Proceedings of ICRC 2001: 635 © Copernicus Gesellschaft 2001

ICRC 2001

Atmospheric monitoring at HiRes - The atmosphere at Dugway

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Abstract. This paper reviews measurements from the atmospheric monitoring program at HiRes collected over the past several years. The detector aperture has been probed locally and over distances approaching 40km using steerable lasers and Xenon Flashers. Distributions of aerosol parameters measured over this time will are presented. Their effects on shower reconstruction will also be discussed.

1 Introduction

The atmospheric monitoring program is a crucial part of the High Resolution Fly's Eye project. The optical air shower measurement technique is calorimetric. The atmosphere is the calorimeter. Aerosols can change its optical properties with location and with time.

Aerosols attenuate the amount of air shower scintillation light reaching the observatory. This attenuation factor is generally larger for more distant showers. Since the flux of air showers decreases rapidly with the energy of the primary particle, higher energy showers are generally farther from the detector than are lower energy showers. This leads to an atmospheric aerosol correction factor that correlates with shower energy and has the potential to cause apparent structure in a measured energy spectrum unless treated properly. In addition, aerosols can also increase the measured light from a shower by scattering Chrenkov light out of the shower axis. Aerosols also affect the size of the detector aperture, although showers with energies in the vicinity of the GZK cutoff produce signals in the detector that are well above threshold, even at distances of 30km.

The optimal choice for handling aerosols would be to do the experiment in a place where there are none. This search may lead future experiments to space or to high mountain tops. However, a region of atmosphere having sufficient material to allow shower development will also have aerosols, at least some of the time. HiRes was intentionally located desert where the air is relatively dry and clear. One some nights this clarity approaches aerosol-free molecular viewing conditions. The detectors were also located on hills to be above ground level dust and fog.

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2 Strategy of "the Good, the Bad, and the Ugly"

Having built the experiment in a relatively clear location, the next step was to devise a means to classify different observation periods according to the amount of aerosols present. The scheme adopted by HiRes is to divide the observation periods in to hours and classify these as "Good", "Bad" or "Ugly".

"Good" means that conditions are molecular, or nearly so. Showers recorded during "good" viewing conditions will require minimal corrections aerosol scattering.

"Bad" conditions are those with a distribution of aerosols for which an accurate correction can not be made. This includes clouds since they are typically variable and highly non-uniform. It also includes especially hazy nights with relatively large optical depths. Data collected during "bad" periods will not be used for most physics analysis, especially energy spectrum measurements.

"Ugly" conditions fall between "good" and "bad". The data is used, but a correction for aerosols must be applied. Determining these corrections lies at the heart of the air fluorescence technique.

3 A Signature of Aerosols

HiRes measures scattered light from pulsed beams produced by steerable lasers (Roberts et al. 2001a, Wiencke et al. 1999b,2001a) and by fixed geometry Xenon "flashers" (Wiencke et al. 1999a). These devices fire throughout the sky while the experiment is operating. The scattered light is recorded by the same detectors that record light from air showers. The amount of light reaching the detector is a

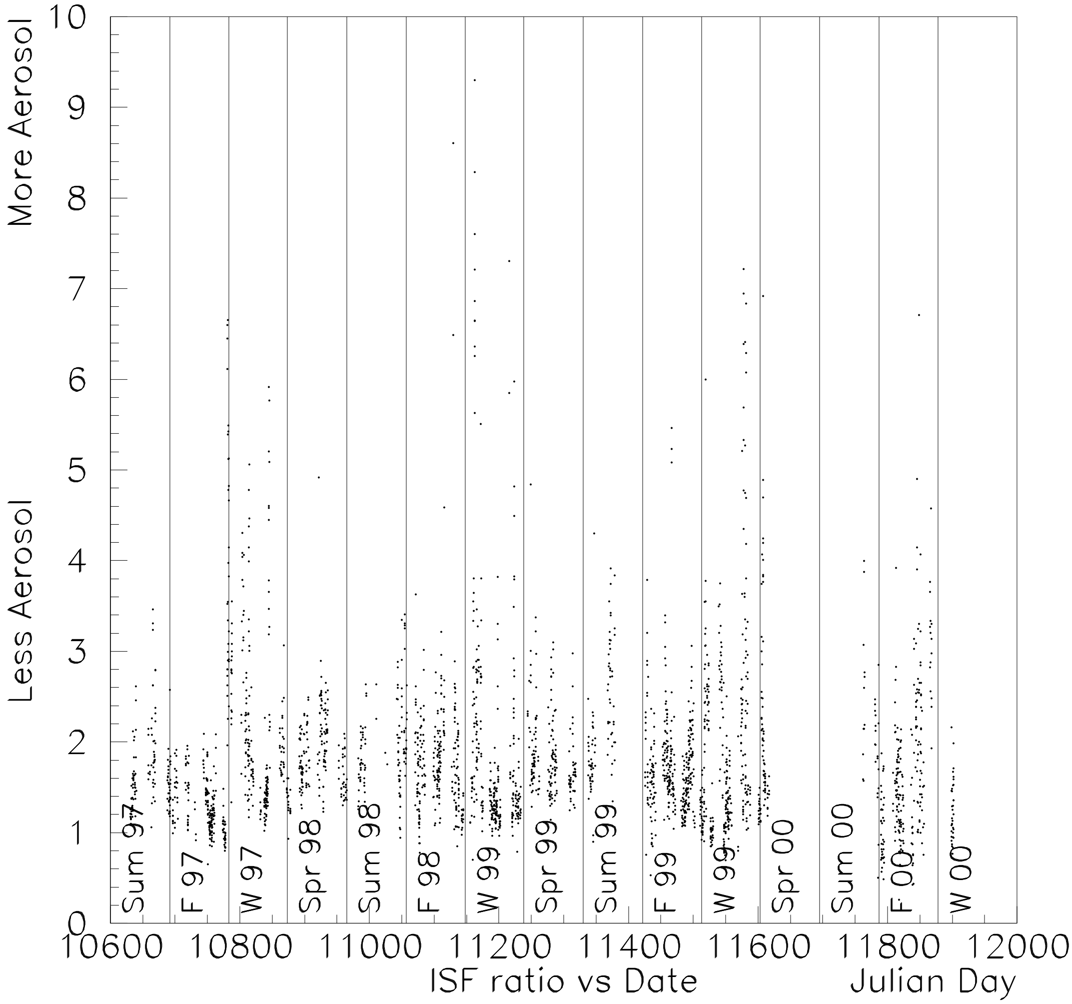

Fig. 1. This figure shows a qualitative ratio that is sensitive to local aerosols. The ratio is derived from measurements of the HiRes-1 detector of light scattered from a beam produced by a Xenon Flasher (see text).

function of the transmission from the source to the scattering point, the scattering, and the transmission to the detector. Aerosols affect each part of this three stage process and consequently affect the amount of light reaching the detector. Generally the data from flashers provides a qualitative test for the presence of aerosols and the data from lasers provides both a qualitative and quantitati mmeasurement (Roberts et al. 2001b).

It is well known, and has been verified by analysis of HiRes laser data (Roberts et al. 2001b) that the aerosol scattering cross-section is an asymmetric function of scattering angle. An increase in small angle scattering (less than 40 degrees) is a classic signature of aerosols. At larger angles the aerosol scattering cross-section reaches a minimum in the vicinity of 100 degrees becoming significantly smaller than the Rayleigh cross-section. One of the HiRes flashers, dubbed the ISF, provides this signature in the profile of scattered light recorded by HiRes-1. Figure 1 shows the ratio of light measured at 40 degree scattering to light measured at 110 degrees as a function of day for a three year period. This period extends to summer 1997 when monocular observations were started with the HiRes-1 detector. A larger ISF ratio indicates more forward scattering which indicates more aerosols. A smaller ratio indicatess fewer aerosols. Although this measurement is local, extending a few km horizontally and less than a km vertically, it demonstrates that aerosols follow seasonal variations. The extreme values, both the clearest and the poorest viewing occurs in the winter. Local ground fog at the flasher location may account for some of the apparently large values. On average, Fall tends to be the clearest season and summer the poorest. Haze from range and forest fires probably contribute to the poorer view-

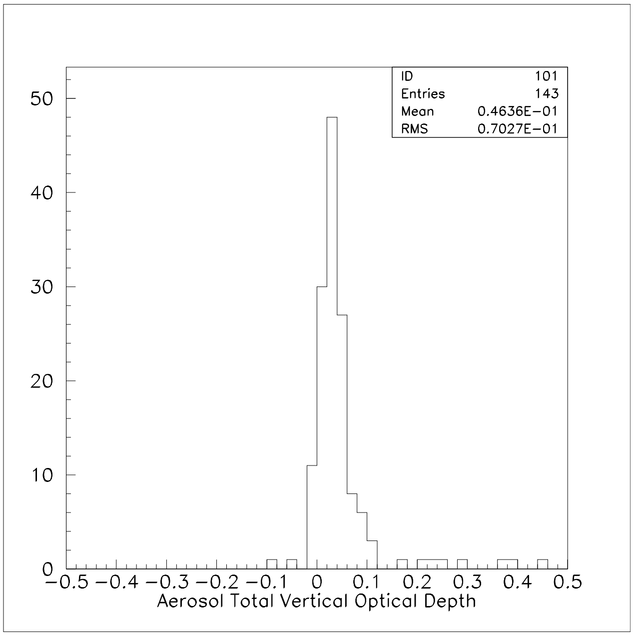

Fig. 2. Aerosol Vertical Optical Depth measured using vertical laser shots observed at the HiRes-1 detector 12.6 km distant.

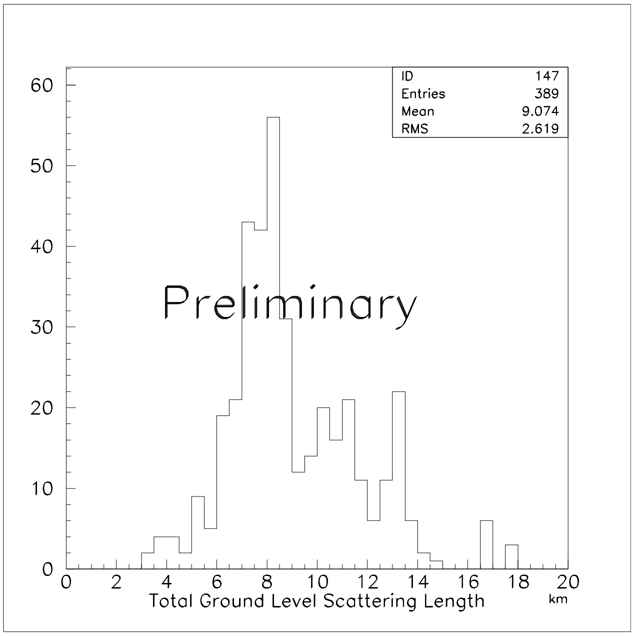

Fig. 3. Total Scattering Length at Ground Level determined using horizontal laser shots fired across either side of the HiRes-1 detector

ing conditions in summer.

4 Measuring Aerosols

The stereo laser data extends to spring 1999 when HiRes began stereo observations. We have analyzed more than one year of laser data from the system located at HiRes-2 and viewed by HiRes-1. Analysis of data from the second laser system is in progress.

A variety of quantitative aerosol measurements have been extracted from laser data. The total vertical aerosol optical depth (AOD) is extracted from vertical laser shots. For light produced by an air shower (or scattered out of a laser beam) at a height above the aerosol distribution the AOD provides a direct measure of the aerosol transmission correction (T) back to the detector. T=e(-OD/sin(a)) where a is the elevation angle of the detector element. Although extracting AOD is simple conceptually, it requires an absolute calibration of the laser and the HiRes detector. A distribution of AOD measurements over a one year period is shown in figure 2. The mean value for AOD is about half that of the the equivalent value used in the preliminary analysis of the monocular spectrum (Jui et al. 1999a). Measurements of AOD extracted from inclined laser shots fired throughout the detector aperture correlate with the AOD measurements obtained from vertical laser shots.

Horizontal laser shots fired across either side of the HiRes-1 detector have been used to obtain a measurement of the atmospheric scattering length at ground level (Fig. 3). Like the measurement of optical depth, this measurement is consistent with an atmosphere that is clearer than that the parameterization described by the by a standard desert aerosol model.

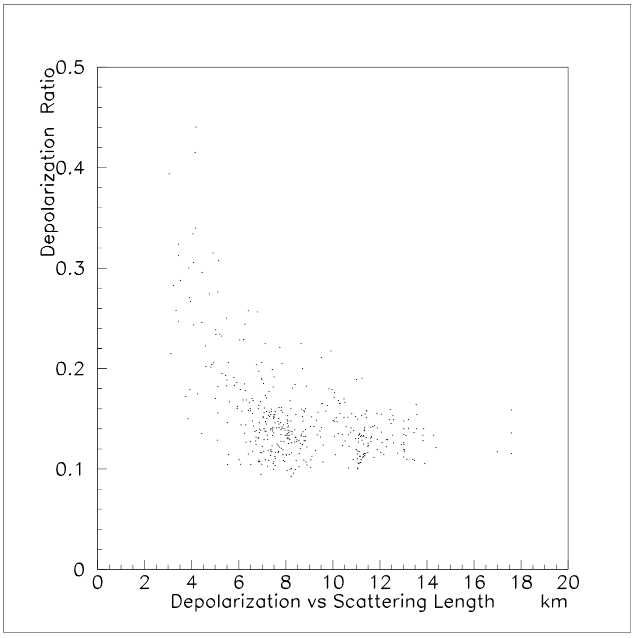

Fig. 4. Measurements made with horizontal laser shots. The horizontal axis corresponds to the total ground level scattering length. The vertical axis to the depolarization the laser beam as determined from the ratio of horizontally to vertically polarized laser shots measured at 90 degree scattering. (see text)

This measurement used a circularly polarized laser beam and depends on the detector and laser calibration. One demonstration the technique is sensible may be obtained by comparison to linearly polarized laser shots fired at the same geometry. Shortly after each set of horizontal circularly polarized shots, the laser fired shots of linear polarizations, one perpendicular and the other parallel to the scattering plane. The ratio of light scattered from these beams indicates beam depolarization which in turn is sensitive to aerosols. One would therefor expect an increase in aerosols will cause a simultaneous decrease in scattering length and increase in beam depolarization. Figure 4 shows that such a correlation is observed.

5 Conclusion

Methods to measure vertical optical aerosol depth and the ground level scattering length have been developed using lasers and the HiRes detectors. Using these techniques it has been found that the average atmosphere at Dugway Utah is clearer than that described by the standard desert aerosol model used the preliminary monocular HiRes analysis. Work is in progress to determine the vertical distribution of aerosols. A data base of atmospheric measurements is being generated to classify observation times and provide atmospheric correction factors for air shower reconstruction. We are in the process of including these measurements in the selection of event candidates and in their analysis of the air shower spectrum measured by HiRes-1.

Acknowledgements. This work is supported y US NSF grants PHY 9322298, PHY 9974537, PHY 9904048, PHY 0071069 and by the DOE grant FG03-92ER40732 and by the Australian Research Council. We gratefully acknowledge the contributions from the technical staffs of our home instiutions. The cooperation of Colonel Fisher, US Army and Dugway Proving Ground staff is appreciated.

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