Implications of LIDAR Observations at the H.E.S.S. Site in Namibia for Energy Calibration of the Atmospheric Cherenkov Telescopes

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Abstract

Scattering values returned by a LIDAR installed at the H.E.S.S. site may be used for calculating optical depth profiles. One may then construct model atmospheres which fit these using the commercially available MODTRAN atmospheric radiation transfer code. Examples of the results of Monte Carlo simulations of the telescope response for two characteristic atmospheres are shown.

1. Introduction

As an instrument for ground-based astronomy the atmospheric Cherenkov telescope (ACT) is unusual in that the atmosphere is an integral part of the detection system. Its stucture, essentially the pressure-altitude profile, controls the particle shower development and the Cherenkov emission. The atmospheric attenuation, as a function of altitude and wavelength, determines the probability of the Cherenkov photons reaching the ACT. Monitoring the properties of the atmosphere is therefore essential for the interpretation of the Cherenkov signal in terms of the energy spectrum of the gamma-rays and source flux variation. The atmospheric attenuation in the 250 to 700 nm range depends on molecular absorption, Rayleigh scattering and Mie scattering by aerosols [1]. Mie scattering is expected to be the most time-variable component. We describe a LIDAR instrument which gives information on this for 7.5 km above the ACT. The generation of model atmospheres to fit the LIDAR measurements is still in development but an example of the differences in ACT response for two characteristic atmospheres is given in the final section.

2. The Ceilometer

The Vaisala CT25K Ceilometer is a commercial LIDAR (LIght Detection And Ranging) which measures cloud heights and vertical visibilities by sending

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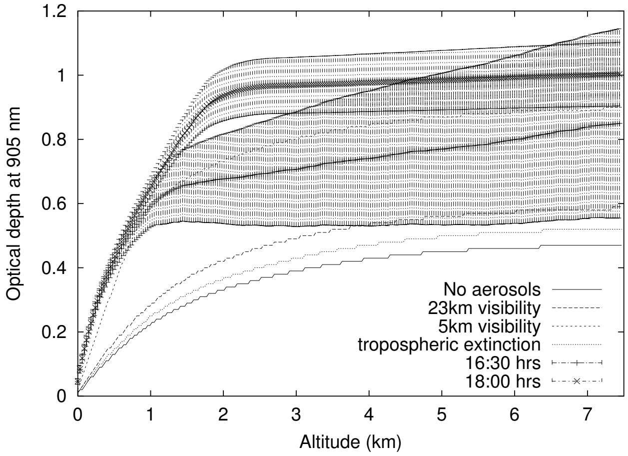

Fig. 1. Optical depth generated by the ceilometer backscatter data (the 2 graphs with large error bars) and calculated by MODTRAN for different visibilities

out light pulses at (905 ± 10)nm with a pulsed InGaAs diode laser. As the laser pulse traverses the sky, the resulting backscatter profile signal strength over height is stored and processed with a sampling interval of 100 ns, resulting in a spatial resolution of 30m.

The general description of the instantaneous return signal strength is given as the LIDAR equation

$$P_r(z) = E_0 \frac{c}{2} \frac{A}{z^2} \beta(z) e^{-2\tau(z)} \tag{1}$$

where $P_r(z)$ is the instantaneous power received from distance z, E_0 the effective pulse energy in Joules (taking all optical attenuation into account, measured by internal monitoring), c the speed of light, A the receiver aperture (in m^{2}sr), $\beta(z)$ the volume backscatter coefficient at distance z (in m^{-1}sr^{-1}) and $\tau(z) = \int_0^z \alpha(z')dz'$ the optical depth (OD) at z produced by an attenuation coefficient $\alpha(z)$, the factor 2 accounting for the travel out and back.

2.1. The Backscatter Coefficient

The volume backscatter coefficient $\beta(z)$ is a result of combined molecular (Rayleigh) and aerosol (Mie) scattering. Although the attenuation $\alpha(z)$ is unknown, it can be assumed to correlate the backscatter with the attenuation via the Lidar Ratio k: $\beta(z) = k\alpha(z)$ [3]. The Lidar Ratio can take values between 0.02 in high humidities to 0.05 in low humidities, but is mostly assumed to be 0.03 [2]. Figure 1 shows OD profiles which have been generated from the backscatter data by summing the backscatter values over the sampled time-bins like $\tau(z) = \sum_z \frac{\beta(z)}{k}$. Also plotted are model OD profiles generated by MODTRAN

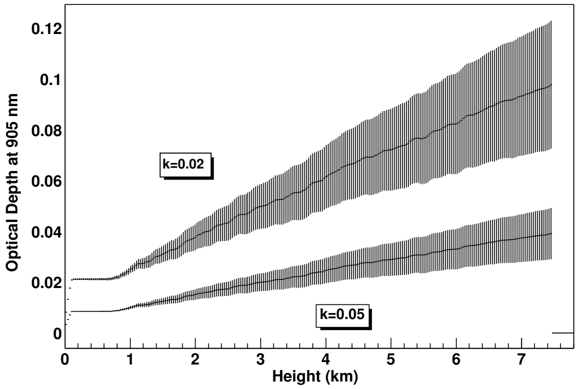

Fig. 2. Optical densities created from ceilometer backscatter data on a very clear night for 2 different values of the lidar ratio

4 [4] for a default tropical atmosphere with differing aerosol profiles ranging from a minimal OD for no aerosols included (solid line) to a rural profile with 5 km visibility (dashed line inside the errors of the lower ceilometer profile).

Fig. 2 Shows preliminary OD profiles generated from backscatter data taken under clear sky conditions for 2 different values of the lidar ratio k (0.05 and 0.02 respectively). These curves lie beneath the minimum curve for the OD resulting only from Rayleigh scattering and molecular absorption of Fig. 1 (no aerosols). This is because the ceilometer's internal algorithm's primary purpose is to identify significant backscatter from cloud layers. Distances between 100 and 900 m from the receiver have the optimum signal to noise for determining this and when no significant scatter is detected the machine automatically sets scatter to zero in this region. This drawback can be compensated for with the modelling done with the MODTRAN package, this is ongoing work and results are expected to be shown on the conference poster accompanying this paper. Once out of the optimum signal to noise range the algorithm once again starts to give non-zero, albeit noisy, values. Starlight extinction measurements and the observation of a calibrated light source on a distant hill will help resolve uncertainties in the backscatter coefficient.

3. Monte Carlo Simulations

Radio sonde measurements at Windhoek show that the annual mean atmospheric pressure profile is close to the MODTRAN 'tropical' model. Monte Carlo simulations using the MOCCA shower code and an adaptation of the CAMERA-HESS ACT simulation code show that the seasonal variation from this model have a significantly smaller effect on the ACT response than likely variations in the

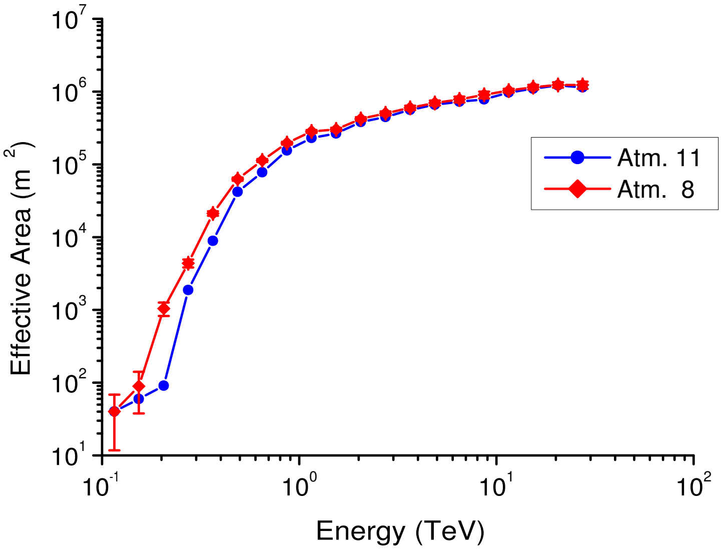

Fig. 3. The effective area of a single H.E.S.S. ACT for triggering by gamma-rays incident at 50° zenith angle for two characteristic aerosol profiles.

atmospheric attenuation. The current standard atmospheric attenuation model for Monte Carlo simulations of H.E.S.S. ACT response is a maritime haze aerosol model from 0 to 2 km above sea level, a tropospheric spring-summer model for 2 to 10 km and a layer of default stratospheric dust. This is referred to as Atm.8 in figure 3. The zenith angle is typical of that for observations of the Crab nebula. The site, being at an altitude of 1.8 km, is above most of the model's maritime haze as was the the HEGRA site on the island of La Palma, for which the model was chosen. As H.E.S.S. is on a plateau more than 100 km from the sea this model could be regarded as being among the lower of the levels of attenuation likely to be encountered. A straightforward variant of this model is Atm.11 which puts the base of the 2 km of maritime haze at 1.8 km. Both have the 'tropical' structure. The reduction in effective area for triggering is shown in figure 3.

4. References

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