Internal characteristics of magnetic clouds at 1 AU

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Abstract

Magnetic clouds (MCs) are a subset of interplanetary coronal mass ejections (ICMEs). They are important due to their internal magnetic field configuration, which resembles a magnetic flux rope, and because they represent the most geoeffective type of solar transient. In this study, we analyze their internal structure using a superposed epoch method of a large set of events detected at L1, between 1996 and 2006. We compare their internal parameters with those seen in the solar wind and with respect to solar cycle variations. In particular, we are interested in the density increase seen at the trailing part of some magnetic clouds. Furthermore, we link events with their solar counterparts and compare the remote observations in EUV and white-light with the in situ data. With Solar Orbiter we will be able to do this study closer to the Sun and provide new insights into the linking of CMEs and ICMEs.

Introduction and data analysis

In this work we analyze magnetic clouds (MCs) using a superposed epoch analysis. The events are taken from the list of "Near-Earth Interplanetary Coronal Mass Ejections Since January 1996", compiled by I. Richardson and H. Cane. The magnetic field and plasma data are from the ACE and WIND spacecraft with a 1 minute cadence.

The superposed epoch analysis is used to create an average profile of MCs characteristics, such as velocity, magnetic field, etc. To perform this analysis, an equal number of data points are required to represent each magnetic cloud. For the purpose of our study we resampled each cloud to 100 points, plus 100 points before and after the event (300 points in total). After resampling, each MC in the dataset will begin at data point 100 and finish at point 199. The analysis then averages corresponding data points over all magnetic clouds, so data point 1 from each magnetic cloud will be combined and averaged, followed by data point 2, etc. This procedure is done for temperature, density, speed, temperature, magnetic field and oxygen charge state ratio (O^{7+}/O^{6+}). The results are shown in Figure 1

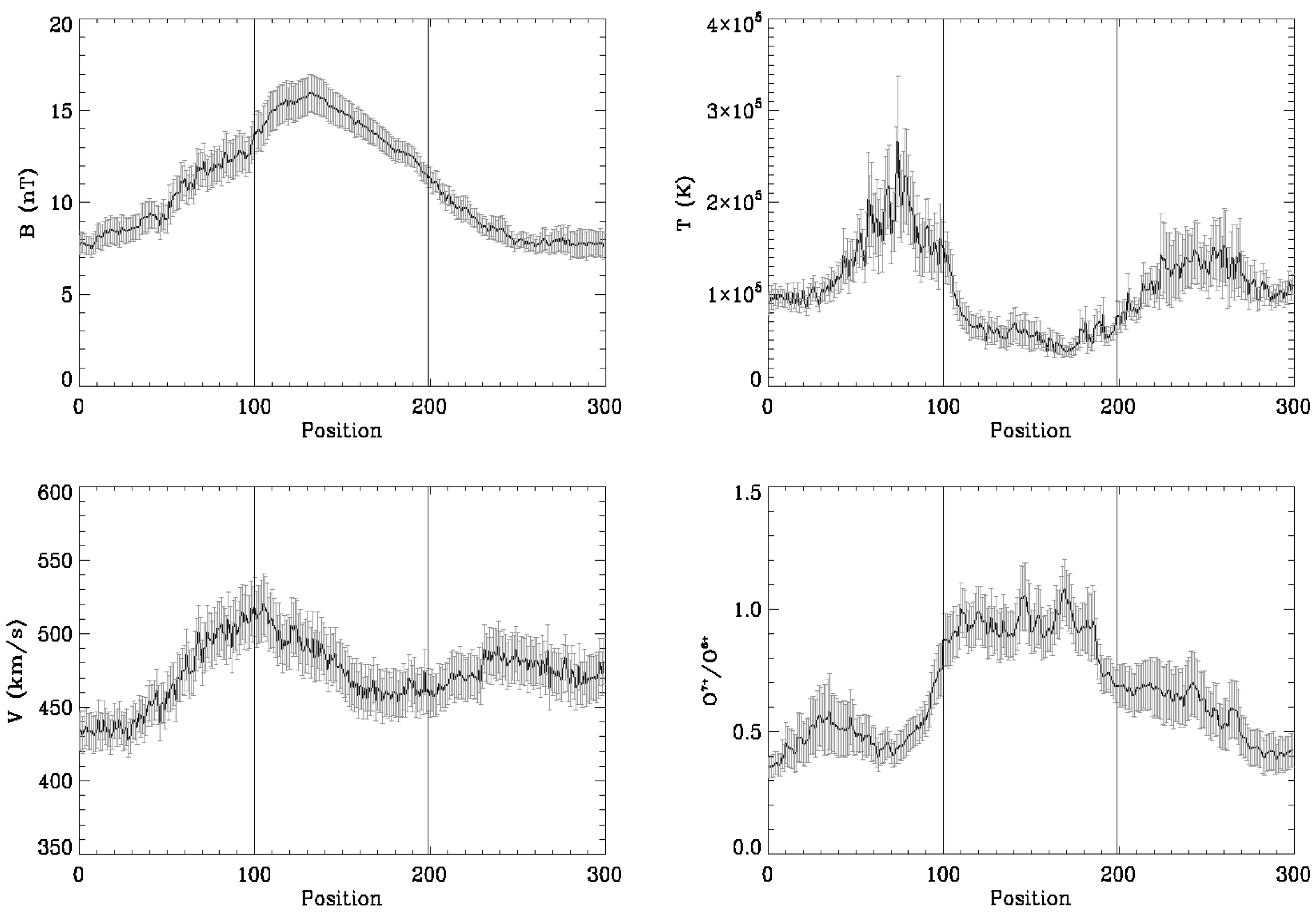
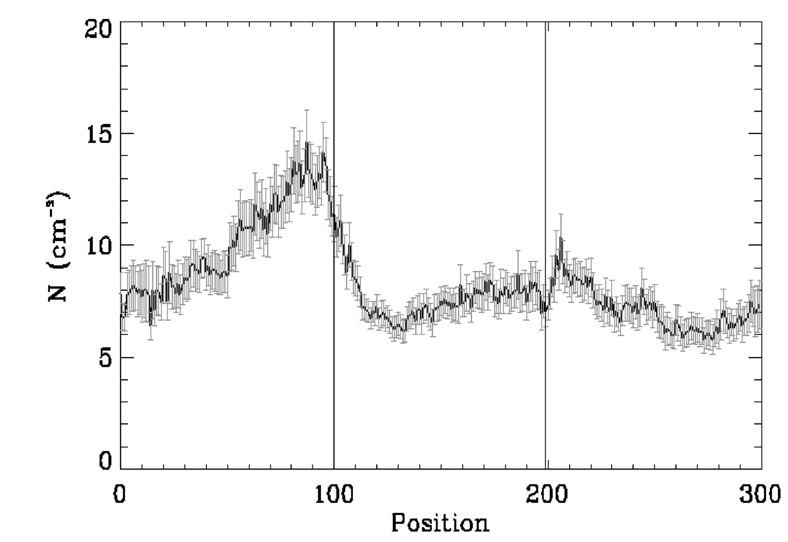


Figure 1. Profiles of plasma and magnetic field characteristics of magnetic clouds close to the Earth (at the L1 point). The plot was created by applying a superposed epoch method to 80 MCs. Points 100 to 199 represent the MC itself (defined by the flux rope. Top right: magnetic field components), 0 to 99 and 200 to 299 are periods taken before and after the MC (with the same duration of the MC itself). Error bars represent the standard deviation of the mean.



In the density profile (see last panel of Figure 1), a first peak is seen to correspond to the sheath material before the flux rope (around point 90), and a smaller second one right after it (point ~210). In order to understand the origin of this second peak, we analyzed each event separately and found that 27 of them show a density increase in this region. This can be caused by three different processes. The first one is due to a fast speed stream coming behind and compressing the MC (right column of Figure 2). The second one is because of the presence of prominence material, which is seen remotely in coronagraph images and less frequently in situ. Finally, the compression produced by the expansion of the flux rope against the back of the cloud could also account for this increase. In Figure 2 we compare two cases with and without a fast speed stream coming behind the MC.

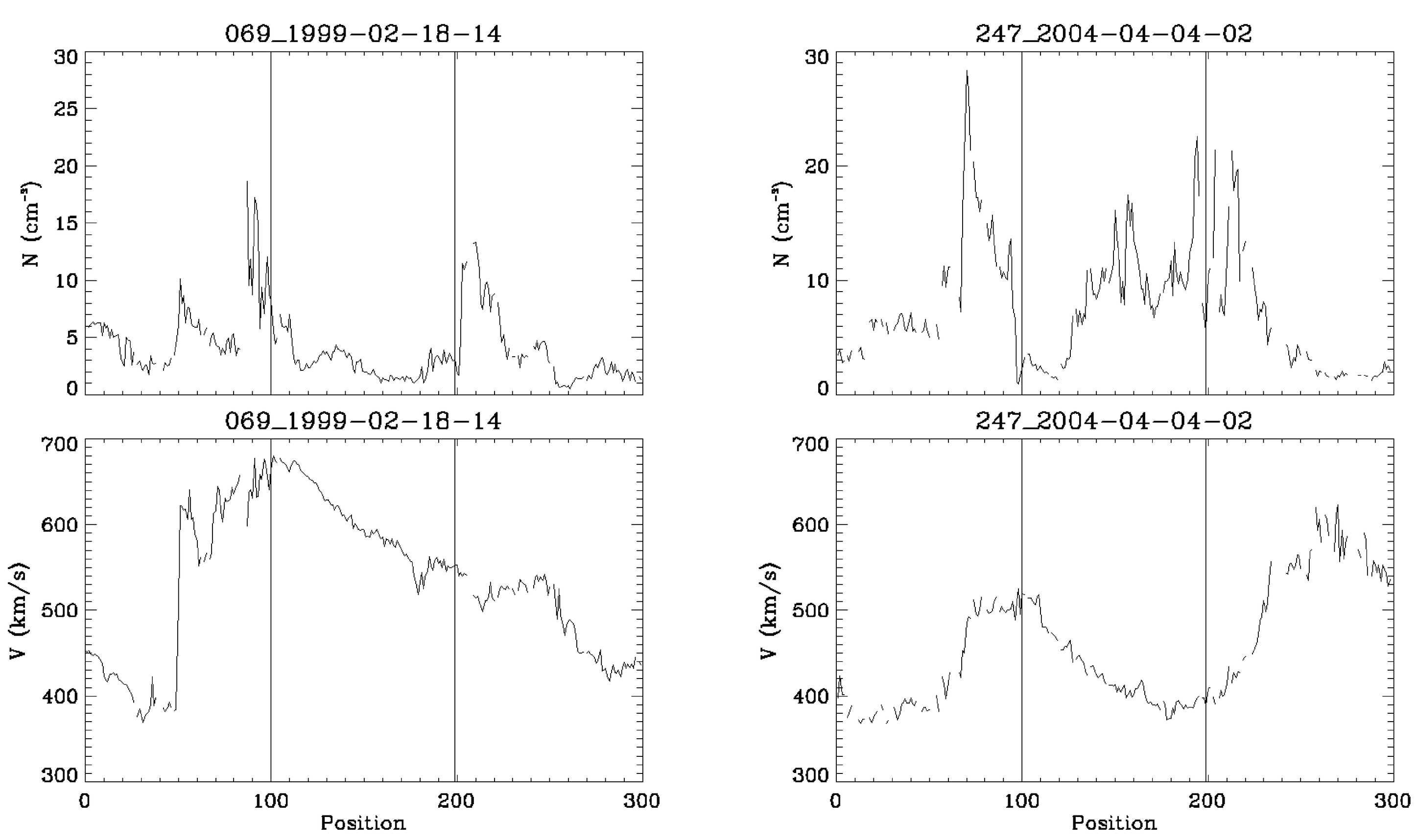


Figure 2. Density and velocity for 2 MCs. The column on the right shows a case where the peak in density at the rear part of the MC is due to compression from the trailing fast speed stream, whereas in the case on the left there is no fast speed stream.

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Average values

Table 1 shows the typical values of these parameters in the solar wind and in magnetic clouds.

Parameter	Slow solar wind	Fast solar wind	Magnetic clouds
N (cm^{-3})	8	3	7.6
T (10^4 K)	4	20	6
V (km/s)	350	700	480
B (nT)	~5	~3	14
O^{7+}/O^{6+}	0.2	0.6	0.92

Table 1. Typical values for parameters in the solar wind (adapted from Schwenn 1991 and Henke et al., 2001) and magnetic clouds (this work).

Solar associations

We looked for the solar counterpart of these MCs, we found 52 associations, for the rest (28) it was not possible to find an unambiguous link. For the 27 events that showed a density increase close to the end of the MC, we identified the corresponding sources in 14 cases. For only 2 of them filament eruptions were found. For the majority of the cases then, the density peaks could not be associated with filament material. Figure 3 shows the location and type of solar activity associated with the MCs, and their distribution in time. There is a clear trend for the source regions to be located on the western hemisphere.

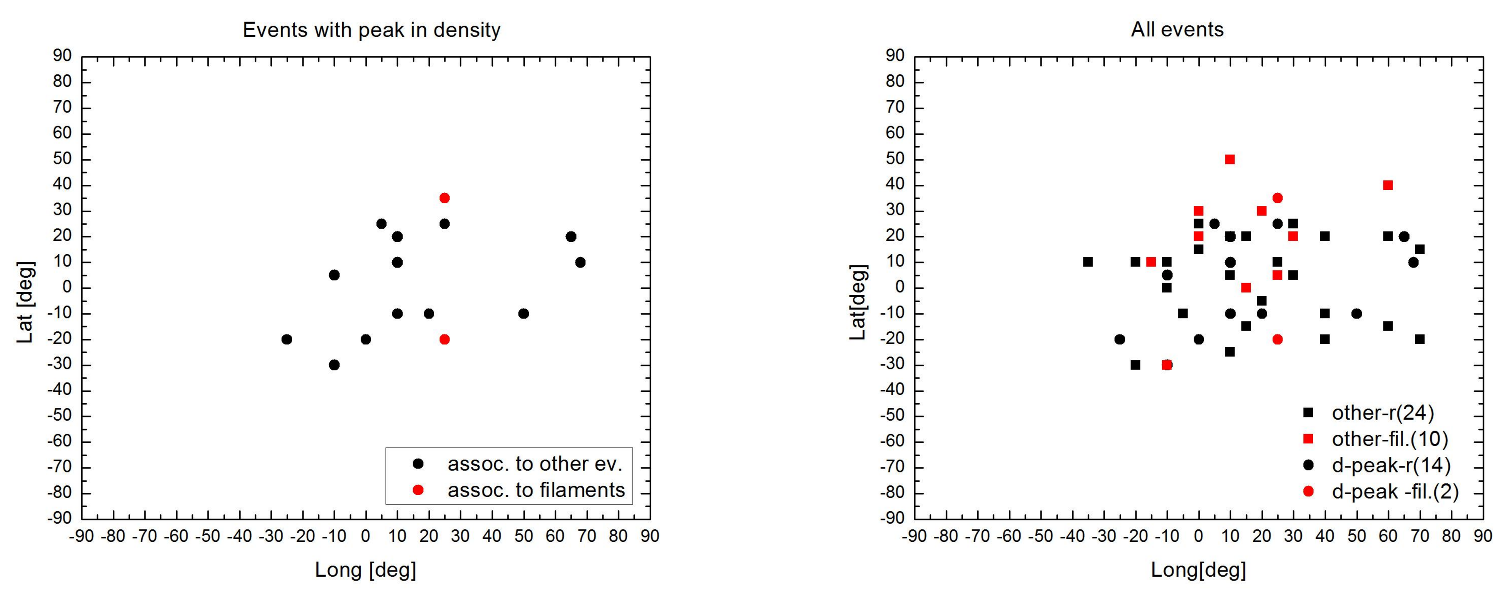
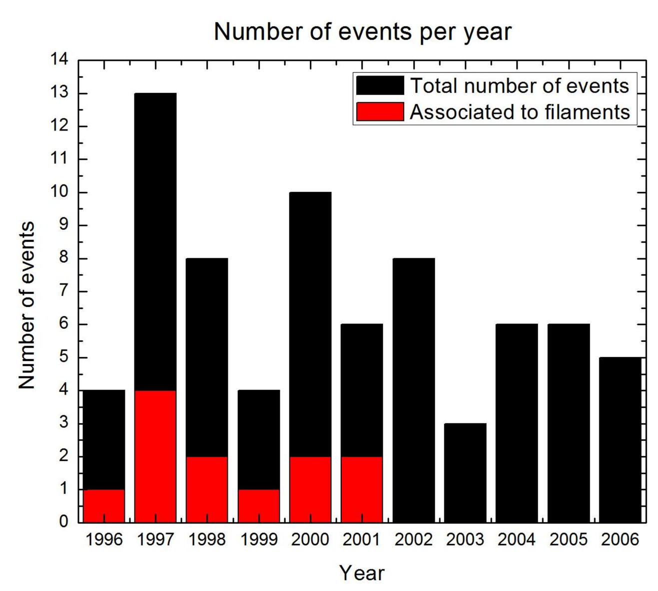


Figure 3. Top left: Solar location of the source region of the MCs showing a peak in density close to the end of the flux rope. Top right: Solar location of the source region of all the MCs studied here. Red color indicates that the event is associated with a filament, black color events are not associated with filaments. Circles are events with density peaks in situ, squares are those without density increases. Bottom: Distribution of events (MCs) per year and those corresponding to filaments.



Summary and conclusions

- Density and temperature peak before the flux rope, this is a consequence of the hot and dense sheath material present there.
- The temperature has a minimum in the MC region.
- The expansion of the cloud can be seen in the negative slope of the speed profile.
- The O^{7+}/O^{6+} has a clear high plateau during the complete duration of the MC, indicating high temperatures in the source region of the CME.
- The magnetic field magnitude B is increased inside the cloud, with the expected shape from a crossing through a flux-rope like structure.
- The peak in B is not symmetric, consequence of the combination between expansion of the MC and a possible spatial asymmetry within the flux rope.
- The density increases towards the end of the MC profile, with a peak in right after the trailing edge of the MC. This could be an indication of prominence material, compression from a fast speed stream and/or compression due to flux rope expansion.
- Filament eruptions were only detected in 2 out of 14 cases where the peak in density is seen in situ.
- There is clear trend for the sources of these MCs to be located in the western hemisphere.
- The density peak is seen both in solar maximum and solar minimum events.
- Events occurring during solar maximum are more powerful (faster, their source region is hotter, sheaths are stronger).

Acknowledgements

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