Atmospheric Depth Models in the Field of View of LHAASO-WFCTA

J. J. Xia[1], F. R. Zhu[1], et al. for the LHAASO Collaboration

1 School of Physical Science and Technology, Southwest Jiaotong University,611756, Chengdu, China

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The Wide Field-of-view Cherenkov Telescope Array (WFCTA) is one of the main components of the Large High Altitude Air Shower Observatory(LHAASO) located in Haizi Mountain,Daocheng County,Sichuan Province.WFCTA probes cosmic rays by observing Cherenkov photons generated by secondary particles in Extensive Air showers.Changes in atmosphere depth will lead to changes in the detection efficiency of WFCTA.Therefore, the variation of atmosphere depth plays an essential role in the calibration of WFCTA. In this proceeding,the temporal variation of atmosphere depth at LHAASO site is studied with the MSIS-90 atmosphere model,and compared with the American standard atmosphere model,Saber satellite experimental data, and observational data collected at the LHAASO site. MSIS-90 is used to obtain monthly atmosphere depth at the LHAASO site.

1. Introduction

LHAASO is a dual-task facility designed for Cosmic-Ray (CR) and Gamma-Ray studies at TeV and PeV energies. It consists of three interconnected detectors, Water Cherenkov Detector Array (WCDA), Kilometer Square Array (KM2A), and Wide Field of-view Cherenkov Telescope Array (WFCTA), located at 4410 m above sea level in the Sichuan province of China .WFCTA is mainly used to observe the Cherenkov or fluorescence light generated by secondary particles produced by cosmic rays entering the atmosphere to probe the primary cosmic rays[1].

In order to simplify the calculation, J. Linsley proposed the American Standard Atmosphere Model.Atmosphere Model.Atmosphere Model.The density variation of the atmosphere with altitude is modeled by 5 layers[2].

This model is often used in the estimation of high-energy cosmic rays shower. However, the Cherenkov radiation or fluorescence in the WFCTA field of view will change with the change of atmosphere depth over time. Therefore, it is very important to quantitatively study the change of atmosphere depth over time in the LHAASO-WFCTA field of view to reduce the systematic error of LHAASO-WFCTA and improve the data accuracy. At present, other experiments to observe Cherenkov light or fluorescence in the world mostly monitor the atmosphere depth.

The Auger Observatory measured the depth of the atmosphere over a 12-month period to build a model of the depth for the atmosphere at their site. The MSIS-90 model describes the neutral temperature and density in the Earth's atmosphere from the ground to the height of the thermosphere.Below 72.5 km, the model is mainly based on the regional averaged temperature and pressure tabulated in the MAP manual drawn by Barnett and Corney[3]. Below 20 kilometers, these data are supplemented by averages from the National Meteorological Center (NMC). Above 72.5 kilometers, the model takes into account the data obtained from the space shuttle flight and the updated incoherent scattering results[3].Compared with the US standard atmosphere model, it can describe the temporal and spatial changes of atmosphere density and temperature. In this proceeding, the LHAASO-MSISE model is established by using MSIS-90 model data.

2. Atmospheric depth of experimental data

The TIMED (Thermosphere Ionosphere Mesosphere Energetics and Dynamics) satellite was launched by NASA in July 2001. Its main instrument include a multi-channel infrared radiometer (Sounding of the Atmosphere Using Broadband Emission Radiometry, SABER). The orbit period of the TIMED satellite is 1.6 h. It runs about 15 orbits every day and survey the coverage observation of the earth once every 60 days.The SABER also measures the temperature in the altitude range of about 14-140 km, the vertical resolution is about 2 km and the horizontal resolution is about 400 km[5]. The mesosphere density measured by MARMOT lidar in Golmud by the Institute of atmosphere Physics, Chinese Academy of Sciences is in good agreement with the measured data from TIMED/SABER satellites and the model value in the middle atmosphere is 1%larger than the measured values from lidar and satellite data20%[6].

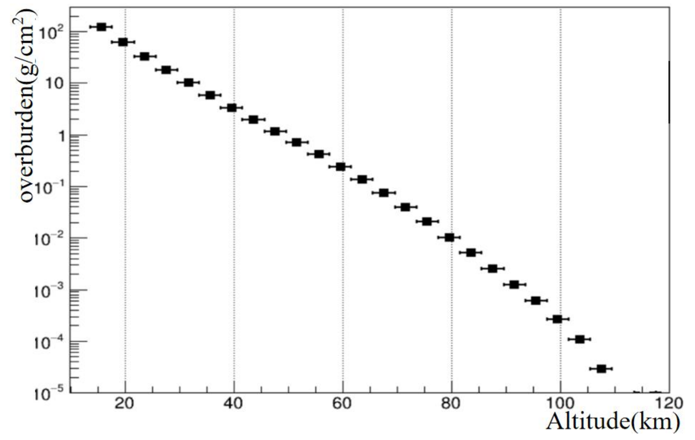

Fig.1 The average of the 31-day SABER data

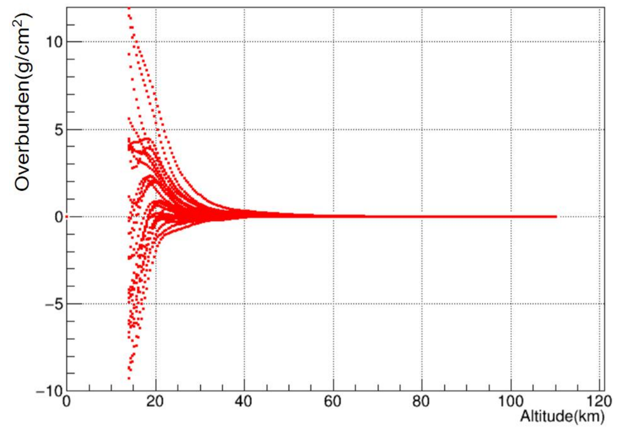

Fig. 2 Comparison of absolu1te values of atmosphere depth

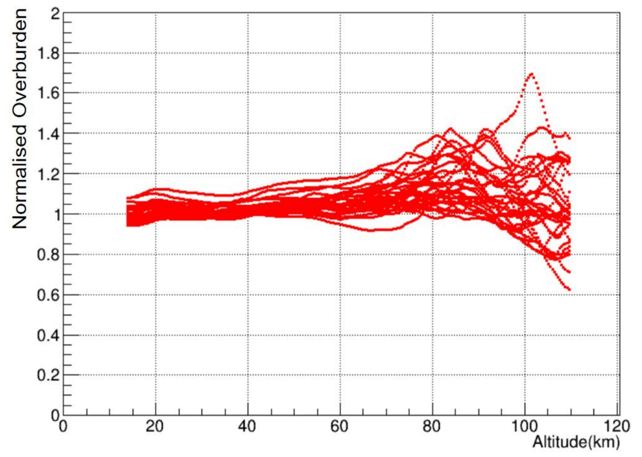

Fig. 3: Comparison of relative values of atmosphere depth

In this proceeding, we downloaded a total of 31 days SABER data from 2013 to 2018. The atmosphere density is integrated in the vertical direction to calculate the atmosphere depth at LHAASO. After averaging the obtained data, and plotting the standard error of the average, the result is shown in Fig.1. it can be seen that the data ranges from 14 km to 110 km since the satellite scanning starts at 14 km.

Fig.2 shows the difference between the satellite's atmosphere depth measurement and the MSIS model from 2013 to 2018. It can be seen that there is a large difference between 14 and 20km, and the maximum difference can reach 20 g/cm2. Figure2(b) shows the ratio of atmosphere depths from obtained from the MSIS model and from the satellite data from 2013 to 2018 and It can be seen that most of these ratios are within 20%..

In order to better study the atmosphere changes at LHAASO, we use the atmosphere pressure data recorded by the standard weather station at LHAASO. The data is obtained every 5 minutes from January 2020 to August 2020.The pressure data is divided by the corresponding acceleration of gravity to get the overburden.

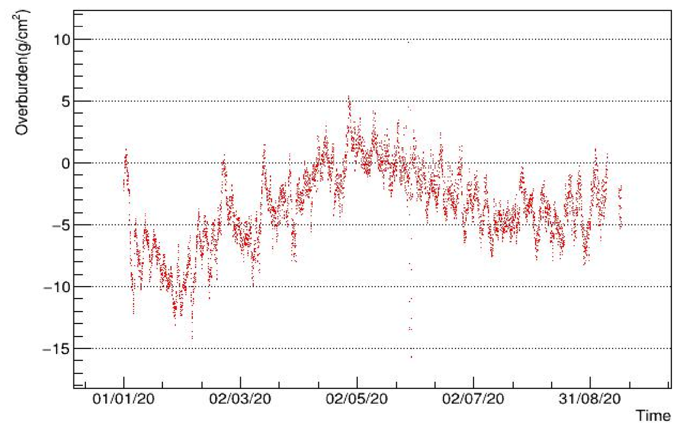

Fig. 5: Absolute difference of atmosphere depth

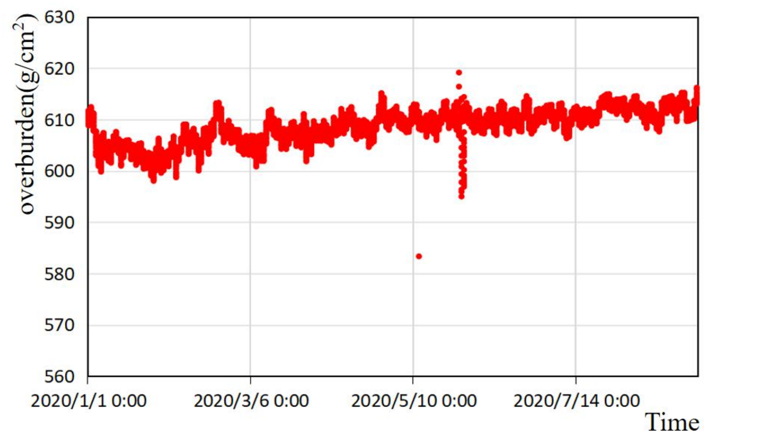

Fig. 4: Variation diagram of surface atmosphere depth in Daocheng over time

At 4.4km, the measured data from January to August of 2020 are selected for comparison with the model data of the same period. Figure 3(b) shows the difference between MSIS and measured data in the same period. The difference between the model value and the measured value is in the range of 0-15 g/cm2. corresponding to a relative change of 1%-3%, and the model value is greater than the measured value during most times.

3.Establishment of LHAASO-model

In this proceeding, we first selected the MSIS-90 model density data from 4.4 km to 100 km in LHAASO site in 2018 and integrated the atmosphere density in the vertical direction to calculate the atmosphere depth. Figure 4(a)shows daily atmosphere depth in April 2018 normalized to that of April 1. It can be seen that the atmosphere depth is changing gradually, and the maximum difference within a month is about 1%. Comparing the monthly average data of atmosphere depth in 2018 with the annual average data, the monthly variation of atmosphere depth at LHAASO is shown in Figure 4(b). The observation time of WFCTA is at night. In order to improve the accuracy of fitting, we select MSIS data from 8:00 pm to 6:00 a.m. every month, and establish LHAASO models by using the fitting formula of American standard atmospheric models. The fitting results are shown in Table 1.

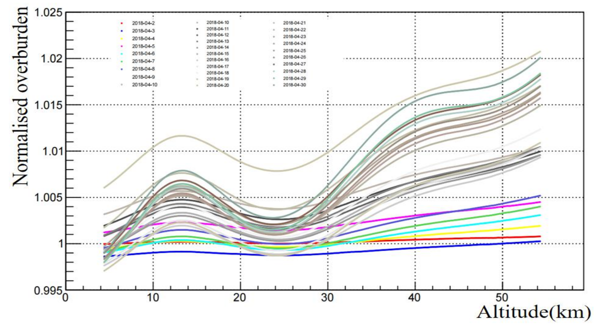

Fig.6 Diurnal variation of atmosphere depth

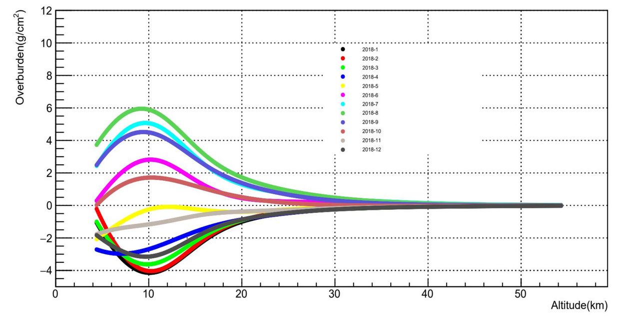

Fig.7 Monthly variation of atmosphere depth

Mouth	Altitude h(km)	ai(g/cm^2)	bi(g/cm^2)	ci(cm)
January	4... 10	-70.19	1511.10	847861
	10... 40	0.7124	1427.82	622405
	40... 70	-0.0198	477.32	791704
	70... 100	-0.0006	234.98	653440
February	4... 10	-69.0042	1152.06	844628
	10... 40	0.7039	1425.44	622829
	40... 70	-0.0232	453.49	800129
	70... 100	-0.0007	2628.73	647197
March	4... 10	-68.4238	1147.93	846844
	10... 40	0.6739	1430.06	622480
	40... 70	-0.0265	427.48	810334
	70... 100	-0.0006	309.36	638828
April	4... 10	-68.8507	1140.99	854446
	10... 40	0.6719	1441.56	621523
	40... 70	-0.0275	418.28	815759
	70... 100	-0.0006	370.57	630105
May	4... 10	-70.3061	1137.10	865141
	10... 40	0.7112	1457.07	621232
	40... 70	-0.0253	436.77	811871
	70... 100	-0.0007	440.73	621805
June	4... 10	-72.1042	1137.32	875334
	10... 40	0.74637	1468.60	622606
	40... 70	-0.02157	475.06	801687
	70... 100	-0.0007	497.69	615581
July	4... 10	-73.4723	1137.96	881852
	10... 40	0.7176	1152.28	625228
	40... 70	-0.0199	509.74	792204
	70... 100	-0.0007	510.33	613543
August	4... 10	-74.0548	1141.99	883373
	10... 40	0.6182	1467.63	627381
	40... 70	-0.0186	519.68	788066
	70... 100	-0.0006	463.06	617474
September	4... 10	-73.9856	1142.26	880356
	10... 40	0.5221	1460.86	627475
	40... 70	-0.0192	507.51	788629
	70... 100	-0.0006	3826.17	626778
October	4... 10	-73.5034	1141.61	873660
	10... 40	0.4991	1151.65	625561
	40... 70	-0.0196	491.88	789852
	70... 100	-0.0006	2998.23	639809
November	4... 10	-72.7183	1142.66	864899
	10... 40	0.5630	1444.27	623294
	40... 70	-0.0184	486.95	789097
	70... 100	-0.0007	2472.46	650721
December	4... 10	-71.5869	1146.50	855582
	10... 40	0.6565	1435.27	622182
	40... 70	-0.0181	487.27	788290
	70... 100	-0.0007	2277.12	655417

Table1:Fitting parameters of the atmospheric model

Based on the above results, at LHAASO, the atmosphere depth values of the MSISE model from 4.4 km to 100 km are slightly larger than the measured values of the experimental data, but compared with the US standard atmosphere model, the agreement with the experimental data is higher,we will use Corsika simulations to analyze the differences in data performance between the model and American standard atmosphere model.

Acknowledgement

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Reference

[1]He, Huihai. Design of the LHAASO detectors[J]. Radiation Detection Technology and Methods, 2018, 2(1):7.
[2] National Aeronautics and Space Administration. NASA Technical Memorandum. Washington D C, 1976. 74335
[3] QIAO S,PAN W,BAN C,et al. Mesospheric density mea-sured by Rayleigh lidar over Golmud[J]. infrared Laser Eng.,2018,47(S1):S106005-1-6
[4]WAN T,LIU H W,FAN J.Error band and confidence coefficient of atmospheric density models around altitude 100 km[J].Scientia Sinica(Physica,Mechanica Astronomica),2015,45(12):66-72.
[5]Picone J M, Hedin A E, Drob D P, et al. NRLMSISE-00 empirical model of the atmosphere: Statistical comparisons and scientific issues. J Geophys Res, 2002, 107: 1468–1483
[6]Weijun Liu,Jiyao Xu,A. K. Smith,Wei Yuan. Comparison of rotational temperature derived from ground- based OH airglow observations with TIMED/SABER to evaluate the Einstein coefficients[J]. Journal of Geophysical Research: Space Physics,2015,120(11).