# Effect of clouds on the Ultra High Energy Cosmic Rays Observations by the JEM-EUSO Space Observatory

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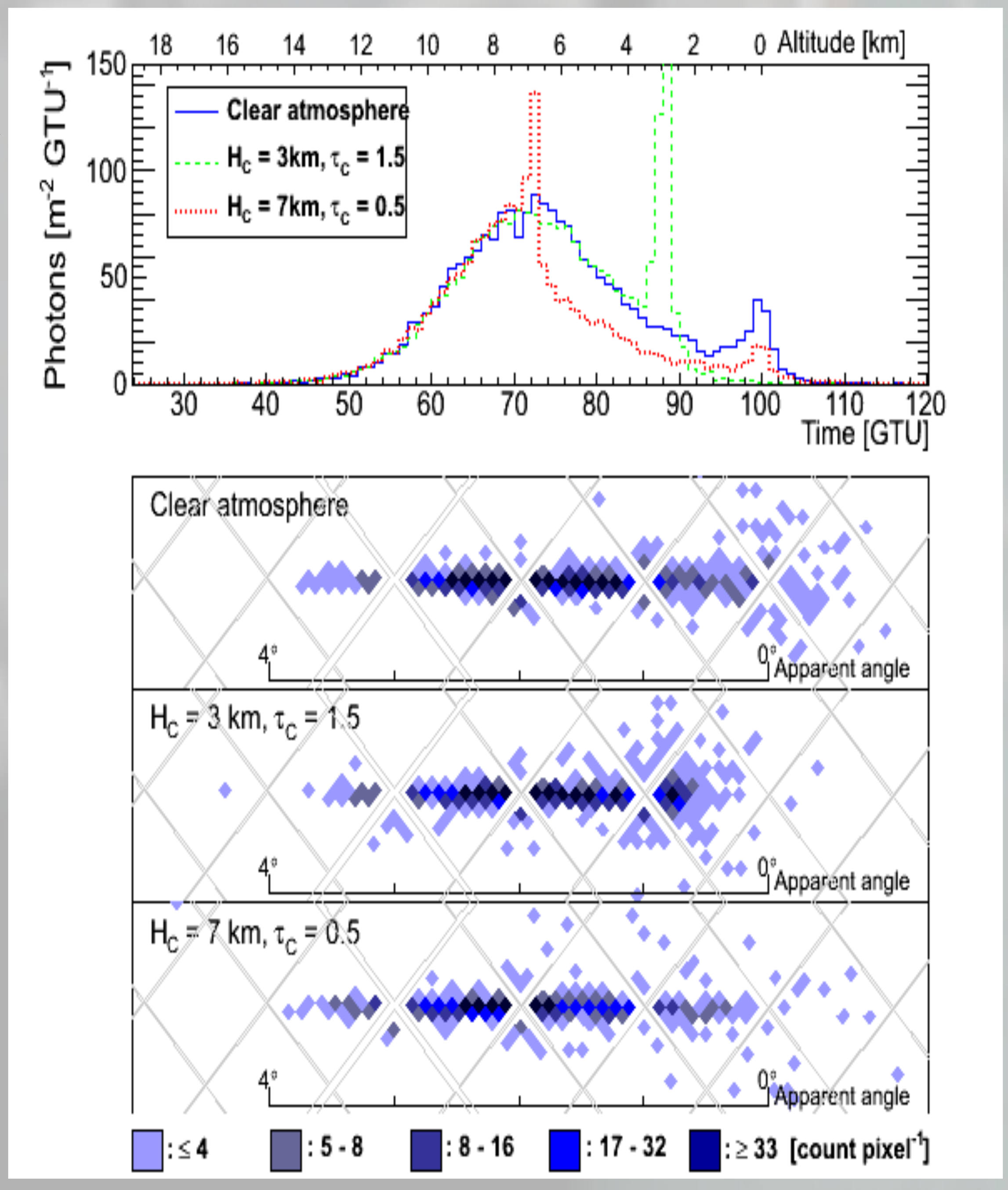
**Abstract:** JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) is a space mission that aims is to detect Ultra High Energy Cosmic Rays (UHECRs) and Extremely High Energy Cosmic Rays (EHECR). Since it will use the atmosphere as a detector, it is important to monitor the atmospheric conditions when an event is detected, to account its effects on the measurements. In this work we will focus on the effects of clouds in the UHECR and EHECR detection.

## Introduction

JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) is the space mission aiming to detect Ultra-High Energy Cosmic Rays (UHECR) and Extremely High Energy Cosmic Rays (EHECR) by observing the Extensive Air Showers (EAS) that they originate while interacting with the atmosphere. To properly determine the energy, arrival direction of the UHECR & EHECR primary cosmic ray and its composition, a measurement of the light profile is needed. However, this profile depends on atmospheric conditions. Therefore, an atmospheric monitoring system as well as a deep understanding on how detection is affected by the atmospheric properties is needed.

## Observation principle of JEM-EUSO

The principle of the space mission is based on the measurement of the fluorescence light emitted in the direction of the telescope and in the Cherenkov light reflected on the Earth's surface (or cloud)




The information of the photons time distribution is important to reconstruct the arrival direction of the UHECR. To reconstruct the energy, the amount of produced fluorescence light is needed.

The first pannel in the right represents the arrival time distribution of EAS photons of $10^{20}$ eV and a zenith angle of 60º for three different atmospheric situations. The solid line shows the case for clear atmosphere. The dashed line, a cloudy case with an optical depth $\tau_c$=1 and an altitude Hc =3 km. And the dotted line, another cloudy case ($\tau_c$=0.5 and Hc= 11). The top axis shows the altitude at which the photons have been produced. The three bottom pannels show the EAS image in the focal surface detector for the three previous cases.

For the clear atmosphere case (second pannel), the apparent movement extends 3º and lasts 60 GTUs (=15 μs). In caseo f the presence of clouds, if $\tau_c$ is large enough, (third pannel) no shower track is visible after the cloud and the apparent EAS image will last few less GTUs and will have a lower apparent angle. However, if the shower maximum is observed, angular reconstruction can be achieved. For a cloud with small $\tau_c$, (fourth pannel), photons originated below the cloud will be attenuated but there will be still some contribution to the EAS signal. Angular reconstruction will not be affected but, due to the attenuation, the energy might be understimated if no correction is applied during the reconstruction with AMS information.

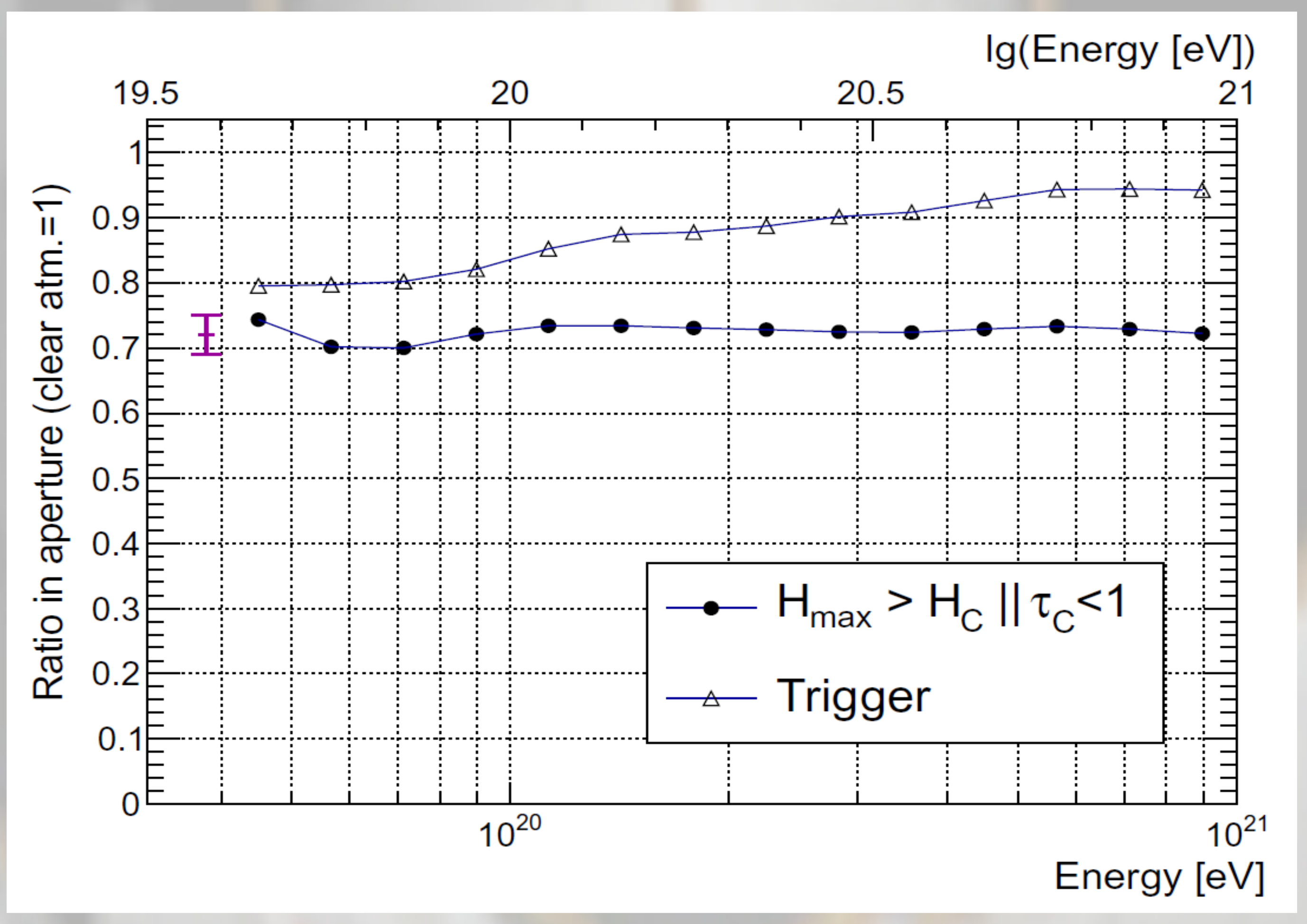
## Impact on trigger efficiency

In order to evaluate the impact on the trigger efficiency due to the cloud presence (ratio of triggered events of cloudy cases in comparison with clear atmosphere, considering an energy spectrum of $dN / dE \propto E^{-1}$ and the JEM-EUSO observation area) we simulated a large sample of EAS events on various cloud conditions.

| Cloud-top altitude | Optical depth $\tau_C$ | | | |
|---|---|---|---|---|
| | 0.05 | 0.5 | 1.5 | 5 |
| $H_C$ = 10 km | 90 | 70 | 26 | 18 |
| $H_C$ = 7.5 km | 89 | 74 | 43 | 37 |
| $H_C$ = 5 km | 89 | 82 | 69 | 66 |
| $H_C$ = 2.5 km | 90 | 88 | 89 | 88 |

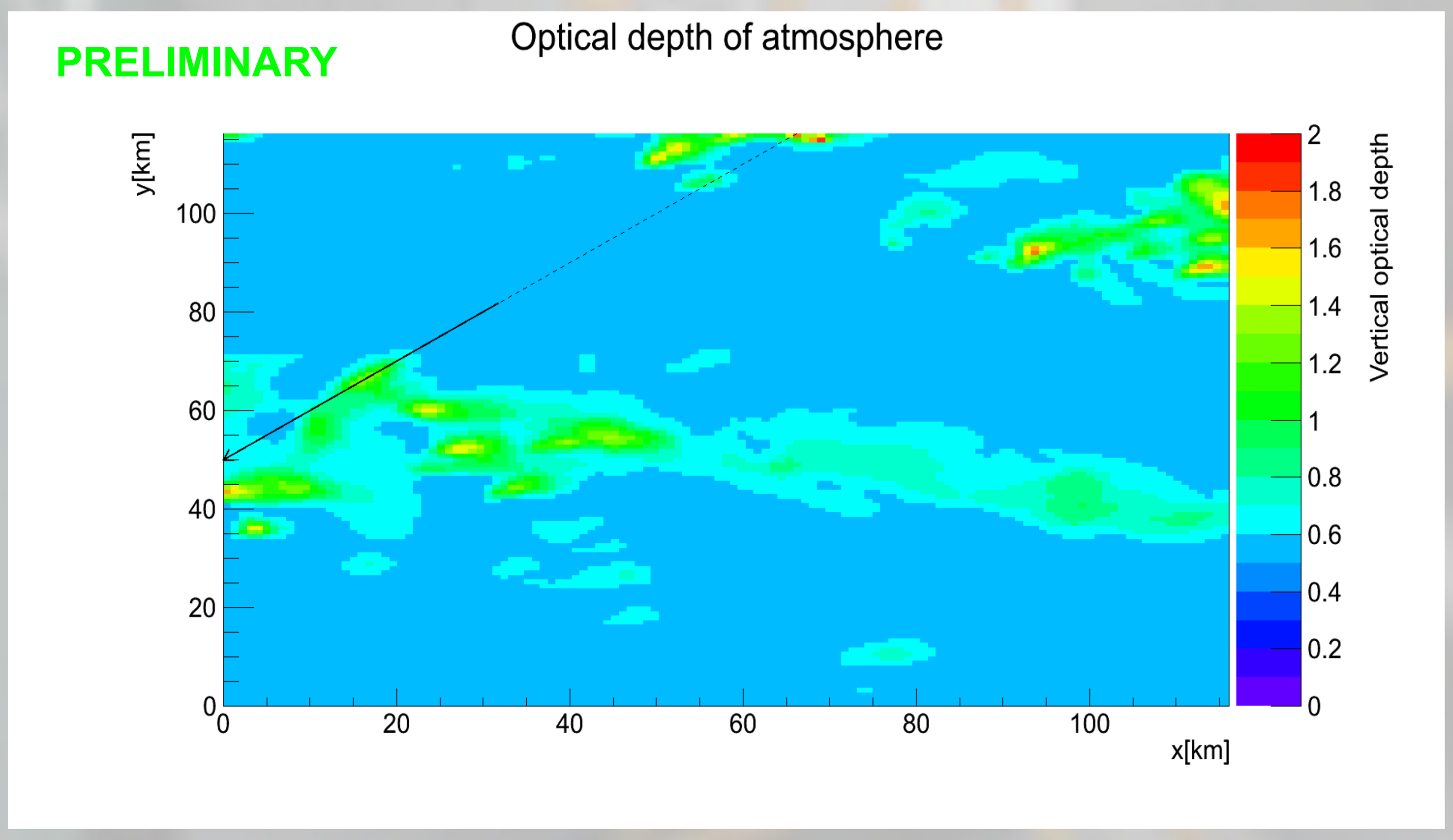
In the table above it is summarized for events above $6.3\times10^{19}$ eV the average trigger efficiency for sixteen different cloudy cases. For the calculation, the cloud probability obtained by Garino et al has been considered. The cloudy trigger efficiency is calculated as a ratio of the number of events that would trigger in cloudy conditions and the ones that would trigger for a clear atmosphere.

If this trigger efficiency for cloudy conditions is represented as a function of the energy (next graph) we determine that it is very little dependent of the energy, and it has a value of ~82%. If we consider only events whose shower maximum are above the cloud top height or $\tau_c$<1 and therefore the shower maximum is visible, this number turns out to be ~70%

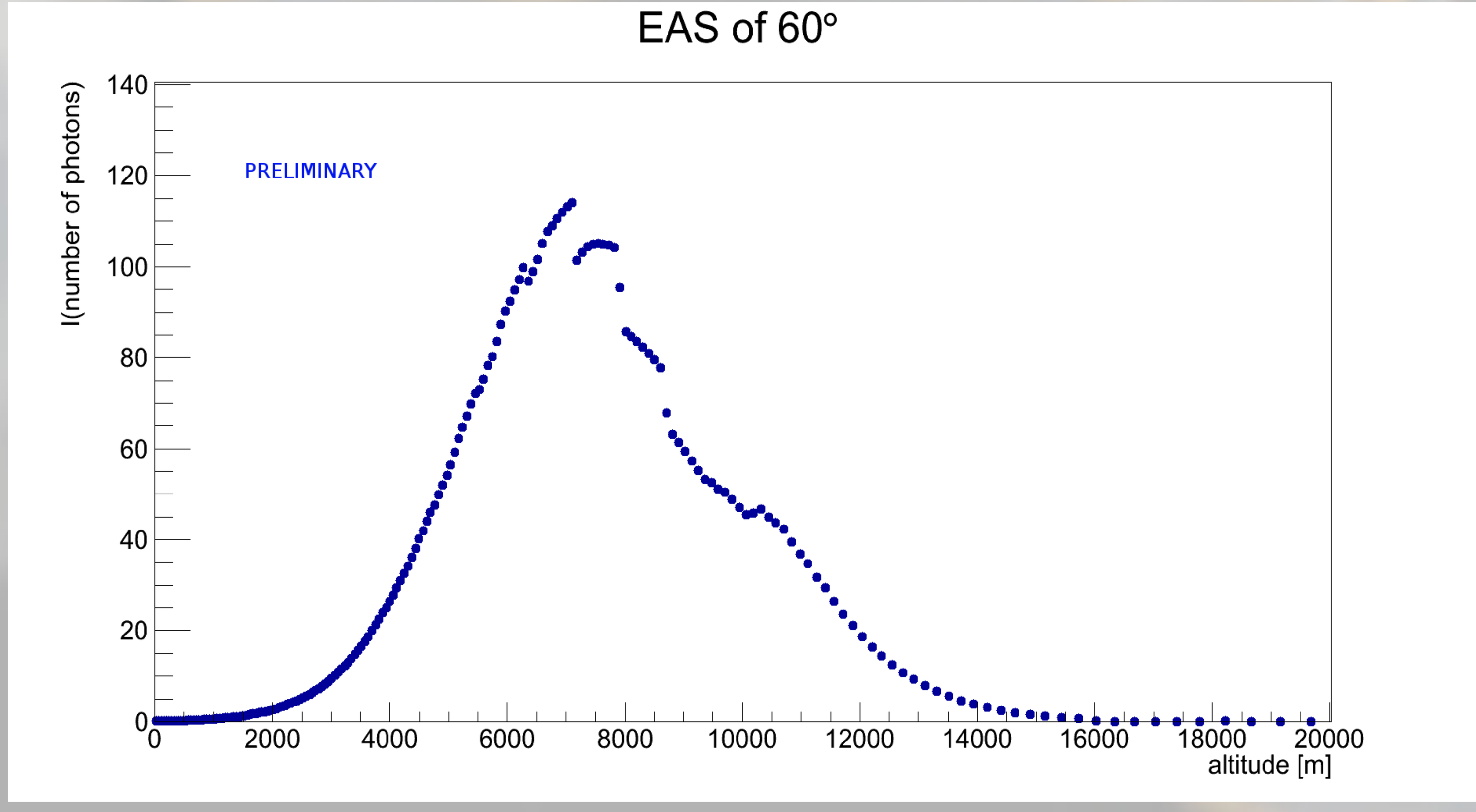



## EAS and End to End IR camera simulations

Up to now we used a simple module consisting of a uniform, homogeneous layer, to include clouds in the atmospheric conditions. However, we are working on a module of propagation of photons through inhomogeneus clouds. These clouds are simulated based on atmospheric simulations from the Satellite Data Simulator Unit (SDSU) software and considering JEM-EUSO infrared camera response.




Top figure: A simulated EAS of 60º in presence of a cloudy scenario from SCSMEX (South China Sea Monsoon Experiment)




Top figure: Number of fluorescence photons reaching the telescope for a 60º shower in the presence of the previous cloudy scenario from the South China Sea Monsoon Experiment

## Conclusion

About 80% of the showers produced in cloudy conditions will be detected. For more than 70% of triggered EAS, cloud effect is limited (shower maximum above the cloud or the cloud is optically thin). Angular reconstruction will not be affected by optically thin clouds. For optically thick clouds, its resolution will be limited. Energy reconstruction will be understimated in cases of optically thin clouds. For optically thick clouds whose top altitude are lower than the shower maximum, energy reconstruction is feasible. To reach a deeper understanding of how clouds affect the EAS detection, a more reallistic model is being developed.

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