Acceleration below Thunder Clouds at Mount Norikura

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Abstract

New results have been obtained concerning particle acceleration beneath thunder clouds. In Summer 2001 an electric field mill was installed at Mount Norikura Cosmic Ray Observatory (2770 m). We have found that (1) the occurrence of particle events has a periodicity of 26 days, (2) there is evidence for proton acceleration in the presence of positive electric field, and (3) evidence has been obtained for increases of secondary cosmic rays under positive electric field.

1. Introduction

Variations of the flux of secondary cosmic rays associated with electric field variations were first reported by the Baksan Group in1985. They noted that the flux of the soft component (> 10 MeV) and the hard component (> 70 MeV) increased in the presence of negative electric field (See Baksan Group, Phys. Lett. A301 (2002) 299). Here a negative field is defined as field pointing from the bottom (+) to the top (−) and vice versa for a positive field. In the presence of a positive field, incoming protons and positive muons are accelerated downward while in a negative field, electrons and negative muons are accelerated. At the Grand Sasso Observatory, short time and long time variations of the cosmic ray flux were found in association with thunderstorms by the EAS Top Group (1999). The short time variation is of interest because it increases the trigger rate of the air shower components. The long time variation is interpreted as being the result of atmospheric washout of radio-isotopes (e.g. Bi^{214}). We have frequently observed the same effect during heavy rainfall in the course of thunderstorms (Norikura Group, Proc. 27th ICRC, 10 (2001) 4027, for further references see this paper).

Our observations have the advantage that four different types of detector are used simultaneously and furthermore, since the summer of 2001, we have operated an electric field mill. Several events have been found in association with highly charged clouds. Here we report on and interpret the results obtained during the past two years (2001–2) and provide an explanation of differences that

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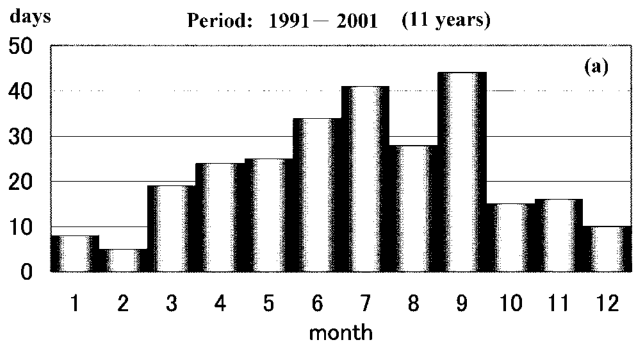


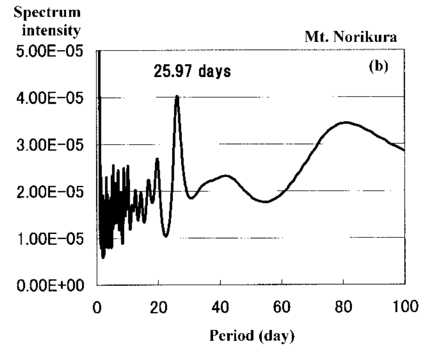


Fig. 1. (a) Monthly distribution of the events

Fig. 1. (b) Periodicity of days with thunder

were found between the results of the Baksan Group and ours.

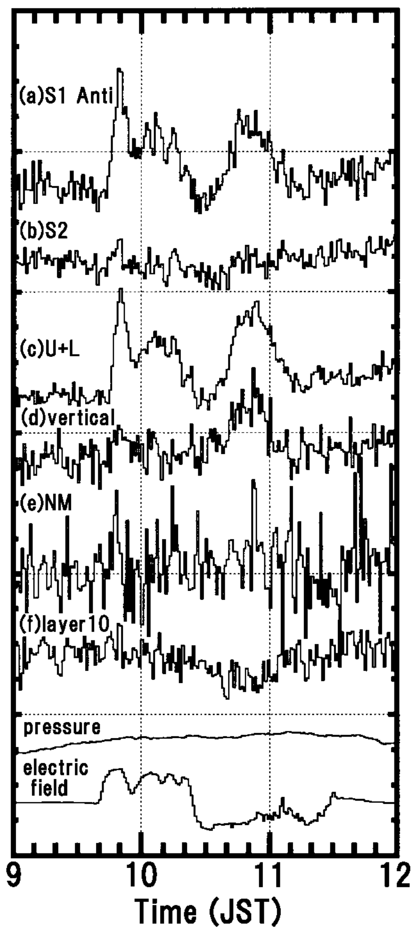
2. Experimental Results

Events were selected using the criterion that the variation of flux should exceed 1% in the U+L channel of the 36 m^2 detector (Nagashima et al., 1989). The distribution of events on a monthly basis is shown in Fig. 1a: it is evident that they are most frequent during the summer but also occur in the winter. A periodicity analysis using the maximum entropy method (Fig. 1b) indicates that there is a periodicity of about 26 days. We suggest that this might be associated with the solar activity since this period lies between the synodic and sidereal periods of the Sun.

A very interesting event, seen in the neutron monitor data of 17 July 2002, is shown in Fig. 2, together with data from the electric field mill. The electric field was measured to be +17 kV/m between 0940 and 1030 local time while between 1030 and 1130 it was measured as −12 kV/m. The neutron monitor showed two 3σ enhancements between 0950 and 1055. An interpretation is given in Section 4. A very clear event was also observed in September 2001: an enhancement of the soft component, produced mainly by photons with energies > 20 MeV can be seen to be associated with positive electric field.

3. Results of Monte Carlo simulations

A Monte Carlo simulation of the behaviour of muons below 10 km altitude has been made using the GEANT 4 program, modified to allow for the presence of a vertical electric field in the atmosphere. We assume the spectrum of muons observed at 10 km altitude and the observed μ^+/μ^- ratio of 1.5 (Grieder, Cosmic Ray at Earth, 2002) as inputs. As can be seen in Fig. 3a, electrons and positrons with energies > 40 MeV shows a net increase with the electric field which approaches 100 kV/m. The reason for the increase is that in a positive electric field, positive muons are preferentially accelerated and these decay into positrons which in turn produce bremsstrahlung photons that can be detected



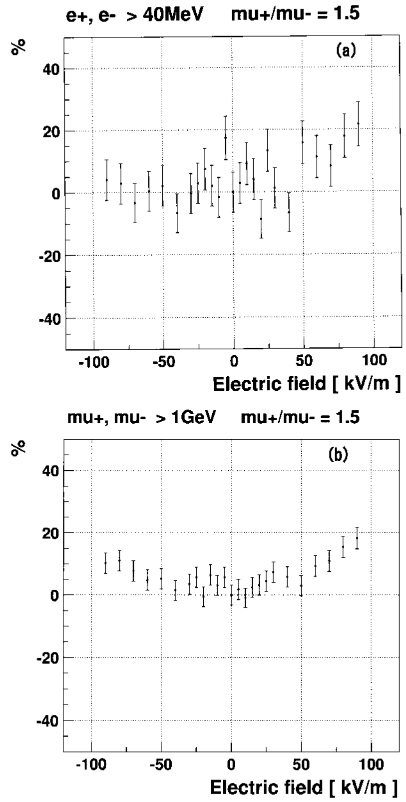


Fig. 3. Results of a Monte Carlo calculations for (a) electrons and positrons induced by muons (E >40 MeV) and (b) the variation (%) of muon flux with E >1 GeV.

Fig. 2. Time profile of July 17th, 2002 event. (a) 64 m^2 scintillation counter with anti- coincidence (photons >20 MeV), (b) 64 m^2 scintillation counter without anti-coincidence (E >40 MeV), (c) 36 m^2 scintillation counter without anti-coincidence, (d) the same detector but for coincidence channel, (e) the neutron monitor 10NM64 and (f) 64 m^2, the bottom proportional counter (E >110 MeV). The scale divisions correspond to 0.5% variation for (a), (b), (c) and 1% for (d), (e), (f). For electric field, the division correspond to 10 kV/m.

in the 'S1 Anti' channel of our system. The Monte Carlo calculation suggests that an increase at small negative electric fields (~ -5 kV/m) is produced by the acceleration of knock-on electrons (Norikura Group, 2001). The variation of the > 1 GeV muon flux with electric field strength is shown in Fig. 3b.

4. Discussion

Several interesting events were observed during the summers of 2001–2. In particular, we found an event in which the soft component was increased by a positive electric field, whereas the Baksan Group has observed such increases

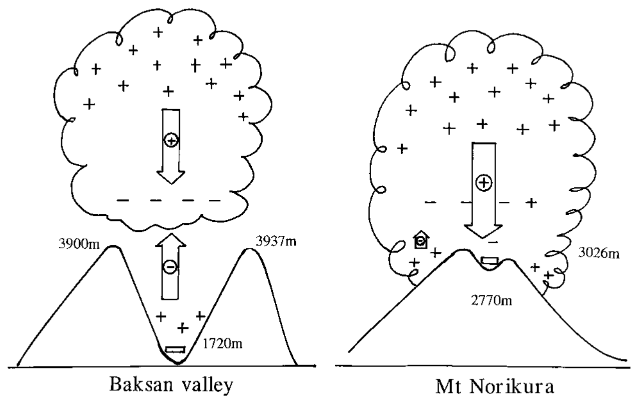


Fig. 3. A hypothetical picture of the charge distribution in clouds, for Baksan and Mt. Norikura. $\oplus$ and $\ominus$ represent positive and negative field respectively.

only during periods of negative electric field. Thus, in the event of 17 July, 2002, increases of the soft component were seen with both positive and negative fields (Fig. 2) and moreover, the neutron monitor recorded short enhancements in the middle of each increase. These neutron monitor enhancements can only be the result of proton acceleration by a positive electric field. Hence there must have been a region of positive field continuously above Mount Norikura between 0940 and 1130 even though the field at ground level measured by the field mill was sometimes negative. The difference between the observations made by the Baksan and Norikura Groups is perhaps the result of differing local topographies. As indicated in Fig. 4, observations at Baksan are made in a valley where the negatively-charged region is $\sim$ 2 km above the ground, whereas at Mount Norikura, the Observatory is on the top of the mountain, usually in the clouds, and may penetrate the negatively-charged region as well as being often in the positively-charged region.

In future we plan to make full Monte Carlo calculations and to install a pure muon monitor. There is scope for carrying out a MC calculation for showers initiated by protons in order to investigate the electron and proton components. So far we have not observed the Gurevich effect, associated with very large electric fields and the occurrence of lightning, which has been reported by the Baksan group. To date our measured field strengths have been an order of magnitude less than that required to cause breakdown in air (e.g. Allkofer, 'Spark Chamber', Karl Thiemig, 1969).

Acknowledgements

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