Atmospheric Effects on the Development and the Fluorescence Detection of Extensive Air Showers

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Abstract

Radiosonde measurements of atmospheric profiles above the Pampa Amarilla in Argentina, the location of the southern Pierre Auger Observatory, have been carried out. A detailed knowledge of the atmospheric conditions and its variations is mandatory especially for the fluorescence technique of air shower observations. The atmosphere influences the shower development and the detection in several ways: Firstly, the shower development is mainly determined by the amount of traversed matter. However, fluorescence telescopes observe the geometrical development. For the transformation from depth to geometrical height, the air density profile is required, otherwise misinterpretations of the shower maximum depth of order 30-50 g/cm^2 are possible. Secondly, the fluorescence efficiency of air depends on the local pressure and temperature. And thirdly, the propagation of light is affected by attenuation and scattering, again depending on the air density profile. The measured air pressure and temperature profiles, taken in all 4 seasons up to altitudes of 25 km, and the resulting variables are presented. The importance of in-situ measurements for the interpretation of fluorescence observations is discussed.

1. Introduction

Using the fluorescence technique for detecting Extensive Air Showers (EAS), informations on the longitudinal shower development are obtained. However for interpreting the measurements, assumptions about environmental conditions are necessary. Usually the US Standard Atmosphere from 1976 (US-StdA) forms the basis. For estimating the influence of realistic atmospheres, we measured temperature (T) and pressure (p) profiles up to 25 km with meteorological radiosondes launched on Helium filled balloons [1]. First of all, the effect of seasonal air density profiles on the shower development is discussed. Afterwards, the fluorescence emission of that showers is calculated. Finally, the transmission of the fluorescence light towards the telescope is outlined.

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2. Longitudinal Shower Development

The EAS development is mainly determined by the amount of traversed air. Thus, the path integral of the air density, called atmospheric depth X, indicates the stage of the EAS. Since the fluorescence telescopes observe the light at given geometrical height h, we have to know the relation between atmospheric depth and geometrical height.

The measured data sets are obtained in sufficiently small height intervals, on average every 20 m. The atmospheric depth profile is calculated by

$$X(h) = X_b + \sum_{h=h_b}^{h_{start}} \Delta X(h), \tag{1}$$

where X_b is the atmospheric depth at the height of balloon burst h_b using the simple proportionality between X and p, and $\Delta X(h)$ is the local additional atmospheric depth $= 1/2 \cdot (\rho(h_1) + \rho(h_2)) \cdot (h_2 - h_1)$ within each measured interval [3]. For using the measured atmospheric profiles in the shower simulation program CORSIKA [2], the atmospheric depth profiles are fitted according to

$$X_i(h) = a_i + b_i \cdot exp(-h/c_i), \tag{2}$$

subdivided into $i = 1 - 4$ ranges up to 100 km. The differences between the measured profiles and the US-StdA can be seen in Fig. 1. The solid lines are fits

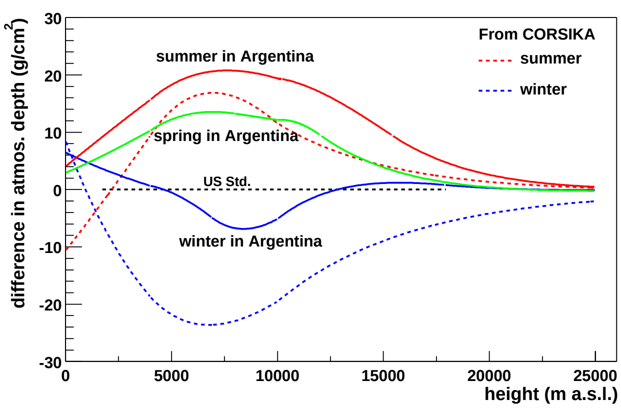

Fig. 1. Difference of measured atmospheric depth profiles to the US-StdA.

to several measured data obtained in different seasons, and the dashed curves are extreme atmospheres for Europe available in CORSIKA. The largest differences of $\Delta X \approx 27$ g/cm^2 between summer and winter in Argentina occur at 7 - 10 km a.s.l. At that height, 40° - 65° inclined EAS of 10^{19} - 10^{20}eV reach their maximum. The maximum position of an EAS with zenith angle Θ is shifted by $\Delta X/cos\Theta$. The data were recorded in August and November 2002, as well as in February 2003. Representative curves were found out neglecting daily variations. In total 33 launches were carried out. 2002 was an *El Niño* year perhaps being untypical.

The particles of the EAS lose energy during their passage through the atmosphere, exciting the nitrogen molecules in air. Part of the de-excitation happens via isotropic fluorescence emission. The Fluorescence Yield is proportional to the local energy deposit. Thus, we simulate the longitudinal development of the energy deposit [4] for different seasons in Argentina (see Fig. 2). The position of the shower maximum depends on the type of the primary particle. However, it also depends on the atmospheric depth profile. The example in Fig. 2 shows averages of 100 simulated iron induced EAS. The shift in the shower maximum position amounts to 580 m in vertical height between summer and winter conditions.

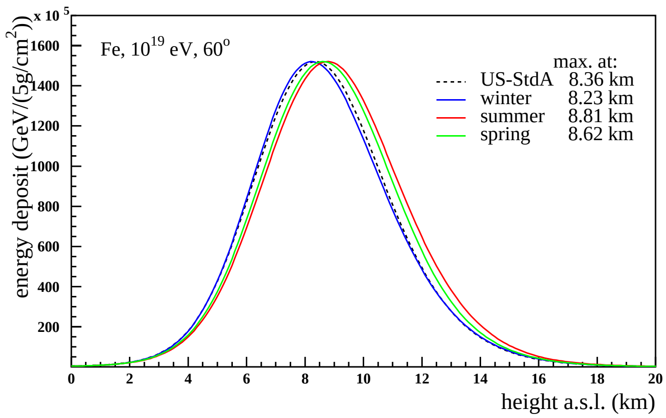

Fig. 2. Longitudinal energy deposit profiles for EAS in measured atmospheres in Argentina.

3. Fluorescence Light Emission and Transmission

The fluorescence light production is one part of the de-excitation of the nitrogen molecules in air. It competes with collisional quenching which depends on the rate of impacts by further molecules. This process is determined by the collisional cross sections and also by the temperature and density ρ of the gas affecting the speed of molecules. Thus the Fluorescence Efficiency depends on the atmospheric profiles and also the resulting Fluorescence Yield defined as

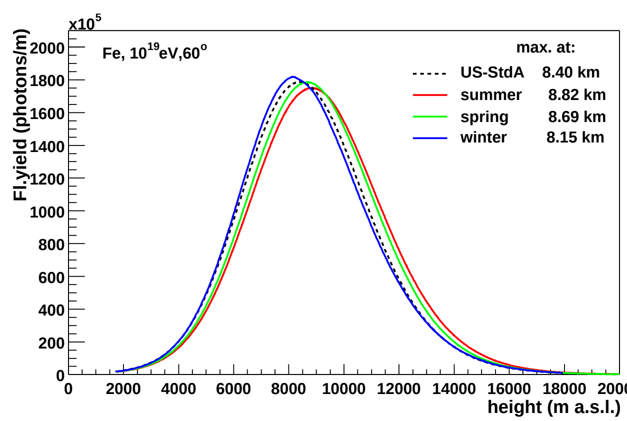

Fig. 3. Longitudinal Fluorescence Yield profiles for EAS in measured atmospheres in Argentina.

$$Fl.Yield\ [\text{photons/m}] = Fl.Eff.\ [\text{photons/GeV}] \cdot \frac{dE}{dx} \cdot \rho_{air}. \qquad (3)$$

The emitted light curves for the EAS shown above are plotted in Fig. 3. The Fl. Yield curve is additionally shifted and distorted as against the energy deposit.

The position of the fluorescence maximum is separated by 670 m between summer and winter conditions. The pure Fl. Yield difference amounts to 5%.

The difference in the maximum position between iron and proton induced EAS is nearly 80 g/cm^2 or 770 m for 60° inclined EAS of 10^{19}eV in the US-StdA (Fig. 4). Combining the effects of deeper penetrating proton EAS and

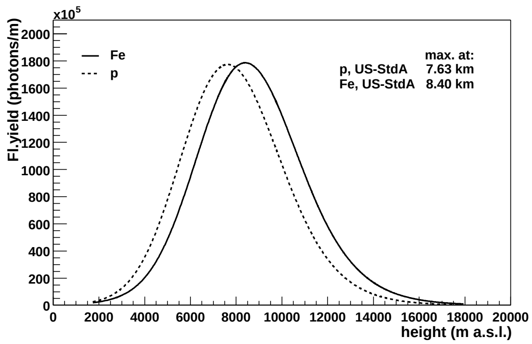

Fig. 4. Fluorscence Yield profiles for iron and proton induced EAS in the US-StdA, 10^{19}eV, 60° inclination.

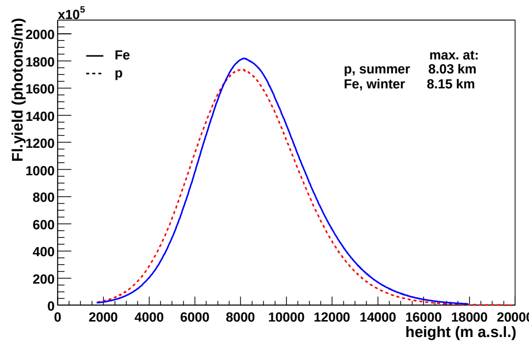

Fig. 5. Fluorescence Yield profiles for iron EAS in winter and proton EAS in summer,10^{19}eV, 60° inclination.

earlier developing EAS in summer, the possible misinterpretations concerning the primary particle mass become obvious (Fig. 5). The clear detectable seperation of 770 m between proton and iron EAS has shrunk to 120 m for the measured atmospheres.

During the propagation towards the telescope, the light suffers absorption and scattering. Since Rayleigh scattering is T and p dependent, seasonal effects show up. For a distance between EAS and telescope of 15 km, the difference in the transmission between summer and winter in Argentina yields ≈ 5% depending on the wavelength.

4. Conclusions

The atmosphere influences the longitudinal EAS development as well as their detection in terms of different light production and transmission. Measurements of atmospheric profiles and comparisons with the US-StdA show significant effects on the interpretation of EAS data especially concerning the type of the primary particle by shower maximum determinations.

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