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Air Fluorescence Detector Site Elevation Issues

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Abstract

Air fluorescence detectors view extensive air showers at 10s of kilometers from the fluorescence detector site(s). To minimize transmission losses/corrections these experiments are located in dry, desert locations and the detectors are placed on hill tops to be above fog and some of the atmospheric aerosols. However placement of the detectors on hill tops may significantly increase installation costs and/or result in unacceptable environmental (visual) impact. This note compares two fluorescence sites $\sim$ 150m and $\sim$ 300m above the local minimum in the terrain.

1 Introduction

Air fluorescence detectors view extensive air showers at 10s of kilometers from the fluorescence detector site(s). Thus the fluorescence measurements are influenced by scattering and absorption of light in the atmosphere between the air shower and the fluorescence detector(s). To minimize these effects, fluorescence experiments are located in dry desert areas with typically excellent visibility. Furthermore the fluorescence detectors are placed on hill tops to be above fog and some of the atmospheric aerosols. However placement of the detectors on hill tops may significantly increase installation costs and/or result in unacceptable environmental (visual) impact. Thus site elevation issues, that impact the performance of the fluorescence detectors, need to be understood.

It is instructive to review the site information of the Fly's Eye and High Resolution Fly's Eye (HiRes) experiments in Utah. Both Fly's Eye [1] and HiRes [2] experiments place the detectors at two sites to observe the air showers in *stereo*. The HiRes 1 and 2 sites are at elevations of 1597m and 1553m above sea level respectively. As the local minimum in the region is at an elevation of $\sim$ 1320m, these fluorescence sites are $\sim$ 277m and $\sim$ 233m above the *local low* region. In the older Fly's Eye experiment one of the sites, Fly's Eye I, is the same as HiRes 1. The second site, Fly's Eye II, was at an elevation of $\sim$ 1445m above sea level or $\sim$ 125m above the *local low* region.

The experience at the HiRes sites is that both HiRes 1 and 2 sites are almost always above fog. Fog does form in winter months, often late at night/early in the morning, but is typically just near the *local low* region. The HiRes sites are (usually) not above layers of *haze*. Haze can be present any time but is more prevalent in winter months or during periods of significant forest fires. The vertical distribution of *haze* is probably the same as attributed to aerosols; *i.e.* characterized by a *mixing layer* of approximately constant density above which the aerosol density decreases exponentially with a typical *scale height* of 1 $\sim$ 2km. In the winter *haze* is often related to temperature inversions and thus with a *mixing layer* (of one to several hundred meters height).

We include two studies in this note.

- The first uses data from a nearly horizontal, pulsed light beam (inter-site flasher) that originates at the Fly's Eye II site and passes near the HiRes 1 fluorescence detector. Light scattered out of this beam is viewed over a large range of light scattering angles. As Mie scattering on aerosols is typically much more forward peaked than Rayleigh scattering, a comparison of scattered light intensities for $\sim 45^\circ$ scattering to those for $\sim 120^\circ$ scattering is a sensitive monitor of aerosols [2] in the atmosphere. Approximately 2 years of data [2] provide a monitor of light conditions between FE II and HiRes 1 sites.

- The second study compares the expected light transmission factors [5] for two sites separated by 150m in elevation (*i.e.* similar to the $\sim$ 152m between the

Fly's Eye II and HiRes 1 sites).

2 Measurements and Analysis

2.1 HiRes Inter-site Flasher Data

The use of the HiRes inter-site flasher to monitor (local) aerosols is discussed in Ref. [2]. Briefly, Mie differential scattering cross section is large at small angles and has a minimum for angles $\sim 120°$. In contrast Rayleigh scattering has a $1 + cos^2(\theta)$ angular distribution, where θ is the angle of scattering with respect to the original light (beam) direction. Furthermore the Mie and Rayleigh total cross sections are comparable at 360nm (the middle of the HiRes acceptance) on *typical* viewing nights. Thus Mie scattering is comparable to or dominates Rayleigh scattering at $\theta \sim 45°$ and Rayleigh scattering dominates Mie scattering at $\theta \sim 120°$. Thus the ratio of $45°/120°$ light intensities provide a monitor sensitive to changing amounts of aerosols in the atmosphere.

The HiRes inter-site flasher is a pulsed, collimated light beam that originates at the Fly's Eye II site and crosses the field of view of the HiRes 1 fluorescence detector. Light scattered from the beam is monitored for scattering angles $40° < \theta < 170°$ [2]. The inter-site flasher fires several times each hour. Data cover the interval July 1997 to July 1999. A plot of the $45°/120°$ light intensity ratio data is shown in Fig. 1. This figure shows that most of the time the aerosols are rather stable (peak region) with the $45°/120°$ light ratio, $R \leq 4$. There is also a tail of poorer visibility nights with the intensity ration, $4 < R < 7$. Finally there is a small tail with $R > 7$. While these R-regions are somewhat arbitrary they follow the pattern of the data.

The number of observations in the three R-regions *versus* time of year are shown in Fig. 2a-c. Fig. 2a, which corresponds to periods of good visibility with the least aerosols, is rather flat with time. Fig. 2b, which corresponds to periods of intermediate visibility shows some localizations with enhanced occurrences in mid-summer and in the late fall and winter months. These are periods when the atmosphere appears somewhat hazy. Finally Fig. 2c, which corresponds to periods of significantly enhanced levels of aerosols, are almost exclusively in the months of November through February. A review of the HiRes log records for the full period of these data show operators' record of *fog* almost exclusively during the (same) months of November through February. Furthermore the logs show the most operator records of fog during December 1998. Log records for haze are much more frequent (55 occurrences to 16 for fog) and are more spread over all months of the year. The bad fog month of December 1998 was also a bad month for haze.

To explore whether the inter-site flasher data are monitoring haze or fog I have focused on three months: November 1997, December 1998 and February 1999 which show the largest number of observations with $7 < R$, see Fig 2c. To try to separate periods of haze *versus* periods of fog I have looked a the $45°/120°$ light ratio, R, as a function of time during the night. For this purpose the time was divided into 5 time intervals of duration: 3 hours, 3 hours, 1 hour, 3 hours and 3 hours. The 1 hour interval was at the middle of the night. The first time interval was just after sunset and the last time interval was just before sunrise. We expect a fog signature to be an increase in the number of $7 < R$ events late in the night. In winter months a lowering of the height of an inversion layer with time during the night might (also) cause a *fog*-like signature. In contrast haze is more likely early in the night (if wind produced) or to be rather uniform in time. The time records for November 1997, December 1998 and February 1999 are shown in Fig. 3a-c respectively. The number of observations with $7 < R$ increases with time in Fig. 3a consistent with a *fog*-like signature (for November 1997) [3]. The number of observations with $7 < R$ is approximately constant (or decreasing) with time in Fig. 3b,c consistent with a *haze* signature (for December 1998 and February 1999) [4].

If we assume that all of the observations with $7 < R$ are consistent with fog between the Fly's Eye II site and the HiRes 1 site, then the fraction of time that the Fly's Eye II site would be impacted is $916/59725 \approx 1.5\%$. In practice only one month, November 1997, or about half of observations with $7 < R$ have a *fog*-like signature. Thus these data suggest that $\sim 1\%$ of nights for a site ~ 150m above the local low area will be impacted by fog. If some of the observations with $4 < R < 7$ are also fog then the percentage of nights that a site ~ 150m above the local low area will be impacted by fog will increase. If we include all the observations during November through February with $4 < R$ this is $\sim 4100/59725 \approx 6.7\%$. Based on the $7 < R$ observations this is probably an overestimate by (at least) $\sim 50\%$. For example the month of December 1997 shows up as a large excess of $4 < R < 7$ observations, see Fig 4, however there is no obvious time structure to the distribution during the time of night. In summary the fraction of nights that a fluorescence site ~ 150m above the local low area is consistent with being on the order of a few percent (or possibly less).

2.2 Relative Transmission Corrections

In the comparison of performance of two fluorescence sites, one at an elevation ~ 150m above the local low area and one ~ 300m above the local low area, it is important to compare the light transmission factors that would apply for two sites observing an air shower at the same horizontal distance. If the ratio of the transmission factors is very different from one it would argue for placing the fluorescence detectors at the 150m higher elevation.

For this comparison we use a simple and fairly standard parameterization of the aerosol density:

1. the density (times cross section) of aerosols at the lower fluorescence site is set by a horizontal attenuation length, Λ^a. Values used in the study are 10km, 20km and 40km (at the elevation of the lower of the two fluorescence sites). For reference 20km is typical of the horizontal attenuation length at 355nm measured by the HiRes experiment.

2. the height of a (possible) mixing layer, h_m, where the aerosol density (times cross section) is taken to be constant. Values used in this study are 0m and 600m; these are elevations with respect to the lower of the two fluorescence sites. Typical values used in HiRes analyses are $0 \sim 100$m.

3. the scale height, h_a, for the exponential decrease of the aerosol density (times cross section) with elevation. Values used in this study are 600m, 1200m and 1800m. The typical value used in HiRes analyses is 1200m.

Light transmission factors, T, including both Rayleigh and Mie scattering, were evaluated as a function of the horizontal distance to a shower for two fluorescence viewing (elevation) angles: 3° and 10°. The elevation angle is defined for the higher fluorescence site. 3° corresponds to the fluorescence detector elevation angle, with respect to the horizontal, of the lowest phototubes; 10° corresponds to a typical elevation angle to view shower maximum for the highest energy showers. The ratio of the transmission factors: $T_{lower\ site}/T_{higher\ site}$ is shown as a function of the horizontal distance to a shower in Fig. 5 a and b for elevation angles 3° and 10° respectively. Except for the worst viewing conditions, with $\Lambda^a = 10$km, the transmission factor at the lower site is within 10% of that at the higher site. These values increase by $< 2\%$ when only the aerosol transmission factors are used in the ratio.

In summary the lower fluorescence site will have light transmission factors that are $\sim 10\%$ less than the 150m higher site. In desert areas with good visibility, *i.e.* $\Lambda^a \sim 20$km, there is thus little advantage in placing the detectors at the additional elevation.

3 Summary

A study comparing two fluorescence detector sites, separated in elevation by ~ 150m, suggests that the lower site will perform almost as well as the higher site. The caveat is that the lower site is well above, *e.g.* 150m above, the *local low* region in the area (to minimize occurrences of fog), and that the typical atmospheric visibility is good, *e.g.* the horizontal extinction length $\Lambda^a(355nm) \sim 20$km. Lower fluorescence sites, *e.g.* on ridges rather than hill tops, may provide sites with reduced development costs and/or with less environmental (visual impact) concerns.

Acknowledgements

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References

[1] R. M. Baltrusaitis, et al, Nucl. Instrum. Methods **A240**, 410 (1985)

[2] T. Z. AbuZayyad, *The Energy Spectrum of Ultra High Energy Cosmic Rays*, thesis, May 2000

[3] The operations log reports 2 fog entries and 1 haze entry for November 1997.

[4] The operations log reports 3 fog and 6 haze entries for December 1998 and 0 fog and 1 haze for February 1999.

[5] Roger Clay, et al, *Fluorescence Detector Optical Calibration and Atmospheric Monitoring for the Pierre Auger Experiment*, Pierre Auger Note 2000-033 (2000) http://www-hep.phys.unm.edu/~johnm/jpg_draft_v13.ps

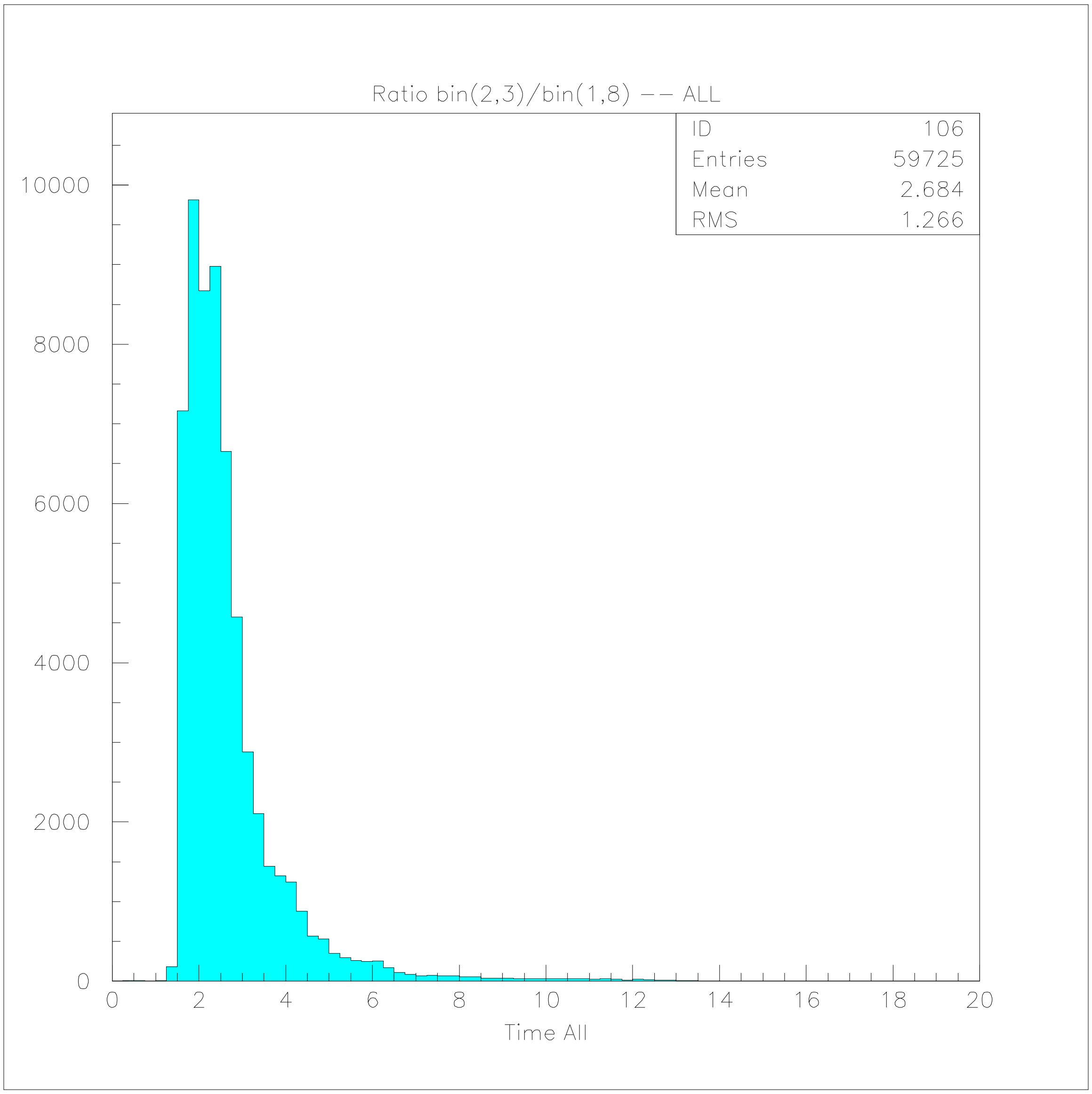

Fig. 1: A plot of the 45°/120° light intensity ratio, R, for July 1997 to July 1999.

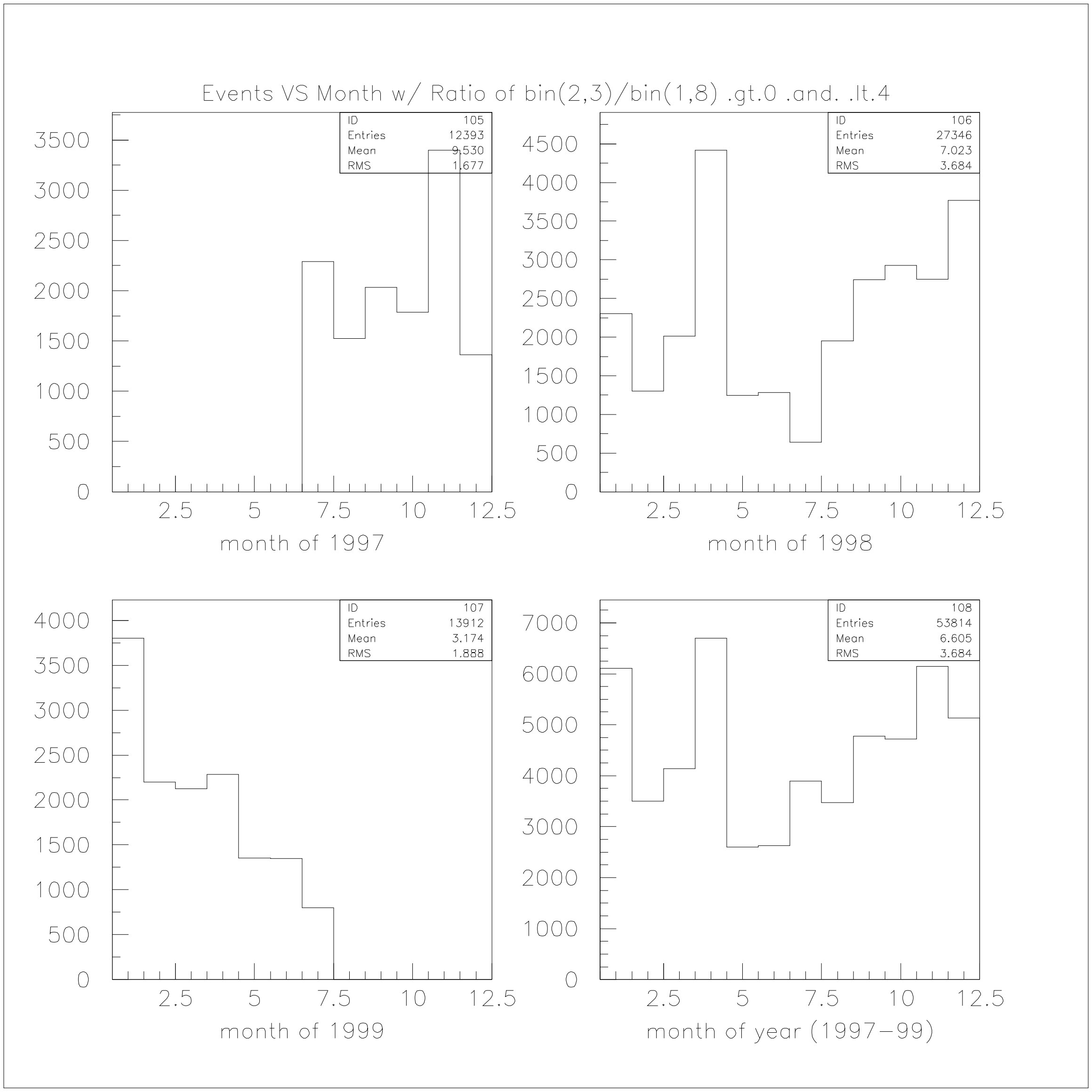

Fig. 2a: A plot of the number of measurements with the 45°/120° light intensity ratio $R < 4$ *versus* time of year.

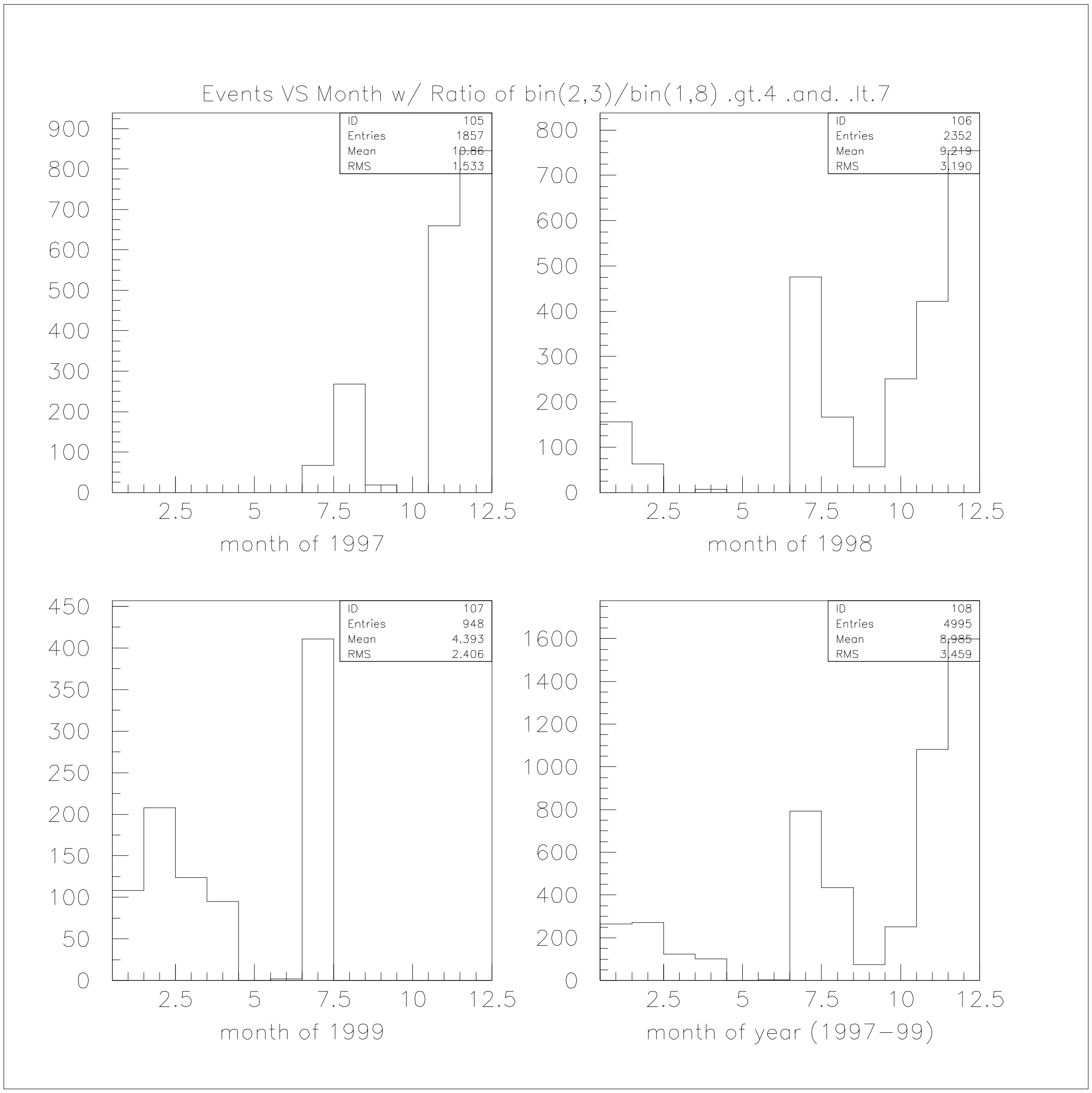

Fig. 2b: A plot of the number of measurements with the 45°/120° light intensity ratio $4 < R < 7$ *versus* time of year.

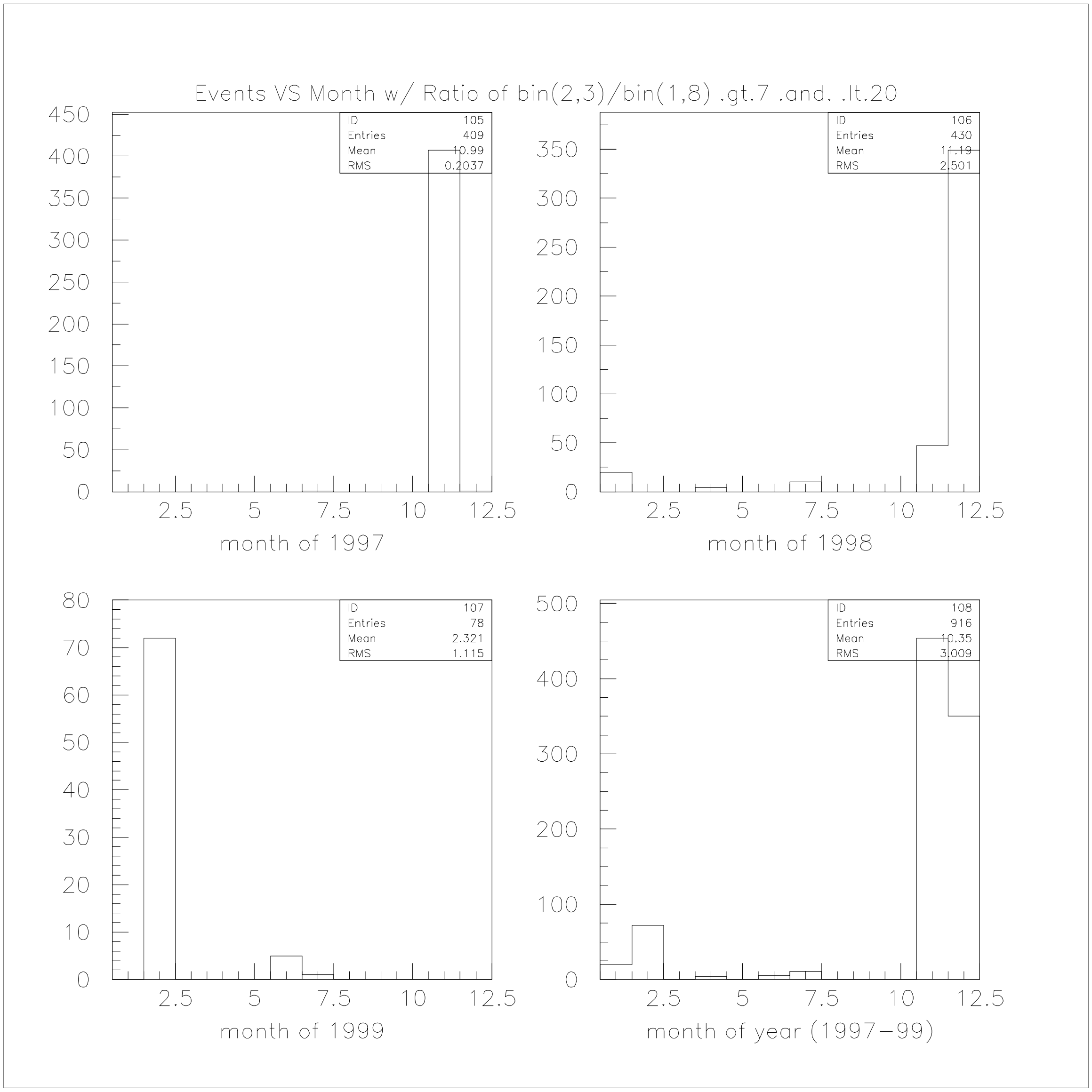

Fig. 2c: A plot of the number of measurements with the 45°/120° light intensity ratio $7 < R$ *versus* time of year.

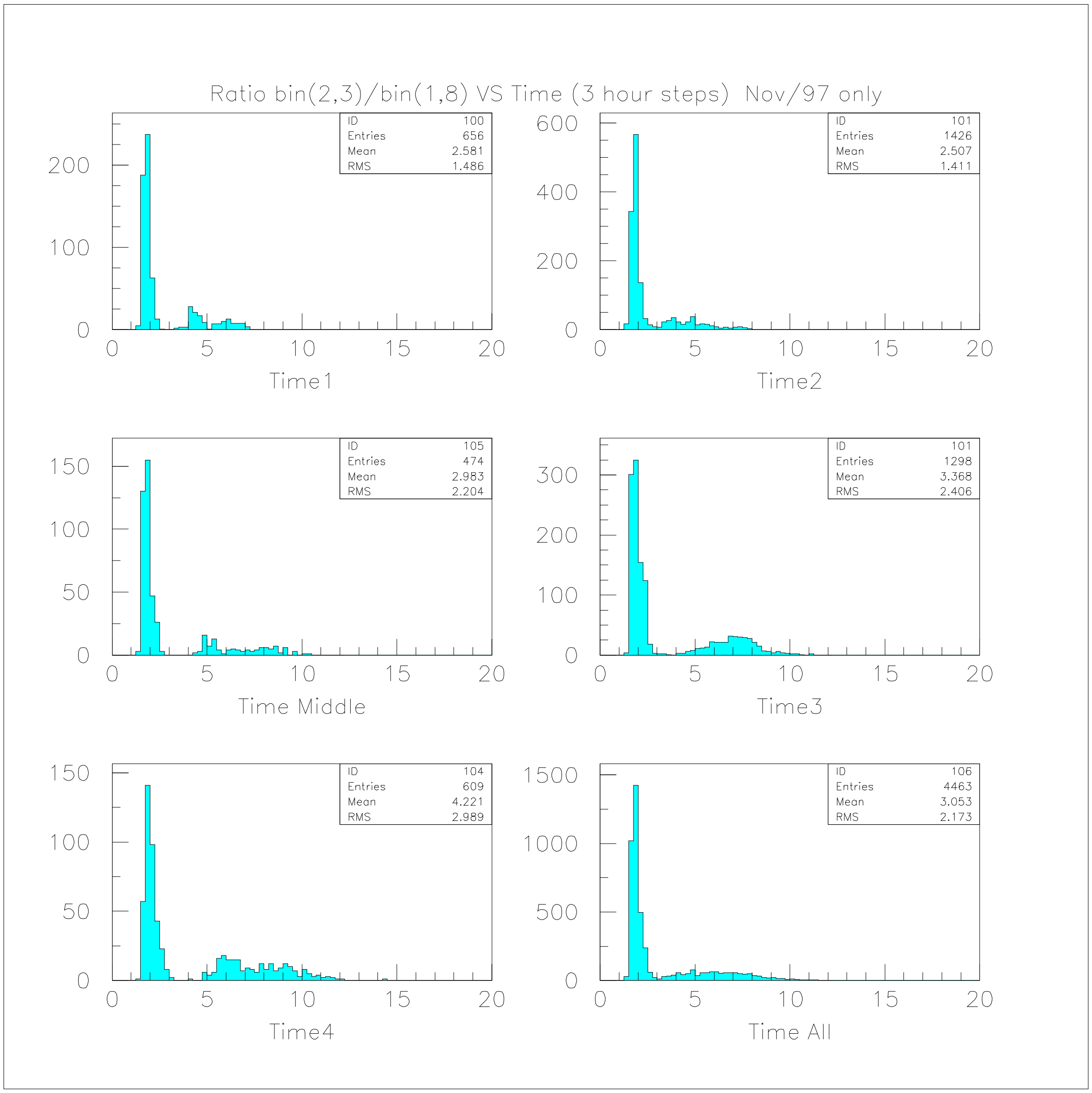

Fig. 3a: A plot of the 45°/120° light intensity ratio, R, in different time intervals each observing night in November 1997.

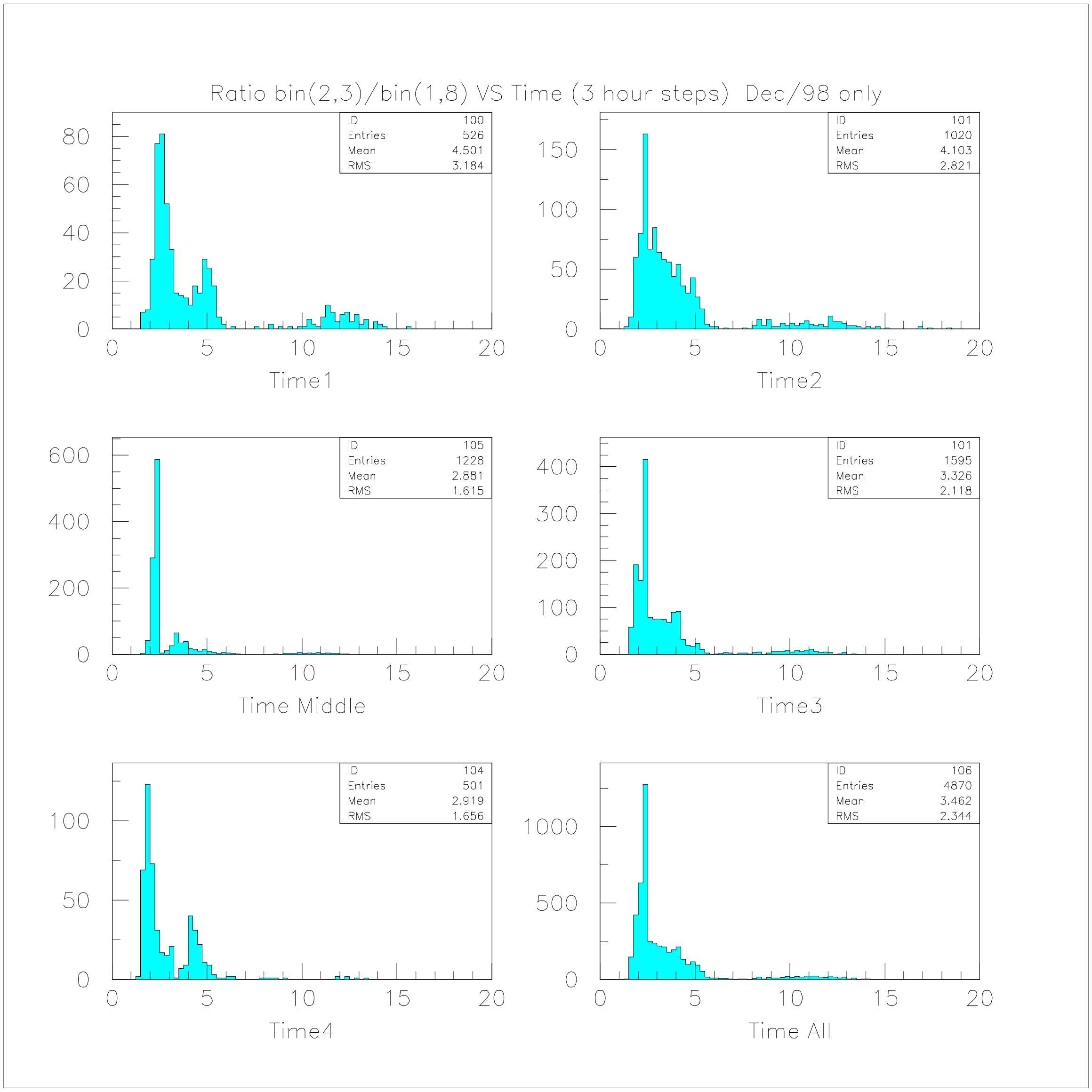

Fig. 3b: A plot of the 45°/120° light intensity ratio, R, in different time intervals each observing night in December 1998.

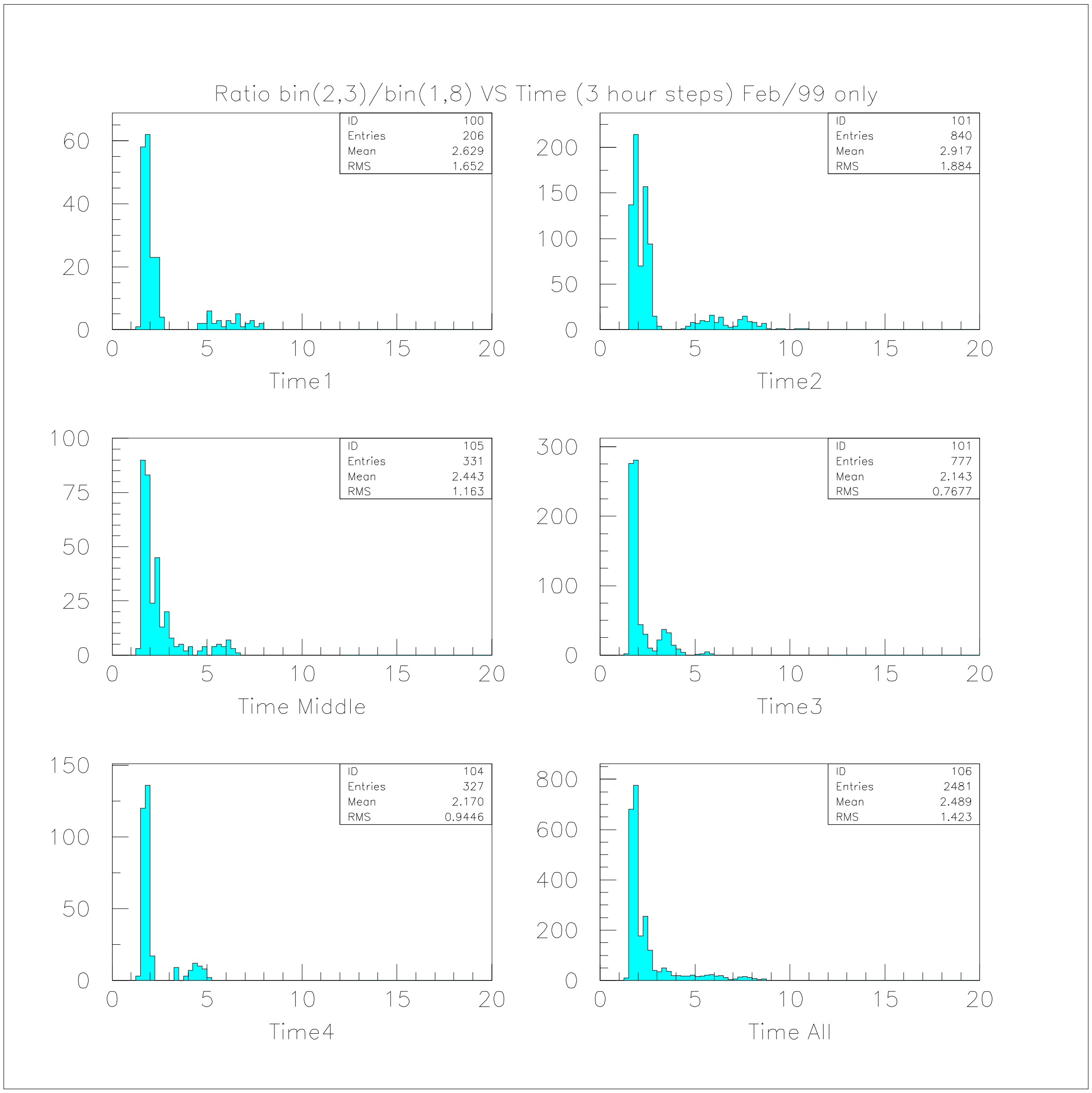

Fig. 3c: A plot of the 45°/120° light intensity ratio, R, in different time intervals each observing night in February 1999.

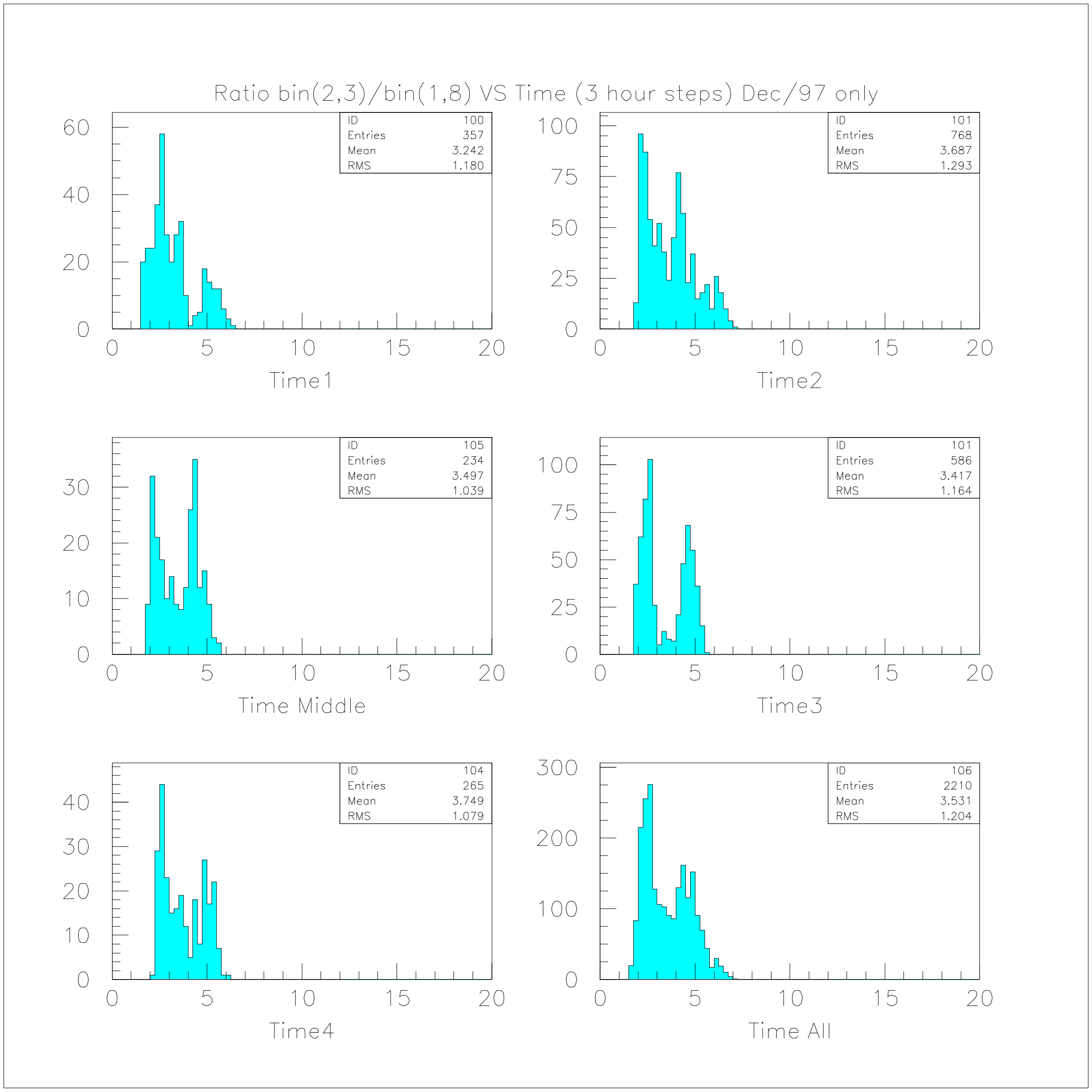

Fig. 4: A plot of the 45°/120° light intensity ratio, R, in different time intervals each observing night in December 1997.

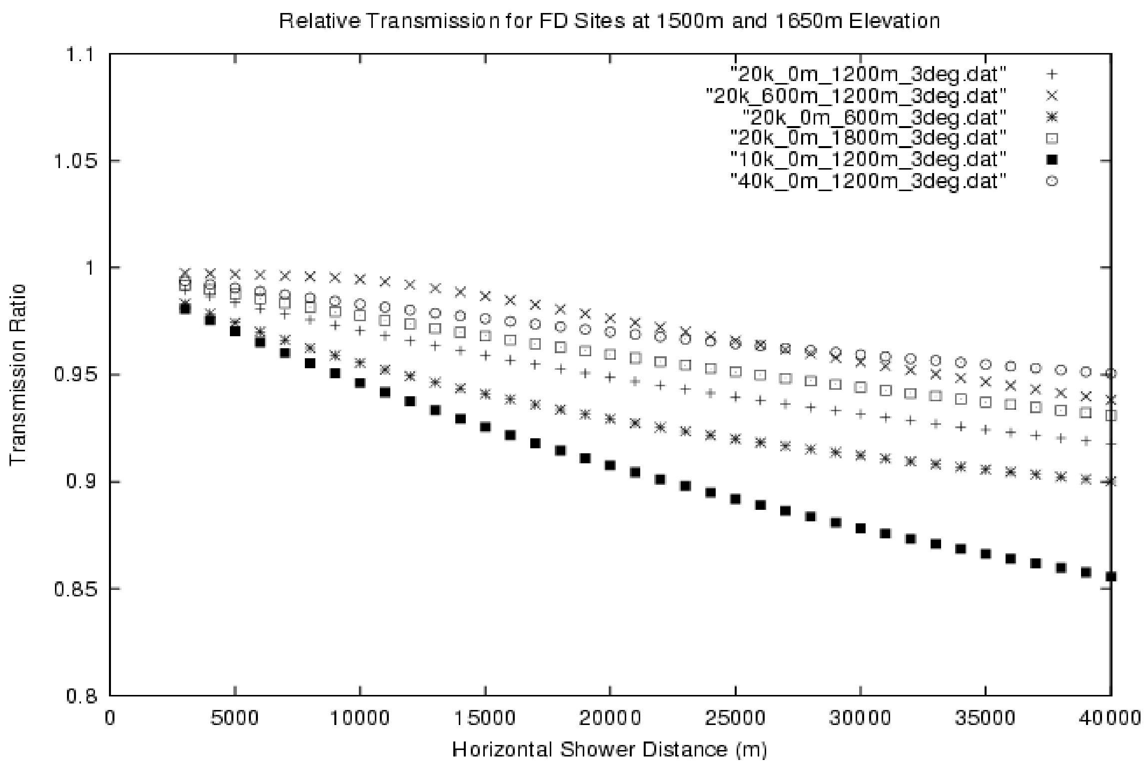

Fig. 5a: A plot of the ratio of transmission factors *versus* horizontal distance to the air shower for two fluorescence sites separated by 150m vertically. Each aerosol *model* (see text) appears as a different curve in the figure. The fluorescence observational (elevation) angle to the horizontal is 3°.

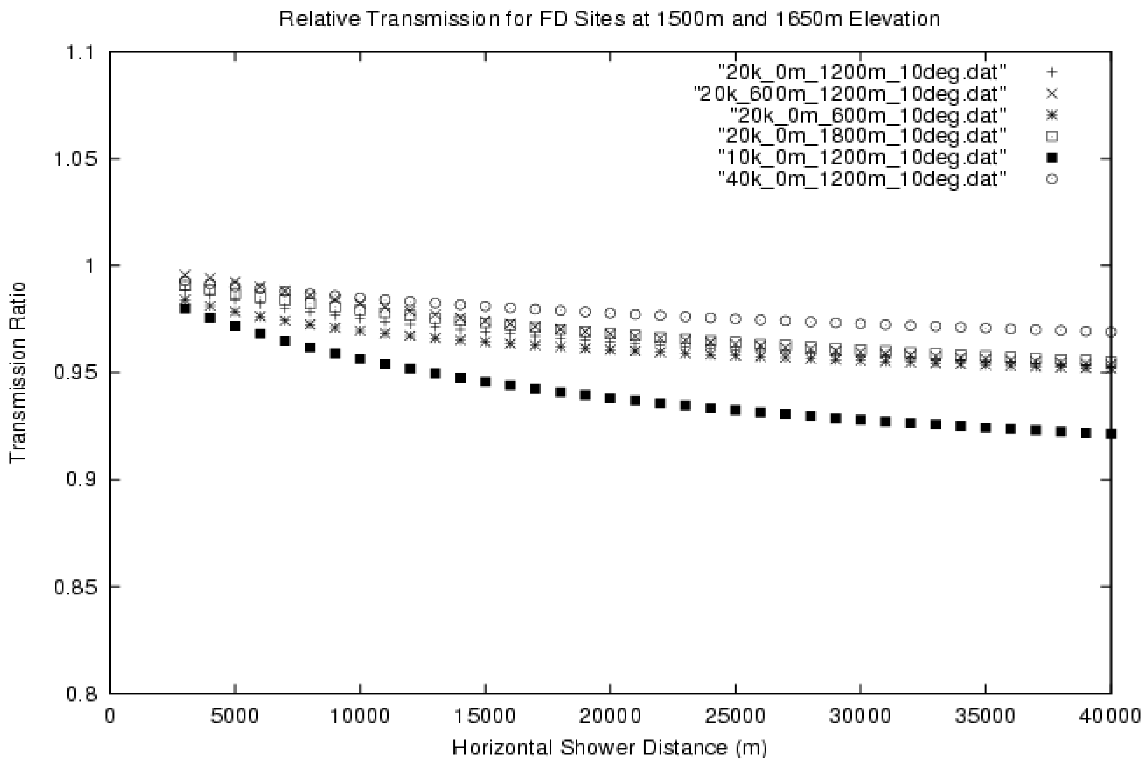

Fig. 5a: A plot of the ratio of transmission factors *versus* horizontal distance to the air shower for two fluorescence sites separated by 150m vertically. Each aerosol *model* (see text) appears as a different curve in the figure. The fluorescence observational (elevation) angle to the horizontal is 10°.