المؤتمر العلمي السنوي الثالث والعشرون الموسوم
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The Grad B Drifts Of The Electron And Proton (Seps) At Solar Corona

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Abstract
The research deals with drifts velocities of the solar wind particles at corona region with distance ranging between 1 to 15$R_\odot$ for different values of angles. It has been examined, that drifts velocities in parker spiral model within single particle motion model, in spherical coordinates system (local coordinate system within axis parallel to the magnetic field). In this research, it was found that, the grad B drift velocity has high result at pole region and have been getting only the slow solar wind proton with value reach to10^8 m/sec. and the fast solar wind vanished.

Keywords: Solar Corona, solar wind, drifts Velocity, Grad B drift, solar energetic particles

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

The Sun's corona steadily expands into the space between planets, emitting a faint flow of ionized plasma and magnetic fields outward. The flow of solar wind occurs due to a significant contrast in gas pressure between the Sun's corona and the space between planets. Even though the Sun exerts a massive gravitational force, the plasma expands outward because of the pressure differential, forming what we know as the interplanetary medium.

In the orbital plane of earth (also called the ecliptic plane), it takes approximately four days for the solar wind to travel and reach earth, the solar wind comprises both a slow and fast solar wind components. During solar

This research is adapted from the first researcher's thesis[*]

minimum, the fast solar wind streams emanate from the high solar latitude polar coronal hole regions at a speed of about 800 km s^{-1} (Lee 2010), whereas the slow speed travels at speed of about 400 km s^{-1} (Encyclopedia of Astronomy and Astrophysics 2001), mostly streams from the low latitude, equatorial coronal hole regions. During solar maximum the separation of the slow and fast speed solar wind regions is not as organized, where the fast speed streams can form from lower solar latitude coronal hole regions in additional to the polar coronal holes. The structure of the solar wind in interplanetary space is that of a spiral. The solar wind can be envisioned as a continuous flow of fluid-like particles originating from a stationary source on the Sun. However, due to the Sun's rotation, this source moves relative to the radially emitted particles, creating a dynamic and shifting stream of solar wind. Over time, a solar wind fluid parcel will follow a spiral trajectory, commonly referred to as either an Archimedean or a Parker spiral. This phenomenon can be likened to the pattern created by water spraying from a rotating sprinkler hose. At 1 AU in the ecliptic plane, the spiral makes an angle of about 45◦ (Lee 2010).

1-1 Solar Energetic Particles (SEPs)

The solar energetic particles (SEPs) are an important Phenomenon in the study of space science, where the source of energetic particles is a sun. The SEPs commonly 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!). Energetic particles can travel from the Sun to the earth in under an hour. The term SEPs generally refers to protons (Zheng & Evans 2014). The open coronal magnetic fields transfer the solar energetic particles (SEPs) to the earth's atmosphere, and its flow along magnetic field (Dinku 2014), the transport of solar energetic particles (SEPs) in the inner heliosphere is a very important issue which can affect our daily life, The SEPs also can harm astronauts in space and finish the instruments on board spacecraft, the interplanetary magnetic field is the medium in which solar energetic particles travel, The journey of solar energetic particles (SEPs) from their origin, throughout the heliosphere, remains a significant unresolved challenge in heliophysics. Most of SEPs measurements have been taken either near the earth or near the ecliptic plane (Pei 2007). Energetic particles originating from the solar corona form the fundamental constituents of the solar wind, establishing a connection with Earth through interactions with its magnetic field. Is therefore necessary to study the drifts of these particles, so that we can deal with them on the earth through knowledge their energy and velocity.

In previous studies in 2020, S.Dalla presented 3D simulations of relativistic proton propagation from the Sun to 1 AU, which included 3D effects associated with particle drift and the presence of a HCS (Helispherical Current Sheet) (S.Dalla 2020). And A. Hutchinson in 2021 use 3D test particle simulations, which naturally incorporate the effect of drifts, to simulate the propagation of SEPs from a moving shock-like source, and investigate the effect of an expanding shock-like source propagating through interplanetary space, as opposed to an SEP source within the corona, on the observable properties (A Hutchinson 2021). In addition, N.Wijsen study the effect of the magnetic gradient and curvature drifts on the pitch-angle dependent transport of solar energetic particles (SEPs) in the heliosphere of SEPs at 1 AU and at locations nearer the Sun(N. Wijsen 2021). And Lulu Zhao describe one physics-based solar energetic particle model, called Solar-wind with Field-lines and Energetic-particles (SOFIE), this model is designed to simulate the acceleration and transport processes of solar energetic particles in the solar atmosphere and interplanetary space (Lulu Zhao 2023).

1-2 Material and Method

The grad B drift velocity of SEPs happens when there is a gradient in the magnetic field in the direction perpendicular to B. This is called the gradient drift (Steven et. al 2004).

In this research, it found the azimuthal and colatitude grad B drift velocity, $V_{\nabla B\varphi'}$, $V_{\nabla B\theta'}$, for fast and slow electron and proton according to equations (2), (3) where the grad B $V_{\nabla B\varphi'}$, $V_{\nabla B\theta'}$ components depending on energy of the particle and the value of this energy for electrons is equal to 0.0016 eV and for proton is equal to 2.85 eV at corona near photosphere region (Tan 2014). The equation derivative by Dalla et. al to compute the grad B drift velocity in SEPs at corona region under the conditions of the parker model (Dalla et. al 2013):

$$V_{\nabla Bl} = 0 \tag{1}$$

$$V_{\nabla B\varphi'} = \frac{\mu c}{q}\frac{1}{(r^2+a^2)} r\cot_\theta \tag{2}$$

$$V_{\nabla B\theta'} = -\frac{\mu c}{q}\frac{1}{(r^2+a^2)^{\frac{3}{2}}}(r^2+2a^2) \tag{3}$$

Where a is a function of colatitude θ and is defined as:

$a = \frac{u_s}{\Omega \sin_\theta}$, u_s: The speed of the solar wind (4)

- The fast solar wind is equal to 800 Km sec^{-1}.
- The slow solar wind is equal to 400 Km sec^{-1} (Encyclopedia of Astronomy and Astrophysics 2001).

The grad-B drift depends on the particle species and on velocity. The direction of the grad-B drift is opposite for electrons and ions. In the nonrelativistic approximation, the magnetic moment μ is given by:

$$\mu = \frac{m\, u_\perp^2}{2B} \quad (5)$$

Where $u_\perp$: is the component of a particle velocity in a plane perpendicular to the magnetic field and B=|**B**|.

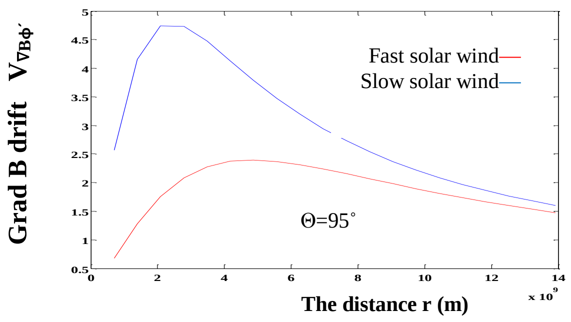
1-4 The result and Discussion

This results and calculation made for the solar energetic particles (SEPs) at corona regions of the sun at distance ranging from (1 to 15) R_Θ (R_Θ is the radius of the sun) (Patzold et. al 1987). Obtained the results by equations programing by matlab version 2014, these calculations made in (SI) system unit using spherical coordinates (r, θ, φ) to analysis and computes the values and results for the influences of the magnetic field in spherical coordinates that act on the movement of the particles at this region. By using some specific constants and values of the corona region as follows: r_o is the radial distance from the sun $1R_\Theta$ and it's equal to 6.69×10^{8} m, the distance is conversion from AU to M, Ω is the solar rotation rate is equal to 2.86×10^{-6} rad sec^{-1}. (Dalla et. al 2013), finally B_o is the surface solar magnetic field is equal to 1830 $\times10^{-9}$ Tesla (Tautz et. al 2010), The results of this research were compared to the results of Dalla et.al 2013 for proton and were approach to them.

1-4-1 Azimuthal Grad B Drift Velocity

It has been found that the azimuthal grad B drift velocity $V_{\nabla B\varphi'}$ for slow and fast solar wind electron has the best result at the pole region at θ equal to 360° for slow solar wind is equal to10^5m/sec. as is shown in figure (1) panel g. All results for slow solar wind electron better than the fast solar wind electron and at the polar region the fast solar wind are vanished and the slow solar wind still and has highest results.

The results of grad B drift, $V_{\nabla B\varphi'}$ for solar wind proton, are higher in comparison with the solar wind electron, where the best value for slow solar wind for proton is at the pole region where, θ is equal to 360° which is equal to 10^8 m/sec. As is shown in figure (2) panel g, In generally grad B drift $V_{\nabla B\varphi'}$ for proton has high results at most of regions except the equator, at the pole region the slow solar wind proton has highest results and the fast solar wind proton is vanishing.



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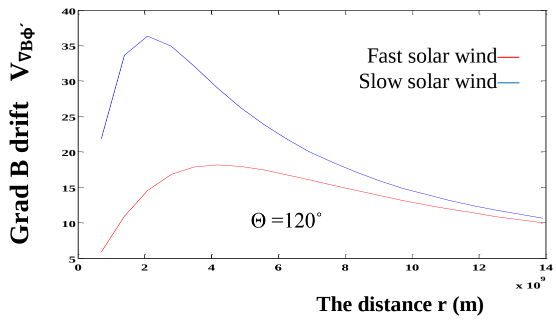

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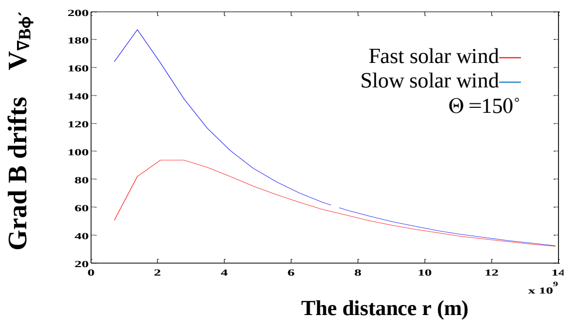

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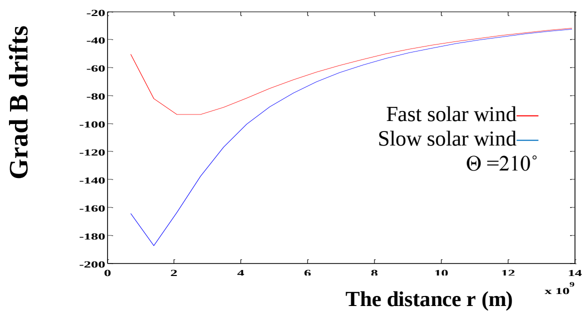

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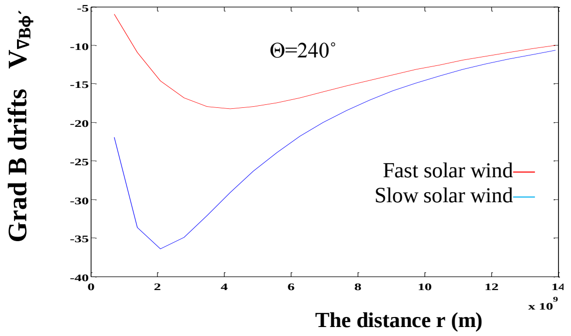

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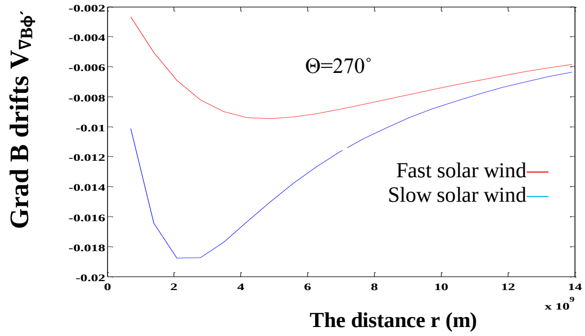

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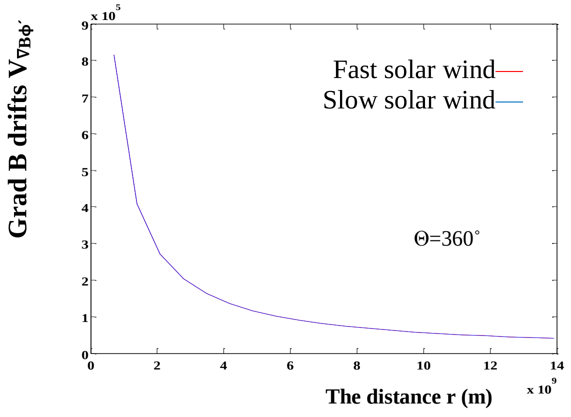
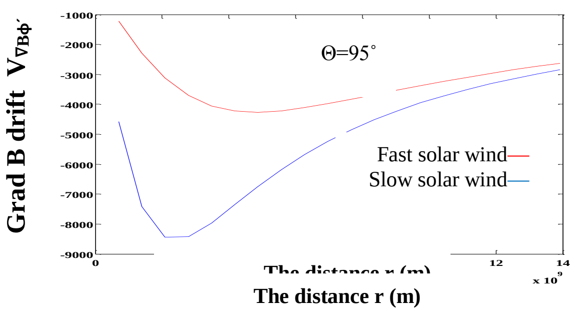


(g)

Figure (1) The variation of grad B drift $V_{\nabla B\varphi'}$ (m /sec.) with distance r (m) for **electron**



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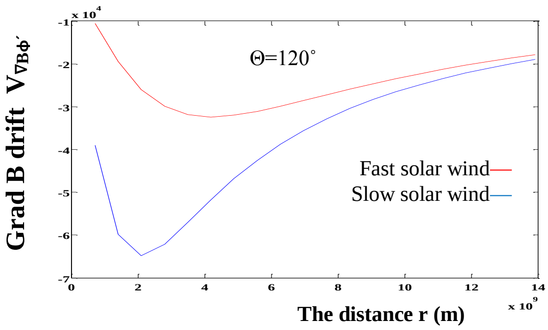

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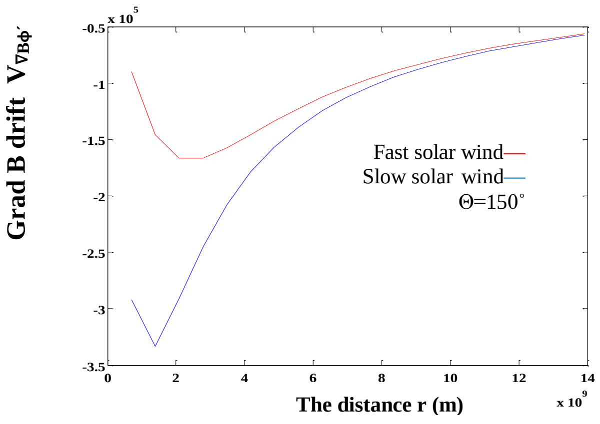

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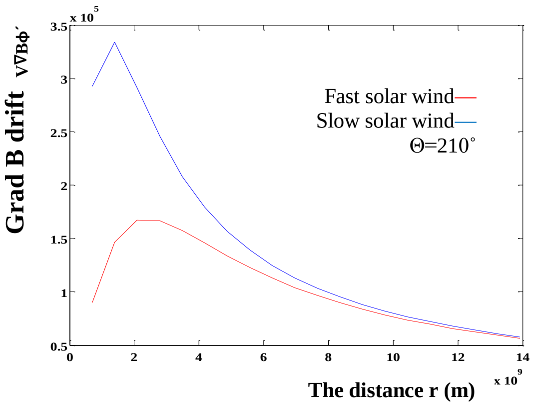

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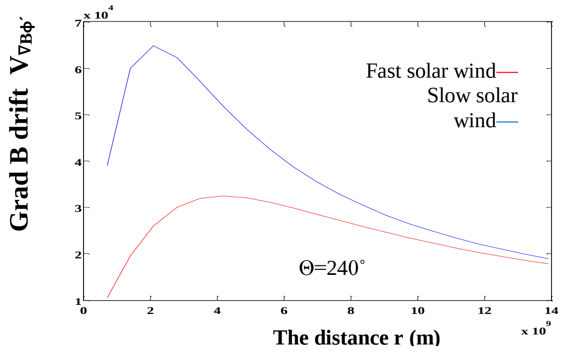

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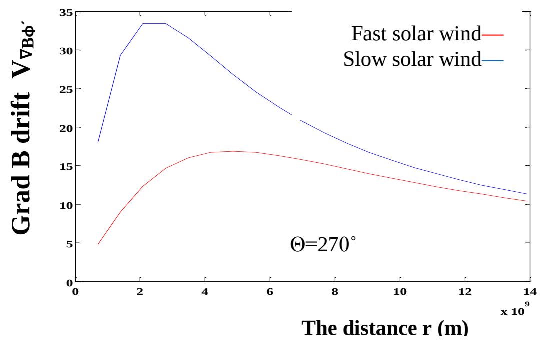

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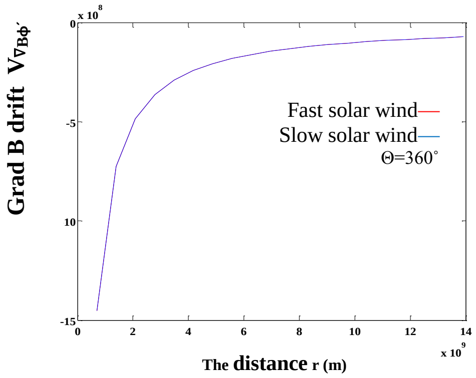

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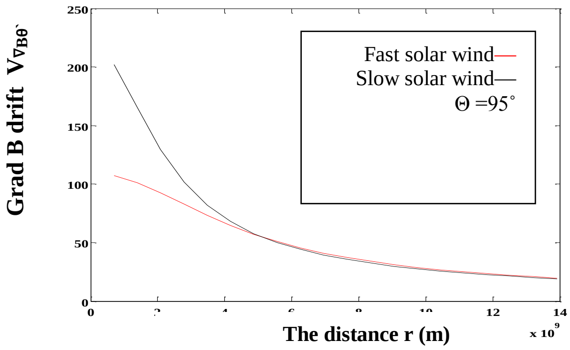
Figure (2) The variation of azimuthal grad B drift $\mathbf{V_{\nabla B\varphi'}}$ (m /sec) with distance **r** (m) **for proton**

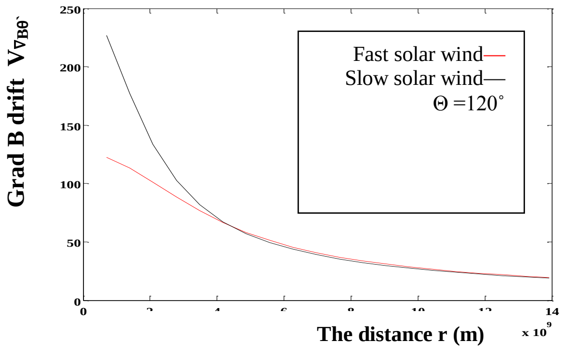
1-4-2 Colatitude Grad B Drift Velocity

The colatitude grad B drift velocity $V_{\nabla B\theta'}$ for electron is weak and $V_{\nabla B\theta'}$ component has the same low results at different values of angle θ shown in figure (3) In generally, the slow solar wind electron has values better than fast solar wind electron and at the pole region the fast solar wind is vanish where the slow solar wind still and has results. The changing of the value of the angle θ doesn't effect on the colatitude grad B drift $V_{\nabla B\theta'}$ of electron.

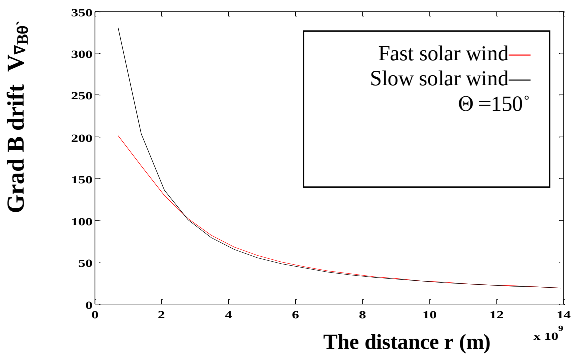
The grad B drifts velocity $V_{\nabla B\theta'}$ for proton is very high in all regions (equator and pole) for different values of the angle θ and these results are very close to each other which is equal to 10^5 m/sec. as is shown in figure (4) In generally the slow solar wind proton has the high values in comparison with fast solar wind proton where at the pole region the fast solar wind proton is vanishes while the slow solar wind proton is still have high values.


Grad B drift $V_{\nabla B\theta}$
The distance r (m)
x 10^9
Fast solar wind—
Slow solar wind—
Θ =95°

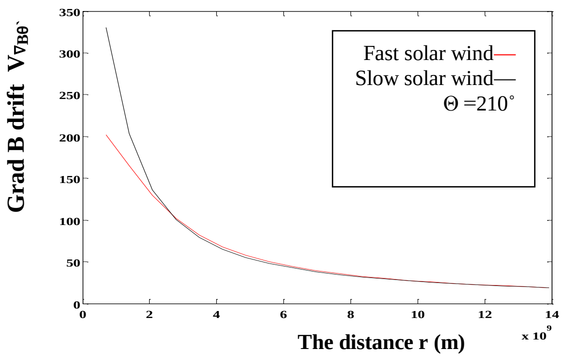
(a)


Grad B drift $V_{\nabla B\theta}$
The distance r (m)
x 10^9
Fast solar wind—
Slow solar wind—
Θ =120°

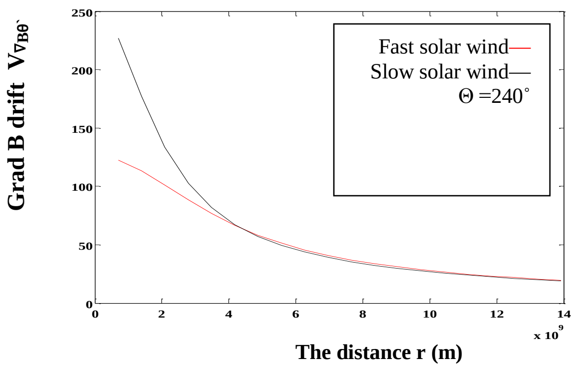
(b)


Grad B drift $V_{\nabla B\theta}$
The distance r (m)
x 10^9
Fast solar wind—
Slow solar wind—
Θ =150°

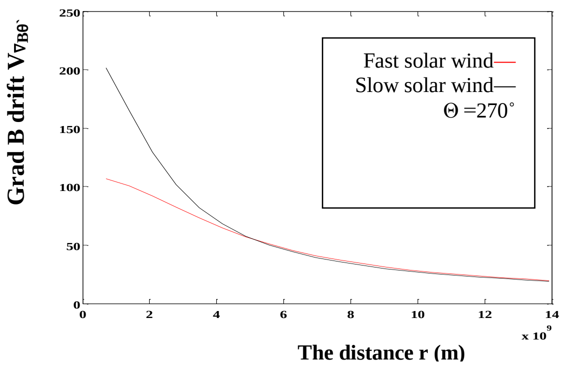
(c)


Grad B drift $V_{\nabla B\theta}$
The distance r (m)
x 10^9
Fast solar wind—
Slow solar wind—
Θ =210°

(d)


Grad B drift $V_{\nabla B\theta}$
The distance r (m)
x 10^9
Fast solar wind—
Slow solar wind—
Θ =240°

(e)


Grad B drift $V_{\nabla B\theta}$
The distance r (m)
x 10^9
Fast solar wind—
Slow solar wind—
Θ =270°

(f)

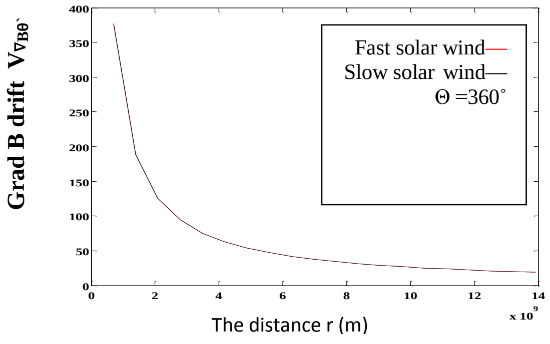


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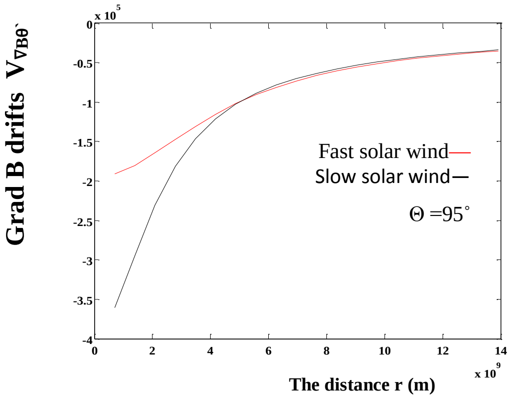
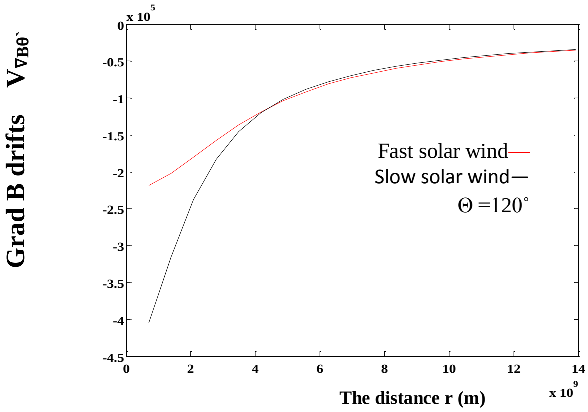
Figure (3) The variation of colatitude grad B drift $\mathbf{V_{\nabla B\theta`}}$ with distance **r (m) for electron**





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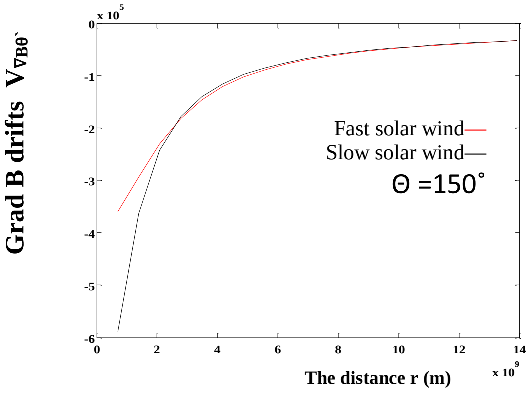

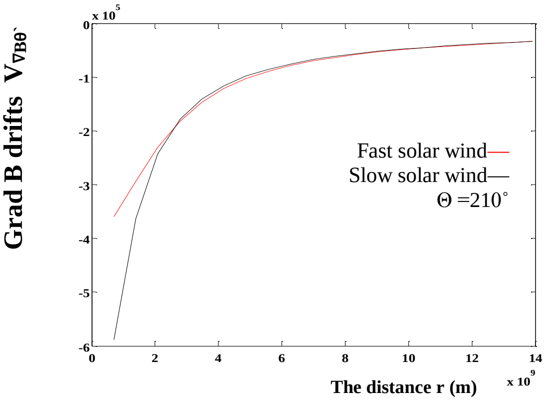

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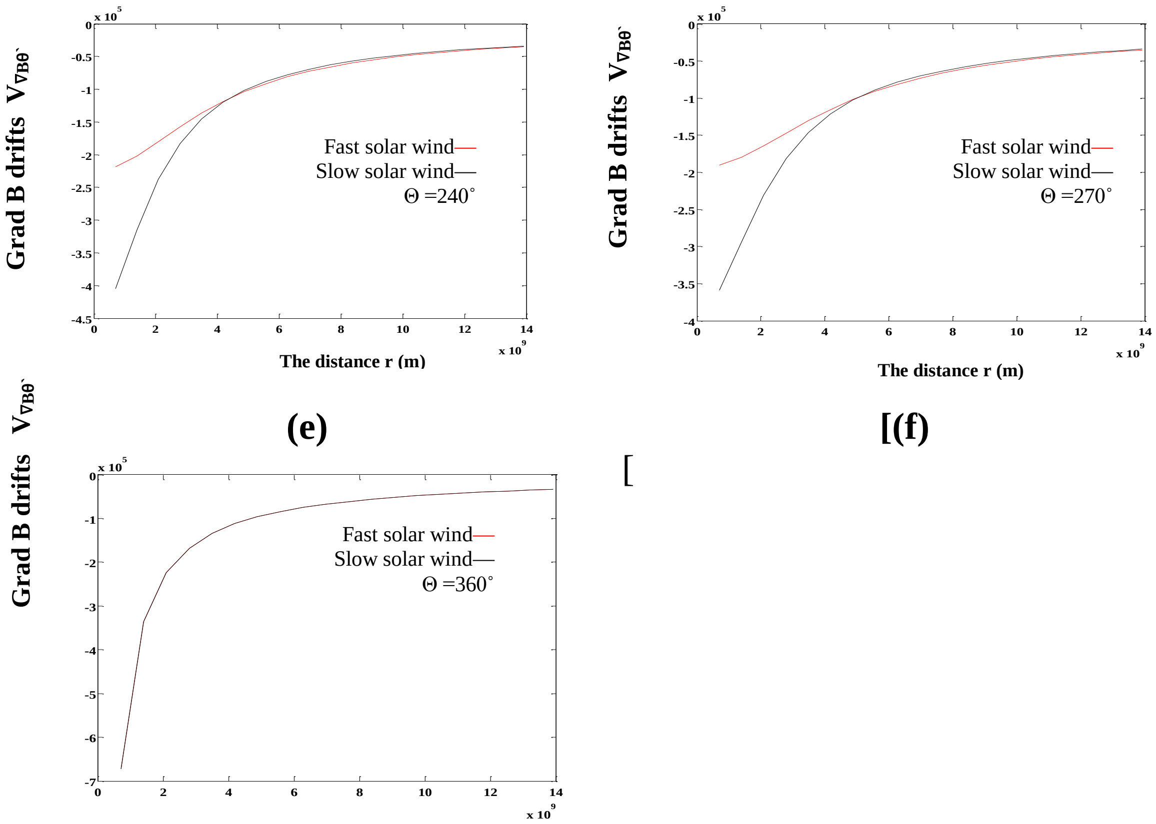

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(g)

Figure (4) The variation of the colatitude grad B drift $\mathbf{V_{\nabla B\theta`}}$ with distance **r** (m) **for proton**

Conclusion

- The grad B drift velocity $V_{\nabla B\varphi'}$, $V_{\nabla B\theta`}$ components where the $V_{\nabla B\varphi'}$ component has weak result at all regions except the pole has high result for electron reach to10^5 m/sec. and high result for proton at all regions between 10^4 -10^6 except the equator regions between 35-200 m/sec. where at the pole reach to10^8 m/sec. at pole region we get only the slow solar wind and the fast solar wind vanished at the pole region. The $V_{\nabla B\theta`}$ component has approximate weak results for electron at all regions between 250-400 m/sec. and proton has high approximate results at all regions with value reach to $10^5$m/sec. We see the variation of the angle θ doesn't effect on the $V_{\nabla B\theta`}$ component.

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انجراف انحدار B للإلكترون والبروتون (SEPs)في الهالة الشمسية

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مستخلص البحث:
يتناول البحث سرعات الانجراف لجسيمات الرياح الشمسية في منطقة الهالة بمسافة تتراوح بين 1 إلى RO15 لقيم مختلفة من الزوايا. وقد تم دراسة سرعات الانجراف في نموذج باركر الحلزوني ضمن نموذج حركة جسيم واحد، في نظام الإحداثيات الكروية (نظام الإحداثيات المحلية داخل المحور الموازي للمجال المغناطيسي). في هذا البحث، وجد أن سرعة انجراف انحدار B لها نتيجة عالية في منطقة القطب وتم الحصول فقط على بروتون الرياح الشمسية البطيئة بقيمة تصل إلى 10^8 م / ثانية. وبروتون الرياح الشمسية السريعة تلاشى.

الكلمات المفتاحية: الهالة الشمسية، الرياح الشمسية، سرعة الانجراف، انجراف انحدار B، الجسيمات الطاقية الشمسية.