Prediction of the Geoeffectiveness of CMEs From Solar Observations: Possibility and Problem

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Abstract

Intense geomagnetic storms are usually initiated by long intervals of large southward interplanetary magnetic field within magnetic clouds, or magnetic cloud $B_s$events. The characteristics of 26 magnetic clouds used in previous studies (Zhao and Hoeksema, 1997; 1998) have been recomputed using the expanding flux rope model (Marubashi, 1997).

We find a much clearer link between the central axial field direction of the associated disappearing solar filament (DSF), the angle of the magnetic cloud central axial field relative to the ecliptic and, finally, the characteristics of magnetic cloud $B_s$events. The effect of other magnetic cloud parameters on the magnetic cloud $B_s$events is studied. The association of the impact parameter (the closest approach distance to the axis of a magnetic cloud from the spacecraft) with the position of the CME-associated DSF is analyzed.

A multiple regression analysis is used in analyzing the possibilities and problems of predicting the geoeffectiveness of CMEs from available solar observations.

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1. Introduction

Large geomagnetic storms are believed to be caused by CME-driven interplanetary disturbances. However, only about 1 in 6 CME-driven disturbances striking the Earth's magnetosphere is effective in stimulating large geomagnetic storms (Gosling, 1997). One of the important questions in space weather is which characteristics of Earth-directed CMEs make CME-driven interplanetary disturbances geoeffective?

The two major characteristics of geoeffective interplanetary disturbances are long-duration (> 3 hours) and strong-intensity (< -10 nT) southward interplanetary magnetic field (IMF) (Gonzalez and Tsurutani, 1987). Such long-duration, strong-intensity southward IMF (B_s) events occur partly or entirely within magnetic clouds. Magnetic clouds, or interplanetary flux ropes, are the magnetic signatures of CMEs in the solar wind. They are believed to be interplanetary extensions of CME-associated disappearing solar filaments (Rust, 1994) and/or the surrounding coronal flux ropes. Thus to find a way to predict the geoeffectiveness of CMEs from available solar observations, we first need to find out which characteristics of the coronal flux ropes and, subsequently, which characteristics of the interplanetary flux ropes, determine the occurrence of magnetic cloud $B_s$events and significantly affect their duration and intensity.

The observed characteristics of magnetic clouds, described as force-free cylindrical flux ropes, may be parameterized in terms of the direction and strength of the cloud central axial field ($\mathbf{B}_{ax}$), the radius and helicity of the rope, and its impact parameter (the closest approach distance of the rope axis to the spacecraft). The cloud $\mathbf{B}_{ax}$direction here is given by the latitude and longitude with respect to the ecliptic plane and the SunEarth line.

26 CMEs have been characterized previously, 14 using the static flux rope model (Lepping et al., 1990) and 12 using the expanding flux rope model (Marubashi, 1997). Using the characteristics of the 26 clouds in the combined data set and the associated magnetic cloud $B_s$events and DSFs, we have determined the correlations of the duration and intensity of magnetic cloud $B_s$events with the ecliptic latitude of the cloud $\mathbf{B}_{ax}$direction as well as the correlation between the ecliptic latitude of the cloud $\mathbf{B}_{ax}$direction and the direction of DSF $\mathbf{B}_{ax}$. However, the correlation coefficients obtained using the values computed with the expanding flux rope model are systematically greater than with the static flux rope model.

This work recomputes the characteristic parameters for the 26 magnetic clouds using the expanding flux rope model. The results are presented in Sections 2 and 3 and summarized in Section 4.

2. Magnetic Clouds and MC B_s Events

Figures 1, 2, 3, and 4 show which characteristics of magnetic clouds significantly affect the duration and intensity of magnetic cloud B_s events.

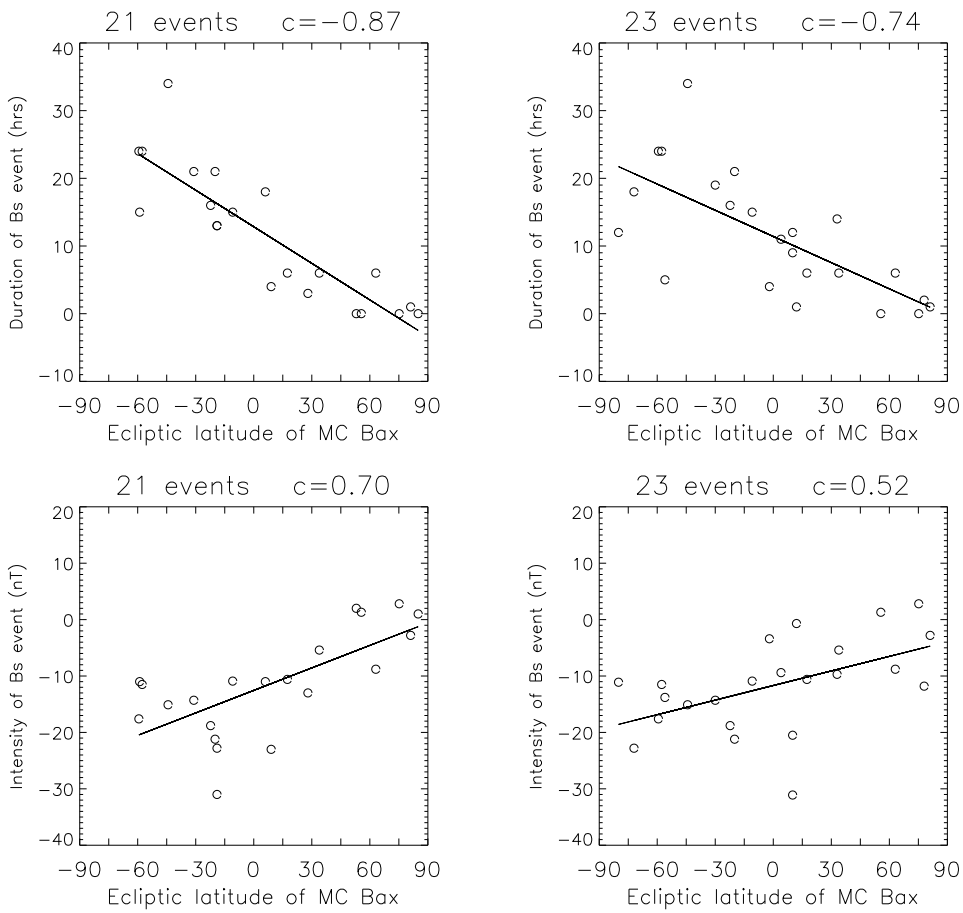

Figure 1. Scatter plots of the duration and intensity of magneic cloud $B_s$events versus the ecliptic latitude of the magnetic cloud central axial field ($\mathbf{B}_{ax}$) direction. The straight lines are linear least squares fits to the scatter plot. 'c' in each panel denotes the correlation coefficient. The coefficients obtained using the data computed with the expanding flux rope model (left column) are significantly greater than those obtained using the combined data set (right column).

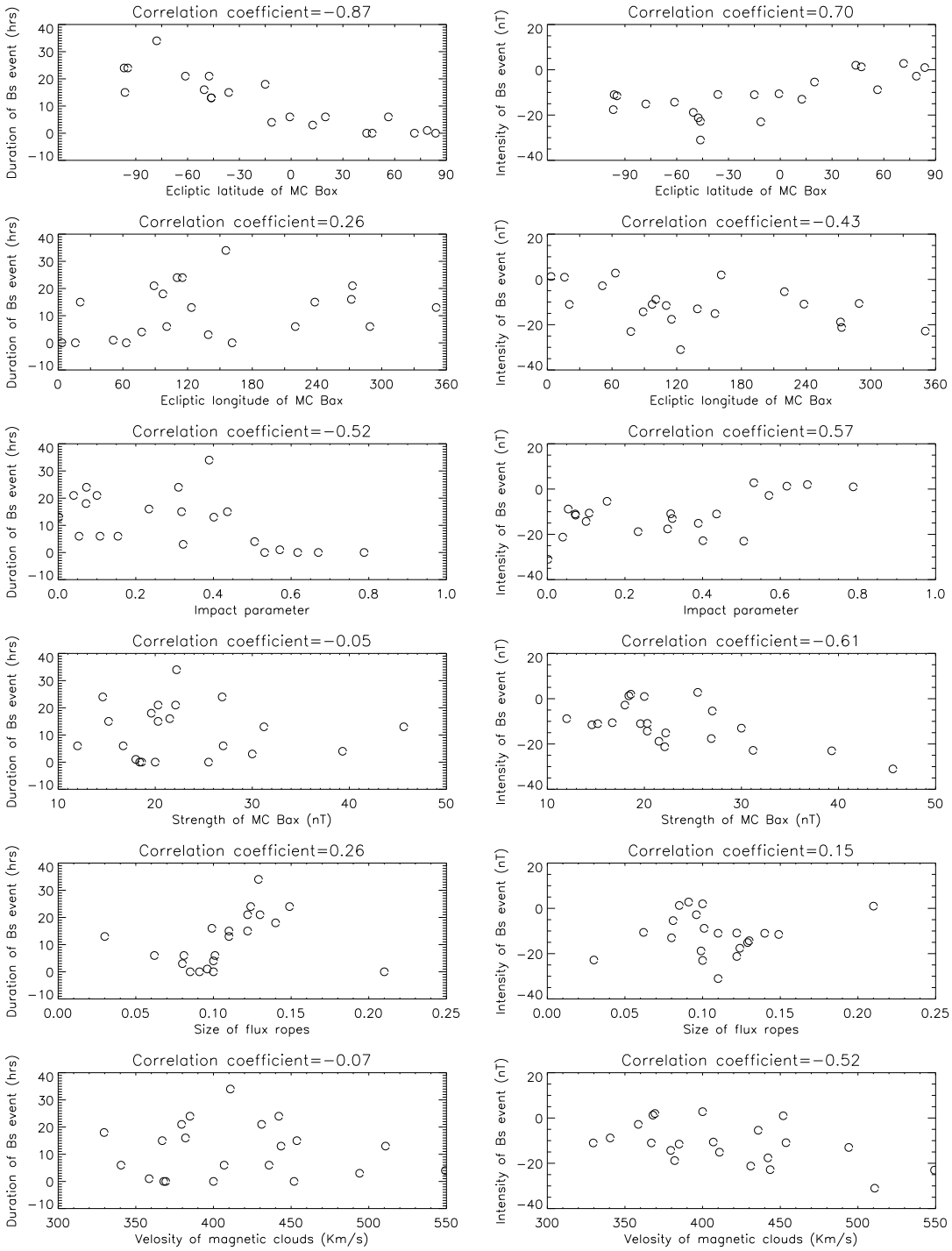

Figure 2. Scatter plots of the duration (left column) and intensity (right column) of magnetic cloud $B_s$events versus various parameters that characterize magnetic clouds described as interplanetary magnetic flux ropes. the correlation coefficient are shown at the top of each panel.

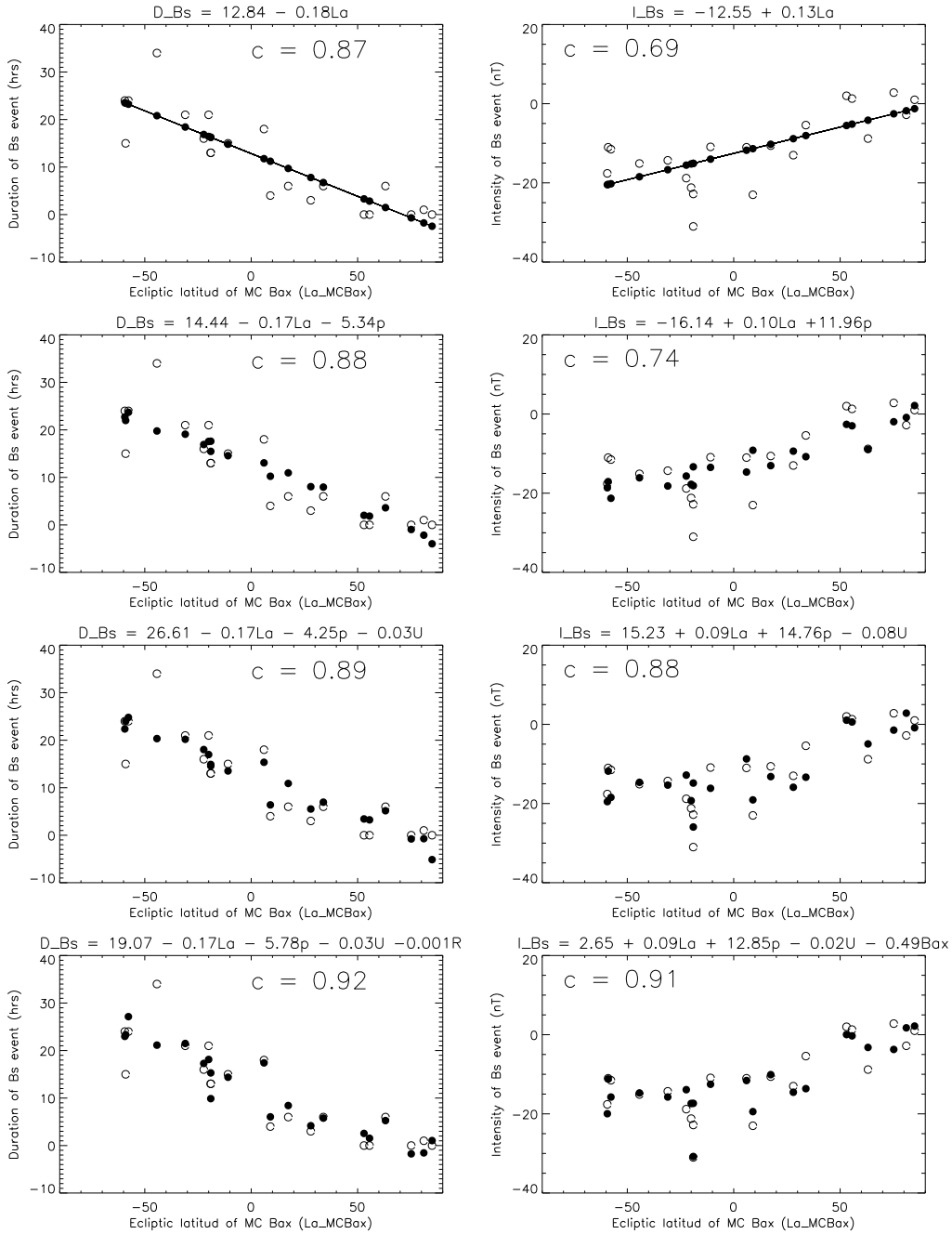

Figure 3. Multiple correlation coefficients ('c' in panels) and multiple regressions relating MC $B_s$events and magnetic clouds. A $B_s$event is characterized by its duration (D_Bs) and intensity (I_Bs). The parameters selected to characterize magnetic clouds are the ecliptic latitude (La) and strength (Bax) of the magnetic cloud central axial field, the radius (R) and velocity (U) of the cloud, and the impact parameter (p). The open circles denote the observed duration and intensity of MC $B_s$events. The filled circles are calculated using multiple regressions at the top of panels.

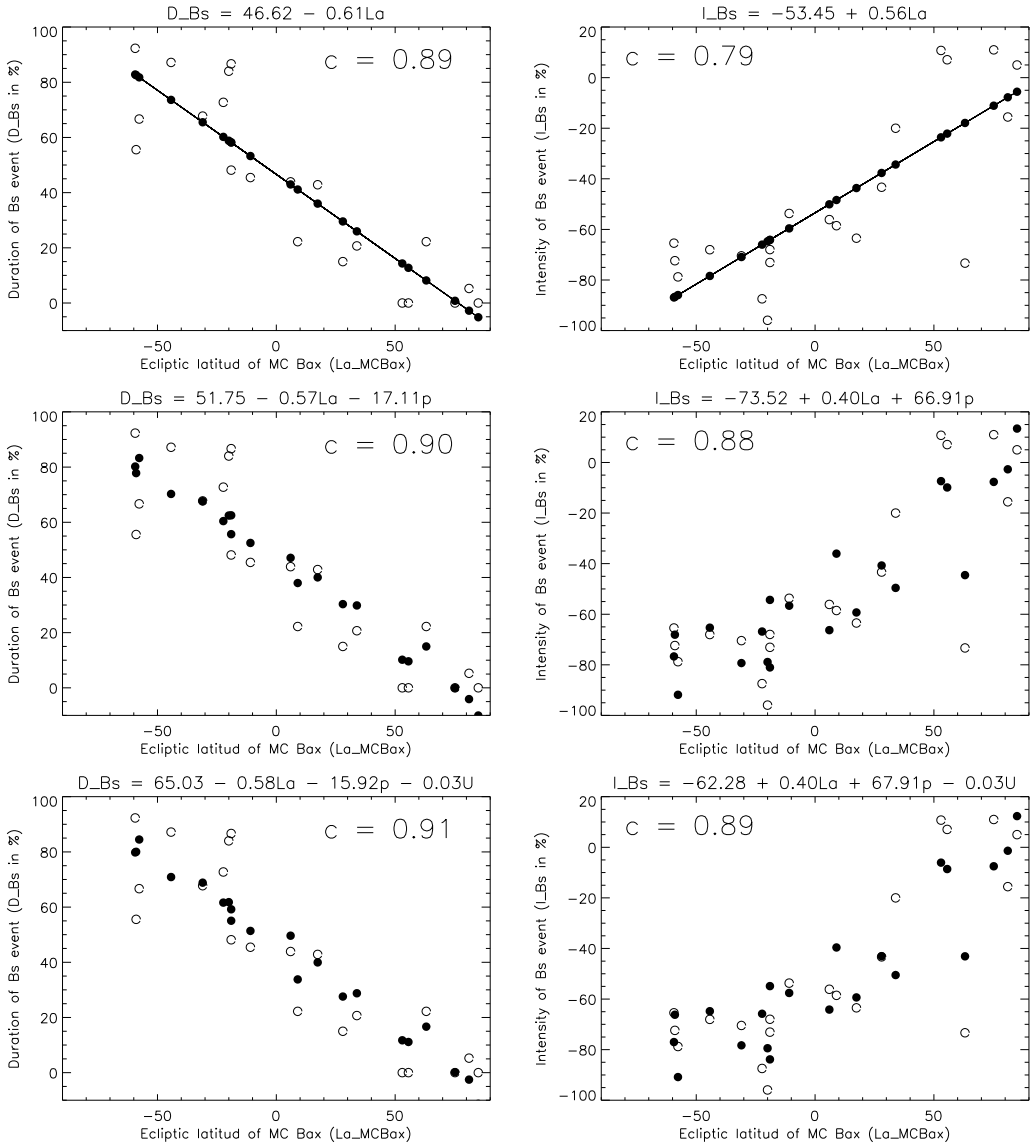

Figure 4. Multiple correlation coefficients ('c' in panels) and multiple regressions relating MC $B_s$events and magnetic clouds. $B_s$events are characterized by their duration (D_Bs) and intensity (I_Bs) normalized to the duration and central axial field strength of the corresponding magnetic cloud The cloud characteristics used are the ecliptic latitude (La) and strength (Bax) of the cloud central axial field, the velocity (U) of the cloud, and the impact parameter (p). The open circles denote the observed duration and intensity of MC $B_s$events. The filled circles are calculated using multiple regressions at the top of panels.

3. Magentic Clouds and Disappearing Solar Filaments

Eruptive prominences (DSFs on the solar disk) often exhibit helical structures. The magnetic fields in quiet filaments have been found to be preferentially sinistral heliform in the southern hemisphere and dextral in the northern hemisphere, regardless of solar cycle (Martin et al., 1994).

Solar filaments are assumed to be basically parallel to the solar surface and observed in their projection against the chromosphere. The orientation of the DSF $\mathbf{B}_{ax}$may be expressed in terms of the angle from the local east-west line.

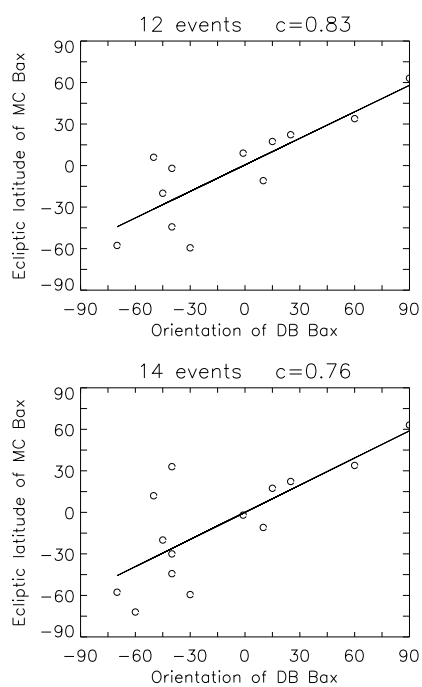

Figure 5. Scatter plots of the ecliptic latitude of the cloud central axial field ($\mathbf{B}_{ax}$) direction versus the orientation of the central axial field of the disappearing solar filament (DSF), defined as the angle between the filament and the local latitude. The straight lines are linear least squares fits to the scatter plot. 'c' in each panel denotes the correlation coefficient. The coefficients obtained using the data computed with the expanding flux rope model (left panel) are significantly greater than those obtained using the combined data set (right panel).

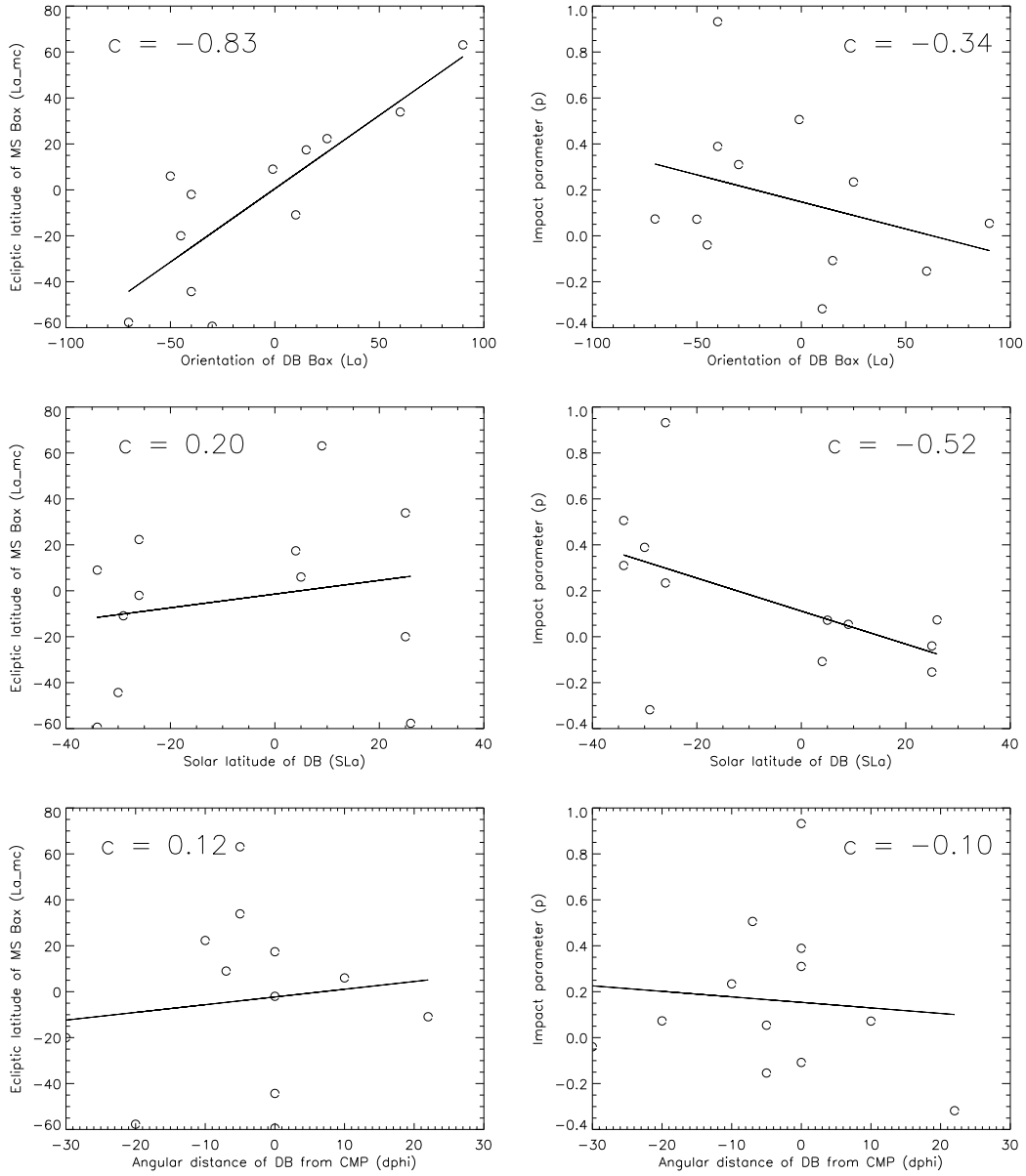

Figure 6. Multiple correlation coefficients (c in panels) and multiple regressions (expressions on the top of panels) relating magnetic clouds (MC) and disappearing solar filaments (DSF). The parameters to be predicted from available solar observations are the ecliptic latitude of the magnetic cloud central axial field direction (La_MC$\mathbf{B}_{ax}$) and the impact parameter (IP). The independent variables determinable from solar observations are the orientation of disappearing filament central axial field direction (La_BD$\mathbf{B}_{ax}$), the solar latitude (SLa) and the distance from the central median passing (dcmp) of associated disappearing filaments. The open and filled circles denote observed and predicted ecliptic latitude and impact parameter of magnetic clouds.

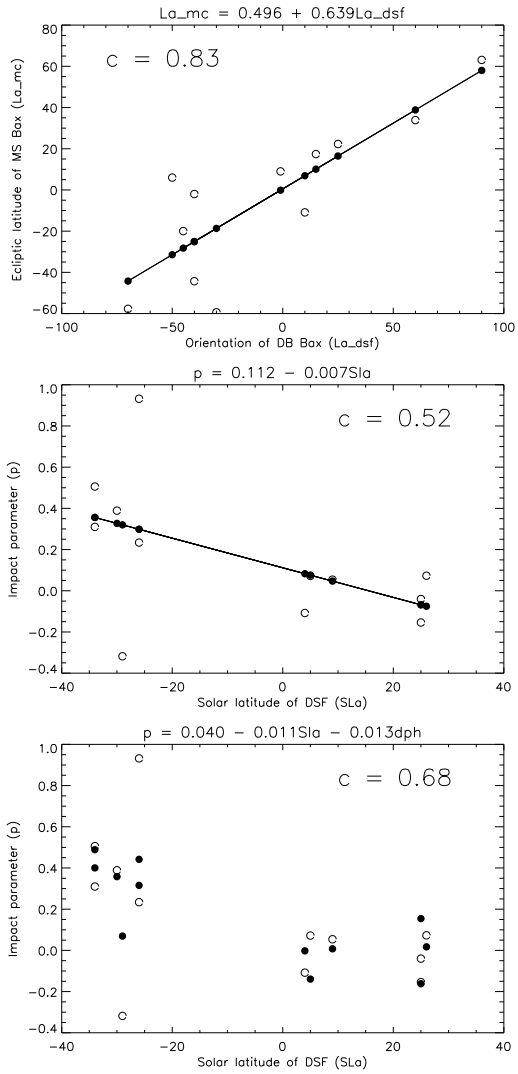

Figure 7. Multiple correlation coefficients (c in panels) and multiple regressions (expressions on the top of panels) relating magnetic clouds (MC) and disappearing solar filaments (DSF). The parameters to be predicted from available solar observations are the ecliptic latitude of the magnetic cloud central axial field direction (La_MC$\mathbf{B}_{ax}$) and the impact parameter (IP). The independent variables available from solar observations are the orientation of disappearing filament central axial field direction (La_BD$\mathbf{B}_{ax}$), the solar latitude (SLa) and the distance from the central median passing (dcmp) of associated disappearing filaments. The open and filled circles denote observed and predicted ecliptic latitude and impact parameter of magnetic clouds.

4. Summary

• The 6 parameters characterizing 26 magnetic clouds have been recomputed using the expanding force-free cylindrical flux rope model. The correlation coefficients relating the duration and intensity of magnetic cloud $B_s$events to the cloud central axial field direction are significantly greater than those obtained using the combined data set (Figure 1). The correlation coefficients relating the cloud and DSF central axial field directions are also greater (Figure 5). This suggests that the expanding flux rope model is probably better in modeling magnetic clouds.

• The correlation coefficients relating the duration and intensity of magnetic cloud $B_s$events to the 6 parameters (Figure 2) showed that the ecliptic latitude of the magnetic cloud central axial field direction and the impact parameter are the most important factors determining both the duration and intensity of magnetic cloud $B_s$events. These two parameters may be associated with the central axial field direction and the location of the CME-associated DSF (Figure 6). The DSF parameters may be inferred from the currently available solar observations (Figure 7). Thus it should be possible to predict the geoeffectiveness of CMEs from currently available solar observations.

• There is long way to go in increasing the correlation coefficients both between magnetic clouds and their $B_s$events and between DSFs and magnetic clouds. The multiple regressions (Figures 3, 4 and 7) seems to hold the promise for fruitful returns, however its theoretical statistical basis is not adequately known.

• The most difficult problem in developing the prediction scheme is the determination of the source of CMEs. The LASCO, EIT and MDI instruments on SOHO provide a unique opportunity to more accurately determine the source of CMEs and the central axial field direction in DSFs. It would be very helpful if we could find an association between H_α filaments and some kind of EIT feature.