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Comment on "Source regions and storm effectiveness of frontside full halo coronal mass ejections" by X. P. Zhao and D. F. Webb

Yu. I. Yermolaev

Space Research Institute, Russian Academy of Sciences, Profsoyuznaya

84/32, 117997 Moscow, Russia

Yu. I. Yermolaev, Space Research Institute, Russian Academy of Sciences, Profsoyuznaya 84/32, 117997 Moscow, Russia. (yermol@afed.iki.rssi.ru)

Abstract.

Attention is drawn to the fact that the storm effectiveness of coronal mass ejections in paper by *Zhao and Webb* [2003] is in conflict with other results, including ones published in papers by *Wang et al.*[2002], *Yermolaev and Yermolaev* [2003a] analyzing the same data set and paper by *Cane and Richardson* [2003] analyzing CME possibility to generate interplanetary CME near the Earth. Our brief review of published results and methods of data processing shows that estimation of storm effectiveness of coronal mass ejections in paper by *Zhao and Webb* [2003] is likely to be overestimated and requires a further investigation.

1. Introduction

Recently *Zhao and Webb* [2003] (ZW03 hereafter) studied the storm effectiveness of frontside full halo CMEs observed during 1996-2000 by the LASCO coronagraph on the SOHO spacecraft [*Brueckner et al.,* 1995] and presented interesting results on the storm effectiveness variations in the solar cycle. Unfortunately this paper does not allow one to estimate reliability of the presented results for several reasons: (1) the paper does not contain the detailed description of the used methods of selection and the data analysis, (2) list of references does not include several important works (including the works analyzing the same data set), and (3) the authors do not make a comparison with the earlier published results and do not give explanations of their essential divergences.

In the literature there are various estimations of CME geoeffectiveness, from 35-45% [*Plunkett et al.,* 2001; *Berdichevsky et al.,* 2002; *Wang et al.,* 2002; *Yermolaev and Yermolaev,* 2003a] up to 83-100% [*Brueckner et al.,* 1998; *St.Cyr et al.,* 2000; *Zhang et al.,* 2003] (see also [*Webb et al.,* 1996; *Webb et al.,* 2000; *Crooker,* 2000; *Li et al.,* 2001; *Webb,* 2002; *Yermolaev and Yermolaev,* 2003b]). Similarly, interplanetary CME (ICME), ejecta and magnetic cloud (MC) geoeffectiveness ranges from 25% [*Vennerstroem,* 2001] up to 82% [*Wu and Lepping,* 2002] (see also [*Gosling et al.,* 1991; *Gopalswamy et al.,* 2000, 2001; *Webb et al.,* 2000; *Yermolaev et al.,* 2000; *Richardson et al.,* 2001; *Yermolaev and Yermolaev,* 2002; 2003a,b; *Cane and Richardson,* 2003]) which do not agree with each other. It should be noted that previous papers by *Wang et al.* [2002] and *Yermolaev and Yermolaev* [2003a] have studied the geoeffectiveness of the same CME data set as ZW03 and obtained values that are less than in ZW03. The aim of this paper is to make a brief review of published results on the CME geoeffectiveness and to discuss possible reasons of their differences.

2. Methods of data analysis

A method of effectiveness study includes (1) data selection and (2) comparison of 2 (or more) different types of selected events, as a rule, in different space areas. So, first of all we should describe methods of selection of the magnetospheric storms, interplanetary events and coronal mass ejections.

The magnetosphere state is described by different indexes: AE, aa, Ap, and others [*Mayaud,* 1980]. It is customary to use two indexes for the description of magnetic storms: 3-hour Kp and 1-hour Dst which are determined by measurements of several mid-latitude and equatorial ground magnetic stations, respectively. Because the magnetic storm is connected basically with the Earth's ring current laying near to the equator, the Dst index is suggested to be more exact for the description of magnetic storms [*Grafe,* 1999]. In some cases the so-called corrected Dst index is used. This index is obtained by subtraction from an initial index of that part, which is defined by currents on the magnetopause and can be calculated using measured dynamic pressure $Pdyn$ of the solar wind: $Dst(corr) = Dst + A\,Pdyn + B = Dst - (0.02\,v\,n^{1/2} - 20nT)$, where v[km/s] and n[cm^{-3}] are the velocity and density of the solar wind respectively [*Burton et. al.,* 1975; *Gonzalez et al.,* 1989].

Since various papers used both different types of indexes and different levels of indexes for classification of magnetic storms, it is necessary to find quantitative connection between the storms determined with various indexes in order to compare the results of these works. As different sets of stations were used for construction of indexes, these indexes include the responses of different currents of the magnetosphere/ionosphere system, and, strictly speaking, describe the different physical systems related to one global phenomenon: magnetic storm. In this case it is impossible to expect full coincide of behavior of various indexes during one and the same event (see, for example, paper by *Vennerstroem* [2001]). However, it is possible to assume, that at sufficient statistics one can find correlation between various indexes during the maxima of magnetic storms. Such analysis, for example, was made for 1085 magnetic storms for the period of 1957-1993 [*Loewe and Prolss,* 1997]. We have repeated a comparison of Dst and Kp indexes for the period of 1976-2000 and have received rather close result [*Yermolaev and Yermolaev,* 2003b]. These investigations showed that Kp and Dst indexes may be used for classification of moderate and strong storms which are defined as storms with $Kp > 5$ and $Kp > 7$ (or $Dst <$ -50 and $Dst <$ -100 nT), respectively. Because in the range of $-50 < Dst <$ -60 nT there are many overlapping storms, we used uncorrected Dst index and stronger criterion for moderate storm $Dst <$ -60 nT [*Yermolaev and Yermolaev,* 2002, 2003a] which corresponds to the value $Kp > 5_+$.

Data on the interplanetary medium are mentioned but not discussed in details in ZW03. We briefly discuss the methods of solar wind event identification on the basis of *in situ* measurements of plasma and magnetic field, because this information will be used bellow.

Geomagnetic storms have been also classified as recurrent (or corotating) and transient (or sporadic). Recurrence usually refers to solar/interplanetary disturbances that repeat with the 27-day synodic rotation period of the Sun. A recurrent source is usually attributed to a fast solar wind stream emanating from a coronal hole which reacts with a slow stream from a coronal streamer and leads to a compressed region on the leading edge of the fast stream named corotating interaction region (CIR)(see reviews by *Crooker and Cliver* [1994]; *Tsurutani et al.* [1995]; *Gosling and Pizzo* [1999] and references therein).

Initially the occurrence of transient storms was connected with "driver gas" or "pistons" which propagate in the solar corona and/or interplanetary medium and can generate interplanetary shocks when their velocity is higher than the velocity of enviroment plasma. Now this term is usually replaced with such terms as "magnetic clouds (MC)", "ejecta" and "interplanetary CME (ICME)". Magnetic clouds are frequently considered as special cases of two other types which, apparently, can be considered as synonyms. For identification of these phenomena the observation of several conditions (in various combinations) is usually supposed to be met: (1) Plasma (ion and electron) components are colder than an environment, (2) There is stable (with a low level of fluctuations) and slowly rotating magnetic field, (3) The ratio of thermal pressure to magnetic one is low (parameter β <1), (4) The high abundance of α-particles and other minor ion components of the solar wind is observed, (5) There exist bidirectional thermal electrons, (6) There exist bidirectional energetic (> 20 Kev) protons, (7) There is the decrease of energetic (> 1 Mev) ions, (8) Unusual ionization states of thermal ions is observed in the solar wind [*Burlaga et al.,* 1990; *Yermolaev,* 1991; *Gosling, 1993*; *Shodhan et al.,* 2000; *Richardson et al.,* 2001; *Vennerstroem,* 2002; *Cane and Richardson,* 2003]. High magnetic field in comparison with environmental plasma of solar wind is usually consider as a distinctive feature of magnetic clouds. Rather frequently all these criteria are not carried out simultaneously (correlation coefficients for various pairs of parameters are found to lie in range of 49-93% [*Richardson et al.,* 1993]). It is necessary to note that some of these characteristics are rare in occurrence: for example, only several tens events with single-ionized atoms of helium He^+ were observed for the space age [*Zwickl et al.*, 1982; *Yermolaev et al.,* 1989; *Skoug et al.,* 1999]. Therefore sometimes even one and the same phenomenon can be classified differently by different authors depending on the criteria chosen, and in this case identification of the interplanetary phenomena can have ambiguous character.

If the data about magnetospheric indexes and the phenomena in the interplanetary medium are measured *in situ*, the data on the solar phenomena in the atmosphere of the Sun are obtained by remote sounding (ground- or space-based) in different frequency ranges of electromagnetic waves. Thus, the received signal is an integrated characteristic on full length of the line of sight. Frequency of emission is connected to conditions in the radiating volume of plasma, and, generally speaking, the measurements, carried out in various frequency ranges, give the characteristic of different areas of the Sun. To determine the dynamics of a solar phenomenon including the spatial motion (especially along a line of sight) is sufficiently difficult and ambiguous problem, since it is supposed that some aspects of the phenomenon (variable in their characteristics and position) are observed by one frequency channel/instrument, while other features are observed by others, and these measurements by several channels/instruments can be combined and used for research of this phenomenon.

This complex procedure is used for studying halo-CME motion on the basis of measurements of the *SOHO* space observatory: the position of dimming which is considered as the beginning of CME is determined on the solar disk with measurements by the EIT instrument in ultra-violet range, while CME motion behind the disk is determined by the LASCO white light coronagraph at which coronagraph's occulting disk closes (cuts out in sight) area equal to the size of solar disk and C2 and C3 channels allow one to study the corona at distances of 2-6 and 3-32 solar radii (see paper by *Brueckner et al.,* [1995] and site http://lasco-www.nrl.navy.mil). Thus, these two specified instruments measure emission not only in different ranges of frequencies, but also in different spatial areas and at different time. This comparison is very important for solving the key question: whether halo-CME goes to the Earth or away from it, but another question: how these two phenomena, measured by two instruments, are connected to each other, in our opinion, requires the further studying. Nevertheless, this procedure was used in previous papers by *Wang et al.* [2002] and *Yermolaev and Yermolaev* [2003a] and is used by ZW03.

Before an analysis of events in different spatial areas we should compare more critically those data analysis methods used for study of correlation of solar, interplanetary and magnetospheric phenomena which were described in previous papers. In addition to the ambiguity of comparison of the results connected with different approaches to event classification there is also an ambiguity connected with a technique of comparison of phenomena in two space areas. If two phenomena with samples $X1$ and $X2$ were chosen for the analysis and conformity was established for number of phenomena X12, then the "effectiveness" of the process $X1 \rightarrow X2$ is usually defined as a ratio of values $X12/X1$, which differs from the "effectiveness" of the process $X2 \rightarrow X1$ equal $X21/X2 = X12/X2$, because samples $X1$ and $X2$ are selected by various criteria and can be of different value. Thus, the "effectiveness" determined in different works depends on the direction of analysis of the process. If one takes into account that sometimes sample $X2$ is not fixed prior to the beginning of the analysis, i.e. the rule (or criteria) of selection of events for sample $X2$ originally is not fixed, the ambiguity of calculation of process "effectiveness" can be additionally increased.

As in solar-terrestrial physics we investigated 2-step process: the Sun - solar wind and the solar wind - magnetosphere, the data on the intermediate link (if available) can increase the reliability of estimations for the entire chain. Let us assume that there are data sets on the Sun ($X1$ and $Y1$), in the interplanetary medium ($Y2$ and $Z1$) and in the magnetosphere ($X2$ and $Z2$), for which some estimations of "effectiveness" of the processes $X1 \rightarrow X2$ (equal to $X12/X1$), $Y1 \rightarrow Y2$ ($Y12/Y1$) and $Z1 \rightarrow Z2$ ($Z12/Z1$) were obtained. In this case it is natural to assume that the "effectiveness" of the entire process should be close to a product of "effectivenesses" of each of its parts, i.e. $X12/X1 = (Y12/Y1)(Z12/Z1)$. In particular, it means that the "effectiveness" of the entire process can not be higher than the "effectiveness" of each of parts: $X12/X1 \leq Y12/Y1$ and $X12/X1 \leq Z12/Z1$. The published works contain the data sufficient for such an analysis and we make it below.

It is important to note that many authors frequently treat as "geoeffectiveness" of a phenomenon completely different values obtained with different procedures. In strict sense of this word, geoeffectiveness of the solar or interplanetary phenomenon is defined as percentage of corresponding set of the solar or interplanetary phenomena that resulted in occurrence of magnetic storms, and storms of a certain class. In other words, first of all it is necessary to select the solar or interplanetary phenomena by a certain rule, then one should examine each phenomenon from this list using a certain algorithm of occurrence of a storm . The time of delay between the phenomena which should be stacked in some beforehand given "window" is used as an algorithm of comparison of the various phenomena: either characteristic times of phenomenon propagation between two points, or time delay determined on some initial data.

Some authors apply an opposite method and use the back tracing analysis: initially they take the list of storms and extrapolate them back to the interplanetary space or on the Sun to search there for suitable phenomenon. This method allows one to find candidates for the causes of given magnetic storms in the interplanetary space or on the Sun rather than to determine geoeffectiveness. The phenomena of different classes (if they are suited on time) are frequently used as such candidates and this is one of the reasons of divergence of results in many papers.

3. Comparison of results

The results of comparison of CMEs and the various interplanetary phenomena with geomagnetic storms for last few years are shown in Tables 1 and 2. First of all it is necessary to note, that we have selected results in both the pairs of compared phenomena and the direction of tracing. For example, the record "$CME \rightarrow Storm$" means that the CME list was taken as the initial data set (the number of analyzed cases of CMEs is presented in the column "Number of events") and CMEs are compared with magnetic storms (the storm intensity is defined by an index presented in the column "Remarks"). Thus, we summarized the published data in 6 types of phenomena comparisons (3 space areas and 2 directions of tracing): $I. CME \rightarrow Storm$, $II.\ CME \rightarrow Magnetic\ clouds, Ejecta$, $III.\ Magnetic\ clouds, Ejecta \rightarrow Storm$, $IV.\ Storm \rightarrow CME$, $V.\ Storm \rightarrow Magnetic\ clouds, Ejecta$ and $VI.\ Magnetic\ clouds, Ejecta \rightarrow CME$. In II, III, V and VI we included both magnetic clouds and ejecta(ICME) which are close in their physical characteristics, but in the column "Number of cases" we noted the identification of authors by symbols MC (Magnetic clouds) and E (Ejecta).

Geoeffectiveness of CME is shown as direct tracing $I.\ CME \rightarrow Storm$, which includes 8 data sets, and it changes from 35 up to 71% [*Webb et al.,* 1996; *Webb et al.,* 2000; *Plunkett et al.,* 2001; *Berdichevsky et al.,* 2002; *Wang et al.,* 2002; *Webb,* 2002; *Yermolaev and Yermolaev,* 2003a,b and ZW03]. The data sets 6, 7 and 8 are likely to include the same halo-CME list. The result with 71% [*Webb et al.,* 2000] (later reproduced in papers by *Crooker* [2000] and *Li et al.* [2001]) was obtained with rather small statistics of 7 cases. Paper by *Webb* [2002] does not give information about statistics and its value 92% was observed only in 1997 (see Table 3). Other results obtained with statistics from 38 up to 132 CMEs are in the range of 35-50% and are in good agreement with each other. In our preceding paper [*Yermolaev and Yermolaev,* 2003a] the result of 35% was obtained for magnetic storms with $Dst < -60$ nT, and if we include weaker storms with $Dst < -50$ nT in analysis (this corresponds to storms with $Kp > 5$ in work by *Wang et al.* [2002]) we obtain geoeffectiveness CME $\sim$ 40% [*Yermolaev and Yermolaev,* 2003b]. Thus, it is possible to make a conclusion, that geoeffectiveness of Earth-directed halo-CME for magnetic storms with $Kp > 5 (Dst < -50\text{nT})$ is 40-50% at sufficiently high statistics of 38 up to 132 CMEs, and the values obtained in papers by *Webb* [2002] and ZW03 are overestimated. Probably, it is possible to explain by a suggestion that ZW03 rejected partial halo CMEs, but unfortunately ZW03 contains no obvious indications on the used technique (in particular, at what quantitative level there is a boundary between full and partial halo CMEs) and its comparison with the techniques used in the previous works.

Results of back tracing analysis $IV.\ Storm \rightarrow CME$ contain 3 data sets with correlations from 83 up to 100% and at lower statistics from 8 up to 27 of strong magnetic storms with $Kp > 6$ and $Dst < -100$ nT [*Brueckner et al.,* 1998; *St. Cyr et al.,* 2000; *Li* *et al.,* 2001; *Zhang et al.,* 2003]. These results are in good agreement, but it is not high geoeffectiveness of CME that is shown by them: they indicate that it is possible to find possible candidates among CMEs on the Sun for sources of strong magnetic storms with a high degree of probability.

The comparison of direct and back tracings $II.$ $(CME \rightarrow Magnetic\ clouds,\ Ejecta)$ and $VI.$ $(Magnetic\ clouds,\ Ejecta \rightarrow CME)$ for Earth-directed halo-CMEs shows that in the first case values of 60-70% are observed at statistics of 8-89 events [*Cane et al.,* 1998; *Webb et al.,* 2001], and in the second case 42% is observed at statistics of 86 events [*Cane et al.,* 2000]. Other results are obtained for any CMEs [*Lindsay et al.,* 1999; *Gopalswamy et al.,* 2000; *Burlaga et al.,* 2001; *Berdichevsky et al.,* 2002; *Cane and Richardson,* 2003], and they are not so reliable as for mentioned above results.

From comparison $III.$ $(Magnetic\ clouds,\ Ejecta \rightarrow Storm)$ it follows that the correlation for magnetic clouds is a little bit higher (57-82% [*Gopalswamy et al.,* 2000; *Yermolaev et al.,* 2000; *Yermolaev and Yermolaev,* 2002; *Wu and Lepping,* 2002]) than for ejecta, 40-50% (44% in paper by *Gosling et al.* [1991], $\sim$ 41% is average of 19 and 63% [*Richardson et al.,* 2001] and 43-50% [*Cane and Richardson,* 2003]). Back tracing *V.* $(Storm \rightarrow Magnetic\ clouds,\ Ejecta)$ yields inconsistent results: 67-73% [*Gosling et al.,* 1991; *Webb et al.,* 2000] and 25% [*Vennerstroem,* 2001]. It is necessary to emphasize that in all cases the definitions of storms and ejecta are different. For magnetic clouds in the period 1976-2000 our estimations is 33% for moderate and strong storms (25% for moderate storms and 52% for strong storms) [*Yermolaev and Yermolaev,* 2002], and they are in good agreement with results of work by *Vennerstroem* [2001].

The analysis of a sequence of 2-step direct tracing $II.$ ($CME \rightarrow Magnetic\ clouds$, $Ejecta$) and $III.$ ($Magnetic\ clouds$, $Ejecta \rightarrow Storm$) allows us to estimate a probability of the entire process $CME \rightarrow Storm$ as the product of probabilities, and for magnetic clouds we obtain a value 0.63 * (0.57 $\div$ 0.82) = 0.36 $\div$ 0.52, which is close to above mentioned results (40-50%) for the direct analysis of process $I.$($CME \rightarrow Storm$) and is lower than the estimation obtained by ZW03. For ejecta this approach resulted in lesser value. The analysis of a sequence of 2-step back tracing $V.$ ($Storm \rightarrow Magnetic\,clouds$, $Ejecta$) and $VI.$ ($Magnetic\,clouds$, $Ejecta \rightarrow CME$) does not allow us to obtain the high correlation $Storm \rightarrow CME$ in comparison with 83 - 100% in the entire process IV : (0.25 $\div$ 0.73) * (0.42 $\div$ 0.82) = 0.11 $\div$ 0.57. Thus, the results of comparison of two-step and one-step processes for direct tracing $CME \rightarrow Storm$ are in good agreement while results of two-step process for back tracing differ severalfold from the results of one-step process. It means that the techniques of the analysis of processes ($Storm \rightarrow Magnetic\ clouds$, $Ejecta$), ($Magnetic\,clouds$, $Ejecta \rightarrow CME$) and ($Storm \rightarrow CME$) require significant improvement.

Though storm effectiveness obtained in papers by *Webb et al.* [2000]; *Webb* [2002] and ZW03 relates to process $I.$($CME \rightarrow Storm$) and is lower, than in process $IV.$($Storm \rightarrow CME$), the values obtained in these papers are (1) regularly higher than in other papers in process $I.$($CME \rightarrow Storm$), (2) higher than in process $III.$ ($Magnetic\,clouds$, $Ejecta \rightarrow Storm$) (excluding paper by *Wu and Lepping,* [2002]), (3) close to values of papers related to process $II.$ ($CME \rightarrow Magnetic\,clouds$, $Ejecta$), and (4) higher than for 2-step process $II.$ ($CME \rightarrow Magnetic\ clouds$, $Ejecta$ * $III.$ ($Magnetic\ clouds$, $Ejecta \rightarrow Storm =$

$(0.6 \div 0.8) * (0.2 \div 0.8) = 0.1 \div 0.6$. Thus, effectiveness in papers by *Webb et al.* [2000]; *Webb* [2002] and ZW03 is likely to be overestimated.

Table 3 presents the data on solar cycle variation in several parameters for the period of 1997-2002: (1) the number of storms with $Dst < -60$ nT generated by magnetic clouds [*Yermolaev,* 2000], (2) percentage of storms with $Dst < -60$ nT generated by magnetic clouds [*Yermolaev and Yermolaev,* 2002], (3) percentage of interplanetary CME (ICME) resulting to storms with $Dst < -50$ nT [*Cane and Richardson,* 2003], (4) percentage of CME resulting in storms with $Dst < -50$ nT [*Webb,* 2002], (5) and (6) number of frontside full halo CME and percentage of these CMEs resulting to storms with $Dst < -50$ nT and for the CME located near the central meridian of the Sun, respectively [ZW03]. All parameters (1-4) have a maximum in 1997 and then decrease: (1), (2) and (4) decrease until 2000, (3) has a second small maximum in 1999-2000. Numbers of CMEs in (5a and 6a) increase but percentages in (5a and 5b) decrease down to 1999 and increase in 2000. It is necessary to note that the value in the second line (percentage of storms with $Dst < -60$ nT generated by magnetic clouds) has 2 maxima per cycle and change in antiphase with persentage of storms generated by the corotating interaction regions during 1976-2000 [*Yermolaev and Yermolaev,* 2002]. Because the storm effectiveness of CME ($CME \rightarrow Storm$) in paper ZW03 is higher than the storm effectiveness of ICME ($Ejecta \rightarrow Storm$) in paper by *Cane and Richardson* [2003] it is possible to suggest that yearly averaged results in ZW03 are also overestimated.

4. Conclusions

The presented comparison of methods and results of the analysis of the phenomena on the Sun, in the interplanetary space and in the Earth's magnetosphere shows that in addition to different methods used in each of areas, a way of comparison of the phenomena in various areas or for different direction of data tracing is of great importance for research of the entire chain of solar-terrestrial physics. To study the geoeffectiveness of the solar and interplanetary phenomena (i.e. their abilities to generate the magnetic storms on the Earth) it is necessary originally to select the phenomena, respectively, on the Sun or in the solar wind and then to compare the phenomenon with event at the following step of the chain. Thus, the obtained estimations of CME influence on the storm both directly (by one step $CME \rightarrow Storm$) and by multiplication of probabilities of two steps ($CME \rightarrow Magnetic\,cloud, Ejecta$ and $Magnetric\,cloud, Ejecta \rightarrow Storm$) are close to each other and equal to 40-50% [*Webb et al.,* 1996; *Cane et al.,* 1998; *Yermolaev et al.,* 2000; Gopalswamy et al., 2000; *Plunkett et al.,* 2001; *Wang et al.,* 2002; *Berdichevsky et al.,* 2002; *Wu and Lepping,* 2002; *Yermolaev and Yermolaev,* 2002, 2003a,b; *Cane and Richardson,* 2003]. The effectiveness obtained in papers by *Webb et al.* [2000]; *Webb* [2002] and ZW03 is likely to be overestimated. This value strongly differs from results of 83-100% obtained in papers by *Brueckner et al.* [1998]; *St.Cyr et al.* [2000] and *Zhang et al.* [2003] by searching for back tracing correlation, which characterizes the probability to find the appropriate candidates among CME for magnetic storms rather then geoeffectiveness of CME. The obtained value of 83-100% are not confirmed by the two-step analysis of sources of storms since at steps $Storm \rightarrow Magnetic\,cloud, Ejecta$ and $Magnetric\,cloud, Ejecta \rightarrow CME$ these values are (25-73)% [*Gosling et al.,* 1991; *Vennerstroem,* 2001; *Yermolaev and Yermolaev,* 2002] and $\sim$ 40% [*Cane et al.,* 2000], each of which is less than the value obtained by the one-step analysis $Storm \rightarrow CME$. Thus, to remove this contradiction the techniques of the analysis of the data suggested in papers by *Brueckner et al.* [1998]; *St.Cyr et al.* [2000] and *Zhang et al.* [2003] require the further development.

The obtained estimations of CME geoeffectiveness (40-50%) are close to estimations of geoeffectiveness of solar flares (30-40%) [*Park et al.,* 2002; *Yermolaev and Yermolaev,* 2003a] and exceed them slightly. As we have shown in paper by *Yermolaev and Yermolaev* [2002], for random distribution of the solar processes and the magnetic storms the formally calculated coefficient of correlation can be 30-40%. It means that the obtained estimations of CME and solar flare geoeffectiveness can be partially a result of random processes and, therefore, the forecast of geomagnetic conditions on the basis of observations of the solar phenomena can contain high level of false alarm.

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Table 1. Correlation between solar, interplanetary and magnetospheric phenomena.

N	%	Number of events	Remarks	Reference
		I. CME → Storm		
1	50	38	Kp	*Webb et al.,* 1996
2	71	7	$Dst < -50$	*Webb et al.,* 2000; *Crooker,* 2000; *Li et al.,* 2001
3	35	40	$Kp > 6$	*Plunkett et al.,* 2001
4	45	20	$Kp > 5$	*Berdichevsky et al.,* 2002
5	35-92	?	$Dst < -50$	*Webb,* 2002
6	45	132[a]	$Kp > 5$	*Wang et al.,* 2002
	20	132[a]	$Kp > 7$	
7	35	125[a]	$Dst < -60$	*Yermolaev and Yermolaev,* 2003a
	40	125[a]	$Dst < -50$	*Yermolaev and Yermolaev,* 2003b
8	64	70[b]	$Dst < -50$	*Zhao and Webb,* 2003
	71	49[c]	$Dst < -50$	
		II. CME → Magnetic cloud, Ejecta		
1	63	8	Earth-directed halo-CME	*Cane et al.,* 1998
2	60-70	89	Frotside halo-CME	*Webb et al.,* 2001
3	80	20	halo-CME	*Berdichevsky et al.,* 2002
		III. Magnetic cloud, Ejecta → Storm		
1	44	327 E	$Kp > 5$	*Gosling,* 1991
2		28 MC		*Gopalswamy et al.,* 2000
	67		$Dst < -60$	*Yermolaev and Yermolaev,* 2002
3	63	30 MC	$Dst < -60$	*Yermolaev et al.,* 2000
4		48 MC		*Gopalswamy et al.,* 2001
	57		$Dst < -60$	*Yermolaev and Yermolaev,* 2003b
5	19	1273 E	$Kp > 5_-$, Solar minimum	*Richardson et al.,* 2001
	63	1188 E	$Kp > 5_-$, Solar maximum	
6	82	34 MC	$Dst < -50$	*Wu and Lepping,* 2002
7	50	214 E	$Dst < -50$	*Cane and Richardson,* 2003
	43	214 E	$Dst < -60$	

[a] - Earth-directed halo-CME, [b] - frontside halo CME,

[c] - centered frontside halo CME.

Table 2. Continuation of Table 1

N	%	Number of events	Remarks	Reference
			IV. Storm → CME	
1	100	8	$Kp > 6$	*Brueckner et al.*, 1998
2	83	18	$Kp > 6$	*St.Cyr et al.*, 2000; *Li et al.*, 2001
3	96	27	$Dst < -100$	*Zhang et al.*, 2003
			V. Storm → Magnetic cloud, Ejecta	
1	73	37	$Kp > 7_-$	*Gosling*, 1991
2	67	12	$Dst < -50$	*Webb et al*, 2000
3	25	?	$Dst(corr)$	*Vennerstroem*, 2001
4	33	618	$Dst < -60$	*Yermolaev and Yermolaev*, 2002
	25	414	$-100 < Dst < -60$	
	52	204	$Dst < -100$	
			VI. Magnetic cloud, Ejecta → CME	
1	67	49 E	CME	*Lindsay et al.*, 1999
2	65	86 E	CME	*Cane et al.*, 2000
	42	86 E	Earth-directed halo-CME	
3	82	28 MC	CME	*Gopalswamy et al.*, 2000
4	50-75	4 MC	halo-CME	*Burlaga et al.*, 2001
	40-60	5 E	halo-CME	
5	56	193 E	CME	*Cane and Richardson*, 2003
6	48	21 MC	halo-CME	*Vilmer et al.*, 2003

Table 3. Year variations in correlation between solar, interplanetary and magnetospheric phenomena.

N	Correlated parameters	1997	1998	1999	2000	2001	2002	Reference
1	$Storm \rightarrow Magnetic\ cloud$	14	10	7	6			*Yermolaev,* 2001
2	% $Storm \rightarrow Magnetic\ cloud$	74	59	32	26			*Yermolaev and Yermolaev,* 2002
3	% $ICME \rightarrow Storm$	68	46	60	60	57	50	*Cane and Richardson,* 2003
4	% $CME \rightarrow Storm$	92	54	39	35			*Webb,* 2002
5a	$FFHCME^a$	11	13	13	33			*Zhao and Webb,* 2003
5b	% $FFH, CME^a \rightarrow Storm$	92	54	38	70			
6a	$FFHCME^b$	8	7	9	25			
6b	% $FFHCME^b \rightarrow Storm$	100	71	44	72			

[a] - Frontside Full Halo CME, [b] - centered Frontside Full Halo CME