АСТРОФИЗИКА

ТОМ 55 ФЕВРАЛЬ, 2012 ВЫПУСК 1

NORTH-SOUTH ASYMMETRY IN SOLAR, INTERPLANETARY AND GEOMAGNETIC INDICES

M.A.EL-BORIE[1], M.EL-ABSHEHY[1], S.TALAAT[2], W.M.ABOU TALEB[2]

Received 4 September 2011
Accepted 23 November 2011

Data of hourly interplanetary plasma (field magnitude, solar wind speed and ion density), solar (sunspot number, solar radio flux) and geomagnetic indices (Kp, Ap) over the period 1970-2010, have been used to examine the asymmetry between the solar field north and south of the heliospheric current sheet (HCS). A persistent yearly north-south asymmetry of the field magnitude is clear over the considered period, as well as there is no magnetic solar cycle dependence is evident. There is a weak N-S asymmetry in the averaged solar wind speed and exhibited well at times of maximum solar activities. The solar plasma is more dense north of the current sheet than south of it during the second negative solar polarity epoch ($qA < 0$). Moreover, the N - S asymmetry in solar activity (*Rz*) can be statistically highly significant. The sign of the average N - S asymmetry depends upon the solar magnetic polarity. The annual magnitudes of N - S asymmetry depend positively on the solar magnetic cycle. Most of the solar radio flux asymmetries occurred during the period of positive IMF polarity.

Key words: *solar north-south asymmetry:interplanetary magnetic field: geomagnetic activity indices:solar activity:solar wind speed*

1. *Introduction*. The unequal distribution of various interplanetary plasma and solar parameters between the north and south hemispheres of the Sun (north-south asymmetry) is well known for many years and has been studied by many authors (e.g., [1-10]). Most interplanetary plasma parameters are highly variable on time scales ranging from minutes to the solar activity cycle and vary with heliographic latitude and longitude [11,12]. The state of the interplanetary plasma permanently changes in conformity with cyclicity in the solar activity. Besides the 11-year variations in the velocity and scintillation index, there is also an increasing linear trend of these variables, which is presumably due to a secular 80-90-year cycle of solar activity. The observed differences between the 11-year variations and trends in the solar wind velocity and interplanetary scintillation index suggest that the 11-year and secular cycles have different origins [13]. It has been found that these trends occur in different periods in each link of the Sun-Earth system: in the solar activity indices, in the characteristics of the interplanetary medium and practically in all characteristics of the geophysical, demographical and other Earth's processes. From the entire set of facts, we can conclude that most of the analyzed Earth's processes are dominated not by anthropogenic factors, but by the effects of the

secular cyclic processes of the solar activity [14].

The solar magnetic field is frozen in the solar plasma and carried outward by the solar wind. When the Sun rotates, the field at equatorial latitudes forms a spiral structure. In addition, a neutral sheet results from this structure, maintaining a separation between northern and southern regimes. This averaged warped heliospheric current sheet (HCS) separates regions with opposite polarities of the magnetic field. The structure of the HCS changes substantially during the 11-year sunspot Cycle [15-20], with a relatively flat sheet at the solar minima years, but neutral sheet waves extend up to 70° heliolatitude at solar maxima epochs. Furthermore, the solar field polarity reverses at each solar maximum giving rise to a 22-year periodicity in the heliomagnetic field.

Recently, it has been found that the heliospheric magnetic field (HMF) sector that is prevalent in the northern solar hemisphere dominates the observed HMF sector occurrence for a few years in the late declining to minimum phase of the solar cycle. This leads to a persistent southward shift or coning of the heliospheric current sheet (HCS) at these times, which has been described by the concept of the bashful ballerina. This result was later verified by direct measurements of the solar magnetic field which showed that the average field intensity was smaller and the corresponding area larger in the northern (heliographic) hemisphere than in the southern hemisphere during roughly 3 years in the late declining to minimum phase of the cycle. During these years when the HCS was shifted southwards, the solar quadrupole moment was found to be systematically non-zero and oppositely oriented with respect to the dipole moment [21]. A dramatic reorientation of the HMF as the solar dipole rotates between axial and equatorial orientations; solar cycle variation of the total heliospheric magnetic flux and its response to changes in solar magnetic fields; the unusual on-going solar minimum and its effects; a connection between magnetic flux and solar wind mass flux in the heliosphere and at the source; a recurrent north-south heliospheric asymmetry at solar minimum and the equatorial offset of the solar magnetic dipole [22].

The interplanetary medium and the terrestrial magnetic field respond to most of solar parameters and their evolution. In addition, to the solar phenomena, the interplanetary plasma and magnetic field, cosmic rays and the terrestrial magnetic field were also found to respond to the solar N-S asymmetry. The N-S asymmetry was found in many parameters related to interplanetary medium [3,4,7,10]. Results of El-Borie [7] and El-Borie et al. [6] showed that the dependence of N-S asymmetry of field magnitude (B) upon the interplanetary solar polarities is statistically insignificant. There is no clear indication for the presence of N-S asymmetry over the solar cycles. In addition, the solar plasma was more dense and cooler south of the HCS than north of it, and the solar flux component of toward field vector is larger in magnitude than those of away field vector during the epoch of negative polarity (1981-1989), and no asymmetry observed during the epoch of positive polarity (1971-1979). Analysis of solar wind data observed during (1964-2004) by [10], showed that solar wind velocity V_{SW}, interplanetary magnetic field (IMF) B_Z component and geomagnetic activity index (*Ap*) exhibit a clear heliospheric N-S asymmetry. In general, the amplitudes of N-S asymmetry are maxima during the minimum phase of solar cycles. For V_{SW} and IMF B_Z component, the amplitude of the asymmetry is greater during even cycles 20 and 22 compared to the odd cycles 21 and 23. Wang et al. [23] showed that the plasma sheet becomes colder and denser, indicating a larger increase in the cold than in the hot population, with increasing N_{SW} or $|B_{zIMF}|$ or with decreasing V_{SW}.

The spectrum of large-scale fluctuations in the solar wind ion density has revealed the existence peaks with the solar rotation period (27 days) and broad peak near 1.3 years and the observed variations in ion density appeared to reflect the true variations in the solar wind speed [e.g., 24,25]. The existence of the periodic 1.3-year enhancements in SWS from 1987 to 1995 have been reported [26,27]. In addition, similar periodicities in *Ap* (a measure of geomagnetic disturbances) have been observed. Yearly averaged variations in interplanetary plasma (SWS, *N* and *T*), and magnetic-field magnitude (*B*) over more than two solar cycles were studied in detail [8,24,25]. Some clear periodicities were evident and some of the observations showed solar cycle dependence. The solar wind speed clearly showed an increase at solar maximum and the annual mean of ion density reached its minimum values near years of maximum solar activity. The ion density was not correlated with the other plasma parameters during the three solar cycles (from 20th to 22nd). During the declining phase of solar activity cycles, large values of SWS, plasma *T* and IMF magnitude *B* were observed, with low values of *N*. Results by El-Borie and Al-Thoyaib [8] showed that the solar plasma north of the current sheet is hotter, faster, and less dense than south of it during the epoch of negative polarity (1981-1987) and an asymmetry in the averaged magnetic field is absent in solar cycle 21. From the analysis of 110 years of sunspot number, it was found that, in general, northern hemisphere activity peaks about two years after sunspot minimum and this peak is greater during even cycles, suggesting a 22 year periodicity in N-S asymmetry of solar activity [7,8,10]. The work of Temmer et al. [9] displayed that for all cycles studied, N-S asymmetries are found for the declining and increasing phases, as well as times of maxima. T' asymmetry based on the absolute asymmetry index is enhanced near the cycle maximum. On the other hand, study of the periodic behavior of the normalized N-S asymmetry time series of solar activity parameters agree about the presence of two significant periodicities, one having a very long period and the another around 11 years [28].

In the present work, we examine the N-S asymmetries in the interplanetary parameters (field magnitude *B*, ion density *N* and solar wind speed SWS). Then we compared the observed results with the asymmetries in the solar indices (sunspot number R_Z and solar radio flux SRF) and geomagnetic indices (*Kp*, *Ap*). The last section discusses and summarizes our conclusions.

2. ***The north-south asymmetry of field magnitude and plasma parameters***. It may be useful to compare the north-south asymmetry in the interplanetary plasma and solar parameters with the observed variations. Detailed discussion of the yearly mean variations of magnetic field and plasma are given elsewhere [5,6,8 and 26,27,29]. In this section, we have used the hourly averages of IMF magnitude *B* and plasma parameters (solar wind speed SWS and ion density *N*), taken near 1 AU by a variety of spacecraft, which were provided by the National Space Science Data Center, over the time interval 1970-2010. These parameters have been analyzed according to the IMF sense to examine the presence of the north-south asymmetry. A day is considered in our analysis only if it has at least 12 hourly averages of IMF magnitude and 12 or more hourly averages of either plasma parameters available for that day. The field direction is calculated on a daily basis in the geocentric equatorial coordinated system. Thus, we have separated the field direction into two polarities; away (*A*) polarity if the solar ecliptic azimuthal angle of the IMF daily averages lies between 45° and 225°; otherwise it is considered toward (*T*) the Sun. We have removed days on which the IMF is truly mixed. This may effect the accuracy of the final result and could be the reason for sudden change in the value of N-S asymmetry during the period. We have then separated the considered data into two groups according to away or toward daily average IMF vector, over the 1970-2010 period.

Fig.1 displays from the top the yearly difference variations of field magnitude *B*, solar wind speed SWS and ion density *N*, between the positive and negative polarity days (Toward-Away days). Curves indicate the centered 3-year running averages over the period 1970-2010. Estimated error is shown for each year, for each parameter. Times of the magnetic-field reversal at the Sun's north (*N*) and south (*S*) poles are added at the top of the figure. A persistent yearly north-south asymmetry of the field magnitude is clear over the considered period.

From the top panel, [*B*(*T*) - *B*(*A*)], there are seven obvious negative N-S asymmetries in the averaged magnetic field occurring in 1970, 1980, 1983, 1999, 2000, 2004 and 2005. In addition, there are eleven positive asymmetries occurred in 1972, 1976, 1979, 1987, 1990, 1993, 2002, 2003, 2007, 2009 and 2010. Note that toward sectors occur north of the current sheet during negative solar polarity and south of the current sheet during positive polarity. In general, the average behavior of field magnitude differences (see the curve) is large (positive peak) north of the current sheet during the first positive polarity period

(1972-1979), while we find a negative peak in the first negative polarity period (1980-1985). The N-S asymmetry in magnetic field displayed a tendency to be positive prior to the solar magnetic dipole reversal that occurred in 1970/2010 and negative following the next reversal in 1980/2000.

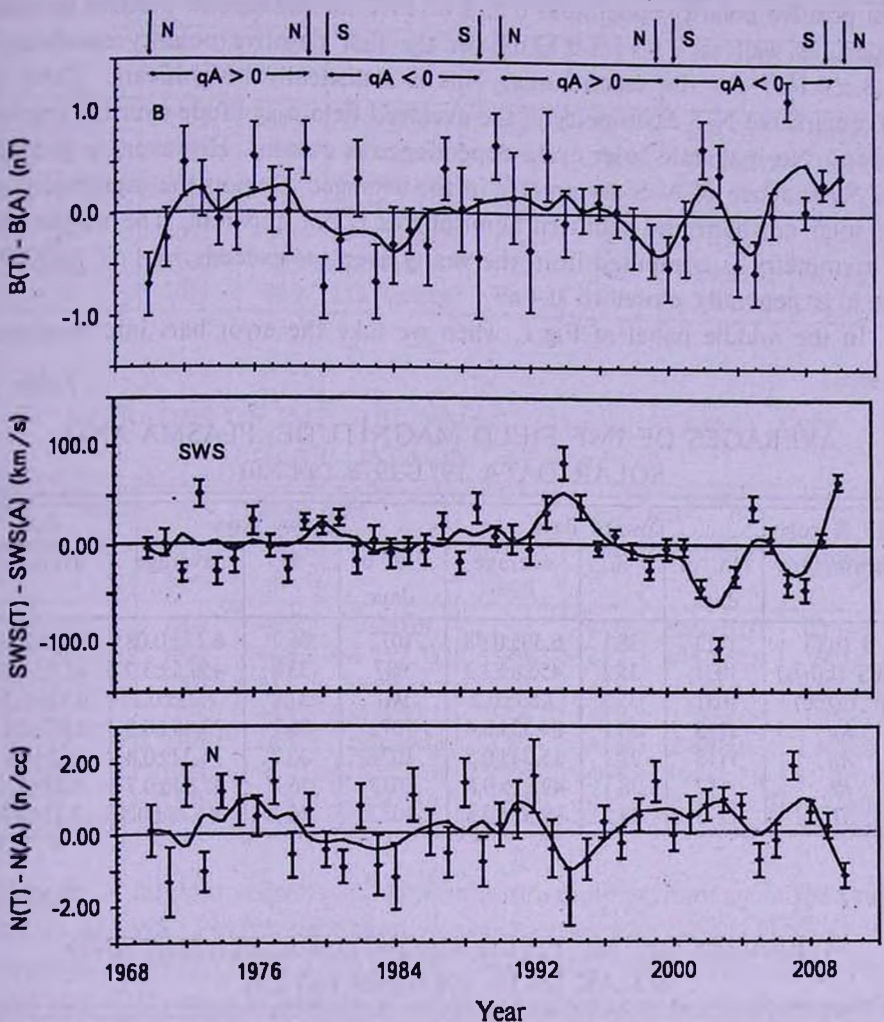

Fig.1. (Top) the differences between the yearly averages of field magnitude north *B*(*T*) and south *B*(*A*) of the current sheet. Middle panel displays the solar wind speed difference SWS (*T*) - SWS (*A*), over the 41-year period. Bottom, the differences between the values of the solar wind ion density north *N* (*T*) and south *N* (*A*) of the current sheet. Curves represent the centered 3-year moving averages of the magnitude difference. Arrows above the top plot show when the Sun's north (N) and south (S) pole magnetic reversals.

Tables 1, 2, 3 and 4 display the averages of field magnitude, plasma and solar parameters for toward and away polarity days, as well as the differences between the two groups over the epochs of positive (1971-1978) and (1991-

1998) and negative (1981-1988) and (2001-2008) IMF polarity years, respectively. The total number and the percentage of days north and south of the current sheet as calculated from each parameter are listed, in the Tables. The grand average differences of field magnitude north and south of HCS are 0.13 ± 0.11 nT for the first positive polarity epoch and 0.05 ± 0.13 nT for the second positive polarity epoch, as well as -0.11 ± 0.12 nT for the first negative polarity epoch and 0.13 ± 0.1 nT for the second one. This is statistically insignificant. There is no remarkable N-S asymmetry in the averaged field magnitude over the former epochs. No magnetic solar cycle dependence is evident. However, in general the dependence of N-S asymmetry in the averaged B upon the asymmetry of the solar northern and southern hemispheres is not apparent. The magnitude of asymmetry as computed from the yearly averages exceeds ~1.1 nT in 2007, but it is generally closer to 0.4 nT.

In the middle panel of Fig.1, when we take the error bars into account,

Table 1

AVERAGES OF IMF FIELD MAGNITUDE, PLASMA AND SOLAR DATA 1971-1978 ($qA > 0$)

IMF & solar parameters	Toward days			Away days			T-A
	No. of days	%	average	No. of days	%	average	average
B (nT)	1113	38.1	6.30±0.08	1072	36.7	6.17±0.08	0.13±0.11
SWS (km/s)	1031	35.3	456.8±3.2	987	33.8	459.5±3.2	-2.7±4.5
N (n/cc)	1031	35.3	7.55±0.2	987	33.8	7.22±0.2	0.33±0.2
Kp	1113	38.1	24.33±0.4	1072	36.7	23.66±0.3	0.67±0.5
Ap	1113	38.1	15.34±0.5	1072	36.7	14.22±0.4	1.13±0.6
Rz	1112	38.1	42.27±0.8	1073	36.7	47.64±0.7	-5.38±1.1
SF	1113	38.1	98.57±0.5	1072	36.7	101.78±0.5	-3.21±0.7

Table 2

AVERAGES OF IMF FIELD MAGNITUDE, PLASMA AND SOLAR DATA 1981-1988 ($qA < 0$)

IMF & solar parameters	Toward days			Away days			T-A
	No. of days	%	average	No. of days	%	average	average
B (nT)	974	33.35	7.0±0.08	944	32.33	7.18±0.1	-0.11±0.12
SWS (km/s)	928	31.78	458.9±3.4	905	30.99	459.9±3.5	-1±4.9
N (n/cc)	928	31.78	7.98±0.17	905	30.99	8±0.18	-0.02±0.247
Kp	974	33.35	25.43±0.34	944	32.33	25.4±0.36	0.028±0.49
Ap	974	33.35	15.58±0.44	944	32.33	15.91±0.5	-0.033±0.66
Rz	974	33.35	67.97±1.12	944	32.33	64.35±1.04	-1.38±1.53
SF	974	33.35	122.37±0.8	944	32.33	120.97±0.8	1.398±1.129

Table 3

AVERAGES OF IMF FIELD MAGNITUDE, PLASMA AND SOLAR DATA 1991-1998 ($qA > 0$)

IMF & solar parameters	Toward days			Away days			T-A
	No. of days	%	average	No. of days	%	average	average
B (nT)	1019	34.9	6.69±0.09	1060	36.3	6.64±0.1	0.05±0.13
SWS (km/s)	1019	34.9	453.5±3.4	1060	36.3	434.2±3.1	19.3±4.6
N (n/cc)	1019	34.9	8.206±0.18	1060	36.3	8.201±0.17	0.005±0.25
Kp	1019	34.9	23.774±0.36	1060	36.3	22.6±0.36	1.18±0.5
Ap	1019	34.9	14.625±0.43	1060	36.3	13.9±0.51	0.63±0.67
Rz	1019	34.9	54.84±0.94	1060	36.3	54.9±0.92	-0.11±1.32
SF	1019	34.9	113.16±0.86	1060	36.3	113.05±0.81	0.11±1.18

Table 4

AVERAGES OF IMF FIELD MAGNITUDE, PLASMA AND SOLAR DATA 2001-2008 ($qA < 0$)

IMF & solar parameters	Toward days			Away days			T-A
	No. of days	%	average	No. of days	%	average	average
B (nT)	1308	44.8	6.07±0.07	1308	44.8	5.94±0.07	0.13±0.1
SWS (km/s)	1308	44.8	445.7±2.75	1308	44.8	473.9±2.8	-28.2±3.9
N (n/cc)	1308	44.8	5.9±0.11	1308	44.8	5.33±0.1	0.57±0.14
Kp	1308	44.8	19.528±0.3	1308	44.8	21.287±0.3	-1.76±0.42
Ap	1308	44.8	11.351±0.38	1308	44.8	12.896±0.4	-1.545±0.55
Rz	1308	44.8	47.85±0.63	1308	44.8	46.08±0.6	1.77±0.87
SF	1308	44.8	114.286±0.63	1308	44.8	112.599±0.55	1.687±0.83

there are 24 random years out of 41 with north-south asymmetry in the yearly average of SWS. Twelve clear positive asymmetries with SWS (T) > SWS (A) happened in 1973, 1976, 1979, 1980, 1981, 1987, 1989, 1993, 1994, 1995, 2005 and 2010, most of which occurred during or near the positive polarity period. In contrast, twelve clear negative N-S asymmetries occurred in 1972, 1974, 1975, 1978, 1982, 1988, 1999, 2002, 2003, 2004, 2007 and 2008. The largest positive N-S asymmetry occurred in 1994 (83.9 ± 17.3 km/s), in contrast with the largest negative one obtained in 2003 (-106.1 ± 11.4 km/s). One can see that, during the periods when the northern sunspots predominate over the southern sunspots (1975-1980 and 2002-2007), N-S asymmetry in the SWS was observed. In contrast, during periods of the Sun's southern hemisphere were more active than the Sun's northern hemisphere (1982-1986 and 1996-2001) the N-S symmetry was observed.

From Tables 1, 2, 3 and 4, we find that the SWS (*T*) for toward days south of the current sheet is larger in magnitude than those for away polarities north of the current sheet SWS (*A*) during the second positive polarity epoch (1991-1998), while the north-south asymmetry is absent during the first positive polarity epoch (1971-1978). Furthermore, we find that the N-S asymmetry is observed during the second negative polarity epoch (2001-2008), while N-S asymmetry is absent during the first negative epoch. This confirms the existence of a weak N-S asymmetry in the averaged SWS and exhibited well at times of maximum solar activities. The moving average curve shows prominent asymmetries near or following the maxima solar activities. The computed toward-away sector SWS asymmetry has a tendency to be positive at, or slightly near, the times of IMF polarity reversals, except in 2000.

Furthermore, the SWS are faster by about 19.3 km/s for toward polarity days (see Table 3) than for away polarity days when the IMF points away from the Sun north of the current sheet and toward the Sun south of it, during the second positive polarity epoch. In contrast, the SWS are faster by about 28.2 km/s for away polarity days (see Table 4) than for toward polarity days when the IMF points away from the Sun south of the current sheet and toward the Sun north of it during the second negative polarity. The present results confirmed earlier results [6,8], that the observed asymmetry in the solar wind speeds was not the source of the observed asymmetry in the IMF winding angles at 1 AU [30]. We should to note that the amplitude of the SWS asymmetry increases during the declining phase of the solar cycles. This means that the asymmetry of the solar speed distribution is such high speed region during the declining phase of a solar cycle. On the basis of these activity features, significant N-S asymmetries were revealed. This may result from the systemically larger extension of polar coronal holes from the Sun's magnetic south pole toward the equator or from different latitudinal distribution of magnetic fields in the two solar magnetic hemispheres [31].

Fig.1 (bottom panel) shows the yearly differences between the ion density north and south of the current sheet. Yearly averages of plasma ion density (for toward and away IMF days) systematically increase from a low value in 1971 to a maximum value in 2007. The average N-S asymmetry of the plasma proton density is absent during the first, second positive polarity epochs, and for the first negative polarity epoch (see Tables 1, 2, 3). The average ion plasma density for toward polarity days north of the HCS during the 2001-2008 epoch is 0.57 ± 0.14 n/cc more dense than those of away polarity days south of HCS. Thus, the solar plasma is more dense north of the current sheet than south of it during the second negative solar polarity epoch ($qA < 0$). Nine out of 41 years show negative asymmetry with the average *N* of the northern heliospheric densities smaller than the average of the southern heliospheric densities which occurred in years (1971, 1973, 1981, 1984, 1989, 1994, 1995, 2005 and 2010). The largest negative asymmetry occurred in 1994 (-1.76 ± 0.81 n/cc). Seventeen positive asymmetries happened in (1972, 1974, 1975, 1977, 1979, 1982, 1985, 1988, 1992, 1998, 1999, 2001, 2002, 2003, 2004, 2007 and 2008). The largest positive asymmetry occurred in 2007 (1.92 ± 0.39 n/cc). Most of the asymmetries occurred during the period of negative polarity epochs. Large asymmetries in *B*, *N* and SWS have been observed in 2007. Moreover, significant changes in the N-S asymmetries have been correlated with the N-S asymmetries of the solar activity in the northern and southern hemispheres.

3. ***The north-south asymmetry of solar indices.*** In this section, we have examined the asymmetry that exists between the very large- scale properties of toward and away sectors of solar parameters. The asymmetry between the northern and southern hemispheres sunspot activity is well known to solar observers and is one of the features used in the morphological description of the solar activity. The northern and southern active periods are generally quite different when long-term activity is considered. Throughout the period of solar cycles 12-21 (1878-1988), the N-S asymmetry of the sunspot numbers with respect to the solar equatorial plane has been studied [2]. This asymmetry revealed an 11-year periodicity with the phase of the maximum in earlier half or in the later half, occurring alternatively in each four solar interval, thus exhibited an 88-year variation. On the other hand, the relationship between solar and geomagnetic activity has been investigated [21,25]. The results clearly indicated that the geomagnetic activity represented by the *Kp* index revealed two maxima for each single maximum in solar activity as represented by sunspot numbers and indicated also that the geomagnetic activity had two discrete components attributed to solar flare effects and corotating streams. Studies by Rangarajan [32] revealed that the Sun's northern hemisphere is, almost always, geomagnetically more active, on average about 20%, than the southern hemisphere. This enhanced activity may be attributed to the inverse relationship between the geomagnetic activity and the strength of the magnetic field. Results by Temmer et al., [9] showed that the asymmetry based on the absolute asymmetry index is enhanced near the cycle maximum, which contradicts to previous results that are based on the normalized asymmetry index, δ, which is based at the time of low solar activity. Moreover, the weak magnetic interdependence between the two solar hemispheres is confirmed by their self-contained evolution during a cycle. The asymmetry of *Ap* index has a northern dominance during cycles 20 and 23 and southern dominance during cycles 21 and 22 and this asymmetry may be due to the existence of a relic magnetic field in the solar convection zone.

Fig.2 displays the yearly differences in *Rz* and SRF between toward and away polarity days for the 41-year interval 1970-2010. The notations are the same as in Fig.1. The solid curve is the 3-year moving averages. The solar radio flux (10.7 cm) adjusted to 1 AU and measured at 1700 UT daily and expressed in units of 10-22 Watts/m^2/Hz. We have separated the daily averaged data into two groups corresponding to away and toward IMF polarities. The yearly averages of these parameters have been calculated for away and toward groups, separately. Only hours when both magnetic field and solar indices were available were used throughout this analysis. Error estimates in the averages are calculated for each group. In top panel, only 27 of 41 years have asymmetry with magnitude more than the estimated error (the years 1981, 1985, 1987, 1988, 1992, 1993, 2002, 2003, 2005 and 2010 have positive asymmetry). The

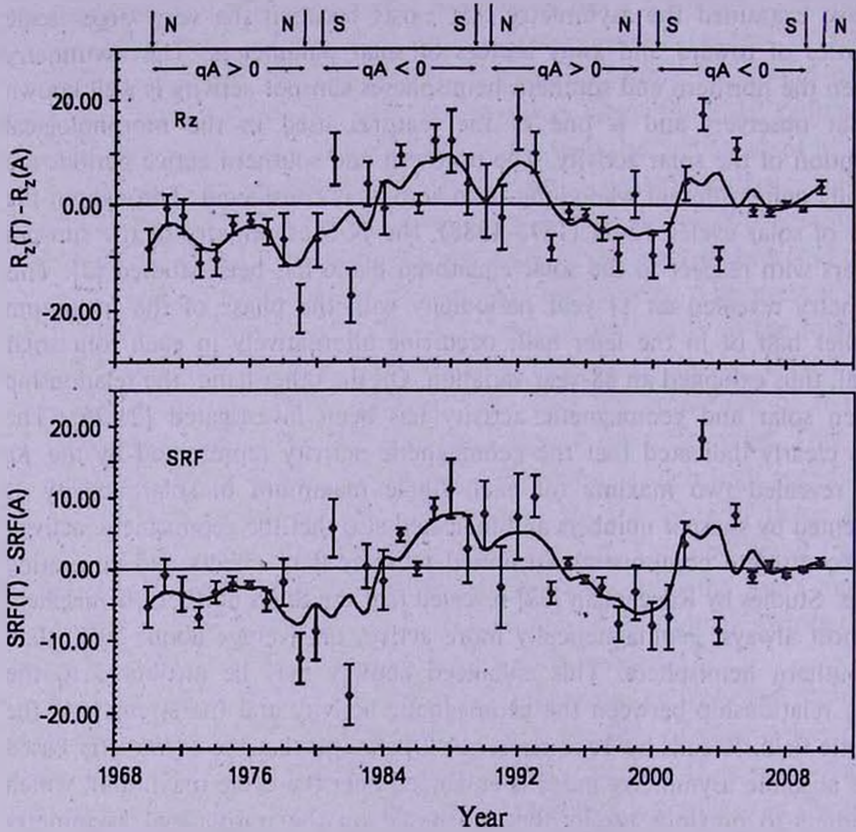

Fig.2. Comparison of yearly difference of the north-south asymmetries in the sunspot numbers Rz, solar radio flux SRF during the 1970-2010 period. Times of Sun's north (N) and south (S) pole reversal magnetic polarities are displayed by arrows in the top panel.

largest positive asymmetry occurred in 2003 (17.44 ± 3.13) and years 1970, 1973, 1974, 1975, 1976, 1977, 1978,1979, 1980, 1982, 1994, 1996, 1997, 1998, 2000, 2001 and 2004 have negative asymmetry). The largest negative asymmetry occurred in 1979 (-19.48 ± 4.8). Most of the asymmetries occurred when the solar southern hemisphere has toward polarity during the negative polarity epoch (1981-1988 and 2000-2009). Five asymmetries occurred in years of IMF mixed polarities (1979, 1980, 2000, 2001 and 2010) and three years (1974, 1994 and 2003) of high-speed solar wind streams. It is interesting to note that the sign of the average N-S asymmetry depends upon the solar magnetic polarity. It is generally positive in negative solar magnetic polarity years (see the curve) and negative in positive polarity years. The toward-away difference in the Rz has a positive peak from 1981-1989 in the first negative solar polarity epoch, and again positive peak near the year of magnetic reversal 1990 to 1993 through the years of the positive polarity, and negative peak during the first positive polarity epoch (from 1971- 1974 and 1975-1979). During years of negative solar polarities (1981-1988 and 2001-2009) toward sector measurements correspond to southern hemispheric fields and away sector measurements corresponds to southern hemispheric field. During the years of positive solar polarities the association is reversed. The N-S asymmetry during the first positive polarity epoch was observed, see Table 1 (-5.38 ± 1.1). We find that $R_Z(A)$ for away days north of the current sheet is larger in magnitude than those for toward days $R_Z(T)$ south of the current sheet during (1971-1978), while the N-S asymmetry is absent during the other epochs, see Tables 2, 3 and 4. Therefore, there is no observable difference between the sunspot numbers of grand averages. In contrast, the annual magnitudes of N-S asymmetry depend positively on the solar magnetic cycle.

The asymmetry of the solar radio flux during 1970-2010 is displayed in the bottom panel of Fig.2. The two curves of R_Z and SRF have nearly the same behavior. Individually, the north-south asymmetry in SRF is confirmed over our considered period. It displays that 10 years (1981, 1983, 1987, 1988, 1990, 1992, 1993, 2002, 2005 and 2010) out of 41 with larger *SF* component north of the current sheet, as well as 18 years (1970, 1972, 1973, 1974, 1975, 1976, 1977, 1979, 1980, 1982, 1994, 1996, 1997, 1998, 2000, 2001, 2004 and 2008) with larger component south of the current sheet. Five of these 28 years (1975, 1976, 1996, 2008 and 2010) have insignificant differences. The largest positive asymmetry occurred in 2003 (18.22 ± 2.66) and the largest negative asymmetry occurred in 1982 (-17.55 ± 4.19). Most of the asymmetries occurred during the period of positive IMF polarity. Again, we should note that the toward (away) sectors occur north (south) of the current sheet during the negative solar polarity epoch and the IMF directions reverse during the positive polarity period. The grand average of the solar flux is -3.21 ± 0.7 for the 1st positive polarity period, 1.398 ± 1.129 for the 2nd one and 0.11 ± 1.18 for the 1st negative period, 1.687 ± 0.83 for the 2nd one, see Tables (1, 2, 3, 4).

Fig.3 displays the yearly differences in the geomagnetic indices (*Kp* and *Ap*) between toward and away polarity days for the 41-year interval 1970-2010. The notations are the same as in Fig.1. The solid curve is the 3-year moving averages. The yearly averages of these parameters have been calculated for away and toward groups. In top panel, during the former period we see that out of 41 years there are 18 years with differences more than estimated errors (ΔKp is more than 1σ during the years 1973, 1976, 1979, 1987, 1990, 1993, 1994, 1995, 2005 and 2010 with positive asymmetry and years 1975, 1978, 1985, 1999, 2002, 2003, 2004 and 2008 with negative asymmetry. Four of these 18 years (1979, 1990, 1999 and 2010) occurred during the years of polarity reversals of IMF. There are a large positive peak during the 2nd positive polarity epoch (1992-1996) and a large negative peak during the 2nd negative polarity epoch (2001-2005). The largest negative asymmetry occurred in 2003 (-5.27 ± 1.21) and two nearly equal positive asymmetries in 1976 and 1994 (~6.07 ± 1.63). The average north-south asymmetry of *Kp* index is absent during the 1st positive and negative polarity periods (see Tables 1, 2). The average N-S asymmetry is observed during 2nd positive and negative polarity periods (see Tables 3, 4). We should note that, the asymmetry of *Kp* index appears similar to that of SWS. The asymmetry of SWS and geomagnetic activity may be due to the existence of a relic solar magnetic field in the solar convention zone.

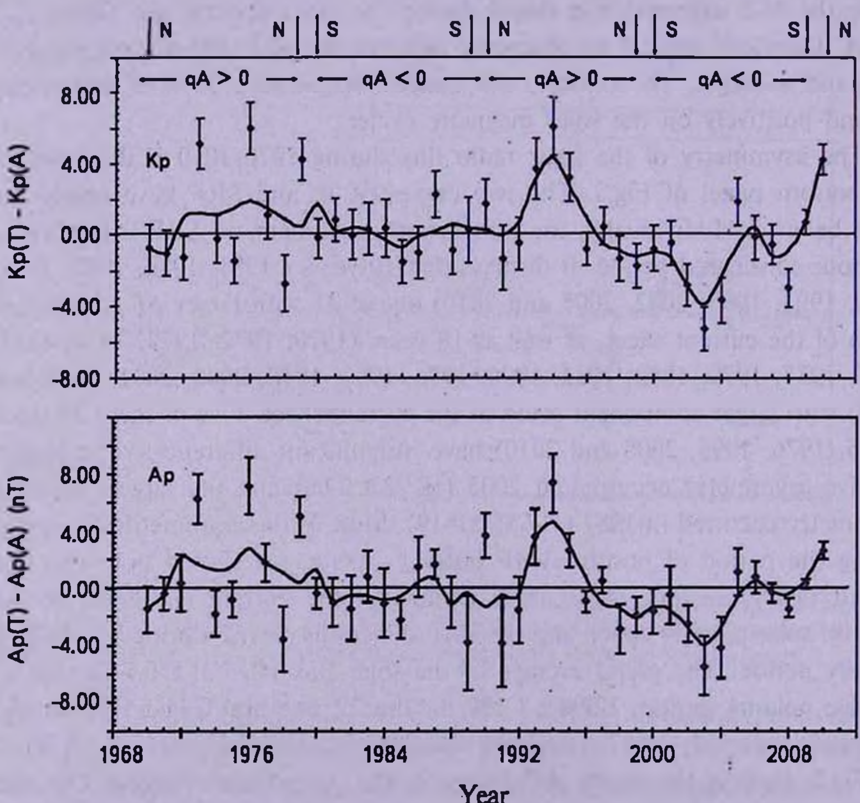

Fig.3. Comparison of yearly difference of the north-south asymmetries in the geomagnetic indices (*Kp*, *Ap*) during the 1970-2010 period. Times of Sun's north (N) and south (S) pole reversal magnetic polarities are displayed by arrows in the top panel.

The asymmetry of *Ap* index during 1970-2010 is displayed in the bottom panel of Fig.3. The two curves of *Kp* and *Ap* have the same behavior. The N-S asymmetry in *Ap* index is confirmed over the former period. We get 10 of 41 years which have positive asymmetries (1973, 1976, 1977, 1979, 1987, 1990, 1993, 1994, 1995 and 2010) and years (1974, 1978, 1985, 1989, 1991, 1996, 1998, 1999, 2002, 2003, 2004 and 2008). The average north-south asymmetry of *Ap* index is absent during the 1st negative polarity periods and the 2nd positive polarity period (see Tables 2, 3). The average N-S asymmetry is observed during 1st positive and 2nd negative polarity periods (see Tables 1, 4). Finally, we think that the north-south asymmetry of the Sun's activity, together with the north-south asymmetry observed in the geomagnetic index *Kp*, may provide multiple causes for producing the observed asymmetric modulations of cosmic rays [6,7]. Mulltiple factors may give rise to north-south asymmetric modulations. The observed cosmic-ray modulations were related to a corresponding N-S asymmetry of solar activity as indicated by the sunspot numbers. Other [21,24] suggested that the geomagnetic activity is high during the passage of the interaction regions from both corotating and flare-associated streams because both the negative southward component of the interplanetary magnetic field and the fluctuations of the magnetic field are high in the interaction regions. The *Kp* index values were high in the trailing part of the corotating streams due to the presence of large fluctuations of magnetic field there. The maximum speed values of corotating streams accumulated around small values of geomagnetic index and the high speed values of flare generated streams were extended around greater values of *Kp* [33]. So, any increase or decrease of such geomagnetic activity is related to the rotation with the Sun of alternate sources and in turn, it appears to be related with the active region (geomagnetically) on the Sun (northern or southern hemispheres).

4. ***Discussion and Conclusions***. The well-known north-south asymmetry of the solar activity was observed and studied extensively in the past from a variety of solar activity indices. The solar indices vary on various time scales, namely 27 days, few months, year-to-year (quasi-biennial oscillations), 11 years and probably 80 years and higher. One of the most important properties of solar activity is that it is often asymmetric between the northern and southern solar hemispheres. A solar activity cycle is not symmetric when considering the distribution of activity features separately in the northern and southern solar hemisphere.

This work has analyzed solar and magnetic-field data over 40 years, to examine the large scale structure of the IMF parameters, as well as the asymmetry exists between field north and south of the current sheet. By separating the hourly average values of IMF data according to the field polarity sense (away or toward), we have calculated the daily averages of field magnitude

B, plasma parameters (speed and ion density), solar indices (sunspot *Rz*, solar radio flux SRF), and geomagnetic indices (*Ap* and *Kp*). Only days with more than 12 hours of data were used in this study, except the solar indices data since the daily values were available.

A persistent yearly north-south asymmetry of the field magnitude is clear over the considered period. We displayed that, there is no remarkable N-S asymmetry in the averaged field magnitude over the considered epochs, as well as no magnetic solar cycle dependence is evident. On the other hand, there is a weak N-S asymmetry in the averaged SWS and exhibited well at times of maximum solar activities. The moving average curve shows prominent asymmetries near or following the maxima solar activities. The computed toward-away sector SWS asymmetry has a tendency to be positive at, or slightly near, the times of IMF polarity reversals, except in 2000.

The solar plasma is more dense north of the current sheet than south of it during the second negative solar polarity epoch ($qA < 0$). Most of the asymmetries occurred during the period of negative polarity epochs. Large asymmetries in *B*, *N* and SWS have been observed in 2007. Moreover, significant changes in the N-S asymmetries have been correlated with the N-S asymmetries of the solar activity in the northern and southern hemispheres.

It has been shown that a N-S asymmetric in solar activity (*Rz*) can be statistically highly significant. The sign of the average N-S asymmetry depends upon the solar magnetic polarity. It is generally positive in negative solar magnetic polarity years (see the curve) and negative in positive polarity years. The annual magnitudes of N-S asymmetry depend positively on the solar magnetic cycle. Most of the SRF asymmetries occurred during the period of positive IMF polarity.

Finally, we think that the north-south asymmetry of the Sun's activity, together with the north-south asymmetry observed in the geomagnetic index *Kp*, may provide multiple causes for producing the observed asymmetric modulations of cosmic rays, due to that the multiple factors may give rise to north-south asymmetric modulations.

Acknowledgement. We are deeply grateful to Prof. A.A.Bishara for helpful and valuable discussion.

[1] Physics Dept., Faculty of Science, Alexandria University, Egypt, e-mail: elborie@yahoo.com
[2] Phys. and Chem. Dept., Faculty of Education, Alexandria Uni., Egypt

АСИММЕТРИЯ СОЛНЕЧНЫХ, МЕЖПЛАНЕТНЫХ И ГЕОМАГНИТНЫХ ИНДЕКСОВ В НАПРАВЛЕНИИ СЕВЕР-ЮГ

М.А.ЕЛЬ-БОРИ[1], М.ЕЛЬ-АБШЕЙНИ[1], С.ТАЛААТ[2], Я.М.АБУ ТАЛЕБ[2]

Для исследования асимметрии солнечного магнитного поля в направлении север-юг относительно токового слоя использовались почасовые данные о межпланетной плазме (величина поля, скорость солнечного ветра и концентрация ионов), о солнце (количество пятен, поток радиоизлучения) и о геомагнитных индексах (*Kp*, *Ap*) в течение периода времени 1970-2011гг. В течение указанного времени была выявлена ясная годичная по продолжи-тельности асимметрия магнитного поля в направлении север-юг, а также отсутствие заметной зависимости от солнечного магнитного цикла. У осредненной скорости солнечного ветра асимметрия слабая, но она хорошо проявляется во время максимума солнечной активности. Во второй эпохе отрицательной полярности ($qA < 0$) плотность солнечной плазмы севернее токового слоя была выше, чем к югу от него. Более того, оказалось, что средняя асимметрия N-S у солнечной активности (*Rz*) может быть весьма значительной. Знак данной асимметрии зависит от полярности солнечного магнитного поля. В своем большинстве асимметрия в радиопотоке имеет место в период положительной IMF-полярности.

Ключевые слова: *солнечная N-S асимметрия:межпланетное магнитное поле: индексы геомагнитной активности:солнечная активность:скорость солнечного ветра*

REFERENCES

1. *D.B.Swinson*, *H.Koyama*, *T.Saito*, Sol. Phys., 106, 35, 1986.
2. *T.Murayama*, *T.Nosaka*, Planet. Space Sci., 39, 751, 1991.
3. *C.W.Smith*, *J.W.Beiber*, J. Geophys. Res., 98, 9401, 1993.
4. *I.S.Sabbah*, Ann. Geophys., 279, 1994.
5. *M.A.EL-Borie*, *I.S.Sabbah*, *A.A.Bishara*, Astron. Nachr., 317, 267, 1996.
6. *M.A.El-Borie*, *A.A.Darwish*, *A.A.Bishara*, Solar Phys., 167, 395, 1996.
7. *M.A.EL-Borie*, IL Nuovo Cimento, 24C, 843, 2001.
8. *M.A.El-Borie*, *S.S.Al-Thoyaib*, Il Nuovo Cimento, 25C, 353, 2002.
9. *M.Temmer*, *J.Rybak*, *P.Bendip et al.*, Astrophys. J., 735, 2006.
10. *V.Sanaikumaran*, *S.R.Prabhakaran*, Indian J. Rad. & Space Phys., 37, 391, 2008.

11. *P.R.Gazis*, J. Geophys., 98, 9391, 1993.
12. *P.R.Gazis, A.Barnes, J.D.Mihalov, A.J.Lazarus*, J. Geophys. Res., 99, 6561, 1994.
13. *M.A.El-Borie, M.L.Duldig, J.E.Humble*, Plant. Space Sci., 46, 439, 1998.
14. *V.I.Vlasov*, Geomagnetism and Aeronomy, 51, 30, 2011.
15. *J.T.Hoeksema, J.M.Wilcox, P.H.Scherrer*, J. Geophys. Res., 87, 10331, 1982.
16. *J.T.Hoeksema, J.M.Wilcox, P.H.Scherrer*, J. Geophys. Res., 88, 9910, 1983.
17. *J.T.Hoeksema*, Adv. Space Res., 9, 141, 1989.
18. *M.A.El-Borie*, Astroparticle Phy., 10, 165, 1999.
19. *M.A.El-Borie*, Astroparticle Phy., 16, 169, 2001.
20. *M.A.El-Borie*, Astroparticle Phy., 16, 181, 2001.
21. *K.Mursula*, Adv. Space Res., 40, 1034, 2007.
22. *E.J.Smith*, J. Atmo. & Solar Terr. Phys., 73, 277, 2011.
23. *C.W.Wang, L.Lyons, T.S.Gunobunagi, J.M.Weygand, R.W.Mcentire*, J. Geophys. Res., 112, 12, 2007.
24. *M.A.El-Borie, N.A.Aly, A.El-Taher*, J. Adv. Res., 2, 137, 2011.
25. *M.A.El-Borie, A.A.Darwish*, Il Nuovo Cimento, 29C, 539, 2006.
26. *J.D.Richardson, K.I.Paularena, J.W.Belcher, A.J.Lazarus*, Geophys. Res. Lett, 21, 1559, 1994.
27. *P.R.Gazis, J.D.Richardson, K.I.Paularena*, Geophys. Res. Lett., 22, 1165, 1995.
28. *J.L.Ballester, R.Olive, M.Carbonell*, Astron. Astrophys., 431, L5-L8, 2005.
29. *K.I.Paularena, A.Szabo, J.D.Richardson*, Geophys. Res. Lett., 22, 3001, 1995.
30. *C.W.Smith, J.W.Beiber*, J. Geophys. Res., 98, 9401, 1993.
31. *R.P.Kane*, Ind. J. Rad. & Space Sci., 35, 312, 2006.
32. *G.K.Rangarajan*, J. Geomag. Geoelectr, 43, 613, 1991.
33. *R.P.Kane*, J. Atmo. & Solar Terr. Phys., 67, 429, 2005.