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THE SHORT-TERM FORECAST OF SOLAR WIND MAGNETIC CLOUD PARAMETERS REACHING VICINITY OF THE EARTH

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Abstract

The definition method of orientation a magnetic cloud approach, its cross-sectional size, a magnetic field on its axis and impact parameter on initial measurement components of its magnetic field on a spacecraft is submitted.

1. Introduction

For the first time the term "magnetic cloud" has been entered in [*Burlaga et al.*, 1981]. The magnetic clouds are regions in a solar wind with following properties: significant rotation of magnetic field vector in cloud, strong magnetic field, low temperature and low value β (the relation a thermal plasma pressure (nkT) to magnetic pressure ($B^2/8\pi$)) [*Burlaga et. al.*, 1981, *Lepping et. al.*, 1990]. As has been established later, magnetic clouds are coronal mass ejection subclass [*Bothmer and Schwenn*, 1998]. Interest to studying magnetic clouds is connected to their potential geoefficiency. They contain magnetic field with significant on amplitude vertical Bz component of interplanetary magnetic field (IMF) [*Echer and Gonzalez*, 2004]. For the description of cloud magnetic field configuration in [*Goldstein*, 1983] use a force-free approach [*Lundquist*, 1950] was suggest. In the given approach cloud field configuration is described by six key parameters: a value of magnetic field on cloud axis (*Bo*, nT), a radius (*Ro*, Re), a distance from cloud axis up to the Sun–Earth line (impact parameter, *b*, Re), a magnetic field chirality (H). Cloud axis orientation concerning of an ecliptic plane is determined by a polar angle ε and an azimuthal angle β. For example on Fig.1 the cylindrical magnetic cloud in solar–ecliptic coordinate system (XYZ) is shown.

As is established, magnetic clouds are sources in main strong geomagnetic storms. The most geoeffective cloud parts are its leading region and combination of its sheath and leading region [*Zhang* et al., 2004]. Usually clouds geoeffective special features study already after the cloud completely pass through the Earth [*Wu and Lepping*, 2002, *Zhang et al.*, 2004]. However a forecast for expected geomagnetic storm intensity is possible, if we can establish IMF components behavior at the initial stage of its pass through a magnetosphere.

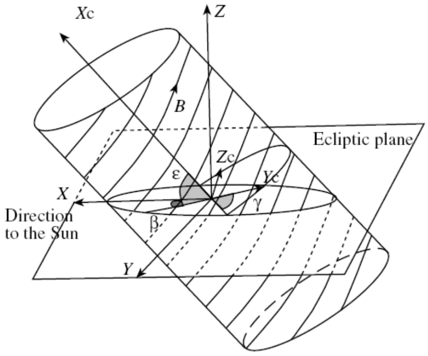

Figure1. A cylindrical magnetic cloud is shown. XYZ – solar–ecliptic coordinate system; Xc, Yc, Zc – coordinate system inside a cloud; ε - a polar angle, an angle between cloud axis and an ecliptic plane, and β – the azimuthal angle which is read out from axis X up to projection of cloud axis on an ecliptic plane

In the given article magnetic clouds are representation as a force-free cylindrical flux rope. The parameters of magnetic clouds by comparison method of initial measurements magnetic field components with corresponding values for modeling clouds are determined. Analytical equations describing magnetic field components behavior inside modeling cylindrical cloud in solar ecliptic coordinate system are received in [*Barkhatov et al.*, 2009].

2. Definition of magnetic clouds parameters on initial measurements of interplanetary space parameters from spacecraft

Definition of magnetic clouds parameters on initial measurements interplanetary space parameters on spacecraft (SC), when SC input into cloud, is based on comparison registered cloud magnetic field components with modeling magnetic cloud field components. The total quantity of modeling magnetic clouds is about 830 000. Each modeling magnetic cloud corresponds to certain set of parameters. Ranges of modeling cloud parameters are established on the analysis of experimental data for real cases solar plasma measurements on ACE and WIND SCs from 1998 till 2001 [*Lynch et al.*, 2003, *Zhang et al.*, 2004]. In result we determined following ranges of modeling cloud parameters: magnetic field on cloud axis $-40 < Bo < 40$ nT (ΔBo=8 nT); cloud's radius 1500 Re $< Ro <$ 3200 Re (ΔRo =850 Re); azimuthal angle $0^0 < \beta < 180^0$ ($\Delta\beta = 30^0$); polar angle $0^0 < \varepsilon < 180^0$ ($\Delta\varepsilon = 20^0$), impact parameter $-1000 < b < 1000$ (Δb=250Re); mean velocity of cloud $350 < V < 650$ km·s^{-1} (ΔV=100 km·s^{-1}), cloud time interval passage through SC $10 < t < 30$ hours (Δt=5 hours).

Process of magnetic clouds parameters definition on initial measurements of interplanetary space parameters on SC included two stages. On the first stage the factors of correlation (R) between an observable field and field of all modeling magnetic clouds are calculated. Factors of correlation calculate consistently for each modeling cloud, since the two first points of measurement. The calculation, when following measured point is added, for all modeling clouds from begin is carried out. In result, after first stage modeling clouds, which have the greatest correlation factors for all IMF components, are taken. At the second stage for selected modeling clouds root-mean-square deviation (χ^2_{norm}) of values of modeling cloud magnetic field components and a velocity from registered values is calculated. Root-mean-square deviation is normalized on background values of a magnetic field (5 nT) and solar wind velocity (320 km·s^{-1}). As result of this stage one modeling cloud was taken for which root-mean-square deviation is minimal. This modeling cloud the most close coincides to a real magnetic cloud. Testing of the developed technique and the computer program of magnetic cloud parameters definition with use initial measurements from SC was conducted on the real events registered from ACE SC and was determined in the literature as magnetic clouds [*Lynch et al.*, 2003]. For example, using developing program, we consider in detail two magnetic clouds from ACE SC (21.00.2000 and 06.11.2000). Data from ACE SC for IMF components and solar wind velocity with 30 minute averaging [http://www.srl.caltech.edu/ACE/, http: // cdaweb.gsfc.nasa.gov/cgi-bin/eval2.cgi] were used.

The magnetic cloud registered on ACE SC 21.02.2000

In Table 1 modeling magnetic cloud parameters, which have been set during definition of real cloud parameters on initial field component measurements from SC are submitted. This parameters received on all measurement sequences are simultaneously submitted. The minimal number of measurements sufficient for an establishment of cloud parameters successfully describing magnetic field configurations is allocated by bold font. For the given magnetic cloud 35% of magnetic field initial measurements need for establishing of magnetic field on its axis, 50% of magnetic field measurements need for establishing of cloud axis orientation (polar ε and azimuthal β angles), 89% of magnetic field measurements need for establishing of cloud radius and impact parameter, 11% of magnetic field initial measurements need for establishing of cloud mean velocity and 57% of magnetic field measurements need for establishing of cloud time interval passage through SC. The factor of correlation between registered and modeling (received with use parameters established on 50% from full cloud) Bz magnetic field component is equal R=0.7. Root-mean-square deviation between these components is equal 0.00004.

Table 1. The parameters of 21.02.2000 magnetic cloud chosen during calculations and received on all sequence of measurements

The parameters of 21.02.2000 magnetic cloud established with use all sequence of measurements							
H = +1	B_0, nT	R_0, Re	β, deg	ε, deg	b, Re	V, km·s^{-1}	t, hour
	17	2868	59.3	67	1275	343.5	23
Number of half-hour measurements		**Modeling magnetic cloud parameters**					
2	24	3200	150	60	100	350	30
	. . . .						
16,17	16	2350	30	160	-1000	350	10
21,22	16	1500	30	160	-1000	350	15
23-25	**24**	**1500**	**0**	**60**	**1000**	**350**	**15**
26-40	24	1500	30	40	1000	350	20
41-46	16	2350	60	60	750	350	25

Comparison of registered magnetic field components and modeling magnetic field components which calculated with use all sequence of measurements on Fig. 2a is shown. The modeling magnetic field components behavior, received on 50% of measurements from full magnetic cloud, on Fig.2b is shown.

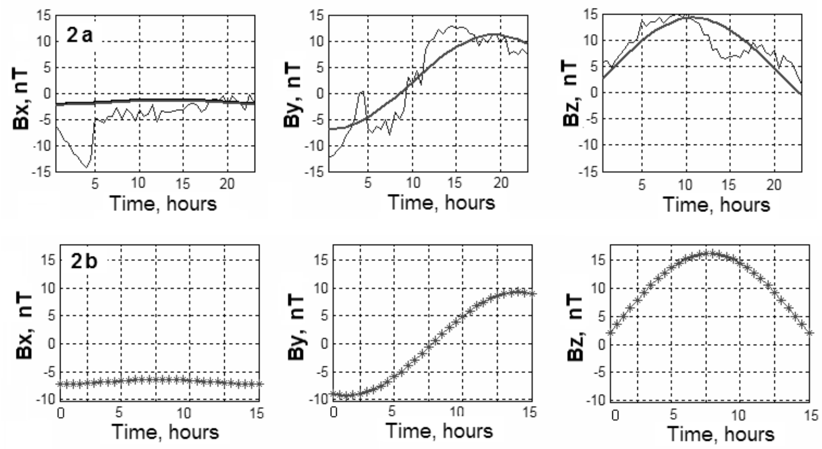

Fig.2. a) Comparison of registered (thin line) magnetic field components and modeling (bold line) magnetic field which calculated with use all measurement sequences. **b)** The modeling magnetic field components behavior, received on 50% of measurements from full magnetic cloud

The magnetic cloud registered on the SC ACE 06.11.2000.

For the given magnetic cloud 38% of magnetic field initial measurements need for establishing of magnetic field on its axis and all magnetic field measurements need for establishing of other cloud parameters. However already after 38% from measurements full cloud is possible to judge behavior field components in it. The factor of correlation between registered and modeling (received with use parameters established on 38% from full cloud) Bz magnetic field component is equal R=0.9. Root-mean-square deviation between these components is equal 0.0013. Comparison of registered and modeling cloud magnetic field components which calculated with use all sequence of measurements on Fig.3a is shown. The modeling magnetic field components behavior, received with use 38% of measurements from full cloud, on Fig.3b is shown.

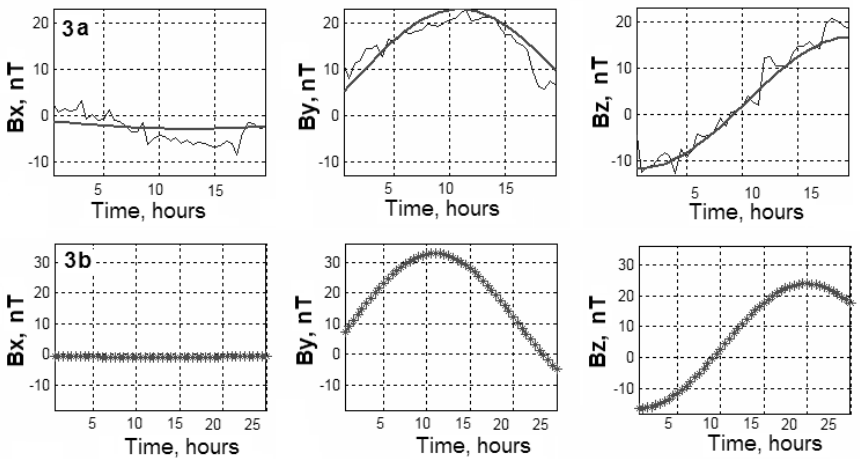

Fig.3. a) Comparison of registered (thin line) magnetic field components and modeling (bold line) magnetic field components which received with use all measurement sequences. **b)** The modeling magnetic field components behavior, received on 38% of measurements from full magnetic cloud

The similar analysis for 9 magnetic clouds has been carried out. In Table 2 the number of the minimal initial measurements (per cents) of cloud magnetic field components enough for an establishment of each particular cloud parameter and their average value is submitted. Also factors of correlation and root-mean-square deviation for registered and modeling values Bz magnetic field component are shown. Grey color in Table 2 allocates the cloud parameters most strongly influencing its geoeffective properties [*Zhao et. al.*, 2001]. Thus from Table 2 follows, that for establishment of cloud magnetic field configuration SC passage through about half from full magnetic cloud enough with use of 830 000 modeling magnetic cloud.

Table 2. Number minimal measurements of the interplanetary space parameters in cloud

Data magnetic clouds	The per cent of registration magnetic cloud necessary for definition of its parameters					R	χ^2_{norm}, 10^{-3}
	B_0, nT	R_0, Re	β, deg	ε, deg	b, Re		
02.05.1998	39%	65%	39%	39%	94%	0.8	1
14.06.1998	53%	53%	61%	55%	81%	0.7	0.02
24.06.1998	30%	93%	30%	30%	100%	0.9	6.2
19.10.1998	20%	94%	61%	48%	61%	0.7	0.8
09.11.1998	34%	73%	35%	83%	83%	0.6	7.0
21.02.2000	35%	89%	56%	50%	89%	0.7	0.04
15.07.2000	25%	34%	25%	25%	64%	0.9	0.045
12.08.2000	42%	34%	34%	34%	98%	0.8	0.8
06.11.2000	38%	38%	38%	38%	100%	0.9	1.3
Average value	35%	64%	42%	45%	86%	0.8	1.9

3. Conclusions

The forecast technique of magnetic cloud parameters with use initial measurements from SC magnetic field components and interplanetary space parameters is suggested. For this purpose modeling magnetic clouds (830 000) is created. The definition of cloud parameters by comparison of field component values real and modeling clouds is carried out. In result of the carried out experiments a quantity of initial measurements of interplanetary space parameters necessary for magnetic cloud parameter definition is appreciated. It is established that cloud orientation and value of magnetic field to its axis can be defined at use in calculations about 45% from full cloud. Definition of cloud radial size and impact parameter demands more than 60% from full cloud, when SC passage through it. Thus at about half from full magnetic cloud SC passage through it is possible to judge the further behavior geoeffective Bz magnetic field component. This, consequently, is possible to predict geomagnetic storm intensity expected at it interaction with the Earth’s magnetosphere.

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