Correction procedures for gamma-ray observations with Cherenkov telescopes under cloud presence using dedicated Monte Carlo simulations or direct image correction

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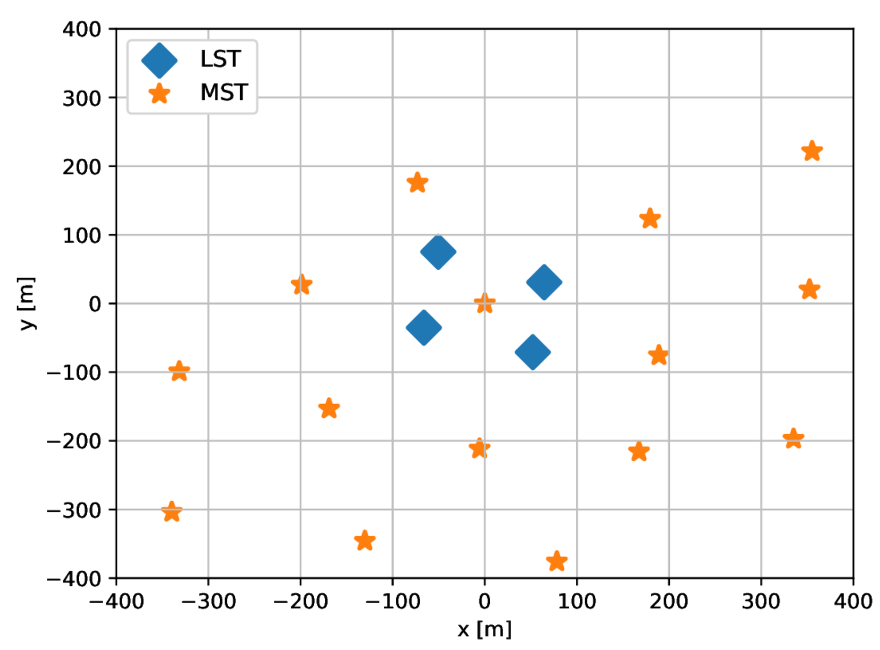
Abstract:
Part of the observations performed with the Cherenkov telescopes in the very-high-energy gamma-ray range above 100 GeV is affected by the presence of clouds. Such observations result in modified collection area, biased energy resolution and worse shower direction reconstruction. Thus, if the effect of the absorption of Cherenkov light in the cloud is not taken into account, increased systematic uncertainties of the measurement have to be considered. In this contribution we present the studies of two complementary methods for such a correction. In the first method we use a dedicated Monte Carlo (MC) simulation to fully take into account the effect of the clouds. In the second method we apply a geometrical model correction to the images in order to correct the bulk of the effect without generation of time-consuming MC simulations.

CTA and reasoning:

Cherenkov Telescope Array (CTA) is the upcoming next-generation, ground-based observatory for gamma rays in range from tens of GeV to hundreds of TeV. While it will have unprecedented sensitivity in this energy range, it will be still limited by only ~ 1000 dark hours available per year, with some of the data affected by cloud presence. To use the observation time efficiently, it is important to devise analysis methods optimal for data affected by the cloud presence allowing analysis without significantly increasing the systematic uncertainties.

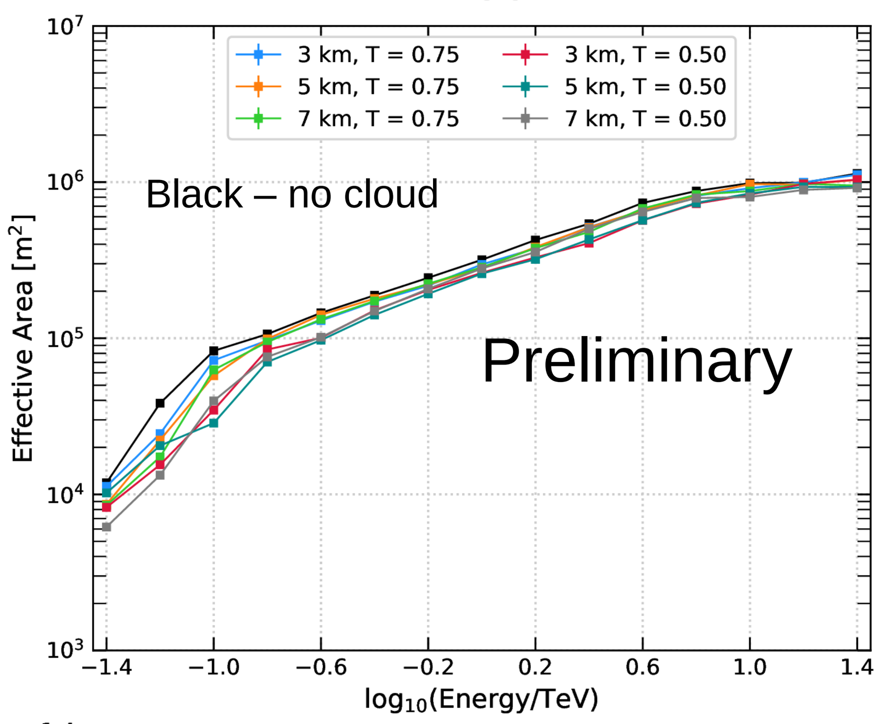
Direct simulation method:

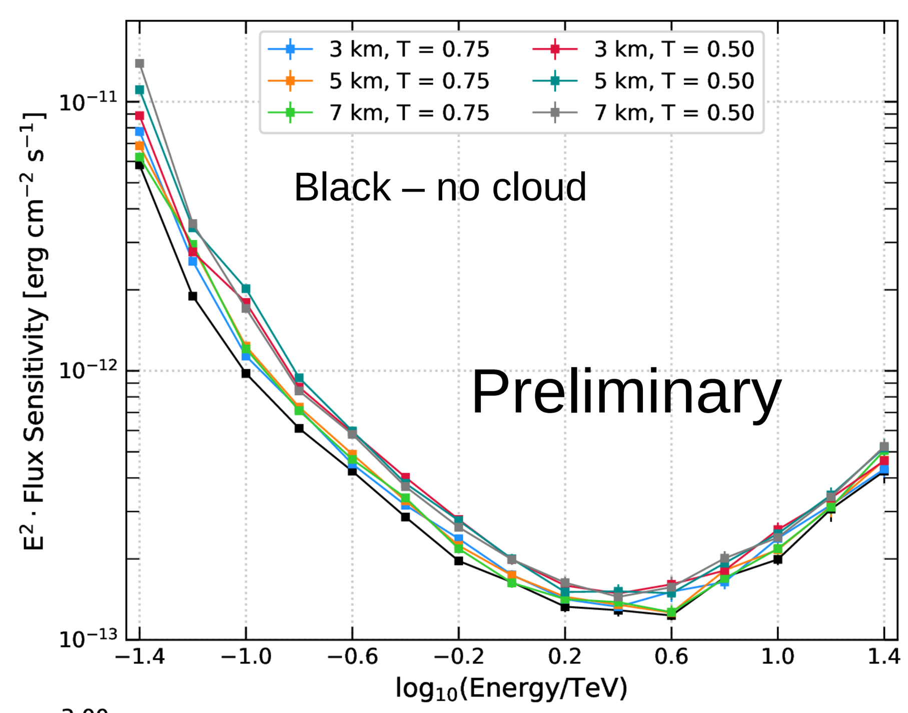
The most natural approach involves full Monte Carlo (MC) simulation of the effect of the cloud, which consists in including additional absorption with a given transmission at a fixed height. The simulations are used both for event reconstruction (gamma/hadron separation, arrival direction, energy estimation) and for evaluating the Instrument Response functions.

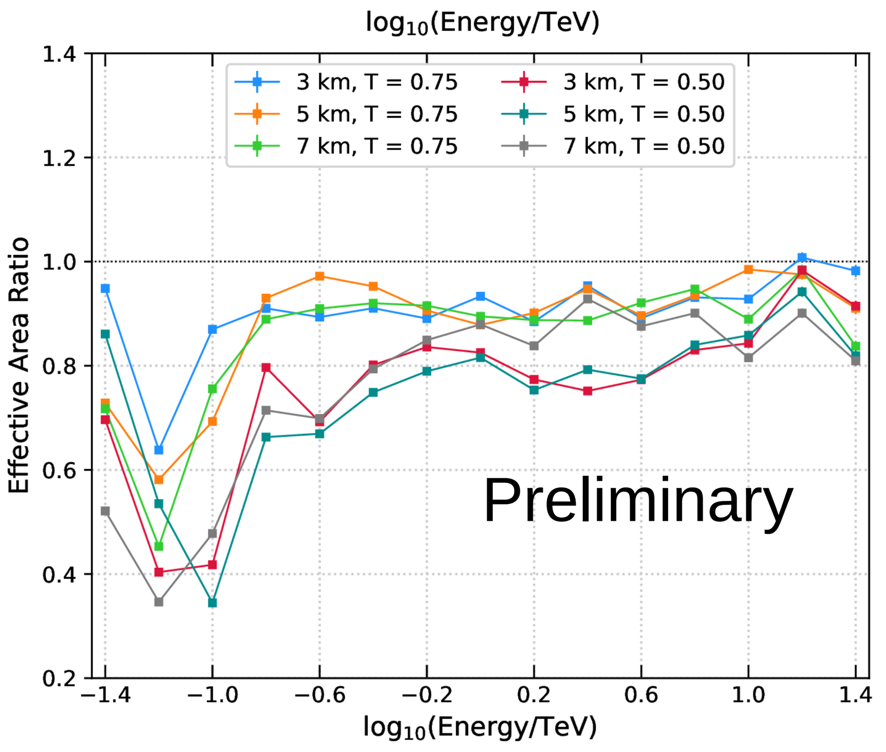


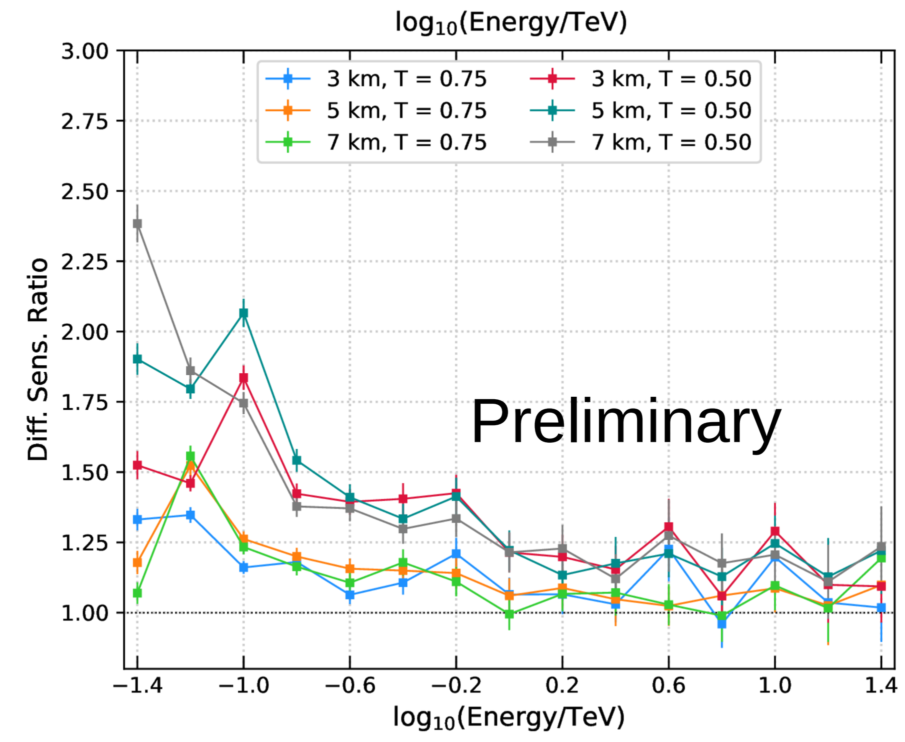
Simulation setup:

CTA North configuration with 4 LST (Large-Sized Telescopes) and 15 MST (Medium-Sized Telescopes) was simulated with the Prod3 settings (Acharyya et al 2019, Astropart. Phys. 111, 35)
Absorption with clouds with heights 3, 5, 7 km a.g.l. and transmission T=0.75, 0.5 were simulated.









Effective area:

The raise of energy threshold with the cloud-affected observations results in a large drop of effective area < 100 GeV. Above 100 GeV there is a rather mild drop by ~20% even for a thick T=0.5 cloud.

Sensitivity:

At the lowest energies the sensitivity gets worse due to the energy threshold increase. At TeV energies there is nearly no drop for T=0.75 cloud, and only ~20% degradation for T=0.5.

Event correction methods:

Alternatively instead of performing costly simulations for each cloud-affected run, general correction procedure can be derived. A study for SST telescopes showed that the energy bias (and large part of the flux underestimation) can be corrected for with a simple phenomenological model.

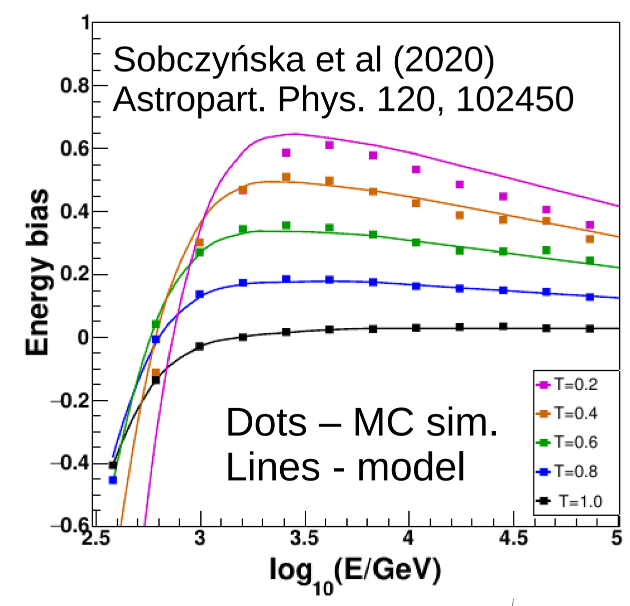
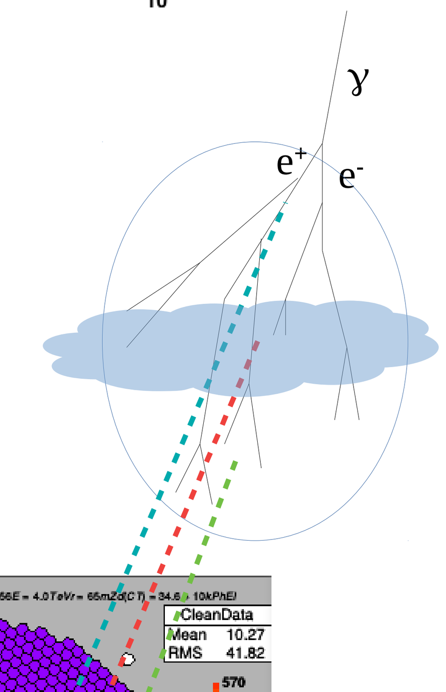
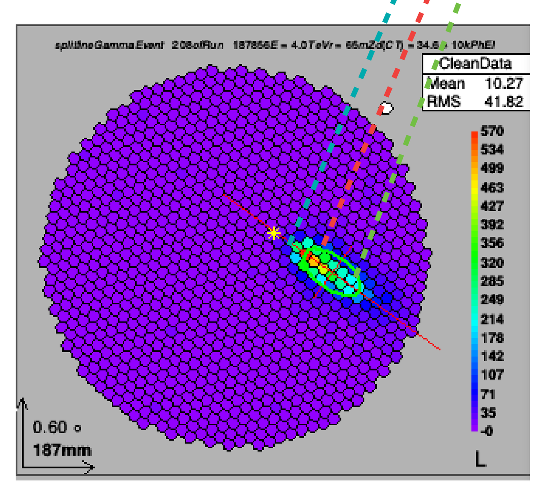


Image correction model:

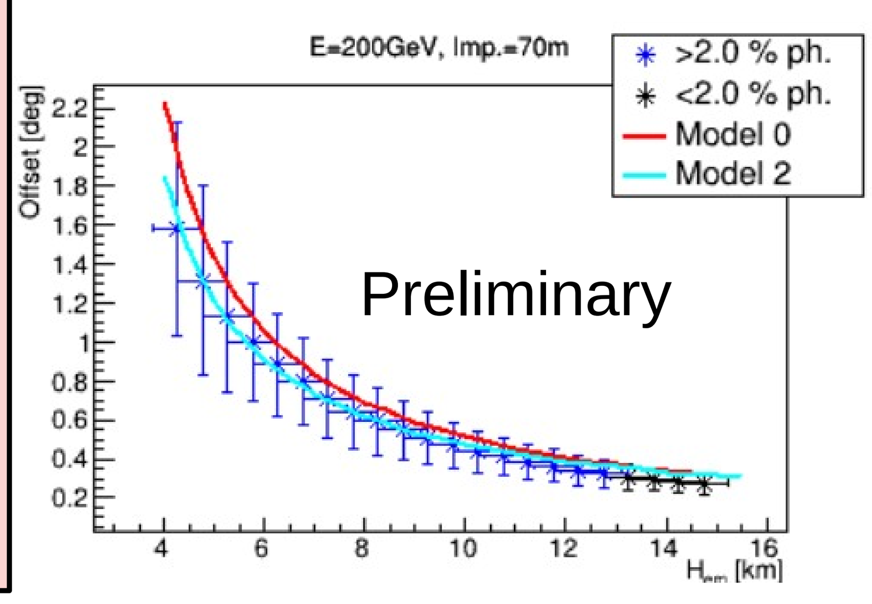
The method of bias correction would still use clear atmosphere simulations for gamma/hadron separation and shower reconstruction for which loss of performance is expected. To improve the method further we need to correct the actual images before the reconstruction
With the assumption that the Cherenkov light is produced close to the axis of the shower, and estimating the arrival direction of the event, each point on the camera can be mapped to a particular height. Knowing cloud height and transmission we can correct the signal in each pixel of the image, based on its estimated emission height below or above the cloud





Height-offset relation:

Using dedicated MC we investigate the offset angle (from the nominal gamma-ray direction) of the light produced at different heights. The relation is described roughly with the simple geometrical formula (Model 0) and can be further improved with simple fit correction (Model 2). We use this fit to assign emission height to each pixel.



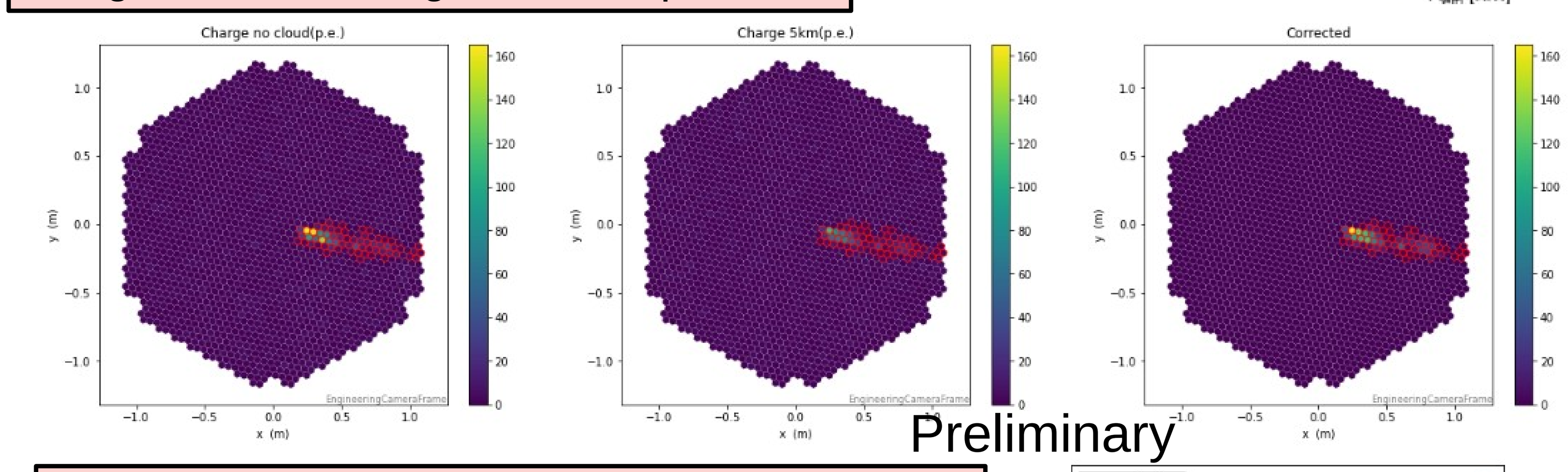
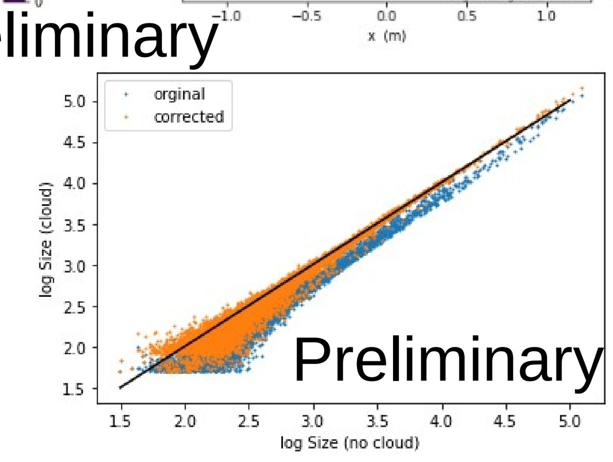


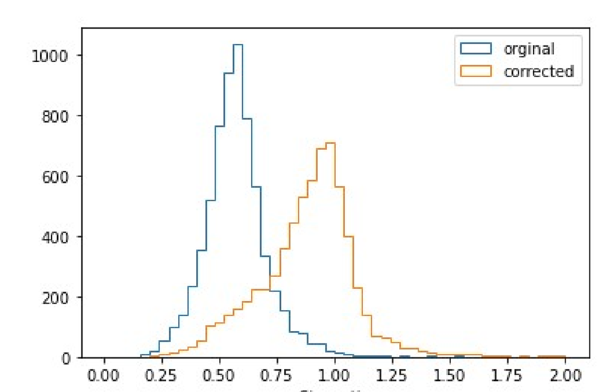
Image correction:

Example image in LST camera without cloud (left) with a 5 km a.g.l. T=0.6 cloud (middle) and with the same cloud after correction (right).



Corrected image parameters

Recomputing the Hillas parameters from the corrected image we are able to recover the average intensity of the image without the cloud. As an example the ratio of the Size parameter with and without the cloud gets close to 1 after the described correction.



Conclusions

Two methods are presented. Full simulation method takes into account the cloud presence already at the simulation level and hence it should recover the proper fluxes and provide optimal performance, but at the price of high computing resources. Second method corrects the images directly without the need for dedicated MC. It provides encouraging first results, however the detailed performance is under investigation.

This research is supported by Narodowe Centrum Nauki grant 2019/34/E/ST9/00224. The work at the University of Rijeka was performed using the supercomputer "Bura" within the Center for Advanced Computing and Modelling. We gratefully acknowledge financial support from agencies and organizations listed here: https://www.cta-observatory.org/consortium_acknowledgments/