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Statistical Study of Interplanetary Condition Effect on Geomagnetic Storms: 2. Variations of Parameters

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Abstract—We investigate the behavior of mean values of the solar wind's and interplanetary magnetic field's (IMF) parameters and their absolute and relative variations during the magnetic storms generated by various types of the solar wind. In this paper, which is a continuation of paper [1], we, on the basis of the OMNI data archive for the period of 1976–2000, have analyzed 798 geomagnetic storms with $D_{st} \leq -50$ nT and their interplanetary sources: corotating interaction regions CIR, compression regions Sheath before the interplanetary CMEs; magnetic clouds MC; "Pistons" Ejecta, and an uncertain type of a source. For the analysis the double superposed epoch analysis method was used, in which the instants of the magnetic storm onset and the minimum of the D_{st} index were taken as reference times. It is shown that the set of interplanetary sources of magnetic storms can be sub-divided into two basic groups according to their slowly and fast varying characteristics: (1) ICME (MC and Ejecta) and (2) CIR and Sheath. The mean values, the absolute and relative variations in MC and Ejecta for all parameters appeared to be either mean or lower than the mean value (the mean values of the electric field E_y and of the B_z component of IMF are higher in absolute value), while in CIR and Sheath they are higher than the mean value. High values of the relative density variation $sN/\langle N \rangle$ are observed in MC. At the same time, the high values for relative variations of the velocity, B_z component, and IMF magnitude are observed in Sheath and CIR. No noticeable distinctions in the relationships between considered parameters for moderate and strong magnetic storms were observed.

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1. INTRODUCTION

The present work is devoted to continuation of studying the mechanisms of energy transfer from the solar wind into the magnetosphere and of geomagnetic storms excitation. In our previous work [1] we have analyzed, based on our "Catalog of large-scale types of solar wind in 1976–2000" [2], the interplanetary sources of 798 magnetic storms with $D_{st} \leq -50$ nT on the basis of the OMNI data archive for the period of 1976–2000. The following large-scale types of solar wind were considered as storm sources: 145 magnetic storms were caused by the CIR events, 96 magnetic storms—by Sheath (12 magnetic storms were generated by the Sheath before MC, ShMC, and 84 magnetic storms by the Sheath before Ejecta, ShE); 62 magnetic storms were associated with magnetic clouds MC (50 storms being caused by MC with Sheath and 12 by MC without Sheath); 161 magnetic storms were associated with the Ejecta events (115 storms being caused by Ejecta with Sheath, and 46 by Ejecta without Sheath). The source of remaining 334 magnetic storms (i.e., 42 % of 798 storms) occurred to be undetermined, mainly because of the absence of a complete set of measurements for separate time intervals in the OMNI database. Unlike our previous studies [3–5], in which we have used the superposed epoch analysis (SEA) method with the reference time (the epoch time) at the storm onset or at the D_{st} index minimum, in the above-mentioned work [1] the double superposed epoch analysis method was used for the analysis. In this technique both time instants were simultaneously taken as reference times, namely, the instants of magnetic storm onset and D_{st} index minimum, and the durations of main phases of all magnetic storms were changed in such a manner, that they should become equal. This allowed us to investigate the dynamics of parameters for storms with various durations of the main phase. Using this technique, we have analyzed the time behavior of some parameters of the solar wind, interplanetary magnetic field (IMF), and magnetospheric indices during the magnetic storm's main phase, this being done separately for various large-scale types of the solar wind.

It was noted in many works, that the solar wind had essentially turbulent character (see, e.g., the materials of the *Solar Wind 12* International Conference held in 2009 [6]), and, therefore, its turbulence influences the magnetospheric disturbance generation processes (see, e.g., reviews and recent papers [7–14], and references therein). For example, Borovsky and Funsten have shown in their paper [10] that the magnetosphere disturbance level, described by various magnetospheric indices, increases with increasing level of fluctuations of the IMF magnitude and components in the presence of both southward and northward IMF components. In a number of papers (see, e.g., recent papers [11, 13–17] and references therein) it was shown that the magnetic storm development can be influenced, along with the value (or slow changes) of various parameters also by fast variations of these parameters.

However, these studies had some drawbacks. First, the variations of IMF magnitude and components have mainly been studied without analyzing the effect of variations of other parameters. Second, the features of various solar wind types were not taken into account, since the analysis was carried out without selecting the data according to such types.

We tried to overcome some of these drawbacks in our previous work [4], where we have studied, by the SEA method (with the epoch beginning at the magnetic storm onset), the variations (1-h standard deviations) of the velocity, temperature, density, and magnitude of IMF for the magnetic storms generated by CIR, Sheath, and ICME. Unlike the previous work [4], in the present paper:

1) we use a more advanced classification of solar wind types including 2 ICME subtypes, namely, MC and Ejecta;

2) we analyze the data according to the double superposed epoch analysis method, as in the previous paper [1];

3) we study the variations of 12 parameters of the solar wind and IMF;

4) we analyze the conditions for moderate and strong storms separately;

5) we analyze not only the absolute values of variations, but relative (i.e., related to the mean values of a corresponding parameter) as well.

The time behavior of hourly mean standard deviations taken from the OMNI database for 1976–2000 [18], is used as initial data in the present paper.

2. METHOD

The technique of identification of large-scale types of the solar wind was described in detail in our work [2], and it consists in the comparison of each point of the OMNI database with the set of threshold criteria in key parameters of the solar wind and IMF. A solar wind event is supposed to result in a magnetic storm, if the D_{st} minimum falls inside the event interval or follows it within the interval no longer than 2 h.

The data for intervals, selected according to solar wind types, have been processed by the superposed epoch analysis method with two checking times (see paper [1] for more details): the time of the magnetic storm onset (time “0”) and the time of the D_{st} index minimum (time “6”). The time interval from “0” to “6” contains artificially changed durations of events; therefore, in order to distinguish these times from a really measured time, we give them in quotation marks. The first 1-h point of sharp decrease of the D_{st} index was taken as the magnetic storm “beginning” [3–5]. For all events (intervals) the time scale between these times was divided into 5 subintervals with equal relative duration, and the data in one subinterval were averaged according to the number of points which had fallen into the given subinterval (their number can be different in different subintervals). This procedure implies that, for real data, the time scale in the range between points “0” and “6” changed linearly, but this change was small (for 2/3 of events the duration has changed no more than by 1/3), since the duration of the main phase of a storm equaled 7 ± 4 h, on the average [2–5]. The time scale before time “0” and after time “6” remained unchanged, and in these intervals the time is indicated without quotation marks. The advantage of this method is the possibility of comparison of the dynamics of interplanetary and magnetospheric parameters during the main phase of magnetic storms having different durations.

In accordance with the SEA method, the data were processed within the intervals from –12 to “0” and from “6” to +24, the duration of each interval of the given solar wind type being taken into account. According to our results, the durations of various solar wind types for the 1976–2000 interval were equal to: 20.6 ± 12.2 hours for CIR, 29.8 ± 20.5 for the Ejecta, 28.2 ± 13.4 for MC, and 15.7 ± 10.1 for Sheath [2], and they were close to average durations of these solar wind types, which resulted in magnetic storms [3–5,19]. Therefore, the number of points in the intervals of averaging noticeably decreases (accordingly, the error becomes larger) to the edges of the chosen interval from –12 to +24, especially for Sheath.

The only principal distinction of the present paper from previous one [1] is the fact, that in this paper the variations of plasma and IMF parameters (hourly standard deviations) were analyzed, rather than the parameters themselves. These standard deviations taken from the OMNI database are designated here with symbol s, i.e., sV for velocity, sT for temperature, sN for density, etc. Since the standard deviations for some parameters is not included into the OMNI database, for them we were compelled, for each hour i, to calculate variations proceeding from the variations of parameters, which appeared in their calculation formulas and contained in the OMNI database:

$[s(T/T_{\exp})]_i = (T/T_{\exp})_i\{[(sT)_i/T_i)]^2 + [2(sV)_i/V_i)]^2\}^{1/2}$ for the ratio of the measured proton temperature to the temperature estimated from velocity magnitude,

$(sP_d)_i = (P_d)_i\{[(sN)_i/N_i]^2 + [2(sV)_i/V_i)]^2\}^{1/2}$ for kinetic pressure,

$(sP_t)_i = (P_t)_i\{[(sN)_i/N_i]^2 + [(sT)_i/T_i]^2\}^{1/2}$ for thermal pressure,

$(s\beta)_i = \beta_i\{[(sN)_i/N_i]^2 + [(sT)_i/T_i]^2 + [2(sB)_i/B_i]^2\}^{1/2}$ for the ratio of thermal and magnetic pressures and

$(sE_y)_i = (E_y)_i\{[(sV)_i/V_i]^2 + [(sB_z)_i/(B_z)_i]^2\}^{1/2}$ for the electric field component. Further, the variations of parameters from the OMNI database and these calculated variations were processed uisng the double SEA method. The obtained results were presented in two forms: as variations of parameters (standard deviations) and as relative variations (variations divided by the mean values of parameters for given solar wind types).

3. RESULTS

Figure 1 shows, in the compressed form, the results, which have been discussed in more detail in our previous paper [1], and presents the average values of some solar wind and IMF parameters (the left column: V is velocity, T and $T/T_{\exp}$ are the measured proton temperature and the temperature related to the temperature calculated from the average temperature-velocity dependence [20], E_y is the electric field component, B_z is the magnetic field component, β is the ratio of thermal and magnetic pressures; the right column: N is density, P_d and P_t are the dynamic and thermal pressures of the solar wind, B_x, B_y, and B are the components and magnitude of the IMF), and magnetospheric D_{st} and K_p indices. Different lines in figures designate different types of the solar wind: (MC+Ejecta), MC and Ejecta, Sheath, CIR and IND (indeterminate type). Designations of solar wind types are given at the bottom of figure together with the indication of statistics (this statistics corresponds to the number of events; the number of points in separate intervals can differ from this number).

The data presented in Fig. 1 show, that: (1) irrespective of the solar wind type any magnetic storm begins in 1–2 h after IMF turn southward and is terminated in 1–2 h after sharp decrease of the southward IMF component; (2) the magnetic storms for Sheath and CIR develop, as a rule, at higher velocity, temperature, IMF magnitude, dynamic and thermal pressure, and β-parameter; (3) Sheath turns out to be the most effective interplanetary cause of the storms from all types.

Figure 2 shows variations of the same solar wind and IMF parameters, as in Fig. 1. The time behavior of mean values of magnetospheric indices D_{st} and K_p was taken without changes from Fig. 1. Variations are higher in Sheath and CIR for the same parameters, for which the mean values are higher, except for the β-parameter. In these solar wind types the variations of all IMF components, including B_z, are higher as well.

Figure 3 shows the relative (i.e., normalized with respect to the mean values in a given interval of averaging for the same solar wind type) variations of the same parameters as in Fig. 2. One should note that some relative variations exceed 1000 %, since the mean values are close to zero, and such parameters (β-parameter, IMF components, thermal pressure) should be analyzed with care. Figure 3 shows that the relative variations for all types of streams are very close between each other, and only relative variations of the IMF magnitude and the value of velocity sV/V are 1.5 times higher in Sheath and CIR. It should be noted that variations of the most geoeffective interplanetary parameters sB_z and sE_y turn out to have minimum on the main phase of a storm for all solar wind types.

The mean values of parameters discussed above, their absolute and relative variations separately for moderate ($-100 < D_{st} \leq -50$ nT) and strong ($D_{st} \leq -100$ nT) magnetic storms are shown, respectively, in Figs. 4 and 7, 5 and 8, 6 and 9. As in Figs. 1–3, in these figures the statistics (the number of events) is indicated below in brackets, near the lines for a corresponding solar wind type. A higher degree of scatter of parameters in Figs. 7–9 (for strong magnetic storms with $D_{st} \leq -100$ nT) is mainly associated with lower statistics than in previous figures (Figs.1–6). Except for different values of the southward component of the IMF and electric field E_y, all parameters and their variations for moderate and strong magnetic storms behave in a similar manner both qualitatively and quantitatively. The comparison will be made in more detail in the next Section of the paper.

4. DISCUSSION AND CONCLUSIONS

Thus, the behavior of mean values of parameters (and their absolute and relative variations) at the main phase of magnetic storms, generated by various large-scale solar wind types, has been analyzed in the present work by the double superposed epoch analysis method similar to that used in paper [1]. This behavior is shown in Figs. 1–3, 4–6 and 7–9, for "all" ($D_{st} \leq -50$ nT), moderate ($-100 < D_{st} \leq -50$ nT) and strong ($D_{st} \leq -100$ nT) magnetic storms, respectively. The data presented for the main phase (time "0"–"6") of these figures are summarized in Table. This table qualitatively presents, for various solar wind types (horizontally) and various parameters (vertically) the behavior (level designated by letters "l," "m," and "h") of the corresponding parameter with respect to the behavior of other solar wind types, i.e., the low (lower than the mean), mean (about the mean position), and high (higher than the mean) value, respectively. The mean values, the absolute and relative variations are presented for each solar wind type (the corresponding columns are marked by labels $\langle\rangle$, s, and $s/\langle\rangle$), where all data on the mean variations and relative variations are subdivided into "all", moderate, and strong storms, which are presented in 3 neighboring columns, respectively. Since Figs. 1, 4, and 7 represent the information of paper [1]

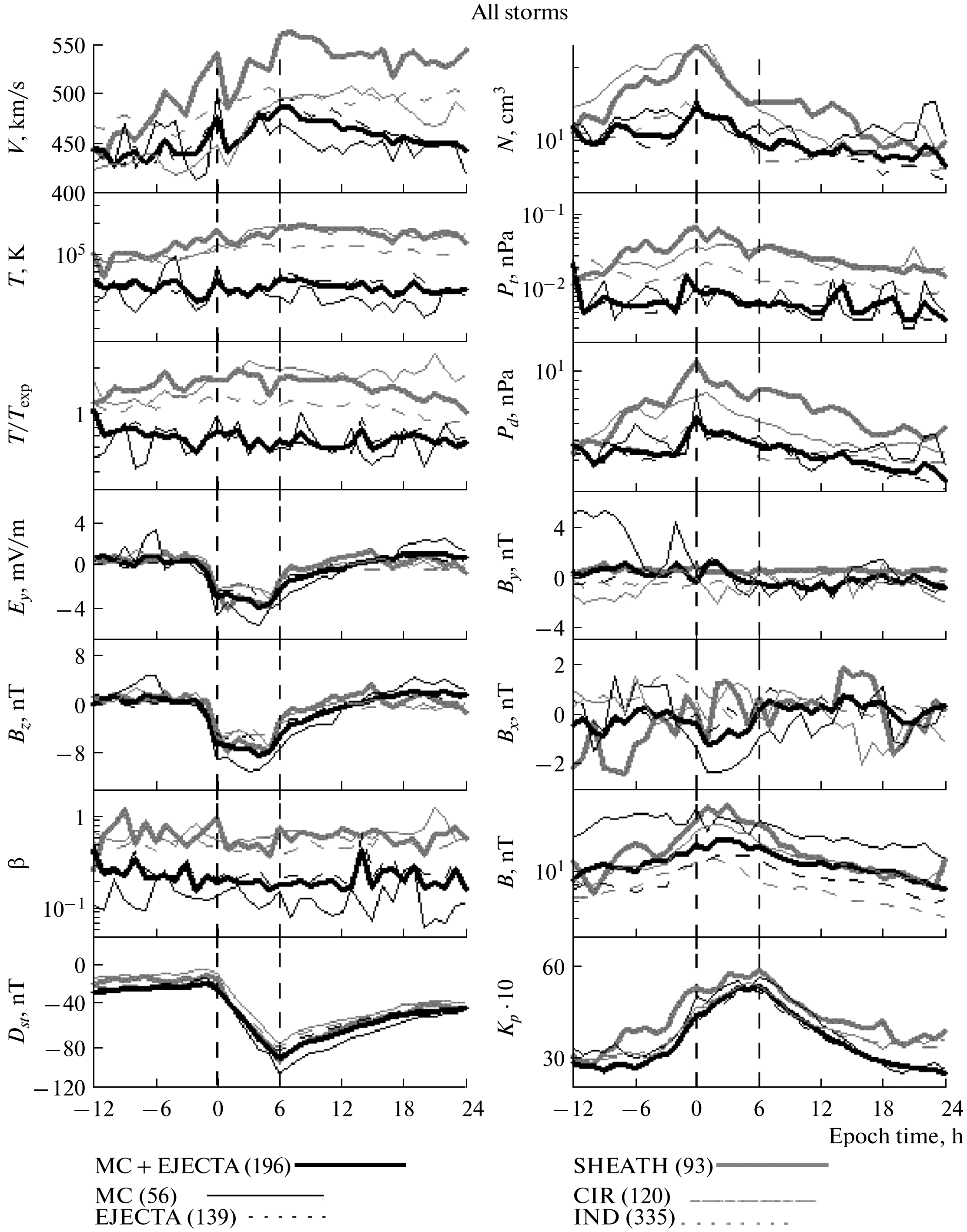

Fig. 1. Time dependence of mean values of 12 solar wind and IMF parameters and 2 magnetospheric indices obtained by the double superposed epoch analysis method for all storms with $D_{st} \leq -50$ nT.

in a more compressed form than in the original, Table also summarizes the results of the mentioned paper in columns marked by the label <>.

Before starting the discussion about the obtained results, one should remind the following points.

1. The hourly average standard deviations of OMNI database parameters used by us as variations were obtained by various instruments and may contain some peculiarities of method (see "Discussion" in paper [4]) for more details).

2. For some composite parameters (see the "Method" Section) there are no direct measurements of variations in the OMNI database, and we have estimated these parameters on the basis of variations of

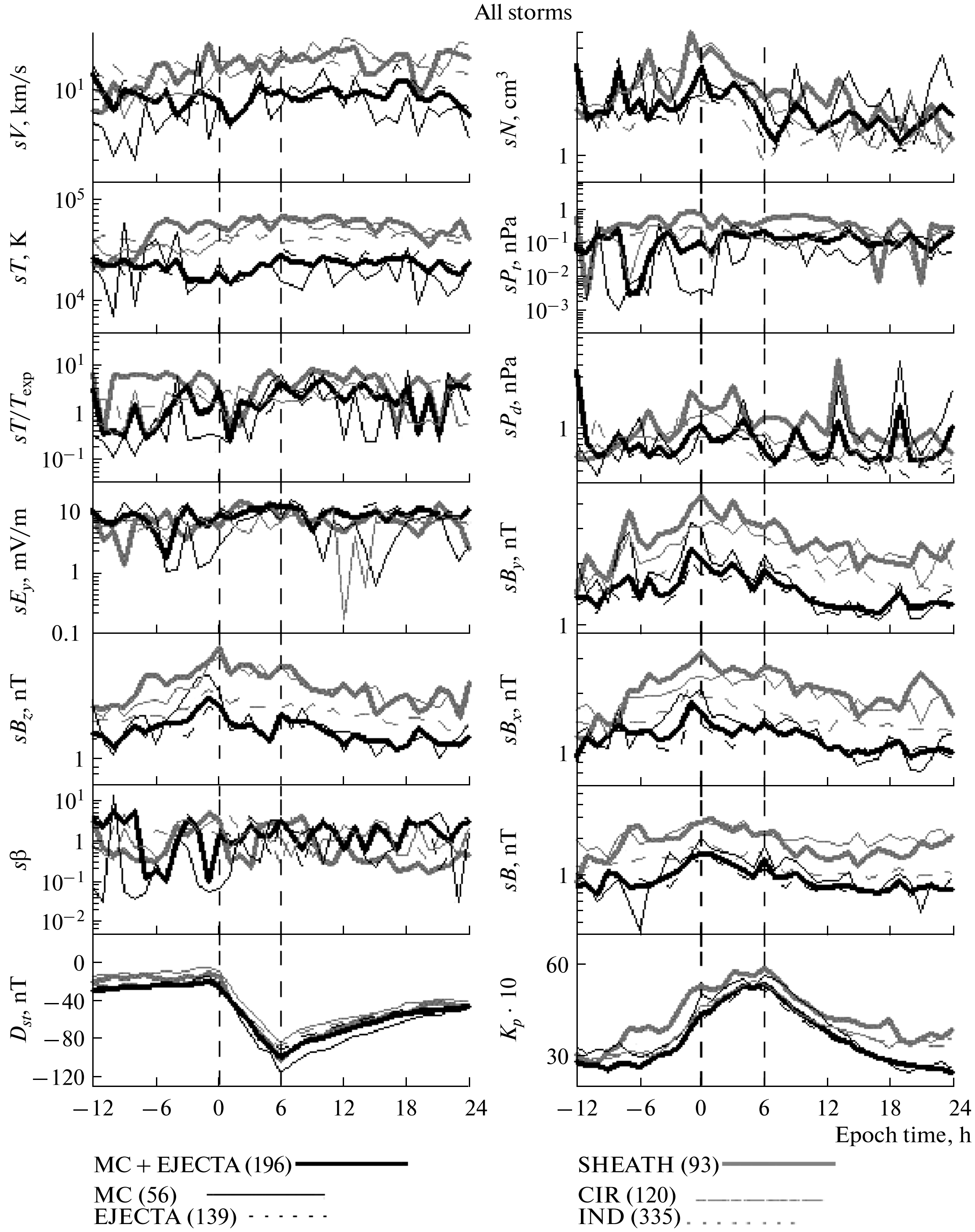

Fig. 2. Time dependence of averaged values of standard deviations for the same 12 parameters, as in Fig. 1, obtained by the double superposed epoch analysis method for all storms generated by various interplanetary types of streams.

parameters included in these composite parameters, which are included in the OMNI database.

3. The negative values of electric field E_y and B_z components of the interplanetary magnetic field were supposed to be geoeffective, and, consequently, the lower mean values of these parameters for any solar wind type imply the higher values of the quantity (magnitude), i.e., more "energetic" values of disturbing interplanetary factors.

The results on behavior of 10 interplanetary parameters in various solar wind types during the main phase of magnetic storms, presented in figures and in Table, can be formulated as follows.

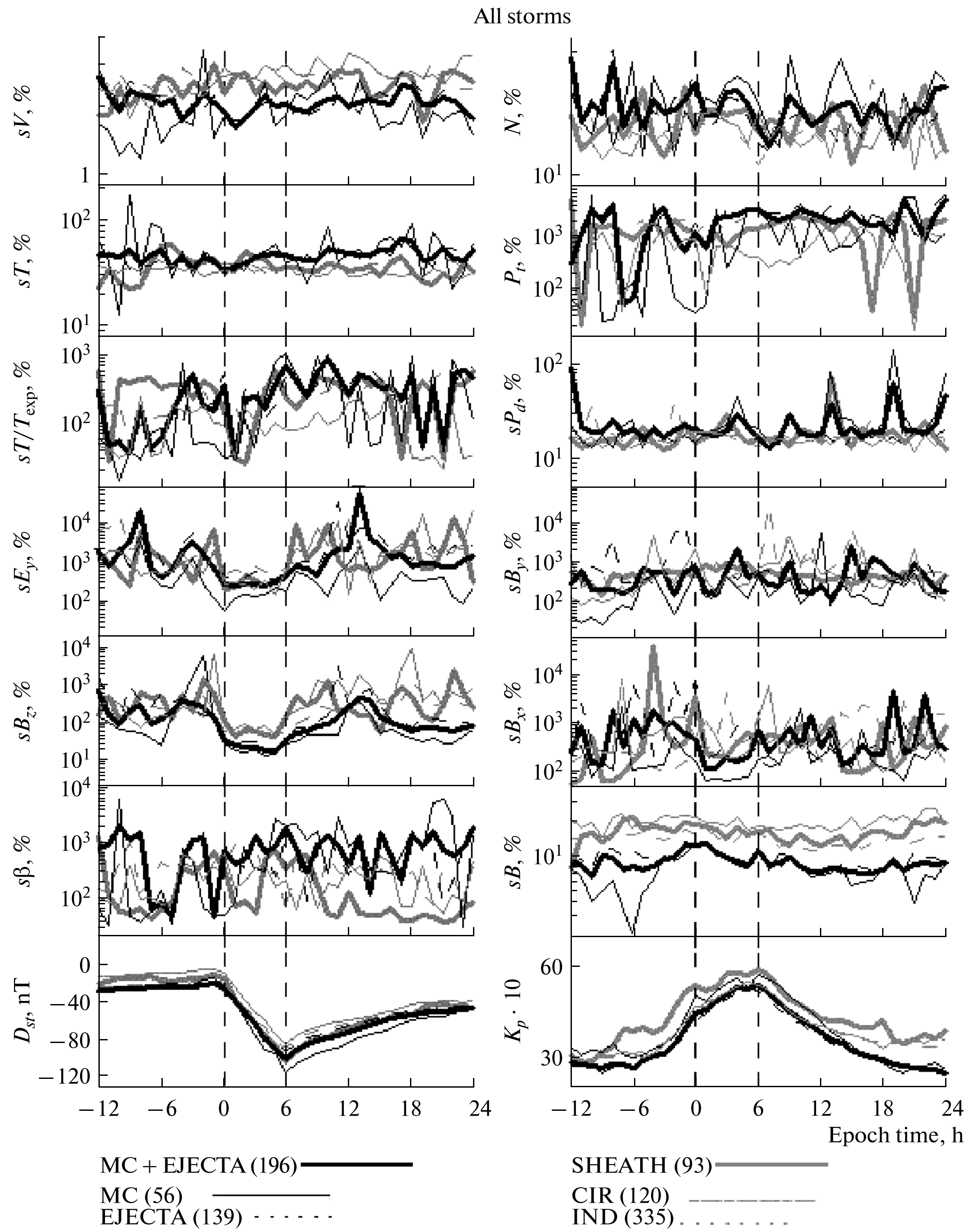

Fig. 3. Time dependence of relative variations (divided by the mean value and multiplied by 100) for the same parameters as shown in Fig. 2.

According to their characteristics, including both the mean values and the absolute and relative variations, all solar wind types resulting in magnetic storms obviously have a bent for two groups: (1) MC and Ejecta and (2) Sheath and CIR. Below we consider these two groups.

1. MC and Ejecta Types of Streams

The mean values, absolute and relative variations for all parameters turn out to be either mean, or lower than the mean values (this also relates to the mean values of the electric field E_y and to B_z-component of the interplanetary magnetic field).

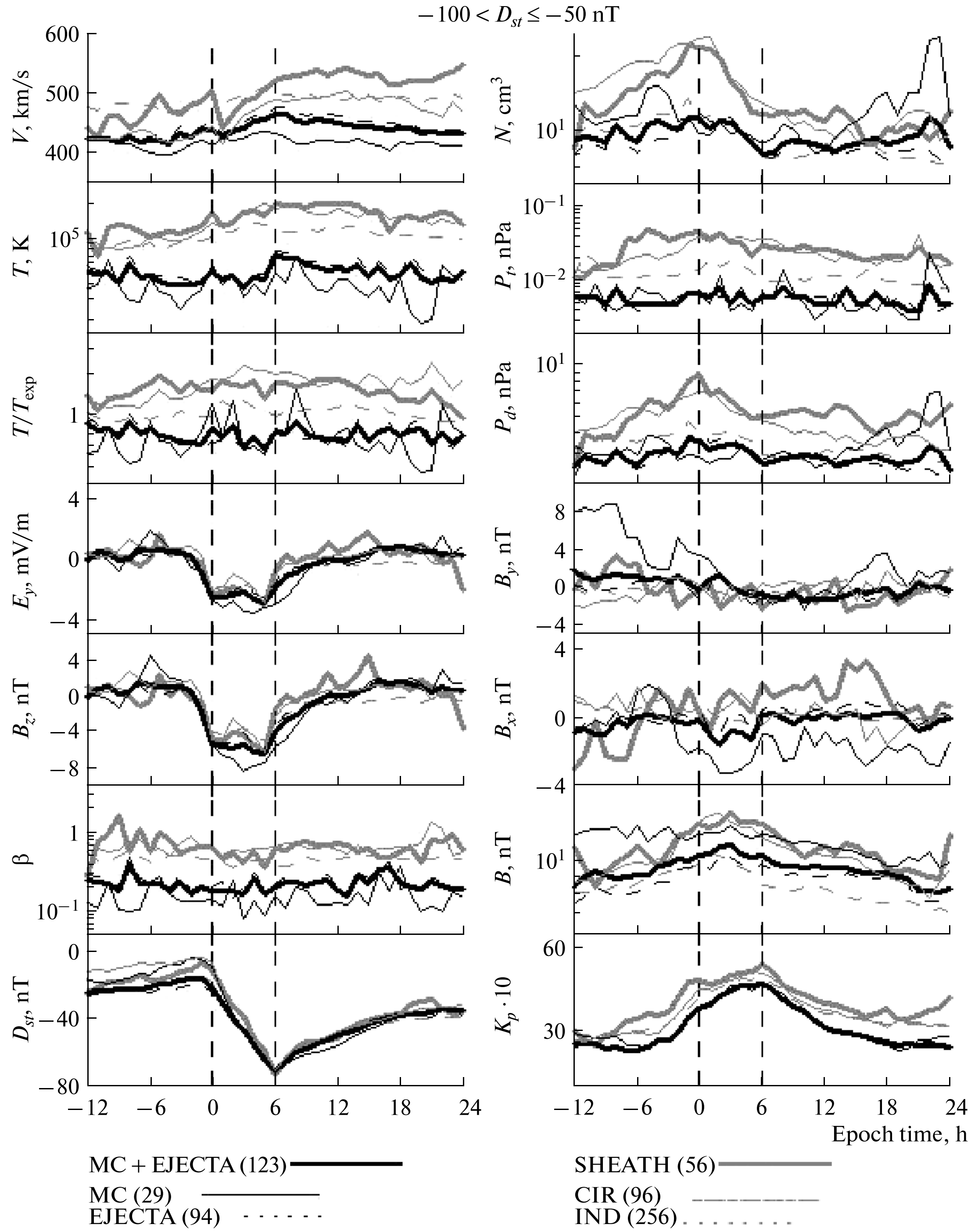

Fig. 4. Time dependence of averaged parameters, as in Fig. 1. Unlike Fig. 1, this figure presents only the data for moderate storms with -100 nT $< D_{st} \leq -50$ nT.

High values of the relative variation of density $sN/\langle N\rangle$ (and, probably, of derivative parameters—the dynamic and thermal pressure) and the mean value of the magnetic field magnitude $\langle B\rangle$ in MC turn out to be an exception.

Unlike the MC events, the components and the value (magnitude) of the magnetic field and the electric field intensity in Ejecta are lower and close to the mean values for all solar wind types.

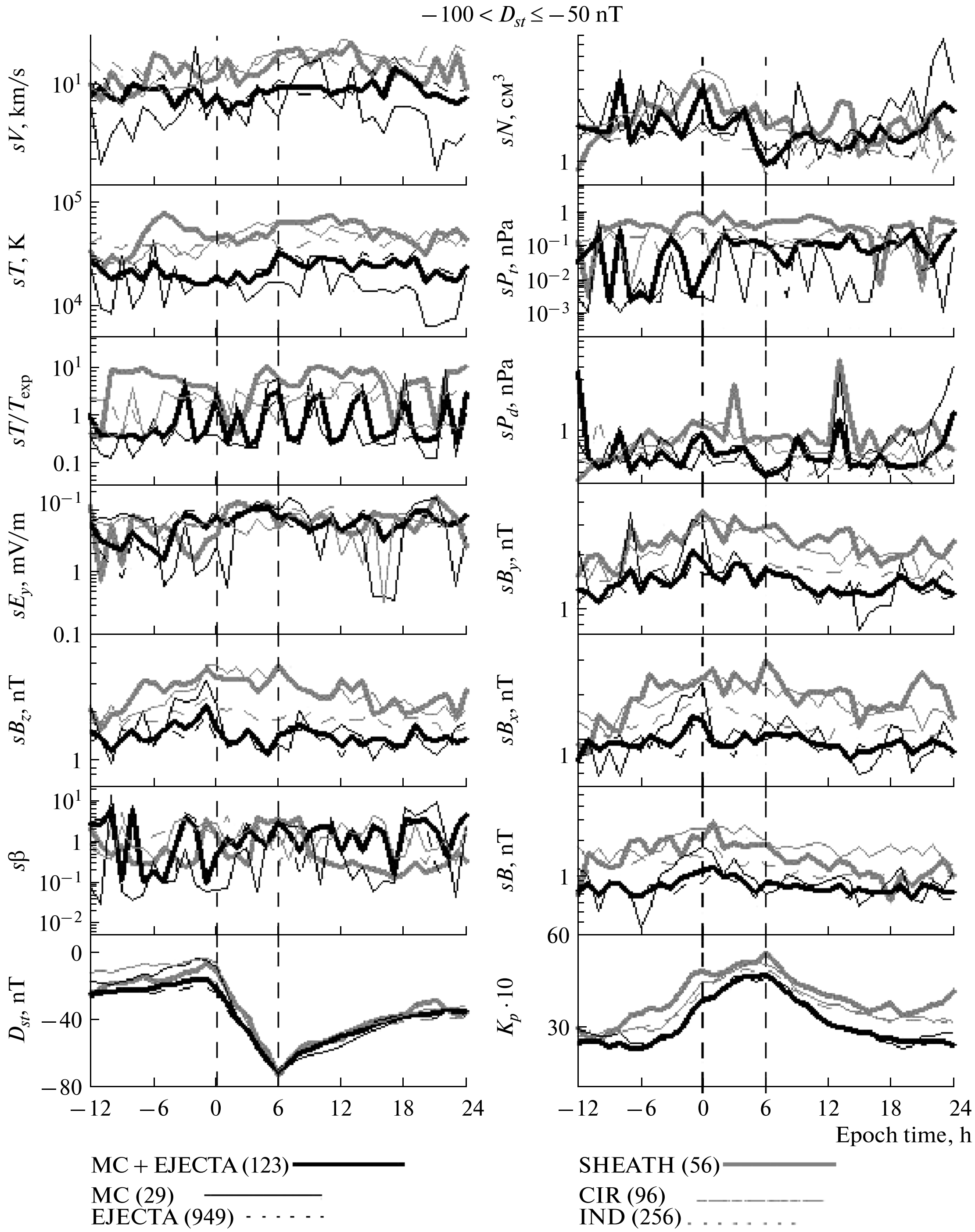

Fig. 5. Time dependence of variations of parameters, as in Fig. 2. Unlike Fig. 2, this figure presents only the data for moderate storms with -100 nT $< D_{st} \leq -50$ nT.

No noticeable distinctions of considered parameters are observed for “all”, moderate, and strong storms.

2. Sheath and CIR Types of Streams

The values and behavior of parameters and their variations in Sheath and CIR are close to each other, and in most cases not only qualitatively, but also quantitatively.

They demonstrate high mean values and absolute variations virtually for all parameters.

High values are observed for the relative variations of velocity, B_z-component, and IMF magnitude.

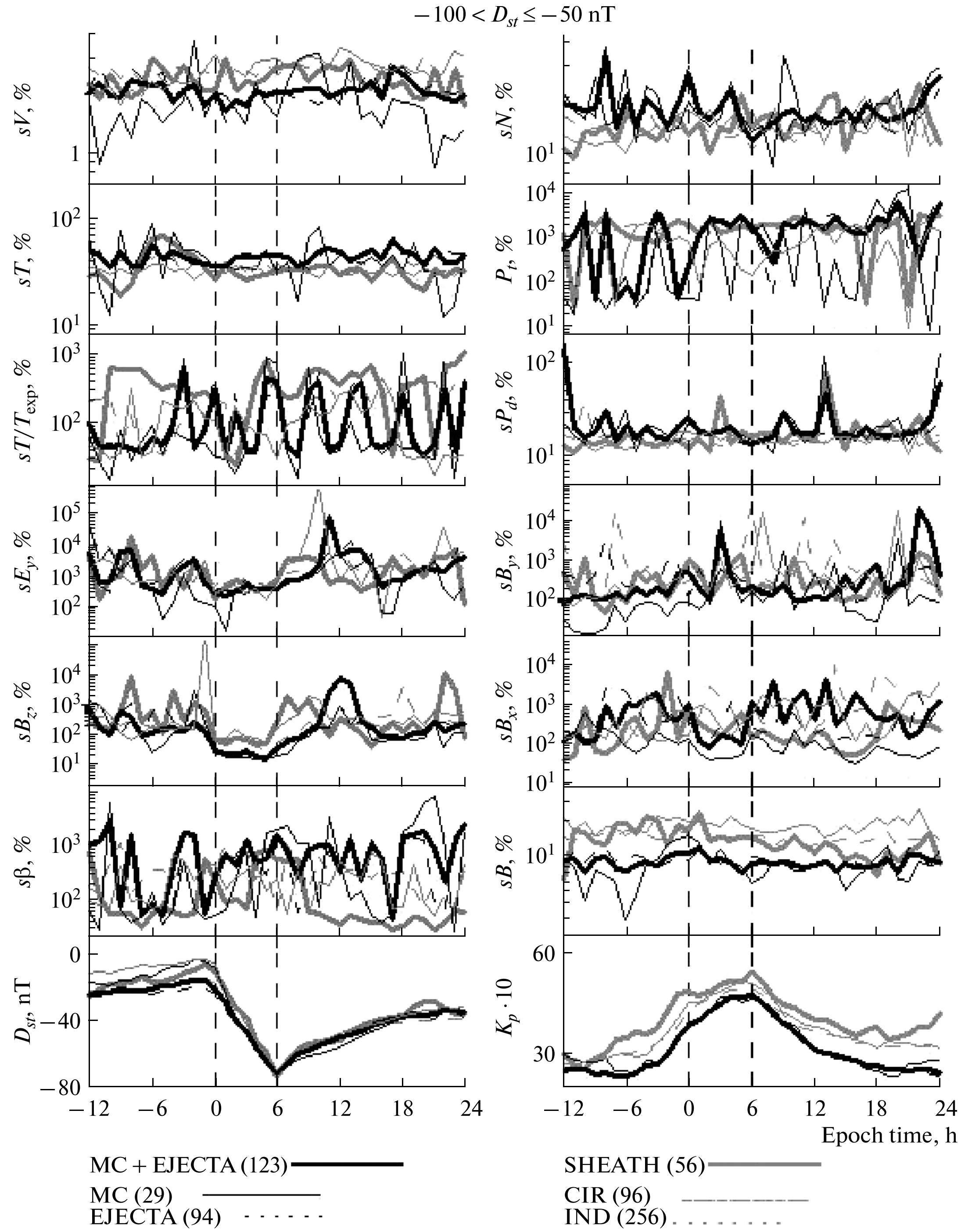

Fig. 6. Time dependence of relative variations of parameters, as in Fig. 3. Unlike Fig. 3, this figure presents only the data for moderate storms with -100 nT $< D_{st} \le -50$ nT.

It is interesting to note that for strong magnetic storms the high relative variations of density were observed, unlike the other parameters, in MC and Ejecta, and they are low in Sheath.

The mean values of parameters are determined, in many respects, by the type of solar wind stream (and by the used classification criteria of solar wind types) and have already been discussed in paper [1]. As it was noted in the Introduction, the variations of some parameters have been rather poorly investigated, and, in general, the presented results satisfactorily agree with earlier published ones [7–17]. However, our results have some advantages:

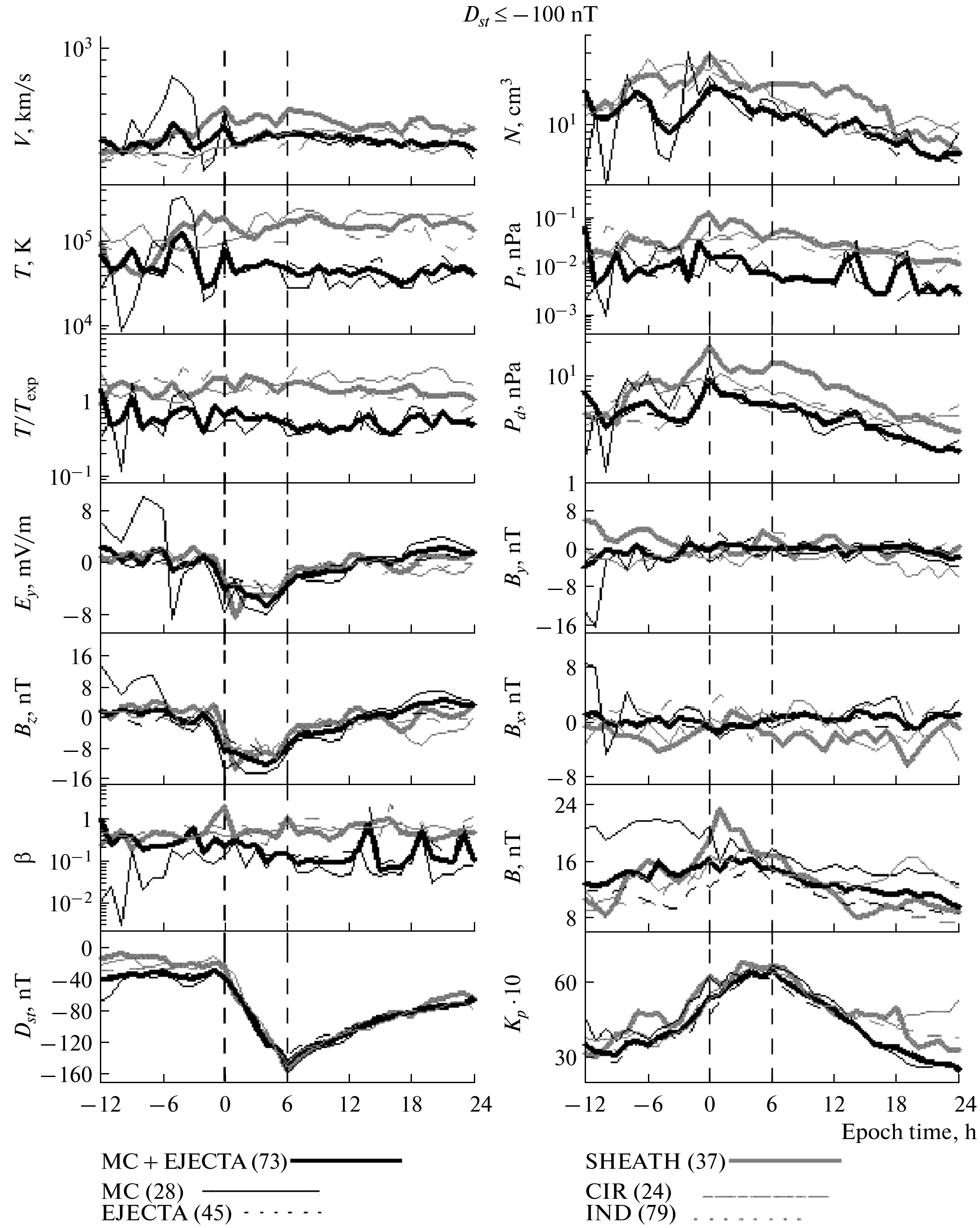

Fig. 7. Time dependence of averaged parameters, as in Fig. 1. Unlike Fig. 1, this figure presents only the data for strong storms with $D_{st} \leq -100$ nT.

1. they use a rather complete (at the modern science development stage) classification of solar wind types, in particular, the separate analysis of two ICME subtypes: MC and Ejecta;

2. they represent the analysis of a rather complete set of solar wind and IMF parameters;

3. the solar wind and IMF parameters were analyzed not only at the magnetic storm maximum, but in the dynamics, during the entire main phase of the magnetic storm (by the double superposed epoch analysis method);

4. not only absolute (or only relative) variations of parameters were compared, but the full set of characteristics (dynamics, mean values, absolute and relative variations) of parameters; and

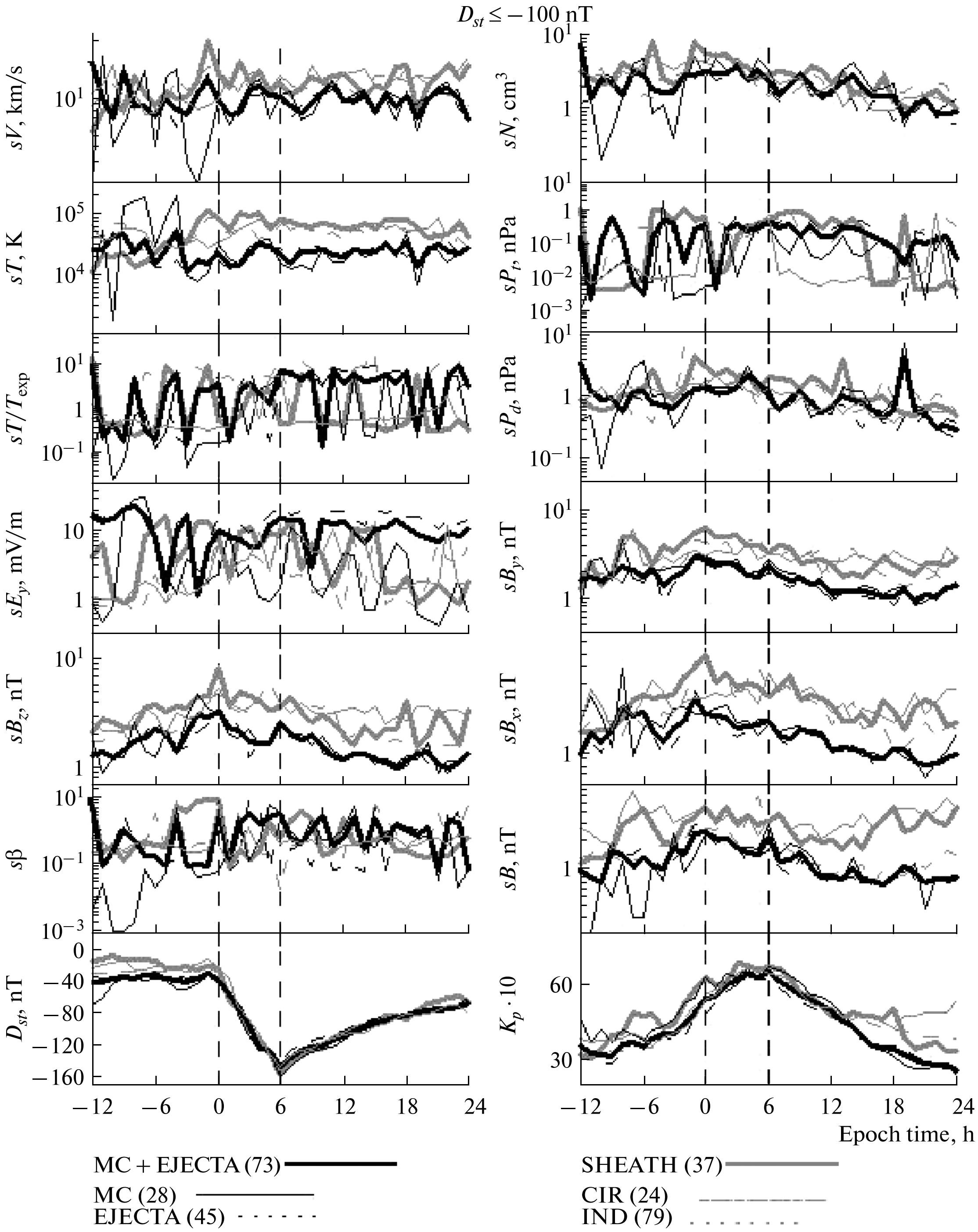

Fig. 8. Time dependence of variations of parameters, as in Fig. 2. Unlike Fig. 2, this figure presents only the data for strong storms with $D_{st} \leq -100$ nT.

5. the conditions for moderate and strong magnetic storms were studied separately.

It is well known that two physical mechanisms are most frequently used in the description of solar wind effect on the magnetosphere: (1) the reconnection of magnetic fields of interplanetary and magnetospheric origin on the magnetopause [21], and (2) viscous interaction of plasma streams of interplanetary and magnetospheric origin on the magnetopause [22]. The dependence of the storm intensity on the IMF southward component (or electric field E_y) value testifies to the effect of reconnection. However, the efficiency of both these mechanisms essentially grows with increasing turbulence level in the interacting streams. The

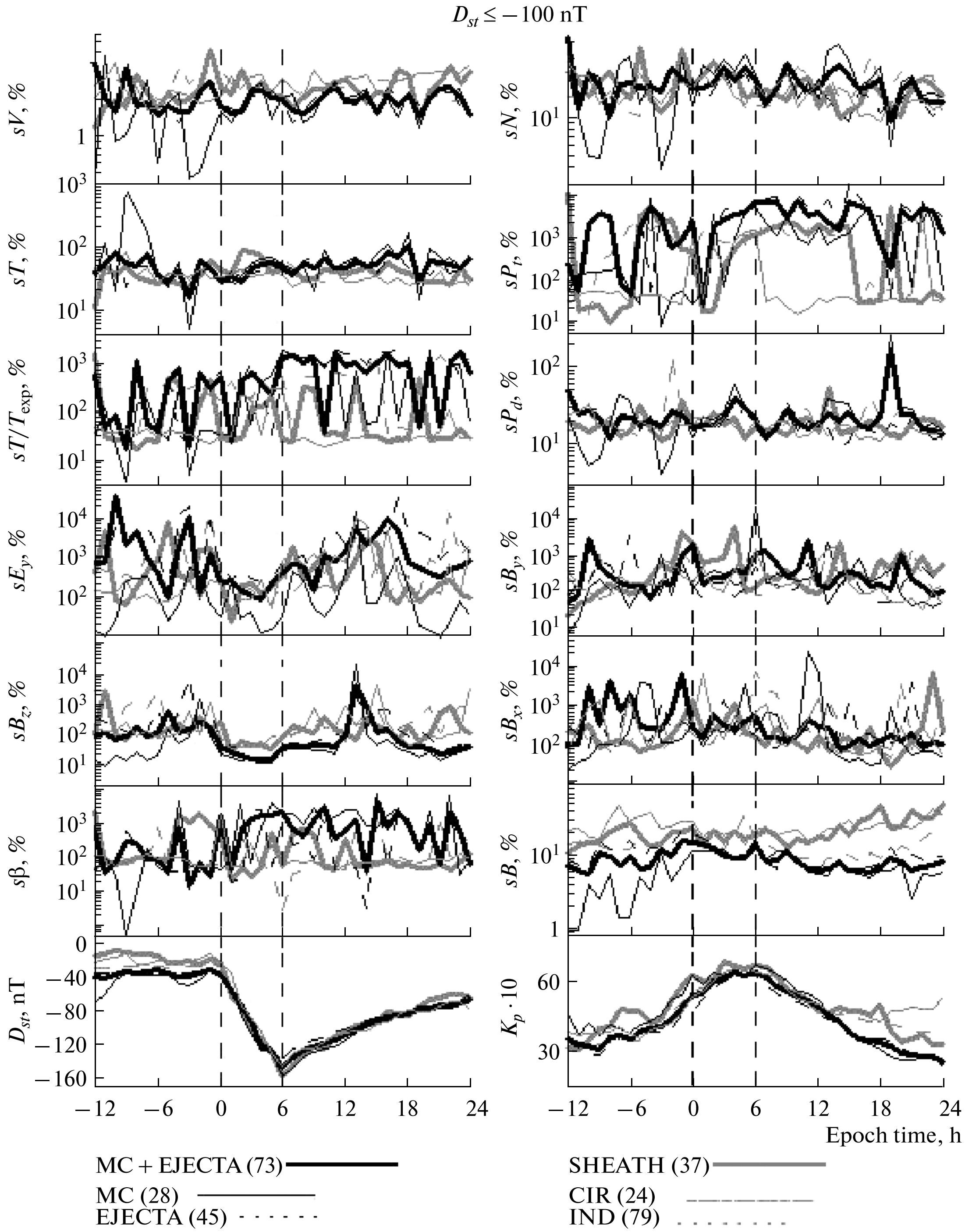

Fig. 9. Time dependence of relative variations of parameters, as in Fig. 3. Unlike Fig. 3, this figure presents only the data for strong storms with $D_{st} \leq -100$ nT.

obtained evidences of the fact that those solar wind stream types, which contain a higher level of variations (Sheath and CIR), more effectively excite magnetic storms than the types with a low level of variations (MC), indicate to possible additional effect of both mechanisms with increasing turbulence level in the incident solar wind stream. A higher level of fluctuations (along with distinctions of mean values for some parameters) in Sheath and CIR as compared to MC can be responsible for different reaction of the magnetosphere on various solar wind types [23–27]. More detailed information on this subject can be obtained by

Character of variation of solar wind parameters in various types of streams reduced to magnetic storms with $D_{st} \leq -50$ nT

Param.	MC + Ejecta			MC			Ejecta			Sheath			CIR			IND		
	<>	*s*	*s*/<>	<>	*s*	*s*/<>	<>	*s*	*s*/<>	<>	*s*	*s*/<>	<>	*s*	*s*/<>	<>	*s*	*s*/<>
V	lll	lll	lll	lll	lll	lll	lmm	lll	llm	hhh	hhh	hhm	lmm	hhh	hhm	mhm	hhh	hhm
T	lll	lll	mmm	lll	lll	mmm	lll	lll	mmm	hhh	hhh	mmh	hhh	hhh	mmm	hhh	hhh	mmm
T/T_{exp}	lll	mlm	mmm	lll	mlm	mmm	lll	mmm	mmm	hhh	mhm	mmm	hhh	mhm	mmm	hmh	mmm	mmm
N	lll	lmm	mhm	lll	llm	hhm	lll	lmm	mhm	hmh	hmh	mlm	hhh	hhm	lmm	llm	lmm	mlm
P_t	lll	mlm	mhm	lll	llm	mlm	lll	mmm	mmm	hhh	hhm	mhm	hhh	mmm	mlm	mmm	mmm	mmm
P_d	lll	lml	mmm	lll	lll	mmm	lll	lmm	mmm	hhh	hhh	mmm	mhm	mmm	mmm	lml	mmm	mmm
E_y	mmm	mmm	mmm	lll	mll	lml	mmm	mmm	mmm	mmm	mmm	mmm	mmm	mmm	mmm	mmm	mmm	mmm
B_z	mmm	lll	lll	lll	lll	lll	mmm	lll	lll	mmm	hhh	hhh	mmm	hhh	hhh	mmm	mmh	hhh
B_x	mmm	lll	mlm	llm	lll	llm	mmm	lll	mmm	hhm	hhh	mmm	mhm	hhm	mmm	mmm	mmm	mmm
B_y	mmm	lll	mlm	mmm	lll	mlm	mmm	lll	mlm	mmm	hhh	mmh	mmm	hhm	mhm	mmm	llm	mmm
B	mmm	lll	lll	hhm	lml	lll	lll	lll	lll	hhh	hhh	hmh	hhm	hhh	hhh	lmm	lmm	hmh
β	lll	mmm	hmh	lll	mlm	mmm	lll	mmm	mmm	hhh	mmm	lml	hhh	mmm	mmm	hhm	mmm	mmm

Designations l, m and h indicate the quantities, which are lower than the mean, close to the mean, and higher than the mean value, respectively.

studying the budget of the energy coming from the solar wind and spent for magnetospheric disturbances [28, 29].

One can often find in literature the statements about the relationship between the magnetospheric activity and high-velocity solar wind streams (see, e.g., paper [30] and references therein).[1] The data presented above do not confirm such statements for magnetic storms: on the average, at the main phase of a storm the velocity magnitudes only slightly differ from the mean values of solar wind velocity and change, depending on the solar wind type, within a rather narrow range of values: 450–550 km/s. More important than mean values of velocity for the magnetic storm generation are velocity fluctuations at the main phase of a storm, since the distinctions in the mean velocity between the types of streams are about 10–20%, while the distinctions in the absolute velocity variations are about 100%, but these fluctuations are mainly associated with the solar wind type (they are observed in the CIR and Sheath compression regions) rather than with its velocity. Since the compression regions are observed before the fast solar wind types (CIR before the fast streams from coronal holes and Sheath before the fast ICMEs), then, though the necessary conditions for storm generation arise in the CIR and Sheath compression regions, the high-velocity solar wind streams are erroneously considered to be the sources of storms. The data we have obtained give evidence in favor of the hypotheses of considerable effect of density and its variations (and derivatives of the density, the dynamic and thermal pressures, first of all) and IMF variations on the magnetospheric activity (see, e.g., papers [31–33] and references therein), and the studies in this direction seem to be rather promising.

[1] Probably, in some papers the used terminology follows from established traditions. However, in our opinion, this terminology does not reflect real physical processes and misleads a reader.

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REFERENCES

1. Yermolaev, Yu.I., Lodkina, I.G., Nikolaeva, N.S., and Yermolaev, M.Yu., Statistical Study of Interplanetary Condition Effect on Geomagnetic Storms, *Kosm. Issled.*, 2010, vol. 48, no. 6, pp. 499–515. [*Cosmic Research*, pp. 485–501].
2. Yermolaev, Yu.I., Nikolaeva, N.S., Lodkina, I.G., and Yermolaev, M.Yu., Catalog of Large-Scale Solar Wind Phenomena during 1976–2000, *Kosm. Issled.*, 2009, vol. 47, no. 2, pp. 99–113. [*Cosmic Research*, pp. 81–94].
3. Yermolaev, Yu.I., Yermolaev, M.Yu., Lodkina, I.G., and Nikolaeva, N.S., Statistical Investigation of Heliospheric Conditions Resulting in Magnetic Storms, *Kosm. Issled.*, 2007, vol. 45, no. 1, pp. 3–11. [*Cosmic Research*, pp. 1–8].
4. Yermolaev, Yu.I., Yermolaev, M. Yu., Lodkina, I.G., and Nikolaeva, N.S., Statistical Investigation of Heliospheric Conditions Resulting in Magnetic Storms, 2, *Kosm. Issled.*, 2007, vol. 45, no. 6, pp. 489–498. [*Cosmic Research*, pp. 461–470].

5. Yermolaev, Yu.I., Yermolaev, M.Yu., Nikolaeva, N.S., and Lodkina, L.G., Interplanetary Conditions for CIR-Induced and MC-Induced Geomagnetic Storms, *Bulg. J. Phys.,* 2007, vol. 34, pp. 128–135.
6. *Twelfth International Solar Wind Conference, Saint-Malo, France, 21–26 June 2009*, vol. 1216 of *AIP Conference Proceedings*, Maksimovic, M., Meyer-Vernet, N., Moncuquet, M., and Pantellini, F., Eds., 2010.
7. Feldstein, Y.I., Modelling of the Magnetic Field of Magnetospheric Ring Current as a Function of Interplanetary Medium Parameters, *Space Sci. Rev.*, 1992, vol. 59, pp. 83–165.
8. Tsurutani, B.T., Gonzalez, W.D., Gonzalez, A.L.C., et al., Interplanetary Origin of Geomagnetic Activity in the Declining Phase of the Solar Cycle, *J. Geophys. Res.,* 1995, vol. 100, no. A11, pp. 21717–21733.
9. Goncharova, M.Yu. and Maltsev, Yu.P., Correlation of the K_p Index with the Solar-Wind Parameter, *Geomagn. Aeron.*, 2001, vol. 41, no. 3, pp. 305–309.
10. Borovsky, J.E. and Funsten, H.O., Role of Solar Wind Turbulence in the Coupling of the Solar Wind to the Earth's Magnetosphere, *J. Geophys. Res.*, 2003, vol. 108, no. A6, p. 1246.
11. D'Amicis, R., Bruno, R., and Bavassano, B., Is Geomagnetic Activity Driven by Solar Wind Turbulence?, *Geophys. Res. Lett.*, 2007, vol. 34, p. L05108. doi: 1029/2006GL028896.
12. Romanova, N., Pilipenko, V., Crosby, N., and Khabarova, O., ULF Wave Index and Its Possible Applications in Space Physics, *Bulg. J. Phys.,* 2007, vol. 34, pp. 136–148.
13. Jankovicova, D., Voros, Z., and Simkanin, J., The Influence of Solar Wind Turbulence on Geomagnetic Activity, *Nonlin. Processes Geophys.*, 2008, vol. 15, pp. 53–59.
14. Badruddin, V.G., Interplanetary Structures and Solar Wind Behaviour during Major Geomagnetic Perturbations, *J. Atmos. Terr. Phys.*, 2009, vol. 71, pp. 885–896.
15. Yokoyama, N. and Kamide, Y., Statistical Nature of Geomagnetic Storms, *J. Geophys. Res.,* 1997, vol. 102, no. A7, p. 14215.
16. Kershengolts, S.Z., Barkova, E.S., and Plotnikov, I.Ya., Dependence of Geomagnetic Disturbances on Extreme Values of the Solar Wind E_y Component, *Geomagn. Aeron.*, 2007, vol. 46, no. 2, pp. 1–9.
17. Plotnikov, I.Ya. and Barkova, E.S., Advances in Space Research Nonlinear Dependence of D_{st} and *AE* Indices on the Electric Field of Magnetic Clouds, *Adv. Space Res.*, 2007, vol. 40, pp. 1858–1862.
18. King, J.H. and Papitashvili, N.E., Solar Wind Spatial Scales in and Comparisons of Hourly Wind and ACE Plasma and Magnetic Field Data, *J. Geophys. Res.*, 2004, vol. 110, no. A2, A02209. doi: 10.1029/2004JA010804.
19. Yermolaev, Yu.I., Nikolaeva, N.S., Lodkina, I.G., and Yermolaev, M.Yu., Relative Occurrence Rate and Geoeffectiveness of Large Scale Types of the Solar Wind, *Kosm. Issled.*, 2010, vol. 48, no. 1, pp. 3–32. [*Cosmic Research*, pp. 1–30].
20. Lopez, R.E. and Freeman, J.W., Solar Wind Proton Temperature–Velocity Relationship, *J. Geophys. Res.*, 1986, vol. 91, p. 1701.
21. Dungey, J.W., Interplanetary Magnetic Field and the Auroral Zones, *Phys. Rev. Lett.*, 1961, no. 6, p. 47.
22. Axford, W.I. and Hines, C.O., A Unifying Theory of High-Latitude Geophysical Phenomena and Geomagnetic Storms, *Can. J. Phys.*, 1961, no. 39, p. 1433.
23. Borovsky, J.E. and Denton, M.H., Differences between CME-Driven Storms and CIR-Driven Storms, *J. Geophys. Res.*, 2006, vol. 111, A07S08. doi: 10.1029/2005JA011447.
24. Denton, M.H., Borovsky, J.E., et al., Geomagnetic Storms Driven by ICME- and CIR Dominated Solar Wind, *J. Geophys. Res.*, 2006, vol. 111, A07S07. doi: 10.1029/2005AJ011436.
25. Despirak, I.V., Lubchich, A.A., Yahnin, A.G., et al., Development of Substorm Bulges during Different Solar Wind Structures, *Ann. Geophys.*, 2009, vol. 27, no. 5, p. 1951.
26. Huttunen, K.E.J., Koskinen, H.E.J., Karinen, A., and Mursula, K., Asymmetric Development of Magnetospheric Storms during Magnetic Clouds and Sheath Regions, *Geophys. Res. Lett.*, 2006, vol. 33, L06107. doi: 10.1029/2005GL024894.
27. Pulkkinen, T.I. Partamies, N., et al., Differences in Geomagnetic Storms Driven by Magnetic Clouds and ICME Sheath Regions, *Geophys. Res. Lett.*, 2007, vol. 34, L02105. doi: 10.1029/2006GL027775.
28. Yermolaev, Yu.I., Nikolaeva, N.S., Lodkina, L.G., and Yermolaev, M.Yu., Specific Interplanetary Conditions for CIR-, Sheath-, ICME-induced Geomagnetic Storms Obtained by Double Superposed Epoch Analysis, Preprint http://arxiv.org/abs/0911.3315, 2009.
29. Turner, N.E., Cramer, W.D., Earles, S.K., and Emery, B.A., Geoefficiency and Energy Partitioning in CIR-Driven and CME-Driven Storms, *J. Atmospheric and Solar-Terrestrial Physics,* 2009, vol. 71, no. 10–11, pp. 1023–1031.
30. Borovsky, J.E. and Denton, M.H. Magnetic field at geosynchronous orbit during high-speed stream-driven storms: Connections to the solar wind, the plasma sheet, and the outer electron radiation belt, *J. Geophys. Res.,* 2010, no. 115, A08217. doi: 10.1029/2009JA015116.
31. Khabarova, O.V. and Yermolaev, Yu.I. Solar wind parameters behavior before and after magnetic storms, *J. Atmospheric and Solar-Terrestrial Physics,* 2008, vol. 70, pp. 384–390. doi: 10.1016/j.jastp.2007.08.024.
32. Weigel, R.S. Solar wind density influence on geomagnetic storm intensity, *J. Geophys. Res.,* 2010. doi: 10.1029/2009JA015062.
33. Simms, L.E., Pilipenko, V. and Engebretson, M.J. Determining the Key Drivers of Magnetospheric Pc5 Wave Power, *J. Geophys. Res.,* 2010. doi: 10.1029/2009JA015025.