Magnetic Clouds: The Cylindrical Elliptic Approach

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Abstract: Magnetic clouds, as subsets of Interplanetary Coronal Mass Ejections, are modulating the interplanetary space. We present six observed magnetic clouds and simulate them according to the circular and the new elliptic cylindrical models. Both models correspond to magnetic clouds attached to the sun and the simulations estimate the characteristics of the clouds, such probable shapes, orientation of their axis, duration, etc. In general, magnetic clouds can be described by closed (attached) cylindrical models and an elliptic expanding body when the solar wind velocity inside is characterized by a smooth and low negative gradient.

Introduction

The in situ measurements of the temperature speed and density of the solar wind by satellites in space, like VELA and IMP-6, uncovered new phenomena in interplanetary space [1]. Among the characteristic phenomena of the solar wind is the occasionally observed low temperature of protons and electrons. Their possible structures have specific characteristics and form plasma clouds that are ejected from the Sun and propagate into the solar wind. The existence of plasma clouds are widely investigated, particularly when they reach the Earth, as a subset of Coronal Mass Ejections. Such plasma clouds today are called "magnetic clouds". The term magnetic cloud [2] is used in order to describe a specific structure of an interplanetary solar ejectum with the following characteristics (at 1 AU):

(a) Relatively strong magnetic field.
(b) Large and smooth rotation of the magnetic field with period of about 1 day.
(c) Lower proton temperature than the ambient solar wind.

These three criteria should be satisfied in order to recognize and characterize a structure as a magnetic cloud. It is remarkable that magnetic clouds are structures carrying solar ejections into the interplanetary space.

At near-Earth space (1 AU) the intensity of the magnetic field of a magnetic cloud is larger than in surroundings. In most cases the temperature is low with respect to the surrounding solar wind.

A large number of magnetic clouds have been identified and studied up to today. The topology of the magnetic field inside the magnetic cloud is still under study. One basic structure for the clouds is the cylindrical circular topology, according to which the magnetic cloud is presented as a large loop (flux-rope), which can be locally described as a cylinder. The intersection of a perpendicular to its axis plane forms a circle. The magnetic field lines are attached to the sun surface and they have thermal connection with the solar corona.

According to this model the magnetic field lines are wrapped around the axis of the magnetic clouds, helically and the magnetic field depends on the radial distance from the cloud axis only (Fig. 1).

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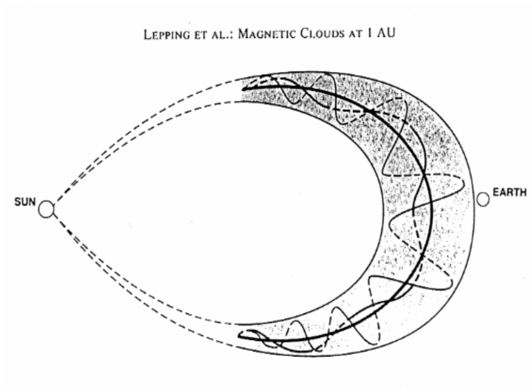
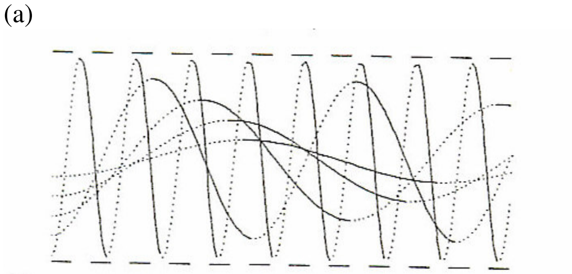


(a)



(b)

Figure 1: (a) Magnetic cloud as a magnetic loop attached to the sun [3]. Reproduced by permission of American Geophysical Union.
(b).Magnetic field lines for different distances from the axis for a cylindrical magnetic cloud [4]. Full lines are above the plane of the sheet and dotted lines below. Dashed line is the cloud's boundary forming the peripheral of a circle.

A recent topology is the cylindrical elliptic one, according to which the magnetic cloud is attached to the sun too and forms oblate cylindrical regions of magnetic field. The intersection of a perpendicular plane forms an ellipsis rather than a circle. (Fig. 2) [5].

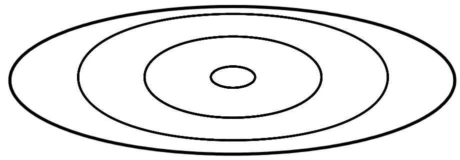


Figure 2: Magnetic field lines for an elliptic cylindrical magnetic cloud. It is a cross section; the cloud's axis is perpendicular to the sheet. From the side view, the appearance would be similar to Fig. 1b.

Simulations and observations

This paper presents the structure of three magnetic clouds. The data are obtained from the database Omni web Data Explorer (http://omniweb.gsfc.nasa.gov) (Figs. 3-5) that combine data from geocentric satellites. The study of the structure of these clouds is done with the help of a simulation program via which we examine whether the circular or the elliptic model fits better to the experimental data [4],[6].
The plots for three magnetic clouds (Figs. 3-5) present the magnetic field magnitude, B_x, B_y, and B_z components, and the plasma velocity, density and proton temperature inside. In addition, the created geomagnetic storm is also shown measured on the ground by D_{st} index. (http://omniweb.gsfc.nasa.gov), (Figs. 3-5). The determination of the cloud boundaries is derived by using the plasma temperature and speed and is indicative.
Fig. 3 demonstrates the fact that B profile fits better the data for the elliptic model than the circular one, while the three B components fit well the data for both models.
Fig. 4 is similar to the previous one. Here, B for the elliptic model corresponds better to the data, while its components correspond to the data quite good for both models.
And Fig. 5, represents a case of a short cloud, but very intense. This special case shows a clear distinction between the models in fitting data. B and its components are quite similar to the data for the elliptic cloud, while for the circular the deviation is obvious. Probably, due to the large value of B (~ 60 nT) and the negative orientation of the field of the cloud, a rather intensive geomagnetic storm is created with a D_{st} value of about -500 nT.

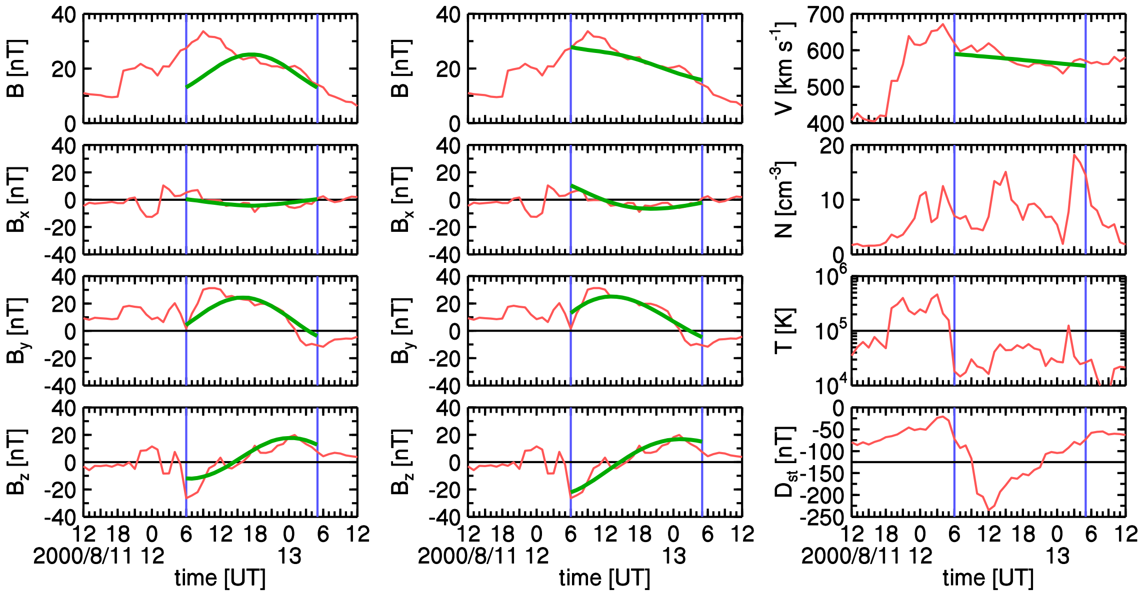


Figure 3: Magnetic field magnitude B, and components B_x, B_y, B_z, for circular (left column) and elliptic (central column) cylindrical clouds. Speed V, density N, proton temperature T of plasma inside the cloud and D_{st} index (right column). Thin line (red) is the experimental data, bold line (green) the simulated data. Vertical thin lines (blue) are the cloud's boundaries.

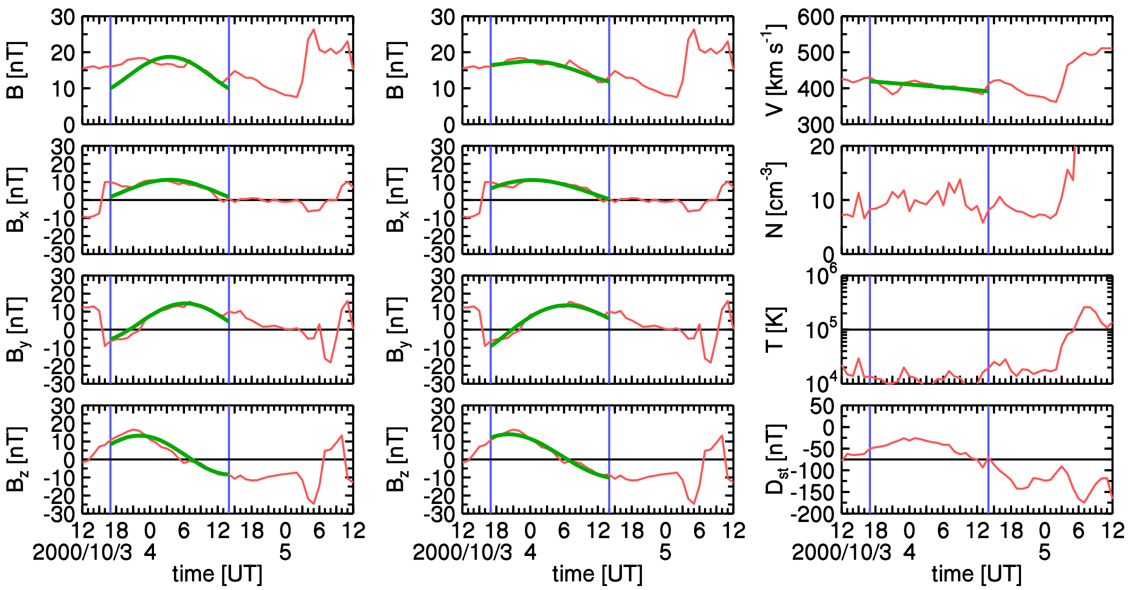


Figure 4: Magnetic field magnitude B, and components B_x, B_y, B_z, for circular (left column) and elliptic (central column) cylindrical clouds. Speed V, density N, proton temperature T of plasma inside the cloud and D_{st} index (right column). Thin line (red) is the experimental data, bold line (green) the simulated data. Vertical thin lines (blue) are the cloud's boundaries.

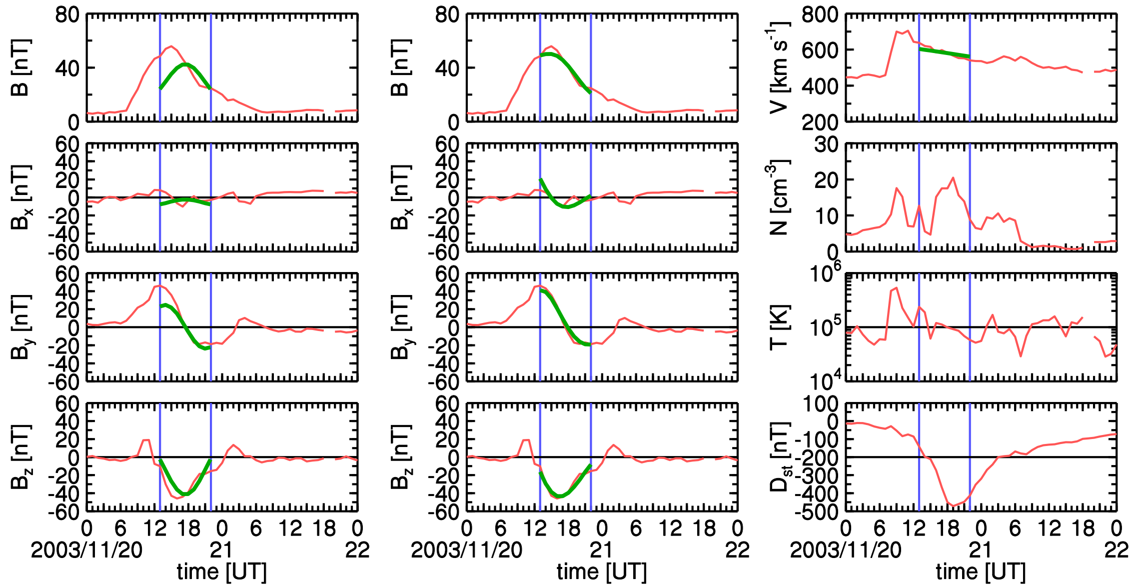


Figure 5: Magnetic field magnitude B, and components B_x, B_y, B_z for circular (left column) and elliptic (central column) cylindrical clouds. Speed V, density N, proton temperature T of plasma inside the cloud and D_{st} index (right column). Thin line (red) is the experimental data, bold line (green) the simulated data. Vertical thin lines (blue) are the cloud's boundaries.

Conclusions

The comparison of the profiles of the intensity of the magnetic field and its components shows that the elliptical model can also describe the magnetic cloud satisfactory like the circular one. Moreover, in some extreme cases (Figs. 3-5) the fit to the data is even better. From the simulations we made, it appears that the elliptic model corresponds with success to clouds with simple, but also asymmetric profiles of magnetic field.

Acknowledgments

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