Statistic Study of Geomagnetic Storm Dependences on Solar and Interplanetary Events

Y. I. Yermolaev, [a] M. Y. Yermolaev, [a] G. N. Zastenker, [a]
L. M. Zelenyi, [a] A. A. Petrukovich [a]

[a] *Space Research Institute RAS, Moscow, Russia*

J.-A. Sauvaud [b]

[b] *CESR, Toulouse, France*

Abstract

We present a brief review of published results on the geomagnetic storm effectiveness of CMEs and solar flares as well as of interplanetary events. Attention is drawn to the fact that the published values of storm effectiveness are in conflict to each others, and we discuss possible reasons of their differences. 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 space areas or for different direction of data tracing is of great importance for research of the entire chain of solar-terrestrial physics.

Key words: geomagnetic storm, coronal mass ejection, solar flare, interplanetary events, methods of data analysis

1 Introduction

One of the key questions of the Space Weather program is our possibility to predict occurrence of geoeffective disturbances in the interplanetary space and geomagnetic storms on the basis of the Sun observations. General concept, describing connection of the geomagnetic phenomena with processes on the Sun, does not change during many years. An energy source of the geomagnetic phenomena is the Sun which transfers energy to the Earth's magnetosphere by means of streams of the solar wind. The magnetosphere is usually closed

Preprint submitted to Planetary and Space Science – special issue13 October 2003

for solar wind, and energy from solar wind put in magnetosphere only in a case when interplanetary magnetic field (IMF) has a significant component parallel to the terrestrial magnetic dipole, i.e. approximately negative (southward) IMF B_z component (see, for example, papers by Russell and McPherron (1973); Akasofu (1981); Gonzalez (1999); Petrukovich et al. (2001) and references therein). In a case when rate of energy input is higher than rate of its quasi-stationary dissipation, energy collects in the magnetosphere. When its amount reaches and exceeds some certain level, any small disturbance outside or inside magnetosphere can result in release of this energy (so-called "trigger" mechanism) as reconnection of magnetic field, global reorganization of current systems of magnetosphere and heating/acceleration of plasma, i.e. generate magnetospheric disturbance.

Quasi-stationary solar wind usually does not contain long intervals of southward IMF components since the field basically lays in the ecliptic plane. However sometimes the large-scale disturbances propagate in the solar wind, such as interplanetary shocks (IS), magnetic clouds (MC), regions of compression on boundary of slow and fast streams (corotating interaction region - CIR) and some other ones which contain inside itself or/and modify an environment in such a manner that appreciable southward IMF B_z component can be presented in the solar wind within several hours. Such behavior of IMF can result in energy input into the magnetosphere and in generation of magnetospheric disturbances (Gosling et al., 1991; Gosling and Pizzo, 1999; Gonzalez, 1999; Crooker, 2000).

It has been historically developed in such a manner that originally from all active processes on the Sun the solar flares were discovered and during long time all disturbances in the solar wind and the Earth's magnetosphere were connected extremely with the solar flares. After discovery of other powerful solar process - coronal mass ejection (CME) in the beginning of 70th years during long time CMEs were studied by only separate researchers and as a whole they were not used almost in consideration of a chain of solar-terrestrial connections. However after known paper by Gosling (1993) the situation has significantly changed, and now CME is considered almost as the unique cause of all interplanetary and geomagnetic disturbances.

At the present time the quantity of publications on this theme steadily grows. However the attention is drawn to the fact that these publications contain strongly distinguished estimations of geoeffectiveness of those or other solar phenomena (Yermolaev and Yermolaev, 2003b). For example, estimations of CME geoeffectiveness change 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 papers by Webb et al. (1996, 2000); Crooker (2000); Li et al (2001); Webb (2002); Zhao and Webb (2003); 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 papers by Gosling et al. (1991); Gopalswamy et al. (2000, 2001); Yermolaev et al. (2000); Webb et al. (2000); Richardson et al. (2001); Yermolaev and Yermolaev (2002, 2003a,b); Cane and Richardson (2003)). Recently new papers on the statistical analysis of connection between geomagnetic storms and solar flares were published and they gave estimations 30-45% (Park et al., 2002; Yermolaev and Yermolaev, 2002, 2003a), in earlier works there are the data on flare geoeffectiveness from 59% (Krajcovic and Krivsky, 1982) up to 88% (Cliver and Crooker, 1993). We believe that both CMEs and flares are different (with different spatial and temporal scales) manifestations of one global process on the Sun (see for example discussions (Harrison, 1996; Forbes, 2000; Low, 2001; Cliver and Hudson, 2002) and references therein). A question, what from these processes is better to use as an indicator of the solar events resulting in the interplanetary disturbances and then to the geomagnetic storm, remains open. Therefore in this paper we analysed also last data on connection between solar flares and geomagnetic storms. It is necessary to note, that under the term "geoeffectiveness" various authors mean the different values obtained by different techniques, and this fact is necessary to take into account in the comparison of results of various papers and it will be discussed below.

Because such an analysis covers a chain of different physical objects researched by various methods, the result can strongly depend on a technique of the analysis of (1) each part of entire chain and (2) effectiveness of relation between separate parts. Thus, one of the problems of present paper is a comparison of used methods of data analysis and quantitative estimation of the results received by different methods. Comparison of techniques in each of 3 areas (solar atmosphere, solar wind and geomagnetosphere) is a subject of a corresponding field of knowledge and is in detail analyzed in the special literature. As the question on relations between the phenomena in various areas frequently appears outside interest of experts we try to concentrate our attention basically on the analysis of methods studying the correlations of the phenomena in various parts of the solar-terrestrial chain.

2 Methods

Methods of identification of solar (CMEs and solar flares), interplanetary (MCs, ICMEs, ejecta and others) and geomagnetospheric (magnetic storms) events can be found in he literature (see, for examples, our brief reviews (Yermolaev and Yermolaev, 2003b; Yermolaev, 2003) and references therein). 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 Results and Discussion

The results of comparison of CMEs, solar flares and the various interplanetary phenomena with magnetic storms for several last years are shown in table 1. First of all it is necessary to note, that we selected results on the comparing phenomena and the direction of tracing. For example, record "$CME \rightarrow Storm$" means that for the initial data set the CME list was taken, the number of analyzed cases of CMEs is presented in a column "Number of cases". The CMEs are compared with magnetic storms, the value of storm is defined by an index which is submitted in a column "Remark". Thus, we summarized the published data by 6 types of phenomena comparison (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, IV and V we included both magnetic clouds and ejecta(ICME) which are close under the physical characteristics, but in a column "Number of cases" we noted identification of authors by symbols MC (Magnetic clouds) and E (Ejecta). The table also presented data on $VII.\ Flare \rightarrow SSC, Storm$ and $VIII.\ Storm \rightarrow Flare$ correlations.

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, 2000; Plunkett et al., 2001; Berdichevsky et al., 2002; Wang et al., 2002; Webb, 2002; Yermolaev and Yermolaev, 2003a,b; Zhao and Webb, 2003). 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. 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

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]	$Dst < -50$	
[a] - Earth-directed halo-CME, [b] - frontside halo CME,[c] - centered frontside halo CME.				
			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 et al. (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	$Dst < -60$	
			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 et al. (1991)
2	25	?	$Dst(corr)$	Vennerstroem (2001)
3	33	618	$Dst < -60$	Yermolaev and Yermolaev (2003a)
	25	414	$-100 < Dst < -60$	
	52	204	$Dst < -100$	

Table 2
Conuation.

N	%	Number of events	Remarks	Reference
			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)
			VII. Flare → SSC, Storm	
1	35-45	4836	$\geq M0$	Park et al. (2002)
2	32	653	$\geq M5$	Yermolaev and Yermolaev (2003a)
			VIII. Storm → Flare	
1	59	116	$Kp > 7_-$	Krajcovic and Krivsky (1982)
2	20	204	$Dst < -100$	Yermolaev and Yermolaev (2003a)
3	88	25	$Dst < -250$	Cliver and Crooker (1993)

Zhao and Webb (2003) are overestimated (Yermolaev, 2003).

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.

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 Zhao and Webb (2003). 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 Zhao and Webb (2003) 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 Zhao and Webb (2003) is likely to be overestimated (see detailed analysis in paper by (Yermolaev, 2003)).

Data presented in table 1 are schematically illustrated by Figure 1: top panel shows 1-step and 2-step results for direct tracing and bottom panel shows the same values for back tracing. The obtained probabilities for all types of processes are presented below each panel.

As it has been shown above and in our previous study (Yermolaev and Yermolaev, 2003a) we carried out direct tracing events $Flare \rightarrow Storm$ and estimated geoeffectiveness of 653 solar flares of importance (on X-ray emission) $\geq M5$ which in $\sim$ 40% cases resulted in magnetic storms with $Dst < -60$ nT. If we carry out back tracing $Storm \rightarrow Flare$ and take the list of strong magnetic storms with $Dst < -100$ nT, among the given set of flares only 20% can be sources of storm. In paper (Krajcovic and Krivsky, 1982) in which back tracing $Storm \rightarrow Flare$ was analyzed on large set of solar flares (on optical emission), it was shown that for the period 1954-1976 for 116 storms with $Kp > 7_{-}$, among flares were revealed 59% possible sources. In paper by Cliver and Crooker (1993) back tracing $Storm \rightarrow Flare$ also is analyzed and it was shown that for 25 strongest magnetic storms with $Dst < -250$ nT observed in 1957-1990, at least in 22 (88%) cases it is possible to offer solar flare as the candidate of source. High values of "effectiveness" in papers by Krajcovic and

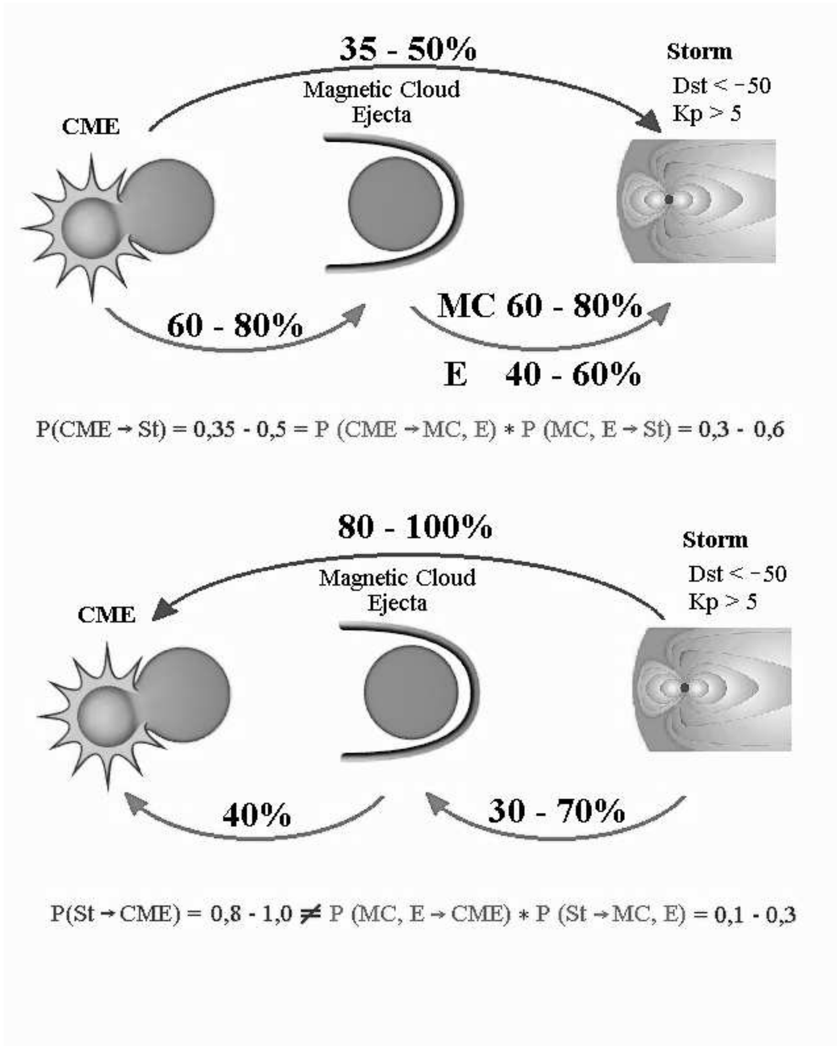

Fig. 1. Correlations between CME, MC, ejecta and magnetic storms.

Krivsky (1982); Cliver and Crooker (1993) in addition to the back direction of comparison of the phenomena, apparently, is connected with fact that even weak solar flares can be considered as possible sources of storms while in our work we analyzed only strong flares.

Comparison of events $Flare \rightarrow SSC$ (i.e. not with geomagnetic storms, and with the phenomena which frequently precede storms) was carried out in recent work (Park et al., 2002) for 4836 flares of importance $\geq M1$ for the period September, 1, 1975 - December, 31, 1999. In result the estimation of geoeffectiveness for time of delay of 2-3 days for all flares was 35-45 % and for long duration flares - a little bit more 50-55%.

4 Conclussion

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 $Magnetic\ cloud, Ejecta \rightarrow Storm$) 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); Zhao and Webb (2003) is likely to be overestimated (Yermolaev, 2003). This value strongly differs from results of 83-100% obtained in papers by Brueckner et al. (1998); St.Cyr et al. (2000); 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 $Magnetic\ cloud, Ejecta \rightarrow CME$ 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); 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. Thus, there is a paradoxical situation when the modern science in the retrospective approach successfully can explain an origin almost all strong geomagnetic disturbances, but can not predict their occurrence with a sufficient degree of reliability on the basis of observation of the Sun. To increase reliability of the forecast, the further analysis of the solar data and revealing of characteristics which would allow us to select the phenomena among CMEs and/or flares with higher geoeffectiveness are required.

The authors gratitude the international scientific data centers SEC NOAA, NSSDC/GSFC NASA and WDC-C2 for the information, R.A.Kovrazhkin and J.L.Rauch for attention, help and useful discussion of materials of the paper and I.Yu.Yermolaev for help in figure preparing. The work was in part supported by grants INTAS 99-0078, RFBR 01-02-16182, 02-02-17160, 04-02-16131, by Program N16 of Physics Sciences Department of RAS and by French - Russian scientific cooperation program (PICS grant APIC0090 and RFBR grant 00-02-22001).

References

Akasofu, S.-I., 1981. Energy coupling between the solar wind and the magnetosphere. Space Science Reviews 28, no. 2, 121-190.

Berdichevsky, D. B., Farrugia, C. J., Thompson, B. J., Lepping, R. P., Reames, D. V., Kaiser, M. L., Steinberg, J. T., Plunkett, S. P., Michels, D. J. Halo-coronal mass ejections near the 23rd solar minimum: lift-off, inner heliosphere, and in situ (1 AU) signatures, *Annales Geophysicae, 20*, Issue 7, pp.891-916, 2002.

Brueckner, G. E., Delaboudiniere, J.-P., Howard, R. A., Paswaters, S. E., St. Cyr O. C., Schwenn, R., Lamy, P., Simnett, G. M., Thompson, B., Wang, D., 1998. Geomagnetic storms caused by coronal mass ejections (CMEs): March 1996 through June 1997. Geophysical Research Letters 25, 15, 3019.

Burlaga, L. F., Skoug, R. M., Smith, C. W., Webb, D. F., Zurbuchen, T. H., Reinard, A., Fast ejecta during the ascending phase of solar cycle 23: ACE observations, 1998-1999, *J. Geophys. Res., 106*, N 10, 2001, pp.20957-20978, 2001.

Cane, H. V., Richardson, I. G., St. Cyr, O. C., 1998. The interplanetary events of January-May, 1997, as inferred from energetic particle data, and their relationship with solar events. Geophysical Research Letters 25, 14, 2517.

Cane H. V., Richardson I. G., St. Cyr O. C., 2000. Coronal mass ejections, interplanetary ejecta and geomagnetic storms. Geophysical Research Letters 27, 21, 359.

Cane, H. V. and Richardson, I. G. Interplanetary coronal mass ejections in the near-Earth solar wind during 1996-2002, *J. Geophys. Res., 108*, N A4, pp. SSH 6-1, DOI 10.1029/2002JA009817, 2003.

Cliver E. W., Crooker N. U., 1993. A seasonal dependence for the geoeffectiveness of eruptive solar events. Solar Physics 145, 2, 347.

Cliver, E. W., Hudson, H. S., 2002. CMEs: How do the puzzle pieces fit together? Journal of Atmospheric and Solar-Terrestrial Physics 64, 2, 231-252.

Crooker, N. U., 2000. Solar and heliospheric geoeffective disturbances, Journal of Atmospheric and Solar-Terrestrial Physics 62, 1071.

Crooker, N. U., Cliver, E. W., 1994. Postmodern view of M-regions, Journal of Geophysical Research 99, A12, 23,383-23,290.

Forbes, T. G., 2000. A review on the genesis of coronal mass ejections, Journal of Geophysical Research 105, A10, 23153-23166.

Gonzalez, W. D., Tsurutani B. T., Clua de Gonzalez A. L., 1999. Interplanetary origion of geomagnetic storms. Space Science Review 88, 529.

Gopalswamy N., Lara A., R. P. Lepping R.P. et al., 2000. Interplanetary acceleration of coronall mass ejections, Geophysical Research Letters 27, 145.

Gopalswamy N., Lara A., Yashiro S., Kaiser M. L., Howard R. A., 2001. Predicting the 1-AU arrival times of coronal mass ejections. Journal of Geophysical Research 106, A12, 29207.

Gosling J.T., 1993. The solar flare myth. Journal of Geophysical Research 98, 18937.

Gosling J. T., McComas D. J., Phillips J. L., and Bame S. J., 1991. Geomagnetic activity associated with Earth passage of interplanetary shock disturbances and coronal mass ejections. Journal of Geophysical Research 96, 7831.

Gosling, J. T., Pizzo V. J., 1999. Formation and evolution of corotating interaction regions and their three-dimensional structure. Space Science Review 89, 21.

Harrison, R. A., 1996. Coronal Magnetic Storms: a New Perspective on Flares and the 'Solar Flare Myth' Debate. Solar Physics 166, 441-444.

Krajcovic, S., Krivsky, L., 1982. Severe geomagnetic storms and their sources on the sun. Astronomical Institutes of Czechoslovakia, Bulletin, 33, N 1, 47.

Li Y., Luhmann J.G., Mulligan T., Hoeksema J. T., Arge C. N., Plunkett S. P., St. Cyr O. C., 2001. Earthward directed CMEs seen in large-scale coronal magnetic field changes, SOHO LASCO coronagraph and solar wind. Journal of Geophysical Research 106, A11, 25103.

Lindsay G.M., Luhmann J.G., Russell C.T., Gosling J.T., 1999. Relationship between coronal mass ejection speeds from coronagraph images and interplanetary characteristics of associated interplanetary coronal mass ejections. Journal of Geophysical Research 104, 12515.

Low, B. C., 2001. Coronal mass ejections, magnetic flux ropes, and solar magnetism. Journal of Geophysical Research 106, A11, 25141-25164.

Park, Y. D., Moon, Y.-J., Kim, Iraida S., Yun, H. S., 2002. Delay times between geoeffective solar disturbances and geomagnetic indices, Astrophysics and Space Science 279, 4, 343-354.

Petrukovich, A. A., Klimov, S. I., Lazarus, A., Lepping, R. P., 2001. Comparison of the solar wind energy input to the magnetosphere measured by Wind and Interball-1. Journal of Atmospheric and Solar-Terrestrial Physics 63, 15, 1643-1647.

Plunkett S.P., Thompson B.J., St.Cyr O.C., Howard R.A., 2001. Solar source regions of coronal mass ejections and their geomagnetic effects. Journal of Atmospheric and Solar-Terrestrial Physics 63, 389-402.

Richardson I. G., Cliver E. W., Cane H. V., 2001. Sources of geomagnetic storms for solar minimum and maximum conditions during 1972-2000. Geophysical Research Letters 28, 2569.

Russell C.T., McPherron R.L., 1973. Semiannual variation of geomagnetic activity. Journal of Geophysical Research 78, 241.

St. Cyr O. C., Howard R. A., Sheeley N. R. Jr., Plunkett S. P. et al., 2000. Properties of coronal mass ejections: SOHO LASCO observations from January 1996 to June 1998. Journal of Geophysical Research 105, A8, 18169.

Vennerstroem, S., 2001. Interplanetary sources of magnetic storms: Statistic study. Journal of Geophysical Research 106, 29175-2914.

Vilmer N., Pick M., Schwenn R., Ballatore P., Villain J. P., On the solar origin of interplanetary disturbances observed in the vicinity of the Earth, Annales Geophysicae, vol. 21, Issue 4, pp.847-862, 2003

Wang, Y. M., Ye, P. Z., Wang, S., Zhou, G. P., Wang, J. X., 2002. A statistical study on the geoeffectiveness of Earth-directed coronal mass ejections from March 1997 to December 2000. Journal of Geophysical Research 107, A11, 10.1029/2002JA009244

Webb D.F., Jackson, B. V., Hick, P. 1996. Geomagnetic Storms and Heliospheric CMEs as Viewed from HELIOS. In Solar Drivers of Interplanetary and Terrestrial Disturbances, ASP Conference Series 95, 167.

Webb D.F., Cliver E.W., Crooker N.U. et al., 2000. Relationship of halo coronal mass ejections, magnetic clouds, and magnetic storms. Journal of Geophysical Research 105, 7491.

Webb D.F., Crooker N.U., Plunkett S.P., St.Cyr O.C. The solar sources of geoeffective structure, In Space Weather, AGU Geophys. Monogr. 125, p.123, 2001.

Webb, D. F. CMEs and the solar cycle variation in their geoeffectiveness In: Proceedings of the SOHO 11 Symposium on From Solar Min to Max: Half a Solar Cycle with SOHO, 11-15 March 2002, Davos, Switzerland. A symposium dedicated to Roger M. Bonnet. Edited by A. Wilson, ESA SP-508, p. 409 - 419, 2002.

Wu C.-C., Lepping R.P., 2002. Effects of magnetic clouds on the occurrence of geomagnetic storms: The first 4 years of Wind. Journal of Geophysical Research 107, A10, SMP 19-1 to SMP 19-8 10.1029/2001JA000161.

Yermolaev Yu. I., Zastenker, G. N., Nikolaeva, N. S., 2000. The Earth's Magnetosphere Response to Solar Wind Events according to the INTERBALL Project Data. Kosmicheskie Issledovaniia 38, 6, 563. (in Russian, translated Cosmic Research 38, 6, 527.)

Yermolaev Yu. I., Comment on "Source regions and storm effectiveness of frontsidefull halo coronal mass ejections" by X. P. Zhao and D. F. Webb, Journal of Geophysical Research 108, 2003, 2003JA010140 (in press)

Yermolaev Yu. I., Yermolaev M. Yu., 2002. Statistical relationships between solar, interplanetary, and geomagnetic disturbances, 1976-2000. Kosmicheskie Issledovaniia 40, 1, 3. (in Russian, translated Cosmic Research 40, 1, 1.)

Yermolaev Yu. I., Yermolaev M. Yu., 2003a. Statistical relationships between solar, interplanetary, and geomagnetic disturbances, 1976-2000,2. Kosmicheskie Issledovaniia 41, 2, 115. (in Russian, translated Cosmic Research 41, 2, 105)

Yermolaev Yu. I., Yermolaev M. Yu., 2003b. Statistical relationships between solar, interplanetary, and geomagnetic disturbances, 1976-2000,3. Kosmicheskie Issledovaniia 41, in press.

Zhang J., Dere K.P., Howard R. A., Bothmer V., 2003. Identification of Solar Sources of Major Geomagnetic Storms between 1996 and 2000. Astrophysical Journal 582, 520.

Zhao, X. P., and D. F. Webb, Source regions and storm effectiveness of frontside full halo coronal mass ejections, J. Geophys. Res., 108(A6), 1234, doi:10.1029/2002JA009606, 2003.