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Statistical Investigation of Heliospheric Conditions Resulting in Magnetic Storms

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Abstract—Time behavior of the solar wind and interplanetary magnetic field parameters is investigated for 623 magnetic storms of the OMNI database for the period 1976–2000. The analysis is carried out by the superposed epoch technique (the magnetic storm onset time is taken to be the beginning of an epoch) for five various categories of storms induced by various types of solar wind: CIR (121 storms), Sheath (22 storms), MC (113 storms), and "uncertain type" (367 storms). In total, the analysis conducted for "all storms" included 623 storms. The obtained data, on one hand, confirm the results obtained earlier without selecting the intervals according to the solar wind types, and, on the other hand, they indicate the existence of distinctions in the time variation of parameters for various types of solar wind. Though the lowest values of the B_z-component of IMF are observed in the MC, the lowest values of the D_{st}-index are achieved in the Sheath. Thus, the strongest magnetic storms are induced, on average, during the Sheath rather than during the MC body passage, probably owing to higher pressure in the Sheath. Higher values of nkT, T/T_{exp}, and β parameters are observed in the CIR and Sheath and lower ones in the MC, which corresponds to the physical essence of these solar wind types.

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1. INTRODUCTION

One of the key issues of solar-terrestrial physics is the determination of conditions in the solar wind which are responsible for inducing magnetospheric disturbances in general and magnetic storms in particular. Though the direct measurements in the interplanetary medium have shown long ago that geomagnetic storms are mainly associated with the interplanetary magnetic field (IMF) orientation in the southward direction, i.e., with $B_z < 0$ [1, 2], and a large body of experimental material on the conditions in the interplanetary medium and magnetosphere during magnetic storms was accumulated and analyzed (see, e. g., papers and reviews [3–16] and references therein), many questions remain open till now.

In the usual quasistationary solar wind the magnetic field lies in the ecliptic plane, and it does not contain at all a considerable and long-term B_z component of the IMF sufficient for inducing a magnetic storm. However, some disturbed types of the solar wind streams and, first of all, such as magnetic clouds (MC) and compression regions at the boundary of a slow and fast streams of the solar wind (the corotating interaction region—CIR), can contain a large and prolonged B_z component of the IMF, including that of southward orientation, which results in the magnetic storm [6, 9, 17–21]. Though these facts are well known and have been widely discussed in the science literature, their analysis can be criticized for some drawbacks.

1. When analyzing the time behavior of solar wind parameters during a magnetic storm the solar wind intervals are not selected according to the types of streams (see, e. g., one of recent[1] papers [8]). Any other selection of intervals (for example, according to phases of the solar activity cycle) results only in a different proportion between different number of solar wind types in the averaged time variation of parameters, and these averaged parameters can significantly differ from really observed solar wind parameters. For example, in CIR one observes the values of temperature, density and β-parameter, which are higher than mean values in ordinary solar wind, while in MC these values are lower than mean ones, and the averaged values will differ both from those observed in CIR and in MC.

2. If the selection of solar wind types was performed, then the only fact of presence of any type of stream was analyzed without statistical processing of the time variation of parameters, or the time variation

[1] When this paper was already submitted for publication, the work was published by Zhang, J.-C., Liemohn M.W., Kozyra, J.U., *et al.*, "A Statistical Comparison of Solar Wind Sources of Moderate and Intense Geomagnetic Storms at Solar Minimum and Maximum," *J. Geophys. Res.*, 2006, vol. 111, doi: 10.1029/2005JA011065 in which also no selection over the types of solar wind streams has been done (http://arxiv.org/abs/physics/0603251).

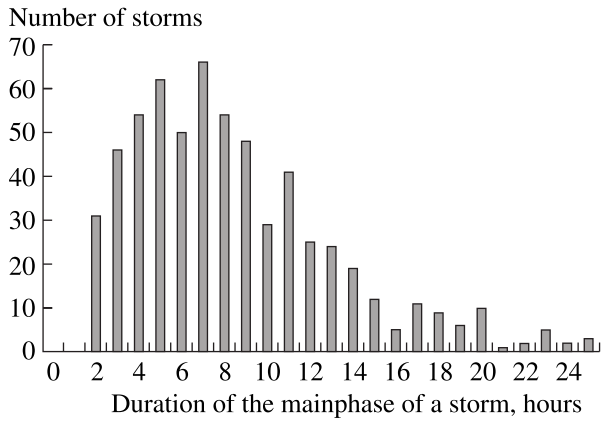

Fig. 1. The histogram of durations of the main phase of magnetic storms with $D_{st} < -60$ nT for the period of 1976–2000.

was studied for separate events without statistically revealing characteristic features for the given solar wind type (see, e. g., [6, 9, 17, 20]).

One should mention paper [22], in which the time variation of key solar wind and IMF parameters is presented for magnetic storms during CIR and MC. The fact is that the CIR and MC durations equal about one day, on the average, and do not exceed 2 days, as a rule. But, according to the figure presented in the paper, the parameters have been calculated over the interval from –3 to +5 days relative to the D_{st}-index minimum, i.e., over the interval of 8 days. The comparison of the processing interval duration with CIR and MC durations raises a question on the possibility of such a calculation and natural doubts in correctness of the used data processing technique.

In the present work we continue investigation of the conditions in the solar wind, which cause magnetic storms [6, 23]. For this purpose we, using the OMNI database, analyze by the superposed epoch technique the interplanetary conditions for 623 magnetic storms with $D_{st} < -60$ nT for the period of 1976–2000; in so doing we consider various solar wind types separately. Unlike our previous work [6], in which we have investigated NCIR and MC, in this paper we consider separately the region of the magnetic cloud itself and the compression region in front of the magnetic cloud (the Sheath) whose formation nature is close to that of CIR. But in the given case it is the MC that plays a part of a "piston" rather than the fast solar wind stream as in the case of CIR.

2. DESCRIPTION OF THE TECHNIQUE

We have selected for the analysis 623 magnetic storms with $D_{st} < -60$ nT for the period of 1976–2000, because for these storms the OMNI database contained measurements of solar wind and/or IMF parameters. The types of solar wind streams were determined for the intervals, which included the period before a storm and after its beginning, and the instants of beginning (onsets) of magnetic storms were distributed in the solar wind types as follows: CIR—121 storms, Sheath—22, MC—113, and "uncertain type"—367. To the "uncertain type" were mainly attributed the intervals, for which either some parameters were absent (this did not allow one to reliably identify the type of a stream) or the phenomenon had such a complicated character that it did not allow one to separate unambiguously long intervals of any of presented types of streams. Thus, the interplanetary conditions (types of streams) were determined for the magnetic storms composing less than a half of all storms. One should mention here that this percentage was the lowest at the beginning of the 25-year interval and has grown to the middle of 1990s, when nearly continuous solar wind patrolling began. For comparison with the works which did not take into account the existence of differing solar wind types, the parameters were determined for all storms without selection as well, and these results are presented here with the designation of "all storms."

As to the technique of determining the solar wind types, it is necessary to note that, though many researchers agree in definition of these stream types qualitatively, there exist quantitative disagreements both in a number of parameters used for identification and in numerical values of parameters when the threshold criteria are used. This leads to the situation, when for some events the identification can be ambiguous and dependent on the criteria utilized. By this reason we have attributed such cases to the "uncertain type." The criteria we have used are described more accurately in paper [6], the Sheath criteria of definition being the same, as those for CIR but in contrast with CIR, after Sheath we observed MC rather than high-speed solar wind.

To study the time variation of interplanetary medium parameters near the magnetic storm onset, the superposed epoch technique was used. This technique is similar to the method described in [8], but differs from it in the fact, that we have preliminarily selected the intervals into 4 solar wind types. We should make here a short comment concerning the choice of a zero epoch ("zero" time) when this technique is used. The fact is that in the overwhelming majority of works, where this technique was applied, the time of the D_{st}-index minimum was used as a "zero" time. In our opinion, this approach is suitable for studying the interplanetary causes of termination of the main phase of a storm, but not in the case of a cause of the storm onset. The point is, that the time of the D_{st}-index minimum can be separated from the storm onset by different time. Figure 1 shows the histogram of time duration of the main phase for all storms from our data set. It should be noted that the visual analysis of the time variation of the D_{st}-index has shown that virtually for all storms with the main phase duration of more than 15 h, the

D_{st}-index profile was not monotonous, and, hence, the magnetic storm cannot be considered as isolated one. Thus, the duration of the main phase of an isolated storm varies, according to our data, from 2 to 15 h (the mean duration equals 7 ± 4 h). This implies that, if the D_{st}-index minimum time is taken to be a zero time, then in the region of times preceding the D_{st}-index minimum by 2–15 h, the parameters will be averaged both before and after the onset, and in this case one can not judge from the results of analysis, which particular variations of parameters have directly caused the storm onset.

With due account of the above considerations, we have taken the first point corresponding to a sharp decrease of the D_{st}-index to be a zero point (see Fig. 2). The points of the main phase of a storm were approximated by the cubic function, which, on one hand, allowed us to smooth the profile in case of nonsmooth profile of the D_{st}-index, and, on the other hand, this allowed us to choose a zero point more reliably, leaning first of all on a set of all points of the main phase rather than on separate points near SSC and onset. Since CIR, Sheath, and MC have duration shorter than the magnetic storm duration, we have used in the analysis, along with a zero time, also the times of intervals of the given type of the solar wind. In the case of sufficient statistics we have restricted the duration of analyzed intervals by limits from –12 to +12 h for CIR and Sheath, and from –12 to +18 h for MC.

For the sake of comparison with previous works that use the D_{st}-index minimum as a zero point, we have carried out the analysis also for such an approach, when the D_{st}-index minimum was used as a zero point. Figure 3 shows the results of using the superposed epoch technique for two approaches to zero point determination. In the case of using the D_{st}-index minimum as a zero point, the time profile of a usual magnetic storm (with a sharp main part, flat minimum and slow recovery part) is distorted, and the prominent storm onset disappears. Nevertheless, such an approach allows one to investigate the causes in the interplanetary medium, leading to termination of the main phase and transition to the recovery phase of a storm. The analysis of results, obtained in this way, will be given in the subsequent paper. However, in the present paper we concentrate our attention on the interplanetary causes resulting in a storm and, accordingly, we compare our results only with those works, in which the storm onset time was chosen as a zero time for the superposed epoch technique.

3. RESULTS

We begin the presentation of results with the description of the D_{st}-index (Fig. 4). As it should be expected, the plot for the "uncertain type" (Fig. 4a) only slightly differs from that averaged over "all storms." The behavior for CIR (Fig. 4c) also slightly differs from the average one, but the curves for Sheath (4b) and MC (4d) pass noticeably lower than that averaged over all storms, the medium curve of the D_{st}-index for Sheath being the lowest. Thus, the results of analysis have shown that, on average, the strongest magnetic storms are induced by the compression region ahead of the magnetic cloud body rather than by the magnetic cloud itself.

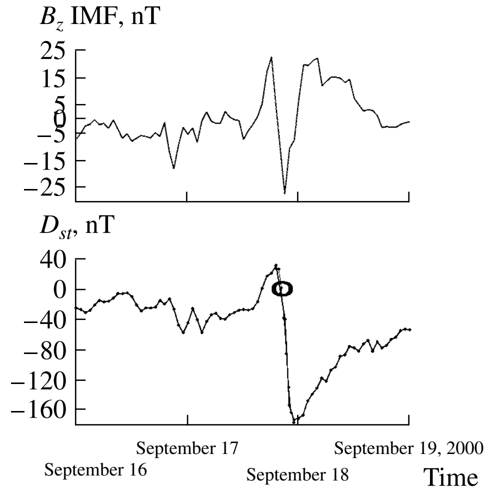

Fig. 2. Time profiles of the B_z-component of IMF and of the D_{st}-index for September 16–19, 2000, explaining the choice of a "zero" point (a circle) in the given work.

Here it should be noted that the calculated values of dispersion (standart deviation) for this and subsequent figures are often comparable with the mean values of parameters themselves because of a large scatter of the parameters. In Figs. 12–17, presented in the logarithmic scale, some points on the lower plot and the whole plot (the "mean value"– "dispersion") are not shown, since the values turn out to be negative. In this case the distinctions in the mean behavior of parameters for various types of streams can be treated only as an assumption, and with a certain fraction of caution. For higher reliability it is necessary to considerably increase the observation statistics.

The behavior of the corrected D^*_{st}-index (Fig. 5) is similar to the behavior of the D_{st}-index for all types of the solar wind. In this case the tendency of the minimum value of the D^*_{st}-index being reached in the Sheath is exhibited more clearly than for the uncorrected D_{st}-index. Of interest is the fact that the curves on the b–d panels turn out to be more indented (nonmonotonous). This fact is, first of all, due to a lower statistics of the cases with the corrected index, since in a considerable number of cases there were no measurements of the interplanetary medium parameters required for calculating this index.

Figure 6 presents the time variation of the K_p-index. This index for all types of the solar wind begins to grow some hours before the storm onset in accordance with the D_{st}-index: 4–6 h before for all solar wind types

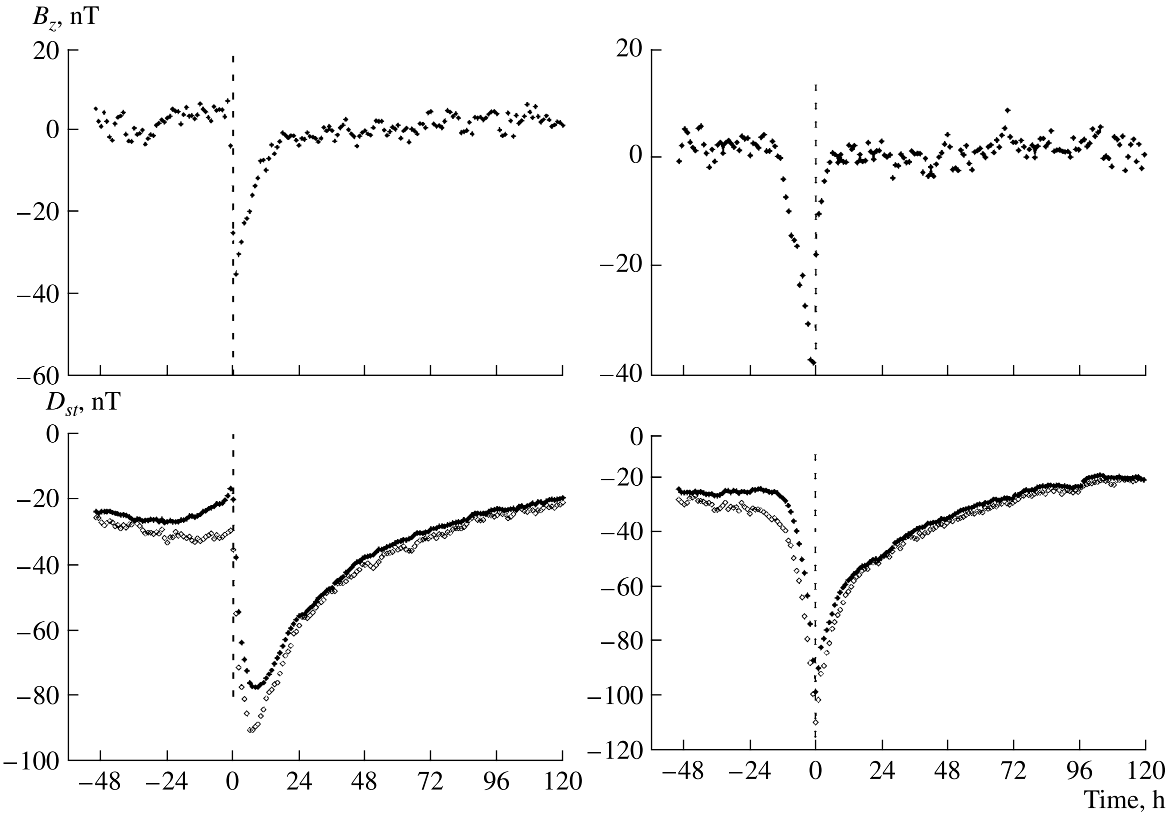

Fig. 3. Time profiles of the B_z component of IMF, uncorrected D_{st} (dark symbols), and corrected D^*_{st} indices, obtained by the superposed epoch technique for all storms with zero points chosen as in Fig. 2 (on the left) and as the D_{st}-index minimum (on the right).

except the Sheath, for which the growth begins 10 h before. During the storm the K_p-index is higher for Sheath than for other types; in addition, it is higher by unity than the mean not only during the storm, but 10 h before it as well.

Figure 7 presents the behavior of the magnetic field magnitude B. In total, the magnetic field for storms during the CIR, Sheath, and MC periods is higher (and in the "uncertain type" lower) than for "all storms." For "all storms," for "uncertain type," and for CIR the field magnitude reaches a maximum near the storm onset

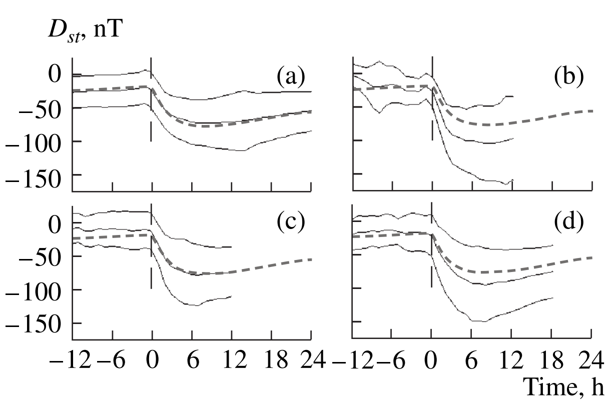

Fig. 4. Time variation of the D_{st}-index obtained for all events (the gray dashed line on all panels) for the "uncertain type" (a), CIR (c), Sheath (b) and MC (d). The central line on the a–d panels shows the behavior of the mean value, and the upper and lower lines are offset by the dispersion value.

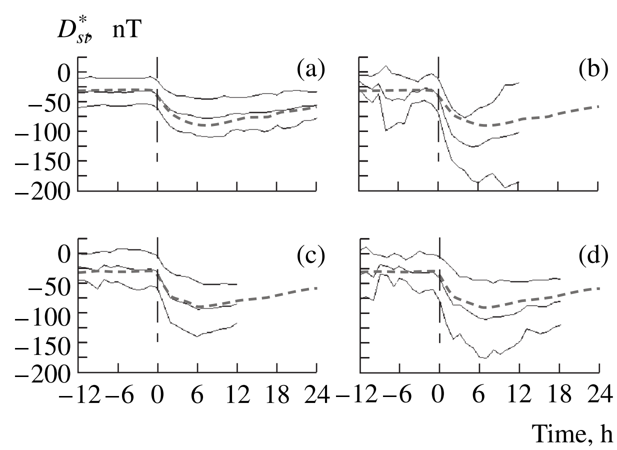

Fig. 5. The same as in Fig. 4 for the corrected D^*_{st}-index.

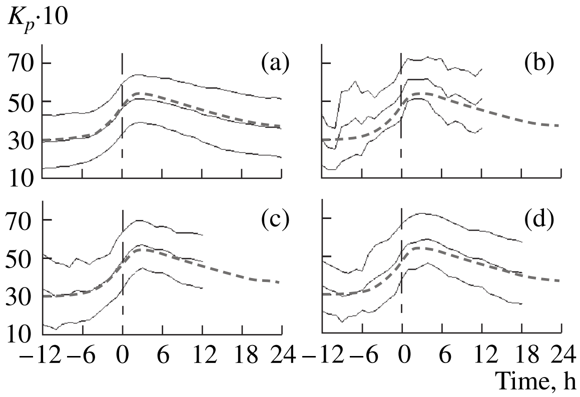

Fig. 6. The same as in Fig. 4 for the K_p-index.

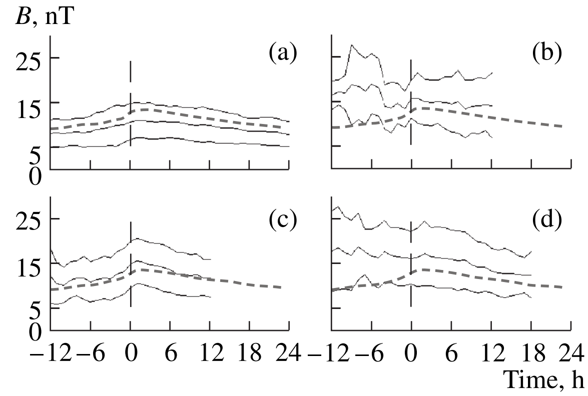

Fig. 7. The same as in Fig. 4 for the magnitude B of the IMF.

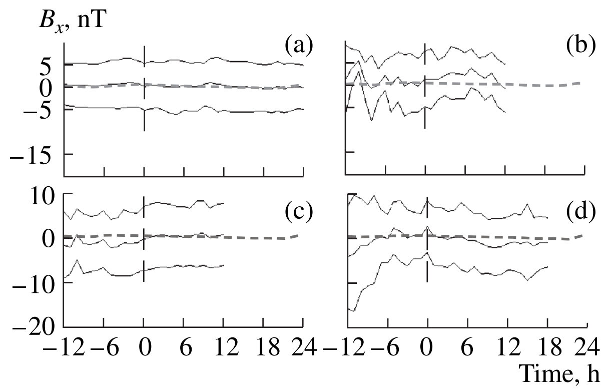

Fig. 8. The same as in Fig. 4 for the B_x component of the IMF.

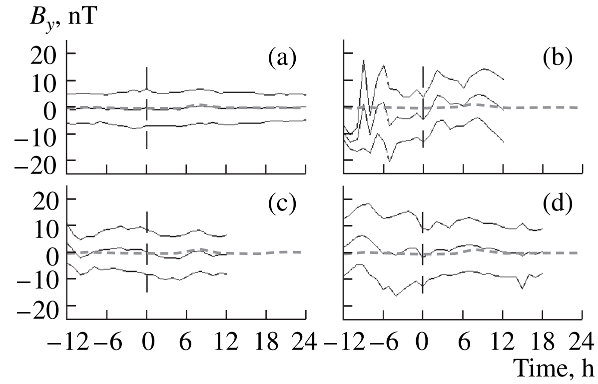

Fig. 9. The same as in Fig. 4 for the B_y component of the IMF.

(i.e., in 1–2 h), while for Sheath and MC it has a falling character within the limits of plots.

The B_x and B_y components of the IMF (Figs. 8 and 9), apparently, have no prominent tendency near the magnetic storm beginning instant, since, on average, they only slightly differ from zero. The only specific feature is observed in the interval from –6 to +1 h for Sheath, when the mean B_y component was about –5 nT.

A more obvious dependence is observed for the B_z-component of the IMF (Fig. 10), when for all solar wind types the B_z-component turns southward (i.e., becomes negative) 1–2 h before the storm onset, on the average. Then it continues to decrease for 1–2 h after the storm onset, and then slowly returns to zero values in half a day. It is important to note that, in the average in absolute value and in the integral over time the B_z-component reaches the largest values during the MC period. Nevertheless, the strongest storms are observed during the Sheath time, which is, probably, associated with higher values of velocity, density, and thermal and dynamic pressures at the initial stage of a storm in the Sheath (see Figs. 11, 13, 14 and 15).

The solar wind velocity (Fig. 11) for "all storms" and for storms induced by the solar wind of "uncertain type" monotonously grows 3 h before the storm from 450 to 500 km/s, and for CIR the wind velocity continues to grow after the storm onset as well. The wind velocity for MC decreases from 550 down to 450 km/s, and in the Sheath it reaches a maximum of about 550 km/s just after the storm onset. Temperature (Fig. 12) does not change, virtually, for "all storms" and for storms induced by the solar wind of "uncertain type"; it grows near the storm onset for CIR and Sheath and drops after the storm onset for MC. Density (Fig. 13) has short maxima near the storm onset for all types of the wind, and only for Sheath the high density is observed during the long interval before the storm and after it.

The behavior of dynamic pressure (Fig. 14) is similar to the behavior of density shown in the preceding figure. The thermal pressure (Fig. 15) for "all storms," for storms induced by the solar wind of "uncertain type," and by Sheath is similar, qualitatively, to the behavior of dynamic pressure; however, it grows for CIR and Sheath, and drops for MC with changing time near the storm onset.

Parameter β (Fig. 16) is not subject to strong time variations (except for the Sheath, where the statistics is scarce); it turns out to be higher than the mean one in

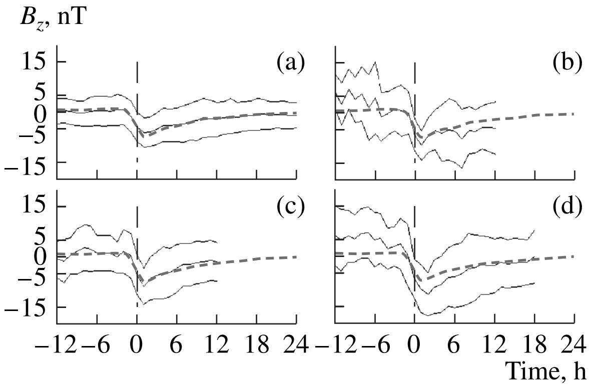

Fig. 10. The same as in Fig. 4 for the B_z component of the IMF.

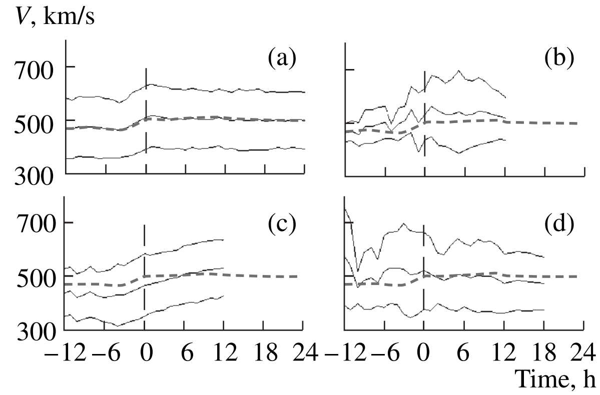

Fig. 11. The same as in Fig. 4 for the solar wind velocity.

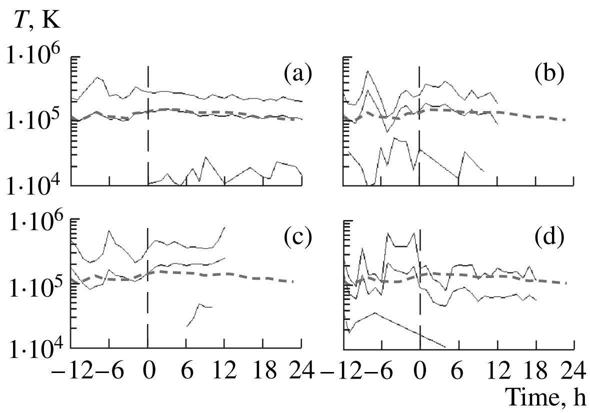

Fig. 12. The same as in Fig. 4 for the proton temperature of the solar wind.

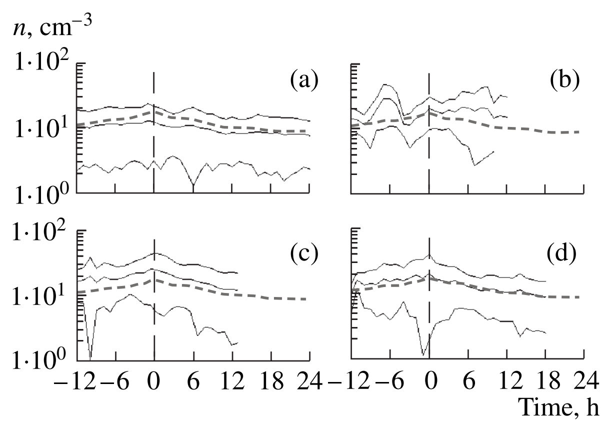

Fig. 13. The same as in Fig. 4 for the solar wind density.

CIR and Sheath and lower than the mean in MC. As for the T/T_{exp} parameter, it also varies slightly. It is close to the mean for the "uncertain type" and Sheath, higher than the mean in CIR, and lower than the mean in MC.

4. DISCUSSION OF RESULTS

The results we have obtained without selection based on the solar wind types (for "all storms" and for the "uncertain type") well agree, in general, with earlier published results obtained with choosing the storm onset instant as a zero time [8, 24, 25, 26]. (In the subsequent publication we are going to demonstrate that our results well agree with similar works [27, 28] also in the case, when the D_{st} minimum is chosen as the time of epoch beginning). However, the data selection according to the solar wind types made it possible to update some results and to obtain new ones as well.

In many works it was pointed out that the strongest magnetic storms are induced by the magnetic clouds [3, 6]. Our results confirm this conclusion; however, they show that, on average, the greatest storms are induced by the compression region ahead of the magnetic cloud body (in the Sheath) rather than by the body itself. It is important to note that, on average, the B_z-component of IMF is slightly smaller in MC than in the Sheath, but this smallness, apparently, is fairly compensated by higher values of dynamic and thermal pressures and density in the Sheath during the main phase of a storm.

In paper [8], where the storm onset time was taken as a zero time, it was found that the small negative B_y-component of the IMF was observed before the storm onset, and this fact was interpreted as an indication of compression of the region ahead of the fast solar wind stream. We have detected such a behavior of the negative B_y-component of the IMF only before the magnetic storms induced by the Sheath. This implies that our results confirm the result obtained in paper [8], but refine it in the respect, that it is observed in the Sheath only, thus confirming also the interpretation, where the magnetic cloud acts as a fast stream of the solar wind.

Unlike many previous works, we presented here the average time behavior of the thermal pressure *nkT*, the ratio of measured-to-estimated temperature T/T_{exp}, and the ratio of thermal-to-magnetic pressure β, since these

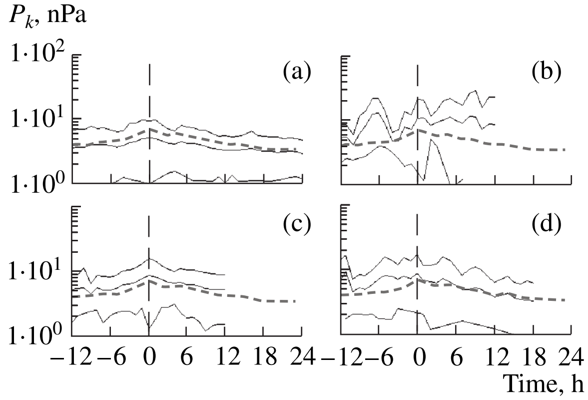

Fig. 14. The same as in Fig. 4 for the dynamic pressure of the solar wind.

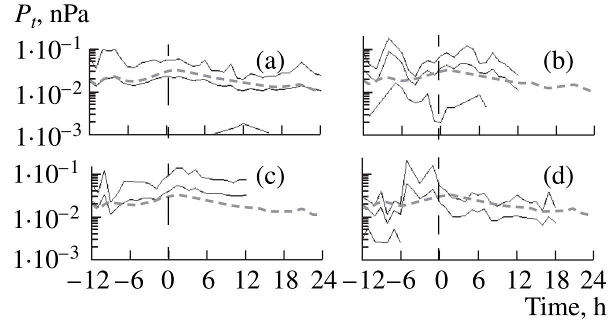

Fig. 15. The same as in Fig. 4 for the thermal pressure of the solar wind.

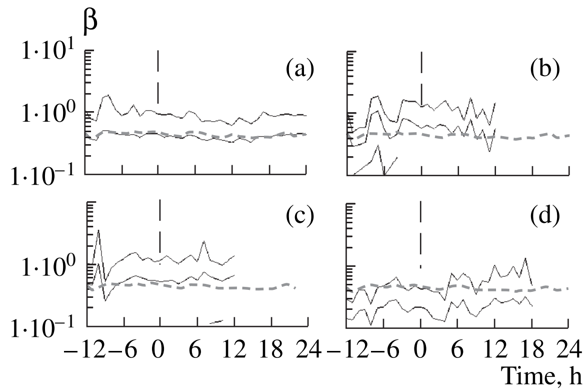

Fig. 16. The same as in Fig. 4 for the ratio of thermal and magnetic pressures in the solar wind.

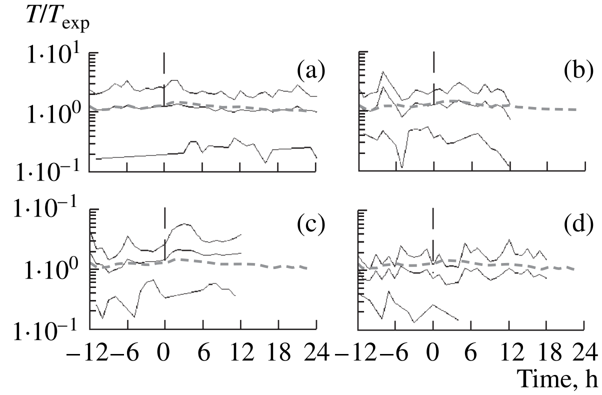

Fig. 17. The same as in Fig. 4 for the ratio of measured solar wind temperature to the temperature estimated from the solar wind velocity.

parameters are often used for identifying various types of the solar wind and, in particular, CIR, Sheath, and MC. Taking into account that, on average, the squared solar wind velocity is proportional to temperature T and inversely proportional to density n [29], one can easily notice that the nkT and T/T_{exp} parameters should change in a similar manner [30], which is just confirmed by our results in Figs. 15 and 17. In general, the fact that the nkT, T/T_{exp}, and β parameters are high in CIR and Sheath, and low in MC, are not surprising and indirectly confirm the selection of solar wind types made by us.

CONCLUSION

Thus, the analysis of 623 magnetic storms with $D_{st} < -60$ nT during the 1976–2000 period was carried out. The analysis was performed by the superposed epoch technique (with zero time equal to the storm beginning time) for the OMNI database parameters, supplemented by some parameters calculated on the basis of this database, separately for CIR, Sheath, and MC. The investigations have shown the following.

1. The behavior of solar wind parameters during magnetic storms essentially differs for various types of the solar wind; however, for all types of the wind the B_z-component of the IMF turns southward 1–2 h before the storm onset (reaching a minimum in 2–3 h after the storm onset) together with increasing solar wind density and dynamic pressure.

2. Though the lowest values of the B_z-component of the IMF are observed in the MC, the lowest values of the D_{st}-index are achieved in the Sheath. Thus, the strongest magnetic storms are induced during the Sheath rather than during the MC body passage, probably, owing to higher pressure in the Sheath.

3. Higher values of nkT, T/T_{exp}, and β parameters are observed in the CIR and Sheath and lower ones in the MC, which corresponds to the physical essence of these solar wind types and indirectly confirms the correctness of thus performed selection of the wind types.

4. The fact, that the B_y-component of the IMF is negative before the storm onset, found in paper [8], has been confirmed only for storms occurring during the Sheath time. This confirms the hypothesis discussed in paper [8] that plasma is compressed before the storm by some "piston."

ACKNOWLEDGMENTS

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REFERENCES

1. Russell, C.T., McPherron, R.L., and Burton, R.K., On the Cause of Magnetic Storms, *J. Geophys. Res.*, 1974, vol. 79, p. 1105.
2. Burton, R.K., McPherron, R.L., and Russell, C.T., An Empirical Rela*tionship between Interplanetary Conditions and* D_{st}, *J. Geophys. Res.*, 1975, vol. 80, pp. 4204–4214.
3. Bothmer, V. and Schwenn, R., The Interplanetary and Solar Causes of Major Geomagnetic Storms, *J. Geomagn. Geoelectr.,* 1995, vol. 47, p. 1127.
4. Gonzalez, W.D., Tsurutani, B.T., and de Gonzalez, A.L.C., Interplanetary Origin of Geomagnetic Storms, *Space Sci. Rev.*, 1999, vol. 88, pp. 529–562.
5. Vennerstroem, S., Interplanetary Sources of Magnetic Storms: A Statistical Study, *J. Geophys. Res.*, 2001, vol. 106, p. 175.
6. Yermolaev, Yu.I. and Yermolaev, M.Yu., Statistical Relationships between Solar, Interlanetary, and Geomagnetospheric Disturbances, 1976–2000, *Kosm. Issled.*, 2002, vol. 40, no. 1, pp. 3–16.
7. Daglis, I.A., Kozyra, J.U., Kamide, Y., *et al.*, Intense Space Storms: Critical Issue and Open Disputes, *J. Geophys. Res.*, 2003, vol. 108, no. A5, p. 1208. (doi:10.1029/2002JA009722).
8. Lyatsky, W. and Tan, A., Solar Wind Disturbances Responsible for Geomagnetic Storms, *J. Geophys. Res.*, 2003, vol. 108, no. A3, p. 1134. (doi:10.1029/2001JA 005057).
9. Huttunen, K.E.J. and Koskinen, H.E.J., Importance of Post-Shock Streams and Sheath Region as Drivers of Intense Magnetospheric Storms and High-Latitude Activity, *Ann. Geophys.*, 2004, vol. 22, p. 1729.
10. Rusanov, A.A. and Petrukovich, A.A., Influence of Solar Wind Parameters on the Level of Geomagnetic Field Fluctuations, *Kosm. Issled.*, 2004, vol. 42, no. 4, pp. 368–375.
11. Maltsev, Y.P., Points of Controversy in the Study of Magnetic Storms, *Space Sci. Rev.*, 2004, vol. 110, no. 3, pp. 227–277.
12. Veselovsky, I.S., Panasyuk, M.I., Avdyushin, S.I., *et al.*, Solar and Heliospheric Phenomena in October–November 2003: Causes and Effects, *Kosm. Issled.*, 2004, vol. 42, no. 5, pp. 453–508.
13. Gonzalez, W.D. and Echer, E., A Study on the Peak D_{st} and Peak Negative B_z Relationship during Intense Geomagnetic Storms, *Geophys. Res. Lett.*, 2005, vol. 32, no. 18. (doi:10.1029/2005GL023486).
14. Yermolaev, Yu.I., Zelenyi, L.M., Zastenker, G.N., *et al.*, Solar and Heliospheric Disturbances that Resulted in the Strongest Magnetic Storm on November 20, 2003, *Geomagn. Aeron.*, 2005a, no. 1, pp. 23–50.
15. Yermolaev, Yu.I., Zelenyi, L.M., Zastenker, G.N., *et al.*, A Year Later: Solar, Heliospheric and Magnetospheric Disturbances in November 2004, *Geomagn. Aeron.*, 2005b, no. 6, pp. 723–763.
16. Dmitriev, A.V., Crosby, N.B., and Chao, J.-K., Interplanetary Sources of Space Weather Disturbances in 1997 to 2000, *Space Weather*, 2005, vol. 3, no. 3. (doi: 10.1029/2004SW000104).
17. Huttunen, K.E.J., Koskinen, H.E.J., and Schwenn, R., Variability of Magnetospheric Storms Driven by Different Solar Wind Perturbations, *J. Geophys. Res.*, 2002, vol. 107, no. A7, p. 1121. (doi:10.1029/2001JA900171).
18. Richardson, I.G., Cane, H.V., and Cliver, E.W., Sources of Geomagnetic Activity during Nearly Three Solar Cycles (1972–2000), *J. Geophys. Res.*, 2002, vol. 107, no. A8, p. 1187. (doi: 10.1029/2001JA000504).
19. Veira, L.E.A., Gonzalez, W.D., Echer, E., and Tsurutani, B.T., Storm-Intensity Criteria for Several Classes of the Driving Interplanetary Structures, *Solar Physics*, 2004, vol. 223, nos. 1–2, pp. 245–258. (doi: 10.1007/s11207-004-1163-2).
20. Echer, E. and Gonzalez, W.D., Geoeffectiveness of Interplanetary Shocks, Magnetic Clouds, Sector Boundary Crossings and Their Combined Occurrence, *Geophys. Res. Lett.*, 2004, vol. 31, no. 9. (doi: 10.1029/2003GL019199).
21. Yermolaev, Yu.I., Yermolaev, M.Yu., Zastenker, G.N., *et al.*, Statistical Studies of Geomagnetic Storm Dependencies on Solar and Interplanetary Events: A Review, *Planet. Space Sci.*, 2005, vol. 53, nos. 1–3, pp. 189–196.
22. Miyoshi, Y. and Kataoka, R., Ring Current Ions and Radiation Belt Electrons during Geomagnetic Storms Driven by Coronal Mass Ejections and Corotating Interaction Regions, *Geophys. Res. Lett.*, 2005, vol. 32. (L21105, doi: 10.1029/2005GL024590).
23. Yermolaev, Yu.I., Yermolaev, M.Yu., and Nikolaeva, N.S., Comparison of Interplanetary and Magnetospheric Conditions for CIR-Induced and ICME-Induced Magnetic Storms, *European Geosciences Union. Geophysical Research Abstracts*, 2005b, vol. 7. (01064).
24. Taylor, J.R., Lester, M., and Yeoman, T.K., A Superposed Epoch Analysis of Geomagnetic Storms, *Ann. Geophys.*, 1994, vol. 12, pp. 612–624.
25. Davis, C.J., Wild, M.N., Lockwood, M., and Tulunay, Y.K., Ionospheric and Geomagnetic Responses to Changes in IMF B_z: A Superposed Epoch Study, *Ann. Geophys.*, 1997, vol. 15, pp. 217–230.
26. Yokoyama, N. and Kamide, Y., Statistical Nature of Geomagnetic Storms, *J. Geophys. Res.*, 1997, vol. 102, no. A7, p. 14215.
27. Maltsev, Y.P., Arykov, A.A., Belova, E.G., *et al.*, Magnetic Flux Redistribution in the Storm Time Magnetosphere, *J. Geophys. Res.*, 1996, vol. 101, p. 7697.
28. Loewe, C.A. and Prölss, G.W., Classification and Mean Behavior of Magnetic Storms, *J. Geophys. Res.*, 1997, vol. 102, no. A7, pp. 14209–14214.
29. Yermolaev, Yu.I., Transport of Mass, Momentum and Energy from the Sun to the Earth by Different Types of Solar Wind Streams, *ASP Conf. Ser.*, 1996, vol. 95, pp. 288–299.
30. Yermolaev, Yu.I. and Yermolaev, M.Yu., Statistic Study on the Geomagnetic Storm Effectiveness of Solar and Interplanetary Events, *Adv. Space Res.*, 2006. vol. 37, p. 1175. (doi: 10.1016/j.asr.2005.03.130).