Atmospheric monitor for Telescope Array experiment

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Abstract. The atmospheric monitoring is very important for the observation of air shower by air fluorescence technique.

In Telescope Array (TA) experiment, LIDAR (LIght Detection And Ranging) system and CLF (Central Laser Facility) system have been used for the measurement of atmospheric transparency. LIDAR system is located in the southeast of TA site. The CLF is located in the center of the TA site. The usefulness of the CLF and LIDAR systems are demonstrated by analyzing the time variation of atmospheric transparency with the systems. The two atmospheric monitor systems are complementary. Therefor, monitoring efficiency is advanced by new LIDAR system that was installed at CLF system.

Clouds are observed with CCD camera, IR camera and eye scan visual check. In addition, we have also measured atmospheric parameters at the ground level using several weather systems.

1 Introduction

The TA experiment was constructed in the desert southwest of Delta, Utah in the USA. Three air Fluorescence Detector (FD) stations comprised of 38 telescopes were built on the perimeter of the TA site for measuring fluorescence emission by extensive air showers induced by UHECRs. Some of the UV fluorescence light is scattered and lost along the path of propagation to the FD telescopes. The main cause of this loss is Rayleigh scattering (from air molecules) and aerosol scattering (from dust and other particles) in the atmosphere. Rayleigh scattering can be understood from a theoretical calculation. However, measurements of atmospheric transparency due to aerosols is required. The main cause of this loss is due to Rayleigh scattering from air molecules, and Mie scattering from aerosols in the atmosphere. The calibration of this loss due to scattering is very important to the calibration of the FDs.

In TA, we employ a variety of measuring systems for atmospheric monitoring. Among these are two laser systems. The first laser system is LIDAR (LIght Detection And Ranging), which observes

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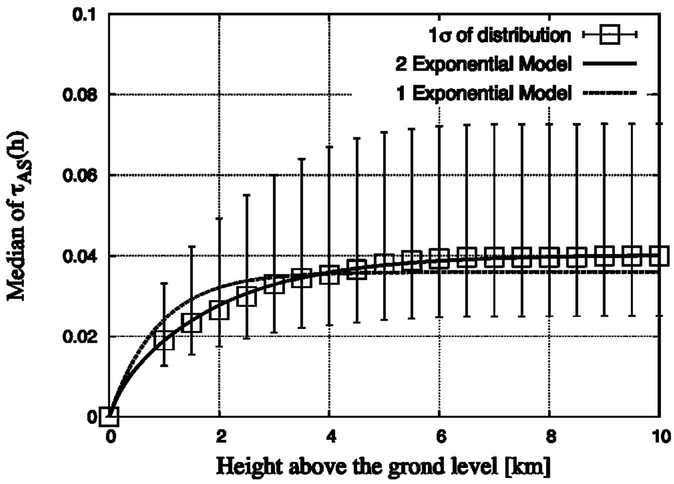

Fig. 1. Median of $T_{LIDAR}(x)$ measured by LIDAR system as a function of the height

the back scattered light from a laser.[1][2][3] LIDAR is widely used for ground based aerosol measurement. The LIDAR is operated before the beginning and after the end of an FD observation, twice a night. The second laser system is the CLF which is located at the geometric center of all three FD stations.[2][3] It fires a vertical beam of UV light, the scattered photons which are seen by telescopes at all three FDs.

In FD observation, cloud reduces the capacity of the observation, and be bad the quality of the observation. IR camera is shooting the clouds that shield the field of view of the FD, CCD camera is used to verify the coverage of the clouds of all-sky.[4][5] IR camera is installed at near the LIDAR system. CCD cameras are installed at several FD stations and CLF. To other, the eye-scan cord is the observation for the star of night sky by FD operator of FD observation night.

In addition, In several FD stations and CLF are also installed weather monitor.

2 Atmospheric transparency monitoring system

2.1 LIDAR system

LIDAR system is located near the FD-station in the southeast (BRM-station). LIDAR fires 500 pulses of 355 nm laser light with a pulse width of ~5 nsec at a rate of 1 Hz, and maximum energy of the laser is 4 mJ. The amount of backscattered light is measured by a PMT at the focus of a telescope mounted in parallel with the laser beam. By measuring the backscattered light as a function of time, LIDAR is able to obtain the extinction coefficient α (e.g., the reciprocal of the attenuation length) as a function of height. From α, the attenuation factor $T_{LIDAR}(x)$ for photons that propagate in the atmosphere for a distance x is given by equation (1).

$$T_{LIDAR}(x) = \exp\left[-\int_0^x \alpha(x')\,\mathrm{d}x'\right]. \tag{1}$$

The α for aerosols is obtained by subtracting the calculated α for Rayleigh scattering at each height from the α measured by the LIDAR at the corresponding height. LIDAR measures the α in detail at ground level by making a horizontal shot and with altitude by firing a vertical shot. However, low altitudes (less than 1 km) are not measured in the vertical shot because too much light is scattered from close by the LIDAR and saturates the system. We need 30 minutes to take a full series of laser shots needed for a measurement.

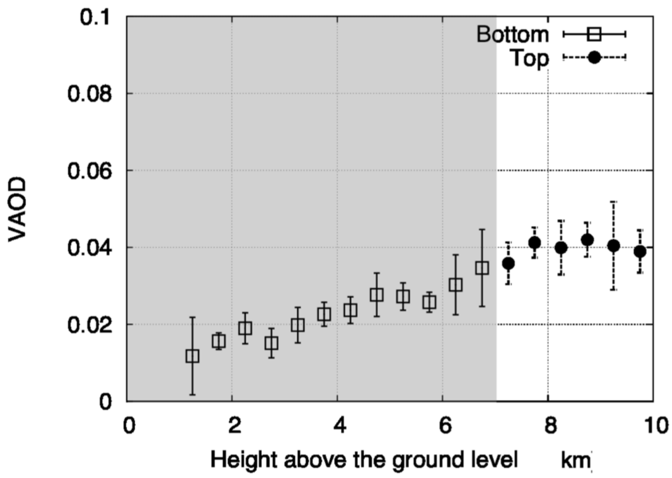

Fig. 2. VAOD measured by CLF system as a function of the height

Fig.1 shows the median of $T_{LIDAR}(x)$ and a 1σ of distribution in each 500 m from the ground by LIDAR observation of 2 years. The solid line in Fig.1 shows integral value of model function (2).

$$\alpha(h) = 0.19 \exp\left[-\frac{h}{1.9}\right] + 0.21 \exp\left[-\frac{h}{0.2}\right]. \tag{2}$$

The systematic fluctuation by atmospheric variationof a model function for the VAOD is +84%/-40%.

2.2 CLF system

CLF was constructed at the center of the fields of view of all three FD stations. The vertical laser of the CLF fires a series of shots every 30 minutes during FD observations. Telescopes at each of the FD stations measure the side-scattering light of laser pulse. The laser of CLF fires 300 shots at 355 nm with pulse of width ~7 ns at 10 Hz synchronized with the GPS 1PPS signal, and laser power is set to approximately 4 mJ. The atmospheric transparency as the Vertical Aerosol Optical Depth (VAOD) can be obtained by comparing each observation data and the clear night or simulation data.

The VAOD(h) is equal to the integral of $\alpha(h)$ from 0 to h km. The attenuation factor $T_{CLF}(h)$ for photons that propagate vertically through the atmosphere from height h is given by equation (3).

$$T_{CLF}(h) = \exp\left[-\mathrm{VAOD}(h)\right]. \tag{3}$$

2.3 Comparison of LIDAR and CLF

Temporal variation of the transparency by the aerosol can be measured during a night of FD observations. Folding in the angular dependence of the scattering, the VAOD obtained from CLF measurements accurately reflects the total amount of aerosols because the photons pass at low altitude from the CLF to the FD. However, atmospheric scattering that includes aerosol scattering is complex due to the relationship to atmospheric molecules scattering. Therefor, calculation of the VAOD is difficult at low altitude where most Fig aerosols exist.

Fig.3 compares the measured VAOD at high altitude (over 8 km above the ground) by both systems for a cloudless night. The measured VAOD obtained from both systems are good correlation.

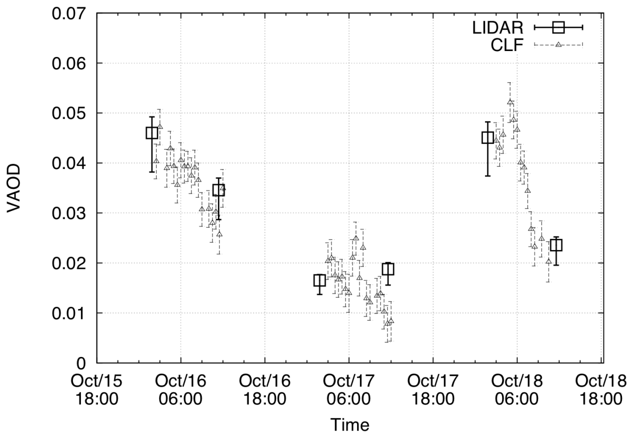

Fig. 3. Time variation of VAOD at 8km above the ground.

3 Cloud monitoring system

3.1 IR camera

The IR camera is installed near the LIDAR system at BRM station for the cloud monitoring system. As specification of this IR camera, it can measure sensitive in a wavelength range of 8~14 μm, in temperature range of − 20~300 °C. This IR camera measures sky temperature in a FOV of 25.8°×19.5° (slightly larger than that of FD) and digitizes in 320×236 pixels for one image. The IR camera is mounted on steering table that be changed in elevation and azimuthal directions via PC control. In an observation sequence, 14 IR images are taken every half hour, 12 IR images for the directions of the FDs in the station (two elevation angles 10.5° and 25.5°, and 6 azimuthal directions for each elevation), and the horizontal and the vertical directions. The time required to take one IR image including a direction change is ~30 second, it takes about 7 minutes for an observation sequence. An example of the "night sky image" is shown in Fig.4. One picture is divided into 4 sections at four elevation angles. To evaluate the rate of cloud-ness in each section. Cloudiness is determined in each section in a photo, one session evaluates cloud coverage by 48 scores that is maximum. Fig.5 shows the distribution of cloud cover. Our FD observation night are high rate of fine weather.

In addition, there is no contradiction between the cloud-ness evaluation by CLF observation and cloud-score of the IR camera. The blue boxes in the figure show clear sky by the CLF observation, and the red boxes show cloudy sky by CLF.

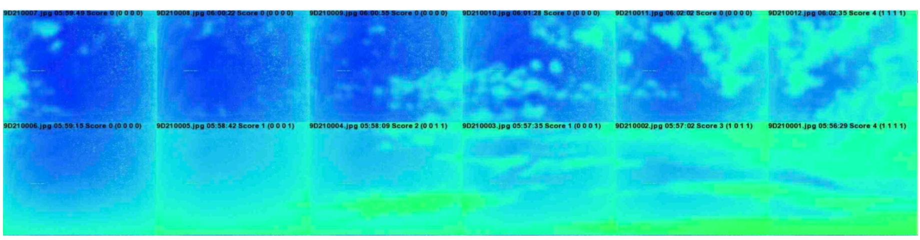

Fig. 4. The night sky image by IR camera

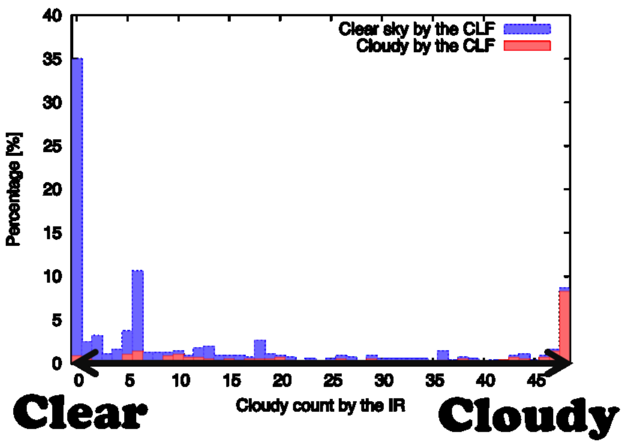

Fig. 5. The cloud-ness score by IR camera.

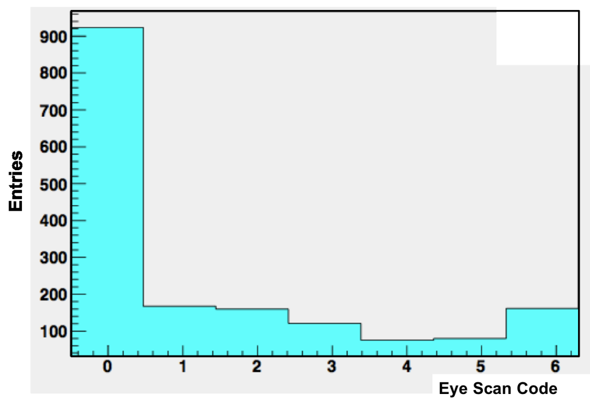

Fig. 6. The cloud-ness score by Eye-scan method.

3.2 Eye-scan code

The clasic cloud monitor is Eye-scan method from old time. Eye-scan Code is checked existence of the cloud by our eyes. As same as IR camera analysis, the sec- tion if flagged "1" (Cloudy), or "0" (Clear). We divide the sky roughly into six sections for Eye-scan, North, South, West, East, zenith, and near horizontal area looking from Black Rock Mesa. We difine the socres of Eye-scan Code from 0 to 6 summing the 0/1 flags of the six sections. The distribution of total scores in Eye-scan Code is shown in Fig.6. Evaluation of the cloud of Eye-scan code are consistent with IR camera.

3.3 CCD camera

CD camera are installed at several FD stations and CLF to shoot the night sky. The camera with a fisheye lens can take almost the whole sky. Stars are clearly visible, and the cloud is blurred more than IR camera's picture. However, determination of the cloud cover is well possible from a photograph of the CCD camera. Fig.7 shows CCD-camera (left) and photograph of the CCD camera (right).

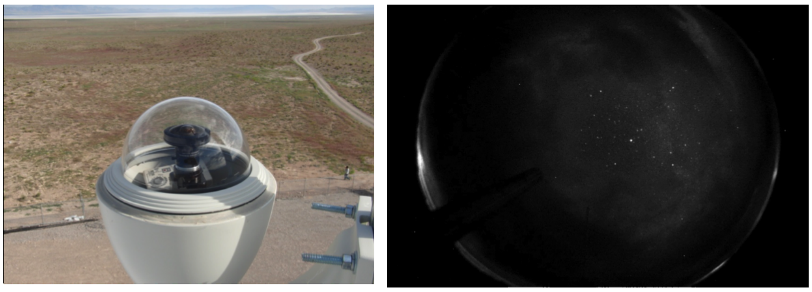

Fig. 7. The cloud-ness score by Eye-scan method.

4 Conclusion

TA experiment is to measure the atmospheric conditions at the time of observation using a variety of equipment. The atmospheric transparency has been measured using the CLF system and the LIDAR system, and both observation is correlated. The cloud coverage are evaluated by IR camera, Eye-scan code and CCD camera. The evaluation of cloud-ness are not contradiction between IR camera, Eye-scan and CLF. The atmospheric monitoring systems of the TA experiment have been successful.

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