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Zenith Angle Distribution and Atmospheric Effect for EAS with LAAS experiments

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Abstract: The zenith angle distributions of extensive air shower (EAS) at sea level were measured by the EAS arrays of Large Area Air Shower (LAAS) experiments. The distributions observed at each array were well fitted as an exponential function of $(\sec\theta - 1)$. The absorption lengths λ obtained in the zenith angle distribution were about 106 ± 6 g/cm^2 for $\theta \leq 45\,\mathrm{deg}$. The results were also consistent with the simulation results and the results obtained by other experiments.

The atmospheric effect of barometric pressure variation were also obtained in the analysis of diurnal variation of cosmic ray intensities observed at several EAS arrays. The diurnal variations of cosmic ray intensity are well described as a diurnal barometric pressure variation and higher order ones.

Introduction

The zenith angle distribution of EAS was studied by numerous measurements, and the absorption length lies around 120 g/cm^2 for various shower size [1, 2].

The longitudinal development of the electromagnetic part of EAS approximately are going to be exponentially decreased in the number of particles as increasing the atmospheric depth after the shower maximum. The definition is for the absorption length Λ,

$$j(>N_e,\theta) = j(>N_e,0)\exp[-\frac{X_0}{\Lambda}(\sec\theta - 1)]$$

where j($> N_e, \theta$) is the intensity, N_e is the shower size, and X_0 is the vertical atmospheric depth of the array altitude, and θ is the zenith angle. On the other hand, the attenuation length λ of the number of electron components is defined as the following function,

$$N_e(\theta) = N_e(0)\exp[-\frac{X_0}{\lambda}(\sec\theta - 1)].$$

Assuming that a power law dependence of N_e spectrum is well described, the absorption length Λ depends on the steepness γ of the power law of primary energy spectrum [2, 3, 4]. We can convert Λ into λ by multiplying the index of power-law primary cosmic ray intensity under the assumption of one composition of primary species, and no fluctuations of EAS. And the relation between the absorption Λ and attenuation length λ is written in the equation as $\Lambda = \lambda/(\gamma - 1)$.

The attenuation length λ also depends on the hadronic interaction cross sections and primary compositions which interact with the atmospheric nuclei. Thus the attenuation or absorption lenght measurements are important to study primary cosmic ray compositions.

In order to confirm the effect of atmospheric depth on EAS intensity, we also have analyzed the diurnal variation of EAS intensity with and without barometric pressure corrections. The diurnal variation of barometric pressure were well described in terms of diurnal, semi-diurnal and Ter-diurnal harmonics. And these effects are interpreted into the Λ value. We evaluated Λ values from the barometric pressure effect in intensity variation analysis.

LAAS Experiment and Data Analysis

In LAAS experiments[5], the compact arrays are deployed in large part of Japan. And EAS arrays located in each institute, of which arrays are synchronized by 10MHz oscillator maintained by GPS signals, and the time stamp system provides UT with accuracy of $1\mu\,\mathrm{sec}$. Each array consists of 5 or 8 scintillation counters(0.25 m^2), of which area is about 200 m^2. And the ADC and TDC values of each detector were registered with PC-LINUX system. The trigger rate is typically about 5000 EAS events per day. EAS arrival direction were determined by the fitting the plane for the shower front structure derived from TDC data.

In the simulation study of array performance with CORSIKA Monte Carlo code [6], the energy observed at each array ranges from 80 TeV to 1.5 PeV in FWHM, and the median energy is about 600 TeV. The arrays designed to enable to measure the zenith angle (θ) up to 60 deg. The data have been analyzed for $\theta \leq 45\,\mathrm{deg}$.

Results

Zenith Angle Distributions

In this analysis, we applied the coincidence condition that all scintillation detectors had ADC signals more than 1 m.i.p. in order to take the advantage of better angular resolution. Data from seven EAS arrays in LAAS experiments were used in this analysis. The typical zenith angle distributions obtained at each array, were shown in Figure 1, where the vertical axis represents the number of events. These distributions were broadly tailed over large zenith angles because of poor angular resolutions, but for $\theta \leq 45\,\mathrm{deg}(\sec\theta - 1 \approx 0.4)$ they were well fitted by single exponential function of $\sec\theta - 1$. The slope parameters and Λ were listed in Table 1. The obtained slope values range from -3.8 to -4.6, and the Λ values do from 96 g/cm^2 to 116 g/cm^2 by using average atmospheric depth 1032.8 g/cm^2. The average value of Λ is 106 ± 6 g/cm^2, which is consistent with the simulated zenith angle distributions at the primary energy around $10^{15} \sim 10^{16}$ eV in Figure 1, because of median energy (600TeV) observed with EAS arrays.

Diurnal Variations of Cosmic Ray Intensity

The cosmic ray intensity is influenced by the barometric pressure at observation altitudes, and its regression coefficient of counting rate variation is about -0.7 %/hPa. In LAAS EAS observations, the regression coefficients were obtained and ranges from -0.5 to -1.2%/hPa. We can evaluate the average value of absorption length from these values and it is 120 ± 20 g/cm^2. This absorption length is consistent with the absorption length Λ obtained from zenith angle distributions. Then we applied the barometric pressure correction for cosmic ray intensity. In order to confirm the correction, diurnal intensity variation were analyzed. It is well known that the diurnal barometric pressure variations with the first, second and third harmonic terms, due to atmospheric (thermal) tide effects [7]. The diurnal variation of cosmic ray intensity obtained by LAAS EAS arrays and barometric pressure and temperature data archived by Japan Meteorology Agency (JMA) are shown in Figure 2 as a function of local solar hour (LSH). The plot before applying the correction of the barometric pressure effects in Figure 2 (a), varies with higher order harmonics in LSH, but after correction applied in Figure 2 (b), the first order harmonic function is dominated, indicated by the solid curve in the same figure. The data observed in every one hour by JMA for barometric pressure and temperature are plotted in Figure 2 (c), respectively. The temperature curve shows the first harmonic term,

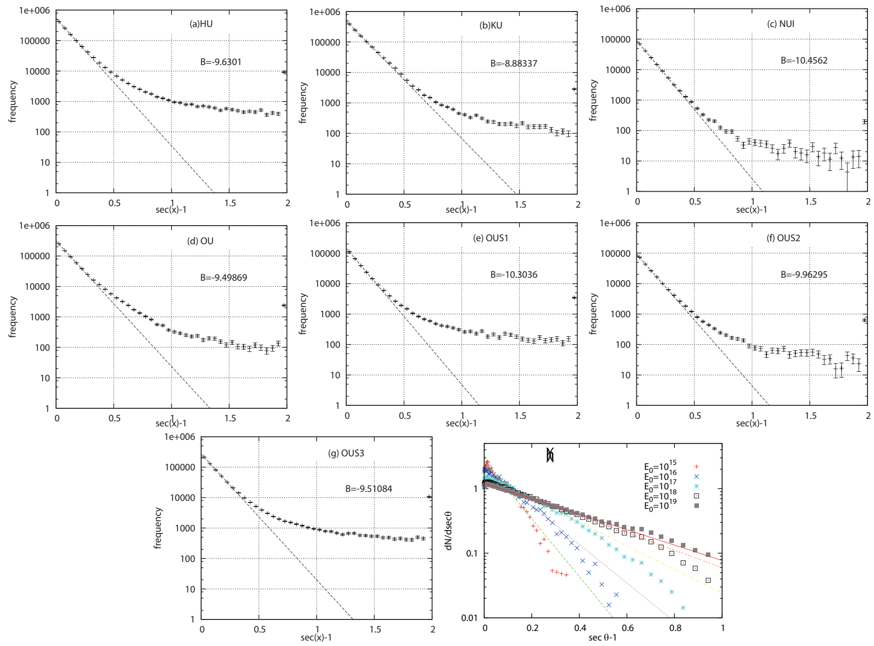

Figure 1: Zenith angle distributions at each LAAS EAS array, (a) Hirosaki University, (b) Kinki University, (c) Nara University of Industry, (d) Okayama University, (e)(f) Okayama University of Science, and (g)AIRES simulation results for several primary energy .

while the pressure curve consists of higher order harmonic term, similar to the intensity without corrections. The delay in the LSH axis, between the barometric pressure and intensity were clearly seen in comparison with Figure 2 (a) and (c). The values of delay hours were measured as 4 hours at 6:00 LSH(15:00 JST, day time) and 6 hours at 18:00 LSH(03:00 JST, night time).

Conclusions

The zenith angle distribution of EAS were measured by LAAS EAS arrays, and the average absorption length Λ derived from the slope values of a exponential function fitting to data, is 106 ± 6 g/cm^2, and which is consistent with the value came from the regression coefficient value of barometric pressure effect to cosmic ray intensity, 120 ± 20 g/cm^2.

The barometric pressure effect due to atmospheric tide (or thermal tide) can well describes the variation of cosmic ray intensity, especially for higher order variations. And 4 to 6 hour time lag of cosmic ray intensity exists behind the barometric pressure variations. The mechanism to raise these time lags we found, can not be concluded.

Acknowledgments

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References

[1] C. Bacci, et al., Results from the argo-ybj test experiment, Astropart. Phys. 17 (2002) 151–165.

[2] D. Ciampa, R. W. Clay, The zenith angle distribution of extensive air showers at sea level: A measure of shower development, J. Phys. G14 (1988) 787–792.

Site	N	slope value	Λ_{abs} [g/cm ^{2}]
HU	5	-4.18	107
KU	5	-3.86	116
NUI-A	7	-4.54	98.8
NUI-B	7	-4.38	102
OU-A	8	-4.13	109
OU-AZ	8	-3.97	113
OU-B	8	-3.96	113
OU-C	8	-4.25	106
OU-D	8	-4.27	105
OU-E	8	-4.25	106
OUS1-A	4	-4.47	100
OUS1-B	8	-4.64	96.6
OUS1-C	8	-4.53	99.1
OUS1-D	8	-4.60	97.5
OUS1-DE	8	-4.48	100
OUS1-E	8	-4.59	97.8
OUS1-F1	8	-4.53	98.9
OUS1-F2	8	-4.49	99.9
OUS1-F3	8	-4.53	99.0
OUS2-A	4	-4.22	106
OUS2-B	5	-4.63	96.9
OUS2-C	8	-4.33	104
OUS2-D	8	-4.09	110
OUS2-E	8	-3.84	117
OUS3-A	4	-4.13	109
OUS3-AB	5	-4.10	110
OUS3-B	5	-3.85	117
OUS3-C	5	-3.90	115

Table 1: The fitting parameter of zenith angle distributions observed at each EAS array with the same detection condition(index like -A). N is the number of detectors. The average atmospheric depth is assumed as 1032.8 g/cm^2.

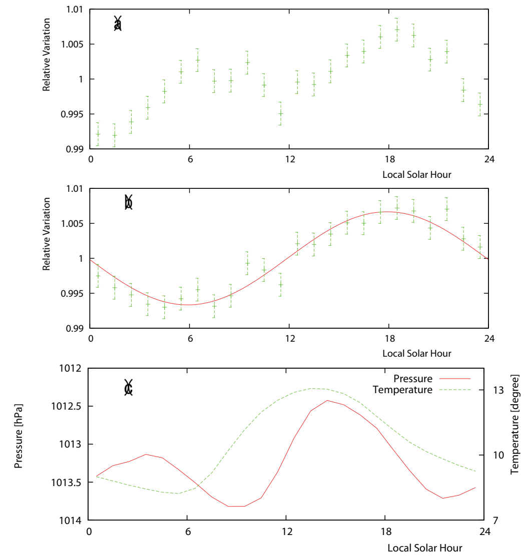

Figure 2: The solar diurnal variation of cosmic ray intensity for no barometric pressure correction (a), corrected one (b) and the variation of temperature and pressure(c).

[3] K. Ghosh, S. Sarkar, R. Chhetri, Measurement of electron size spectra and absorption length of eas below and above the knee of primary, 29th International Cosmic Ray Conference (ICRC 2005), Pune, India, Pune 6 (2005) 149–152.

[4] K. Asakimori, T. Maeda, Y. Misaki, K. Nishijima, Y. Toyoda, K. Yamamoto, M. Yoshida, T. Kameda, Size spectrum and electron lateral distribution of eas, Proc. 18th Int. Conf. on Cosmic Rays Bangalore 11 (1983) 189–192.

[5] N. Ochi, et al., Search for large scale coincidences in network observation of cosmic ray air showers, J. Phys. G29 (2003) 1169–1180.

[6] D. Heck, G. Schatz, T. Thouw, J. Knapp, J. N. Capdevielle, Corsika: A monte carlo code to simulate extensive air showersFZKA-6019.

[7] K. IWAI, E. MIYASHITA, Diurnal, semi-diurnal and ter-diurnal pressure variations at the stations of central mountain area of japan, Tenki 52 (11) (20051130) 831–836.