Cosmic Ray Solar Modulation Studies at the Pierre Auger Observatory

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Abstract**. Since data-taking began in January 2004, the Pierre Auger Observatory has been recording low energy threshold rates for the self-calibration of its surface detectors. After atmospheric corrections are applied, solar modulation and transient events are observed. In this study, we present an analysis of the available data, with special emphasis on the observation of Forbush Decreases. A strong correlation with neutron monitor rates is found. The high total count rates allow us to determine temporal variations of solar origin with high accuracy.**

Keywords**: Pierre Auger Observatory, Solar Modulation, Forbush decrease**

I. Introduction

The Pierre Auger Observatory [1] has been designed to study the physics of cosmic rays of the highest energies. The Observatory combines two detection techniques in a hybrid design: the observation of the fluorescence light produced by the secondary particles as they propagate through the atmosphere; and the measurement of particles reaching ground level. The Pierre Auger Observatory has been taking data in a stable way since January 2004. The Surface Detector (SD) [2] is an array of more than 1600 water-Cherenkov detectors in a triangular grid with a spacing of 1500 m, covering 3000 km^2.

Each water-Cherenkov detector consists of a $10\,m^2$ area polyethylene tank containing 12 tonnes of high-purity water in a highly-reflective liner bag. Cherenkov radiation generated by the passage of charged particles through the detector is collected by three 9” photomultipliers (PMTs). The water-Cherenkov detector is also sensitive to high energy photons, as they convert to e^+e^- pairs in the water volume. The signals in the PMTs are processed by a fast analog-to-digital converter with a sampling rate of 40 MHz. A GPS system is used for timing and synchronization. Each detector is powered by a solar panel and batteries, working as an autonomous station linked to the central data acquisition system in Malargüe through a dedicated WAN-like radio network. Typically, more than 98% of the stations are operational at any time.

Previous work reported on the sensitivity of the Pierre Auger Observatory to Gamma Ray Bursts (GRBs) [3] using the *single particle technique* [4]. This method, in use in other cosmic ray experiments, consists in recording low threshold rates with all the surface detector stations, and looking for significant excesses in these rates.

In March 2005, a first set of scalers was implemented in each station of the Surface Detector of the Pierre Auger Observatory, mainly intended for the search of GRBs and for long term stability and monitoring studies. They consist in counters which register signals above a very low threshold, corresponding to an energy of $\sim 15\,$MeV deposited by individual particles in the detector. The typical station rate is $3.8\,$kHz. In order to remove signals produced by muons and to improve the signal to noise ratio for GRB searches, an upper threshold of $\sim 100\,$MeV was introduced in September 2005, reducing the station rate to $2\,$kHz [3]. These rates are read every second and sent to the Central Data Acquisition System for their storage and further analysis.

II. Scaler data treatment

In addition to the fact that the rate of low energy particles is not intrinsically constant, some instrumental instabilities and the atmospheric weather conditions are known to modify further this rate. They have to be taken into account before searching for transient events that last longer than a few minutes, or for effects such as the solar modulation of the galactic cosmic ray flux.

A data cleaning procedure optimized for the search of GRBs has been previously reported [3]. However, due to the very different time scales involved here, different cleaning procedures are needed.

First, stations with rates lower than $500\,$Hz are removed, as such a low rate may be an indication of temporary malfunction. For each individual second we also discard data from those stations with extreme rate counting (upper and lower 2.5%). The second step is to remove those periods where less than 97% of the array is in operation, resulting in a loss of less than 10% of data. This step is needed because individual stations have different average counting rates, due to many factors, from detector calibration to pressure effects coming from the different altitudes at which detectors are deployed.

Data for the two different periods (before and after September 2005, when the upper threshold was implemented) was analyzed independently. For both periods the average scaler rate was computed for each station

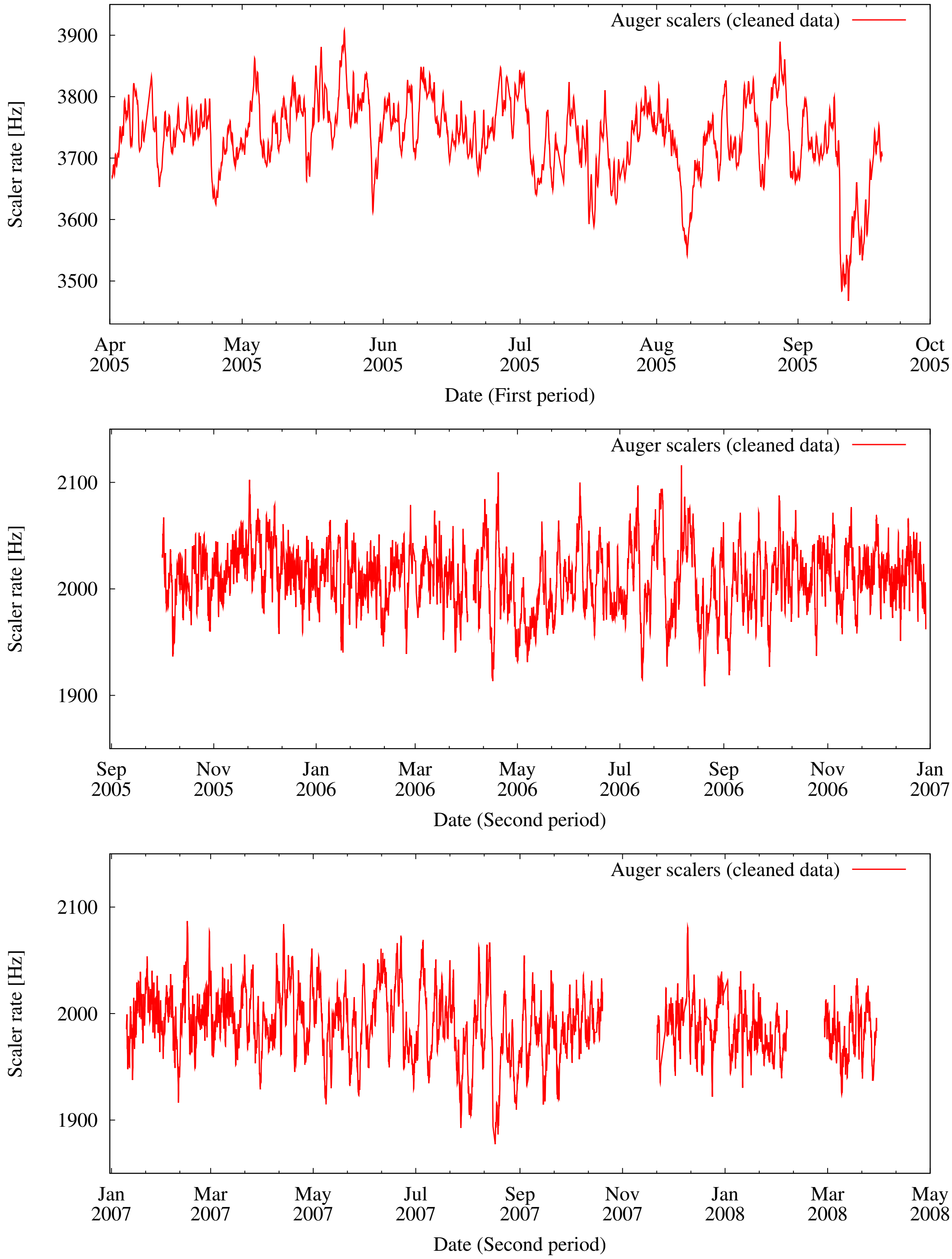

Fig. 1. Pierre Auger Observatory scaler rates after the data cleaning procedure described in the text, for the first period (before September 2005, top), and for the second period (after September 2005, middle and bottom). Each data point is the average scaler rate over one hour.

over the lifetime of the detector. Detectors showing an RMS of more than twice the square root of the rate were excluded, keeping more than 90% of the stations after this cut. Brief spurious events (such as high frequency noise produced by lightnings) were removed by computing the average scaler rate for each detector over a 5 minutes period in which data is available for at least 4 minutes, removing the upper and lower 25% extreme values. Figure 1 shows the scaler data obtained for both the first and second scaler mode periods.

Atmospheric pressure variations are known to modify the flux of secondary particles at ground level, due to the different mass of atmosphere above the detector: an increase in the atmospheric pressure is correlated

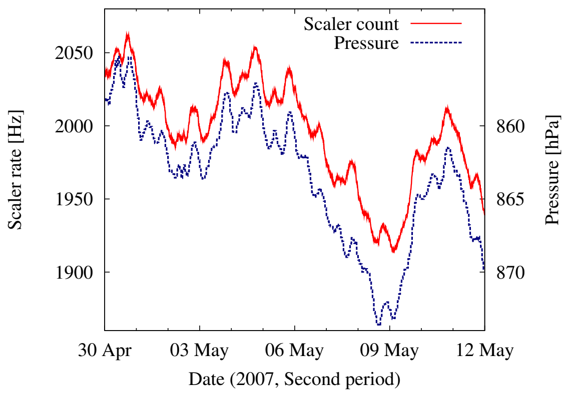

Fig. 2. Average scaler rate (solid line) and atmospheric pressure (dashed line, please note the reversed scale for pressure) for the first ten days of May of 2007.

with a reduction in the background rate. Figure 2 shows the average scaler rate after the cleaning procedure, correlated with the flux of secondary particles at ground level, for the first ten days of May 2007, compared with the atmospheric pressure, as measured by several weather stations monitoring the array.

The aforementioned correlation is observed and corresponds to about -0.27% (-0.36%) per hPa before (after) the upper threshold implementation. This also implies that an additional correction of 0.03% (0.04%) per metre of difference in altitude between stations has to be included.

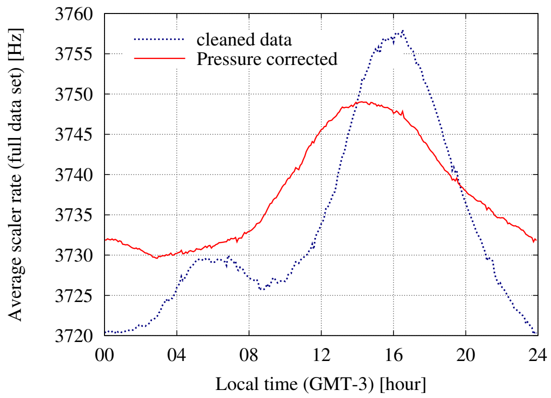

Fig. 3. Averaged scaler rates for the first period (before September 2005) as a function of local hour of day (ARS, GMT-3) for the cleaned (dotted line) and for the atmospheric pressure corrected data (solid line).

III. Solar Modulation

Figure 3 shows the average daily dependence. After atmospheric pressure correction, a 0.25% modulation remains, peaked at 17h45 UT (14h45 local time).

To show that the cleaned, pressure corrected, data set is of relevance for solar studies [5], we compare the Pierre Auger Observatory SD scaler rates with data from McMurdo neutron monitor of the Bartol Research Institute [6]. Figure 5 shows the excellent agreement found: Forbush decreases are clearly visible in the scaler data for both periods. The upper threshold introduced on September 2005, intended to optimize signal over noise ratio for GRB detection, is probably not the ideal one for these studies, where the muon flux at ground level might be better correlated to the primary cosmic ray flux than the electron one.

As an example, Figure 4 shows the evolution of the scaler rates during the 11 Sep 2005 Forbush decrease [7]. A 4% variation is observed, in agreement with the 14% measured at McMurdo once taken into account the rigidity cut-off of 9.5 GeV at Malargüe, Argentina (35.3^{o}S, 69.3^{o}W).

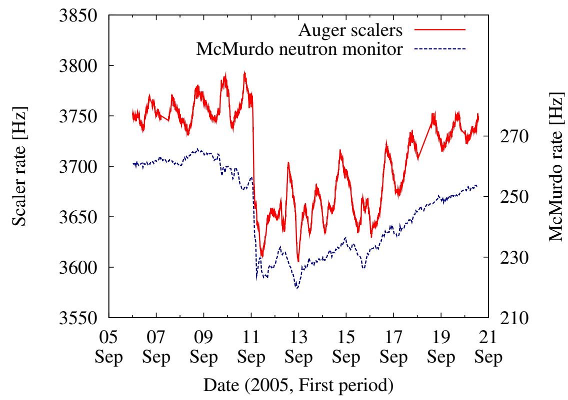

Fig. 4. Averaged, cleaned and pressure corrected scaler rate for the 11 Sep 2005 Forbush decrease, compared with the McMurdo neutron detector rate (dotted line). A 4% variation is observed.

IV. Conclusions

Low energy radiation rates are registered with high statistics at each surface detector station of the Pierre Auger Observatory since March 2005. A data cleaning method, based on a previous one intended for the search of GRBs, has been implemented and optimized to study solar modulation effects. After correcting for pressure, an excellent agreement with data from McMurdo neutron monitor is found, evidencing the high sensitivity that water-Cherenkov detectors, operating in scaler mode, have for the detection and measurement of Forbush decreases and other transient events related with the solar modulation of Galactic cosmic rays. Additional analyses of scaler rates at individual detectors and scaler thresholds optimisation are underway, together with low energy cosmic ray simulations in order to determine the energies of the primaries responsible for the observed modulation.

References

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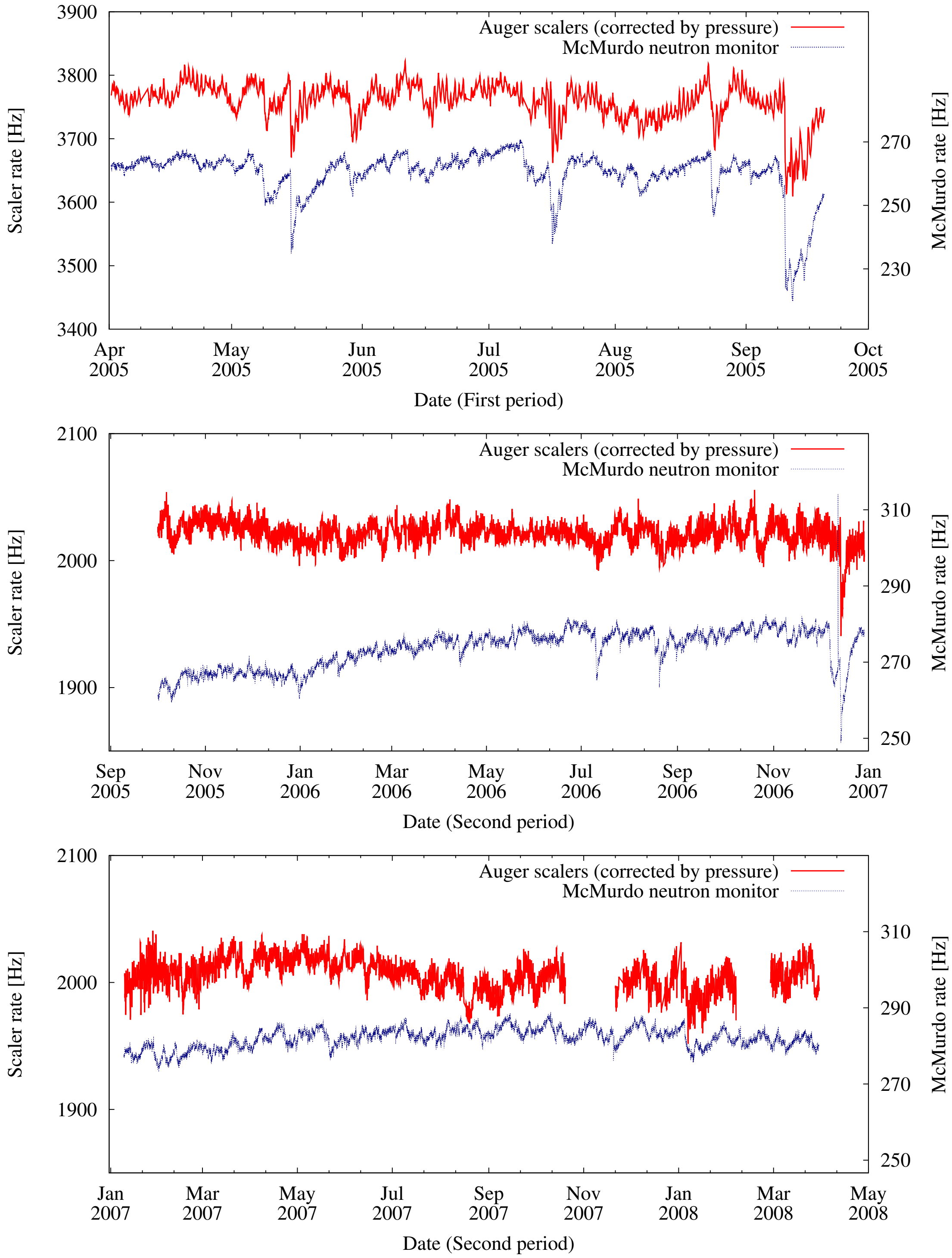

Fig. 5. Pierre Auger Observatory scaler rates (solid lines) after cleaned procedure and atmospheric pressure correction, compared to McMurdo neutron detector data (dotted line), for both periods, before (top) and after September 2005 (middle and bottom).

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