

Forbush decreases in a year of 2000 observed by air shower detectors at Mt. Chacaltaya

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Abstract. Forbush decreases have been detected by unshielded and shielded air shower detectors at Mt.Chacaltaya in June, July and November of 2000. The deficits of cosmic ray counting rates were recorded ones of 3% – 6% in each event. While a time structure of deficit in June gives a simple feature, one in July has rather complicated structure in the stage of decrease and also in a period of recovering of counting rate. Characteristics of Forbush decreases are introduced and discussed on it together with the information of neutron monitor located at Mt.Chacaltaya.

a velocity of $\sim 1000\text{kms}^{-1}$ and the magnetic shield effect after the passage. The time structure of deficit, in general, shows a quick decrease of cosmic ray intensity in an order of hours when CME arrives. Then, an intensity becomes increase slowly with a recovering time of 1 or 2 weeks. This profile is not commonly formalized as a simple shape and sometimes shows complicated feature(ie.Wibberenz,1997). It has to be affected by a size, a velocity and a strength of irregular magnetic field of CME and associated shock wave. A report suggested a pre-cursory decrease which happened preceded the Forbush decrease(Morishita,1997). This is also one of unsolved phenomena.

1 Introduction

Solar flares accompanied with CME(Coronal Mass Ejection) have been reported in June, July and November of 2000 as listed below,

A:11h25mUT of June 06(51701.47569MJD) X2.0/3B
 B:14h18mUT of June 23(51718.59583MJD) M3.0/1F
 C:21h05mUT of July 10(51735.87847MJD) M5.7/2B
 D:18h47mUT of July 11(51736.78264MJD) M1.1/1N
 E:10h18mUT of July 12(51737.42916MJD) X1.9/2B
 F:10h03mUT of July 14(51739.41875MJD) X5.7/3B
 G:06h45mUT of July 19(51744.28125MJD) M6.4/3N
 H:11h17mUT of July 22(51747.47014MJD) M3.7/2N
 I:02h43mUT of July 25(51750.11319MJD) M8.0/2B
 J:05h34mUT of Nov. 23(51871.23194MJD) C5.4/1F
 K:21h00mUT of Nov. 25(51873.87500MJD) X1.0/2N

Forbush decrease has been considered as a deficit of galactic cosmic ray intensity due to the CME cloud which is produced by a reconnection of solar magnetic field associated with a big solar flare. A deficit of intensity is due to the passage of condensed and irregular magnetized shock with

2 Experimental

Air Shower array and Emulsion Chamber experiment at Mt.Chacaltaya (AS-EC Experiment at 5200m a.s.l) has been carried out from 1979 to study the chemical composition of primary cosmic ray and high energy particle interaction in an energy region of 10^{14}eV – 10^{17}eV (Kawasumi, 1996).

Air shower array consists of 40 and 4 unshielded scintillation detectors (N-detectors) with an area of 0.25m^2 and of 1.0m^2 , respectively, to determine a lateral distribution of charged particles in an air shower as shown in fig.1(upper). 8 and 5 fast timing scintillation detectors(FT-detectors) with an area of 0.25m^2 and of 1.0m^2 are located in a central region of air shower array to determine an arrival direction of air shower. In addition, 8m^2 hadron detector which consists of 32 shielded scintillation detectors(B-detectors) with an area of 0.25m^2 is used for the detection of high energy hadronic component in air shower core as shown in fig.1(lower). Each B-detector is covered with 15cm thickness lead plate(30 c.u.) and it can detect muon component with a threshold energy of 0.34GeV for vertical incident one. Signals of background secondary particle produced by primary galactic cosmic rays

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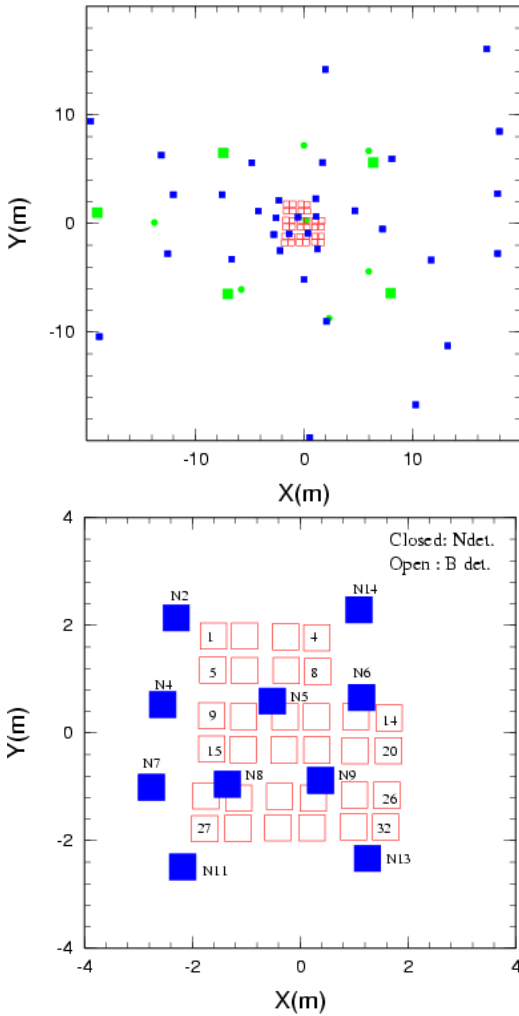


Fig. 1. Air shower array at Mt.Chacaltaya. N and FT detectors are shown by small squares and closed circles, respectively(in top figures). $8m^2$ hadron detector is located in a center of air shower array and positions of B-detectors are drawn by open squares together with some N-detectors in a bottom figure.

from N and B detector are monitored independently and continuously. An integrated number of cosmic ray particles is recorded in every 10 seconds interval.

Signal of N-detector is considered to be caused by a passage of secondary electromagnetic particles(electrons and gamma-rays) and muons component produced by primary galactic proton. At higher altitude, electromagnetic component is not enough absorbed in the atmosphere, and a contribution to output signal of electromagnetic particles still appears as 45% of the numbers of signals from a simulation. Furthermore, signal of B-detector is mainly produced by muon component with an energy greater than 0.34GeV. A mode energy of primary cosmic ray which gives a signal at the ground is roughly estimated as $\sim 60\text{GeV}$ and $\sim 70\text{GeV}$ for recorded particles by N and B-detectors from a response function taking into account of an effect of geomagnetic field at this geometrical location(a longitude, a latitude and a height

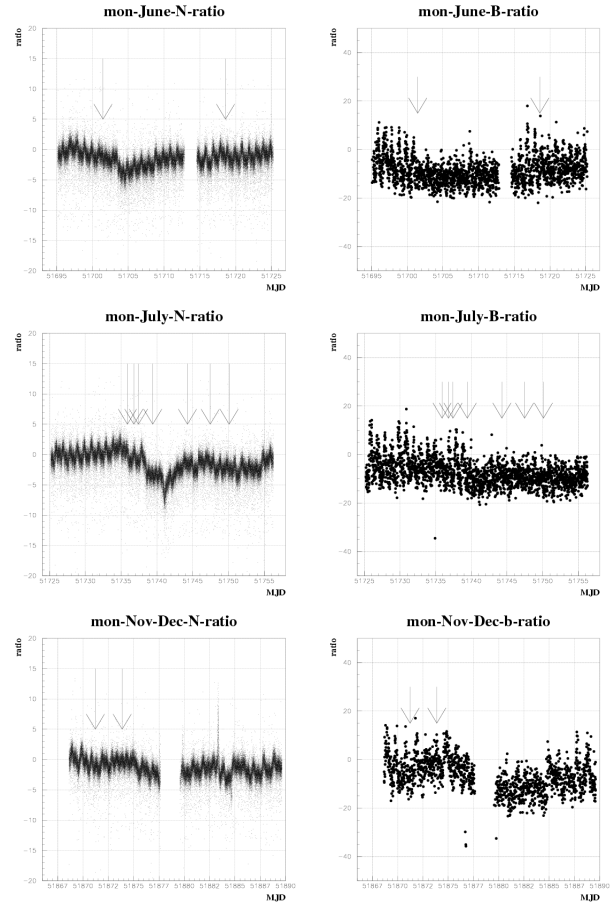


Fig. 2. Forbush decreases in June, July and November of 2000 are shown. Three upper figures show cosmic ray counting rates (a sum of all N-detectors) as a function of MJD. Three lower ones show cosmic ray counting rate (a sum of all B-detectors). Its counting rate is defined as a deviation in % from the average. Times of solar flares are shown by the arrows in each figure.

of the site) and the detector characteristics. 12NM64(super neutron monitor) has been also operated in air shower array for monitoring the solar neutron and it has observed the neutron intensity in every 1 minute with an information of atmospheric pressure at the site. Time variations of cosmic ray counting rate listed below, have not made any corrections on effects of an atmospheric pressure, a temperature and a daily modulation of galactic cosmic rays.

3 Results and Discussion

In fig.2, events of Forbush decreases in June, July and November of 2000 are shown. Three left figures show cosmic ray counting rate (a sum of all N-detectors) as a function of MJD. A counting rate is defined as a deviation in % from the average counting rate. Three right figures show ones from a sum of all B-detectors. Times of solar flares listed before are indicated by arrows in each figure. The maximum deficit

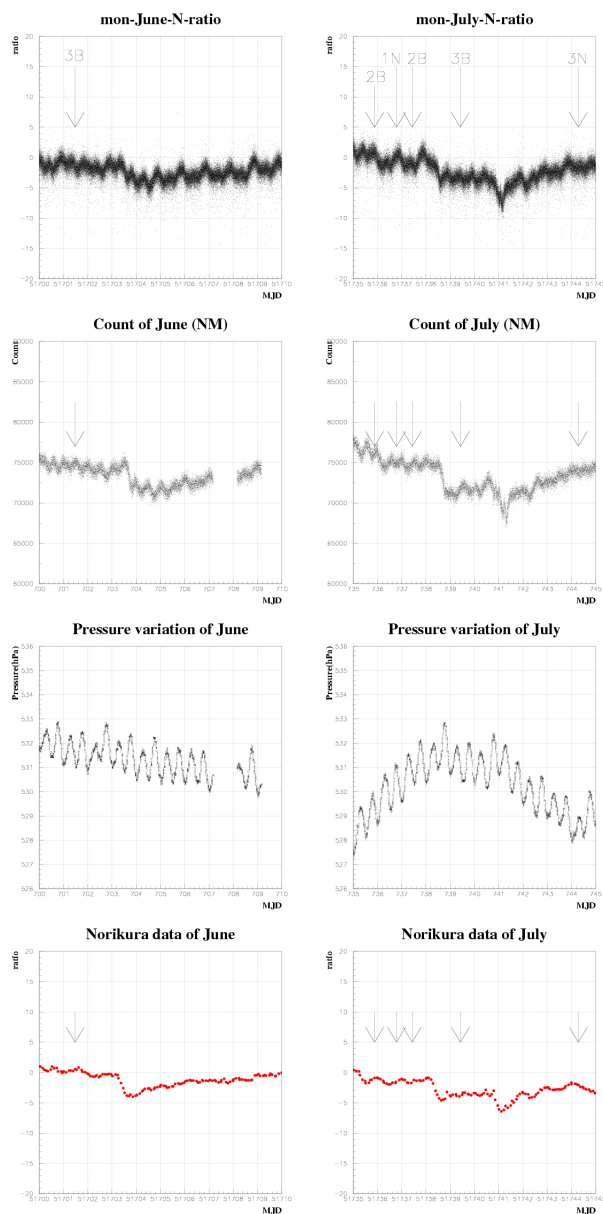


Fig. 3. Counting rate variations in 10 days around solar flares of June and July. Top figures are cosmic ray counting rate of N-detectors in a period of June 5 – June 15 and July 10 – July 20. Forbush decrease detected by 12NM64 in June and July are also given in the second column of the figures. Atmospheric pressure variations in the same periods are shown in the third column. Results of Forbush decreases observed at NORIKURA Muon Telescope are shown in the bottom figures.

of cosmic ray intensity observed by N-detectors is 3.8% and 5.5% for events in June and July, respectively. A time structure of deficit observed in June has rather simple form, but one in July seems to have a characteristic feature with two steps structure in a stage of decrease and a longer recovering time of 15 – 20days after a time of the minimum deficit. Deficits in data observed by B-detectors also show somewhat

larger values of 6% and 6.5% for events in June and July. Another feature in the deficit is a smaller amplitude of periodic variation of cosmic ray counting rate around a period of Forbush decrease. An amplitude of periodic variation suddenly decreased and became to nearly a half of usual one. Then, it became to the usual amplitude when Forbush decrease finished. This profile can be also seen in a time variation of N-detectors with smaller changes.

Fig.3 shows detail time variations of counting rate in 10 days around solar flares of June and July. Top figures are cosmic ray counting rate from N-detectors in a period of June 5 – June 15 and July 10 – July 20. Results of Forbush decreases from 12NM64 are given in the second column. A counting rate of neutrons in every 1 minute is shown in a vertical axis. Results of Forbush decrease detected by NORIKURA Muon Telescope are also shown in the bottom figures(private communication). Times of solar flares in this periods are shown by arrows with a magnitude of solar flare in optical measurement in these figures. Profiles of time structures observed by three different equipments and at different location of Japan and Bolivia are likely to be consistent with each other. There is a complex structure in Forbush decrease of July. This is a reason of the contributions of seven solar flares with CME occurred in a short period of July. This time structure which seems to be affected by a physical structure of magnetic field in a shock created by high velocity shock fronts, CMEs and also by magnetic barrier caused by outgoing CMEs. A time structure in a stage of intensity recovering dose not show a simple one and has presented a longer effect. This fact suggests that a structure of magnetic field in outgoing shocks was not static and has strong irregularity exceed to one of typical structure.

There can be seen that neutron counting rate observed by 12NM64 has a periodic variation of ~ 12 hours. This feature can be explained by a 12-hours variation of atmospheric pressure caused by a tide-generating force by the sun. Atmospheric pressure variations recorded at Mt.Chacaltaya are shown in the third column of the figures. A half day atmospheric pressure variation has been observed with an amplitude of ± 0.6 [hPa] at Mt.Chacaltaya. According to a simulation, this variation promises to give a contribution of $\pm 0.45\%$ in a total amplitude of variation. An amplitude of a half day variation in experimental neutron counting rate in the figures is almost consistent with this expectation. Periodic variations in profiles observed by N and B-detectors can be also seen and show a larger amplitude in comparison with one of neutrons. This is considered as a result of overlapped contribution of 12 hours atmospheric pressure variation, a temperature effect to the detector and a daily modulation of galactic cosmic rays. It is easy to suppose that an effect of temperature variation has to be dominant because a temperature control to air shower detectors has not performed for air shower detectors. However, if the fact that a decrease of amplitude of periodic variation in a period of Forbush decrease mentioned before is significant, an explanation for a decrease of amplitude has to be seek in a global physical effect belong to a flow of galactic cosmic rays outside of atmosphere. Defi-

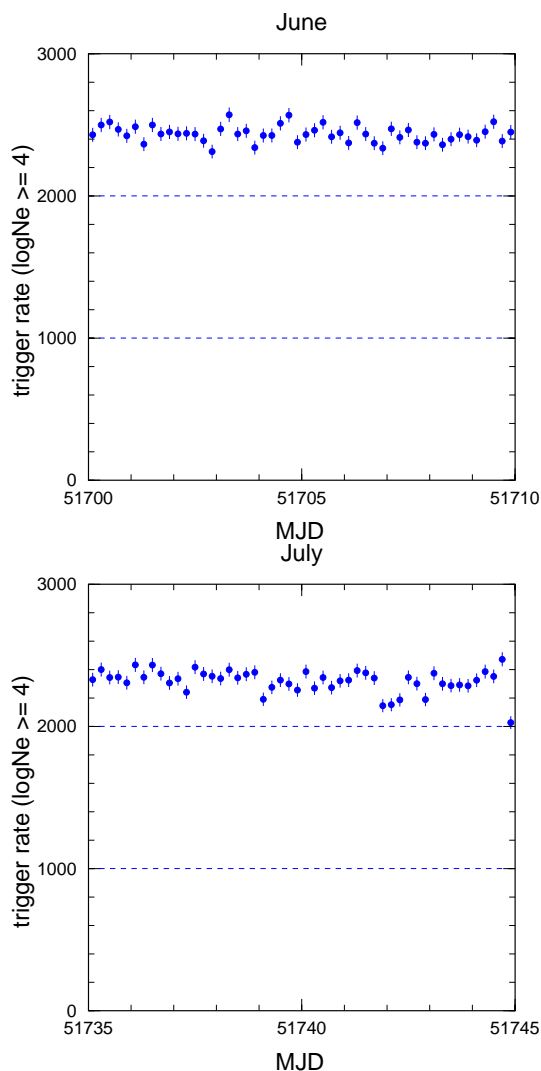


Fig. 4. The numbers of showers with Ne greater than 10^4 and zenith angle less than 44° . Results of June and July are shown in a top and a bottom figure, respectively.

nite answer to this question is still open, but it is required to make a continuous examination.

Our air shower array has been observed air showers and the numbers of air showers has been analyzed in such period of Forbush decreases. The numbers of showers with zenith angles less than 44° and Ne greater than 10^4 , which corresponds to an primary energy of 30TeV at Mt.Chacaltaya, are shown in a top(June) and a bottom(July) of fig.4. No significant deficit of the number of air showers in such period could be seen. This shows an intensity of magnetic field and structure around the earth dose not give an effect for galactic cosmic rays with such energies even in a time of solar flare.

We have not made a detail discussion on the Forbush decrease in November because of lacks of N(and B) detectors data in some days during a period of Forbush decrease. However a time structure of deficit seems to be almost same with one recorded in June. Another event in March 2001 has been already recorded in our data and more statistics will be expected in a couple of year. Detail experimental analysis will be done after making corrections for effects of atmospheric pressure and temperature on the counting rate of N(and B) detectors, and then characteristics of deficit has to be examined for existed and next coming Forbush decrease. Any simulation of a time structure of deficit will be also requested with assumptions of temporal structure of CME shock wave to explain the experimental characteristics.

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