Magnetosphere Size of Earth and Jupiter during 2016-2018: A Comparative Study

Mays M. Al-Gbory, Noora M. Saleem

Department of Physics, College of Education, Al-Iraqia University, Baghdad, IRAQ

Abstract

Magnetosphere is a region of space surrounding planets and an astronomical object, the formation of planetary magnetosphere depends on many parameters such as; surface magnetic field of the planet, an ionized plasma stream (solar wind) and the ionization of the planetary upper atmosphere (ionosphere). Tow planets with dipole magnetic field from our solar system are selected in this research, the criteria for selecting these planets are according to the strength of the surface magnetic field: Earth from inner planets (with strongest surface magnetic field from all inner planets) and Jupiter form outer planets (with strongest surface magnetic field from all outer planets).The main objective of this research is to find the different between the magnetosphere size (R_{MP}) for Earth and Jupiter, for the period 2016, 2027 and 2018. From results we found that there is a fluctuation in the monthly behaviour of the (R_{MP}) for two planets and years selected in this research, for Earth (R_{MP}) values ranged between (9-15R_E) and for Jupiter ranged between (37-44R_J). Results show that, Earth have the less magnetosphere with respect to other selected planet, while Jupiter have the largest one.

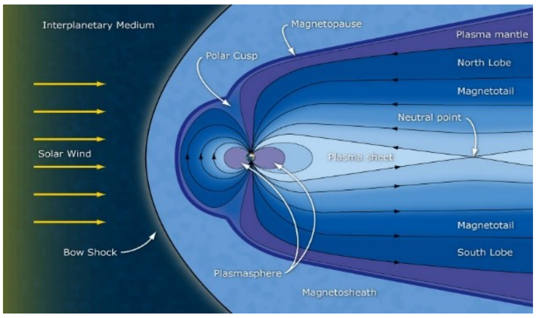
Keywords: Solar system; Inner planets; Outer planets; Earth; Jupiter; Magnetosphere size (RMP)

Received: 17 April 2025; **Revised:** 19 May 2025; **Accepted:** 26 May 2025; **Published:** 1 July 2025

1. Introduction

The Magnetosphere is a region of space surrounding planets and an astronomical object, it shields the planets from incoming plasma and protecting its atmosphere. The interaction between the solar wind and Earth magnetic field (magnetosphere) effect on a human health, harm communications and power grids and even damage satellites. So, the study of magnetosphere benefits not only the science society, but also the economy to accurately model the dynamics and to predict adverse events. The magnetosphere comprises regions with different particle temperature, densities and magnetic field strength [1-4]. To form a magnetosphere, there are three parameters are required: a strong planetary magnetic field, solar wind plasma and the ionization of the planetary upper atmosphere (ionosphere). The structure of the magnetospheres depends on several characteristics of each planet: the spin period of the planet, magnetic dipole axis, and solar wind flow velocity [5]. There are four types of magnetosphere: The heliosphere for the Sun, Interactions of the solar wind with asteroids and comets, Magnetospheres of magnetized planets (Earth, Mercury, Jupiter, Saturn, Uranus and Neptune) and Magnetospheres of unmagnetized planets (Mars and Venous). The third type is taken which is related to the planets selected in this research. The Earth magnetosphere is a magnetic region around the Earth created by the interaction of the solar wind with the Earth magnetic field. In this region, the terrestrial magnetic field is dominant, and the shape is distorted from that of a perfect dipole due to the solar wind pressure. When the supersonic solar wind encounters the sun facing side of the Earth magnetic field, it exerts a pressure on the dayside of the Earth magnetic field and is compressed towards Earth forming a structure like head having radius of about 8-15R_E. The night side of the field is stretched out to form a long magnetic tail whose diameter is about 50R_E, as shown in Fig. (1a) [6].

The solar wind particles cannot penetrate the Earth magnetosphere because the charged particles are deflected by the geomagnetic field, so the Earth magnetosphere shields the Earth from the harmful high energy particles emitted from Sun, but there are times when a small fraction of the incident energy enters into the magnetosphere, the amount of solar wind particles entering into the Earth magnetosphere depends on many factors such as the Interplanetary Magnetic Field (IMF) and solar wind parameters (density and velocity) [7]. The plasma distribution inside the magnetosphere is not uniform and can be grouped into different regions with different densities and temperatures. The Earth magnetosphere is divided into two regions: inner magnetosphere and outer magnetosphere. The regions of the magnetosphere, where the geomagnetic field lines are closed are called the inner magnetosphere, the inner magnetosphere is subdivided into different regions include ionosphere, plasmasphere and van Allen radiation belts. Also, the regions of the magnetosphere where the geomagnetic field lines are either deviated to a great extent from a perfect dipole shape or open to the solar wind in the far tail region are called the outer magnetosphere, the two tail lobes, the Plasma Sheet Boundary Layer (PSBL) and the current sheet are the main regions in the outer magnetosphere [8]. The interior of the Jupiter is the place of a strong dynamo that produces a surface magnetic field with strength about 4 Gauss (1 Gauss = 10^{-4} Tesla). This strong magnetic field and its fast rotation about 9h 55minute; create a special magnetosphere in the solar system, as shown in Fig. (1b). The Jupiter magnetosphere different from all other magnetospheres; that it derives much of its plasma internally from the Jupiter moon Io [9].



(a)

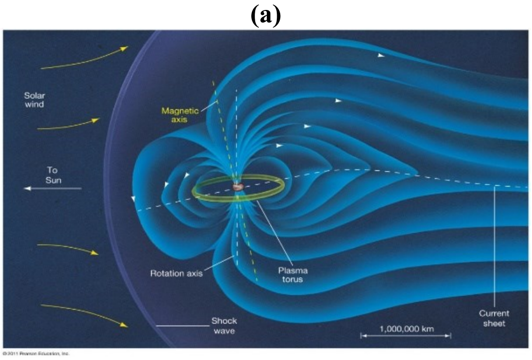


Fig. (1) The magnetosphere of (a) Earth and (b) Jupiter [14]

The observations from Galileo show that, the field and current strengths are not symmetric in Jupiter's magnetosphere, but show local time asymmetries similar to those observed in the Earth's magnetosphere. This finding suggests that the solar wind drives a convection system in Jupiter magnetosphere in ways similar to the Earth magnetosphere [10]. The magnetosphere of Jupiter is divided into three regions: inner <$10R_J$, middle 10-$40R_J$ and outer > $40R_J$. The inner magnetosphere is the seat of plasma production for the magnetosphere. In the inner magnetosphere, the warm and cold plasma is confined to the centrifugal equator, a surface defined by the site of points where each field line reaches its maximum distance from the rotational axis of Jupiter. The information on the location of the dipole has to be continually propagated outwards from the inner magnetosphere [11]. In the middle magnetosphere, the plasma corotation with Jupiter magnetosphere gradually breaks down because the weakly ionosphere of Jupiter is not able to impart enough angular momentum to the out flowing plasma. The radial currents, which enforce corotation on the middle magnetosphere plasma, create aurora in the Jupiter ionosphere by accelerating electrons into the ionosphere. In this region, the magnetic field becomes highly stretched as it acts to contain the plasma against the strong centrifugal and thermal pressure forces. The plasma temperature is high and it is not understanding what processes are accountable for bracing the warm plasma to high values in this region [12]. In the outer magnetosphere, the plasma velocity lags corotation by a factor of two or more. Through the dayside this region is depending on the solar wind dynamic pressure the dayside magnetopause can be found from a distance of about 45-100R_J and in the night side outer magnetosphere, an additional current system occur that connects the magnetodisc current to the magnetopause currents. This current system, called the magnetotail current system further stretches the magnetic field lines, creating a long magnetotail, length more than 7000 R_J, which has been known to extend to the Saturn orbit [13].

3. Results and Discussion

The planetary magnetic field is strong enough to deflect the charged particles of the solar wind. The condition for successfully deflecting the solar wind is that the pressure of planetary magnetic field must be equal pressure due to the solar wind [14]. The magnetosphere size in units of planetary radii is given by [15]:

$$R_{MP} = R_p \left(\frac{B_0^2}{2\mu_0\, \rho_{sw}\, v_{sw}^2}\right)^{1/6} \qquad (1)$$

In general, according to the (R_{MP}) values the magnetosphere can be classified as: Intrinsic magnetosphere for $R_{MP} >> R_p$, (when the main opposition for the flow of solar wind is the magnetic field of the object). Mercury, Earth, Jupiter, Saturn, Uranus, and Neptune have intrinsic magnetospheres. And Induced magnetosphere for $R_{MP} << R_p$, (when the solar wind is not opposed by the object magnetic field, while it interacts with the atmosphere/ionosphere of the planet, or surface if the planet has no atmosphere), Venus and Mars is an example for this type. Venus has an induced magnetic field because it has no dynamo, the only magnetic field present is that created by the solar wind covering around the physical obstacle of Venus [12].

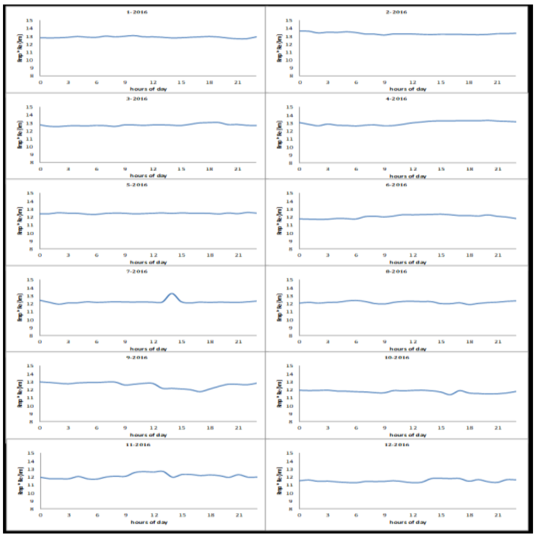
In this study, two planets with dipole magnetic field from the solar system are selected in this research to study the size of planetary magnetosphere (R_{MP}), and years 2016-2018 chosen as available data from the site. The data were obtained from the GSFC/SPDF OMNI Website interface, (https://omniweb.gsfc .nasa.gov/form/dx1.html) for the solar wind velocity (v_{sw}), solar wind density (ρ_{sw}), the criteria for selecting these two planets is according to the strength of the surface magnetic field: one from inner planets (Earth with strong surface magnetic field) and one from outer planets (Jupiter with strong surface magnetic field). A program is setting up by using (C sharp is programming language) to calculate the surface magnetic field (B_o) for the magnetized planets. We will mention below the data analysis and results first for the Earth and then for the Jupiter: Figure (2) represented the monthly median of the Earth magnetosphere size (R_{MP} in km), for same period respectively, the R_{MP} is calculated by using Eq. (1). From this figures we show that, there are a fluctuation in the monthly median behaviour of the Earth magnetosphere size along the three years chosen, the Earth R_{MP} values ranged between 9-14R_E (R_E is the Jupiter radius). The reason for this fluctuation is due to changes in the magnetic field and the speed and density of the solar wind, which is variable with the solar activity and it changes every hour, so this fluctuation occurs in the radius of magnetosphere. Figure (3) shows the calculated monthly median of the magnetosphere size (R_{MP} in km) for Jupiter by using Eq. (1), along the same three years 2016, 2017 and 2018, respectively. The results illustrated that, there are a variation in the monthly median behaviour of Jupiter magnetosphere size (R_{MP}) along the years chosen. Where the R_{MP} value for Jupiter ranged between 37-44R_J (R_J is the Jupiter radius). From results found that, Earth have the less magnetosphere size with respect to two selected planets because the Earth surface magnetic field is weak compared with Jupiter magnetic field and the solar wind close to the Sun is very dense, while Jupiter have the largest one because the Jupiter with strongest surface magnetic field from chosen planets in our study.

4. Conclusion

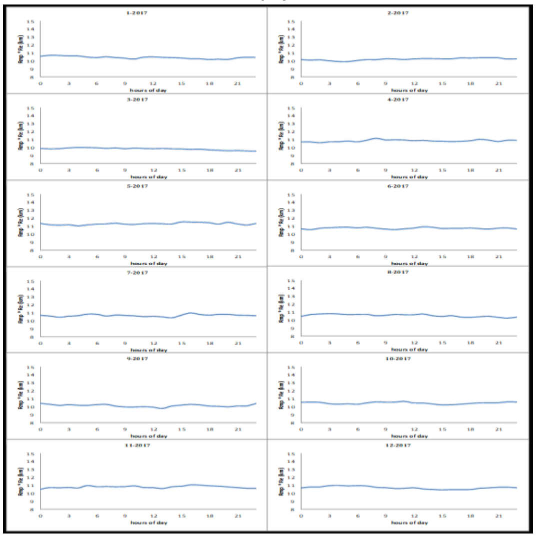
Based on the results obtained, Earth has a less magnetosphere size (R_{MP}) while Jupiter has the largest one, depending on their surface magnetic field strength and their distance from the Sun. Not only planets with strong surface magnetic field that have large magnetosphere but also the planet whose weak magnetic field create moderately large magnetosphere in the tenuous solar wind far from the Sun.

References

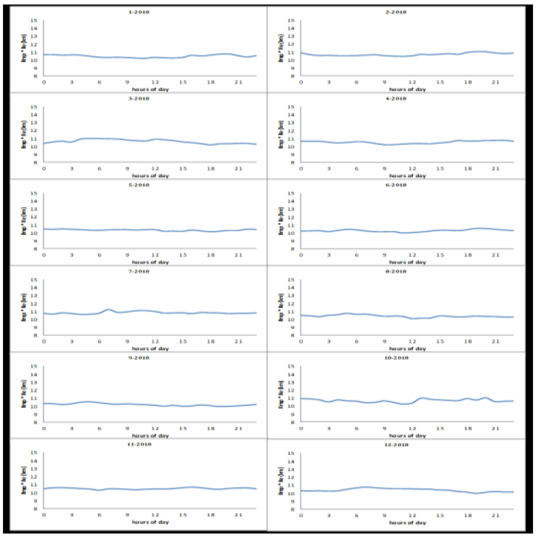
[1] M. Woolfson, Astronom. Geophys., 41(1) (2000) 1-12.
[2] R.P. Singhl, "Elements of Space Physics", New Delhi (2009) 110001.
[3] D.J. Stevenson, Earth Planet. Sci. Lett., 208 (2003).
[4] B.P. Ivy et al., "The Formation of a Magnetosphere with Implicit Particle-in-Cell Simulations", Elsevier, 51 (2015) 1178–1187.
[5] B. Michel, R. Kallenbach and N.V. Erkaev, Space Sci. Rev., 116 (2005) 227–298.
[6] G.K. Parks, "Physics of Space Plasmas_An Introduction", Ch. 2, Westview Press (Berkeley, 1991), pp. 22-46.
[7] F. Califano et al., Nonlin. Process. Geophys., 16 (2009) 1-10.
[8] S. Baraka and L. Ben-Jaffel, Ann. Geophys., 29 (2011) 31–46.
[9] S.P. Joy et al., J. Geophys. Res., 107 (2002) 17-1_17-16.
[10] B. Fran, Ann. Rev. Earth Planet. Sci., 20 (1992) 289-328.
[11] C.T. Russell, Rep. on Prog. in Phys., 56(6) (1993) 687–732.
[12] B. Michel, R. Kallenbach and N.V. Erkaev, Space Sci. Rev., 116 (2005) 227–298.
[13] K.K. Khurana et al., "The Configuration of Jupiter's Magnetosphere", ResearchGate, https://www. Research gate. net/publication/41624624_The_configuration_of_Jupiter's_magnetosphere (2004).
[14] G.K. Margaret and B. Fran, "Encyclopaedia of the Solar System", 2nd ed., Academic Press (2007), pp. 520-540.
[15] M.M. Yousef, M. Shahinaz and A. Walid, "Quantizated Variability of Earth's Magnetopause Distance", 5th Int. Conf. on Mod. Trends in Phys. Res. WSP MTPR-014, Vol. 9914 (2016) pp. 77-83.
[16] R. Barbara and M.P. Bradly, **"Foundations of Astrophysics"**, Int. ed., Addison-Wesley (San Francisco, 2011), pp. 220-221.



2016

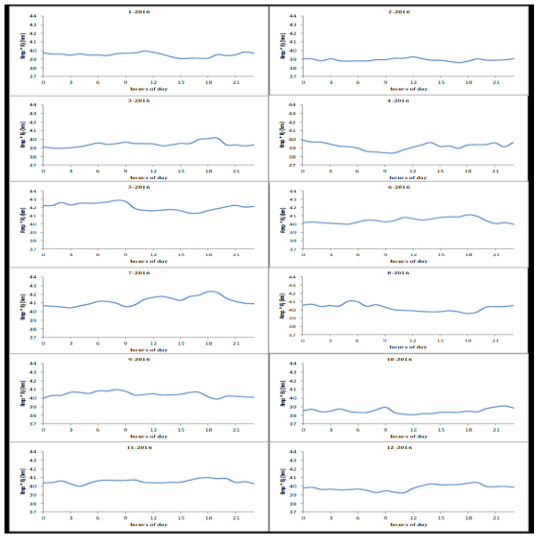


2017

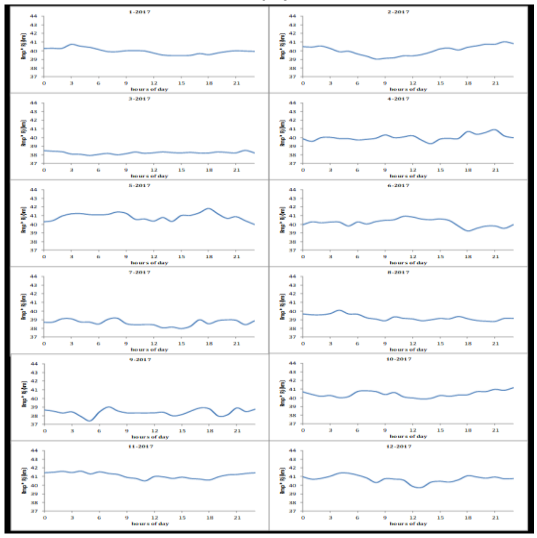


2018

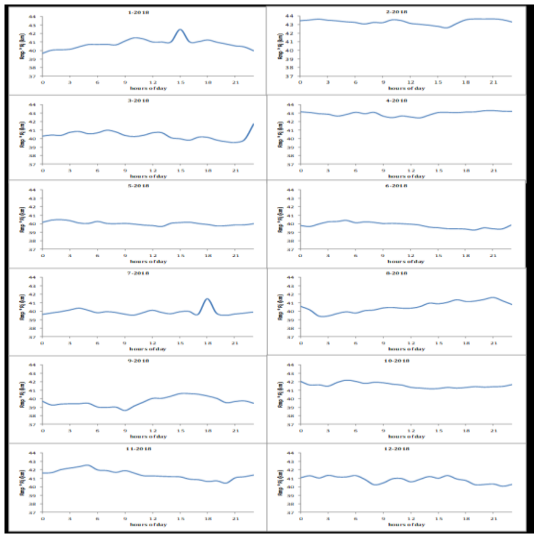
Fig. (2) Calculated monthly motion of the Earth magnetosphere size for the years 2016, 2017, and 2018



2016



2017



2018

Fig. (3) Calculated monthly motion of the Jupiter magnetosphere size for the years 2016, 2017, and 2018