Magnetic cloud events during 2005 and their geoeffectiveness

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Abstract. Magnetic cloud events represent one type of solar energy emission into Interplanetary Space, and are often associated with Coronal Mass Ejections (CME). They are characterized by a sharp increase in solar wind velocity and ion density, lowered plasma temperature, and low β ratios (Kinetic Energy to Magnetic Energy). Not all Magnetic cloud events are Geoeffective i.e., capable of causing electromagnetic disturbance and satellite anomalies in the Earth's space environment, and for many reasons, it is worthwhile to understand features associated with "Geoeffectiveness". In this work a study is made of Magnetic Cloud events during 2005. Interplanetary physical parameters during Magnetic clouds are examined for their enhancement with respect to normal values of the parameters. These are related to their 'Geoeffectiveness' in terms of changes in the Dst, Kp indices, CRNM count and electron flux variations in the Geomagnetosphere and their ability to cause satellite anomalies. While it is recognized that the southward component of the Interplanetary Magnetic Field Bz is important for 'Geoeffectiveness', we point out here that the rate of change of the magnetopause distance and the CRNM count are two other parameters which indicate the 'Geoeffectiveness' of solar disturbance.

Index Terms. Cosmic ray neutron monitor count, interplanetary parameters, magnetic cloud events, magnetopause distance.

1. Introduction

Magnetic Clouds (henceforth referred to as MC) are large-scale disturbed structures in Interplanetary (IP) Space, which originate from the Sun, and encompass enhanced solar wind speeds and densities, but lowered plasma temperatures. They contain magnetic fields which remain enhanced over time-scales of tens of hours (Burlaga et al., 1981; Klein and Burlaga, 1982; Blanco-Cano and Bravo, 1999). MC are characterized by low values of β (ratio Plasma Energy density/Magnetic Energy Density i.e., $NkT/B^2/8\pi$).

Over 50% of MC are associated with massive eruptions on the Sun called Coronal Mass Ejections or CME (Gosling 1990). The expansion of MC into IP space is believed to be structurally confined by Magnetic flux ropes whose ends remain attached to the Sun (Wilson and Hildner, 1984; Bothmer and Schwenn, 1998). At Earth's orbit of 1 AU, the dimensions of MC can exceed 0.25AU and they can envelope Earth over periods of 1-3 days (Farrugia et al., 1993).

2. Objectives and methodology

In this work we have examined 8 MC during the first half of 2005 for their 'Geoeffectiveness'. This term implies their ability to affect 1). Solar and IP parameters, the latter being recorded at the Lagrangian point L1 located between the Sun and the Earth, at distance 0.01AU from Earth 2). Geomagnetic parameters such as the distance of the Geomagnetopause, the Dst and Kp indices, and the Cosmic Ray Neutron Monitor (CRNM) count measured at the ground 3). Fluxes and fluences of relativistic electrons (0.6 MeV and 2.0 MeV) at geostationary orbit of 6.6 R_e and 4). The ability to cause "operational anomalies" on geostationary satellites. Limited aspects of the above-mentioned have been examined by Wu et al. (2000), Gopalswamy et al. (2005) and Farrugia et al. (1997).

Each MC wherever feasible is traced back to its possible origin on the Sun (i.e., Solar latitude and longitude of the Active region (AR)), the type of Solar flare or CME associated with the AR, through its manifestations in terms of solar energetic particles recorded on the SOHO Coronagraph at the L1 point, and the solar wind speeds, densities and IP magnetic field intensities measured at L1 by the ACE satellite. The response to the MC of the Geomagnetopause, the geomagnetic indices and the ground based CRNM count at Beijing (eastern longitude) are also studied for each event. Each of the parameters mentioned above (except for CRNM count) is normalized with respect to the quiet-time value of the parameter concerned, following the technique extensively used by Rastogi and Rajaram (1965) Rajaram and Rastogi (1969) and Rajaram (1971).

Each of these parameters is then stacked such that the Zero time is the time when the MC reaches L1. The superposed Epoch Analysis (referred to as SUPEPAN) technique used by earlier workers (Rajaram, 1971; Wilson, 1987; Rangarajan, 1987) is then used to average these separate parameters over ±5 days about the Zero time. For the sake of brevity it was not possible to show all the figures, but their characteristics are listed under sections 3(a) and 3(b).

3. Results

Results from this SUPEPAN place the MC events studied into two distinct categories, one which is highly Geoeffective (including the ability to cause 'operational anomalies' on geostationary satellites) and the other which is less Geoeffective in every sense. Table 1a and 1b lists these two categories.

Table.1a. List of 'Highly Geoeffective' MC Events

Date/time/year	Time (UT)	Sunspot no. Latitude /Longitude	Flare type	CME	Shock type
21//1/2005	1648	AR0720 N12W58	20 Jan 0701 X7.1 flare	Halo CME on 20th Jan, at 0654 UT	Not mentioned
25/03/2005	1641	Not mentioned	One C flare and one S flare reported	CME (5/6)	nice reverse shock
05/04/2005	0245	Not mentioned	No flare reported	CME (1/5)	CIR related reverse shock
15/05/2005	0219	AR 0759 N12E12	13 May 1657 M8.0 flare	full halo CME on 13th May, at 1712 UT	Not mentioned

Table.1b. List of 'Less Geoeffective' MC Events

Date/time/year	Time (UT)	Sunspot no. Latitude /Longitude	Flare type	CME	Shock type
17/02/2005	2159	Not mentioned	Two C flares and one S flare recorded	CME (1/5)	Not mentioned
28/05/2005	0348	Not mentioned	One M flare reported	full halo CME on 26th May, at 1506 UT	Not mentioned
29/05/2005	0915	AR 0767 S09E14 (approx.)	26 May 1420 B7.5 flare	full halo CME on 26th May, at 1506 UT	Not mentioned

3(a): Highly geoeffective magnetic clouds

1. Seem to originate in major Solar Flares (X Class) from well-defined Sunspots, often as CME.
2. SOHO-LASCO C2 Coronagraph picture at 0.01 AU shows that very large number of Solar Energetic Protons enter CCD Camera.
3. V_{sw} is well above 400 km/sec (max at 1200 km/sec for individual MC).
4. N_{sw} is roughly in vicinity of about 10/cm^3 (max at 50/cm^3).
5. B_z shows sharp variations between -5 nT to +9 nT.
6. All Interplanetary Parameters tend to show steep, rapid enhancements, and rapidly return to normal or above normal values.
7. Magnetopause distance decreases to about 5 Re for individual MC.
8. Dst drops to about -110 nT.
9. Kp rises to about 6 and more.
10. There is a sharp, steep drop in CRNM prior to the Magnetic Cloud (MC) event, followed by rapid recovery within 4 days.
11. Ignoring Diurnal variations, Absolute Electron Flux (2 MeV from GOES 10), tends to remain at values of about 10^4 electrons cm^{-2}sr^{-1}s^{-1}. Ignoring Diurnal variations, Absolute Electron Flux (0.6 MeV from GOES 10), tends to take up values between 10^5 and 10^6 electrons cm^{-2}sr^{-1}s^{-1}.
12. Electron Flux (2 MeV from GOES 10) rises by several orders of magnitude with respect to quiet Control Day, following MC event. Electron Flux (0.6 MeV from GOES 10) rises only by factor of 1 – 10 with respect to quiet Control Day, following MC event.

3(b): Less geoeffective magnetic clouds

1. Solar origin not so clear. Could originate in Prominences or Loops, or in Sunspots or CMEs.
2. SOHO-LASCO C2 Coronagraph does not suggest presence of large number of energetic solar protons.
3. V_{sw} is generally in the vicinity of 400 km/sec (max value 580 km/sec for individual MC).
4. N_{sw} is generally in the vicinity of about 8/cm^3 (max value 15/cm^3).
5. B_z exhibits variations between -7 nT to about +4.5 nT.
6. In general, rise in values of all IP parameters tends to be more diffuse, less intense, and falls off in uneven manner.
7. Magnetopause distance decreases to about 7.7 Re.
8. Dst drops to about -75 nT.
9. Kp rises to maximum of about 4 and more.
10. CRNM does show a sharp drop at time of MC but recovery is slow and oscillating within 48 hr.
11. Ignoring diurnal variations, Electron Flux (2MeV from GOES 10) tends to remain well below 10^3 electrons cm^{-2} sr^{-1} s^{-1}. Ignoring diurnal variations, Electron Flux (0.6 MeV from GOES 10) tends to remain at values below or around 10^5 electrons cm^{-2} sr^{-1} s^{-1}.
12. Rise in Electron flux for both 2 MeV and 0.6 MeV (from GOES 10) normalized with respect to quiet Control day is very marginal, and can even be less than Control Day (i.e. less than 1.0).

Rise of Flux in both energy bands tend to follow similar Electron values, without wide separation between the two bands.

Salient figures pertaining to the above-mentioned results are being shown. These are the parameters 1).

Average values of B_z 2). The Earthward movement of the Geomagnetopause, and its recovery 3). The sharp drop and subsequent rise of the CRNM count and 4). The hardening of the spectrum of relativistic electrons (0.6MeV and 2 MeV) at geostationary orbit, all parameters being presented prior to and after the arrival of MC. These are shown in Fig. 1 (a) and (b), Fig. 2 (a) and (b), Fig. 3 (a) and (b) and Fig. 4 (a) and Fig. 4 (b)

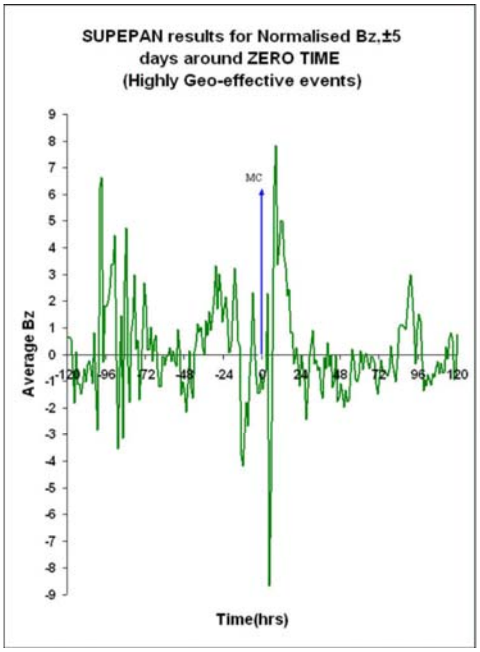

Fig.1a. Average Bz normalized with respect to 1nT for 'highly Geoeffective' MC events. Note the sharp negative Bz at the time of onset of MC.

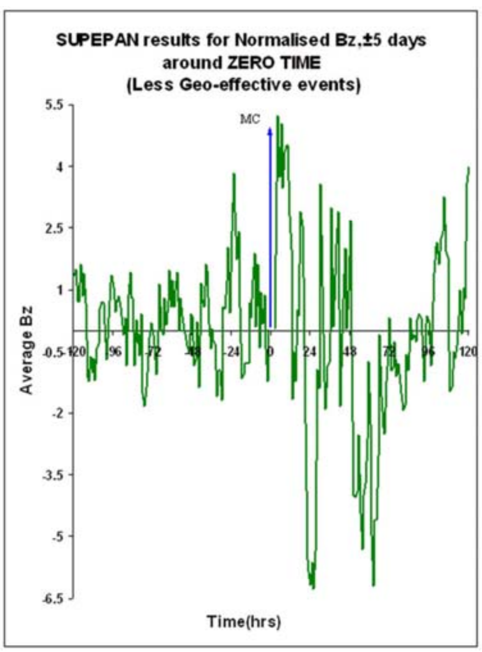

Fig.1b. Average Bz normalized with respect to 1nT for 'less Geoeffective' MC events. Note the absence of clear negative Bz at the time of onset of MC.

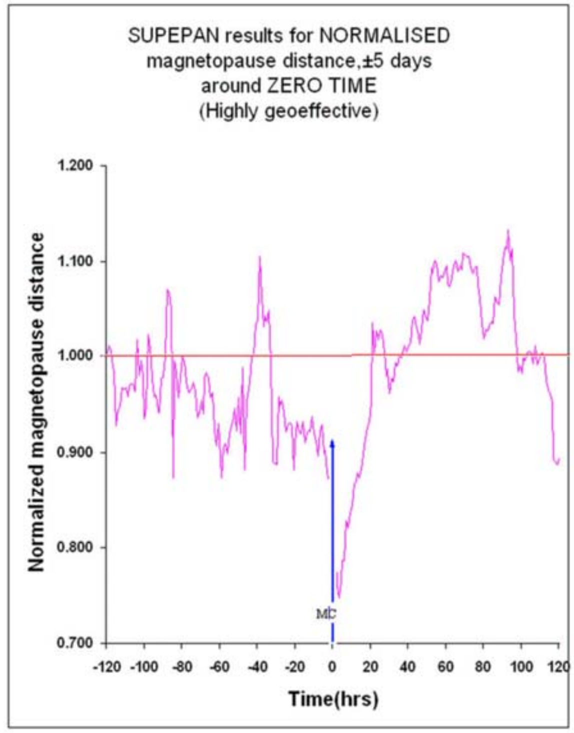

Fig. 2a. Magnetopause distance normalized to 10 Re for 'highly Geoeffective' MC events. Note how the magnetopause distance decreases to about 7.5Re at the time of onset of the MC and how it sharply recovers to values above 10Re.

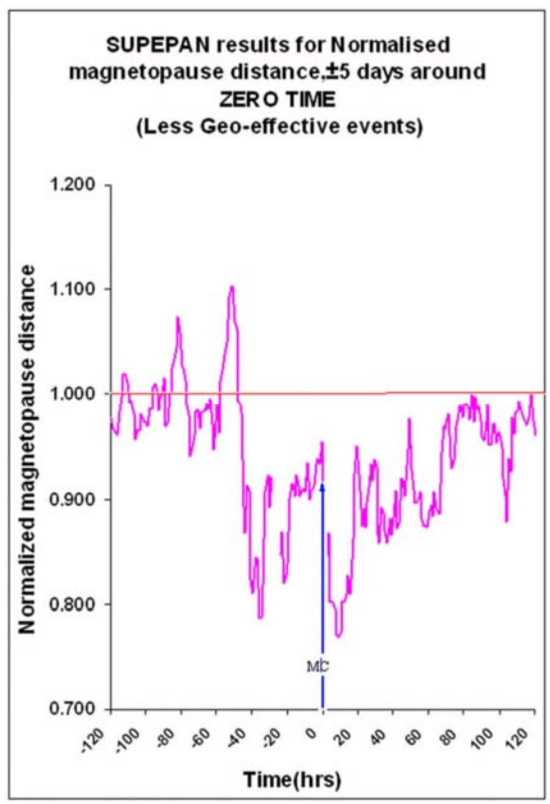

Fig. 2b. Magnetopause distance normalized to 10 Re for 'less Geoeffective' MC events. Note that although the magnetopause distance drops to ~8Re at the time of onset of MC, recovery is not sharp, but of a highly oscillatory nature.

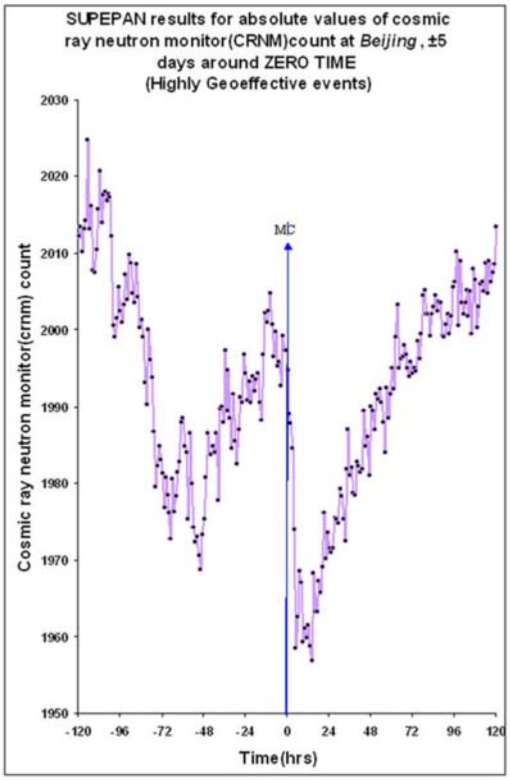

Fig. 3a. Average absolute Cosmic Ray Neutron Monitor Count (CRNM) for 'highly Geoeffective' events. Note the sharp drop in CRNM at the time of onset of MC and the rapid recovery within 48 hrs.

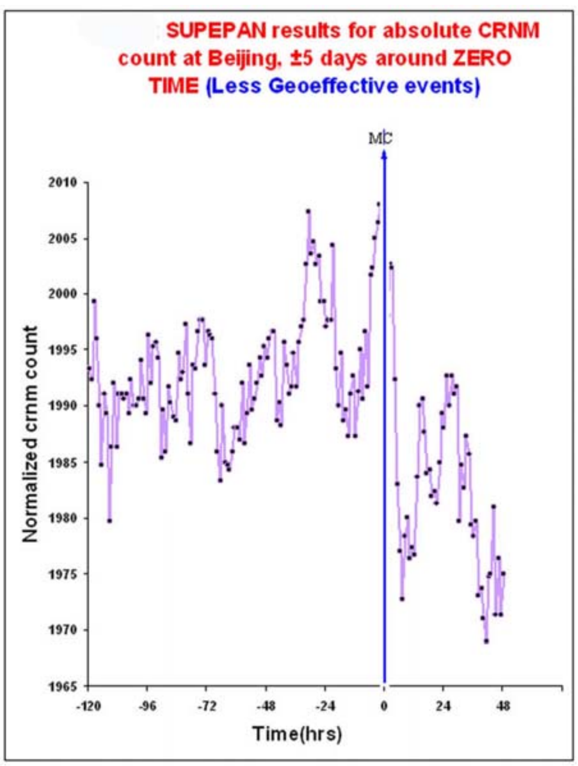

Fig. 3b. Average absolute Cosmic Ray Neutron Monitor Count (CRNM) for 'less Geoeffective' events. Note the sharp drop in CRNM at the time of onset of MC but recovery remains low and oscillating even upto 48hrs.

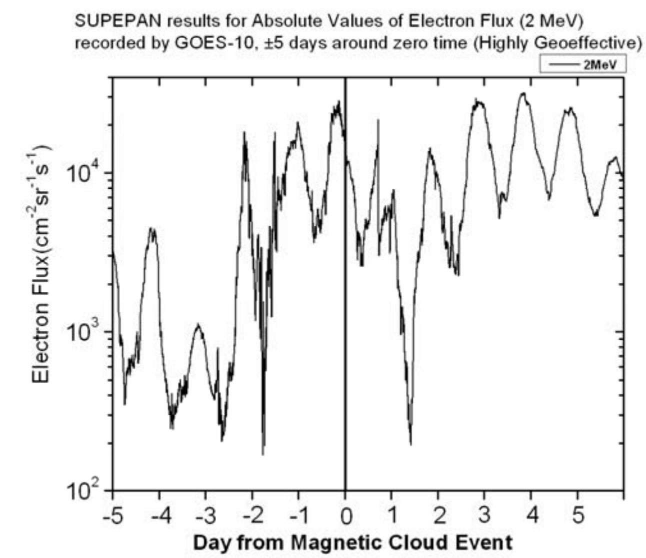

Fig. 4a. Average absolute electron flux of 2MeV particles at geostationary orbit for 'highly Geoeffective' MC events. Notice that flux drops by two orders of magnitude at the time of onset of MC and thereafter recovers to values above 3.10^4 pfu.

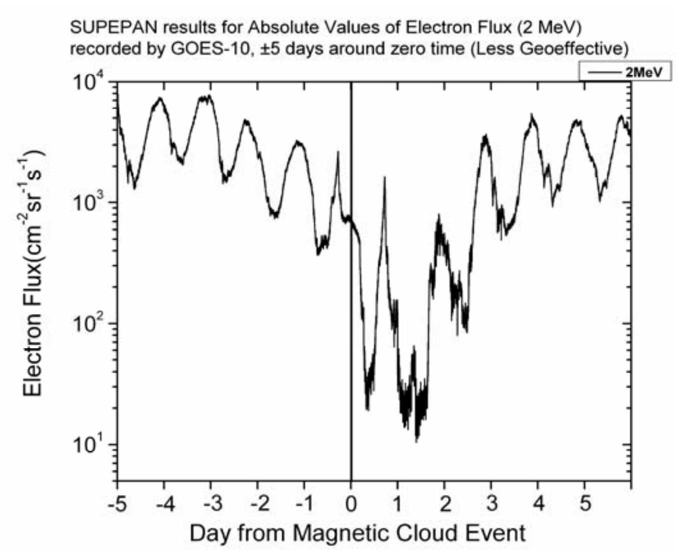

Fig. 4b. Average absolute electron flux of 2MeV particles at geostationary orbit for 'less Geoeffective' MC events. Note that the values of the electron flux are well below 1e3 pfu even at the time of onset of the MC, and thereafter recover to values which are well below 10^4 pfu.

4. Conclusions

We plan to present the complete set of results for all the above-mentioned parameters in a forthcoming research paper. Here we emphasize two points, namely:-

1. The hardening of the relativistic electron spectrum at geostationary orbit. The 2 MeV electron flux rises by some orders of magnitude during highly geoeffective MC events, while the 0.6 MeV electrons rise by just a factor of 2-5. Baker et al. (2000) have pointed out the positive role of 2 MeV electrons in satellite operational anomalies, but have not discussed the hardening of the spectrum during solar disturbances.

2. The large Forbush drop in CRNM count even before the MC reaches Earth, possibly even when the cloud is on its Earthward journey from the Sun. The second drop after the MC reaches Earth is accompanied by changes in geomagnetic indices. Earlier studies (Webber (1987) from the PIONEER 10 and 11, and VOYAGER 1 and 2 spacecraft) of Cosmic ray variations in the Heliosphere show that this parameter is rapidly and greatly affected by the state of field and particle emission from the Sun. Clearly Cosmic rays are "messengers from outer space" and they "remote sense" the disturbed state of fields and particles between Sun and Earth, long before the disturbance actually reaches Earth. Forbush decrease in Galactic and Solar Cosmic rays have been noticed since many decades, both on ground and in IP space (Simnett, 2006). We believe that the CRNM count recorded at many locations on Earth has great potential for predicting Space Weather. We are currently using the CRNM count and the hardening of the relativistic Electron spectrum at geostationary orbit for understanding 'operational anomalies' on geostationary satellites.

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