Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 5 (HE part 2), pages 1025–1028

ID 803

Atmospheric Monitoring with a LIDAR and an Infra-red Camera at Black Rock Mesa in the Utah desert

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Abstract: An extinction coefficient and a Vertical Aerosol Optical Depth(*VAOD*) are determined by an experiment using LIDAR. We found consistent results with a calculation of the Rayleigh scattering obtained for the vertical extinction coefficient for altitude of several kilometres in conditions of calm weather. Also we obtained a value approx. 0.06 for *VAOD*. The current results from the atmospheric monitoring with the LIDAR and the IR camera will be presented in detail..

Introduction

An atmospheric monitoring system has been installed at Black Rock Mesa(BRM) in the Utah desert to study properties of the atmosphere using a LIDAR(Light Detection And Ranging) system and an infra-red(IR) camera for cosmic rays experiment. The aims of atmospheric monitoring are to calibrate observed energy of the cosmic ray and to determine detectable region of the fluorescence detectors. For these reasons, the atmospheric extinction coefficient and the cloudiness should be determined precisely as possible.

The LIDAR system consisits of a laser device and a light receiver with a photo multiplier tube(PMT) mounting on a steerable base. The laser emits pulse lights successively into the atmosphere and the receiver detects scattered faint lights by the PMT. To determine the atmospheric extinction coefficient, a large amount of data has been acquired using LIDAR system at Black Rock Mesa commencing from July 2005. A lot of data are analized by means of the so-called slope method and/or the Klett's method after due consideration of atmospheric pressure effect.

Atmospheric Monitoring System

LIDAR

The LIDAR system at BRM consists of next parts:
- laser emitter : energy 5mJ, wave length 355nm, pulse width 5ns
- beam splitter and a λ/4 plate
- laser power metre
- light receiver : 30 cm diameter telescope
- PMT with a UV filter
- digital oscilloscope
-control C

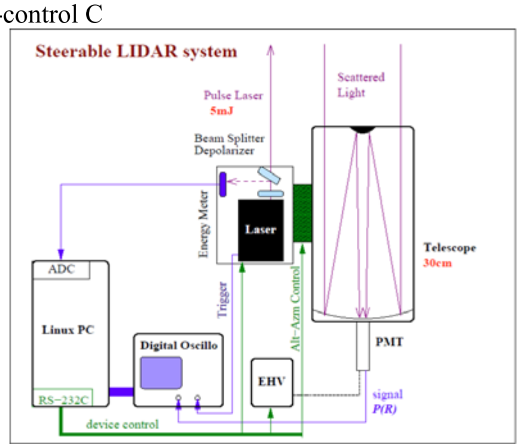

Figure 1: A block diagram of the LIDAR system.

The laser and the optical system with the telescope are mounted on a steerable mechanism. All devices are controlled by a Linux PC through RS-232C communication as shown in Fig 1.

Cloud Monitoring by IR camera

The cloudiness of the night sky is measured using an IR camera(AVIO TVS-600S). Temperature is considered valuable information for off-line analysis to determine cloudiness of the night sky. The information of temperature is recorded as digital values for each pixels of the images.

Specification of the IR camera are as follows:

- field of view: 25.8 degrees x 19.5 degrees
- no. of pixels : 320 x 236pix.
- sensitivity : wave length 8-14 μm

A sample of the cloud image and its temperature distribution is shown in Fig 2.

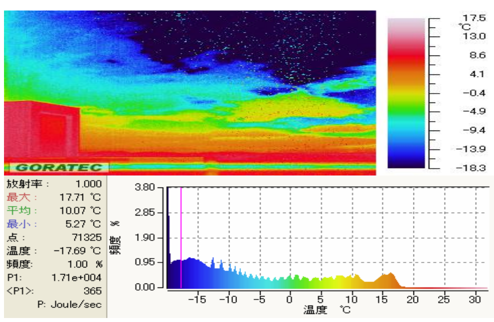

Figure 2: A sample of the cloud image and its temperature distribution

Data Analysis

Model for the Atmosphere

(a) one-dimensional atmospheric structure

We assume the atmosphere has a one-dimensional structure for vertical direction, i.e., the atmospheric density depends on only height. For the atmospheric density, the US atmospheric standard model is used so far, and a radio sonde data is also used in this analysis.

(b) extinction coefficient

The extinction coefficient α is expressed next form.

$$\alpha = \sigma(\lambda)N = \frac{24\pi^3}{\lambda^4 N_S{}^2}\left(\frac{n_S{}^2-1}{n_S{}^2+2}\right)^2\left(\frac{6+3\rho_n}{6-3\rho_n}\right)\cdot N_S\cdot\frac{P}{P_0}\cdot\frac{T_0}{T}$$

where, $\sigma(\lambda)$ is the Rayleigh scattering cross section, N_S is the molecular number density, λ is the wave length, n_S is the refractive index, ρ_n is the depolization factor, P and T are the pressure and the temperature, their subindex 0 stands for initial condition at the ground surface.

LIDAR Equation

We analize the LIDAR data by the slope method and the Klett's method derived from this next LIDAR equation.

$$P(R) = P_0\eta_0 Y(R)\frac{ct_p}{2}A\frac{\beta(R)}{R^2}\exp\left(-2\int_0^R \alpha(R')dR'\right)$$

where, $P(R)$ is the return signal from a distant of R, P_0 is the output energy of the laser, η_0 is the efficiency of the optical system, $Y(R)$ is the superposition of the receiver and transmitter, $c\tau_p$ is the spatial length of the laser pulse, A is the effective area of the mirror, $\beta(R)$ is the volume back scattering cross section of the atmosphere, $\alpha(R)$ is the extinction length of the atmosphere.

From the above LIDAR equation, we introduced the slope method and the Klett's method briefly.

(a) slope method

The slope method is based on a principle of "Lambert law"(exponential attenuation) for passing through the light in the matter. The slope parameter α corresponds to the extinction coefficient of the atmosphere.

$$\alpha = -\frac{1}{2}\frac{d\ln X(R)}{dR}$$

where, $X(R)= P(R)\,R^2$ denotes the corrected light intensity. the ground surface. Next Figure 3 shows the received light intensity with a least squared fit line.

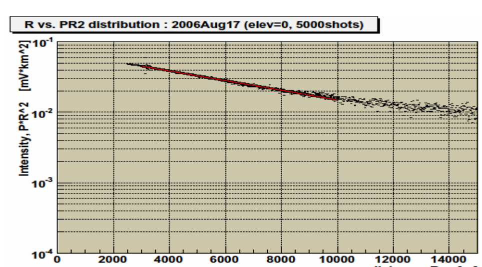

Figure 3: Corrected light intensity vs. path length of the light

(b) Klett's Method

To solve the LIDAR equation, a relationship between β and α is assumed to be a power law of the form,

$$\beta = B \cdot \alpha^k$$

where, B is a function of R, k is a constant. Then the solution to the LIDAR equation becomes next equation[1,2].

$$\alpha(R) = \frac{X(R)}{\dfrac{X(R_c)}{\alpha(R_c)} + 2\int_R^{R_c} X(R')dR'}$$

where, Rc is the critical range of the data analysis. For the vertical laser shooting, Rc is selected of the height of about 10km, because the Rayleigh scattering is a dominant process for 10km above

A sample result of the Klett's Method is as shown in Figure 4, calculated Rayleigh prediction is also distinguished by a red line in the right panel.

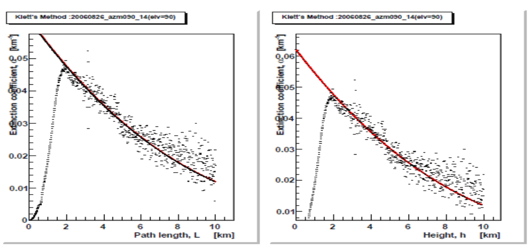

Figure 4: A sample result of the Klett's Method to the data of 26 August 2006. The laser pulses are emitted to the vertical direction.

We checked an effect of the cloud to the calculation of the Klett's method using dummy data with spurious Gaussian shaped cloud and some kind of Mie scattering components. A sample is shown in Figure 5. In the figure the left panel is dummy data to analize by the Klett's method, the right panel is a result of Klett's integral. In this case the normalize point is chose far point at 10km.

(c) flow of the data analysis

A flow of the data analysis is as follows:

1. DAQ: records $P(R)$
2. calculates average data for $P(R)$ (eg. 500 laser shots)
3. calculates $P(R)R^2$
4. calculates an extinction coefficient fit an exponential function to the data : the slope method
5. corrects data the PMT linearity (Figure 6)
6. calculates extinction coefficient by the Klett's method

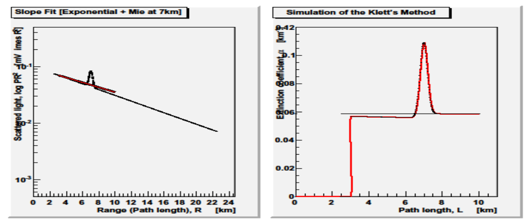

Figure 5: Calculation result of the Klett's integral for a dummy data with a spurious Gaussian shaped cloud.

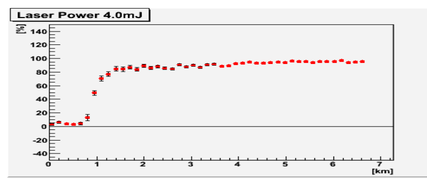

Figure 6: A sample of the correction factor for the PMT signal obtained using PMT and/or LED data for the laser energy 4mJ.

The estimation of the Extinction Coefficient and the Vertical Aerosol Optical Depth for the Atmosphere

We estimate the extinction coefficient and the vertical aerosol optical depth for the atmosphere at BRM.

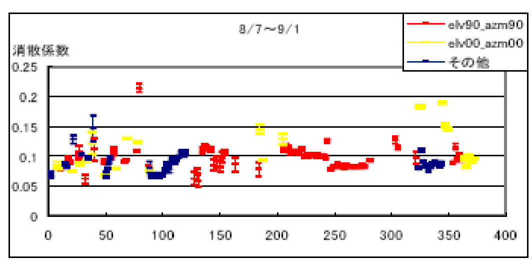

Figure 7: Daily variation of the extinction coefficient α obtained by the slope method. (7August to 1 September 2006)

θ= 0 deg.	α=0.113±0.006 (km^{-1})
θ=90 deg.	α=0.096±0.004 (km^{-1})

Table 1: Average values of the extinction length by the slope method (7August to 1 September 2006).

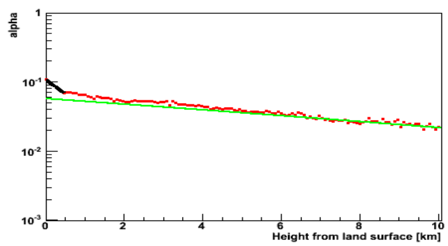

Figure 8: An example of analysis for a modified Klett's method. Red dots are data, black line is Mie component, and green line denotes a prediction from Rayleigh scattering.

For a light attenuation rate through a process of pure Rayleigh scattering, we obtained the next attenuation.

$$I = I_0 \times 0.69$$

For a light attenuation rate through a processes of pure Rayleigh and Mie scattering, we obtained the next attenuation.

$$I = I_0 \times (0.65 \pm 0.01)$$

Then, *VAOD* is defined by next expression[3];

$$VAOD \equiv (\alpha_{Experimet} - \alpha_{Rayleigh}) \cdot L$$

where, $\alpha_{Experiment}$, $\alpha_{Rayleigh}$, and L are the extinction coefficients of experiment and of pure Rayleigh scattering, and a path length of light, respectively. Finally, we obtained *VOAD* ;

$$VAOD = \frac{0.69 - 0.66}{0.69} = 0.06 \pm 0.02$$

Daily variation of the *VAOD*. for the period from 7 August to 1 September 2006 is shown in Fig. 9. Values vary from approximately 0 to 20%.

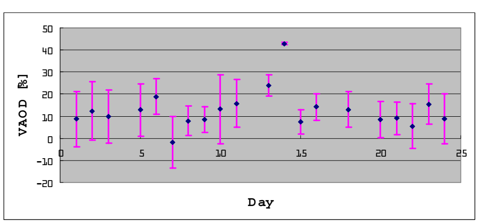

Figure 9: Daily variation of the *VAOD*. (7August to 1 September 2006[4])

Summary

A consistent result with a calculation of the Rayleigh scattering is obtained for the vertical extinction coefficient above an altitude of several kilometres in a calm weather. It is also found that the one-dimentional atmospheric density model is reasonable assumption on a limitative condition in the Utah desert.

1. A daily variation of extinction coefficient is obtained by the slope method. The estimated values are α=0.113±5% for horizontal and 0.096±5% for vertical direction.
2. *VAODs* is calculated by the Klett's method with pressure data using a radio sonde. For example, *VAOD*=5.6% is obtained and the Rayleigh scattering is dominant for the height above few km (6km-10km).
3. Temperature information of the infra-red images by an IR camera is extremely useful to estimate the cloudiness and the effective field of view in the dark night.

Acknowledgements

This work is supported by Grant-in-Aid for Scientific Research from FY2006 to FY2007 by the Ministry of Education of Japan.

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