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Comparison of the geometrical and magnetic parameters of plasma clouds and shock waves obtained with help of ACE spacecraft sensors and ground based detectors

N. Bostanjyan and N. Gevorgyan

Cosmic Ray Division of Yerevan Physics Institute, Yerevan 375036, Armenia

Abstract. Using density and speed time profiles of the solar wind measured by the ACE[1] spacecraft we demonstrate the possibility to separate passage of the shock waves from passage of the magnetic clouds. We estimate the size and the strength of magnetic field for magnetized clouds and shock waves, causing strong geomagnetic storms. The magnitude of magnetic field of the shock waves estimated by this method equals to $(2-4.5) \cdot 10^{-4} Gs$. Obtained values are in good agreement with values of direct ACE measurements and are ten fold bigger compared with estimate obtained by measuring of time profiles of Forbush decreases.

1 Introduction

Time profiles of Forbush-decreases (Fd) were used for estimation of the thickness of magnetic clouds and shock waves. The following approximation (Dorman L.I.,1963) was used:

$$L = V_{mc} \cdot T_{Fd} \tag{1}$$

When the Earth plunged into magnetized cloud the decrease of CR intensity was observed. And when it leaves magnetized cloud the recovery phase of the count rate is starting. Thus, the sum of decrease and recovery phases from the neutron monitor time profile gives how long we were in magnetic cloud (T_{Fd}). Speed of magnetic cloud (V_{mc}) was determined by its traveling time T (i.e. from the beginning of flare registered either by optical, radio or X-ray detectors etc to hitting to the Earth)

$$V_{mc} = L_s/T \tag{2}$$

where L_s is the Sun – Earth distance. For determination of thickness of shock wave only the Forbush decrease time (Dorman L.I., 1975) was used. These estimates are rather poor because they depend on unknown distribution of frozen magnetic field in the volume of the magnetized cloud. Besides, this method is possible to apply only to the estimation of the magnetic cloud causing Fd. Estimation of the sizes of magnetic clouds or shock waves is not applicable when modulation cause increase in intensity of the cosmic rays (CR). Measurements of the solar wind velocity (V), proton density (D_p), and proton temperature (T_p) by the ACE spacecraft, allows to make feasible estimations of the magnetic cloud size. Apparatus located at ACE spacecraft provides direct information on distribution of velocities and densities of protons in magnetized plasma. In addition it is possible to separate shock waves from magnetic clouds. That will allow investigation of their properties separately, and thus making possible more precise calculation of the values of magnetic fields of magnetic clouds and shock waves, and their comparison with the theoretical models (G. Wibberenz, et al., 1997).

Study of time profiles of V, D_p, T_p, demonstrates that the starting time of abrupt increase in V, D_p, T_p generally coincides. Abrupt changes of time profiles of V usually lasts tens of hours, and for D_p, T_p generally lasts 1-3 hour. Typical time of D_p, T_p for the same event has almost identical duration and as mentioned above lasts less compared with V. This fact allows to assume that the abrupt changes of D_p, T_p are caused by the shock waves, and hence characterizes its thickness. As we know, the shock wave represents a thin transitional region where a sharp increase of density and temperature of plasma occurs, as observed on many time profiles of D_p, T_p.

For the comparison with ACE, the 1-minute data of the Nor Amberd neutron monitor (NM) located on the altitude of 2000m (Rc=7.6GV) were used. For period from 1998 to mid 2000 there were 7 strong geomagnetic storms occurred with $Kp \geq 8$. Three of them were chosen for further analysis. Two events were large Fd, and one was CR intensity increase of about 3%.

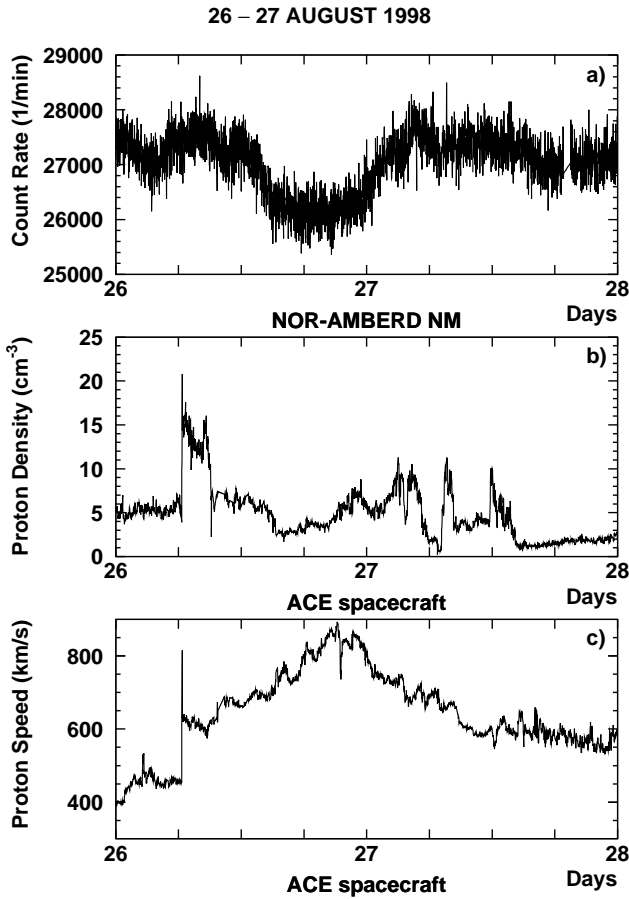*Correspondence to:* N. Bostanjyan
(bostan@crdlx5.yerphi.am)

[1]http://www.srl.caltech.edu/ACE/ASC/

26 – 27 AUGUST 1998

Fig. 1. August, 26 1998

24 – 27 SEPTEMBER 1998

Fig. 2. September 24, 1998

2   August, 26 1998 Event

Nor-Amberd NM observed Fd by clear pre-decrease and pre-increase effects (see Fig.1a). The decreasing phase started at 08:10 UT and was finished at 03:30 UT on August 27th. The decrease phase of Fd lasted 8 hours, and its overall duration (decrease plus recovery phases) covered 19.33 hours. Calculated average solar wind speed during Fd (See Fig.1c) was $V = 740 km/s$. Consequently, from Eq.1 the size of a magnetic cloud was: $L_{mc} = 5 \cdot 10^7 km$, and size of the shock wave (by time of decrease): $L_{sw} = 2 \cdot 10^7 km$.

Taking into account distribution of amplitudes and using the coupling functions method (Dorman L. I., 1963) we could estimate the mean energy of particles for this event $E \approx 20 - 40 GeV$. Then, we could calculate value of magnetic field from the following formula:

$$E = 300 \cdot H \cdot L \tag{3}$$

From the Equation 3 we can estimate the strength of magnetic field of shock wave and magnetic cloud by substituting the thickness of shock wave or magnetic cloud. In this way we obtain $H_{mc} = 2 \cdot 10^{-5} Gs$, and for a shock wave $H_{sw} = 5 \cdot 10^{-5} Gs$. The value of the B_z-components of interplanetary magnetic field (IMF) for this event measured by
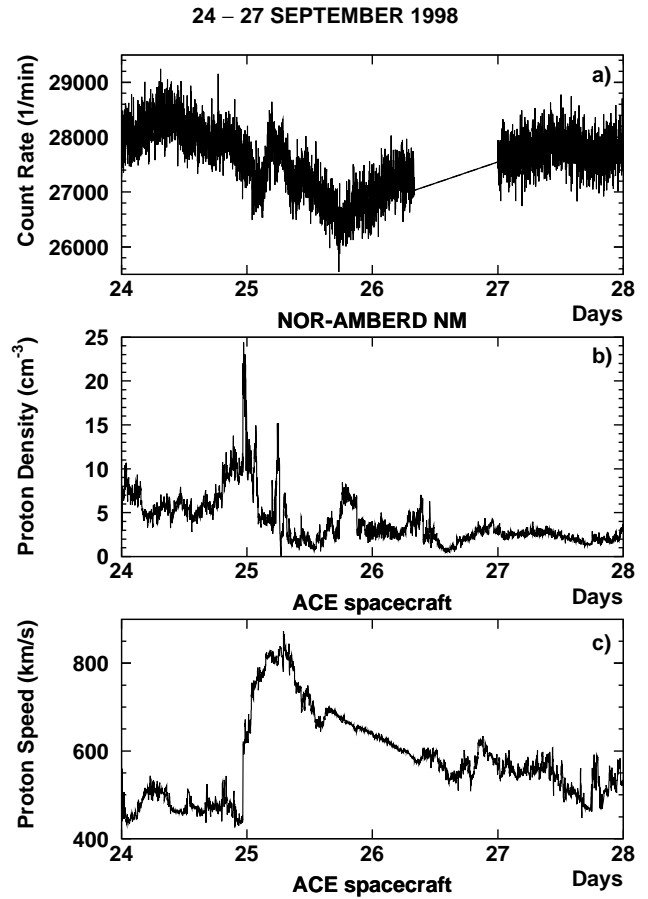
the ACE equals $1.4 \cdot 10^{-4} Gs$, that is more than one order of magnitude bigger than the value obtained by time profile of Fd.

We made estimations of the same parameters using time profiles of D_p, V from ACE, Fig.1(b,c). The shock wave thickness was determined by time profile of D_p where abrupt peak existed (see Fig.1b). Using Eq.1 and 3 we calculate the thickness $L_{sw} = 6 \cdot 10^6 km$ and the value of magnetic field $H_{sw} = 2 \cdot 10^{-4} Gs$. The thickness of magnetic cloud is determined by the time duration when solar wind speed is greater than its mean value. Calculated values are $L_{mc} = 280 \cdot 10^6 km$ and $H_{mc} = 3 \cdot 10^{-6} Gs$. Estimations of the magnetic field in both magnetic cloud and shock wave obtained by two methods described above differ from each other significantly. Meanwhile, the two estimates of the IMF from ACE and from time profile of V and D_p are almost identical. This is another prove that by time profile of proton density and speed it is possible to estimate the thickness of shock waves and magnetic clouds.
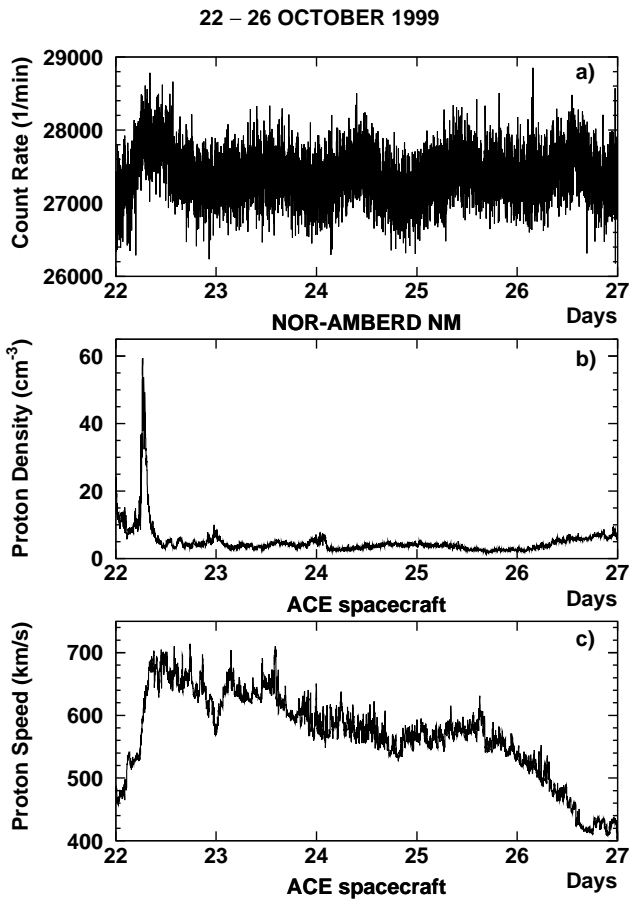
22 – 26 OCTOBER 1999

Fig. 3. October 22, 1999

to $H_{mc} = 10^-5 Gs$, and $H_{sw} = 4.5 \cdot 10^{-4} Gs$ accordingly. Measurements of IMF by ACE for the given event shows that $B_z = 1.8 \cdot 10^{-4} Gs$.

4 October 22, 1999 Event

Nor-Amberd NM registered 3% increase in counting rate beginning at 03:30 UT (see Fig. 3a). This enhancement could be explained by the modulation effects of approaching plasma cloud. Therefore we can't apply described above technique for estimation of strength of magnetic fields.

The time profiles of ACE demonstrates that increase of V and D_p began at 05:56UT, i.e. the increase in counting rate of CR registred by surface detector began 2.5 hours before the magnetic cloud reached the ACE orbit (see Fig. 2b,c).

Using the time profiles of V, D_p, by ACE (see Fig. 3b,c) it is easy to find the size of the magnetic cloud and the shock wave that caused the detected increase. From the time profiles of V as in the previous cases, we find the size of magnetic cloud $L_{mc} = 207 \cdot 10^6 km$, and thickness of a shock wave $L_{sw} = 5 \cdot 10^6 km$. Our geographical location corresponds to primary particles with energies about $10-25 GeV$, thus the magnitude of the magnetic field of a magnetic cloud $H = 5 \cdot 10^{-6} Gs$ and for the shock wave $2 \cdot 10^{-4} Gs$. The value of IMF by ACE equals $B_z = 2.5 \cdot 10^{-4} Gs$.

5 Conclusions

Estimations of the magnitude of magnetic fields in shock waves by analyzing the time profiles of V, D_p by ACE shows, that the stregth of magnetic fields in shock waves are equal to $(2-4) \cdot 10^{-4} Gs$, that 10-40 times exceeds estimates obtained by time profiles of Fd. This result coincides with theoretical prediction (Dorman L. I. 1963).

Thicknesses of shock waves and magnetic clouds causing increase of the counting rate of CR are estimated. The possibility to separate passage of shock waves from magnetic clouds is demonstrated. In all events there are precursor effects that can be used for forecasting of strong geomagnetic storms.

3 September 24, 1998 Event

On the decrease phase of the time profile of Fd, three steep fall and three sharp jumps are observed (see Fig.2a). It is obvious, that proceeding from only the time profile of Fd the sizes of such magnetic cloud can not be estimated, because it is not clear, which of these steep falls characterize a shock wave: only the first, or all of them? The time profiles of V, D_p from ACE (see Fig.2b,c) resolve the problem.

In the time interval (20:30-16:40) UT corresponding to the decrease phase of Fd, when sharp fluctuations in counting rate of CR occurred, one jump at 23:12 UT was observed in the time profile of V. By reaching the maximum value of $V = 820 km/s$ on September 25th, V began to decrease, and at 18:00UT on September 27th restored the initial value. Estimations of the sizes of the given cloud by time profile of V, (see Fig. 2c) gave $L_{mc} = 130 \cdot 10^6 km$. The time profile of D_p shows that at 23:12 UT there was the sharp jump in the value of D_p, which after 1 hour reached its initial value (see Fig. 2b). At that time interval mean V was equal to $620 km/s$. Using these results we obtain the thickness of the shock wave $L = 2.2 \cdot 10^6 km/s$. The mean CR energy for given Fd is also in range $E = (20-40) GeV$, therefore a magnetic field of magnetic cloud and shock wave equals

References

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