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Atmospheric Monitoring at the High Resolution Fly's Eye

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We summarize the atmospheric monitoring program at the High Resolution Fly's Eye. A data base of hourly atmospheric aerosol measurements has been constructed from analyses of patterns of inclined laser tracks observed by the same detectors that measure light from air-showers. A data base of air density profiles has been derived from daily radiosonde measurements. We also describe a number of cross-checks that have been developed and applied to test the atmospheric measurements.

1. Introduction

The High Resolution Fly's Eye observatory (HiRes), located at Dugway Utah, USA measures light produced by high energy air-showers [1] [2]. The technique is calorimetric; the integrated scintillation light produced by an extensive air-shower being nearly proportional to the primary particle energy. However, once this light is produced, the amount that reaches the observatory depends on how this light propagates from the shower through the atmosphere to the detector. The benefit of the atmosphere that makes the air fluorescence technique possible is balanced by the challenge to determine and measure its properties relevant to the reconstruction of air-showers. Addressing this challenge begins with fundamental details of the HiRes design. HiRes is located in a remote desert basin where the average aerosol content, humidity, and cloud cover are relatively low. To be above low-lying aerosols, both HiRes detector stations were built on hills 100 m above the desert floor.

2. The Atmosphere

For this work, we divide the atmosphere into two main components: molecular (M) and aerosol (A). The former is characterized by molecular scattering [3] and air density profiles derived from twice daily Salt Lake City airport (SLC) radiosonde measurements [4]. It is instructive to compare the components in term of their vertical optical depths, denoted τ_M and τ_A. From the 1.5 km elevation of HiRes (850 g/cm^2) and passing through the entire atmosphere, the average τ_M is 0.50 at 355 nm (near the middle of the fluorescence spectrum). When the lower 10 km of the atmosphere above HiRes are considered, the value is 0.37 and for the lower 3.6 km the value is 0.17. Seasonal fluctuations are of order 0.005. For comparison, an analyses of vertical laser shots (described elsewhere [5]) measured an average τ_A between the ground and a 3.5 km height of 0.04. This analysis also found that most of the aerosol at HiRes lies less than 2 km above the detectors.

A cross-check based on 1258 selected stereo air-showers collected over a 4 year span, used shower segments viewed in common by both HiRes detector stations to obtain an independent time-averaged measurement of τ_A [6] (figure 1). This technique is largely insensitive to detector photometric calibration, both relative and absolute. The resulting average was consistent with the average obtained using vertical laser shots.

3. The Hourly Aerosol Database

Because atmospheric aerosol can vary significantly on a timescale considerably shorter than a day, hourly measurements are required to reconstruct air-showers and to determine the detector aperture. [7] [8]. An

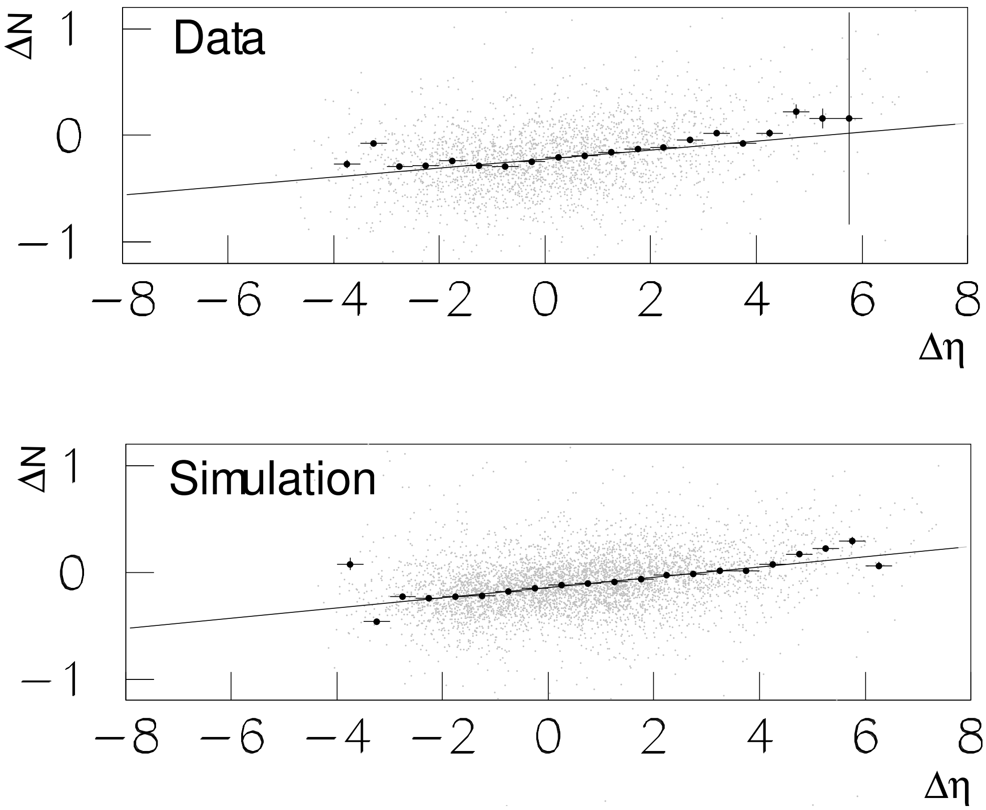

Figure 1. Measurement of average vertical aerosol optical depth (τ_A) using air-showers viewed in stereo. Δ_N (light balance) versus Δ_η (aerosol optical path asymmetry) is shown for real air-showers (top panel) and simulated data (bottom panel). The real data were collected over four years. Each point represents a shower segment viewed in common by both HiRes detector stations. A shower may have several segments. The slope of a line fit to Δ_N vs Δ_η is the average τ_A. Results for the data yield τ_A of $(0.042 \pm 0.006(stat) \pm 0.014(sys)$. The slope for the simulated data is 0.0479 ± 0.002. The simulated set shown was generated with an input τ_A of 0.040 distributed with a 1.2 km scale height.

hourly aerosol data base is derived from HiRes detector measurements of sweeps of inclined laser shots fired each hour by a pair of steerable UV lasers [9]. One laser is located at the HiRes2 detector station and viewed by the HiRes1 detector. In a symmetric arrangement, the second laser is located at HiRes1 and viewed by HiRes2. Changes in atmospheric aerosols change the profile of light reaching the detector. Modeling the detector, the laser, and the atmosphere generates a simulated set of detector measurements. The simulation includes the nightly detector calibration constants and the daily air density profile derived from SLC radiosonde data. The simulated data are fit to the detector measurements of the laser tracks using a simple two parameter aerosol model. The two parameters are aerosol horizontal extinction length (HAL) and scale height (SH). (In this model, τ_A=SH/HAL). Using HAL and SH it is possible to calculate an aerosol transmission factor as a function of elevation angle and distance which is then applied to air-shower reconstruction. An example of aerosol transmission values are shown in figure 2. The assumption of horizontal aerosol uniformity in this model is supported by the correlation between measurements from different laser pointing directions.

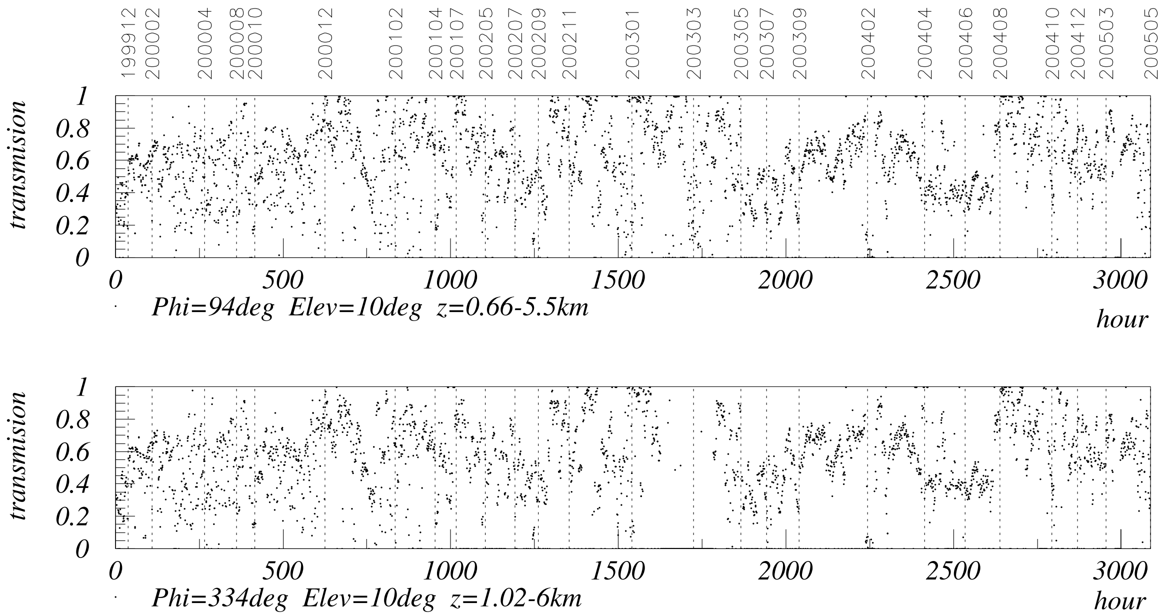

Figure 2. 5+ years of aerosol data from the HiRes hourly atmospheric database. The vertical axis is the transmission through the aerosol component as viewed at an elevation angle of 10 degrees and a distance of 30 km. Data in the top panel was obtained from analysis of laser shots fired from the HiRes 2 UV laser in a direction 60 degrees to the north of the HiRes 1 detector station. Data in the bottom panel corresponds to shots fired 60 degrees to the south. The entire data base includes measurements from 10 different laser pointing directions for each of the two steerable lasers.

4. Tests with a Distant Laser

To test the HiRes photometric resolution, including atmospheric effects, over a distance typical of the highest energy air-showers observed, a vertical 355nm laser was installed 34 km from the HiRes2 detector station. Four times each hour 20 shots are fired at each of five energy settings. At its maximum setting, the amount of light scattered out the laser beam is roughly equivalent to the amount of scintillation light produced by a shower of $5x10^{19}$ eV. This test compares two independent measurements of the laser energy. A calibrated "pick-off" probe at the laser makes one energy measurement. The second energy measurement uses a reconstruction of the laser track recorded by the HiRes2 detector station. Aerosol corrections are applied from the hourly database in this reconstruction. Analysis of 6 months of laser data (figure 3) collected under viewing conditions that ranged from near-molecular to relatively poor (τ_A=0.15), found the RMS of the fractional energy difference to be 18%.

5. Acknowledgments

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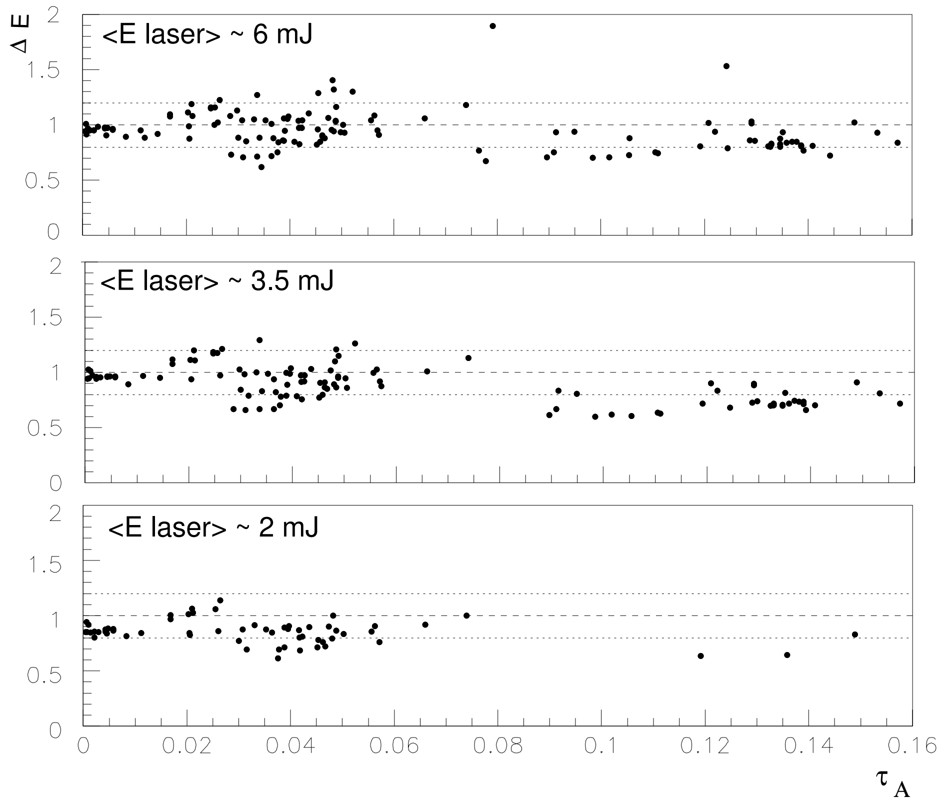

Figure 3. 6 months of measurements by the HiRes2 detector of a vertical laser 34 km distant. The vertical axes (ΔE) is the laser energy as reconstructed by the HiRes2 detector normalized to the the laser energy as measured by the laser energy probe. This analysis includes atmospheric corrections from the hourly aerosol data base. The three panels correspond to three laser energy settings. Data is shown as a function of vertical aerosol optical depth (τ_A). Each point represents an average of 20 laser shots.

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