

The Shrinking of the Heliosphere Due to Reduced Solar Wind

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Abstract. The heliosphere is the space within which the solar wind dominates and the solar interplanetary magnetic field prevails. Its boundary is determined by the balance between stellar and solar winds. Owing to the present reduction in the solar wind pressure, one would expect that the stellar wind would push the heliosphere inward leading to its shrinkage. In this paper we calculate the extent of the heliosphere at different solar wind status. Backward estimation of the extent of the heliosphere since 1890 is done. It is found that the heliosphere oscillated between 75 and 125 AU between 1890 - 2010. Most important is the forecast of the shrinkage and oscillations of the heliosphere and their implications on the earth. The shrinkage of the heliosphere would allow more invasions of cosmic rays to the earth and planets, increased cloud cover and a cooler Earth.

Keywords: Heliosphere, Wolf-Gleissberg cycles, weak solar cycles, the Sun, Solar wind.

1 Introduction

The heliosphere is the cavity curved by the solar wind into the interstellar medium. Its extension is determined by the equality of the solar wind pressure and the stellar wind pressure. For this reason, we will first study past, present and future status of solar activity and then we will reflect this study into the heliosphere. Yousef (1998) predicted a drop of solar wind. The main purpose of this paper is to compute the extent variations of the heliosphere in response to solar stimulations.

1.1 Weak Solar Cycles

The magnetic solar cycles are variable in strength and durations. Figure 1 illustrates such variability since 1700. Strong and moderate solar cycles have duration 10 and 11 year, whilst the weak solar cycles mostly have 12 years duration (Nesme-Ribes et al., 1994).

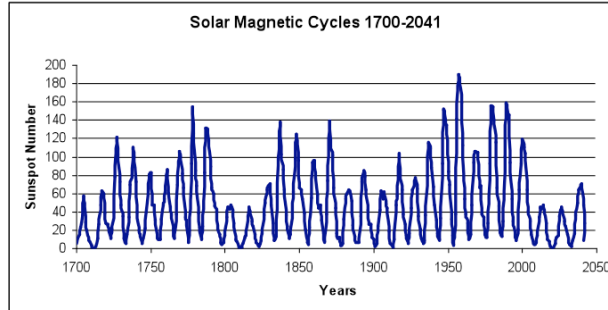


Fig. 1. Time series of the sunspot number illustrating the existence of weak solar cycle's series around 1700s, 1800s, 1900s and 2000s. The prediction of cycles 24, 25 and 26 is given at the extreme right of figure 1 as a repetition of cycles 4, 5 and 6 around 1800s.

1.2 How Are The Weak Cycles Generated By The Solar Dynamo?

The solar differential rotation persists to the bottom of the connective zone. The rotation velocity becomes uniform from pole to pole nearly 1/3 of the way to the core. Lower down the rotation remains independent of latitude acting as if the Sun were a solid body. Shearing motion along this interface may be the dynamo source of magnetism. The top of the radiative zone which rotates at one speed meet the overlying convective zone which spins faster in its equatorial middle. The roughly 20 million meter wide layer where these very different zones meet and shear against one another, called the tachocline, is the likely site of the solar dynamo, the source of the sun's magnetism. The hot circulating gases, which are good conductors of electricity, generate electrical currents that create magnetic fields, these fields in turn sustain the generation of electricity. The dynamo amplifies and regenerates the sun's magnetic field. The strong fields eventually rise through the connective zone and emerge at the photosphere (Lang 2001 and references therein).

There is a temporal variation in the rotation of the Sun in the base of the connective zone and close to the probable site of the solar dynamo in equatorial regions, the rotation speeds up, slows down and speeds up again with a period of 1.3 year. There are observed differences of the rotation rate from the mean at 0.72 R and 0.63 R. When the lower gas speeds up, the upper gas slows down and vice versa.

If we tie up those variations of rotation speed near the tachocline with those observed at the photosphere, it is thus evident that faster rotations of weak solar cycles means slower rotation at the tachocline, i.e. of the solar dynamo and this implies the decline of solar magnetism. Vice versa, for stronger more active solar cycles the equatorial photosphere is observed to rotate slower, implying that the solar dynamo spins faster and that the hot circulating ionized gases generate stronger electrical currents and thus create stronger magnetic fields (Yousef and Hady 2008).

The solar spin rate is generally faster during the start of weak cycle series as evident from Fig 2a for the weak cycles earlier than 1900 and for cycle 20 in the

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1960s (Hoyt and Schatten 1997 after their reference). This faster rotation rate leads to a reduction in solar energy budget emitted from the sun in all wavelengths as well as solar wind flux, density, velocity and interplanetary magnetic field.

Solar induced climate changes do occur at the turning points of the Wolf-Gleissberg cycles whenever there is a change in the solar spin rate. Solar induced climate changes do occur at the start, end of those weak solar cycles and following the Wolf-Gleissberg cycles maximums (Yousef 2006). In addition, solar induced climate changes can occur within the weak cycle's series following the end of 22-year Hale magnetic cycle.

1.3 Solar Spin Rate, Solar Wind, Inter-Planetary Magnetic Field And Temperature On Earth

Svalgaard et al. (2003) have succeeded in working out the near-earth interplanetary magnetic field since 1600. They have also reconstructed solar wind speed since 1890 (fig 2c). The number of 3-hour intervals per year where the aa-index was at its lowest possible values as shown in fig (2b). They studied the IMF during the previous weak solar cycles series (cycles 5-7) and (12-14) around 1800 and 1900. In response to the drop of the level activity, the magnitude of IMF and the solar wind speed dropped. The IMF for cycles 5 and 6 is in the range of 4.5-6.5 nT compared to 8.5 nT for cycle 19 which is the maximum of the Wolf-Gleissberg cycle.

Fig 2. shows that the years 1900-1902 seem to be very special with very low solar wind speed (275-300 km/s). In order to understand what happened in 1900-1902 let us put the pieces together, compare figs(2a,b,c and d) starting from the sun down to Earth. At those years solar equatorial rotation rate abruptly slowed down (Fig. 2a), i.e. the Tachocline spins faster than the convection zone leading to stronger magnetic cycles.

The solar wind speeds up following its drop (Fig. 2c).

Before those years, it was exceptionally quiet with more than half the time there was no measurable geomagnetic activity at all. (Fig. 2b). There was a sudden rise in the temperature of the small town Soria in Spain fig 2d (Donaire, 2000).

In the year 1900 slowing down of the equatorial rotation means that the Tachocline rotation speeds up. It is at those years that a solar induced climate change happened ending the previous one at 1878. This 1878 earlier solar induced climate change occurred with the start of the weak cycle number 12 leading to about 5 degrees sudden drop in the temperature of the little town Soria in Spain. In between 1878 and 1900 the IMF dropped down and it was a geomagnetic quiet period. The sun was spinning much faster for a period of 22 years Hale magnetic cycle. Less irradiance reached the earth in all wave lengths of spectrum and this led to a global cooling. So what counts here is the spin rate of the sun.

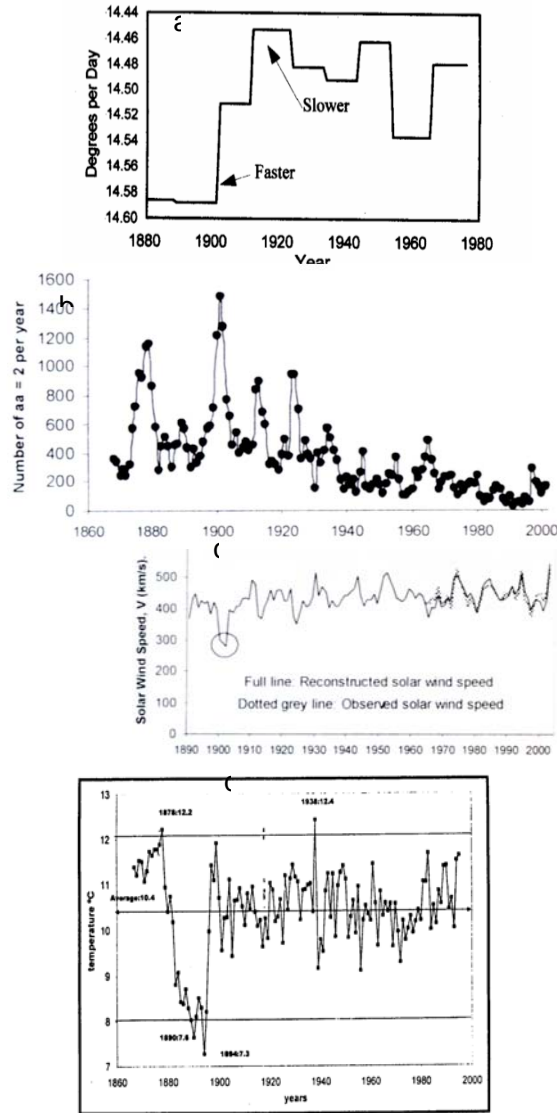


Fig. 2. The variation of spin rate of the sun a (*upper diagram*) 1880-1900 during the weak cycles 12 and 13 as stimuli to the consequences of interplanetary and terrestrial events. B (*second upper curve*) the number of magnetically quiet days show sharp decreases between 1878 and 1900 at the start and end of 22 year Hale magnetic cycle. c (*third upper curve*) drop of solar wind speed prior 1900-1902 to 275-300 km/s, Svalgaard et al. (2003). d (*bottom curve*) Sudden 5 degrees drop in the temperature of Soria (a small town in Spain in 1878 followed by 5°C abrupt rise in 1900 showing end of 1878 solar induced climate change (Donaire 2000).

1.4 Prediction of the State of solar Activity During The Next Few Decades

Weak solar cycles occur at the bottom of Wolf-Gleissberg cycles. They tend to occur in series of 3-4 cycles. A single weak cycle also occurs in between the two maximums of Wolf-Gleissberg cycle. Since the last weak solar cycles occurred around 1900 while the previous ones occurred around 1800 then the newly started cycle 24 should be a weak solar cycle. However, owing to the 200-years de Verie cycle of the sun, it is more likely that the status of the coming solar activity would be something like those weak cycles around 1800 as shown in Fig 1. Svalgaard (2005) also predicted that cycle 24 would be the lowest so far in the past 100 years with the maximum sunspot number around 75.

2 The Heliosphere

The solar wind carves out a cavity in the interstellar medium known as the heliosphere (Fig 3a). The heliosphere is imbedded into the Oort cloud, a cloud of trillions and trillions of comets (Fig 3b).

The radius of the heliosphere can be estimated by determining the standoff distance, or stagnation point, in which the ram pressure, P_{sw} , of the solar wind falls to a value comparable to the interstellar pressure, P_I . As the wind flows outward, its velocity remains nearly constant, while its density decreases as the inverse square of the distance (Lang 2001)

$$P_I = P_{sw} = P_{IAU} \times \left(\frac{IAU}{R_s} \right)^2 = (m_p N_{IAU} V_{IAU}^2) \times \left(\frac{IAU}{R_s} \right)^2 \quad (1)$$

The dynamic pressure of the solar wind therefore also falls off as the square of the distance, and we can use the solar wind properties at the Earth's distance of 1 AU to infer the pressure, P_{sw} , at the stagnation point distance, R_s . Equating this to the interstellar pressure, where the proton's mass $m_p = 1.67 \times 10^{-27}$ Kg, the number density of the solar wind near the Earth is about $N_{IAU} = 5 \times 10^6$ protons m^{-3} and the velocity there is about $V_{IAU} = 4 \times 10^5$ m s^{-1} . To determine the distance to the edge of the solar system, R_s , we also need to know the interstellar pressure, and that is the sum of the thermal pressure, the dynamic pressure and the magnetic pressure in the local interstellar medium. It is about $P_I = (1.3 \pm 0.2) \times 10^{-13}$ Nm^{-2} .

The estimate obtained from the equation is $R_s = 100$ AU, far beyond the orbits of the known outer planets. However, the estimates by different authors gives a broad range for the distance to the edge of the solar system, depending on the uncertain values of various components of the interstellar pressure (Lang Encyclopedia of the Sun 2001).

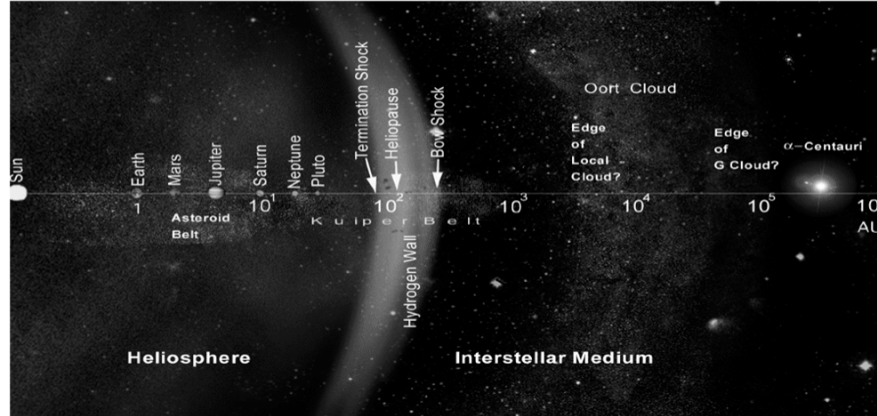


Fig. 3a. The heliosphere structure at the boundary between solar wind and interstellar medium (wikipedia.org). Note that the whole solar system and the heliosphere are imbedded within the Oort Cloud.

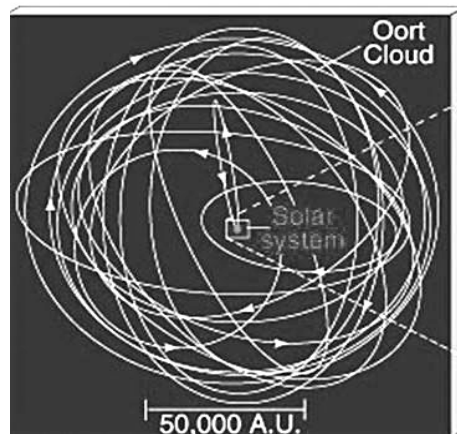


Fig. 3b. The Oort Cloud, where trillions and trillions of comets engulfs the heliosphere and the solar system with their orbits inclined in every direction.

3 The Heliosphere Variability In Response To Stellar and Solar Wind Variability

Computations of the extent of the heliosphere in terms of solar wind pressure variability and stellar wind pressure variability are carried out. Figure 4 shows such variability for normal solar wind velocity of 400 km/s as well as for reduced and enhanced solar wind.

As shown in Fig.5, the extent of the heliosphere R_s is given by:

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$$R_s = \frac{1}{4} V \quad (2)$$

where R_s is measured in astronomical units and V is the velocity of the solar wind in Km/s.

For a given stellar wind pressure, let us now make an estimation of the solar wind speed that would make the boundary of the heliosphere encounter planets of the solar system. Such estimations are given in fig 6.

We have used Svalgaard et al (2003) construction of the solar wind velocity between 1890-2003 to estimate the extent of the heliosphere using the above equation and have extend it to the more than three months in 2010. Reduced solar wind velocities are taken from Yousef and Ali (2010 in this volume). As seen from figure 7, the heliospheric radius oscillated between 75 and 125 AU during that period. Between about mid 2008 and more than 3 months in 2010, there has been a shrinkage of the heliosphere. No correction has been made for the time delay of the shrinkage due to the solar wind reaching the boundary of the heliosphere.

Actual confirmation of the shrinkage was reported under the title 'the Sun's protective layer is shrinking' (Gray 2008). New data has revealed that the heliosphere has weakened by 25 per cent over the past decade and is now at its lowest level since the space race began 50 years ago. The Interstellar Boundary Explorer, or IBEX, was launched into an orbit 150,000 miles above the Earth where it is "listening" for the shock wave that forms as our solar system meets the interstellar radiation.

Just on the contrary to the shrinkage of the heliosphere, an expansion of the earths magnetosphere and other planetary atmosphere must have occurred.

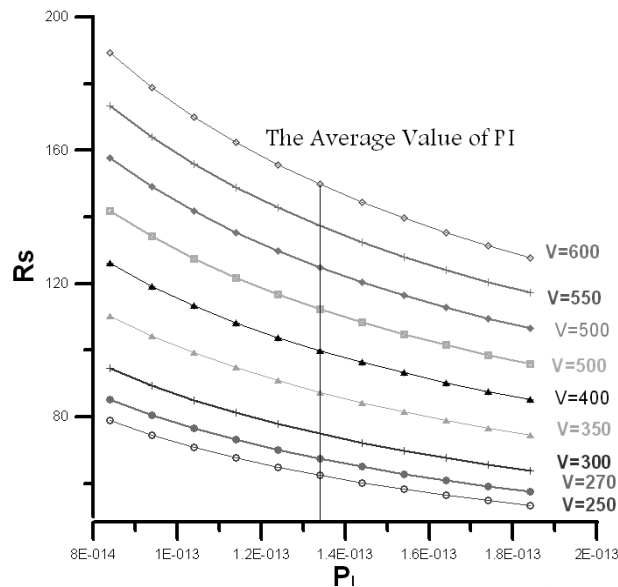


Fig. 4. The extent of the heliosphere as a function of stellar wind pressure for a normal solar wind velocity of 400 km/s and reduced and enhanced sets of velocities.

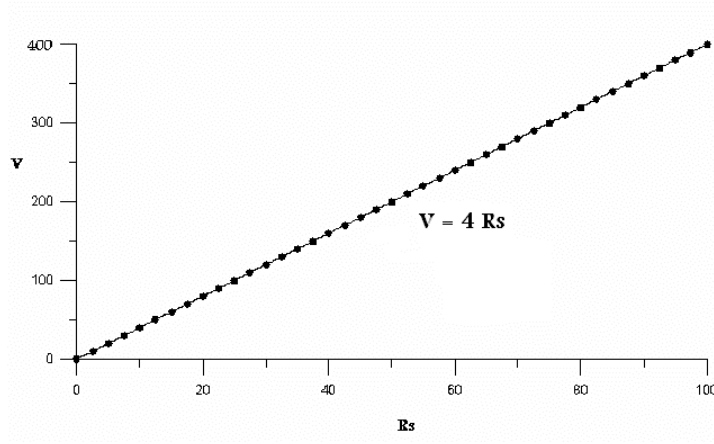


Fig. 5. The relation between the solar wind speed and the radius of the heliosphere $R_s=1/4V$.

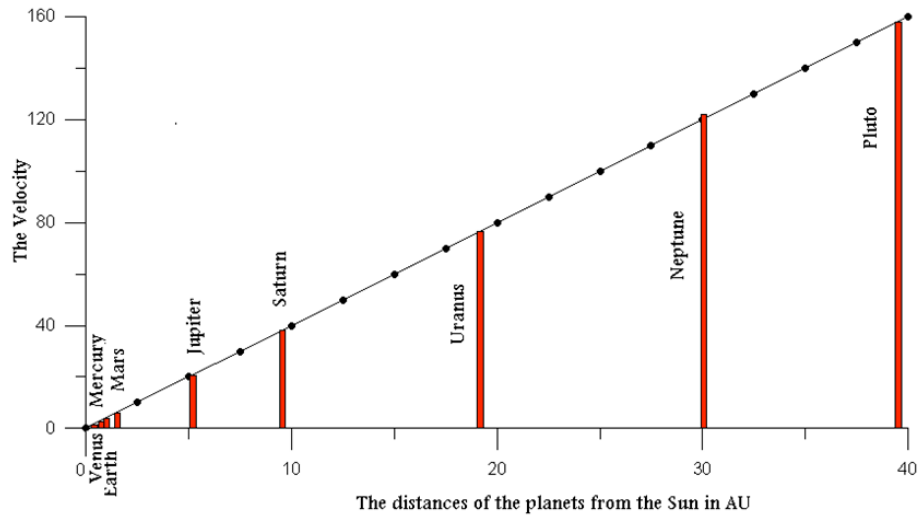


Fig. 6. The estimated solar wind speed at which the boundary of the heliosphere will encounter a given planet.

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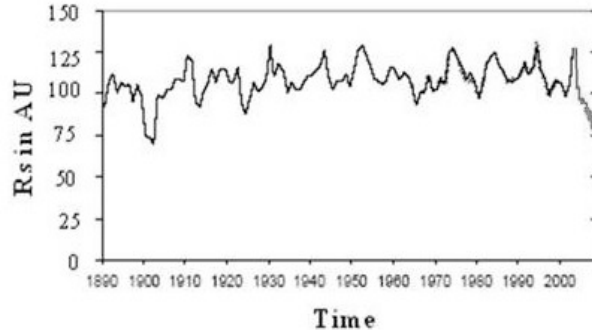


Fig. 7. Constructed heliosphere radius from 1890 to 2010. The extent of the heliosphere between 2006 and 2010 is based on Yousef and Ali (2010).

4 Conclusions

Without the heliosphere the harmful intergalactic cosmic radiation would make life on Earth almost impossible by destroying DNA and making the climate uninhabitable. Slow rotation of the upper radiative zone at the Tacochline which is the site of the solar dynamo induces weak magnetic cycles. This is accompanied by fast photospheric spin of the sun. As a result, slower solar wind is produced. The consequence of this is the shrinkage of the heliosphere. The Earth would thus be subjected to more Cosmic ray flux. This would lead to more cloud cover ,i.e. more precipitation and cooler earth.

Backward investigation of the extent of the heliosphere based on computations of the solar wind velocity by Svallgard et al. reveals that the heliosphere oscillated between about 75-125 AU between 1890-2010. The smallest heliosphere occurred around 1900 due to the presence of weak solar cycles.

5 Predictions

Owing to the 200 years solar cycles, it is anticipated that the present decline of solar activity would be about the same level of activity as cycles 5, 6 and 7 around 1800. These weak cycles are considerably lower than cycles 12,13,14 and 15 around 1900.This implies that we should expect a deeper drop in solar wind speed than those around 1900.leading to further shrinkage of the heliosphere perhaps to 65 AU moving towards the inner part of the Kupier belt. Would this affect the frequency of periodic comets?

More invasions of cosmic rays to the earth are to be expected. Cooling of the earth and other planets is anticipated with more precipitation on the earth.

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