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SHORT COMMUNICATIONS

Strong Geomagnetic Disturbances and Their Correlation with Interplanetary Phenomena during the Operation of the INTERBALL Project Satellites

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The INTERBALL project [1] was aimed at studying the influence of solar and interplanetary conditions on the Earth’s magnetosphere and covered the period from August 1995 to October 2000. This project enabled us to get information in a fairly wide range of parameters both of the solar wind and of various regions of the magnetosphere. In solving some scientific problems, it is necessary to separate the periods of disturbances of the Earth’s magnetosphere and to conduct investigations under various degrees of the disturbances. The present short report deals with the moderate and strong geomagnetic disturbances (magnetic storms with $D_{st} <$ –60 nT) and their interplanetary sources observed in the period indicated above. In our earlier papers [2–4], we initially separated the magnetic clouds in the solar-wind observations for the period of solar minimum and then analyzed the magnetospheric responses to the passage of these magnetic clouds. As distinct from these works, we started in the present paper, first of all, from the analysis of the state of the magnetosphere in the entire period of operation of the INTERBALL project and then found the interplanetary sources for the respective disturbances.

The time behavior of the mean hourly values of the D_{st} index (see http://spidr.ngdc.noaa.gov) in the period 1995–2000 is shown in Fig. 1. This period was partitioned into 27-day intervals to simplify the analysis of presence or absence of recurrent features in the presented data, associated with the 27-day rotation of the Sun. All magnetic storms with $D_{st} <$ –60 nT were correlated with the measurements of parameters of the solar wind and interplanetary magnetic field (IMF), obtained for the most part by the *Wind* satellite (http://cdaweb.gsfc.nasa.gov). The basic source of the magnetic storms in the period under consideration turned out to be the magnetic clouds (MC), which are the interplanetary manifestations of the coronal mass ejections (CME), as well as compressions in the regions of interaction of the solar-wind streams with different velocities, the so-called corotating interaction regions (CIR). For a more detailed description of the respective types of the solar-wind streams, the methods

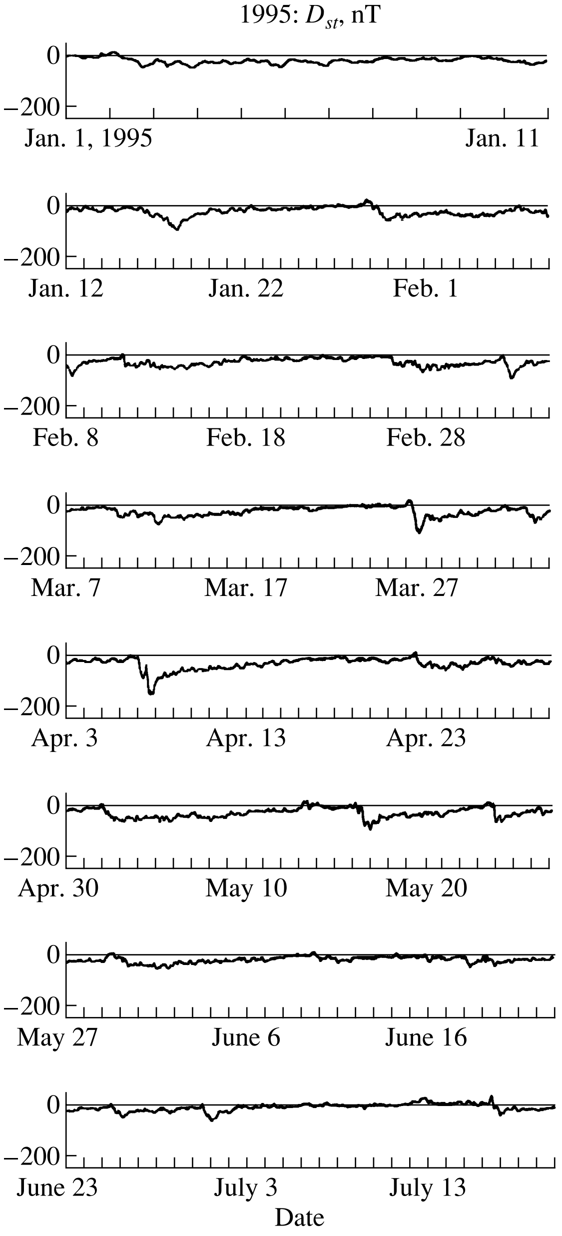

Fig. 1. Time behavior of the mean hourly values of D_{st} index.

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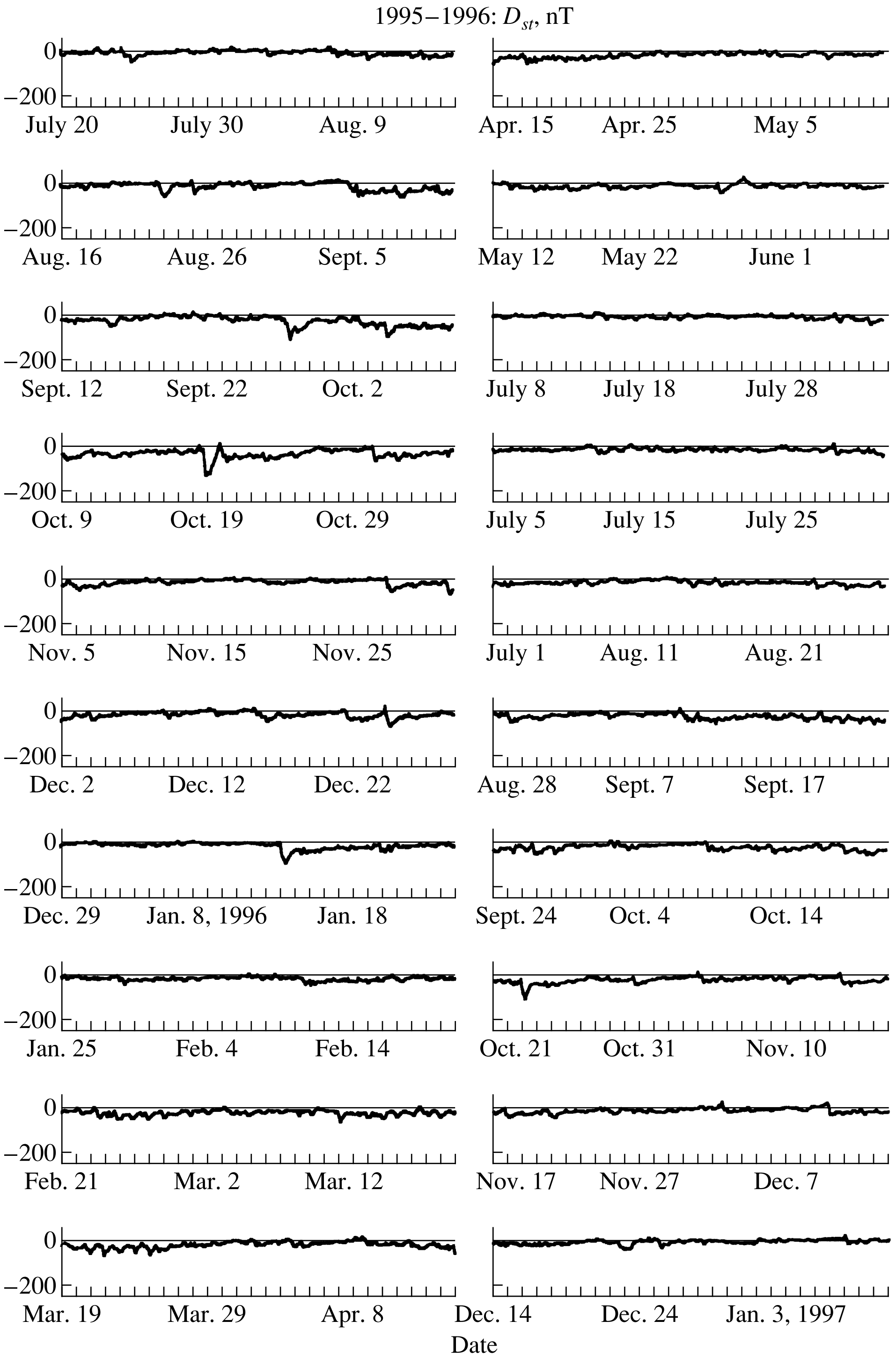
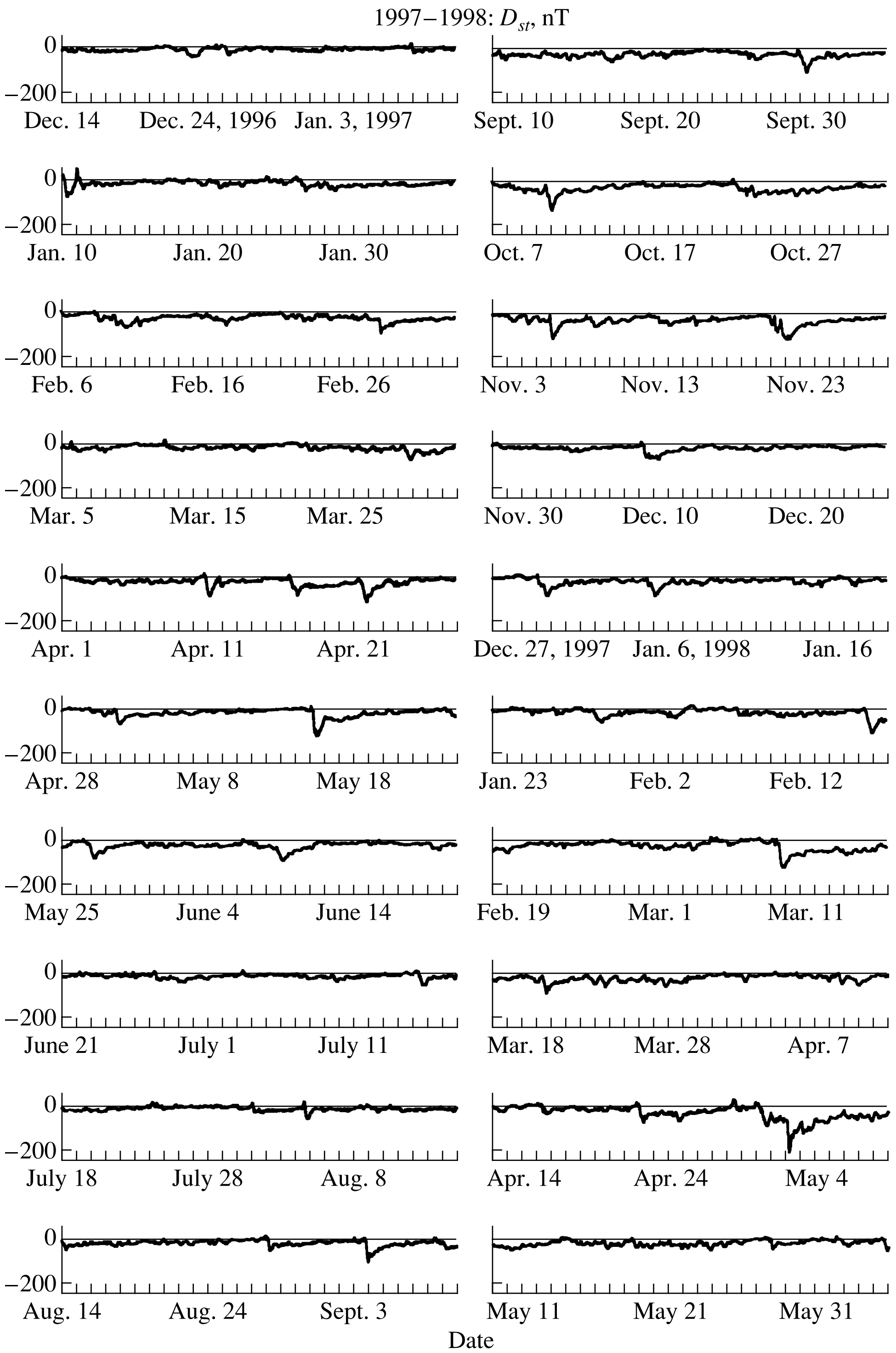


Fig. 1. Continued for 1995–1996.

of their identification, as well as their influence on the magnetosphere see [5–7] and references therein. The results of our analysis are presented in table, which specifies the date and hour of the minimum in the D_{st} index, its value, and our interpretation of its interplanetary source (a more complete information is available at the server of the INTERBALL project http://www.iki.rssi.ru/interball.html).



1997–1998: D_{st}, nT

Fig. 1. Continued for 1997–1998.

Among 101 magnetic storms, 45 events were caused by CIRs, 42 by MCs, and 4 by other reasons. The long intervals of negative (southward) IMF component were observed in all the above-mentioned cases. This fact agrees well with the models describing the input of solar-wind energy to the magnetosphere [6, 8–10]. If only the strong storms with $D_{st} < -100$ nT are taken into consideration, then we get a slightly different propor-

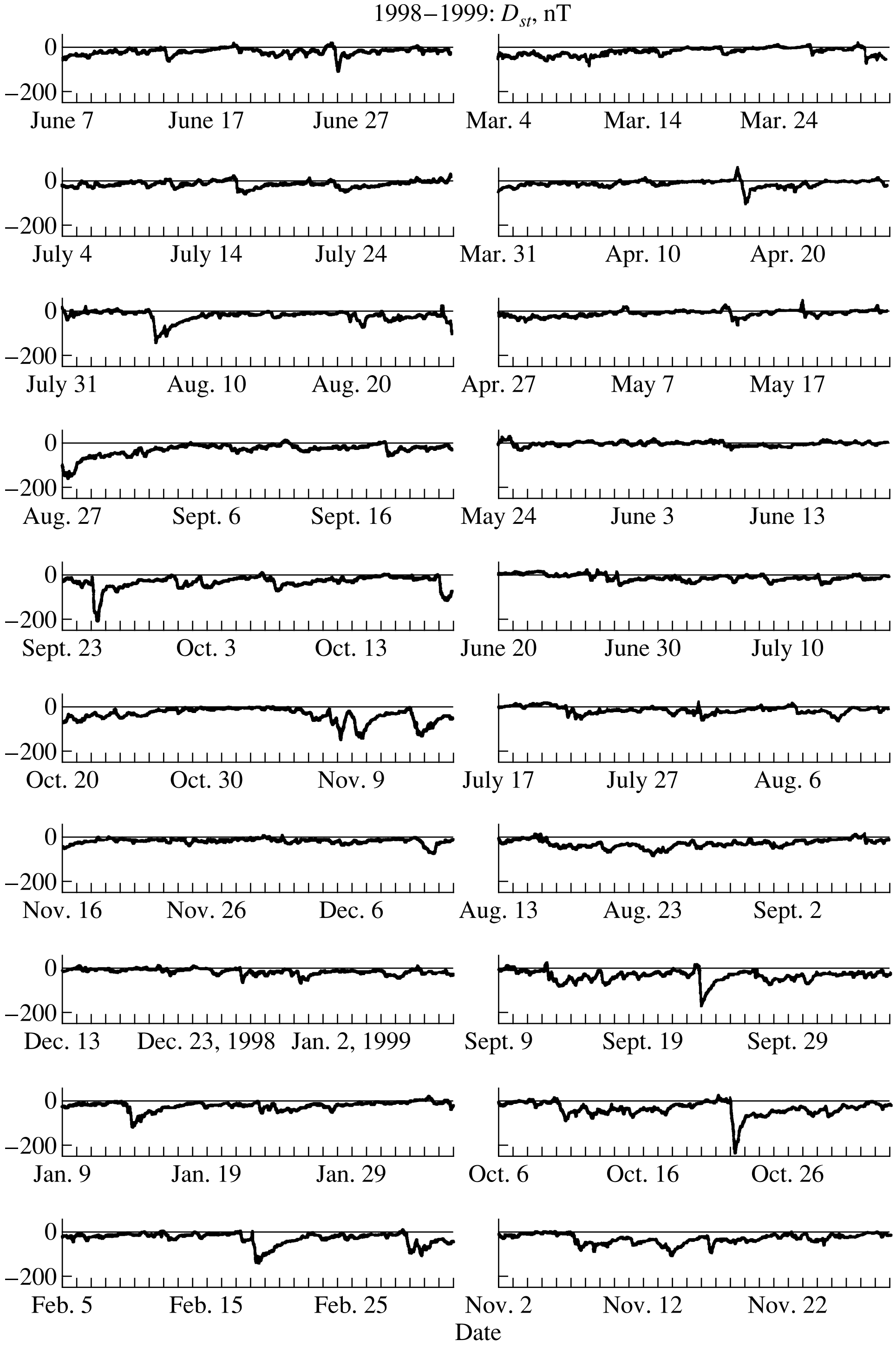


Fig. 1. Continued for 1998–1999.

tion: 22 among the 37 strong storms were caused by MCs and only 15 by CIRs.

The data presented in table enable us to get some statistical results and to compare them with other data. The time behavior of the mean monthly and smoothed sunspot numbers in the period from 1995 to 2000 is shown in Fig. 2a. As is seen, the solar cycle reached its minimum in 1996 and approached the maximum in the

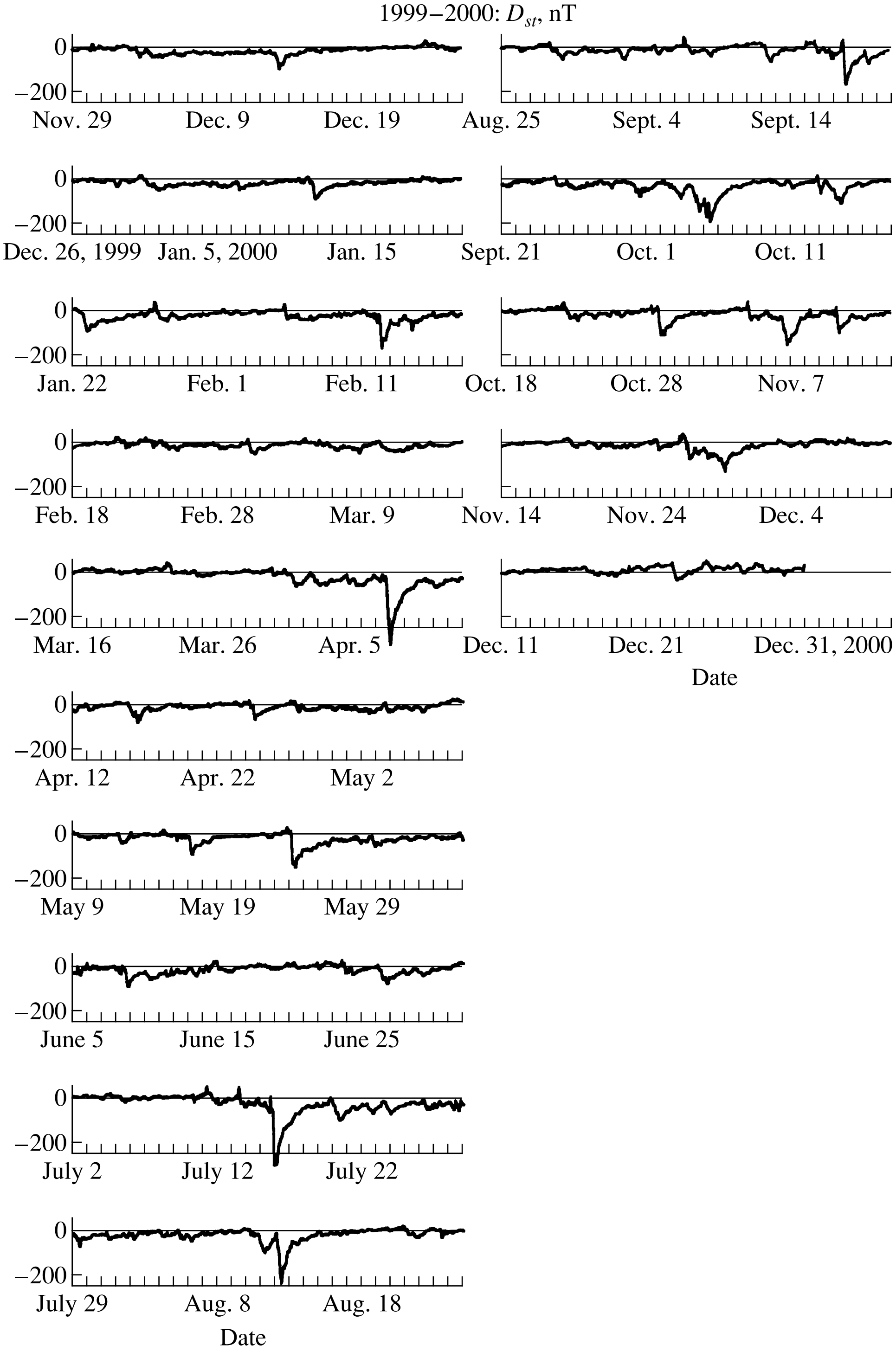


Fig. 1. Continued for 1999–2000.

end of the period under consideration. The mean annual numbers of the magnetic storms with $D_{st} < -60$ nT are given in Fig. 2b (the thin, dashed, and thick lines show the events excited by MCs, by CIRs, and the total number of events, respectively). The number of all strong magnetic storms with $D_{st} < -100$ nT is drawn by the dot-and-dash line. Every above-mentioned line has a minimum in 1996, i.e., in the minimum of the solar

Magnetic storms with $D_{st} < -60$ nT in the period 1995–2000

NN	Date	Hour	D_{st}	Type of solar wind
1	Jan. 18, 1995	06	−95	CIR
2	Feb. 8, 1995	09	−80	MC
3	Feb. 27, 1995	22	−67	$B_z < -10$
4	Mar. 4, 1995	21	−90	MC
5	Mar. 12, 1995	05	−70	CIR
6	Mar. 26, 1995	17	−107	MC
7	Apr. 2, 1995	05	−67	$B_z < 0$
8	Apr. 7, 1995	18	−149	CIR
9	May 16, 1995	22	−93	CIR
10	May 23, 1995	22	−65	CIR
11	Aug. 23, 1995	04	−61	MC
12	Sept. 27, 1995	20	−108	CIR
13	Oct. 4, 1995	13	−92	CIR
14	Oct. 8, 1995	18	−63	$B_z < -5$
15	Oct. 18, 1995	23	−127	MC
16	Dec. 1, 1995	19	−62	$B_z < -5$
17	Dec. 24, 1995	15	−65	CIR
18	Jan. 13, 1996	10	−90	?
19	Oct. 23, 1996	04	−105	CIR
20	Jan. 10, 1997	09	−78	MC
21	Feb. 10, 1997	10	−68	MC
22	Feb. 27, 1997	23	−86	CIR
23	Mar. 28, 1997	23	−63	CIR
24	Apr. 11, 1997	04	−82	MC
25	Apr. 17, 1997	05	−77	CIR
26	Apr. 21, 1997	23	−107	MC
27	May 2, 1997	00	−64	CIR
28	May 15, 1997	12	−115	MC
29	May 27, 1997	04	−73	MC
30	June 9, 1997	03	−84	MC
31	Sept. 3, 1997	22	−98	MC
32	Oct. 1, 1997	15	−98	MC
33	Oct. 11, 1997	03	−130	MC
34	Oct. 25, 1997	02	−64	CIR
35	Nov. 7, 1997	04	−110	MC
36	Nov.23, 1997	06	−108	MC
37	Dec. 11, 1997	10	−60	MC
38	Dec. 30, 1997	19	−77	MC
39	Jan. 7, 1998	04	−77	MC
40	Feb. 18, 1998	00	−100	MC
41	Mar. 10, 1998	20	−116	CIR
42	Mar. 21, 1998	15	−85	CIR
43	Apr. 24, 1998	07	−69	CIR
44	Apr. 26, 1998	17	−63	$B_z < -5$
45	May 2, 1998	17	−85	MC
46	May 4, 1998	05	−205	MC
47	May 9, 1998	19	−63	$B_z < -5$
48	June 26, 1998	04	−101	MC
49	Aug. 6, 1998	11	−138	CIR
50	Aug. 27, 1998	09	−155	CIR
51	Sept. 25, 1998	09	−207	MC
52	Oct. 7, 1998	22	−70	MC
53	Oct. 19, 1998	15	−112	MC
54	Nov. 8, 1998	06	−149	MC
55	Nov. 13, 1998	21	−131	MC
56	Dec. 11, 1998	15	−69	$B_z < -10$
57	Jan. 13, 1999	20	−113	CIR
58	Feb. 18, 1999	14	−134	MC
59	Mar. 1, 1999	19	−97	CIR
60	Mar. 29, 1999	14	−66	CIR
61	Apr. 17, 1999	04	−105	MC
62	Aug. 9, 1999	11	−62	MC
63	Aug. 20, 1999	12	−64	$B_z < -5$
64	Aug. 23, 1999	15	−80	CIR
65	Sept. 13, 1999	04	−71	CIR
66	Sept. 14, 1999	07	−67	$B_z < -5$
67	Sept. 16, 1999	08	−67	MC
68	Sept. 22, 1999	23	−164	CIR
69	Sept. 27, 1999	15	−66	CIR
70	Oct. 10, 1999	14	−84	CIR
71	Oct. 22, 1999	06	−231	MC
72	Oct. 27, 1999	15	−64	$B_z < -5$
73	Oct. 28, 1999	17	−67	CIR
74	Nov. 7, 1999	15	−77	CIR
75	Nov. 8, 1999	13	−81	$B_z < -5$
76	Nov. 13, 1999	22	−100	MC
77	Nov. 16, 1999	15	−86	$B_z < -10$
78	Dec. 13, 1999	09	−92	MC
79	Jan. 11, 2000	21	−83	CIR
80	Jan. 23, 2000	00	−91	$B_z < -10$
81	Feb. 12, 2000	11	−169	MC
82	Feb. 14, 2000	13	−88	MC
83	Apr. 6, 2000	22	−293	CIR
84	Apr. 16, 2000	10	−80	CIR
85	Apr. 24, 2000	14	−65	CIR
86	May 17, 2000	05	−88	$B_z < -10$
87	May 24, 2000	08	−147	CIR
88	June 8, 2000	20	−85	CIR
89	June 26, 2000	17	−74	CIR
90	July 15, 2000	21	−300	CIR
91	July 20, 2000	09	−95	CIR
92	Aug. 11, 2000	06	−103	CIR
93	Aug. 12, 2000	09	−237	MC
94	Sept. 12, 2000	18	−70	CIR
95	Sept. 17, 2000	23	−172	CIR
96	Sept. 19, 2000	14	−80	CIR
97	Oct. 5, 2000	14	−187	CIR
98	Oct. 14, 2000	15	−105	MC
99	Oct. 29, 2000	09	−97	MC
100	Nov. 6, 2000	22	−153	MC
101	Nov. 29, 2000	14	−117	CIR

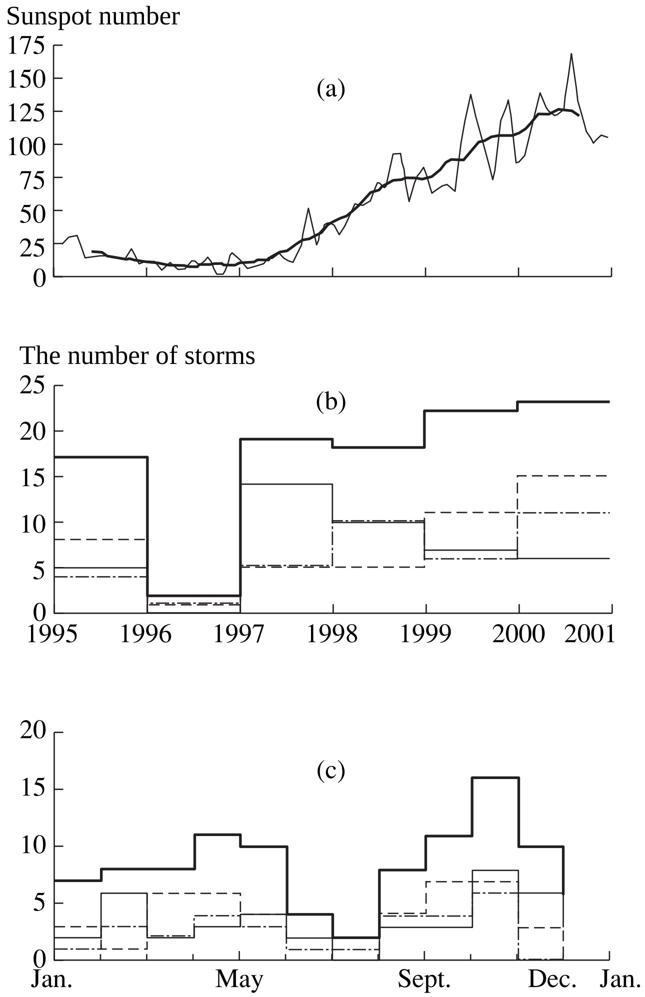


Fig. 2. (a) The mean monthly and averaged numbers of the magnetic spots, (b) the mean annual numbers of the magnetic storms with $D_{st} < -60$ nT (the thin line represents the storms excited by MCs; dashed line by CIRs; and the thick line describes the total number of events) and all strong magnetic storms with $D_{st} < -100$ nT (dot-and-dash line), and (c) monthly dependence of the number of magnetic storms (the same notation as in Panel b).

cycle. It can be assumed that the magnetic storms caused by MCs and CIRs prevail in the beginning and in the end of the phase of growth of the solar cycle, respectively; so that their total number increases only slightly.

The monthly dependence of the number of magnetic storms, obtained by the superimposed-epoch method for all 6 years, is shown in Fig. 2c (with the same notation as in Fig. 2b). We can see two maxima: in March–May and September–November periods. This fact agrees well with the Russell–McPherron effect [11], which is associated with annual evolution of the average tilt angle of the Earth's magnetic dipole with respect to the Sun–Earth line.

CONCLUSION

Thus, the analysis of interplanetary and geomagnetospheric conditions in the period 1995–2000 showed that the number of magnetic storms was minimal during the solar-cycle minimum (1996). The number of magnetic storms (with $D_{st} < -60$ nT) caused by MCs appreciably increases in the beginning of the growth phase of the solar cycle; and the one caused by CIRs, in the end of this phase; so that the total number of the events increases in the period from 1997 to 2000 only slightly, from 19 to 23 per year; and the average numbers of the storms caused by MCs and CIRs are approximately equal to each other: 45 from 101 storms are excited by CIRs and 42 by MCs. As regards the strong magnetic storms with $D_{st} < -100$ nT, the portion of the events produced by MCs turns out to be slightly greater: 22 from 37 storms were excited by MCs and only 15 by CIRs. By using the superimposed-epoch method, we confirmed the Russell–McPherron effect [11], which states that the maximum number of the magnetic storms takes place in spring and autumn months. We hope that the presented results will be useful both in analyzing the data obtained in the course of the INTERBALL project and in comparing with the data by other experiments.

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REFERENCES

1. Galeev, A.A., Galperin, Yu.I., and Zelenyi, L.M., The INTERBALL Project to Study Solar-Terrestrial Physics, *INTERBALL. Mission and Payload. RKA-IKI-CNES*, 1995, p. 11.
2. Yermolaev, Yu.I., Zastenker, G.N., Borodkova, N.L., *et al.*, Statistic Study of Magnetosphere Response to Magnetic Clouds: INTERBALL Multi-Satellite Observations, *Phys. Chem. Earth (C)*, 2000, vol. 25, p. 177.
3. Yermolaev, Yu.I., Zastenker, G.N., and Nikolaeva, N.S., The Earth's Magnetosphere Response to Solar Wind Events according to the INTERBALL Project Data, *Kosm. Issled.*, 2000, vol. 38, no. 6, pp. 563–576.
4. Yermolaev, Yu.U., Zastenker, G.N., Nikolaeva, N.S., *et al.*, Magnetosphere Response to Magnetic Clouds: Multi-Satellite Observations during 1995–1998, *Ann. Geophys.* (France), 2001, vol. 19 (in press).
5. Gosling, J.T. and Pizzo, V.L., Formation and Evolution of Corotating Interaction Regions and Their Three-

Dimensional Structure, *Space Sci. Rev.*, 1999, vol. 89, p. 21.

6. Gonzalez, W.D., Tsurutani, B.T., and Clua de Gonzalez, A.L., Interplanetary Origin of Geomagnetic Storms, *Space Sci. Rev.*, 1999, vol. 88, p. 529.
7. Crooker, N.U., Solar and Heliospheric Geoeffective Disturbances, *J. Atmos. Sol.-Terr. Phys.*, 2000, vol. 62, p. 1071.
8. Kamide, Y., Baumjohann, W., Daglis, I.A., *et al.*, Current Understanding of Magnetic Storm: Storm–Substorm Relationships, *J. Geophys. Res.*, 1998, vol. 103, p. 17705.
9. Petrukovich, A.A. and Klimov, S.I., The Use of Solar Wind Measurements for the Analysis and Prediction of Geomagnetic Activity, *Kosm. Issled.*, 2000, vol. 38, no. 5, pp. 463–468.
10. *Proc. 5th Int. Conf. on Substorms*, Wilson, A., Ed., European Space Agency, 2000, ESA SP-443.
11. Russell, C.T. and McPherron, R.L., Semiannual Variation of Geomagnetic Activity, *J. Geophys. Res.*, 1973, vol. 78, p. 241.