Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 5 (HE part 2), pages 845–848

About the possibility for estimation of the atmospheric transparency on the basis of EAS Cherenkov light registration

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Abstract: The possibility to estimate the atmospheric transparency on the basis of extensive air shower Cherenkov light flux registration is discussed. Several Monte Carlo simulations results are presented. Preliminary measurements are shown.

Introduction

The Basic Environmental Observatory (BEO) Moussala is located on the top of the highest mountain at Balkan Peninsula, precisely at 2925m above sea level. During the last several decades the high mountain observatories have been exploited not only for cosmic ray and astroparticle studies but for environmental studies and observations of the Sun-Earth system. In the last years one of the most existing topics in the area of Sun-Earth system investigations is the possible influence of cosmic ray on terrestrial atmosphere, especially the connection between low energy cosmic ray and the Earth atmosphere. As example the variations of the cosmic rays may be responsible for the changes in the large-scale atmospheric circulation associated with solar activity phenomena [1]. Presently several arguments claims that the Solar activity affects the global climate in different aspects and timescales.

One possibility is based on climate response to changes in the cosmic ray flux and radiative budget. In this connection the transparency is one of the primary measures of the atmospheric state. The precise long term series of atmospheric transparency measurements gives the possibility for quantitative estimate of the variability of air circulation and to make climatologic conclusions with regard to contamination, cloud formation, humidity and radiative exchange. It seems to be possible to estimate the atmospheric transparency on the basis of atmospheric Cherenkov light registration and corresponding Monte Carlo simulations. Measuring the Cherenkov light flux produced in extensive air shower in different atmospheric conditions one obtains different amplitude spectra. This reflects on the slope of the reconstructed spectrum. The different slopes of the reconstructed spectra correspond obviously to different atmospheric conditions.

Detector and technique

In general the atmospheric transparency can be estimated using different techniques. Good example is the LIDAR measurements or with astronomical methods using standard *UBV* photometric system. It is possible to study seasonal and long-term variations of atmospheric extinction connected apparently with motions of the air masses due to the global atmospheric circulation.

Two kinds of scattering are important: scattering by molecules of air, and scattering by solid particles or liquid droplets suspended in the air. Molecular scattering is called Rayleigh scattering. The suspended particles, on the other hand, are collectively known as aerosols, and their contribution is called aerosol scattering.
At the same time it seems to be possible to estimate the atmospheric transparency on the basis of atmospheric Cherenkov light registration (Fig.1.) and corresponding Monte Carlo simulations. The atmospheric Cherenkov light is produced by

charged ultra relativistic particles in extensive air showers (EAS) [2]. The majority of the Cherenkov photons are produced near to the shower maximum [3]. As a consequence the quasi totality of the Cherenkov light passes trough the lower atmosphere. Obviously the atmospheric condition plays an important role and impacts the Cherenkov light propagation.

The registration of atmospheric Cherenkov light is possible using Cherenkov telescope. The existing device at BEO Moussala represents system of two parabolic mirrors with focal length of 1.5m and diameter of 2m, working in a coincidence regime (Fig.2.). Measuring the Cherenkov light flux produced in EAS in different atmospheric conditions one obtains different amplitude spectra. Obviously this reflects on the slope of the reconstructed spectrum. The different slopes of the reconstructed spectra correspond obviously to different atmospheric conditions. Thus it is possible to check the different absorption mechanisms measuring the atmospheric Cherenkov light. Moreover such type of measurements gives the excellent possibility for cross check with LIDAR or starlight extinction measurements and to study different atmospheric profiles.

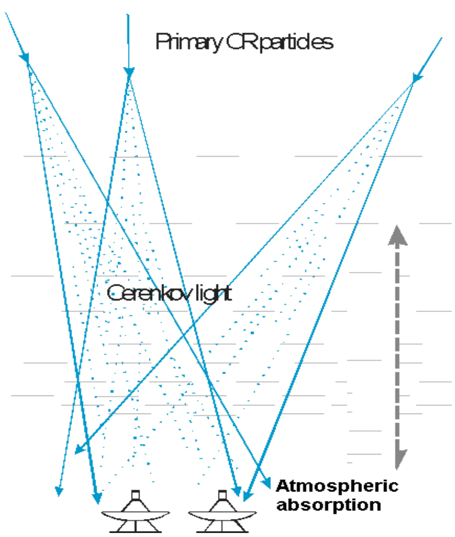

Figure 1: Measurements of atmospheric transparency on the basis of EAS Cherenkov light registration

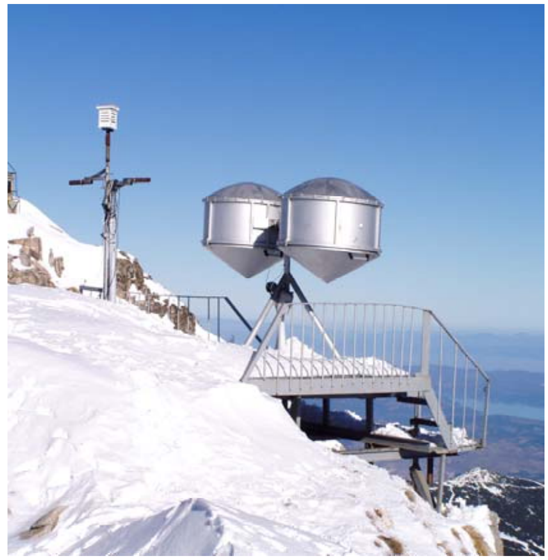

Figure 2: Atmospheric Cherenkov telescope at BEO Moussala

Detector response simulations and first measurements

A Monte Carlo simulation using CORSIKA 6.002 code [4] with GHEISHA [5] and QGSJET [6] hadronic interaction subroutines have been carried out. The aim is in one hand to estimate the detector energy threshold and on the other hand to study the Cherenkov densities spectra in different atmospheric conditions. The simulated primary particles are protons with initial energy of 5×10^{12} eV and distributed according steep spectrum with slope of 2.7. Only vertical events are simulated. The shower axes are distributed uniformly up to 300m from the detectors. The US Standard atmosphere is used for the simulations. The simulations are carried out in two cases – transparent atmosphere i.e. without any absorption or scattering of the light. The second case is with included Mie and Rayleigh scattering according [7]. The results of the simulation as a density spectrum for both cases are presented in Fig. 3 [8]. One can see the very similar shape of the obtained by simulation amplitude spectra. However taking into account the observed difference especially for low amplitudes it seems to be possible to distinguish the atmospheric Cherenkov light flux in different atmospheric conditions. In the case of high amplitudes, obviously a better statistics is necessary for claiming such sentence. Moreover the atmospheric density profiles as well as light absorption and scattering processes depend on geographic position, season and are time-variable [7]. Different density profiles lead to differences in Cherenkov light density of up to 60 %. Seasonal variations at mid-latitude sites are of the order of 15-20 %.

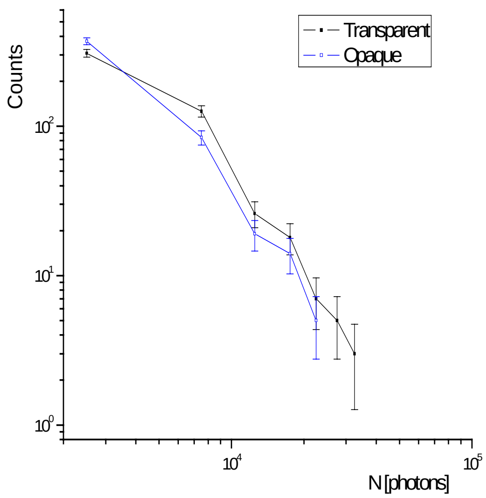

Figure 3: Simulated atmospheric Cherenkov amplitude spectra with CORSIKA code in the case of transparent atmosphere (black squares) and including Mie and Rayleigh scattering (blue squares)

In this connection several experimental measurements using the atmospheric Cherenkov telescope (Fig. 2) are carried out.
In. Fig. 4 and Fig. 5 are shown the measured amplitude spectra in relatively cloudless condition and estimated bad weather (with clouds). In these figures it is possible to observe the apparatus noise, the threshold and real counts used for reconstruction. We want to stress that in the case of very cloudy night, respectively bad weather the registration of atmospheric Cherenkov light is not possible, and in practice one observes only noise. The low statistics of presented results is due essentially on the specific conditions during the observations i.e. the limitations concerning in one hand the moonless night, and on the other hand cloudless night.

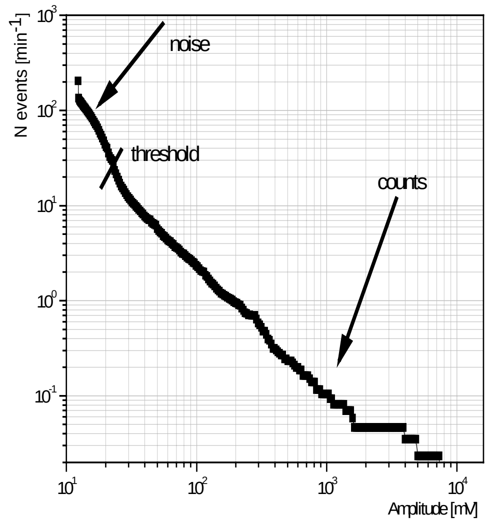

Figure 4: Measured amplitude spectrum with Cherenkov telescope in relatively cloudless conditions

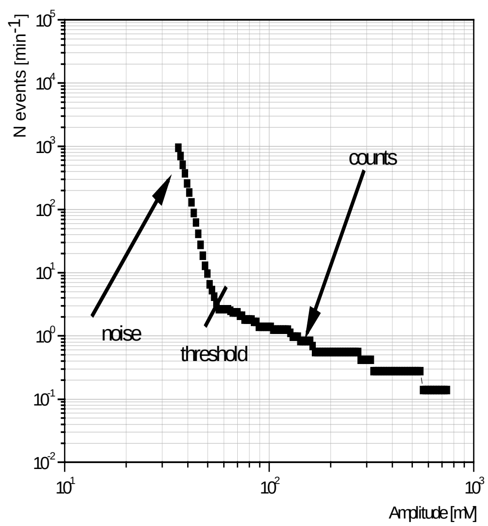

Figure 5: Measured amplitude spectrum with Cherenkov telescope in relatively cloudy conditions

One can see the significant difference in obtained measured amplitude spectra, especially the thre-

threshold and the number of registered events. Even the relatively small statistics these first experimental results confirmed the expectations concerning the different counting rates and slopes of the reconstructed spectra. However additional calculations are necessary. The aim is to obtain precisely the effective detector area as a function of the energy threshold of the telescope and different atmospheric conditions and profiles. This will permit to reconstruct the measured amplitude spectra precisely and therefore the obtained energy spectra slopes. Obviously additional measurements are necessary in attempt the increase the statistics of measured events. Additional comparison with LIDAR measurements is necessary in attempt to provide inter-calibration. Moreover the possibility to provide such experiment at different observation levels is very important in attempt to check the proposed methodology in different atmospheric columns.

Conclusion

In this work are presented several qualitative studies connected with the possibility for atmospheric transparency estimation using EAS Cherenkov light flux registration. The results from Monte Carlo estimations are shown as well several preliminary measurements. The future plans are connected especially with more precise and detailed simulations of different components of EAS at Moussala observation level of 725 g/cm^2. The aim is to obtain in one hand, the effective area of the atmospheric Cherenkov light telescope and therefore to provide more precise analysis of the measured events.

Acknowledgements

This study is in the frame of FP6 project BEOBAL (INCO-CT-2005-016663) and is supported under NATO grant EAP.RIG. 981843. We warmly acknowledge all our colleagues from BEO Moussala and Alomar observatory.

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