Atmospheric Monitoring at the High Resolution Fly's Eye: Atmospheric Scattering

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ATMOSPHERIC MONITORING AT THE HIGH RESOLUTION FLY'S EYE: ATMOSPHERIC SCATTERING

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ABSTRACT

The scattering of ultra-violet light by atmospheric molecules and aerosols is an important constraint on the operation and interpretation of the High Resolution Fly's Eye experiment. A two year study has been carried out into the variability of the aerosol content at the High Resolution Fly's Eye site, using a collimated ultra-violet flasher and the High Resolution Fly's Eye detector. Results from this study will be discussed.

INTRODUCTION

Atmospheric fluorescence cosmic ray detectors, such as the High Resolution (HiRes) Fly's Eye detector (Bird et al 1995a), detect UV signals in the 300-400 nm range from cosmic ray initiated showers. Variations in the molecular and aerosol profiles of the atmosphere will alter the extinction length of the atmosphere in this wavelength range, affecting the aperture of the detector. More subtle atmospheric effects can affect the shower profile measured, in turn affecting shower energy and depth of maximum measurements, both crucial in reconstructing cosmic ray showers and the properties of the primary particle.

A number of methods to monitor the atmosphere have been developed in conjunction with the Fly's Eye and HiRes detectors. The most common involves Xenon flashers emitting vertical collimated beams of light which are observed by the detector. These vertical flashers provide some useful atmospheric information, but more information can be gleaned from a flasher inclined at an angle to the detector aperture.

Such an inclined flasher has been in operation for the past two years at the HiRes site at Dugway, Utah. Preliminary results were presented (Bird et al. 1995b) at the last conference, based on several months of data. The data set now spans two years of observations.

THE INTERSITE FLASHER

This inclined flasher is known as the InterSite Flasher (ISF) as its orientation allows it to be viewed by both HiRes prototype detectors simultaneously, providing useful information about stereo data reconstruction (see e.g. Bird et al. 1995c). It is inclined at an elevation angle of 21 degrees. The flasher consists of a Xenon flash tube positioned at the focal point of an 200 mm diameter spherical mirror. The flasher is housed in a 1.2 m long tube. This arrangement produces a collimated beam of light. The flasher is fired at approximately 1 Hz, five times every eight minutes throughout the night.

This flasher is viewed by the HiRes1 detector at emission angles ranging from 30 to 65 degrees. The emission angle is defined as the angle between the trajectory of the light beam and the trajectory of the scattered light. A small emission angle corresponds to looking head-on at the approaching light and at such angles, scattering from aerosol particles is the dominant scattering process (Mie scattering), while at larger emission angles (closer to 90 degrees), scattering from atmospheric molecules is the dominant scattering process (Rayleigh scattering), the latter being dependent only on local air density. The effect of absorption of light in the region of interest (300nm-400nm) is at least a couple of orders of magnitude less than that of scattering and is considered negligible.

This HiRes flasher trajectory is therefore sensitive to the concentration of aerosols in the atmosphere and can be used to determine atmospheric extinction lengths on a regular basis.

Figure 1 shows two HiRes1 prototype ISF events under different atmospheric conditions. The angular length of the track detected by the HiRes prototype detector, projected onto the sky, is approximately 40 degrees.

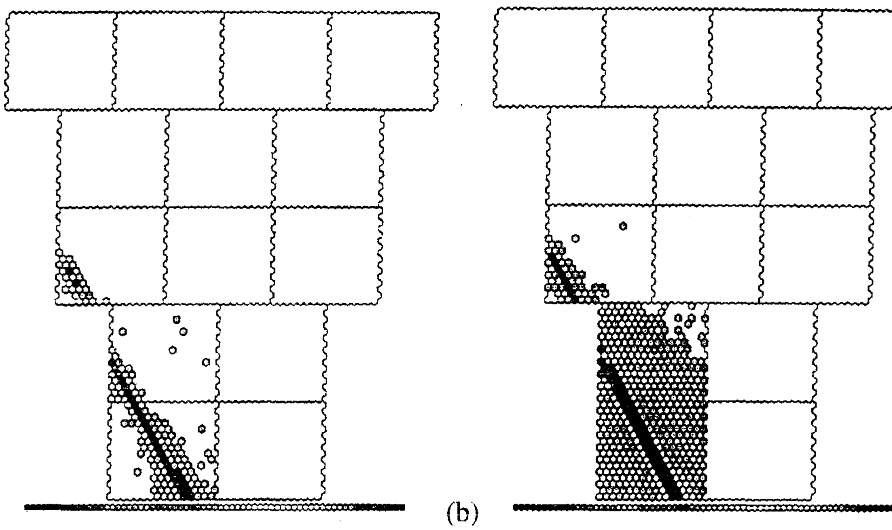

Fig. 1. The InterSite Flasher as viewed by the HiRes1 prototype detector. (a) a clear night with minimal scattering. (b) a hazy night with appreciable scattering. The 14 squares represent the fields of view of the 14 prototype mirrors on the sky.

AN ATMOSPHERIC MODEL

Rayleigh scattering is a well understood process and can be accounted for analytically. However, Mie scattering can only be approximated due to variations in the properties of the scattering aerosol particles (e.g. size and shape distributions, dielectric constants).

A computer model of the atmosphere developed by the USAF (MODTRAN, Kneizys et al. 1988) has been used to predict the atmospheric response to the ISF under different conditions. The standard US atmosphere (1976) model along with the standard desert aerosol model has been chosen for the region of interest (altitudes to 4 km).

MODTRAN differentiates between aerosol concentrations using a wind speed parameter. Fig. 2 shows the expected profiles from the ISF for different model wind speeds, and for a purely molecular atmosphere.

Note that along the first 5 degrees of the track, the emission angle of scattered light ranges from 30 to 34 degrees. This is very sensitive to the aerosol concentration, which has a strong forward scattering effect. There is almost no sensitivity to aerosol concentration along the last 5 degrees of the track, where the emission angles of the scattered light are 60 to 65 degrees. The molecular scattering varies by less than a factor of 50% over the total observed emission angle range.

To quantify observations, a measure known as the Quality Ratio (QR) is defined. This is the ratio of light detected in the first 5 degrees of the track to that in the last 5 degrees of the track. This measure is used to quantitatively grade the atmosphere during observations (see Figs 3, 4).

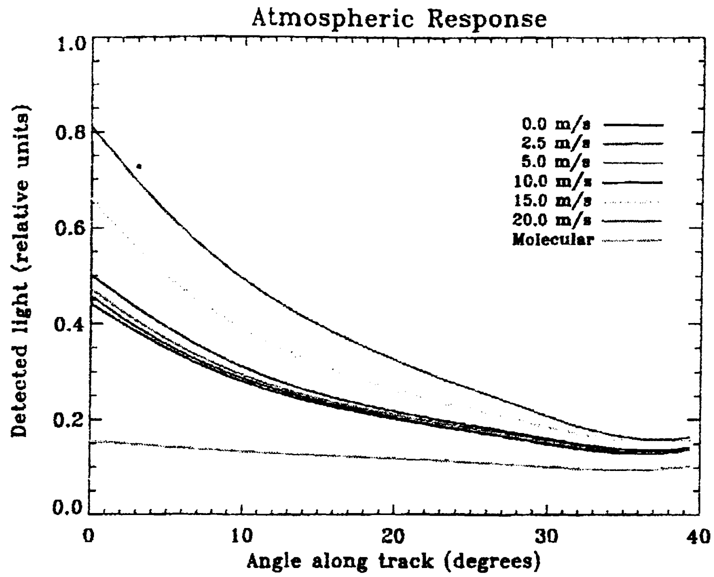

Fig. 2. Expected ISF profiles (detector response as a function of angle in the sky along the track) predicted by MODTRAN for different aerosol model wind speeds. Also plotted is the profile expected for a purely molecular atmosphere (no aerosol content).

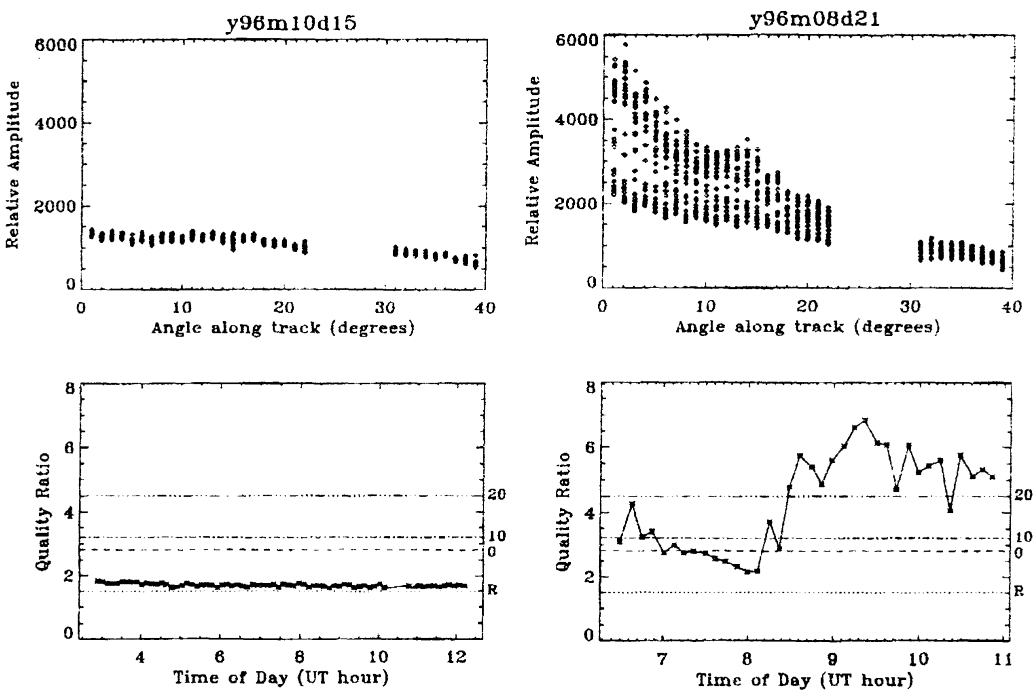

Fig. 3. Examples of two nights of atmospheric monitoring using the ISF. The top plot of each pair shows the superimposed profiles from many ISF shots during the night. The break is due to the ISF path passing outside the HiRes aperture (see Fig.1). The lower plot of each pair is the time history of the ISF response throughout the night (QR). The dashed lines are the QR predicted by MODTRAN for molecular scattering only (R), and three MODTRAN aerosol profiles, denoted by the model wind speed (0, 10, 20 m/s). See Fig. 2. for the predicted profiles. Fig. 3(a) is a stable

clear night, with virtually no aerosol present. Fig 3(b) is a less clear night, with instabilities. The atmosphere changes rapidly from mildly clear to significantly dirty in a period of less than 30 minutes. The bimodal state of the atmosphere on this night can be seen from the two types of profile evident in the upper plot. Note that the signal over the last 5 degrees of the track does not vary significantly during the night, providing an ideal self-calibrator.

RESULTS

Data have been collected through almost two full years of operation of the HiRes1 prototype detector, from December 1994 through November 1996. During this period, data were collected on 273 nights.

The majority of nights examined show a stability of the atmosphere over periods ranging from a night to two weeks (the length of an observing period). The quality of the atmosphere has been found to vary from a stable, near-molecular night to nights with time instability and significant extinction (see Figure 3).

A minority of nights show significant variation of atmospheric quality over periods as short as 20 minutes. These rapid changes in atmospheric quality, usually from extremely good to a rapid deterioration in quality can generally be associated with the passage of a weather front through the aperture. The data set does not demonstrate a large number of nights on which atmospheric quality is particularly poor. This is most likely an observational bias, as the detector will not be operated in such conditions as a general rule.

Figure 4 displays the time history of the QR for a dark period of HiRes observations. Conditions during this period ranged from stable and clear to unstable and hazy.

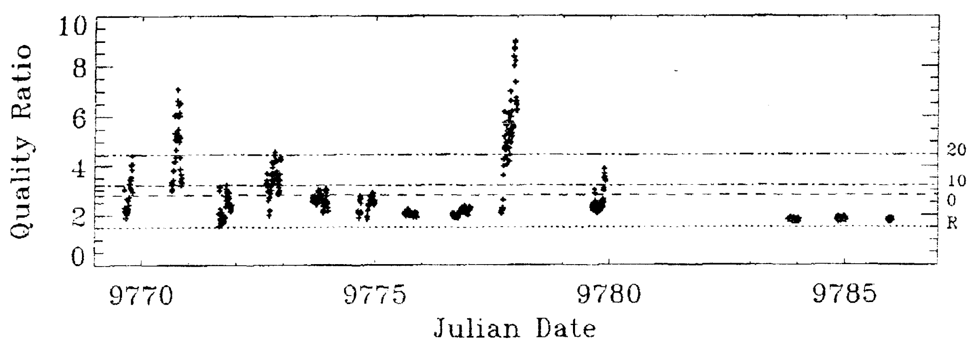

Fig. 4. Data from Feb/March 1995. During this dark period, the atmosphere was initially hazy and unstable. Towards the end of the period, it cleared and settled down. This demonstrates a typical winter pattern at Dugway. The atmosphere becomes stagnant as an inversion layer forms, trapping aerosols in the lower troposphere. The passage of a weather front and associated storms (indicated by 3 nights of non-data collection) cleans the atmosphere, leaving it clear and stable.

Further analysis is underway using a more detailed set of atmospheric models. Correlation of these data with meteorological data is also being carried out.

ACKNOWLEDGEMENTS

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REFERENCES

Bird, D.J., et al., *Proc. 24th ICRC.* 3, 504 (1995a).
Bird, D.J., et al., *Proc. 24th ICRC,* 3, 560 (1995b).
Bird, D.J., et al., *Proc. 24th ICRC,* 3, 548 (1995c).
Kneizys F.X., et al., *"Users Guide to Lowtran 7", Air Force Geophysics Laboratory,* AFGL-TR-88-0177 (1988).