Ground Level Muon Flux Variation in a Cosmic Rays Simulation

A study of tidal frequencies in muon flux ground level detection using Corsika simulations

Elisa Garcia Pereira & **Dimiter Hadjimichef**
Universidade Federal do Rio Grande do Sul (UFRGS)
`elisag.pereira@gmail.com`

IWARA
From Quarks to Cosmos

Abstract

Recent experiments [2] have shown that cosmic rays cascades originate a periodic tidal frequency muon flux at the ground level. Using the Corsika (COsmic Ray SImulations for KAscade) toolkit, we simulate cascade scenarios, in a time scale of a year, which could be responsible for these frequencies, such as an atmospheric density variation.

Introduction

Cosmic rays are particles (mostly protons, but also alpha particles and heavy nucleus) that penetrate the Earth's atmosphere from space. When they do, they interact with the atmosphere molecules and decay, creating an extensive air shower. The toolkit Corsika (COsmic Ray SImulations for KAscade) [1] is a program for detailed simulation of those showers initiated by high energy cosmic ray particles, it allows us to study the interactions and decay of nucleus, hadrons, muons, electrons, and photons of high energy, over 10^{20} eV, in the atmosphere.

Main Objectives

In this work, we shall examine the periodic variation of the atmospheric density as an influence on the muon flux counting at the ground level, using the Corsika toolkit simulations. Our main objective is to compare the simulated results with experimental data that exhibits a tidal frequency behavior.

Methods

In ref. [2], H. Takai *et al.* reports the detection of tidal frequencies in the spectral analysis of time series muon flux measurements realized over a period of eight years. The muon telescope used for these measurements is part of the MARIACHI experiment, located at Smithtown High School East in the state of New York, latitude 40° 52' 14.88"N, longitude 73° 9' 53.103"W, at 43 m above sea level. The large-scale oscillations of the atmosphere, producing tides are those, in general, generated by (a) the gravitational forces of the moon and sun, and (b) the thermal action of the sun [3].

Figure 1 is extracted from [2] where an hourly-averaged, pressure corrected time series of muon data is seen. A striking feature is a yearly modulation with an amplitude of $\pm 5\%$ of the average counts, with maxima and minima during winter and summer seasons, respectively. This modulation is caused by seasonal variations in solar heating that expand or contract the atmosphere. This change in atmospheric thickness lengthens or contracts the muon flight path.

To simulate a similar effect, we used the Corsika toolkit version 7100 and changed its execution parameters in an automated way, by creating simple auxiliary codes in bash, python3, C, and R. In this work, the primary particle is always a proton with an energy of 10 TeV. In order to compare with Fig. 1, our simulation is set for New York, choosing the local magnetic field [4] and placing the detector 43 m above sea level, as is described in [2]. Our simulation is for a time span of one year.

To improve our results, the seed of each run is random, and the final data is the averaged over five runs with the same parameters but different seeds. The atmospheric data was extracted from Corsika's documentation and the magnetic field parameters ware from the NOAA's website [4].

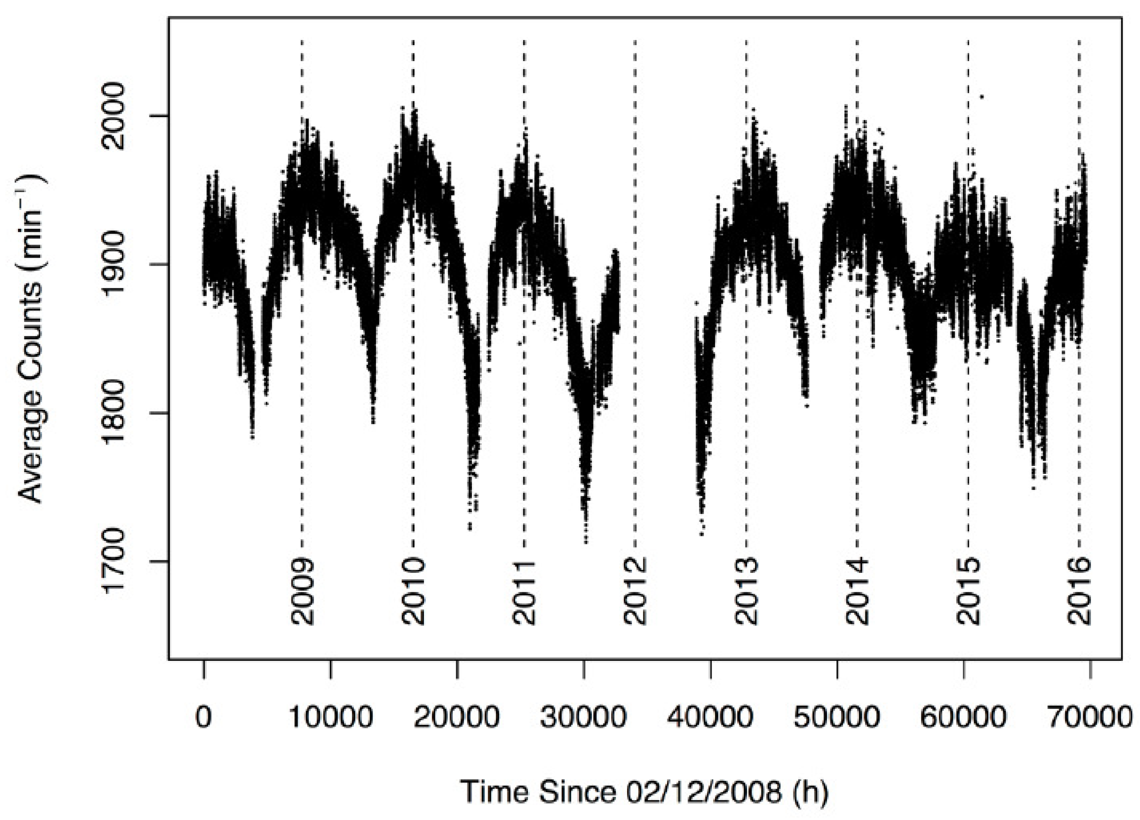

Figure 1: Muon counts over a period of 8 years

The Atmospheric Model

Corsika adopts the Earth's atmospheric composition as 78.1% N_2, 21.0% O_2, 0.9% Ar and its density variation is modeled by 5 layers. In the four lower layers, the density $T(h)$ has an exponential dependence with the height h, while a linear dependence in the fifth layer. All layers are parameterized by coefficients a_i, b_i and c_i with $i = 1, \ldots, 5$, defined in Tab. (1), where we adopt the U.S. standard atmosphere (after Linsley) as is presented in the Corsika documentation.

In our model we modify $T(h)$ with the inclusion of a periodic time dependence in the four lower layers:

$$T(h,t) = \left[a_i + B\sin^2(\omega\, t)\right] + \left[b_i + B\sin^2(\omega\, t)\right] e^{-h/[c_i + B\sin^2(\omega\, t)]}, \quad i = 1,2,3,4 \tag{1}$$

$$T(h) = a_5 - b_5 \cdot h/c_5 \ , \tag{2}$$

where ω is $\pi/364$ and t is in days. The original Corsika atmosphere is regained by setting the phenomenological parameter $B = 0$ in (1). A plot of Eq. (1) is seen in Fig 2 with four different B values and at a height of $h = 6$ km.

Layer i	Altitude h (km)	a_i (g/cm^2)	b_i (g/cm^2)	c_i (g/cm^2)
1	0-4	-186.555305	1222.6562	994186.38
2	4-10	-94.919	1144.9069	878153.55
3	10-40	0.61289	1305.5948	636143.04
4	40-100	0	540.1778	772170.16
5	>100	0.01128292	1	10000000000

Table 1: Parameters of the U.S. standard atmosphere (after Linsley)

Results

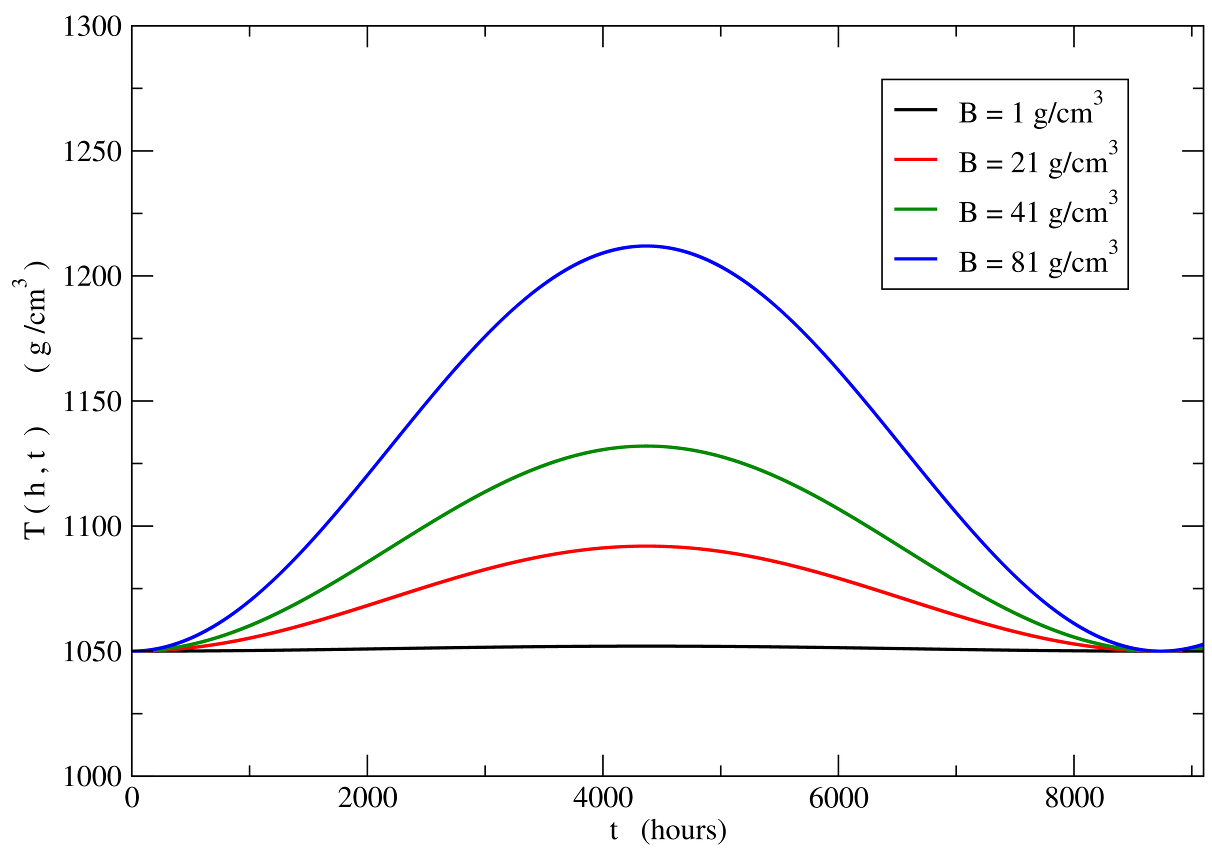

Figure 2: The model atmospheric density function $T(h,t)$

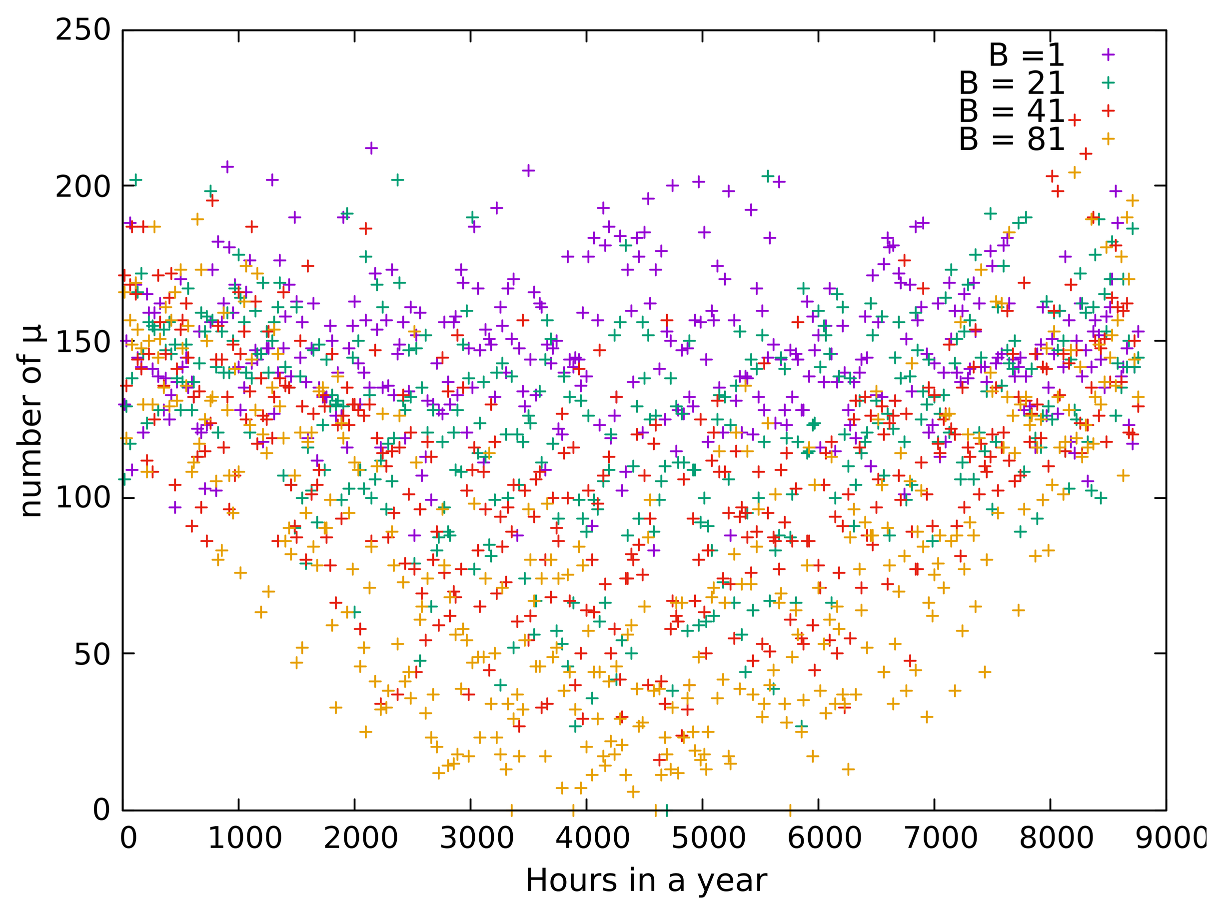

Figure 3: Muon counts over a period of a year, for different B values

In Fig. 3 is shown the simulation for the number of muons per day in a year for different B values. The behavior is consistent with the results presented in Fig 2, when an increase in B value implies a decrease in the number of muons, in the middle of the year (when $\sin^2(\omega t)$ is maximum). These results are in agreement with an annual measurement seen in Fig. 1

Conclusions

The simulation was restricted to a range of a year due to computation time. Still we have shown that a simple phenomenological periodic time dependent density function $T(h,t)$ can reproduce qualitatively the complex atmospheric tides effects that are revealed in the muon data.

Forthcoming Research

We aim in our forthcoming research to explore more realistic atmospheric models, based on the theory of atmospheric and thermal tides. This investigation can provide the sources of periodic excitation and atmospheric response to the excitation.

References

[1] Corsika Website `https://www.ikp.kit.edu/corsika/`

[2] H. Takai et al. *Tidal Frequencies in the Time Series Measurements of Atmospheric Muon Flux from Cosmic Rays* arXiv:1610.05983 [astro-ph.HE].

[3] R. S. Lindzen and S. Chapman, *Atmospheric Tides*, Springer, (1970) ISBN 940103401X, 978-9401034012

[4] NOAA Magnetic Field Calculators
`https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml?#igrfwmm`

Acknowledgements

The authors thank the High Energy Physics Simulations group (HEPsim, `www.ufrgs.br/hepsim`) for all the help and discussion in high energy physics simulations.