Large-scale solar wind structures: occurrence rate and geoeffectiveness

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Abstract. Large-scale phenomena in the solar wind are important elements of heliospheric physics and space weather. On the basis of the OMNI database of interplanetary measurements we identified large-scale structures of solar wind (SW types) for all time intervals during 1976-2000. Our classification includes quasi–steady types: (1) Heliospheric current sheet (HCS), (2) Slow and (3) Fast SW streams, respectively, from closed and open magnetic field structures in the solar corona, and disturbed types: (4) Corotating interaction regions (CIR – compressed regions between slow and fast SW streams), (5) SHEATH (compressed regions ahead of MC/EJECTA) and (6) Magnetic cloud (MC) and (7) EJECTA as well as (8) direct and (9) reverse interplanetary shocks (see catalog on site `ftp://ftp.iki.rssi.ru/pub/omni/` and paper [1]). We discuss several preliminary results obtained with our catalog (see more details in `http://www.iki.rssi.ru./people/yyermol_inf.html`) including effects on the Space Weather.

Keywords: Large-scalr solar wind phenomena, CME, CIR, solar cycle, occurrence rate, geoeffectiveness
PACS: 96.50.Uv, 96.50.Qx, 94.30.Lr

INTRODUCTION

Investigation of large-scale (with characteristic time scale more than 1 hour) types of streams in the solar wind allows one to study, on the one hand, the large-scale phenomena on the Sun and their variations in the solar cycle and, on the other hand, to study a role of large-scale streams in a transfer of energy from the Sun to the Earth and excitation of geomagnetic disturbances [2, 3, 4]. We identified large-scale structures of solar wind (SW types) for every 1-hour point of measurements during 1976-2000 (see paper [1] and site `ftp://ftp.iki.rssi.ru/pub/omni/`). The results of our identification are in good agreement with previous results on selection of individual SW types during shorter time intervals (see, for example, papers [6, 5] and references therein). In comparison with the previous studies our catalog has following advantages: (1) Simultaneous inclusion in the catalog of various large-scale SW types at sufficiently long intervals of time comparable to the solar cycle, (2) Inclusion of the improved set of SW types, in particular, selection of ICMEs on EJECTA and MCs and, accordingly, SHEATH before EJECTA and before MCs. By means of this catalog the estimations of magnetic flux which is carried away by CMEs from the Sun [7] and efficiency of geomagnetic storm generation by various interplanetary drivers [8, 9, 10] have been obtained. In this paper we present several results on occurrence rate and geoeffectiveness of SW types obtained on the basis of our catalog of large scale solar wind phenomena (see paper [11] for details).

METHOD OF DATA PROCESSING

When the types of solar wind streams were classified, we used OMNI database (see `http://omniweb.gsfc.nasa.gov` [12]) for interval 1976-2000 and available world experience in identification of solar wind streams and the standard criteria for following parameters: velocity V, density N, proton temperature T, ratio of thermal to magnetic pressure (β-parameter), ratio of measured temperature to temperature calculated on basis of average "velocity–temperature" relation T/T_{exp}, thermal pressure and magnetic field. This method allows us to identify reliably 3 types of quasi-stationary streams of the solar wind (heliospheric current sheet, fast streams from the coronal holes, and slow streams from the coronal streamers), and 5 disturbed types (compression regions in front of incoming fast streams (CIR), and interplanetary manifestations of coronal mass ejections (ICME) that can include magnetic clouds (MC) and EJECTA with the compression region SHEATH preceding them). In contract with EJECTA, MCs have lower temperature, lower ratio of thermal to magnetic pressure (β-parameter) and higher, smooth and rotating magnetic field [13]. In addition, we have included into our catalog such events (rare enough) as direct and reverse shock waves, and the rarefaction region RARE.

When we calculated yearly averaged values, we have taken into consideration that the OMNI database contains gaps of the data from 0 to 50% time of year. This procedure has been made in the assumption that rate of occurrence of the given SW type is similar both in intervals of data presence and in intervals of data gap. If during chosen year the number of events of selected SW type N_e has been registered in interval of data presence t_d the normalized number of the given SW type in this year was defined by multiplication of occurrence rate of the given SW type N_e/t_d to total duration of year t_y. Error of this estimation decreases with increasing N_e and t_d, and has been estimated as ${N_e}^{-1/2}(t_y - t_d)/t_d$. When we analyzed durations of different SW types, we selected intervals of SW types which have not data gaps at both edges of the intervals.

RESULTS

Average values and their standard deviations of several plasma and magnetic field parameters (1st rows) and their statistics (2nd rows) for 8 SW types are presented in Table 1 (see paper [1] for details). Both types of compressed regions (CIR and SHEATH) have very close values of parameters while the parameters for 2 types of ICME (EJECTA and MC) are different. Density, thermal and kinetic pressures are significantly higher (but β-parameter is lower) in MC than in EJECTA.

Normalized numbers per year, average durations, temporal parts in total times of observations and geoeffectiveness (ratio of number of given SW type leading to magnetic storms with $D_{st} < -50$ nT to total number of this SW type) for various SW types are presented in Table 2. In contrast with previous Table 1, Table 2 consists in two sub-types of SHEATH: SHEATH before EJECTA and SHEATH before MC because these sub-types have different numbers per year and durations while MHD parameters and geoeffectivenesses are similar for both sub-types of SHEATH. We believe that this is first estimation of geoeffectiveness of SHEATH. Numbers and geoeffectivenesses of CIR and SHEATH are approximately equal, but they significantly differ for MC and EJECTA. Though geoeffectiveness of EJECTA is lower than MC (with ratio of 1:7), number of EJECTA is significantly higher (with ratio of 12:1) and part of magnetic storms induced by EJECTA is higher than MC. Table 2 presents 25-year averaged parameters (for example, occurrence of 1-hour measurements for various SW type is shown in Figure 1) while time variations of these parameters with solar cycle are presented in Figure 2-5.

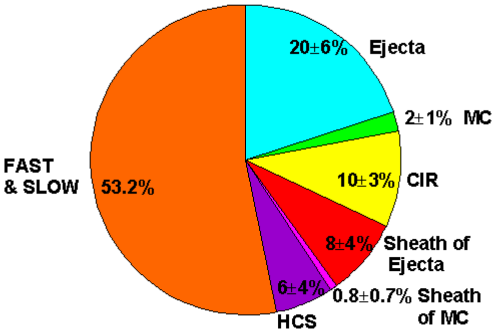

FIGURE 1. Occurance of various SW type measurements during 1976-2000

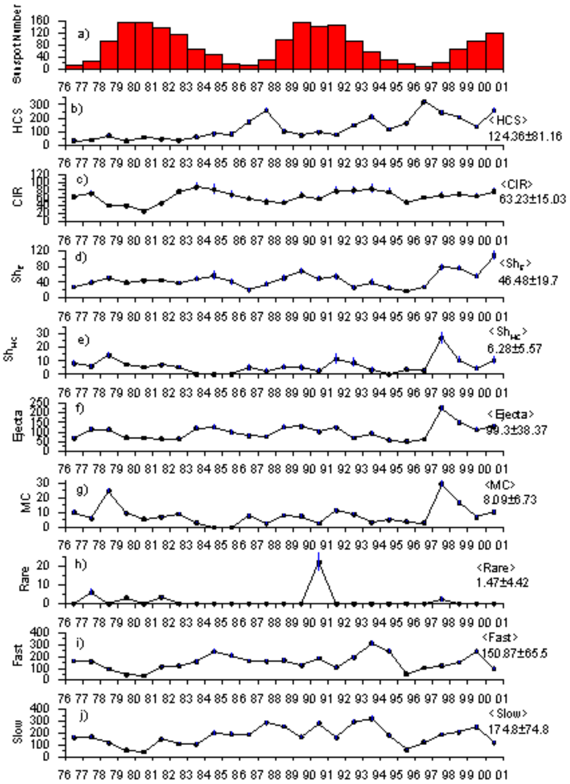

FIGURE 2. Yearly averaged sunspots (upper panel) and normalized numbers of various solar wind types

Figure 2 shows yearly averaged sunspots (upper panel) and normalized numbers of various SW types. HCS and CIR have maxima in minimum and declining phase of solar cycles, respectively. Probably EJECTA have 2 peaks near solar maxima, at rising and declining phases. Statistics for MC is very low and it is difficult to make a clear conclusion. Durations of various SW types (see Figure 3) have large standard deviations and thier dependence on solar cycle phases can not be found. Temporal partions in total times of observations for various SW types (see Figure 4) vary similarly to their normalized numbers (Figure 2).

Figure 5 shows yearly averaged sunspots (upper panel), number of magnetic storms with $D_{st} < -50$ nT (2nd panel) and geoeffectivenesses of various SW types. Geoeffectiveness of CIR is low in minima of solar cycles while geoeffectiveness of EJECTA shows 2 peaks near maxima of solar cycles.

TABLE 1. Average values and their standard deviations of plasma and magnetic field parameters (1st rows) and their numbers of 1-hour points (2nd rows) for various solar wind types

Parameters	HCS	SLOW	FAST	CIR	EJECTA	MC	SHEATH	RARE
N, cm^{-3}	12.1±6.6	10.8±7.1	6.6±5.1	14.1±9.9	7.8±5.3	10.1±8.0	14.3±10.6	1.7 ±1.8
	6208	84299	44543	12647	27259	2225	8596	139
$V, 10^2$ km/s	3.8±0.6	3.7±0.4	5.4 ±0.8	4.5±0.9	4.1±0.9	4.1±1.1	4.5±1.1	5.1±1.6
	6214	84805	44798	12666	27310	2233	8615	146
B, nT	3.9 ±2.2	5.9 ±2.9	6.4 ±3.5	8.7 ±4.1	6.4 ±2.8	12 ±5.2	8.5 ±4.5	6.7 ±2.2
	6322	67719	36179	10493	23857	2237	7286	116
T/T_{exp}	0.8 ±0.9	1.0 ±1.4	1.0 ±0.7	1.7 ±2.0	0.7 ±1.3	0.7 ±1.5	1.5 ±1.2	1.1 ±0.9
	5950	75901	40026	11149	25275	2016	7851	124
$T, 10^4$ K	4.1 ±4.1	4.4 ±4.4	13.1 ±11.8	13.8 ±13.3	4.2 ±5.3	4.5 ±6.6	12.9 ±17.6	11.1 ±10.7
	5950	75901	40026	11149	25275	2016	7851	124
$NkT, 10^{-2}$ nPa	0.6 ±1.3	0.6 ±1.3	1.3 ±2.3	2.2 ±2.8	0.4 ±1.2	0.7 ±2.0	2.2 ±3.6	0.3 ±0.5
	5950	75901	40026	11149	25275	2016	7851	124
mNV^2, nPa	2.9 ±1.4	2.4 ±1.6	3.2 ±2.8	4.4 ±2.8	2.1 ±1.7	3.3 ±3.2	4.9 ±4.7	0.8 ±0.6
	6208	84299	44543	12647	27259	2225	8596	139
$\beta, 10^{-1}$	9.5 ±0.2	5.2 ±0.0	6.1 ±0.1	6.5 ±0.1	3.1 ±0.0	1.6 ±0.1	6.5 ±0.1	2.3 ±0.5
	5878	59669	32244	8829	20518	1725	6465	100
B_Z, nT	-0.01 ±2.3	0.08 ±3.1	0.05 ±3.4	0.2 ±4.4	0.03 ±3.3	-0.8 ±7.7	0.10 ±4.9	0.80 ±2.8
	6322	67719	36179	10493	23857	2237	7286	116
D_{st}, nT	-6.5 ±15.0	-10.7 ±18.2	-28.7 ±25.9	-18.0 ±27.2	-21.1 ±25.4	-52.1 ±45.8	-21.5 ±33	-27.0 ±22.0
	6415	85459	45017	13120	29046	2571	6856	147

TABLE 2. Normalized numbers per year, average durations, temporal parts in total times of observations and geoeffectiveness (for magnetic storms with $D_{st} < -50$ nT) for various solar wind types

Parameters	SLOW	FAST	HCS	CIR	EJECTA	MC	SHEATH before		RARE
							EJECTA	MC	
Number per year	175±75	151±66	124±81	63±15	99±38	8±7	46±19	6±5	1.5±4.4
Duration, h	-	-	5±2	20±4	29±5	25±12	16±3	9±5	4.5±11
Time of observation, %	31±7	21±8	6±4	10±3	20±6	2±1	8±4	0.8±0.7	-
Geoeffectiveness, %	-	-	-	20.2	8	54.5	15.5	15.2	-

CONCLUSIONS

We classified 9 large-scale types of solar wind on the basis of OMNI dataset during 1976-2000 and found.

1. Magnetic clouds and EJECTA have significatly different parameters.
2. Yearly numbers of different structures are 124 ± 81 for HCS, 8 ± 6 for MC, 99 ± 38 for EJECTA, 46 ± 19 for SHEATH before EJECTA, 6 ± 5 for SHEATH before MC, and 63 ± 15 for CIR.
3. Yearly average durations of phenomena are 5 ± 2 h for HCS, 24 ± 11 h for MC, 29 ± 5 h for EJECTA, 16±3 h for SHEATH before EJECTA, 9±5 h for SHEATH before MC, and 20±4 h for CIR,
4. Solar wind observations consist of 6±4% of total time of observations for HCS, 2±1% for MC, 20±6% for EJECTA, 8±4% for SHEATH before EJECTA, 0.8±0.7% SHEATH before MC, 10±3% for CIR.
5. Geoeffectiveness (number of selected SW type resulted in magnetic storms with $D_{st} < -50$ nT divided by total number of this SW type) of MC with SHEATH is the largest (61%), geoeffectivenesses for CIR and EJECTA with SHEATH are medium (20-21%) and types of SHEATH and EJECTA without SHEATH have the lowest geoeffectiveness (15 and 8%, respectively).
6. There is a slight indication that number of EJECTA and thier geoeffectiveness have 2 peaks around maxima solar cycles during 1976-2000.

ACKNOWLEDGMENTS

Paper is supported in part by Physical Department of Russian Academy of Sciences, Program N 15, Presidium of Russian Academy of Sciences, Program N 16, and by RFBR, grants 04-02-16131 and 07-02-00042.

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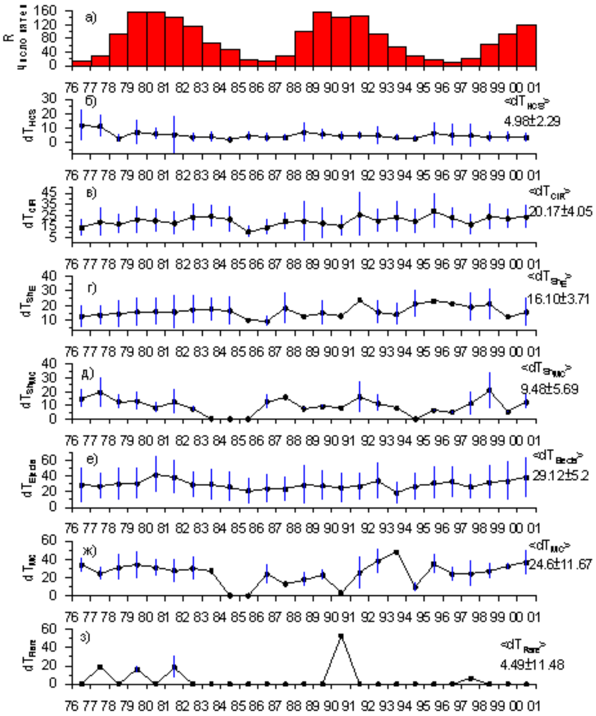

FIGURE 3. Yearly averaged sunspots (upper panel) and durations of various solar wind types

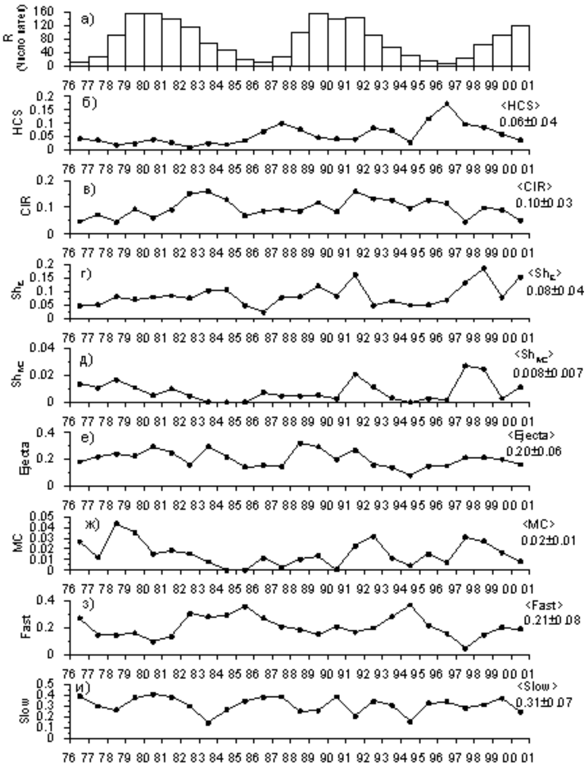

FIGURE 4. Yearly averaged sunspots and temporal parts in total times of observations of various solar wind types

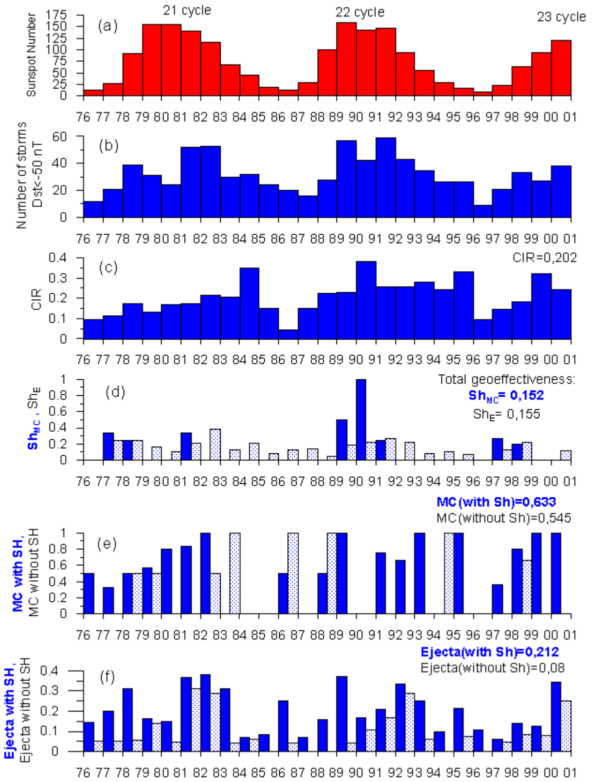

FIGURE 5. Yearly averaged sunspots (1st panel), number of magnetic storms with $D_{st} < -50$ nT (2nd panel) and geoeffectivenesses of various solar wind types

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