A novel image correction method for cloud-affected observations with Imaging Atmospheric Cherenkov Telescopes

Natalia Żywucka[1], Julian Sitarek.[1], Dorota Sobczyńska[1], Mario Pecimotika[2], Dario Hrupec[4], Dijana Dominis Prester[3], Lovro Pavletić[3], Saša Mićanović[3]

[1]Department of Astrophysics, University of Łódź, Poland; [2]Institute Ruđer Bošković, Croatia; [3]Faculty of Physics, University of Rijeka, Croatia; [4]Department of Physics, J. J. Strossmayer University of Osijek, Croatia

FACULTY OF PHYSICS AND APPLIED INFORMATICS
University of Lodz

1. Introduction

The Cherenkov Telescope Array Observatory (CTAO) [1] is an emerging, ground-based observatory to gather γ rays in high energies from tens of GeV to hundreds of TeV. Out of 1500 hours of available dark time per year a fraction of data will be affected by clouds. The gathered data during cloudy nights need to be corrected in order to avoid increased systematic uncertainties. We propose a geometrical model correction of image parameters, aiming to improve the γ/hadron separation and shower direction reconstruction.

2. MC data

We considered the layout of four Large-Sized Telescopes (LSTs). We used CORSIKA 7.741 [3] to simulate the air showers' development induced by γ rays and hadrons. The atmospheric absorption and the Cherenkov detector response were simulated with SIM_TELARRAY Prod 6 [2]. Multiple atmospheric models were simulated: the clear atmosphere (T1) and 1 km thick altostratus clouds with different bases and transmissions. The simulations were analyzed in CTAPIPE 0.12 and LSTCHAIN 0.9.13:

- data reduction and calculation of Hillas parameters from the image,
- tentative stereo reconstruction,
- correction of images with the model,
- recalculation of Hillas parameters,
- gamma/hadron separation, direction reconstruction, and energy estimation with random forest models.

3. Geometrical model

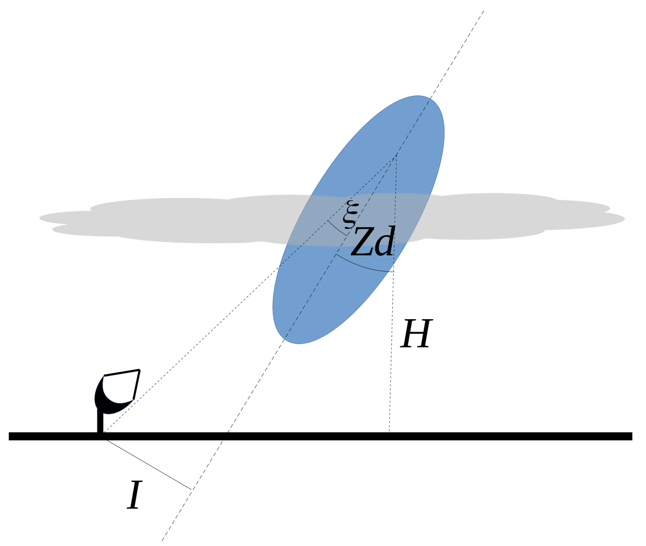

Figure 1: Geometry used in [4].

We built the geometrical model (Fig. 1) to correct the MC data for the presence of clouds at the image level.

To correct a bias, we introduce a phenomenological correction factor optimized for low zenith angle observations and not dependent on the primary γ-ray energy or impact. Subsequently, we use the preliminary estimation of the arrival direction and impact to map each point on the camera to a specific height. Finally, we correct the reconstructed signal in each pixel by an inverse of the transmission from the corresponding emission height.

4. Results

Aiming evaluation of the correction performance with the developed model, we evaluated typical performance parameters of the Cherenkov telescopes, i.e., energy and angular resolution, sensitivity, and compared them with different analysis schemes for cloud-affected data, namely no correction, data correction with/without additional cleaning (AC; by a factor of $1/T_c$), dedicated MC simulations, and for cloudless data.

Fig. 2 shows an example image corrected with our method. The simulations with the cloud result in reduced light yield in the head part of the shower. After the correction, the head part of the image recovers the light level of T1 simulations. The top panels show T1 image, image with additional light attenuation in the cloud, and the corrected image (left to right). The bottom panels display the correction factor applied, the ratio of reconstructed signals of uncorrected image to T1 image, and corrected to T1 images (left to right).

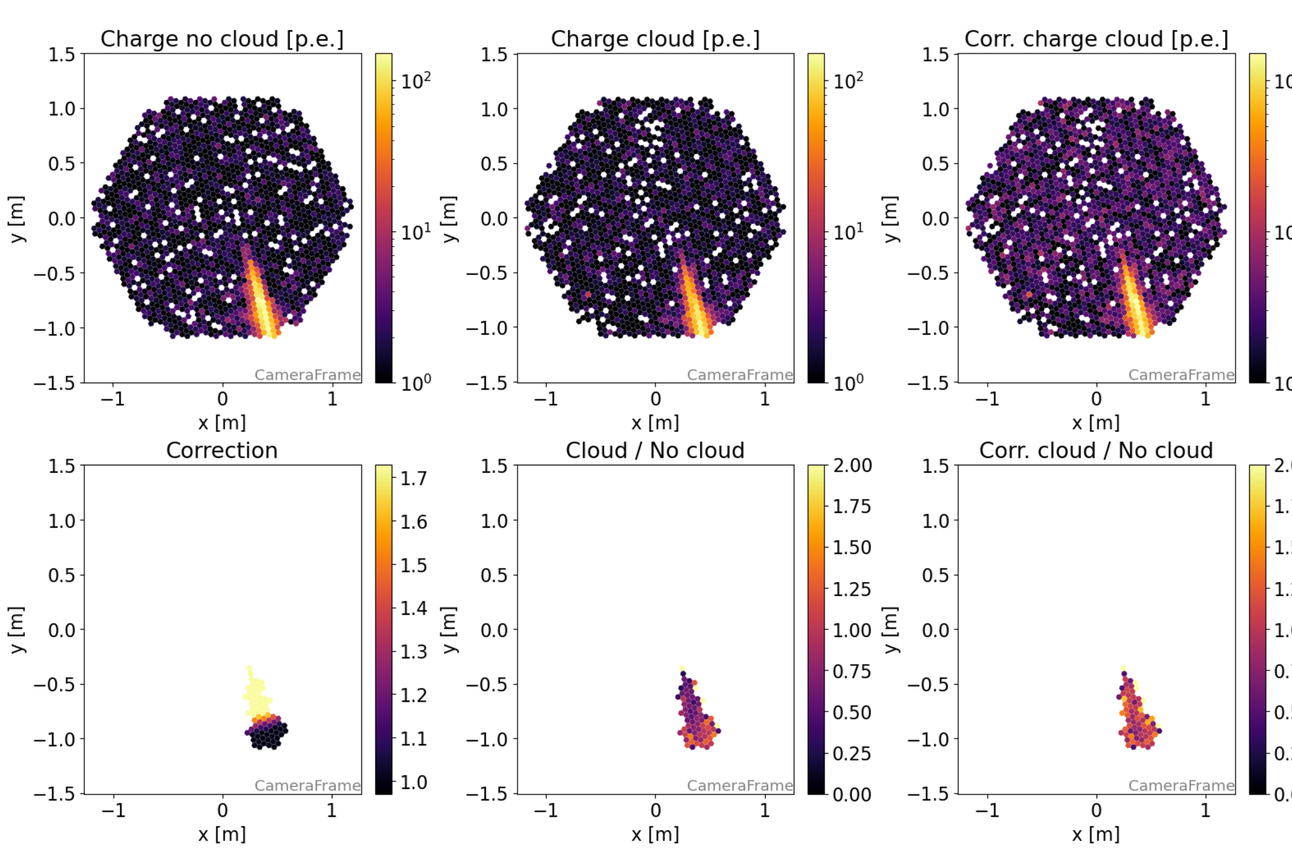

Figure 2: Light attenuation correction (h=7 km, T=0.6 cloud) [4].

Fig. 3 displays performance parameters, namely energy resolution corrected for bias (left panel), angular resolution (middle panel), and sensitivity (right panel) of the MC simulations of h = 7 km and T = 0.4 cloud.

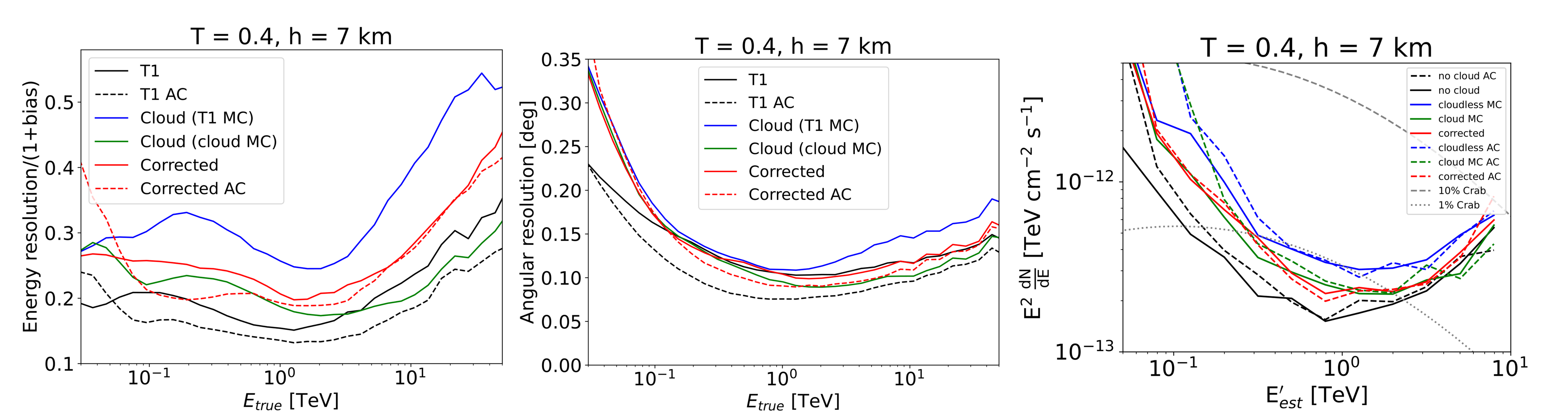

Figure 3: *Left*: energy resolution corrected for bias, *middle*: angular resolution, *right*: sensitivity of h=7 km, T=0.4 cloud [4].

The performed parameters can be recovered with both cases of the correction method (standard and additional cleaning) at the entire energy range. At the price of slightly increased systematic errors, the proposed method can be applied at energies above the analysis threshold for clouds with the transmission of $\gtrsim 0.6$. The method is validated using low-zenith simulations. For observations at a much larger zenith angle ($\gtrsim 45°$), additional factors could reduce its performance and reliability.

5. Conclusions

The geometrical model developed to correct the cloud presence during the data gathering is valid for application in stereoscopic IACT systems, in particular in cases when slight increases of systematic uncertainties are acceptable. Our correction method performs comparably to techniques using the dedicated MC simulations. It corrects the images directly without the need for time-consuming and resource-expensive dedicated MC simulations. One of the practical use cases would include data taken in the presence of fast varying clouds with rather low opacity or medium/high height. Further possible use of the method is the fast online or on-site analysis. Moreover, the method would allow to improve the reliability of derived fluxes for observed flares of fast transients, that need to be circulated quickly within the community. **Check out [4] for more details on the method and analysed cases.**

References

[1] Acharya, B. S., Actis, M., Aghajani, T., et al. 2013, Astroparticle Physics, 43, 3
[2] Bernlöhr, K. 2008, Astroparticle Physics, 30, 149.
[3] K. Bernlöhr, Astroparticle Physics 30 (2008) 149
[4] Żywucka, N., Sitarek, J., Sobczyńska, D., et al. 2024, A&A, 685, A165.

Acknowledgements

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 on: lst1.iac.es/acknowledgements.html