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Solar wind effect on the muon flux at sea level

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We report first results of an ongoing study of the solar wind's effects on the muon background flux produced by galactic cosmic rays. We use the muon flux measurements at sea level made with the TUPI tracking telescope, working at a high counting rate (100 KHz) and always pointing on the IMF lines (45 degrees of pitch angle). An anti-correlation among the arrival of keV protons (observed by EPAM-detector aboard the ACE spacecraft) and sudden depressions in the muon flux at sea level have been observed. The phenomena is discussed in the context that they can be considered as mini-Forbush, caused by a shielding effect of the magnetic fields contained in the plasma cloud emitted from the sun at the time of the coronal mass ejections (CMEs). In several cases there is the pre-Forbush increases in the cosmic ray (muons) intensity profiles.

1. Introduction

Transient depressions reaching a minimum value in approximately one day in the galactic cosmic ray intensity following for a gradual recovery in up to several days have been observed in neutron monitors data. These phenomena, called "Forbush events" have been known over the past 6 decades. It is now known that they are associated with the passage of an interplanetary disturbance (shock and plasma enveloping the Earth) and in most cases they are considered as an interplanetary manifestations of coronal mass ejections.

We present here the results of a experiment dedicated to the investigation of transient solar events such as solar flares and their influence on the galactic cosmic rays at 1 AU. The 720 hours of observation during the summer season 2005 (Southern Hemisphere) correspond to 60 raster scans with a duration of 12 hours each, across parallel lines in declination (Sun's declination) and an hour angle of 3 hours early in relation to the Sun's hour angle, under this conditions the pitch angle is always 45^0 (where 0^0 pitch angle represent sun-ward direction). Figure 2 from the ref. [1]. summarizes the situation. In this summer session we have identified several sudden depressions (already observed previously) in the muon counting rate and we show here that these muon intensity depressions and the arrival of solar protons in the keV energy region at the ACE spacecraft [3] may be a good indicator of the passage of a small interplanetary disturbance (shock and plasma). This is because sudden and/or gradual increases of keV protons (above the proton flux background flux) in the ACE spacecraft coincide with the beginning of the depressions in the TUPI muon intensity at ground level. Details of the experimental setup of the TUPI telescope have been reported in [2].

On the other hand, ref. [4] has reported Forbush events in 30 years of neutron monitor data. Forbush events was observed also in spacecraft experiments [5], in air shower arrays [6], as well as in muon telescopes at ground level [7], the magnitudes of the Forbush depression depend of several factors such as the energy threshold of the detected particles, the geomagnetic cut-off of the observation location, as well as how the data are presented. For instance hourly averages present bigger magnitudes than the daily averages. In the TUPI experiment the Forbush events have been observed as a drastic change in the muon count rate (raw data). The muons detected ($E_\mu > 0.1$ GeV) are produced by primary charged particles (protons and/or ions) with an energy above the geomagnetic cut-off (9.8 GV) and the data is presented in bins of 15 minutes.

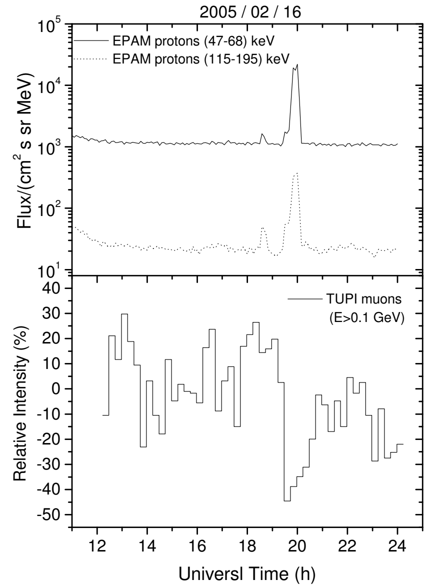

Figure 1. Upper panel: Time profiles of the EPAM protons in two different energy bands. Lower panel: TUPI muon relative intensity after pressure correction for the 2005/02/16 raster scan.

2. Results

Figures from 1 to 2 presents two samples of events observed during the summer season 2005. In all cases, in the lower panels, the TUPI muon relative intensity (pressure corrected) is presented, and in the upper panels the solar proton flux (EPAM protons) as observed by ACE spacecraft in the keV energy band is shown. From these figures it is possible to extract some especial characteristics of Forbush events observed by a narrow angle (9.5^0 of aperture) muon telescope at sea level, with a geomagnetic cut-off of 9.8 GV and always pointing to the IMF lines (45 degrees of pitch angle). These can be summarized by the following: (a) In most cases the sudden depression basically coincide with the arrival at the Earth of solar protons (EPAM protons)in the keV energy band. (b)In all cases the duration of the depression exceed the 23 hours UT when the telescope tracking run is off, and we do not have the duration of the depressions, we have only some evidence indicating a recovery time shorter than 24 hours. However, in order to obtain this information we include in the analysis two events observed out of the summer season 2005, in two consecutive days. Figure 3 summarize the situation. In addition the recovery time can be obtained as 21 hours. This short recovery time contrast with the recovery time (several days to week) observed in Forbush events in NM data. (c)In some cases before the sudden depression a pre-Forbush increase in the muon flux is observed, probably caused by the galactic cosmic ray acceleration at the front of the advancing disturbance. A clear pre-Forbush increases can be observed for instance in the event on 2005/03/03 (see fig.2) and specially on 2005/04/25 (see Fig.3 left). (d)In contrast with Forbush decrease events as observed in neutron monitor (NM) data, characterized with a sudden depression lasting 10 hours to one day to reach a minimum intensity, the Forbush events observed in the TUPI muon flux have a sudden remarkable depression reaching a minimum intensity around one hour. (f)The event on 2005/04/25 (see Fig.6) is possible to see the two step signature of the Forbush depression, the first decrease occurs due to the passage of the turbulent field (shock) followed by the passage of the ejecta (plasma). It is possible to see also which

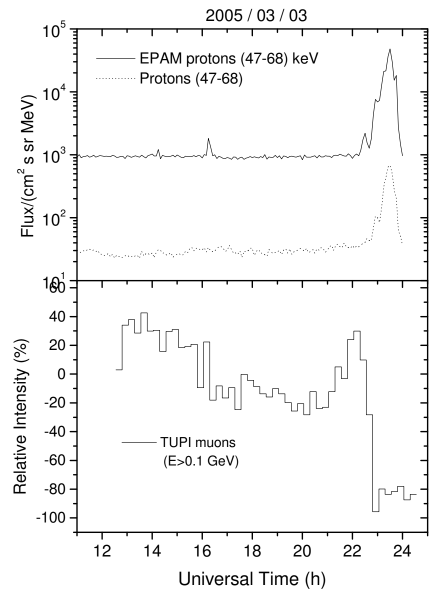

Figure 2. The same as figure 1, only for the rasrer scan on 2005/03/03.

the magnetic cloud is not uniform during its passage to the earth, because anisotropies can be observed in the depressions (see figures 1 and 6 right).

3. Conclusions

The occurrence rates of CMEs at solar minimum is $\sim$ 0.7 per day, meaning that the occurrence rates of Forbush on Earth is 0.1 per day or 3 per month. A preliminary result from the present experiment it indicates a Forbush rates of 9 per month, three times larger than the expected value. This results suggest a second cause or mechanism for the origin of the Forbush events, such as co-rotating high speed streams. On the other hand, the beginning of the TUPI Forbush events correspond, in a straightforward way, to local minima in the hourly average in the Moscow Neutron Monitor flux [8]. However, during the TUPI Forbush events the k_p scale is smaller than 5. The k_p index of 0 to 4 is below magnetic storm, consequently there is not storm notification (or storm level G0) at least according to the NOAA Space Weather Scale. Consequently, we are probably in the front of a new category of Forbush events, and we called mini-Forbush events. They happen in the high energy region and in anti-coincidence with the arrival on the Earth of keV protons and this characteristic can be used as a signature of an interplanetary "thin" disturbance crossing the vicinity of Earth.

4. Acknowledgements

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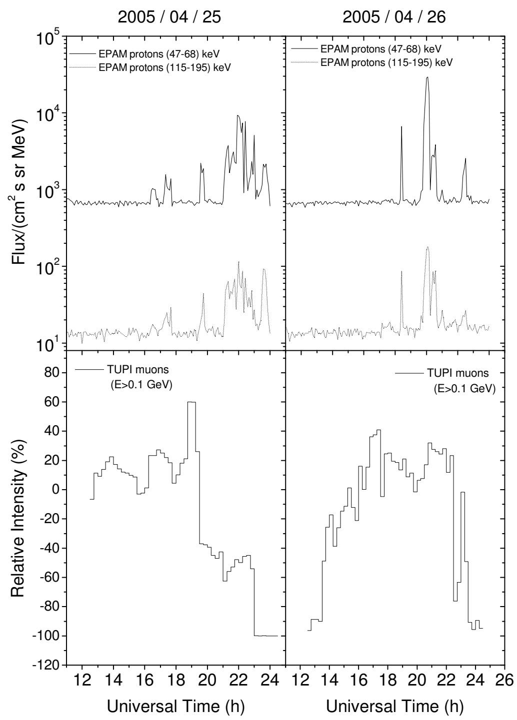

Figure 3. The same as figure 1, only for the rasrer scan on 2005/04/25 and 2005/04/26.

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