"Physics of Auroral Phenomena", Proc. XL Annual Seminar, Apatity, pp. 76-77, 2017

Polar Geophysical Institute

POSSIBLE CAUSE OF SOLAR WIND MAGNETIC CLOUD SHOCK WAVES

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Abstract. The work to the study of the condition and possible causes of the appearance of shock waves on the Solar wind magnetic cloud front is devoted. It is known that magnetic clouds are one of the most geoeffective plasma streams, since they become sources of mostly strong geomagnetic disturbances. Studies shows that the geoeffective properties of magnetic clouds increase with the presence of a shock wave and a shell before them [1]. A simultaneous abrupt increase in the parameters of Solar wind (velocity, concentration, temperature) on the magnetic cloud shock wave is noted. It is followed by a region with fluctuations of interplanetary magnetic field (IMP) components and increased density, called the magnetic cloud cover.

The study was carried out on 75 events registered in near-Earth space from 1973 to 2012 (according to the satellite system OMNI, *http://cdaweb.gsfc.nasa.gov/istp_public/*) and identified in the literature as magnetic clouds [2,3]. Previously, a visual analysis of the dynamics of the Solar wind parameters in front of magnetic clouds to detect shock waves in front of them according to their distinctive features was performed. As a result, it was found that 30 examined clouds had no shock waves, and the remaining 45 they were accompanied. The velocities of the sound waves Vs and Alfven waves Va are compared with the relative velocities Vrel of magnetic clouds to the Solar wind to determine the conditions under which shock waves appear before the magnetic clouds. The sound and Alfven wave velocities were calculated on the basis of the expressions given on the resource [*http: //cdaweb. gsfc.nasa.gov/istp_public/*] together with data on Solar wind parameters:

$$V_s = \sqrt{0.12(T + 1.2 * 10^5)},\ V_a = 20B/\sqrt{n},$$

where T is the temperature of Solar wind plasma (K), B is the magnetic field induction (Tl), and n is the concentration of Solar wind plasma (m^{-3}).

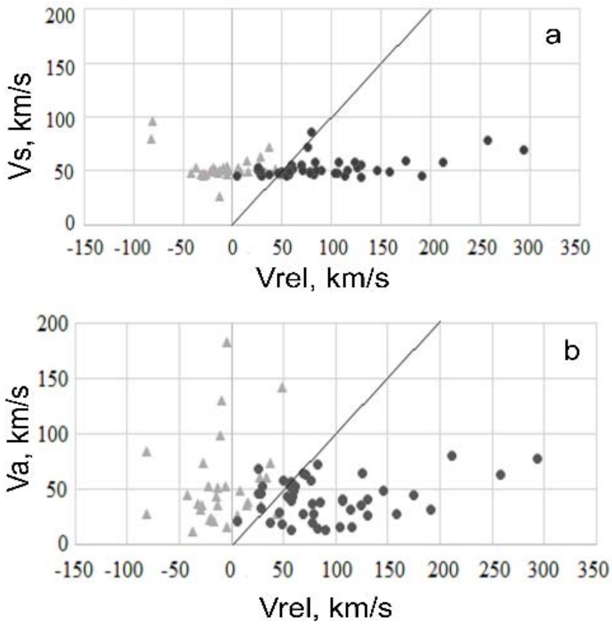

Figure 1

The relative velocity of Solar wind magnetic clouds as the difference between the velocities of the cloud and the mean value of the velocity of Solar wind ahead of it (for clouds without shock waves) or before the shock wave (for clouds with shock waves) was calculated. The resulting ratios of sound velocity Vs and Alfven velocity Va with the relative velocity of magnetic clouds are shown in Figs. 1a and b, respectively. In Fig. 1, the gray triangles correspond to magnetic clouds without shock waves, black circles - to magnetic clouds with shock waves, the straight line corresponds where the velocities is equality. From these relations it follows that for magnetic clouds without shock waves their relative velocity Vrel is lower than the velocities of the sound waves Vs and Alfven waves Va (the gray triangles in Figs. 1 and b are located near the ordinate axis). There is an excess of the relative velocity of clouds over sound and Alfven velocities for magnetic clouds with shock waves (black circles in Figs. la, b). These data lies below the direct line (Fig. 1a, b) which corresponding to the equality of velocities. At the same time, relative velocity of clouds with shock waves exceeds 50 km/s.

It is known that the boundary of the plasma formation remains fixed under the condition that the sum of the gaskinetic nkT and the magnetic $p_м$=$B^2/2\mu_0$ pressures on it is equal [4]. The displacement of the boundaries like expansion or contraction of the given formation, arises as a result of a violation of the balance of pressures. In this study, the relationships of the total gas-kinetic and magnetic pressures (Fig. 2a), gas-kinetic and magnetic pressures separately (Figs. 2b, c), on «Solar wind-magnetic cloud» boundary are devoted. The dependence of the relative velocity of magnetic clouds on these two pressures (Fig. 2d, d) is devoted too. In all the diagrams in Fig. 2, the gray triangles correspond to magnetic clouds without shock waves, black circles to clouds with shock waves. According to Fig. 2a, for magnetic clouds without shock waves (gray triangles) there is balance of the total gas-kinetic and magnetic pressure on «Solar wind-magnetic cloud» boundary (they found along the line of equality of pressures).

In the case of clouds with shock waves (black circles) there is a significant excess of the total pressure at cloud body above the pressure in the Solar wind. Consequently, there is an expansion of magnetic clouds with shock waves, as a result of which their boundaries acquire an additional velocity. Investigation of the ratios of gas-kinetic and magnetic pressures in the Solar wind and in magnetic clouds (Figs. 2b, c) showed that the magnetic pressure in clouds with shock waves exceeds the corresponding values in Solar wind. This indicates the main contribution of magnetic pressure to the acceleration of the leading part of the cloud. Analysis of the dependence of cloud relative velocity on intra-magnetic and intra-gas-kinetic pressures also demonstrates the effect of magnetic pressure on the acceleration of fast clouds (Fig. 2e, black circles). The gas-kinetic pressure in Solar wind and in magnetic clouds are an order of magnitude lower than the magnetic one and does not make a significant contribution to the acceleration of clouds.

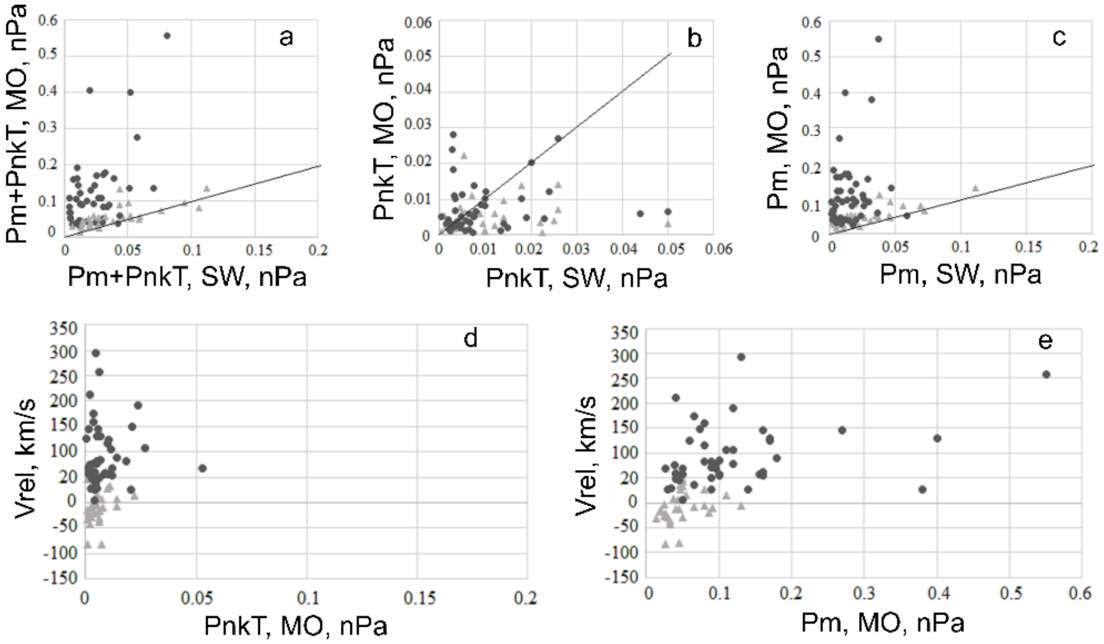

Figure 2

Thus, as a result of the research carried out, it is established that the main condition for the existence of shock waves in front of magnetic clouds is that the velocity of the cloud exceeds the velocity of Solar wind by more than 50 km/s. In this case, the relative velocity of the cloud turns out to be higher than the velocities of the sound waves and Alfven waves in Solar wind. It is shown that the acceleration and expansion of magnetic clouds occurs due to the excess of the magnetic pressure in them above the corresponding pressure in the surrounding Solar wind.

Acknowledgments. This work was supported by grant RFBR №16-05-00608 and State Task of Minobrnauki RF № 5.5898.2017/8.9.

References

[1] Barkhatov N.A., Revunova E.A., Levitin A.E. Classification of space-weather complexes based on solar source type, characteristics of plasma flow, and geomagnetic perturbation induced by it // Geomagnetism and Aeronomy. T. 54. № 2. P. 173-179. 2014.

[2] Zhang J., Liemohn M.W., Kozyra J.U., Lynch B.J., Zurbuchen T.H. A statistical study of the geoeffectiveness of magnetic clouds during high solar activity years // J. Geophys. Res. V. 109. A09101. doi:10.1029/2004JA010410. 2004.

[3] E.K.J. Kilpua, Y. Li, J.G. Luhmann, L.K. Jian, C.T. Russell. On the relationship between magnetic cloud field polarity and geoeffectiveness // Ann. Geophys. V. 30. P. 1037–1050. doi:10.5194/angeo-30-1037-2012. 2012

[4] Kroll N., Trajvelpis A. Basics of Plasma Physics. M.: Mir, 1975. 525 c. (in Russian)