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Geomagnetic Kp Index and Planetary Magnetosphere Size Relationship: for Mercury and Jupiter During two Types of Geomagnetic Conditions

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Abstract:

Kp index correlates with the many magnetosphere properties, which are used to measure the level of magnetic activity. In the solar system, the two different planets, Mercury with weak magnetic field and Jupiter with strong magnetic field, are selected for this study to calculate the planet's magnetosphere radius (R_{MP}) which represents the size of magnetosphere compared with solar activity through Kp index, through two types of geomagnetic conditions; quiet and strong for the period (2016-2018). From the results, we found that there are reversible relations between them during strong geomagnetic storms, while there are direct relations during quiet geomagnetic conditions. Also it is found that there is a reduction in the size of magnetosphere during the strong geomagnetic storms as compared to the magnetosphere size during geomagnetic quiet conditions for the two planets: Mercury and Jupiter. We can conclude from these results that the relation between storm type and magnetosphere size is independent of the strength of planetary surface magnetic field and their distance from the Sun.

Key words: Geomagnetic storms, Kp-index, Magnetic field, Magnetosphere size.

Introduction:

Magnetosphere is the region or size of space surrounding planet's lines magnetic field from which the plasma or charged particles (electrons and protons) of the solar-wind a deviate. Some plasma entering the planet penetrates into the magnetic field lines; also natural dynamical-phenomena indicate that there are direct connections between the solar-wind and the plasma contained in the planet's magnetic field (1). The formation of magnetosphere associated with the three parameters; (i) solar wind plasma, (ii) planetary magnetic field, and (iii) the ionization of the planetary upper atmosphere (ionosphere) especially during geomagnetic storm times (2). Thus, the magnetosphere's size and outer shape that change continuously depend on the solar wind charged particles condition (density and velocity) synchronized with the solar activity through the geomagnetic storms and the strength of planetary magnetic field (3). Many properties of magnetosphere show a great correlation with Kp index, extended from the aurora cusps to the electric fields to the interior of magnetosphere. This relation leads to the use of many space weather applications, the modeling of global magnetic field should be included in this relation (4). In 2004 Thomsen found that the Kp index is a very good indicator of the magnetospheres convection currents, which is due to the strength of the magnetic disturbances at the sub aurora zone to the plasma sheet. The inner boundary of the plasma sheet is greatly affected by the convection currents of the electric field (5). In 2013 Heather et al. found that many variations in the Kp-index and solar wind speed distribution relation are correlated with the effective interaction between the fast speed and slow speed of the solar-wind (6). In 2016 Nemecek found that K indices obtained from the network of the observatories are combined to give a geomagnetic activity index of the planet, after that many developments are made for magnetic indices when Kp-index was suggested, but because of its existence, the Kp-index is an extremely important index for indicating the variations of geomagnetic activities (7). Geomagnetic disturbances are caused by enhanced solar wind magnetospheric energy coupling process. The principal cause of geomagnetic disturbance is the magnetic reconnection that establishes an electro dynamical coupling between the solar wind plasma and magnetosphere (8). The solar-wind provides continuously input of plasma in the form of mass (electrons and ions), momentum and kinetic or thermal energy. If not wasted, plasma stays in the magneto-tail, and then a series of processes of energy loading and stress develop, which leads to reconfigurating the system of magnetosphere. During the geomagnetic storms, in the Van Allen belts the charged particles are accelerated to a very high energy which produces electric current systems causing disturbances in the magnetic field lines of the planets (9).

The aim of our research is to study the relationship between the Kp index and the magnetosphere size for Mercury and Jupiter depending on the strength of surface magnetic field during different geomagnetic conditions and quiet and strong geomagnetic storms that occurred during 2016 to 2018.

Geomagnetic Kp index

The 3-hour range K-index introduced by Bartels in 1939 is the most common index describing the condition of magnetic field, which reveals the disturbed component of observed horizontal magnetic field after removing daily quiet variations, from the K index the global geomagnetic activity index Kp is derived, which is measured by ground based magnetometers from many stations in the world. The calibration of each station is made according to its location and records of the magnetometer depending on the geomagnetic activity which gives the measurements of actual K-indices. The K-index is a three hour quasi-logarithmic local index at the given location and time of the geomagnetic activity compared to a quiet geomagnetic condition day. The maximum deviation of the horizontal magnetic field component is measured and records by a magnetometer at its location, then the global Kp-index is calculated that puts the recorded K values of each station together. The Kp index is normalized from (0 – 9) values, where (0) value for a very little geomagnetic condition and a (9) value for a great geomagnetic storm. Arian Ojeda Gonzalez in 2014 provides a quick and efficient way to make a prediction of Kp index, without using satellite data, they also reported that the forecast results are better when satellite data are used, the data set is important because it is used as one of the many input parameters of magnetosphere and ionosphere models (10).

Size of the Magnetosphere

The scale size of the planetary magnetosphere is given by the radius (R_{MP}) along the planet–Sun line at which the sum of the pressure of the planetary magnetic field and the pressure exerted by plasma confined within that field are equal to the dynamic pressure of the solar wind (the dynamic pressure given by ρu^2 where (ρ) is the mass density and (u) is its flow velocity in the rest frame of the planet), while the thermal and magnetic pressures of the solar wind are small compared with its dynamic pressure (11). Assuming that the planetary magnetic field B_o is dominated by its dipole moment and the plasma pressure within the magnetosphere is small; one can estimate the size of magnetosphere by eq. 1 below, where, B_o is the surface equatorial field of the planet as in eq. 2, M_p represents the planetary magnetic moment and R_p the planetary radius (12).

$$R_{MP} = R_p \left[2B_o^2/ \mu_o \rho u^2\right]^{1/6} \quad \dots 1$$

$$B_o = M_p/R_p^3 \quad \dots 2$$

There are several variables on which magnetosphere depends but they are beyond our research, such as the kind of planet, the sources of creating momentum and plasma, the period of the planet's spin, the nature of the axis about which the planet spins, the axis of the magnetic dipole, and the magnitude and direction of the flow of solar wind (1). For comparison, Table 1 gives the size of the magnetosphere, R_{MP}, for Jupiter which is the largest gas (mainly content of hydrogen and helium) planet and Mercury which is the rocky smallest planet in the solar-system, it also shows the range of scale sizes in terms of its radius and absolute distance from the Sun (13,14).

Table 1. Properties of Mercury and Jupiter parameters (14).

Parameters	Mercury	Jupiter
Distance to the Sun (AU)	0.307	5.2
Solar wind density ρ (cm−3)	35-80	0.4
Radius R_p (km)	2439	71398
Surface magnetic field B_o (Gauss)	$3x10^{-3}$	4.28
Magnetosphere size R_{MP} (km)	1.4-1.6 R_M	42 R_J
Observed size of magnetosphere (km)	1.4 R_M $3.6x10^3$	50-100 R_J $7x10^6$
Planetary magnetic moment M_P (Tesla m^3)	$3x10^{12}$	$2x10^{19}$

Data Selection

In this research two planets are selected for this study, the criteria of selecting these two planets are that the Mercury is the smallest rocky terrestrial planet in the solar system, with weak magnetic field, while Jupiter is the largest gas planet (the biggest in the solar system) with strong magnetic field. The data for solar wind flow velocity (u) are taken from the GSFC/SPDF OMNI website interface (https://omniweb.gsfc.nasa.gov/form/dx1.html) and plasma density ($\boldsymbol{\rho}$) are calculated with respect to data of the Earth. The period for this study is chosen from 2016 to 2018 this period covers approximately twelve Mercury years and three Jupiter's months. The data of geomagnetic Kp index were obtained from the same site and for the same period.

Data Analysis

In this research, the hourly average of geomagnetic Kp index for all years (2016-2018) selected were plotted and illustrated in Fig. 1, which reveals that there are seven strong geomagnetic storms during five days represented in Table 2. For the sake of comparison, also five days from the same stormy months and from the same years are taken for quiet geomagnetic conditions which are represented in Table 3. The surface magnetic field for the two planets are calculated from eq. 2, then the radius of the Mercury and Jupiter magnetosphere is calculated by using eq. 1, Figs 2 and 3 show the hourly average of the magnetosphere radius (R_{MP}) for the two planets Mercury and Jupiter during the years 2016-2018 respectively. Figure 4 reveals the monthly average of Kp index and magnetosphere size for Mercury and Jupiter along the period 2016-2018, while more details are represented in Fig. 5 for the hourly variations of magnetosphere radius and geomagnetic Kp index for the two planets Mercury and Jupiter along the same period.

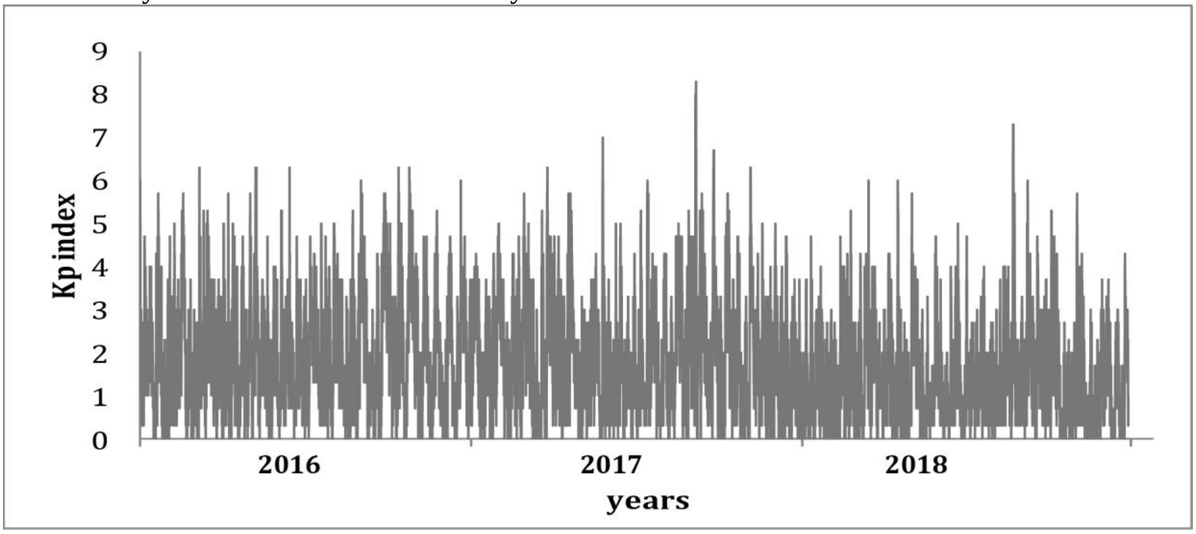

Figure 1. Hourly average Kp index for the years 2016-2018.

Table 2. Hourly values of Kp index for strong geomagnetic storms from years 2016-2018.

event no.	day	Month	year	Hour	Kp index values	storm type
1	1	1	2016	0-1	6, 6	Strong
2	10	10	2016	17	6.3	Strong
3	10	10	2016	23	5	Strong
4	28	5	2017	5-8	7, 6, 6, 6	Strong
5	7	9	2017	0-7	8, 8, 8, 4.7, 4.7, 4.7, 4.3, 4.3	Strong
6	7	9	2017	13-22	8.3, 8.3, 7.3, 7.3, 7.3, 6.3, 6.3, 6.3, 4.7, 4.7	Strong
7	26	8	2018	3-12	6.7, 6.7, 6.7, 7.3, 7.3, 7.3, 4.7, 4.7, 4.7, 4.7	Strong

Table 3. Hourly values of Kp index for quiet selected days from years 2016-2018.

event no.	day	month	year	hour	Kp index values	storm type
1	25	1	2016	0-1	0.3, 0.3	Quiet
2	16	10	2016	17	0	Quiet
3	16	10	2016	23	0.3	Quiet
4	31	5	2017	5-8	1.3, 0.3, 0.3, 0.3	Quiet
5	25	9	2017	0-7	0.3, 0.3, 0.3, 0.7, 0.7, 0.7, 1.3, 1.3	Quiet
6	25	9	2017	13-22	0.3, 0.3, 0, 0, 0, 0.3, 0.3, 0.3, 2, 2	Quiet
7	31	8	2018	3-12	0.7, 0.7, 0.7, 1, 1, 1, 0.3, 0.3, 0.3, 0.3	Quiet

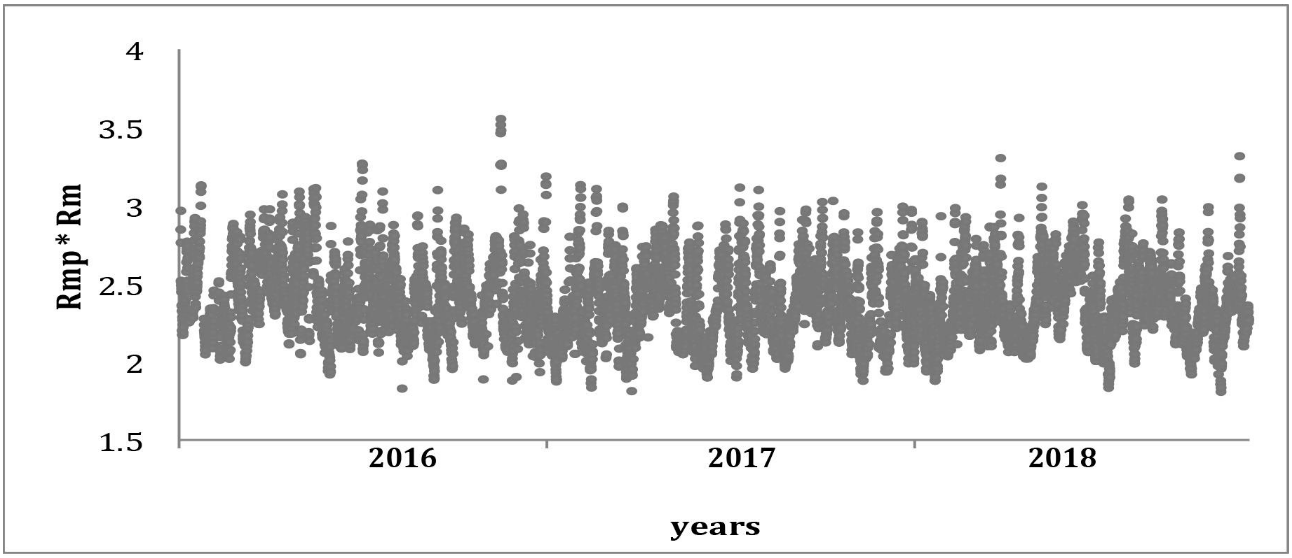

Figure 2. Hourly average Mercury planet magnetosphere size (R_{mp}) for years 2016- 2018.

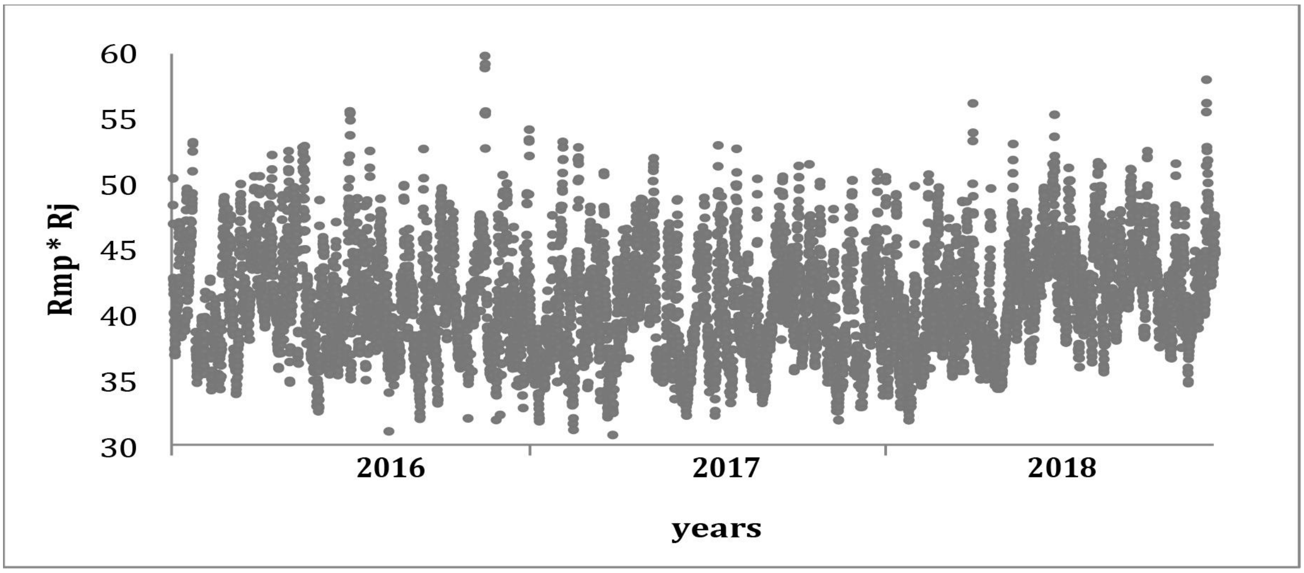

Figure 3. Hourly average Jupiter planet magnetosphere size (R_{mp}) for years 2016- 2018.

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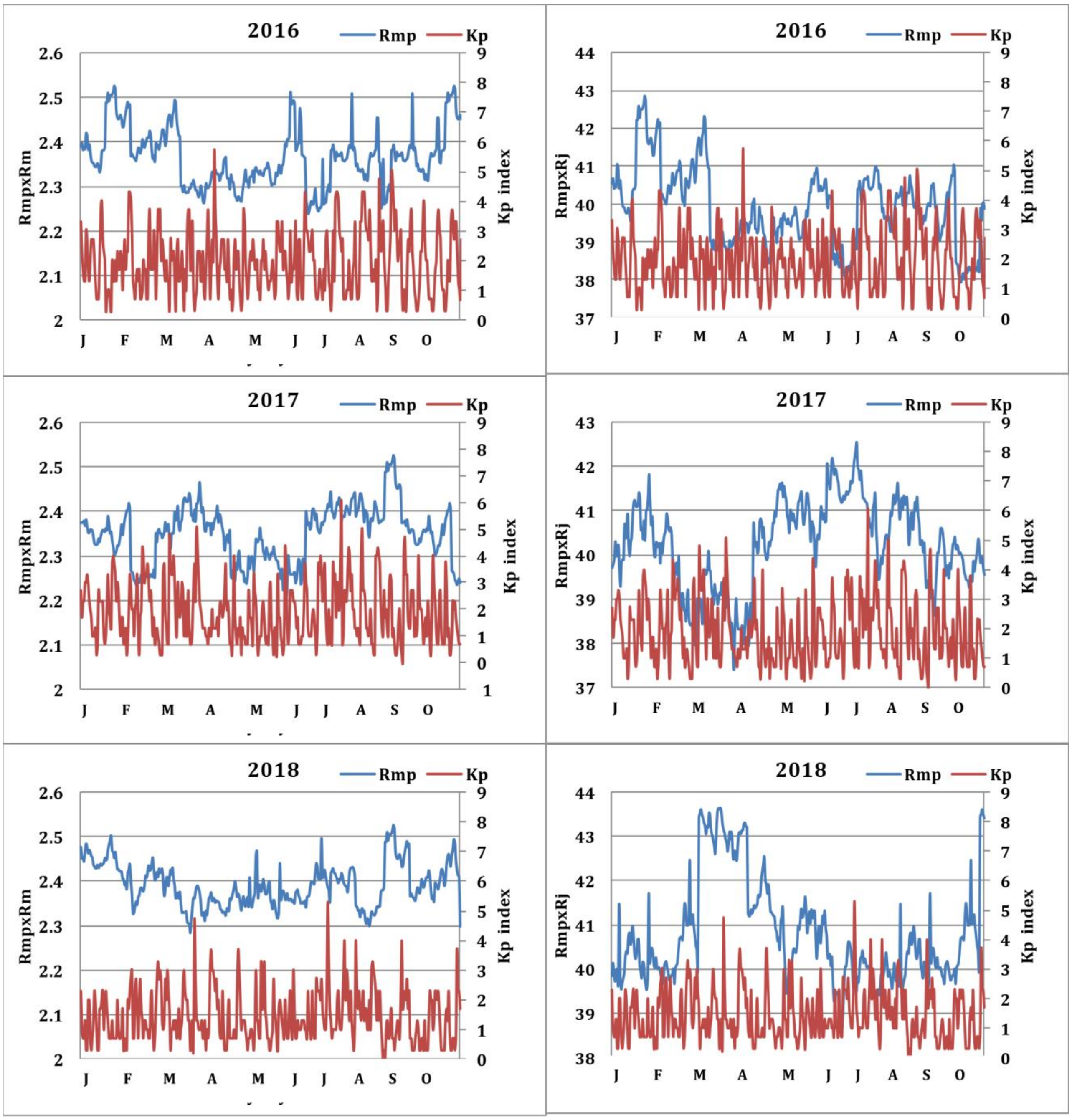

Figure 4. The monthly average of Kp index and magnetosphere size left for Mercury and right for Jupiter along the period 2016_2018.

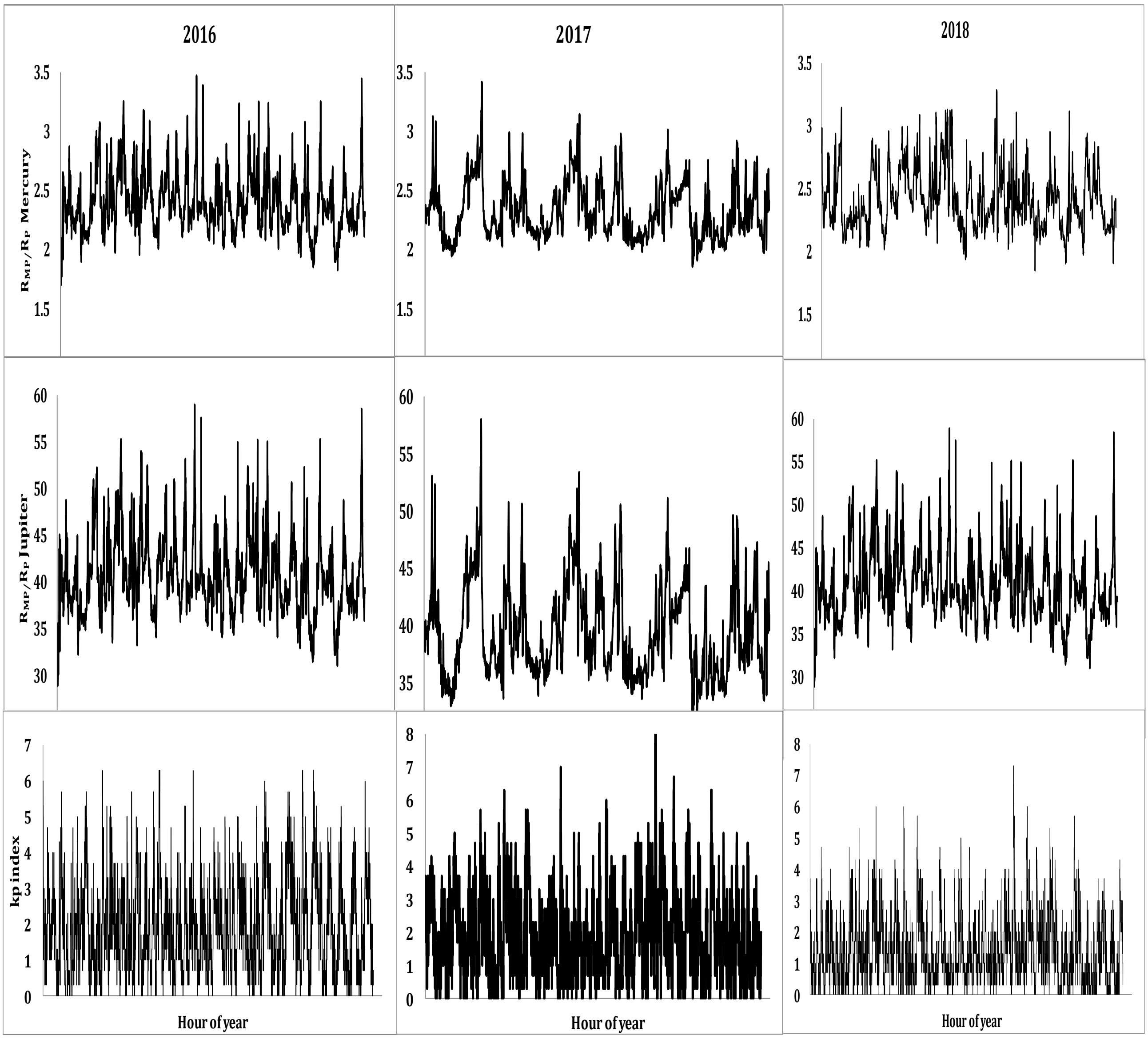

Figure 5. Kp index, Jupiter and Mercury magnetosphere radius for years 2016-2018

Results and Discussion:

From Fig. 1 Kp index values show that in the stormy days from years 2016 and 2018 are smaller than 2017 and the maximum value appeared in the 7th of September 2017. From the hourly average results values of the magnetosphere radius (R_{MP}) we can observe that there is a fluctuation in the behavior of the planetary magnetosphere size along the years chosen, for Mercury their values ranged from 2.2R_M to 2.6R_M (R_M is the Mercury radius) and for Jupiter the values from 30R_J to 60R_J (R_J is the Jupiter radius). From the statistical residual trend eq. 3 below the results are shown in Table 4

$$\bar{R} = \frac{\sum_{i=1}^{n}(S_i - Q_i)}{n} \quad \dots \quad 3$$

where, $\bar{R}$ is the average residual between values of magnetosphere radius during strong geomagnetic storms (S) and quiet (Q) geomagnetic condition, (n) is the total number of hours in which the storm occurred in the stormy day, and (i) refer to a specific value within a group.

Table 4. Residual trend magnetosphere radius between quiet and strong geomagnetic storms.

Event no.	strong	quiet	$\bar{R}$	
	Event date	Event date	Jupiter	Mercury
1	1/1/2016	25/1/2016	-4.0432	-0.4767
2	10/10/2016	16/10/2016	-0.4286	-0.5358
3	28/5/2017	31/5/2017	-2.5490	-0.1587
4	7/9/2017	25/9/2017	-8.1162	-0.4850
5	26/8/2018	31/8/2018	-7.7415	-0.4450

From Table 4, we can see that there is a reduction in the magnetosphere size during the strong geomagnetic storms with respect to the magnetosphere size during quiet geomagnetic conditions for the two selected planets Mercury and Jupiter. This is attributed to the strength of planets surface magnetic field, flow of plasma and the distance of the planet from the sun. The main objective of this research is to find out the relationship between different types of geomagnetic conditions by taking the strong geomagnetic storms ($Kp \geq 5$) from the same years (2016-2018) selected in this research and the magnetosphere size which are explained in Figs. 6 and 7 for the two planets Mercury and Jupiter respectively. Also, the same relations are taken for the quiet geomagnetic conditions ($Kp \leq 2$) which are shown in Figs. 8 and 9 for Mercury and Jupiter respectively. The curve fitting linear equations ($y=a_o+a_1x$) for these four figures gives the slope represented by ($a_1=\Delta R_{MP}/\Delta Kp$) which indicate that the Kp index has a significant impact on the Mercury and Jupiter magnetosphere size. Table 5 appears the coefficients of line equations; the minus sign appears inverse relation for strong geomagnetic storms and plus sign gives direct relation for quiet geomagnetic conditions. The conclusion of this result that the relation between storms type and magnetosphere size are independent on the strength of planetary surface magnetic field.

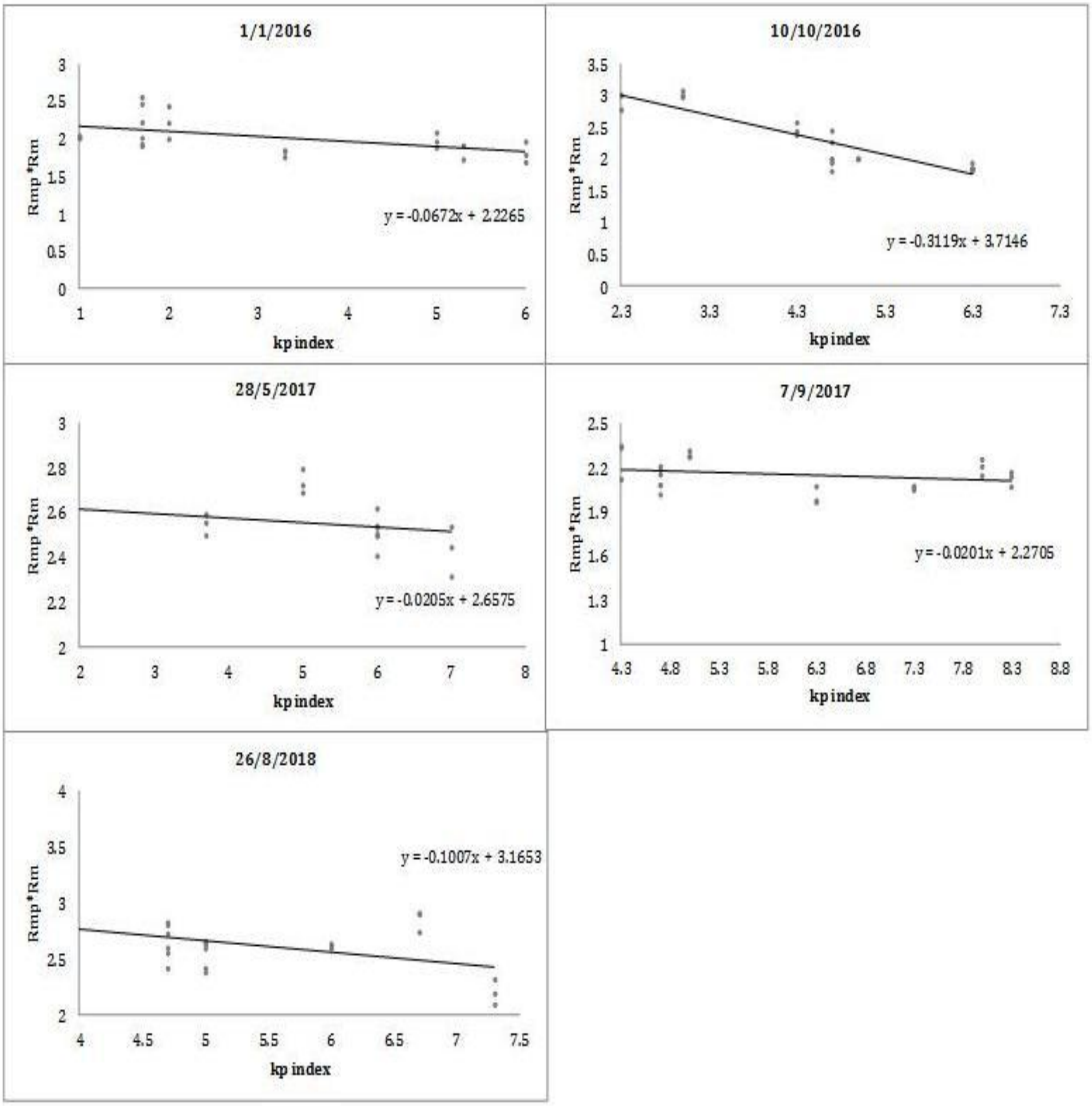

Figure 6. Kp index with the Mercury magnetosphere size during strong geomagnetic storms for the years 2016-2018.

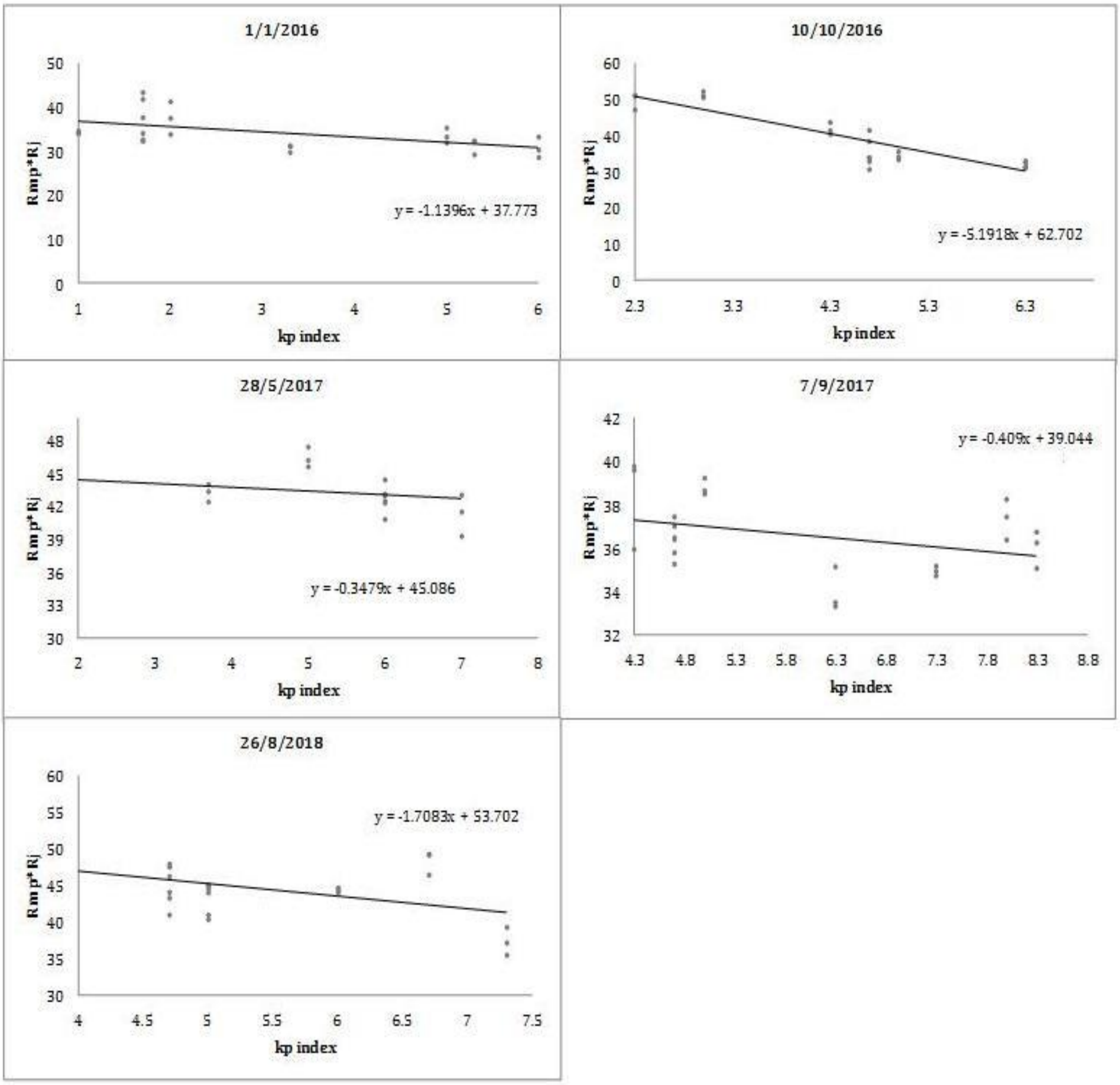

Figure 7. Kp index with the Jupiter magnetosphere size during strong geomagnetic storms for the years 2016-2018.

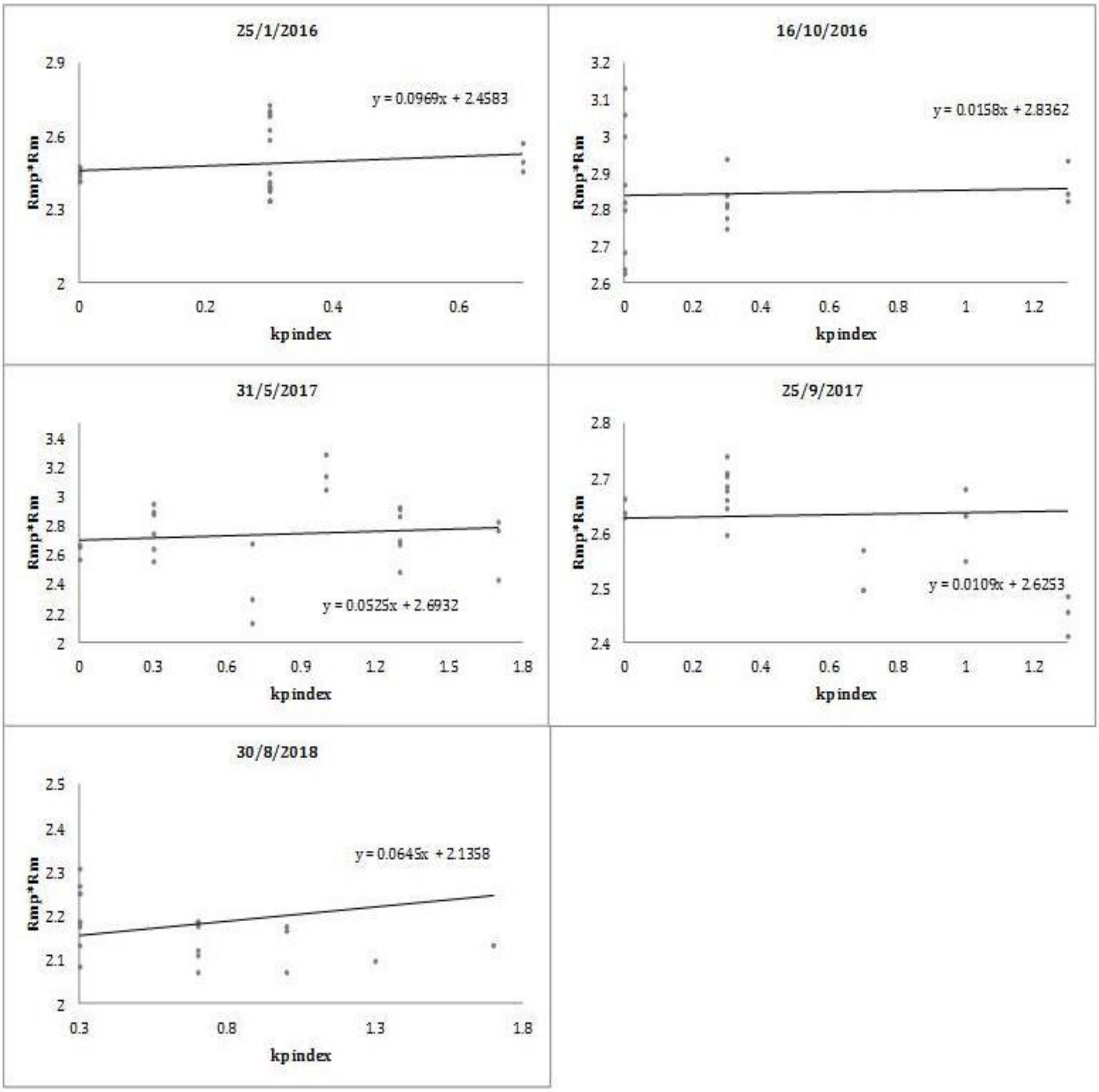

Figure 8. Kp index with the Mercury magnetosphere size during quiet geomagnetic for the years 2016-2018.

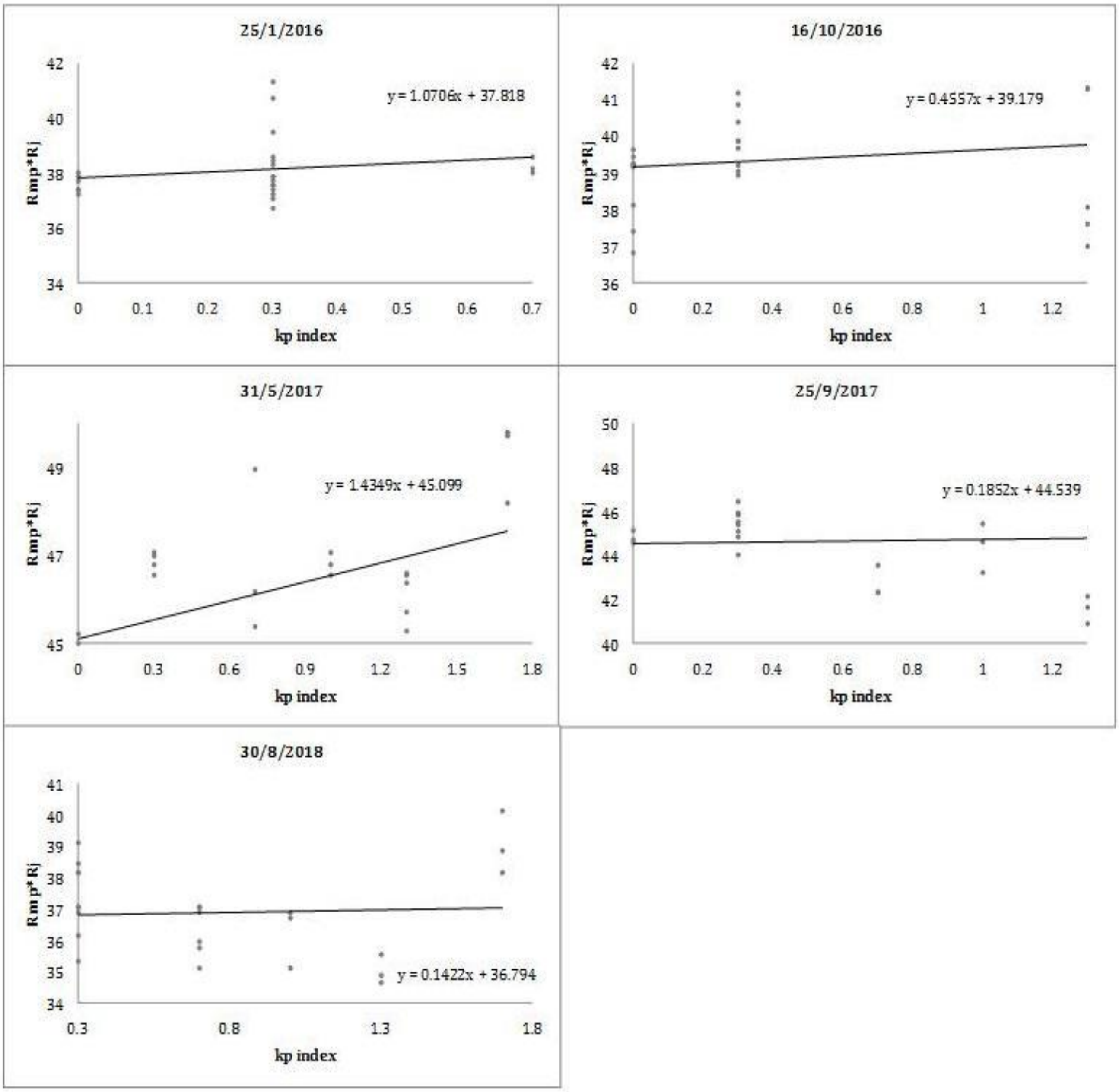

Figure 9. Kp index and the Jupiter magnetosphere size during quiet geomagnetic for the years 2016-2018.

Table 5. The coefficients of curve fitting linear equations during strong geomagnetic storms and quiet geomagnetic conditions selected from the period 2016-2018.

Storm type	Date	Mercury		Jupiter	
		a_0	a_1	a_0	a_1
Strong	1/1/2016	+2.2265	-0.0672	+37.773	-1.1396
	10/10/2016	+3.7146	-0.3119	+62.702	-5.1918
	28/5/2017	+2.6575	-0.0205	+45.086	-0.3479
	7/9/2017	+2.2705	-0.0201	+39.044	-0.409
	26/8/2018	+3.1653	-0.1007	+53.702	-0.409
Quiet	25/1/2016	+2.4583	+0.0969	+37.818	+1.0706
	16/10/2016	+2.8048	+0.2329	+39.179	+0.4557
	31/5/2017	+2.6932	+0.0525	+1.4349	+1.4349
	25/9/2017	+2.6253	+0.0109	+44.539	+0.1852
	31/8/2018	+2.1358	+0.0645	+36.794	+0.1422

Conclusion:

In this research two planets from our solar system, Mercury with weak magnetic field and Jupiter with strong magnetic field are selected to study the relationship between Kp index and magnetosphere size. We can conclude from the results that there are reversible relations between them during strong geomagnetic storms, while there are direct relations during quiet geomagnetic conditions. Also it is found that there is a reduction in the size of magnetosphere during the strong geomagnetic storms comparing to the magnetosphere size during geomagnetic quiet conditions for the two planets. Finally the relation between geomagnetic storm type and magnetosphere size is independent of the strength of planetary surface magnetic field and their distance from the Sun.

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Authors' declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University of Baghdad.

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المؤشر الجيومغناطيسي Kp وعلاقته بحجم الماكنيتوسفير لكوكبي عطارد والمشتري خلال نوعين من الحالة الجيومغناطيسية

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الخلاصة:

يرتبط المؤشر Kp بالعديد من خصائص الماكنيتوسفير، والذي يستخدم لقياس مستوى النشاط المغناطيسي. تم اختيار اثنين من أكثر الكواكب المختلفة في النظام الشمسي، عطارد بمجاله المغناطيسي الضعيف وكوكب المشتري بمجاله المغناطيسي القوي لهذه الدراسة لحساب نصف قطر الماكنيتوسفير للكوكب (R_{MP}) والذي يمثل حجم الماكنيتوسفير ومقارنته بالنشاط الشمسي من خلال المؤشر Kp ولنوعين من العواصف الجيومغناطيسية الهادئة والقوية وللفترة (2016-2018). من النتائج تبين ان هنالك علاقة عسكية بينهما خلال العواصف القوية، في حين ان هذه العلاقة تكون طردية في حالة النشاط الجيومغناطيسي الهادئ. وايضا لوحظ ان هنالك تقلص في حجم الماكنيتوسفير اثناء العواصف القوية مقارنة بالحالة الهادئة وللكوكبين المختارين عطارد والمشتري. يمكن ان نستنتج من هذه النتائج ان العلاقة بين نوع العاصفة وحجم الماكنيتوسفير لايعتمد على قوة المجال المغناطيسي للكوكب وبعده عن الشمس.

الكلمات المفتاحية: العواصف الجيومغناطيسية، المؤشر- Kp، المجال المغناطيسي، حجم الماكنيتوسفير.