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SOLAR CYCLE BY A LOOK OF HIGH SPEED SOLAR WIND STREAMS VARIATION

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Abstract

In this paper are presented variation of the solar wind parameters during last four solar cycles (21÷24) with focus on the high speed solar wind streams (HSS) condition. The averaged values of the parameters for every cycle are calculated and discussed. The results show that Earth is under the HSS influence more than 50% of the total time in each of the last four solar cycles. This fact determines the importance of the studding the behavior of the HSS.

Introduction

High speed solar wind streams (HSS) are one of the solar wind components which originate from unipolar open magnetic field areas known as coronal holes [1, 2]. HSS cause relatively weak, but recurrent and long-lasting geomagnetic storms [3]. The variations of geomagnetic activity closely follow the variations of the number and intensity of HSS within the solar cycle [4]. Coronal holes are the largest and in most geoeffective position during the sunspot declining phase [4], when the second maximum in the geomagnetic activity is observed. In Fig. 1 is presented an SDO/AIA image (Solar Dynamics Observatory/ Atmospheric Imaging Assembly) of the coronal hole CH869 on 15 June 2018. CH869 have been rotated into an Earth facing position on June 19–21.

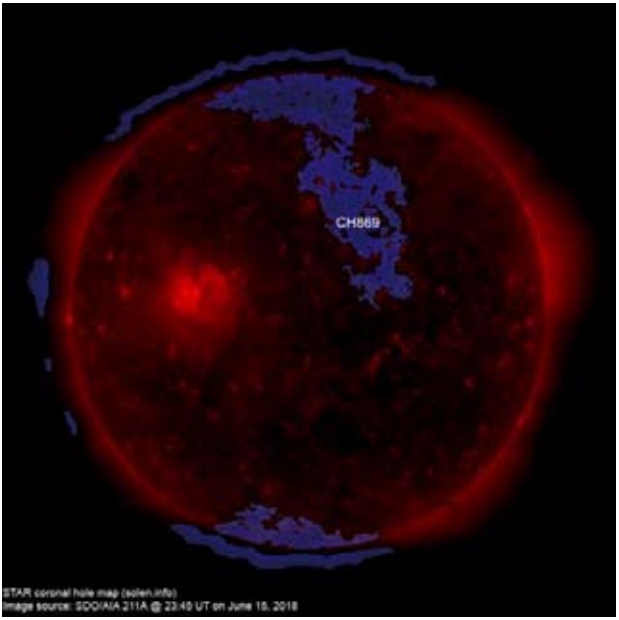

Fig. 1. SDO/AIA image of the coronal hole CH869 at 23:45UT on 15 June 2018 (http://www.solen.info/solar/)

Solar cycle (SC) is generally associated with the 11 year sunspot cycle (Schwabe, 1843) and numerous studies concerning Sun and solar-terrestrial physics are related with it. In Table 1 are presented duration of the last eight SC (17÷24). The 24th is supposed to end within 2018 with duration approximately of ~11 years.

Table 1. Duration of the last eight Solar cycles (17÷24)

Cycle	Started	Finished	Duration (years)
Solar cycle 17	1933 September	1944 February	10.4
Solar cycle 18	1944 February	1954 April	10.2
Solar cycle 19	1954 April	1964 October	10.5
Solar cycle 20	**1964 October**	**1976 June**	**11.7**
Solar cycle 21	**1976 June**	**1986 September**	**10.3**
Solar cycle 22	**1986 September**	**1996 May**	**9.7**
Solar cycle 23	**1996 May**	**2008 January**	**11.7**
Solar cycle 24	**2008 January**	**2018**	**~ 11**

In the current study, the focus will be on the HSS during the last four SC (21÷24). Here the differences of the main parameters (Temperature [K], Speed [km/s], Density [cm-3], Magnetic field [nT]) during the cycles will be discussed. In Fig. 2 are shown the variations of the sunspot number for these cycles. As it can be seen, the last 24^{th} SC is characterized with the lowest values of the sunspot number during the course of the whole cycle in comparison with the other cycles.

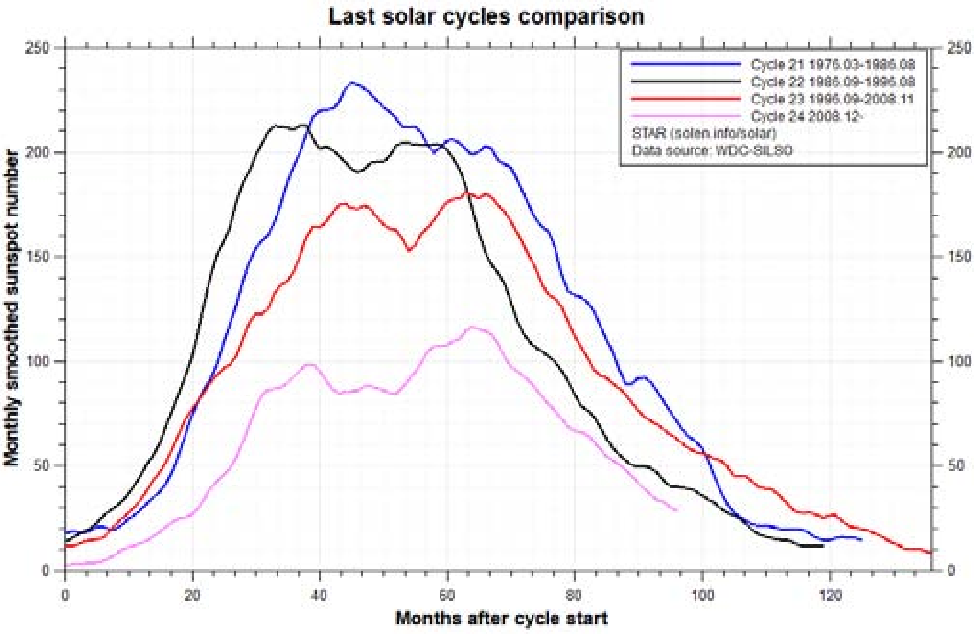

Fig. 2. Comparison of the monthly smoothed sunspot number variation for the last four SC (21-24) (http://www.solen.info/solar/)

Parker suggested that the properties of solar wind flow depend on the solar activity cycle [7]. Several years later series of space probe experiments, as Lunik and Venera [8], Explorer 10 [9] and Venus Mariner 2 [10] confirmed the Parker's theory.

Data

In attempt to identify the periods when Earth is under the influence of the HSS the hourly values of the plasma parameters gathered in OMNI data base are used (http://omniweb.gsfc.nasa.gov/) [11]. The criteria for identifying a HSS include an increase of the solar wind speed by at least 100 km/s in no more than one day to at least 450 km/s for at least five hours [12].

Results

In Tables 2–5 are shown the averaged values of the main solar wind parameters (Different magnetic field components [nT], Temperature of the plasma [K], Density [N/c], Speed [km/s], Flow pressure [nPa]) for the last four SC for different solar wind conditions – Slow solar wind with speed less than 450 km/s, fast solar wind with speed over 450 km/s but different from HSS, coronal mass ejection (CME) and HSS. For every SC are presented the total numbers of hours in which Earth is under the influence of these conditions. The last three rows have shown the averaged values of the geomagnetic *Dst* index and the sunspot number *R*.

Table 2. Averaged values of the main solar wind properties during SC21

	Slow SW $V \leq 450$ km/s	**Fast SW $V > 450$ km/s**	**CME**	**HSS**
Hours	6 120	900	143	7 878
Scalar B, nT	5.41	5.45	11.13	5.85
Bx, nT	–0.22	–0.02	0.30	–0.36
By, nT	0.37	-0.05	–0.45	0.34
Bz, nT	0.12	0.12	–0.56	0.22
T, K	64 495	184 070	69 757	178 230
Dens, N/c	10.78	5.20	8.67	5.60
Speed, km/s	370.45	520.92	394.45	512.18
Pressure, nPa	2.75	2.65	2.54	2.66
R	15.73	21.57	28.44	13.49
Dst, nT	–5.70	–14.03	–27.41	–17.79

At SC21 the number of hours in which HSS is observed is 7 878 which is more than 50 % of the total time of the cycle. Here we can see that the average temperature during HSS is significantly larger than the temperature of the slow solar wind and comparable with the temperature of the fast solar wind. Here it must be noticed what is the difference between fast solar wind and HSS. According to the criteria of HSS there is a requirement concerning duration which is at least five hours. Normally the averaged sunspot number is the largest during the condition of CME.

Table 3. Averaged values of the main solar wind properties during SC22

	Slow SW V ≤ 450 km/s	**Fast SW V > 450 km/s**	**CME**	**HSS**
Hours	3 289	271	105	7 161
Scalar B, nT	5.50	6.73	9.45	5.90
Bx, nT	–0.43	–0.09	–1.52	0.15
By, nT	0.04	–0.51	–0.68	0.03
Bz, nT	0.24	–0.39	–0.61	0.00
T, K	54 590	148 250	73 523	146 090
Dens, N/c	11.83	7.45	7.08	6.14
Speed, km/s	367.02	486.46	422.70	507.98
Press,	2.96	3.41	2.36	2.78
R	18.46	16.99	20.87	16.81
Dst, nT	–4.41	–16.79	-	–19.98

Similarly to SC21, with its 7 161 hours the next SC22 is characterized with more than 50 % of the total time of the cycle in which to the Earth reach HSS. During this time the average density and flow pressure have the lowest values in comparison to the values when it is observed slow and fast solar wind as well as CME.

Table 4. Averaged values of the main solar wind properties during SC23

	Slow SW V ≤ 450 km/s	**Fast SW V > 450 km/s**	**CME**	**HSS**
Hours	7 283	342	132	9 811
Scalar B, nT	3.86	4.58	8.42	4.68
Bx, nT	0.46	–1.61	0.46	–0.19
By, nT	–0.57	1.13	–0.41	0.08
Bz, nT	0.05	0.08	1.13	0.02
T, K	42 251	124 360	61 981	132 840
Dens, N/c	7.02	3.88	5.54	4.06
Speed, km/s	347.06	519.55	399.77	517.74
Press,	1.46	2.03	1.57	1.87
R	5.16	10.32	8.98	4.97
Dst, nT	–1.98	–13.32	–6.25	–12.42

During SC23, time of HSS (9 811 hours) is more than 75 % the total time. This fact determines condition of relatively high temperature, low density and pressure. During the period when Earth is under the slow solar wind the average temperature of the plasma reach its lowest value of 42 251 K.

The general picture has been slightly changed for the last SC24. While the relative duration of the HSS for the cycle remains more than 50 % of the total time, the most of the parameters differ from the previous cycle. Here can be noticed that the average speed drop under 500 km/s for HSS while the temperature increase more than 200 000 K.

Table 5. Averaged values of the main solar wind properties during SC24

	Slow SW **V ≤ 450 km/s**	**Fast SW** **V > 450 km/s**	**CME**	**HSS**
Hours	7 981	655	128	8 690
Scalar B, nT	5.01	5.12	12.68	5.55
Bx, nT	0.10	–1.12	–0.76	0.27
By, nT	–0.02	0.97	0.12	–0.09
Bz, nT	–0.13	–0.21	–0.58	–0.11
T, K	90 625	262 550	80 164	205 240
Dens, N/c	10.33	4.47	8.34	6.97
Speed, km/s	362.73	511.37	402.60	463.32
Press,	2.39	2.19	2.51	2.53
R	10.29	7.85	12.87	11.07
Dst, nT	–6.34	–25.42	–29.84	–17.76

Conclusion

This work presents a study for variation of the solar wind parameters for the different state, as slow and fast solar wind, coronal mass ejection and high solar wind speed. The averaged parameters are calculated and discussed for the last four solar cycles (21÷24). The result can be summarized in the following statements:

- The time in which Earth is under the HSS influence is more than 50 % of the total time in each of the last four solar cycles.
- At SC23 the HSS influence is more than 75 % of the total time.
- Slow solar wind temperature during SC23 reach its lowest value of 42 251 K.
- The averaged parameters of the fast solar wind and HSS have similar values.
- During the last SC24 the averaged HSS speed drops under 500 km/s while HSS temperature increases more than 200 000 K.

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СЛЪНЧЕВИЯ ЦИКЪЛ ОТ ГЛЕДНА ТОЧКА НА ВАРИАЦИИТЕ НА ВИСОКОСКОРОСТНИТЕ ПОТОЦИ СЛЪНЧЕВ ВЯТЪР

С. Асеновски

Резюме

В работата са представени вариациите на параметрите на слънчевия вятър за последните четири слънчеви цикъла (21÷24) с подчертано внимание на условията на високоскоростен слънчев вятър. Средните стойности на параметрите за всеки цикъл са пресметнати и дискутирани. Резултатите показват, че Земята е под въздействието на високоскоростен слънчев вятър повече от 50 % за всеки от последните четири слънчеви цикъла. Този факт обуславя важността от изследване на поведението на тези потоци.