Proceedings of ICRC 2001: 3494 © Copernicus Gesellschaft 2001

ICRC 2001

A prototype muon detector network covering a full range of cosmic ray pitch angles

K. Munakata[1], J. W. Bieber[2], T. Kuwabara[1], T. Hattori[1], K. Inoue[1], S. Yasue[1], C. Kato[1], Z. Fujii[3], K. Fujimoto[4], M. L. Duldig[5], J. E. Humble[6], N. B. Trivedi[7], W. D. Gonzalez[7], M. R. Silva[7], B.T. Tsurutani[8], and N. J. Schuch[7]

[1]Physics Department, Faculty of Science, Shinshu University, Matsumoto, Japan
[2]Bartol Research Institute, University of Delaware, Newark, USA
[3]Solar Terrestrial Environment Laboratory, Nagoya University, Nagoya, Japan
[4]Nagoya Women s University, Nagoya, Japan
[5]Australian Antarctic Division, Kingston, Tasmania, Australia
[6]School of Mathematics and Physics, University of Tasmania, Hobart, Australia
[7]Southern Space Observatory, National Institute for Space Research, OES/CRSPE/INPE, Santa Maria, Brazil
[8]Space Plasma Physics, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA

Abstract. We analyze the pitch angle distributions observed by a prototype muon detector network covering a full pitch angle range. The network includes a new muon detector installed at São Martinho in Brazil. Sample pitch angle distributions are obtained from preliminary analyses for periods including the Easter ground level enhancement (GLE) on April 15 and a large geomagnetic storm on March 31, 2001. It is confirmed in both sample distributions that the pitch angle coverage by the network is greatly improved by the new detector installed in Brazil. The pitch angle distribution also showed a systematic intensity excess from 0° pitch angle (sunward IMF) direction immediately after the onset of the Easter GLE, possibly indicating excess flux of high energy particles being accelerated by the flare and travelling along the IMF from the sun. No clear loss-cone precursor was found during a period preceding the geomagnetic storm on March 31, but the network observed instead intensity excesses around 0° pitch angle, half a day ahead the storm onset. We discuss these results taking account of the possible contribution from the atmospheric temperature effect. It is concluded that extension of the Brazilian detector in size is required for more precise and reliable observations.

1 Introduction.

A systematic survey of cosmic ray precursors of geomagnetic storms recorded by multi-directional muon detector network showed that 89% of large storms with maximum Kp-index greater than 8.0 were associated with precursors seen in the pitch-angle distribution of cosmic-ray intensity in space (Munakata et al., 2000, hereafter referred to as paper 1). The network consisting of three muon detectors at Nagoya, Hobart and Mawson at that time, however, had a big gap in directional coverage over the Atlantic and European regions. Owing to this gap, we were not able to analyze 43.6% of storms. This gap also made it impossible to analyze the intensity distribution over an entire pitch angle range and to precisely determine the appearance time of precursors.

To fill this gap, we recently installed a prototype multi-directional muon detector at the INPE's Southern Space Observatory (Geographic Coordinates: Lat 29º,26',24"S and Long 53º,48',38"W, Alt.: 500m) in São Martinho da Serra, near Santa Maria, southern Brazil and started a preliminary measurement. The detector (hereafter referred to as São Martinho) consists of two horizontal layers of plastic scintillators separated by 1.73 m, with an intermediate 5 cm thick layer of lead to absorb the soft component in cosmic-rays. Each layer comprises a 2×2 array of $1m^2$ unit detectors (1m×1m×0.1m plastic scintillator viewed by a photomultiplier tube of 12.7 cm diameter) giving a total detection area of 4 m^2. We have been planning to increase the detector size to a full scale comparable to Nagoya (6×6 array of $1m^2$ detectors). The nine directional telescopes at São Martinho started its operation on March 8, 2001 with the vertical count rate of

Table 1. Prototype muon telescopes at São Martinho

Telescope Name	Hourly Count, 10^4cph	Count Error %	P_m, GV
São Martinho (29.4ºS, 306.2ºE)			
V	39	0.16	53
N	11	0.30	58
S	11	0.30	57
E	11	0.30	59
W	11	0.30	56
NE	4.7	0.46	64
NW	5.4	0.43	61
SE	5.3	0.43	63
SW	5.5	0.43	60

Correspondence to: Munakata (kmuna00@gipac.shinshu-u.ac.jp)

390,000 counts per hour. Table 1 summarizes characteristics of directional telescopes at São Martinho, including the median rigidity (P_m) of primary galactic cosmic rays calculated by utilizing the response function of muons in the atmosphere to primary particles. In this report, we make a preliminary analysis of pitch angle distribution observed by the prototype network of Nagoya (in Japan), Hobart (in Tasmania, Australia) and São Martinho following the procedures adopted in Paper 1. We analyze the pressure-corrected hourly count rates of cosmic ray muons recorded by total 35 directional telescopes in the network after 8 March, 2001. The telescopes consist of 17 components in Nagoya, 9 in Hobart and 9 in São Martinho. For detail of our analysis, readers can refer to Paper 1.

2 Results.

A sample pitch angle distribution observed by the network over a 1.5 day period (April 14 and 15) including the Easter Ground Level Enhancement (GLE) event recorded in neutron monitors on April 15 is plotted in the lower panel of Fig.1. This plot shows muon intensity as a function of day of year (DOY on abscissa) and the pitch angle (ordinate). Each circle in the panel represents an hourly measurement by a single telescope, with relative excess or deficit of cosmic ray intensity from the average displayed, respectively, as an open or solid circle. The diameter of each circle is proportional to the magnitude of deficit or excess. A pitch angle 0° corresponds to the sunward IMF direction. We used the hourly mean IMF and solar wind data observed by the ACE satellite (ftp://sec.noaa.gov/pub/lists/ace2/). In this panel, we first note that the pitch angle coverage by the network is greatly improved by adding a single detector at São Martinho. Owing to the great difference in viewing longitudes, São Martinho efficiently observes ~0° pitch angle region when the viewing directions of Nagoya and Hobart considerably deviate from the sunward IMF direction. This is important for the network to continuously monitor the loss-cone anisotropy around the IMF.

It is seen in Fig.1 that the intensity excess (open circles) is observed around 0° pitch angle immediately after the onset of the GLE recorded by the Thule neutron monitor (see upper panel). The intensity distribution at 105.604 DOY, corresponding to an hour between 14:00 and 15:00 UT on 15 April, is displayed in Fig.2. A systematic intensity excess of about 2% confined within 60º pitch angle is clearly seen. This might be a signature of excess flux due to high energy particles being accelerated by the flare and traveling along the IMF from the sun. If this is

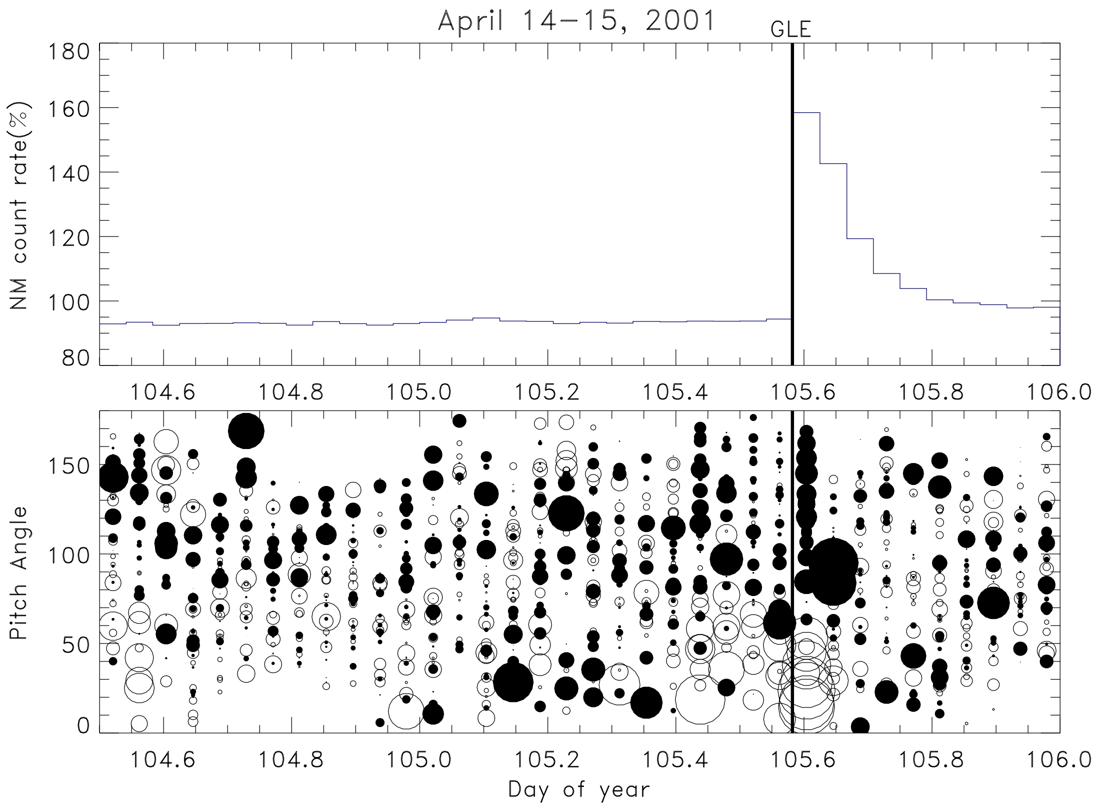

Figure 1. Pitch angle distribution of cosmic ray intensity observed by 35 directional muon telescopes on April 14 and 15, 2001. The lower panel shows the intensity as a function of day of year on the horizontal axis and pitch angle on the vertical axis. A pitch angle 0° corresponds to the sunward IMF direction. Open and solid circles represent, respectively, an excess and deficit of intensity relative to the average, and the size (diameter) of each circle is proportional to the magnitude of excess or deficit. The upper panel shows the hourly count rate of the Thule neutron monitor (ftp://sec.noaa.gov/pub/lists/neutron/). A GLE occurred on April 15 with the onset time indicated by the vertical line.

true, this event is the second high-energy GLE which has been detected by multidirectional muon detectors (the first one on September 29, 1989 was detected by the Nagoya and even seen by the underground muon detectors at Mawson in Antarctica and New Mexico in USA). To confirm this and derive accurate magnitude of excess, however, we need to perform more careful analysis of the possible contribution from the atmospheric temperature effect.

Figure 3 shows another example, including the large geomagnetic storm that occurred on March 31 (90 DOY). The pitch angle distribution is plotted in the third panel in the same manner as Fig.1. Also plotted in this figure are the Kp geomagnetic index, the Thule neutron monitor count rate, IMF magnitude and solar wind velocity. Following the onset of the storm sudden commencement (SSC) indicated by the vertical line, sudden increases in both IMF magnitude and solar wind velocity are recorded. In this example, we again note the pitch angle coverage improved with the additional detector at São Martinho. In this particular event, there appears to be a weak loss cone anisotropy (solid circles localized around 0° pitch angle in the third panel) in the hour immediately preceding the SSC. In addition, we see intensity excesses (open circles) near 0° pitch angle at around the middle of 89 DOY (March 30), but further analysis is required to determine whether this is a true precursor of the March 31 geomagnetic storm.

The intensity distributions in Fig.3 at 89.521 and 89.604 DOY are displayed in Fig.4. In each distribution, a systematic intensity increase with amplitude of about 2 % is seen in the small pitch angle region. It should be noted, however, that these excess profiles are mainly formed by nine data points from São Martinho at small pitch angles (solid circles). The network still has a gap between the small pitch angle region (0°~60°) covered by São Martinho and larger pitch angle region covered by Nagoya and Hobart (90°~180°). Due to this gap, data points by São Martinho are isolated from others without any overlap. This makes it difficult to normalize São Martinho count rates with those of Nagoya or Hobart and to experimentally exclude the possible contribution from the atmospheric temperature effect, which is expected to be different from one detector to the other. This also applies to the distribution in Fig.2 for the Easter GLE event, though the gap in the pitch angle covered is less evident. This difficulty can be overcome experimentally by extending the size of detector at São Martinho. By such extension, we can have more directional channels overlapping with each other and normalize the count rates at São Martinho with those at Nagoya or Hobart using channels with overlapping viewing directions. We are also examining new analysis techniques to overcome this difficulty, but it is more desirable to extend the scale of São Martinho and increase the number of directional telescopes in operation.

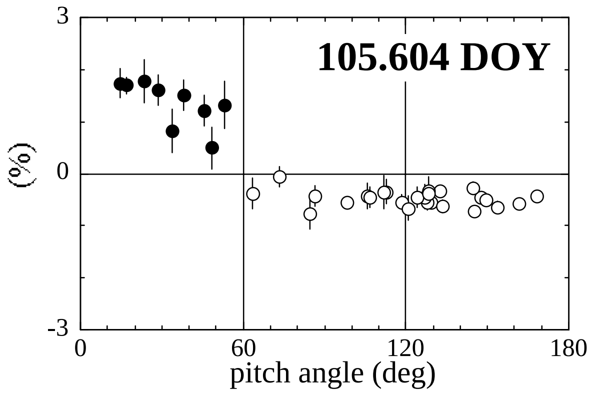

Figure 2. Intensity distribution observed on 105.604 DOY, immediately after the GLE on 15 April, 2001. Solid circles show data points by São Martinho, while open circles show points by Nagoya and Hobart.

3 Summary.

The pitch angle distribution of cosmic ray intensity is observed by a prototype muon detector network covering a full pitch angle range. Sample distributions are presented for two periods including the Easter GLE on April 15 and a large geomagnetic storm on March 31, 2001. A systematic intensity excess from 0° pitch angle (sunward IMF) direction is found immediately after the onset of the Easter GLE, possibly indicating an excess flux of high energy particles accelerated by the flare. A weak loss cone precursor was observed just prior to the onset of the March 31 geomagnetic storm. There was also a strong excess intensity around 0° pitch angle, half a day prior to the SSC.

It was confirmed that the pitch angle coverage is greatly improved by adding a new detector in Brazil to those in Japan and Australia. This is owing to a large difference between viewing longitudes of Brazilian and Japanese/Australian detectors. This large difference in viewing longitudes, on the other hand, isolates the detector in Brazil from others, making it difficult to normalize the count rates between detectors to exclude the atmospheric temperature effect. It was noted that the difficulty can be overcome by extending the size of detector at São Martinho to a scale comparable to other detectors in Japan and Australia.

Acknowledgements. This work is supported by Grant-in-Aid for Scientific Research from the Ministry of Education, Science, Sports and Culture in Japan. The muon observation at São Martinho is also supported by the joint research program of the Solar-Terrestrial Environment Laboratory, Nagoya University. The muon observations at Nagoya and Hobart are supported by Shinshu University and Nagoya University in Japan, and the University of Tasmania and the Australian Antarctic Division in Australia. Thule neutron monitor is operated by the Bartol Research Institute with support from U.S. NSF grant ATM-0000315.

References.

Munakata, K., et al., Precursors of geomagnetic storms observed by the muon detector network, *J. Geophys. Res., 105,* 27,457-27,468, 2000.

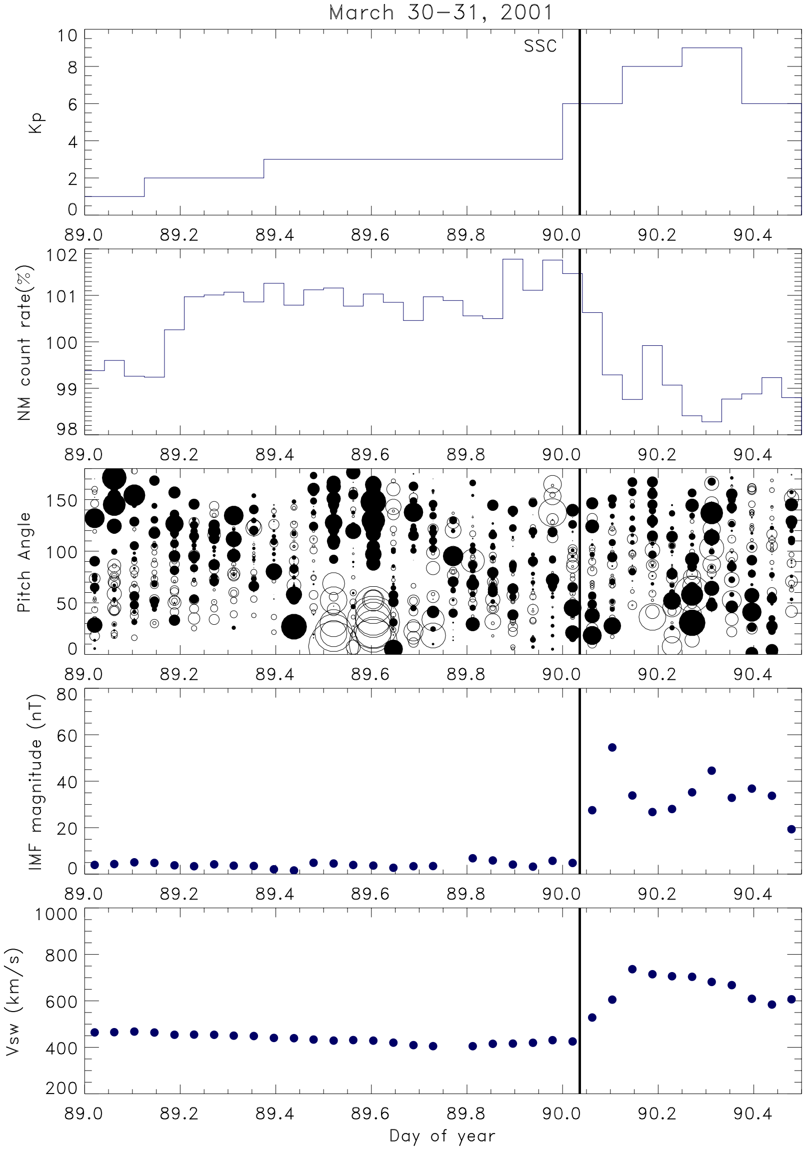

Figure 3. Pitch angle distribution in a period including a geomagnetic storm on March 31, 2001. From top to bottom, the panels show the Kp geomagnetic index, the relative count rate of the Thule neutron monitor, the pitch angle distribution of cosmic rays derived from muon observations, the magnitude of IMF and the solar wind velocity, as functions of time (day of year).

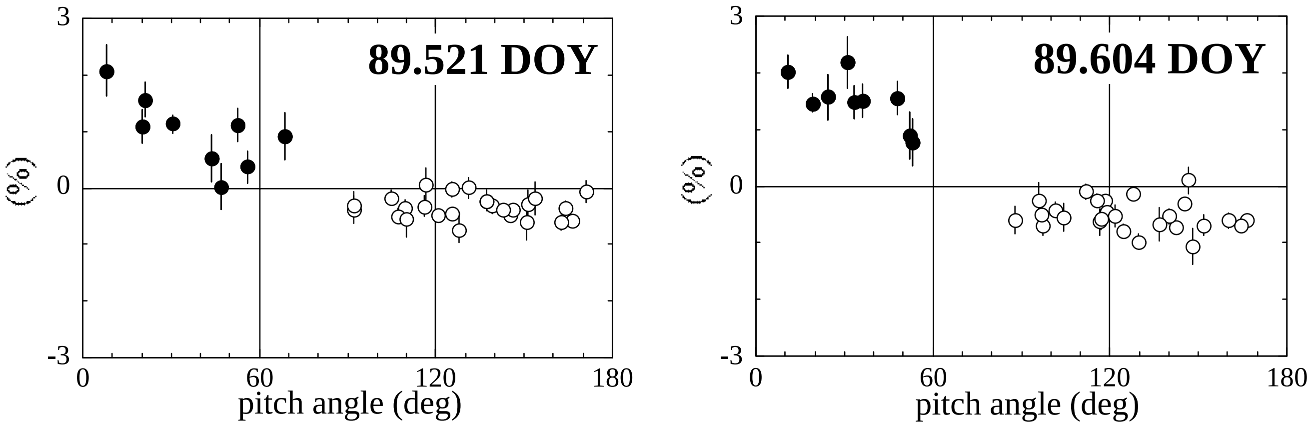

Figure 4. Intensity distributions observed at 89.521 and 89.604 DOY (March 30, 2001) preceding a geomagnetic storm on March 31, 2001.