Study on the cosmic ray intensity variation using scintillation counters for air shower observation

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We report a study on the conversion of a giant cosmic ray observatory for air shower observation to observe cosmic ray intensity variations caused by solar activity, anisotropy associated with interplanetary disturbances, and detection of sudden cosmic ray events on the earth's surface. In this report, we use data from the surface detectors operated by the Telescope Array experiment located at 39°N, 112°W (total detector area: 2250 m2). In order to evaluate the cosmic ray intensity variations, we will compare the data with some of the corrections considered and with available world wide database such as Nagoya Muon detector and other observatories that have been in stable operation at different geographic longitudes. Finally, we will report on the intensity variations due to weather and solar activity recorded during the observation period.

*37*th *International Cosmic Ray Conference (ICRC 2021)*
July 12th – 23rd, 2021
Online – Berlin, Germany

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1. Introduction

There exists a method to observe the changes in the state of interplanetary space due to solar activity through the observation of intensity variations and anisotropy of low energy galactic cosmic rays using ground-based cosmic ray instruments. [1,2,3,4] The main muon instruments currently deployed are the Global Muon Detector Network (GMDN) group, the GRAPES-3 muon telescope in Tamil Nadu, India, and the Nagoya University Muon Telescope, which has been in stable operation for a long time. In monocular observations, the detection of interplanetary disturbances with fine structures, such as Loss Cone-type precursors [4], requires the estimation of intensity distributions in all longitude directions from the integration of 24 hours of data [5]. Therefore, quantitative detection of anisotropy is difficult during the passage of multiple interplanetary disturbances with high variability through the Earth. The purpose of this study is to operate the Telescope Array air shower instrument (TA), which is deployed over an area of about 700 square kilometers in the highlands of Utah, USA, as a muon instrument with a total area of 1500 square meters. The aim is to secure an observation point with high statistical accuracy just on the opposite side of the GRAPES-3 observation field of view. By doing so, we aim to reduce the detection limit of anisotropy from 0.5%, which was the limit of previous studies [5, 6], and to detect amplitude fluctuations in real time.

For the purpose of this study written above, the following tasks (1) to (3) are necessary to convert
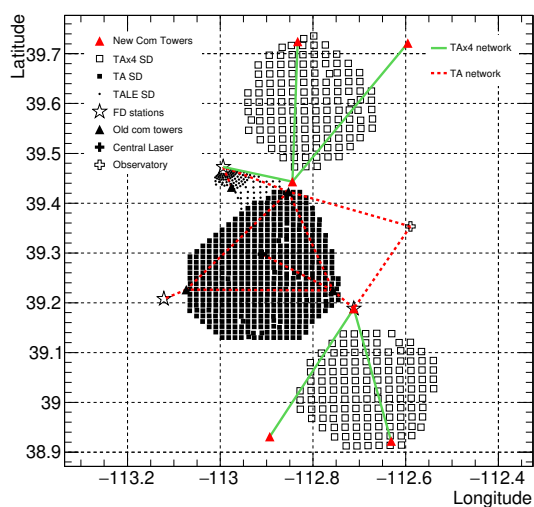

Figure 1: Entire long distance link between sites in TA-TALE-TAx4 experiment.

Figure 2: One of the TA surface detector

the monitoring data of the air shower detector to data equivalent to the existing cosmic ray monitoring equipment.

(1) Record the meteorological conditions in the area where the instrument is deployed.

(2) Estimate the effect of atmospheric pressure and temperature on the particle count rate recorded by the instrument.

(3) Calculate the detector response as function of rigidity and asymptotic direction of primary

cosmic ray.

(4) Comparing the variation of primary cosmic ray intensity estimated by the TA instrument with various instruments in different regions. This will confirm the reliability of the data.

2. Experiment and analysis

2.1 Telescope Array Surface Detector

The TA experiment is located in a desert area about 1,400 meters above sea level at 39.3 degrees north latitude and 112.9 degrees west longitude in Millard County, Utah, USA, about 200 kilometers southwest of Salt Lake City. The purpose of this experiment is to observe cascade showers caused by cosmic rays above 10^{19}eV . Figure 1 shows an overview of the TA surface particle detector and the experimental site.

The surface detector array consisting from 507 thin scintillation detectors with an effective area of 3 m^2 per detector.

Fig.2 shows one of the TA surface detector. The detector is operated with solar panel and battery. Data is collected via wireless lan via control towers located at experimental site.

Atmospheric particles are recorded by the trigger at coincidence between two layer of scintillator. Here we call the trigger as Level-0 trigger. The threshold energy deposit at each layer is about ~ 0.7MeV. The rate of level-0 trigger at each surface detector is about ~ 750Hz. The distribution of integrated FADC count at each Level-0 trigger is recorded at each detector. Here we call this distribution as Mip histogram. The Mip histogram are collected every 10 min together with other monitor information including level-0 trigger rate. Minimum time resolution of level-0 trigger rate is 1 min average.
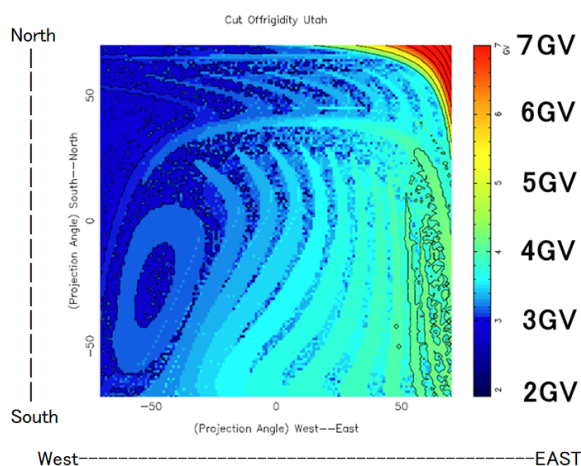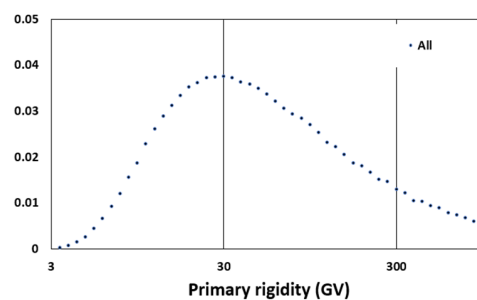

Figure 3: Cut off rigidity at TA site.

Figure 4: Relative response for primary cosmic ray as a function of rigidity.

2.2 Detector response

Using the CORSIKA air shower simulation code, primary cosmic rays are injected from the top of the atmosphere in the range of 2.5GV to 1000GV (zenith angle < 75° to produce atmospheric

particles at the observed height of TA.

Fig.3 shows cut off rigidity at TA site which is calculated independently. The cut off rigidity at the experimental site were calculated for various arriving direction of primary cosmic ray at top of atmosphere. The calculation were done with "backtracking method" assuming IGRF geomagnetic model(2000). Typically 3GV at vertical direction. Fig.4 the response function to intensity variations of primary cosmic ray as a function of rigidity. We also estimated the directional distribution of sensitivity by back tracing the primary cosmic rays which generated atmospheric particles which generated trigger at our detector. In this way, we obtained the sensitivity distribution of our surface detector as a function of rigidity and asymptotic direction. The results are shown in Fig.3 and Fig.4.

2.3 Data analysis

Using the distribution of the energy deposit due to atmospheric particles obtained by TASD, here we call this distribution as Mip distribution. It is possible to obtain the count rate corrected for the variation of the trigger threshold due to the temperature change of the detector. The frequency of the energy loss distribution above half of its maximum value does not depend on the variation of the threshold. This count rate is denoted as N05. Since the shape of the energy loss distribution does not change over a long period of time, this can be used to analyze the following atmospheric correction independent of the detector gain variation. The following atmospheric correction can be analyzed independently of the detector gain variation.
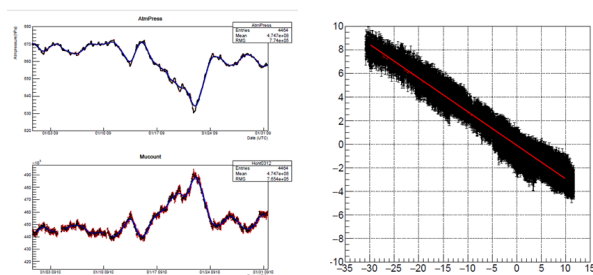

Figure 5: Pressure effect at TA SD. Left-Top: Atmospheric pressure variation for about sampled one month. Left-Bottom Count rate of TASD after local temperature correction. Right: horizontal axis Pressure variation, vertical axis normalized count rate.
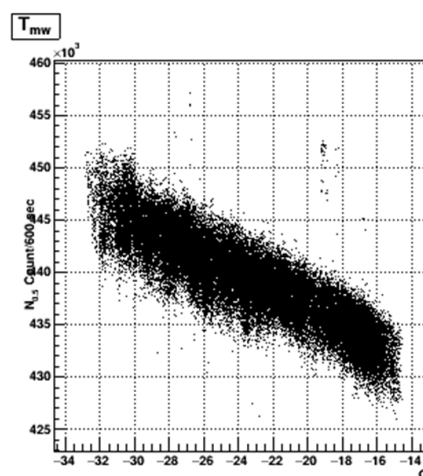

Figure 6: Atmospheric temperature effect at TA SD. horizontal axis shows mass-weight temperature and count rate after applying local temperature and pressure correction

2.4 Meteorological effect

A-1: The counting variation of secondary particles due to changes in atmospheric pressure was investigated using the period of maximum pressure variation per month out of the 12-year observation period in Utah, USA. Fig.5 shows the correlation between pressure change and the

count rate. The pressure coefficient is estimated as $0.282 \pm 0.003\%/hPa$

A-2: Counting changes due to changes in the upper atmosphere, where muons are produced, were investigated in Utah, USA, using real data and upper atmospheric data (GDAS data base), using the method described in [7] of the previous study. Fig.6 shows the correlation between T_{mw} and the count rate. Table.1 summarizes the coefficient obtained using a various parameter of atmosphere.

3. Result and Summary

We calculated characteristics of our observation such as response function and correction of local temperature effect. Also we considered atmospheric temperature effect and obtained data comparable with other observations in other geographical longitudes. After adapting these corrections, we compare our data with other observations of interplanetary disturbance event. Fig.7 shows a Forbush Decrease event which had been observed 2017. The effect of the correction for the effect of the upper atmosphere with and without the correction is shown. In this correction, we used the effective temperature weighted by the atmospheric density at each altitude, which corresponds to T_{mw} in the table.1.

Figure 7: Summary of atmospheric temperature coefficient $H100hPa$ is altitude of 100hPa. T_{mw} is mass-weighted temperature. T_{grd} is ground temperature. $T_{16.5km}$ is temperature at altitude 16.5km

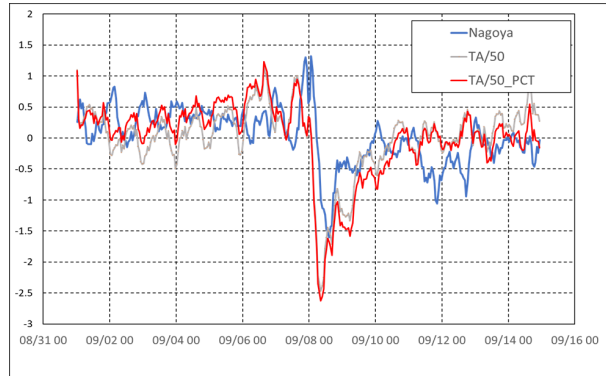| Method	Slope	Error
$H100$hPa	$-3.992\%/$km	$\pm0.01\%/$km
T_{mw}	$-0.186\%/$K	$\pm0.005\%/$K
T_{grd}	$-0.076\%/$K	$\pm0.002\%/$K
$T_{16.5km}$	$+0.142\%/$K	$\pm0.001\%/$K

Figure 8: An forbush decrease event observed in Sep.2017. Blue line shows variation observed Nagoya Muon Telescope. Gray line show TA surface detector data with local temperature and pressure correction. Red line shows TA surface detector data with local temperature , pressure and atmospheric temperature correction.

In the comparison between the vertical direction of Nagoya and the TA, the effect of temperature on 09/02-09/06 before the start of FD, and the effect of temperature around 09/14 were significant. The correction is about 0.3-4% in the larger cases.

Acknowledgements

References

[1] T.Abu-Zayyad et al. Nuclear Instruments and Methods in Physics Research Section A 689, 87-97,2012

[2] K. Munakata et al. Butsuri-Tansa Vol.65 No. 3 (2012) pp. 173-179

[3] Kozai et al. Earth, Planets and Space 66:151 (2014)

[4] K. Munakata, J. Geophys. Res., 105(A12), 27457– 27468

[5] K. Nagashima and K.Fujimoto et al.,Planet space sci (1992) 0 1109

[6] T. Nonaka PhD thesis Osaka City University (2005)

[7] T. Nonaka et al. Proceedings of the 29th ICRC Vol.1 359-362 2005

[8] R. R. S Mendonca et al. Astrophysical Journal 830:88 (25pp) 2016

PoS(ICRC2021)1255

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