
Atmospheric Monitoring for the Pierre Auger Fluorescence Detector

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Abstract

Major uncertainties in the fluorescence energy measurement come from the precision of various atmospheric transmission, air Cerenkov subtraction, light multiple-scattering and cloud corrections. The Auger program for atmospheric monitoring, designed to measure these corrections and to minimize these uncertainties, is summarized in this paper.

1. Introduction

A reliable air shower energy scale and energy resolution is central to the mission of the Pierre Auger ultra-high energy cosmic ray experiment. The Auger Southern Observatory is able to measure the energy of the incoming cosmic rays using fluorescence detectors, and thus calibrate the energy inferred from the surface detectors. Uncertainties in the fluorescence energy measurement must therefore be well understood.

For fluorescence experiments, the atmosphere not only acts as the showering medium for the primary cosmic ray, but it is also an essential part of the read-out system. Thus, the atmosphere must be calibrated, the calibration monitored with time, and then input to the analysis of the fluorescence data. Auger atmospheric monitoring systems include LIDARs, cloud monitors, horizontal attenuation monitors, phase function monitors, meteorological stations, and radiosondes. The main systems deployed on-site are described in this paper.

2. Monitoring systems

2.1. LIDAR Stations

The primary source of atmospheric information for the Auger fluorescence detectors derives from steerable backscattered LIDAR systems. As these are located at each fluorescence site, they are able to probe directly the shower-detector atmospheric path. These systems are used to make routine surveys of the vertical profile of aerosols around the local fluorescence detector. Immediately following a promising shower event, they scan the atmosphere looking for possible

scattering inhomogeneities between the shower and the fluorescence detector.

Each LIDAR station consists of a pulsed laser beam at 355 nm, a receiver telescope with three mirrors, each with a gated, high-speed photon detector [2]. The receiver measures the backscattered photons as a function of time, *i.e.* intensity of photons versus distance to the point where the light backscattered. The aerosol optical depth as a function of height is inferred from these measurements [3].

The first LIDAR telescope was installed at the Los Leones site in February, 2002. This station has been operational since April, 2002. Figure (1.a) shows a typical measurement of the aerosol vertical profile at the Los Leones site. Several inversion methods are currently being compared. The second telescope was installed at the Coihueco site in May, 2003.

2.2. *Horizontal Attenuation Length Monitor*

This system records the horizontal attenuation length at several wavelengths within and near to the acceptance of the fluorescence detectors. For the Auger Southern Observatory three systems will monitor three different light paths across the site.

Each system includes a stable DC light (source) and a UV sensitive CCD camera (photometer). Measurements are made through interference filters at 365 nm, 405 nm, 436 nm, and 542 nm. The total horizontal attenuation length is calculated from the ratio of flux measured at a large distance (~ 50 km) from the light source to the flux measured at a small distance (calibration point).

The first system was installed in May, 2001. It produces three sets of measurements per night.

2.3. *Aerosol Phase Function Monitor*

The goal of this system is to measure the normalized aerosol differential scattering cross section as a function of the scattering angle from the initial light direction. The measurement is made using a horizontal pulsed light beam directed across the field of view of one of the fluorescence detectors [6].

The procedure to measure the phase function employs three xenon flash tube sources which emit $1 \mu\text{s}$ light pulses covering a range of wavelengths [5]. The distance between the light source and the fluorescence building is ~ 1.3 km, which is much less than the total atmospheric attenuation length. This geometry requires only small corrections for transmission and multiple scattering, and allows the fluorescence detector to measure the light scattered out of the beam over the desired range of scattering angles (between 20° and 160°).

The first aerosol phase function light sources were installed in March, 2003.

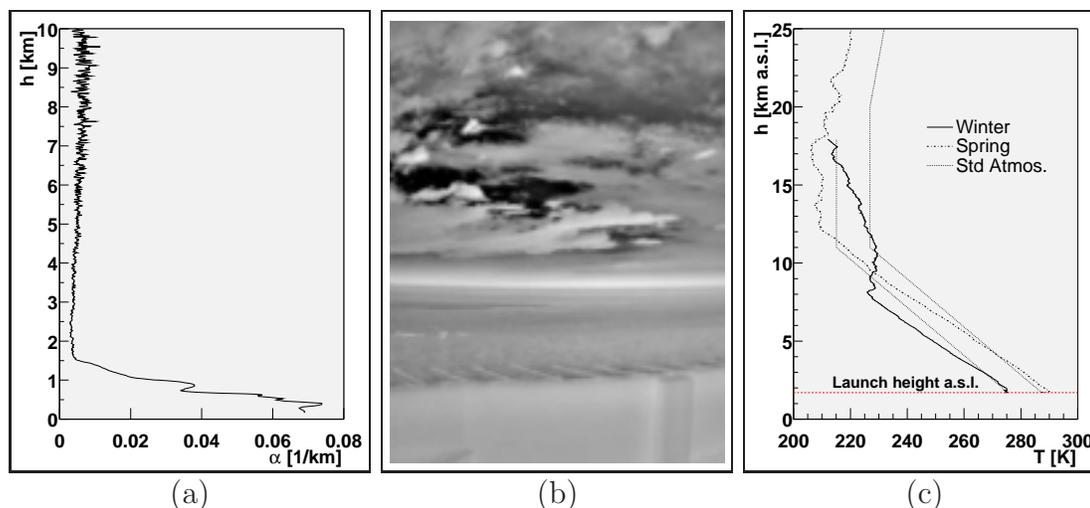


Fig. 1. (a) Aerosol extinction coefficient as a function of height measured with the LIDAR system at the Los Leones site. (b) Sky picture of the field of view of one of the telescopes at the Los Leones site. (c) Temperature profiles measured with radiosondes in two different seasons over the Coihueco site.

2.4. Cloud Cameras

These systems allow cloud detection over the Auger array. Clouds have the potential to modify the fluorescence measurements in an unpredictable way.

The detection of clouds has been proved possible using their strong infrared emission against a much weaker clear sky background [1]. The detector is based on the Raytheon Control-IR 2000B digital camera with a spectral range between 7 and 14 μm , and a field of view of $45^\circ \times 36^\circ$. Operation modes include: scan the field of view of the fluorescence telescopes, produce a full-sky image, and take a picture of a given direction after a trigger from the fluorescence detector.

The prototype, a fixed IR camera, and was installed in July, 2002. It produces 24 representative images per night. A sample image is shown in figure (1.b). Two scanning systems will be installed this year. Work is in progress to improve methods for determining cloud edges, and increasing the sensitivity to high thin clouds.

2.5. Meteorological Stations and Radiosondes

There are three weather stations operating at the Los Leones, Coihueco, and a central site since 2001. They provide daily ground measurements of temperature, relative humidity, wind speed and direction, solar radiance, and pressure.

Meteorological radiosondes are used to measure temperature and pressure as a function of height, and to cross check the results of the standard profiles based on measurements at ground level.

These radiosondes are standard meteorological instruments for measuring pressure, temperature, and humidity. They are launched using helium filled balloons, and raw data, including GPS information, are received by a radio ground station.

Measurement campaigns have been performed since August, 2002 during the local winter, spring, and summer. Balloons are launched from different starting positions at different times during the day and night. Figure (1.c) shows measured temperature profiles for winter and spring over the Coihueco site.

The air density as a function of height is calculated based on these data. Results are compared to standard profiles, and used to study the effects on the longitudinal shower development and fluorescence yield. A detailed description of the radiosondes, the measurements, and the analysis can be found in Ref. [4]. Work in progress concentrates on the development of a corrected standard profile to describe the data based only on ground level meteorological measurements.

3. Cross Checks

To minimize systematic uncertainties, all the atmospheric measurements are made in at least two independent ways. The horizontal attenuation length is compared with the results of horizontal LIDAR measurements. The aerosol optical depth can be cross checked using dedicated Raman LIDAR, and also with a central vertical laser. The side scattered light from a central steerable laser observed at the fluorescence detectors provides an essential cross check of the aerosol model. In addition, LIDAR routine scans can be used to determine cloud base height, which combined with the cloud camera information, produce a detailed 3D picture of the clouds.

4. Conclusions

The main components of the Auger atmospheric monitoring program have already been deployed on-site. Atmospheric data are being analyzed and the first atmospheric data bases are being constructed. The Auger monitoring goal is to limit the atmospheric contributions to the shower energy uncertainty to $\sim 10\%$.

5. References

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