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SOLAR SOURCES AND CHARACTERISTICS OF SOLAR WIND MAGNETIC CLOUDS

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Introduction

The forecast quality for geomagnetic efficiency of coronal mass ejections (CME) as high-energy solar manifestations in the form of magnetic clouds directly depends on the initial physical characteristics of solar sources [1, 2, 3]. For this purpose, at the present study a technique for establishing the localization and orientation of an extended solar source of magnetic clouds from the data of coronagraphs and photosphere photographs EIT MDI SOHO has developed. Further, based on the proposed method, a statistical study of the dependences for CMEs spatial characteristics of magnetic clouds on the location of their sources on the solar disk, on their extent and angular orientation was performed. As a result, dependences of the maximum intensity, of the maximum intensity Bz-component, the latitude and longitude angles of the cloud magnetic field vector, the magnetic cloud velocity from the minimum latitude of the extended solar source and the corresponding longitude are obtained. Attention has been drawn to the existence of auroral electrojets AL index value dependence by parameters of solar sources structures. The relationships of solar source coordinates with the geomagnetic activity of the cloud sheath and with the geomagnetic activity of the magnetic cloud body are found.

The main problems in studying the sources of CME/MC and their transfer in the solar wind are the following: 1) the CMEs sources often do not stand out against the background of the corona or the photosphere and sometimes can be determined by residual phenomena; 2) solitary MC is an extremely rare phenomenon and its source is difficult to detect against the background of a disturbed solar corona or photosphere, 3) the direct passage of solitary MC to the Earth is not fixed by coronagraphs, since the coronagraph detects the MC only in the profile, 4) the huge dimensions of the CME/MC by satellites allows to receive the parameters of the structure and its dynamics only at the object section.

Method for establishing the localization and orientation of an extended solar source of magnetic clouds

A key feature of our approach to investigating MC is to represent its magnetic part in the form of a powerless magnetic tube carried away from the Sun with the observed eruption. However, the mass parts of the "halo" type CMEs are clearly visible on the coronagraphs and, as a consequence, it is possible to reliably determine their solar source.

Determination of the number of possible sources during the day proceeding from the minimum velocity of the CME propagation from the Sun to the patrol spacecraft (SC) was performed. The minimum velocity is assumed to be equal to the average MC velocity plus the average velocity of magnetic sound (according to the SC data). The MC sources are the areas of ascent and eruption of stream loops (fibers) we use. Due to the length of the MC sources, their angular coordinates closest to the center of the heliocentric Cartesian coordinate system were considered. So in the case of high-energy events, the determination from the coronagraph data of the source coordinates was reduced to determining coordinates of the visible regions of these structures output on the photosphere ("pins").

In the general case, if the event was accompanied by cascade eruptive processes involving loops from several regions, then the source was the area in which the final loop collapsed and became invisible in the frequency range of the coronagraph. If the coronagraph resolution was not sufficient to observe the process of eruption itself and the sunspots or sources structure are far from the flow loop representation in the form of an arch (for example, sigmoid), indirect signs of eruption (for example, post eruptive arcades, deflection of "power lines" around an invisible center, areas of darkening) were used. In this case, the ascent area of the loop was determined by arcades, and the "pins" coordinates - by the "force lines" deviations around the invisible center in the areas where the arcade ends. Instead of the point "pins" coordinates, the values of coordinates for boundaries of regions involved in the eruption were used.

A statistical study for dependence of MC characteristics sources on location on the solar disk was carried out at 46 MC events, marked from 1997 to 2012. For them 112 possible solar sources were fixed according to the following catalogs: 1) catalog of coronal ejections of LASCO CME Catalog, (*http://lasco-www.nrl.navy.mil/index.php?p=content/cmelist*); 2) catalog of large-scale solar wind phenomena (*https://cdaw.gsfc.nasa.gov/CME_list/*); 3) catalog of outbreaks indicating the presence of CME and shock waves (*http://umtof.umd.edu/sem/*); 4) catalog of Hα-flashes (*ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/*); 5) catalog of X-ray flares from Virtual Solar Observatory (*http: //vso.nso.edu/cgi/catalogue*).

Selection of probable sources was also carried out with the help of additional possibilities using data on X-ray flares and microwave radiation bursts with a minute resolution. These data with photographs of the solar photosphere EIT SOHO, which made it possible to determine outburst coordinates, were compared. An alternative way to determine the coordinates of the CME/MC sources was to focus on the halo CME appearance. Since the halo can be ejected in the opposite direction from the Earth, the data on x-ray and microwave radiation were used.

In all possible cases obtained coordinates of the CME/MC sources with sunspots coordinates in the region of the emission source from the MDI SOHO images (Fig. 1a) were compared. Satisfactory was considered to coincide with a deviation no more than 2-3° in latitude. In determining the source coordinates, the "shaking" of the SOHO spacecraft around the X GSE axis in the range of ±7.85° was also taken into account. The angles of " shaking " for each case by stars motion on the difference LASCO C3 images within daily interval or less (Fig. 1b, c) were calculated.

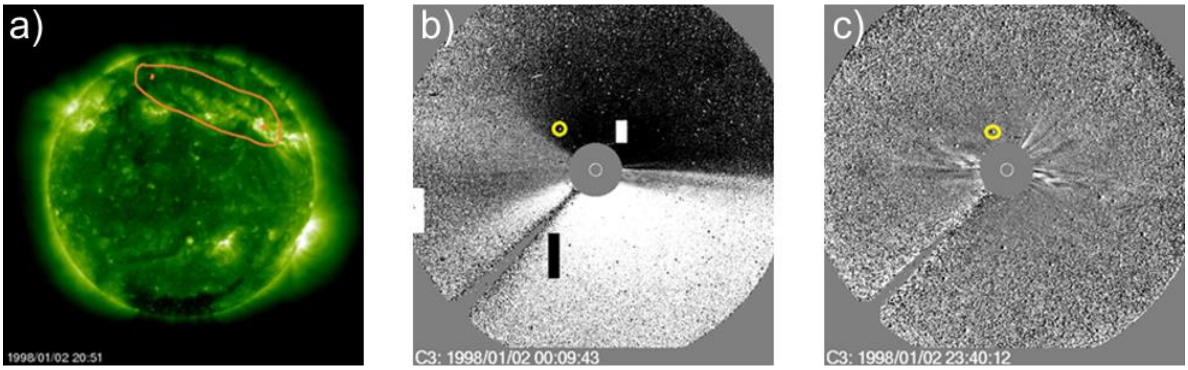

Figure 1. MDI SOHO (***a***), LASCO C3 (***b***, ***c***) images used to determine coordinates of the CME/MC sources

Investigation of dependence for angular orientation of the visible part for 112 possible solar sources on their coordinates showed the following regularities: 1) the source inclination angle to the equator plane in the western hemisphere at northern and southern latitudes has a minimum at zero latitudes, 2) if source closer to the heliographic equator, so it is more extended in the equatorial direction, 3) if farther the source from the equator, so it is more extended in the meridional direction, 4) the longitude dependences corresponding to the minimum latitude appear weak.

Analysis for distribution of various lengths solar sources showed that for the northeastern part of the solar disk there is a clear direct dependence of the source length from its minimum latitude with a minimum in the equatorial region. For the minimum latitude of an extended source located in the region of the midday meridian, its length increases with the longitude of the source from ~10°.

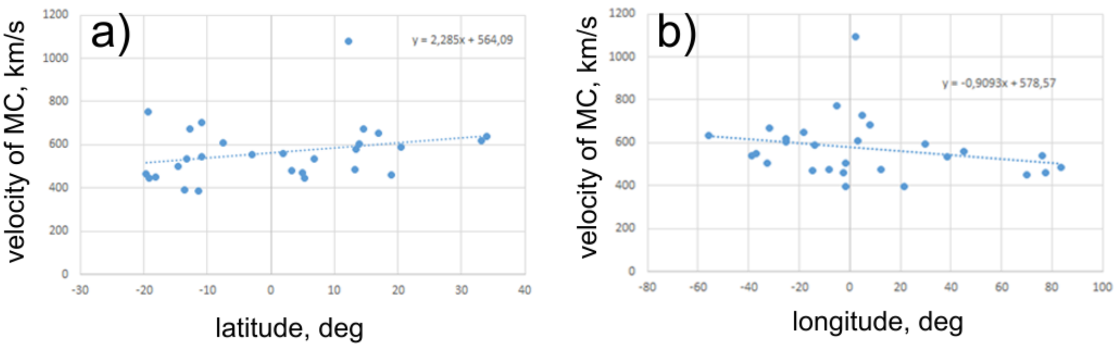

Figure 2. The dependence of MC velocity on the minimum latitude (***a***) and the corresponding longitude (***b***) of the source

A statistical study for dependence of MC characteristics and their substorm geomagnetic activity by the localization of solar sources

Comparison of solar sources parameters with the MC characteristics gave a special point in the heliographic center area related to the CME velocity of the order of ~550-600 km/s. For the northern hemisphere, a direct dependence (R>0.45) of structure velocity on the latitude of the source with a minimum near the equator appears. Dependence of the structure velocity on the source longitude in the northern and southern hemispheres of the Sun according to the quadrants is described by the correlation coefficient from 0.55 to 0.7. It is noted that the structure velocity is higher the east of its supposed source on the Sun (Fig. 2). The character of the obtained dependence excludes the mirror symmetry of the Sun hemispheres.

The study revealed the dependence of the MC maximum magnetic field strength and the corresponding Bz component on minimum latitude of the extended source and corresponding source longitude. Here, a minimum (~10 nT) of the MC maximum magnetic field in the region of the heliographic equator and its maximum (~50 nT) occur in the region of the midday meridian. For a large MC group, the maximum field strength increases with increasing of source latitude. This dependence is particularly noticeable for the northeastern part with a minimum in the equatorial region (R~-0.6). The same dependence on the source longitude has a weak inverse character with the exception of the western hemisphere where R~-0.6. In GSE coordinates, a minimum (~0 nT) for the Bz-component of the maximum magnetic field MC for a source located in the region of the heliographic equator and a maximum (~20-25 nT) for the source near the midday meridian are observed. Moreover, as the latitude of the source increases, the modulus of the Bz component increases, and decreases with longitude increasing.

A comparison of MC orientation with solar sources parameters demonstrates the dependence of the latitude and longitude angles of the magnetic field vector for MC from the minimum latitude of the extended source and the corresponding source longitude. It is noted that there exists a minimum (~0°) of the modulus of the latitude angle of the MC field vector in the region of the heliographic equator and a maximum (~60-90°) in the region of the half-meridian (in GSE). With the increase in the source solar latitude, the latitude angle of the MC increases, and with the increase in the solar longitude, it decreases. A maximum (~90°) of the MC field vector near the heliographic equator and the midday meridian (~60-90°) is noted for the longitude angle MC. With increasing solar latitude and longitude, the longitude angle decreases.

An analysis is made for relationship between geomagnetic activity, described by the AL index of auroral electrojets, MC bodies and their sheaths, with their solar source coordinates. For MC bodies that had sources located at southern latitudes, the index AL is inverted with R~-0.6 from the minimum latitude of the extended source. The dependence of AL on the source latitude increases for the southeast to R~-0.9 with a minimum in the equatorial region. For the southeast, there is also a direct dependence of AL index with R>0.6 on the source longitude corresponding to the minimum source latitude. For the south-west, as for the northern latitudes, there is no way to make any conclusion.

The MC sheath also has geomagnetic activity. For extended MC sources located at the southern latitudes of the MC sheaths, a clear dependence of the AL index on the minimum source latitude (R~-0.6) was found. For sources with a minimum latitude at northern latitudes, a weak inverse dependence may be possible. For the northeastern sources there is a weak inverse dependence of the AL index on its longitude. For northwestern sources, the direct dependence of AL index on its longitude (R~0.7) is manifested. However, for the western hemisphere this dependence is whole weak (R>0.4).

Thus, the dependence of auroral electrojets AL index values, characterizing the intensity of magnetospheric substorms, on the location of extended solar MC sources is noted. It manifests itself through the geomagnetic activity of the magnetic cloud body and its sheath.

Conclusions

A statistical study of dependencies for spatial characteristics of CME sources like as MC on their location on the solar disk is made. Dependences of distribution of localization of solar sources of various extention and angular orientation of their visible part are obtained. A comparison of solar sources parameters with MC characteristics recorded on the spacecraft, determines the following characteristic patterns: the dependence of the MC velocity on the minimum altitude and its corresponding longitude and source; dependence of the maximum magnetic field strength of MC from the minimum latitude and the corresponding longitude of the source; the dependence of the Bz component of the maximum intensity of MC magnetic field from the minimum latitude and the corresponding longitude of the source; the dependence of the latitude and longitude angles of magnetic field vector from the minimum latitude and the corresponding longitude of the source. Taking into account the connection between geomagnetic activity and the body of MC and its sheath, it was possible to determine its dependence on the localization of an extended solar source.

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