CTA performance and joint LST-1 and MAGIC observations of the Crab Nebula in the presence of clouds

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In the very-high-energy range, both the low flux of cosmic gamma rays and their inability to penetrate the atmosphere, limit direct observations of cosmic phenomena. Over the past three decades, the Imaging Atmospheric Cherenkov Technique has become a powerful tool in the very-high-energy gamma-ray astronomy. As their name implies, Cherenkov telescopes observe gamma rays indirectly by capturing short flashes of Cherenkov light produced in the cascade of secondary particles in the atmosphere. Although an integral part of the detector, the atmosphere is also a source of systematic uncertainties. The scattering and absorption of Cherenkov light by aerosols and clouds result in the loss of Cherenkov photons that would otherwise trigger the telescopes, reducing the Cherenkov light yield and effective area.

To investigate the cloud-related effects on the reconstruction of gamma-ray-induced air showers with the Cherenkov Telescope Array, the next-generation observatory for very-high-energy gamma-ray astronomy, an extensive database of dedicated Monte Carlo simulations was generated. The transmission profiles were obtained using the MODerate resolution atmospheric TRANsmission band model algorithm. The effects of clouds were evaluated by analyzing the simulated data and calculating the instrument response functions for two different analyses, depending on the Monte Carlo simulations used to build Random Forest models for classifying the parent particle of the detected air shower and estimating its energy and direction: the *adaptive* Monte Carlo simulations that include clouds and the *standard* Monte Carlo simulations for clear sky conditions.

The effects of clouds on performance parameters such as energy resolution and energy bias can be reduced to the level of standard systematic uncertainties for observations in a clean atmosphere using adaptive Monte Carlo simulations. At the same time, it is important to note that clouds inevitably increase energy thresholds and degrade effective area and differential sensitivity. This cannot be corrected even by applying adaptive simulations, as it is impossible to reconstruct events that are not detected. Using standard MC simulations in the sample to create Random Forest models further degrades the performance of CTA and leads to significant energy bias and poor energy resolution. In such cases, the effective area and differential sensitivity are further decreased (by up to 50% compared to adaptive MC simulations). Nevertheless, for La Palma, where most clouds are located at an altitude of more than 8 km above sea level, their influence on the angular resolution is of minor importance ($\lesssim$ 10%), as no significant differences are observed between standard and adaptive MC simulations.

The method of adaptive MC simulations was also tested on the Crab Nebula data taken during the joint observations of the LST-1 and MAGIC telescopes in the presence of clouds. The results show that the method can reconstruct the spectrum of the Crab Nebula with an accuracy of $\lesssim$ 10% above 100 GeV. By precise modeling of the atmospheric conditions and including them in the simulation chain, systematic uncertainties can be minimized to the level of clear sky observations.

Keywords:

Cherenkov Telescope Array; clouds; Crab Nebula; Imaging Atmospheric Cherenkov Technique; LIDAR; LST-1 Telescope; the MAGIC telescopes