Cloud Monitoring with an Infra-Red Camera for the Telescope Array Experiment

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Abstract. Atmospheric monitoring is the key for air shower experiments with fluorescence techniques. In particular cloud monitoring is of great importance to evaluate "clearness" of night skies which affects shower images obtained by fluorescence detectors (FDs). A multi-pixel infra-red (IR) camera is useful for this purpose by measuring sky temperatures of small direction scales: clouds are measured higher temperatures compared to clear skies. In the Telescope Array (TA) experiment, an IR camera of 320 × 236 pixels and a field of view of 25.8° × 19.5° has been installed at an observation site in the TA experiment to monitor sky temperatures for hourly cloud monitoring during FD observations. The camera is mounted on a steering table to change its directions and controlled by a PC via serial communications. Hourly sky temperature maps are created by taking IR pictures of 12 directions above the site, which correspond to the fields of view of the 12 FDs of the station. The system has been in operation since December 2007, and accumulated IR data for more than one year. This paper describes the quality of the cloud monitoring data and the method of the analysis.

Keywords: UHECRs, Atmospheric monitoring, cloud monitoring, Infra-red

I. INTRODUCTION

In the Telescope Array (TA) experiment we have started hybrid observations with both the surface detector array and the fluorescence detectors in the Utah desert (1, 400 m above the sea level) since May 2008 to study origin of ultra-high energy cosmic rays with energies greater than 10^{18} eV [1]. The TA fluorescence detectors are installed in three observation sites: 12 detectors in "Black Rock Mesa" and "Long Ridge" stations, and 14 detectors at the "Middle Drum" station [2] [4]. The surface detector array consists of 512 scintillation counters in the area of about 700 km² with separations of 1.2 km [3]. For analysis of fluorescence data, atmospheric monitoring is very important since fluorescence lights emitted far from the detectors are scattered or absorbed by molecules, aerosols or clouds in the atmosphere. We developed an atmospheric monitoring system including a LIDAR [5] [6], a standard laser emitter in the middle of the fluorescence detector stations (the Central Laser Facility) [7], and an infra-red (IR) camera for hourly cloud monitoring [5]. This paper describes the cloud monitoring system using the IR camera, and report the data acquisition and the analysis.

II. THE CLOUD MONITORING SYSTEM

The IR camera (Avio TVS-600), which is sensitive in a wavelength range of 8 ~ 14 [μm], was installed at the Black Rock Mesa station for hourly cloud monitoring [5], and the data acquisition has started from December 2007. This camera measures sky temperature in a field of view (FOV) of 25.8° × 19.5° (slightly larger than that of our fluorescence detectors) and digitizes in 320 × 236 pixels. The camera is mounted on a steering table and its orientation can be changed in elevation and azimuthal directions via PC control. In one data acquisition sequence, 14 IR pictures are taken, 12 for the directions of the fluorescence detectors in the station (two elevation angles 10.5° and 25.5°, and 6 azimuthal directions for each elevation), and the vertical and the horizontal directions. The time required to take an IR data including a direction change is ~ 30 seconds, therefore it takes about 7 minutes for one data acquisition sequence. In our hourly cloud monitoring we accumulate 60 ~ 150 IR pictures in one night depending on seasonal observation times, and the data sizes mount to 10 ~ 25 MB. By combining the IR images of all the directions, "cloud maps" above the site are created to monitor sky conditions.
conditions in the fluorescence observation. In Fig. 1 an example of the sky map is shown, the clouds in the sky above the station in a dark night are clearly seen by our IR camera.

III. DATA ANALYSIS

A. Pixel Data Distribution

In Fig. 2, examples of IR pictures of a clear and a partly cloudy skies in the lower elevation angle (10.5°), and the distributions of pixel data $D$ are shown. The pixel data $D = 1100$ corresponds to temperature $\sim -20$ [°C], and $D = 1200$ for $\sim 0$ [°C]. Since there are elevation dependence of sky temperature, an IR image are divided into four “sections” ($320 \times 59$ pixels) in data analysis in the following section. It can be seen that clouds in the sky are measured in higher temperature (the temperature in the section-4 near the ground is always measured higher).

B. Identifying Clouds

In order to evaluate cloud coverage in an IR image, we employ a statistical analysis method. First we define the median $D_{50}$ of a distribution of the pixel data in a section (shown in vertical lines in Fig 2). If there is a cloud the pixel distribution shifts right and gives a larger $D_{50}$. Second we investigate the distributions of $D_{50}$ for eye-selected clear and cloudy sky images (Fig. 3). It can be seen that for each of the four image sections the distributions $p(D_{50})$ of the clear and the cloudy skies are split. Then we determine a threshold on $D_{50}$ of an IR image for each of the sections and the lower and the upper elevations (10.5° and 25.5°). Here the threshold $D_{50}^{th}$ is defined as the 5%-quantile of the distribution of $D_{50}$ for the selected nights, such that

$$\int_{D_{50}^{th}}^{D_{50}} p(D_{50})dD_{50} = 0.05$$

If $D_{50}$ of a section of an IR image is greater than $D_{50}^{th}$, the section is flagged “1” (cloudy), or “0” otherwise (clear). By summing the 0/1 flags of the four sections, we define a score of an IR image from 0 to 4. For example, in Fig. 1, the rightmost-upper image is scored as $0 = (0, 0, 0, 0)$, and the rightmost-lower one is $2 = (0, 0, 1, 1)$. The thresholds for the four sections are determined for the lower and the upper elevation angles independently. We use different thresholds for data of summer (July-September) since sky temperature is measured higher in warm nights (Fig. 4). For example, for the section-1 of the lower elevation direction IR images, the threshold on $D_{50}^{th}$ was determined as 1150 for summer data, and 1087 for other seasons.

C. Results

We carried out the analysis described above using the IR data obtained from 2007/Dec/29 to 2009/Jan/04 (164 observation nights), $\sim 17,000$ IR images. The distribution of the score is shown in Fig. 5. There are peaks at scores 0 and 4. This indicates that if there is a cloud in a section on an IR image, there exist clouds also in other sections, and “partly cloudy” data are rather rare. In Fig. 6, the distribution of total score, a sum of the scores of the 10 directions above the Black Rock Mesa station is shown. (leleftmost 2 directions are excluded.

Fig. 1: The sky above the TA Black Rock Mesa station seen by the IR camera: The elevation angles are 10.5° and 25.5°. One IR image is of a field of view of 25.8° $\times$ 19.5°.

Fig. 2: Examples of IR pictures and distributions of the pixel data $D$ of a clear and a partly cloudy skies (for lower elevation angle, 10.5°). The vertical line for each distribution is the median $D_{50}$.
for a technical reason). This also suggests that if there is a cloud in one direction in the FOV of the camera, most of the sky seen from the station is covered with clouds. Therefore the score or the total scores obtained from the IR data can be used for the data selections of the fluorescence events.

IV. CONCLUSION

The cloud monitoring system using the IR camera for TA experiment has been running quite stably during our one-year FD observations. We developed a statistical analysis method to judge the sky condition by defining the score of the IR images from the distribution of the pixel data and the thresholds. The method employed here is robust and applicable for all the data by using different thresholds for the summer data and the other seasons. We are now also studying another method to “point” the positions of clouds using an edge-detection technique of image analysis applicable for FD event reconstructions and data selections.

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