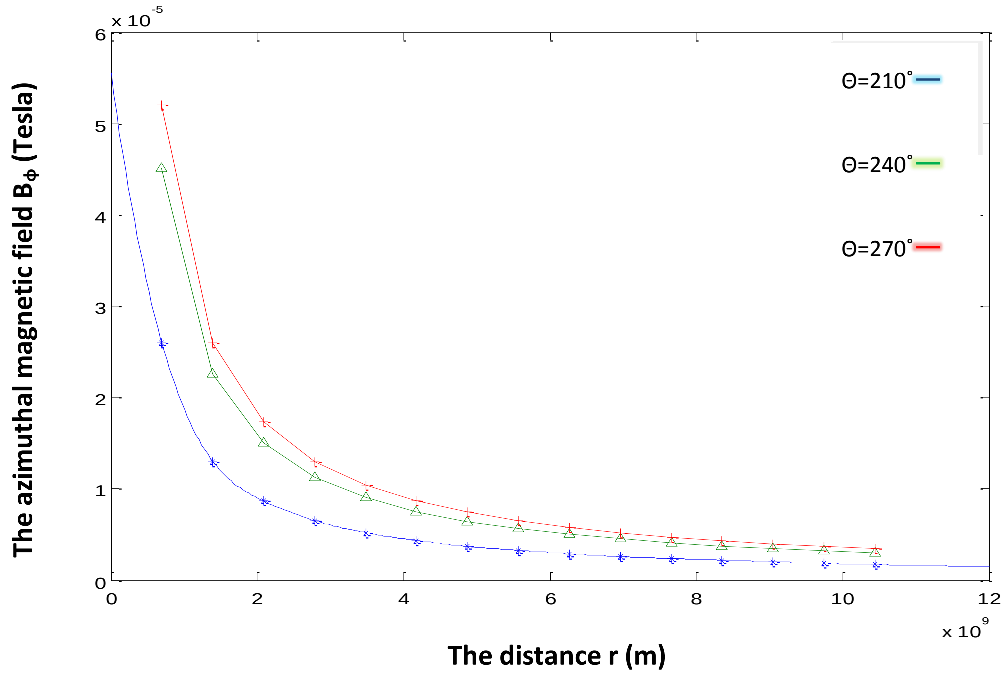

Figure (5) The variation of azimuthal magnetic field $\mathbf{B}_{\varphi}$ with distance **r** for slow solar wind

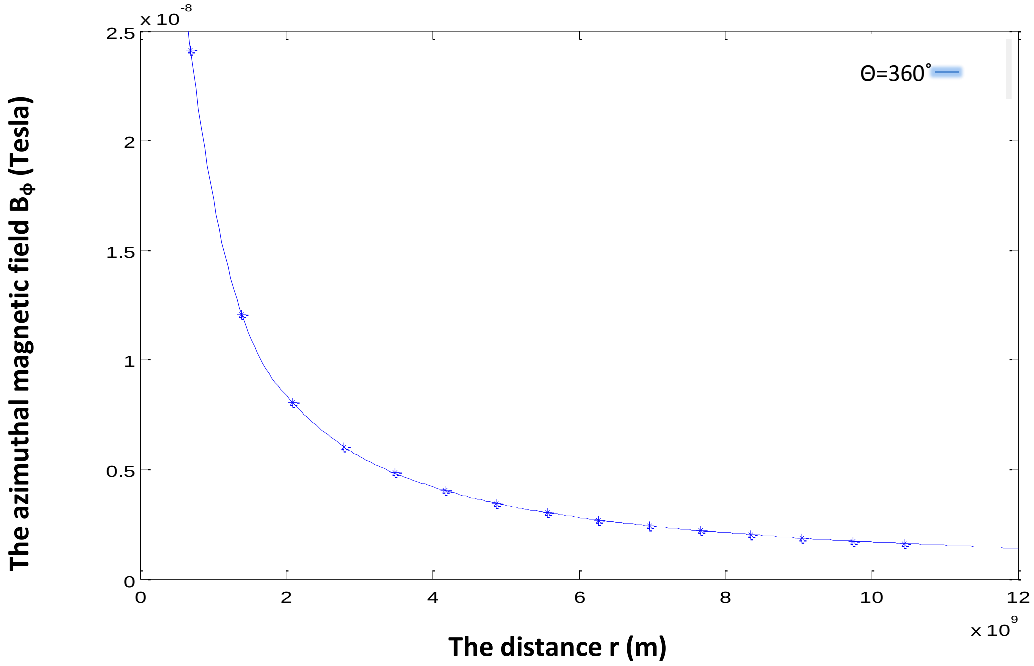

Figure (6) The variation of azimuthal magnetic field $\mathbf{B}_\varphi$ with corona distance **r** for slow solar wind

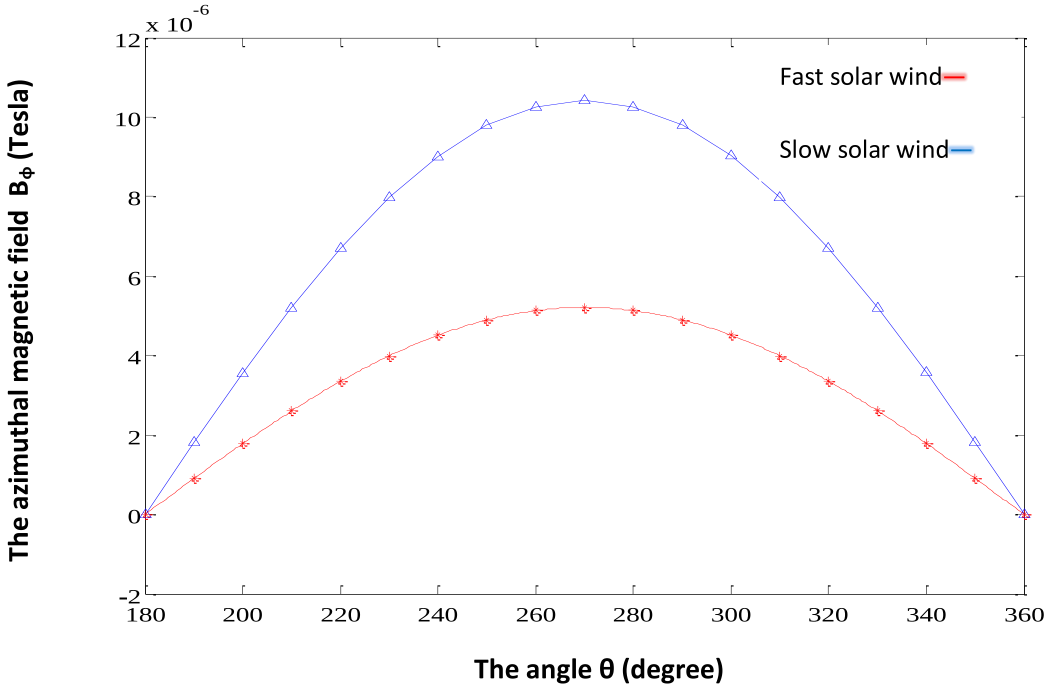

Figure (7) The variation of azimuthal magnetic field $\mathbf{B}_\varphi$ with the angle $\boldsymbol{\theta}$ at constant corona distance for fast and slow solar wind

1-4-2 The Colatitude Electric Field results:

The colatitude electric field E_θ for the corona decreases with increases in the distance far away from the sun within the corona region as the magnetic field and E_θ component at the equator region is stronger than polar region as shown in figures (1-8), (1-9) and (1-10).

The colatitude electric field E_θ is found according to the equation (8) whereas E_r and E_φ components are equal to zero depended on the equations (7) and (9) for different values of the angle θ. where colatitude electric field E_θ at constant distance $5\times R_\odot$ and different values of θ component have the high values at the equator region and the low at the polar regions as shown in figure (1-11). The results indicated that the equator region will be more advantage and effect on the movement of the solar energetic particles that contribute to the solar wind.

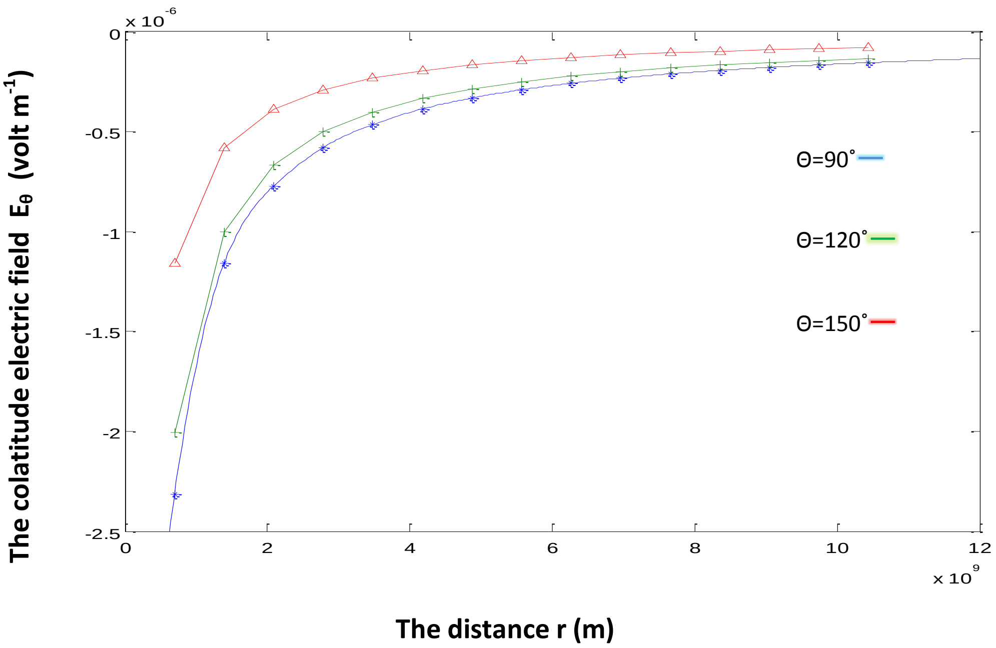

Figure (8) The variation of colatitude electric field $\mathbf{E}_\theta$ with corona distance **r**

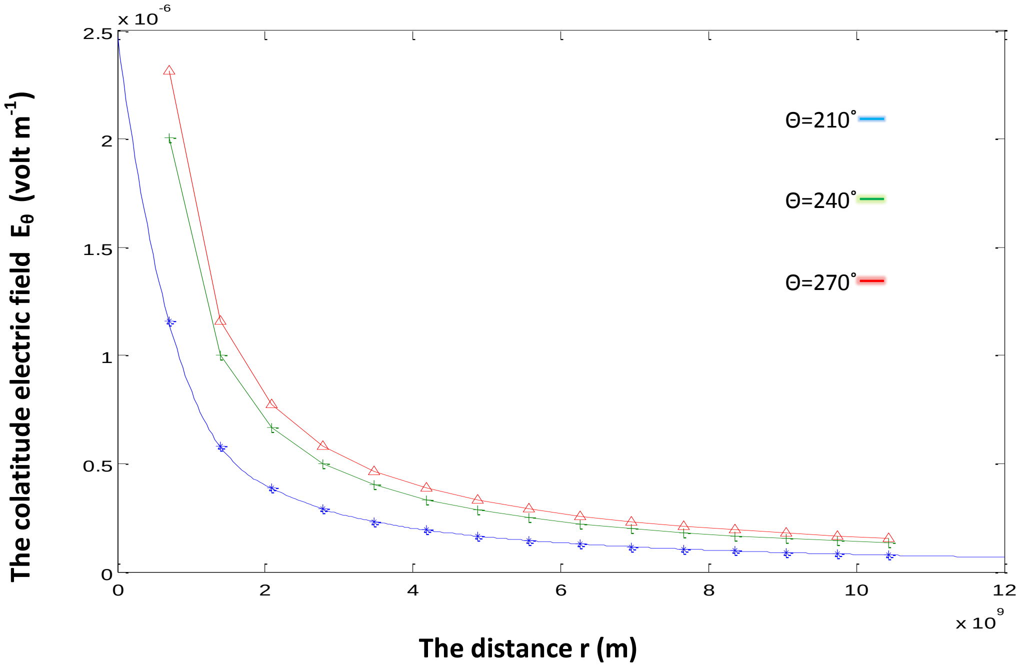

Figure (9) The variation of colatitude electric field $\mathbf{E_\theta}$ with corona distance **r**

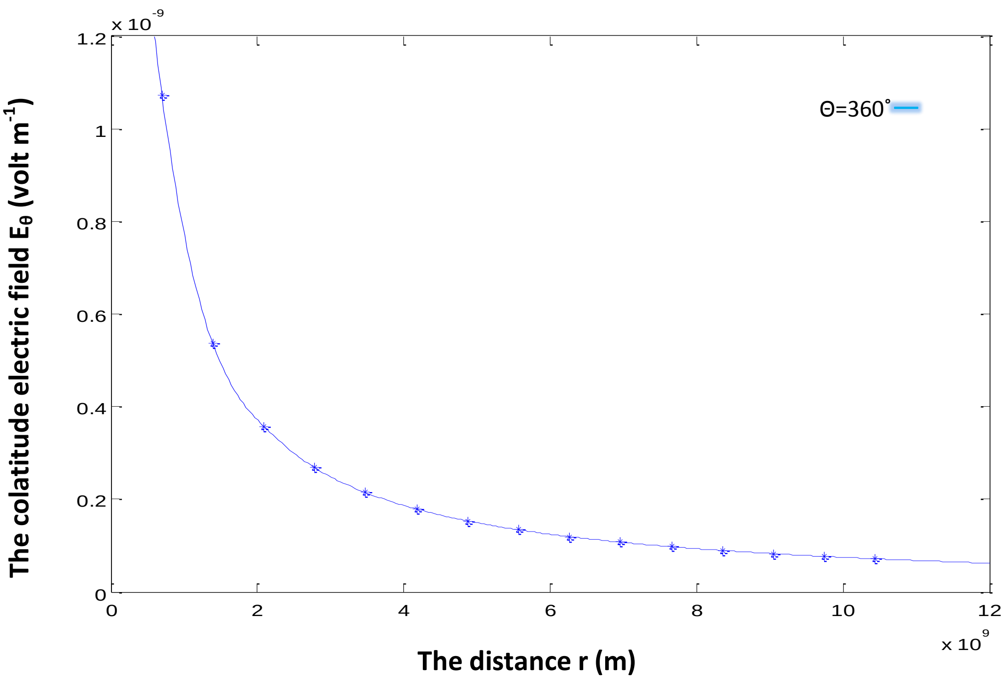

Figure (10) The variation of colatitude electric field $\mathbf{E_\theta}$ with corona distance **r**

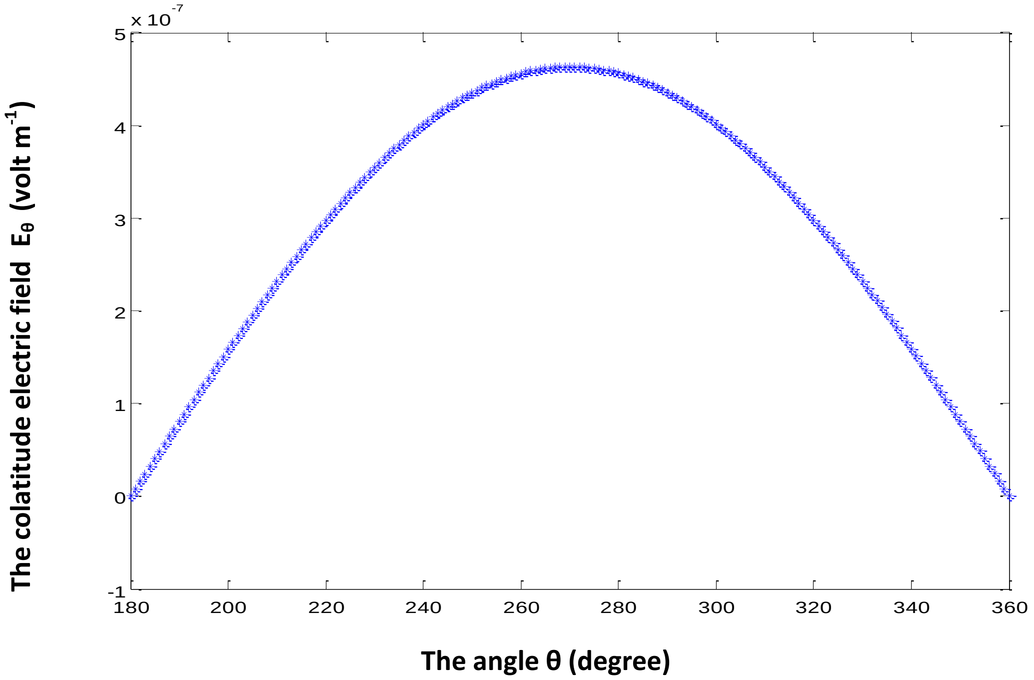

Figure (11) The variation of electric field $\mathbf{E_\theta}$ with the angle $\boldsymbol{\theta}$ at constant corona distance

Conclusion

- The azimuthal magnetic field B_φ results at the pole region is poor value comparison with the rest regions where the value at the pole region is10^{-8} tesla and at the rest regions the value is 10^{-5} tesla for slow and fast solar wind where the slow solar wind has values better than the fast solar wind and can see the variation in the angle θ doesn't effect on the values of the magnetic field except at θ equal to 360° which is the polar region it shown decreases at B_φ component. The magnetic field decreases with increase of the distance away from the sun within corona region.
- The colatitude electric field E_θ results, the electric field E_θ component decreases with increases in the distance far away from the sun within the corona region as the magnetic field and it is relatively stronger in the most regions except the polar region with value 10^{-6} volt m^{-1} and at the polar region the value is10^{-9} volt m^{-1}, the variation of the angle θ doesn't effect on the values of the colatitude electric field E_θ except at θ equal to 360° which is the polar region it shown decreases at E_θ component.

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