Thick & Thin Cloud Top Height Retrieval Algorithm with the Infrared Camera & LIDAR of the JEM-EUSO Space Mission.

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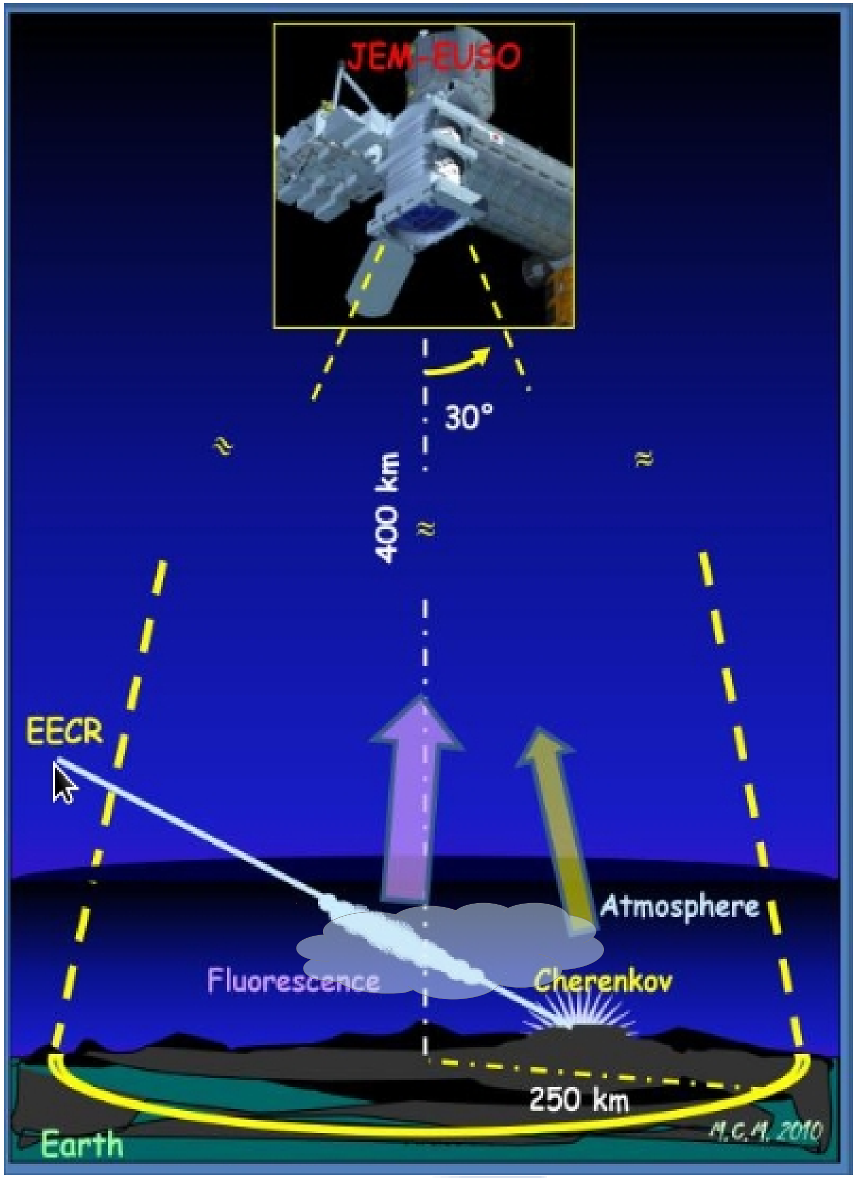
Why it is crucial to detect clouds @ JEM-EUSO FoV ???

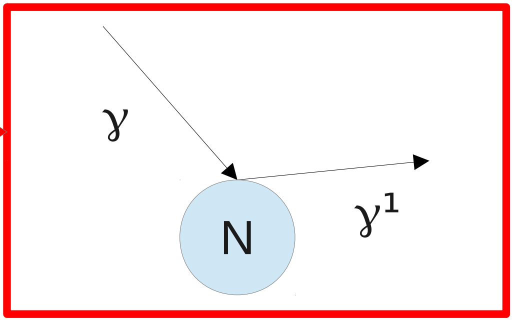
- Cloud effect on the EAS detection
- JEM-EUSO cloud efficiency
- 3D clouds UV simulation
- Cloud top height reconstruction



EAS photon interaction

When photons from the Extensive Air Shower interact with the atmosphere, they can be:

- **Scattered (reflected)**
- Absorbed
- Transmitted



$S \approx N_0 \, e^{-\delta scat(dl)}$

These processes strongly depend on the presence of clouds, leading to systematic errors in the reconstruction of the UHECRs and EECRs.

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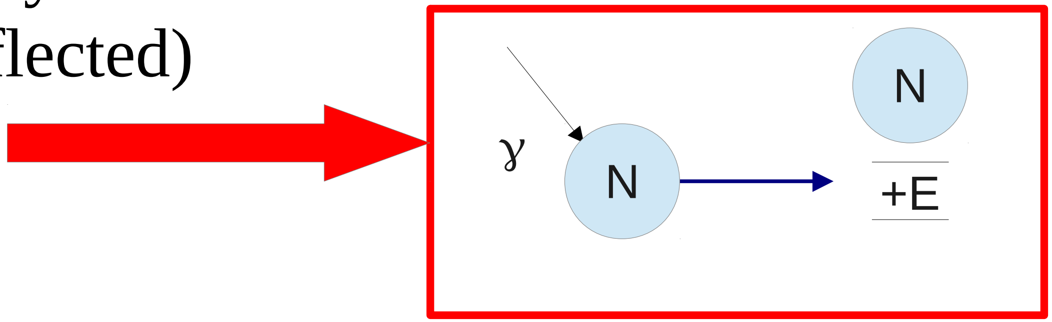

$$A \approx N_0 \, e^{-\delta abs(dl)}$$

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EAS photon interaction

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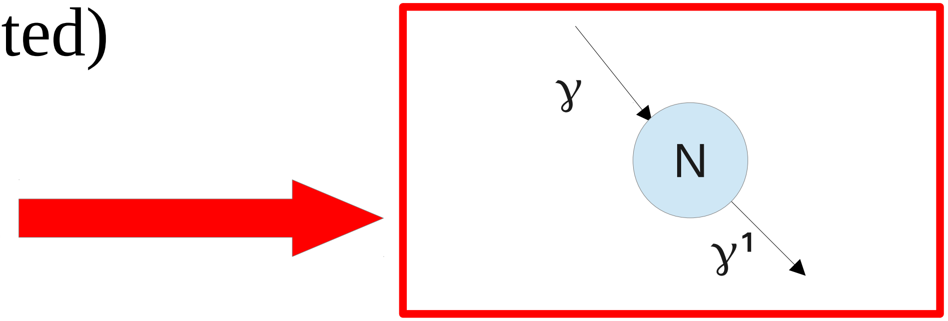
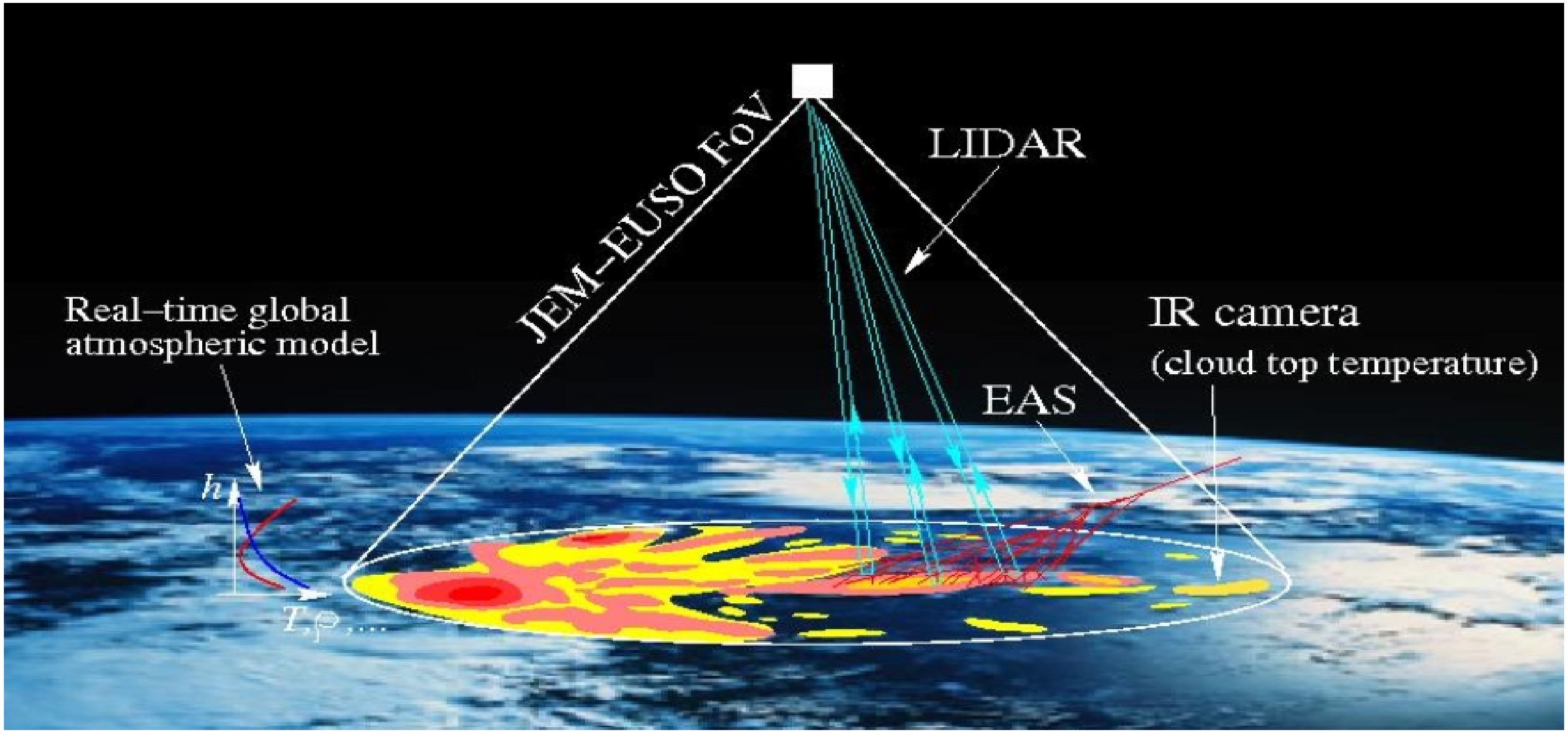


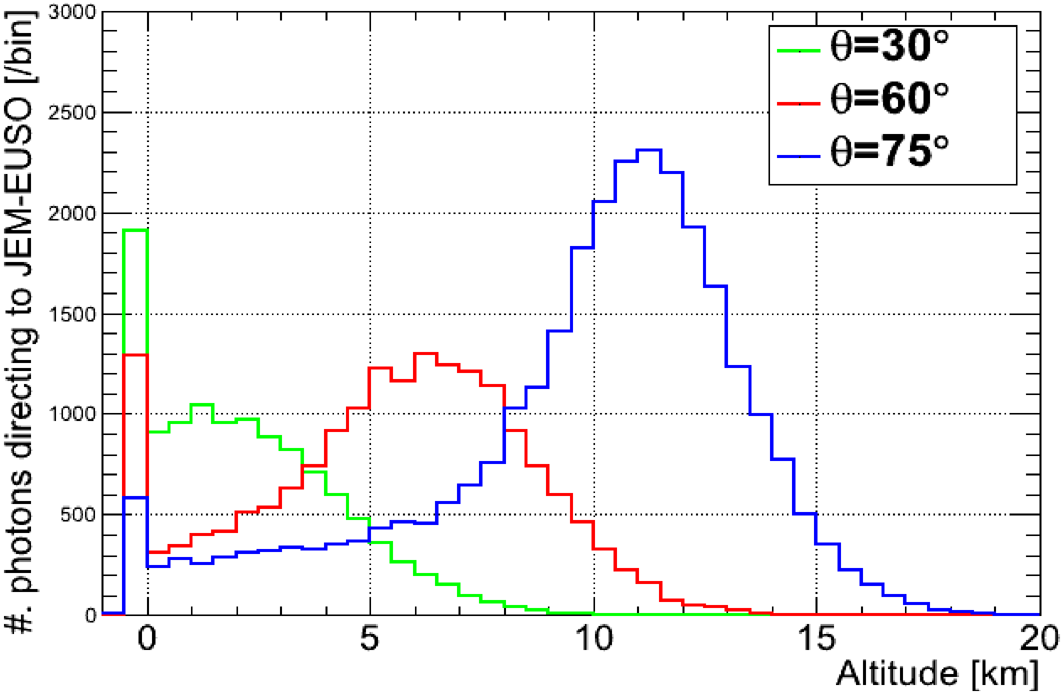
$T \approx (1\text{-}A)(1\text{-}S)$

These processes strongly depend on the presence of clouds, leading to systematic errors in the reconstruction of the UHECRs and EECRs.

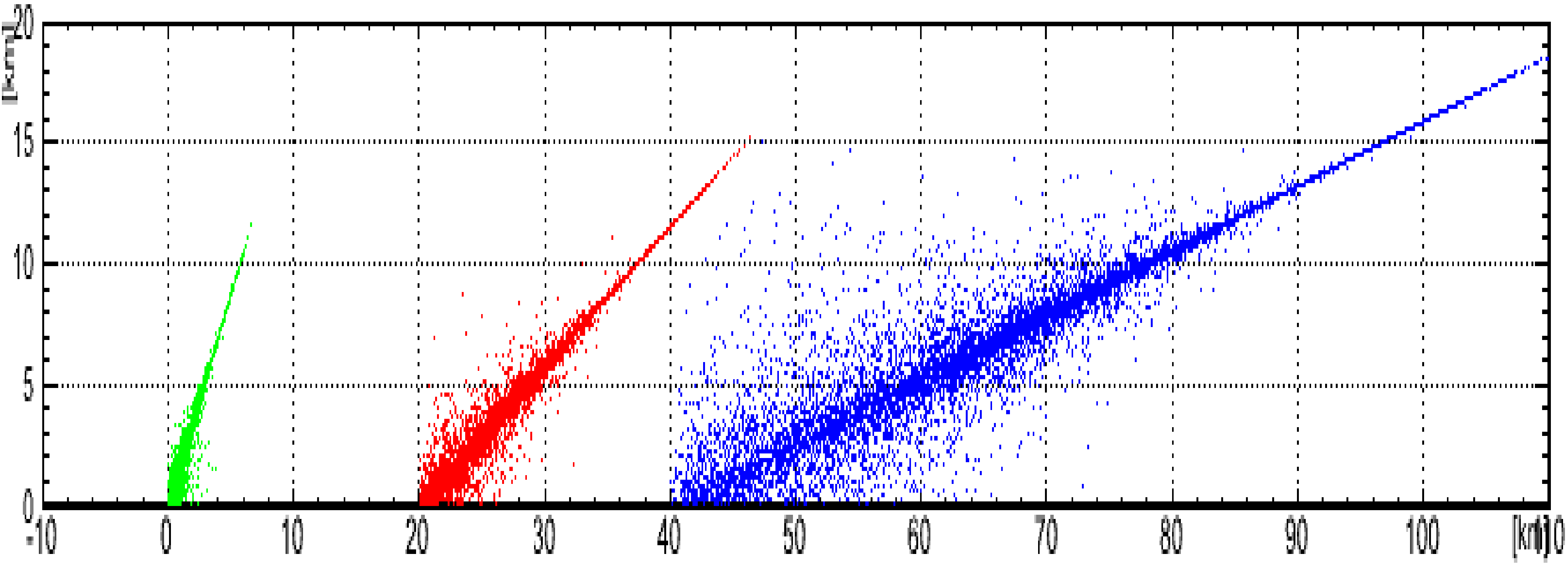
JEM-EUSO traverses over various atmospheric situations within its huge observation area. Space-based telescopes can observe EAS under certain cloudy conditions.



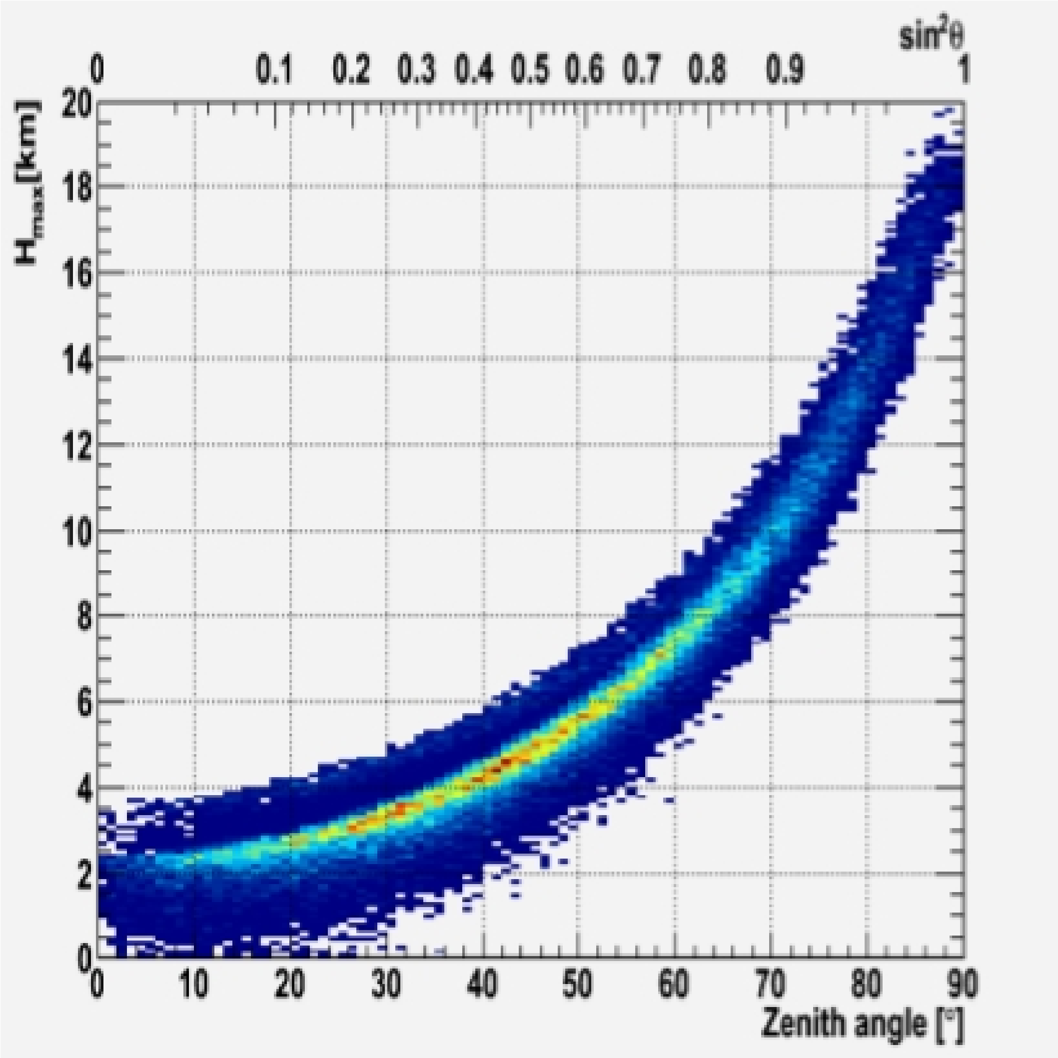
JEM-EUSO AMS payloads:
I. Infrared Camera responsability of Spain
II. LIDAR (LIght Detection And Ranging) responsibility of Japan & Switzerland



Which part of the EAS interact with the cloud depends on the altitude of the cloud, as well as on the properties of the shower (such as arrival direction)

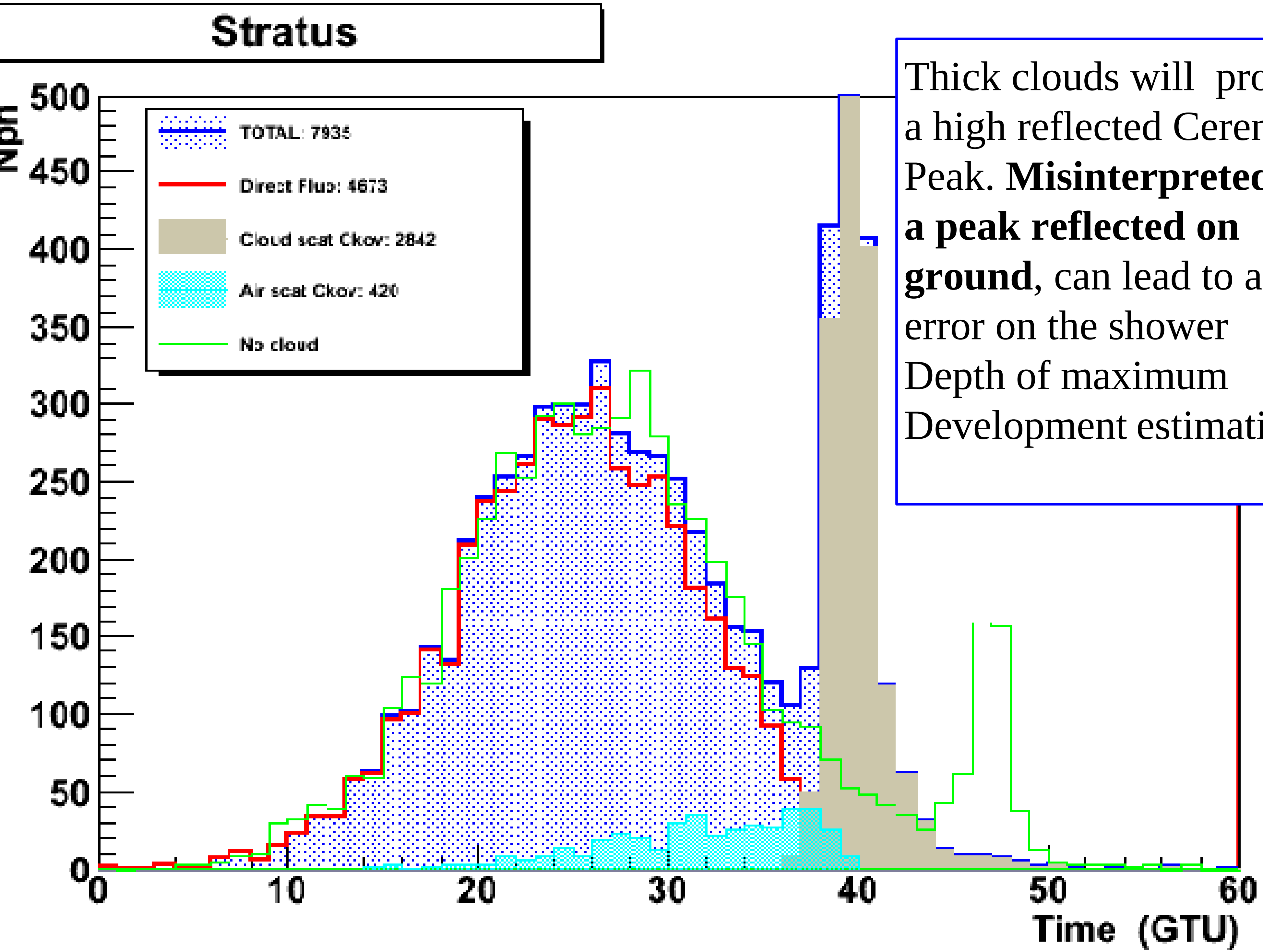


Distribution of the shower maximum depending on the incident angle



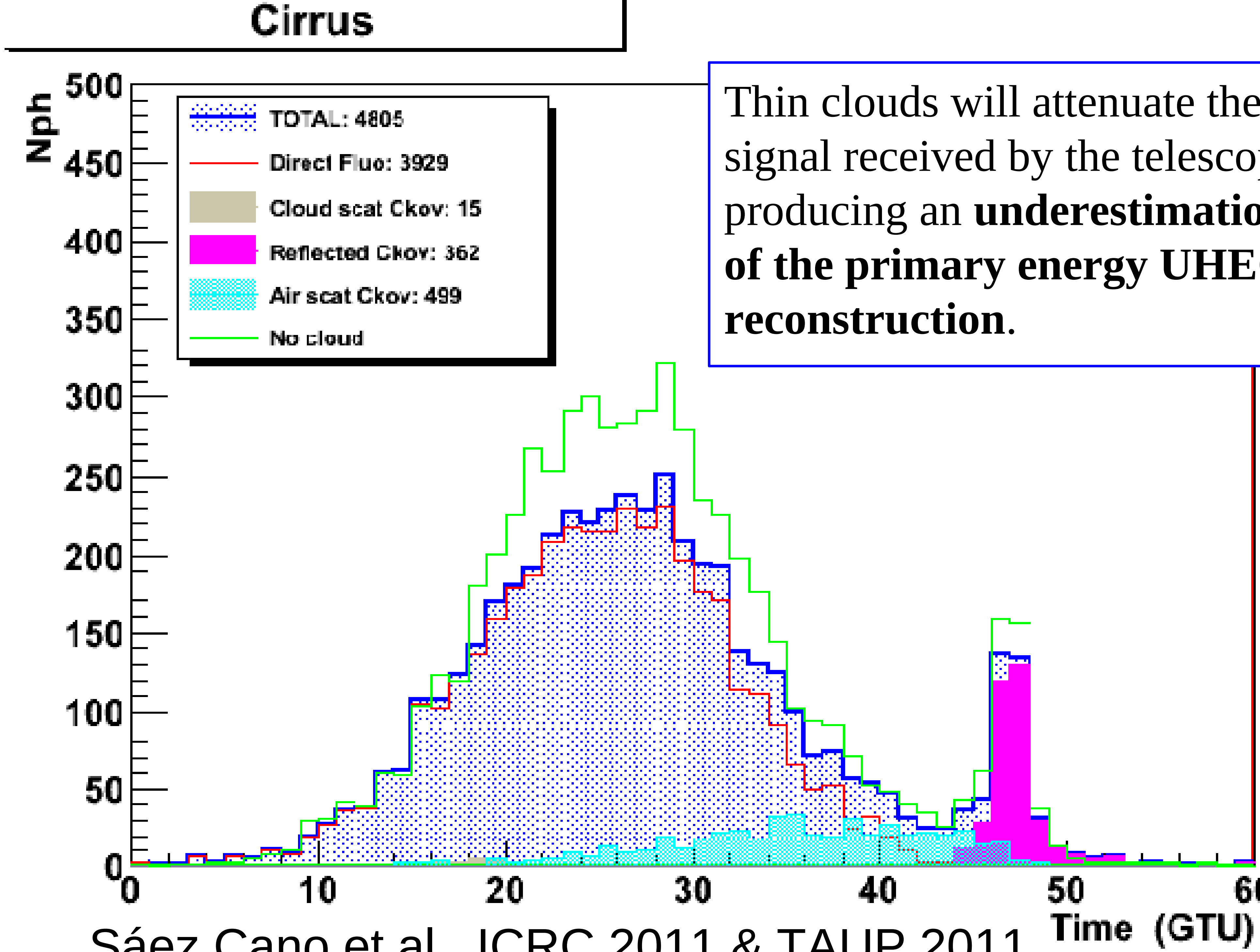
- **Protons**
- **Primary energy:**
- **3×10^{19}-10^{21} eV**

In energy range of interest the depth of EAS development (Xmax) Only varies by ~100 g/cm2. Hmax is dominantly determined by the zenith angle.



Thick clouds will produce a high reflected Cerenkov Peak. **Misinterpreted as a peak reflected on ground**, can lead to an error on the shower Depth of maximum Development estimation.

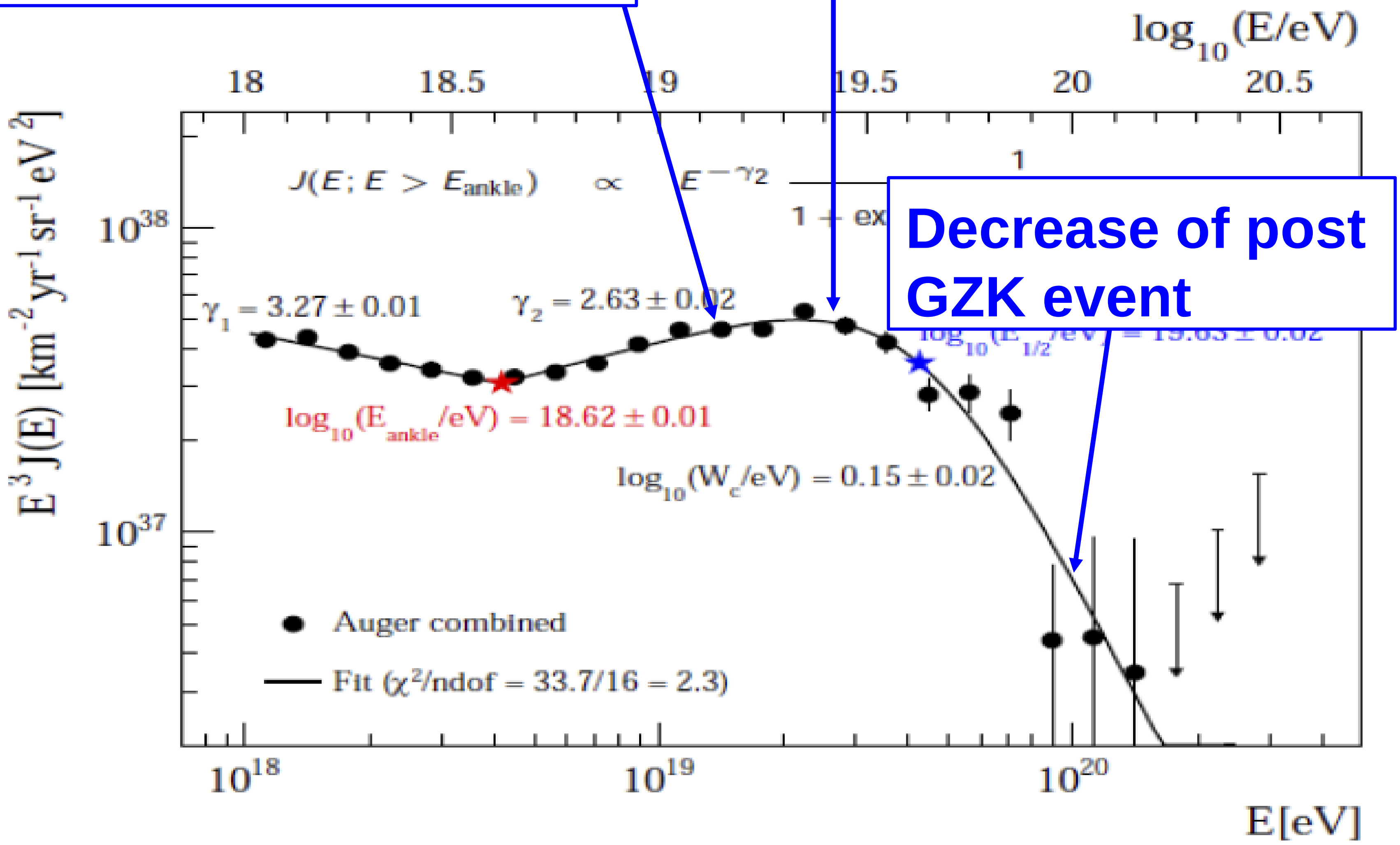
Sáez Cano et al., ICRC 2011 & TAUP 2011



Thin clouds will attenuate the signal received by the telescope, producing an **underestimation of the primary energy UHECR reconstruction**.

Sáez Cano et al., ICRC 2011 & TAUP 2011

Thin clouds effects in the UHECRs energy spectrum

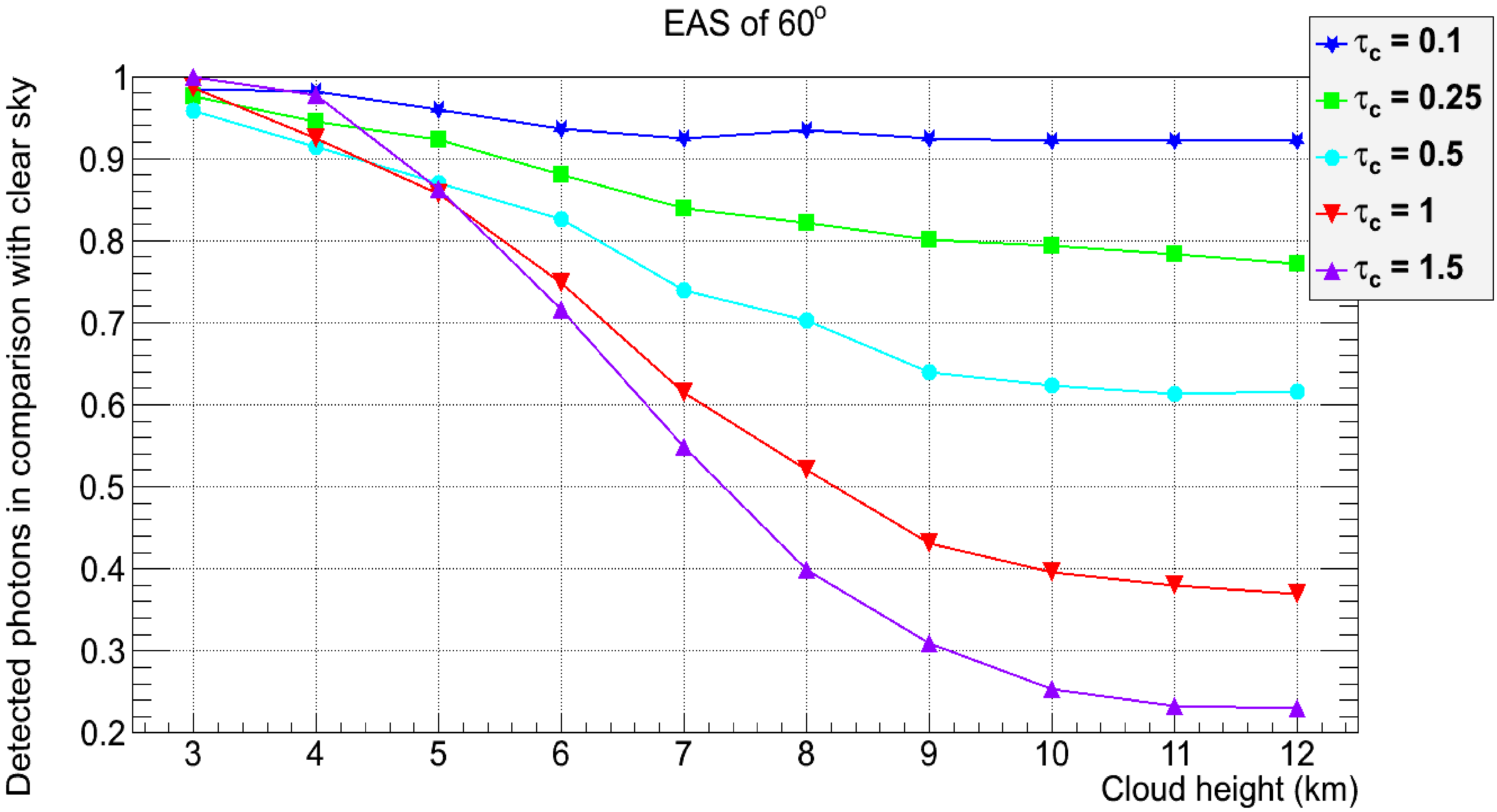


Increase of the pre- GZK abundance

GZK shift to low energies

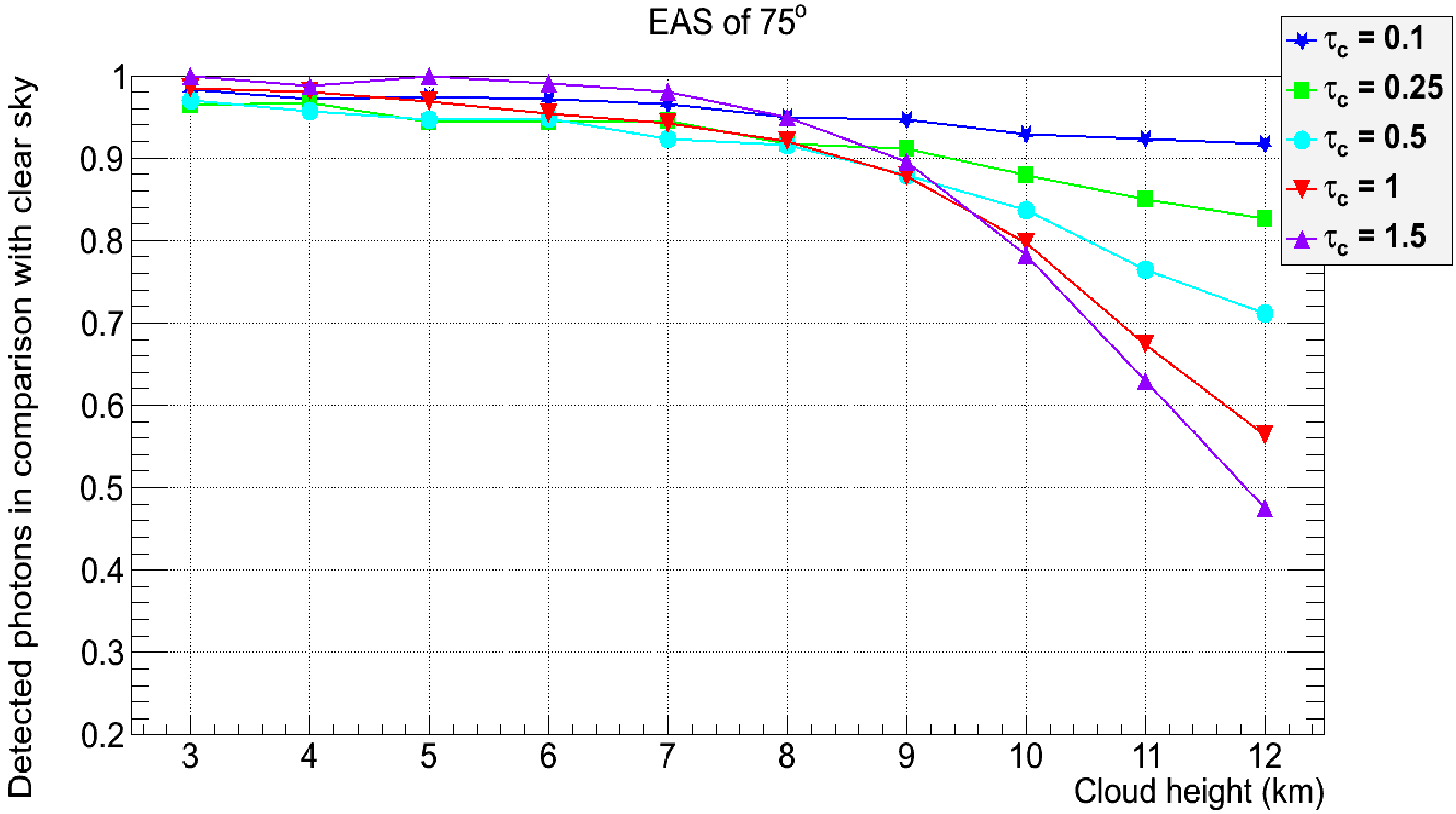
Decrease of post GZK event

Detected EAS photons under different cloudy conditions



Sáez Cano et al., Advances in Space Reseach, 2014.

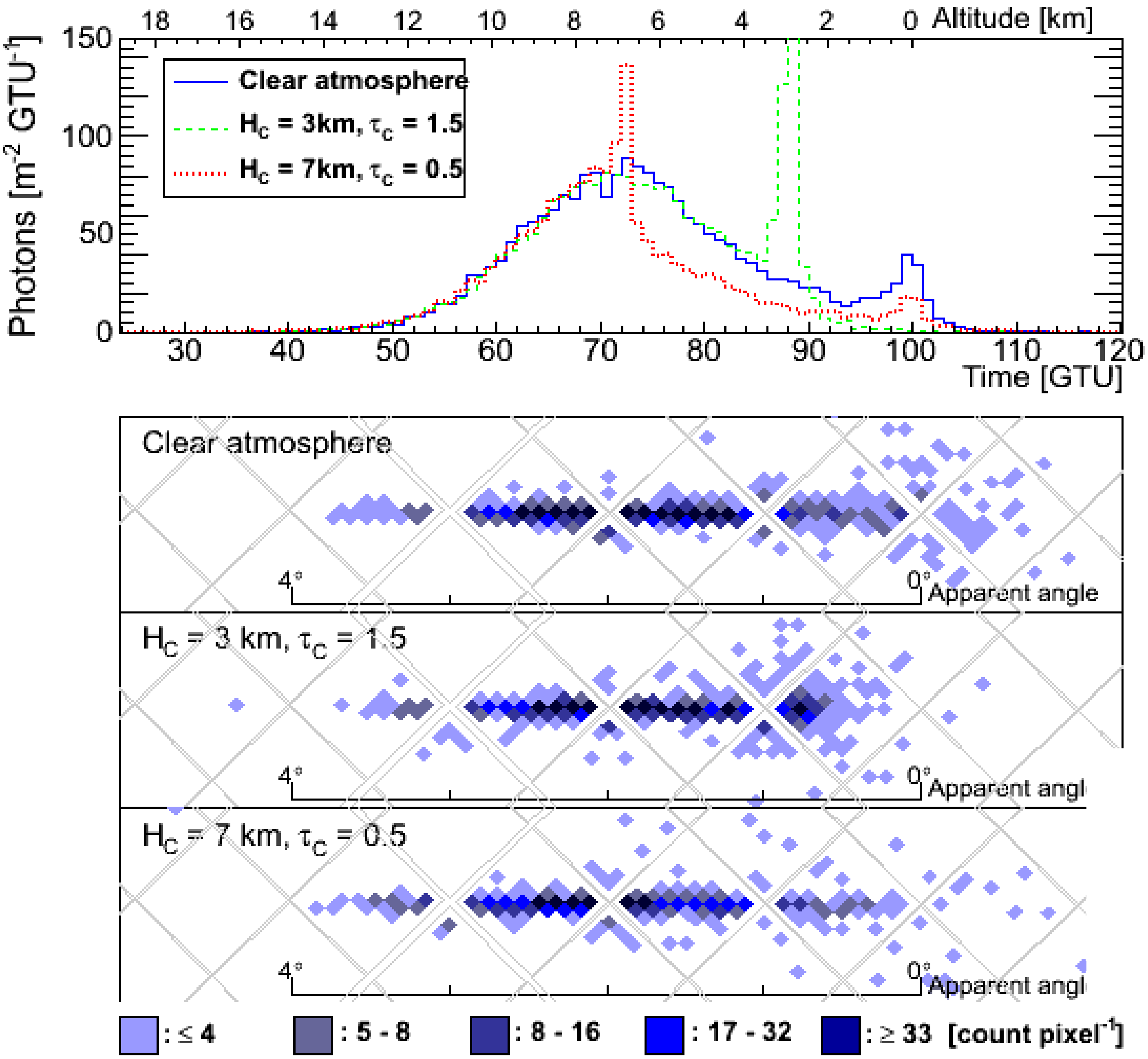
Detected EAS photons under different cloudy conditions



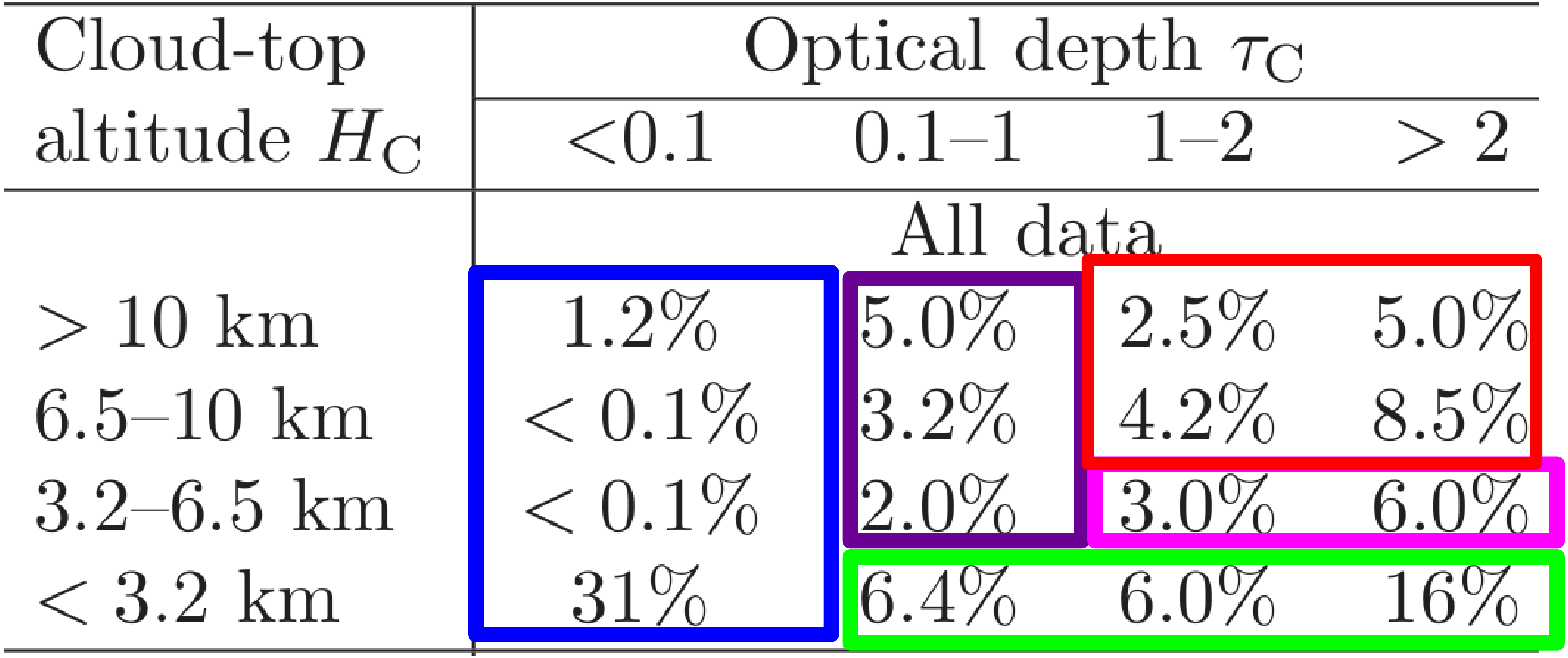
Sáez Cano et al., Advances in Space Reseach, 2014.

EAS FS image affected by clouds

JEM-EUSO coll, Exp. Astronomy 2014, in press



Cloud impact (TOVS). The JEM-EUSO Coll. ApP, 2013.



Cloud-top altitude H_C	Optical depth τ_C			
	<0.1	0.1–1	1–2	>2
	All data			
>10 km	1.2%	5.0%	2.5%	5.0%
6.5–10 km	<0.1%	3.2%	4.2%	8.5%
3.2–6.5 km	<0.1%	2.0%	3.0%	6.0%
<3.2 km	31%	6.4%	6.0%	16%

Clear atmosphere

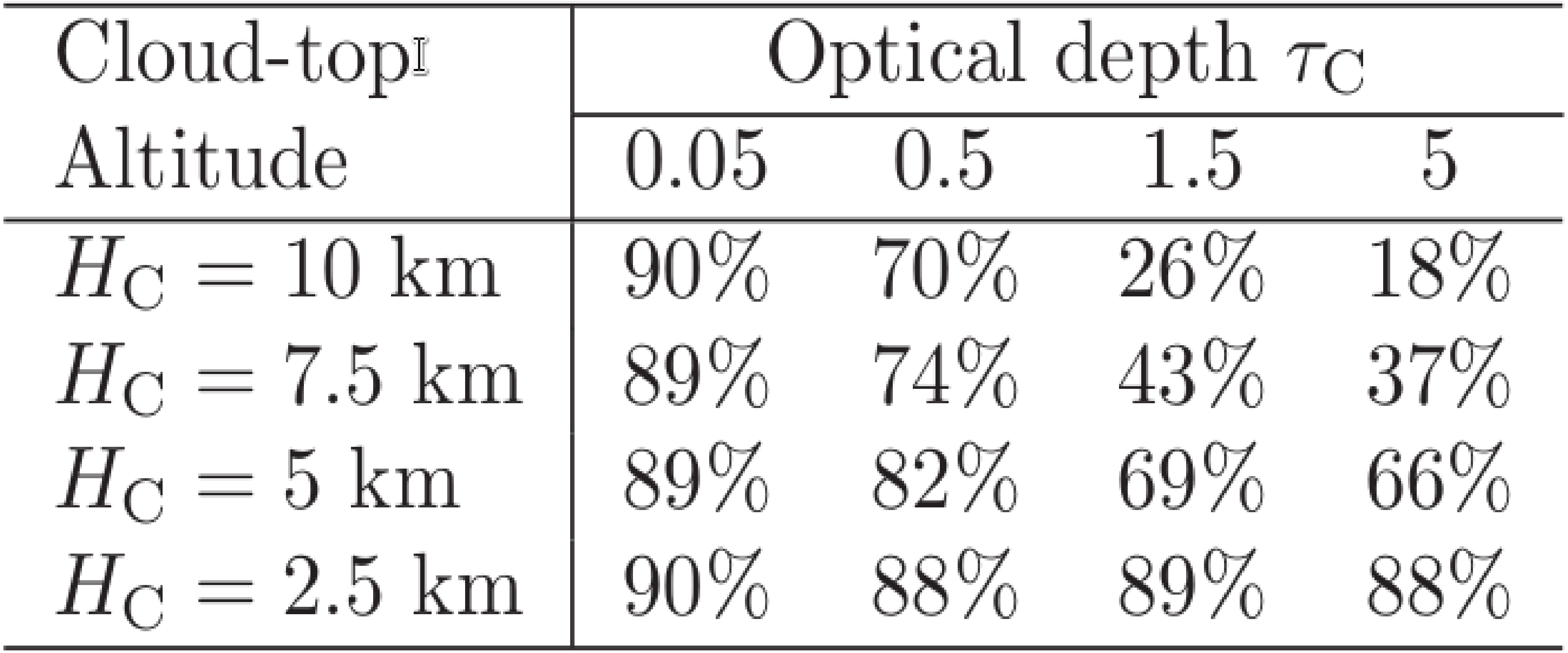
~ clear atmosphere

Observable with reduced signals

Observable for high ZA

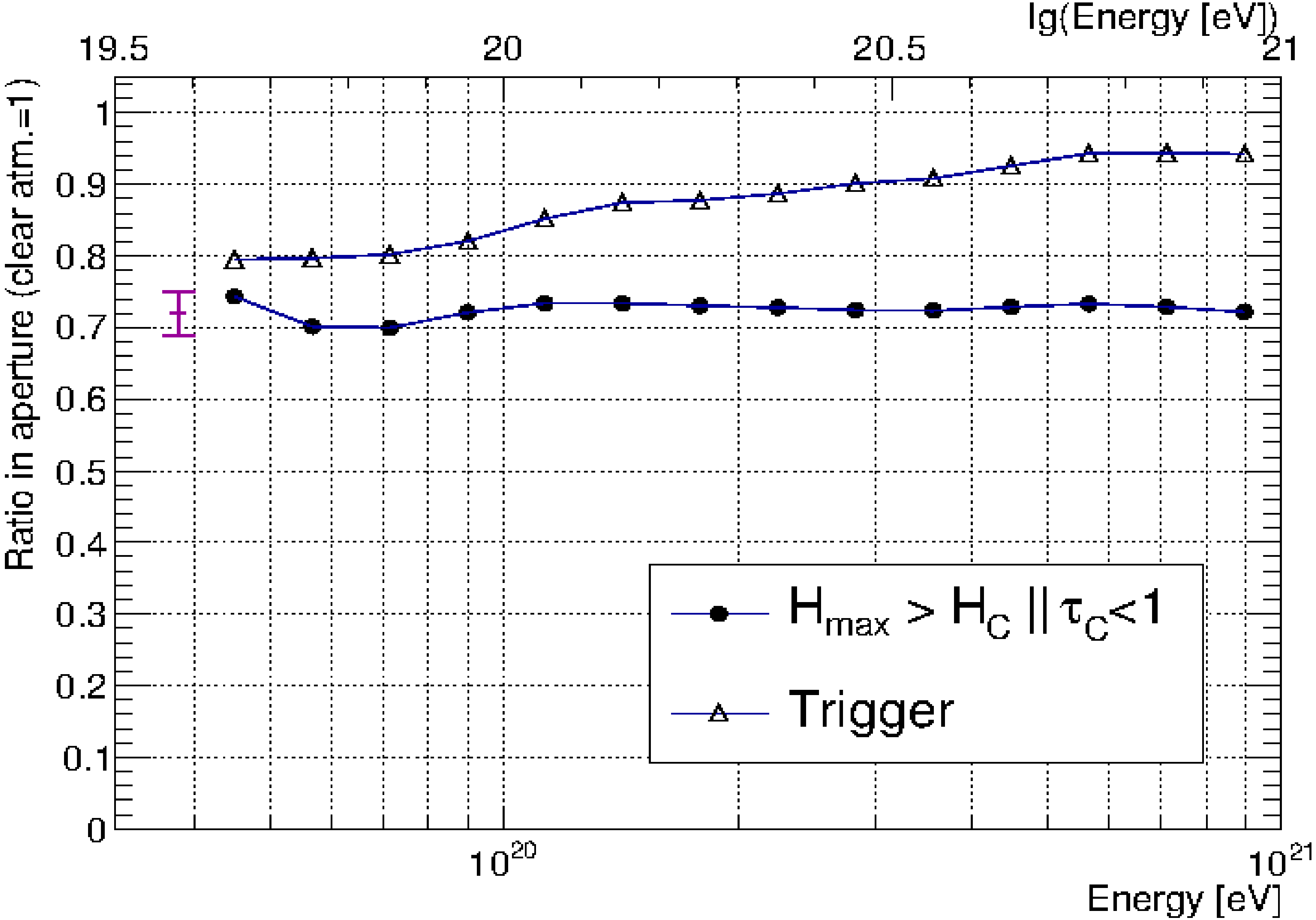
Hardly observable

Cloud efficiency for E> $10^{19.5}$ eV



Cloud-top Altitude	Optical depth τ_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%

The JEM-EUSO Coll, Astroparticle Physics, 2013



The JEM-EUSO Coll, Astroparticle Physics, 2013

Satellite Data Simulation Unit (SDSU)

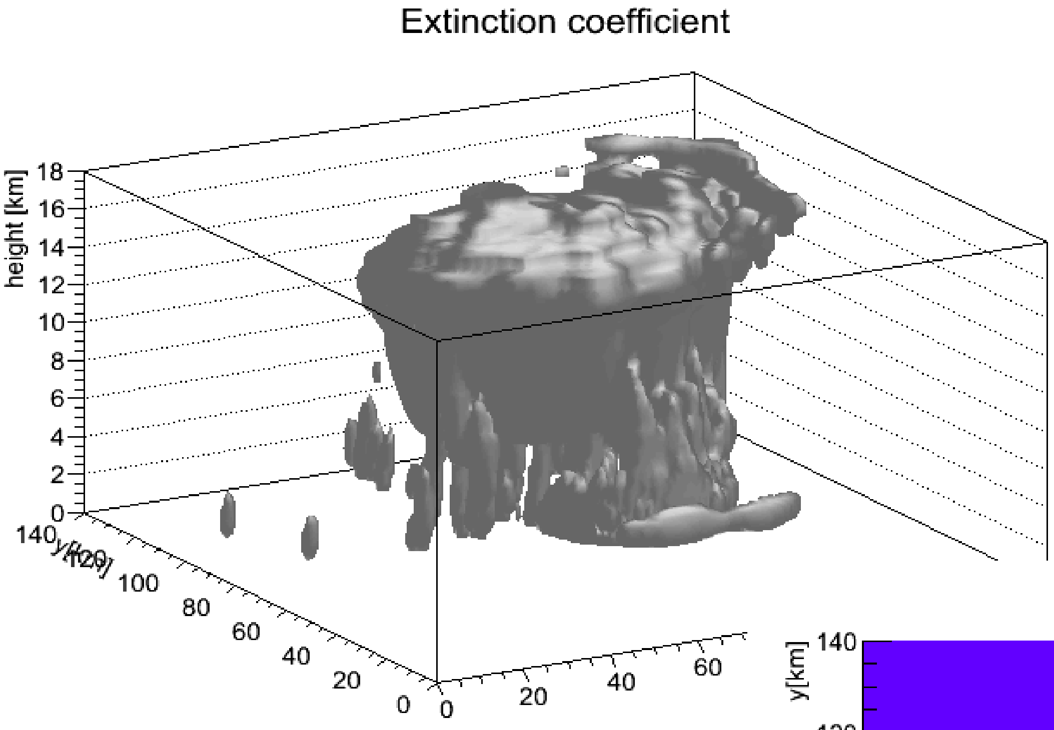
SDSU v2:

- Developed in Nagoya University.
- Simulates from 0.17 - 1000 μm.
  - IR Model: Nakajima et al. (2003).

SDSU code inputs provides for each pixel:

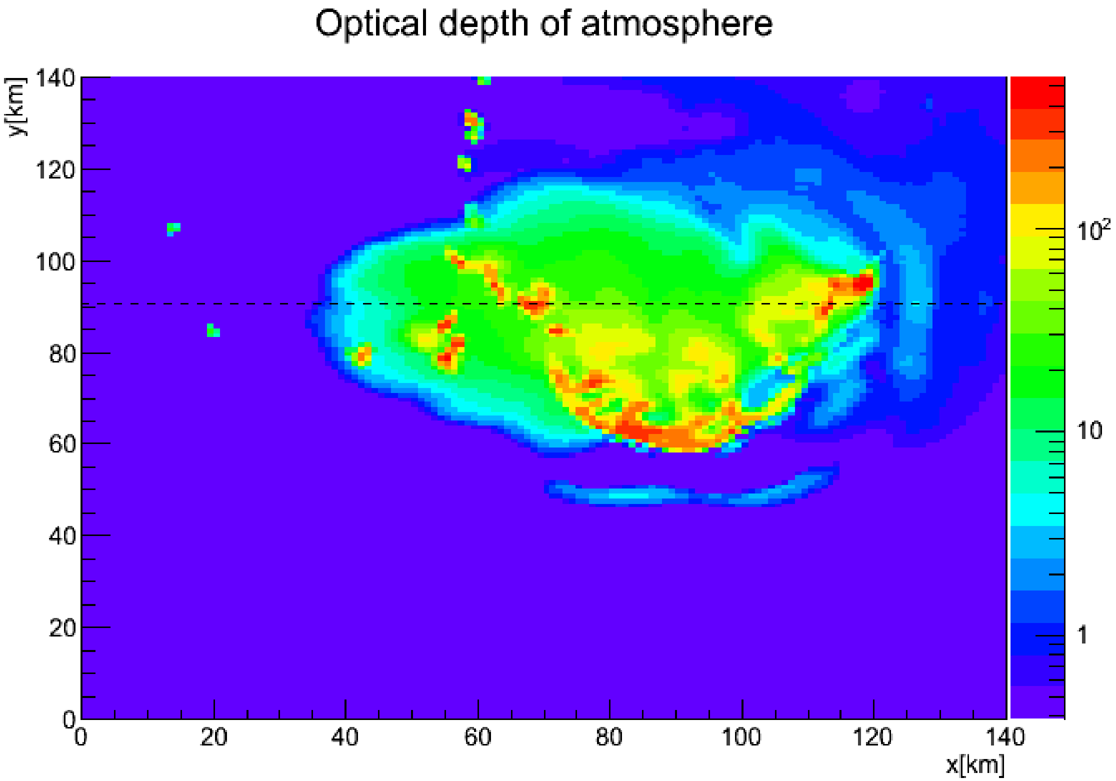
height, pressure, air temperature, relative humidity, cloud water content, rain water content, cloud ice content, snow ice content, graupel ice content, and hail ice content.

Thick cloud 3D UV simulation



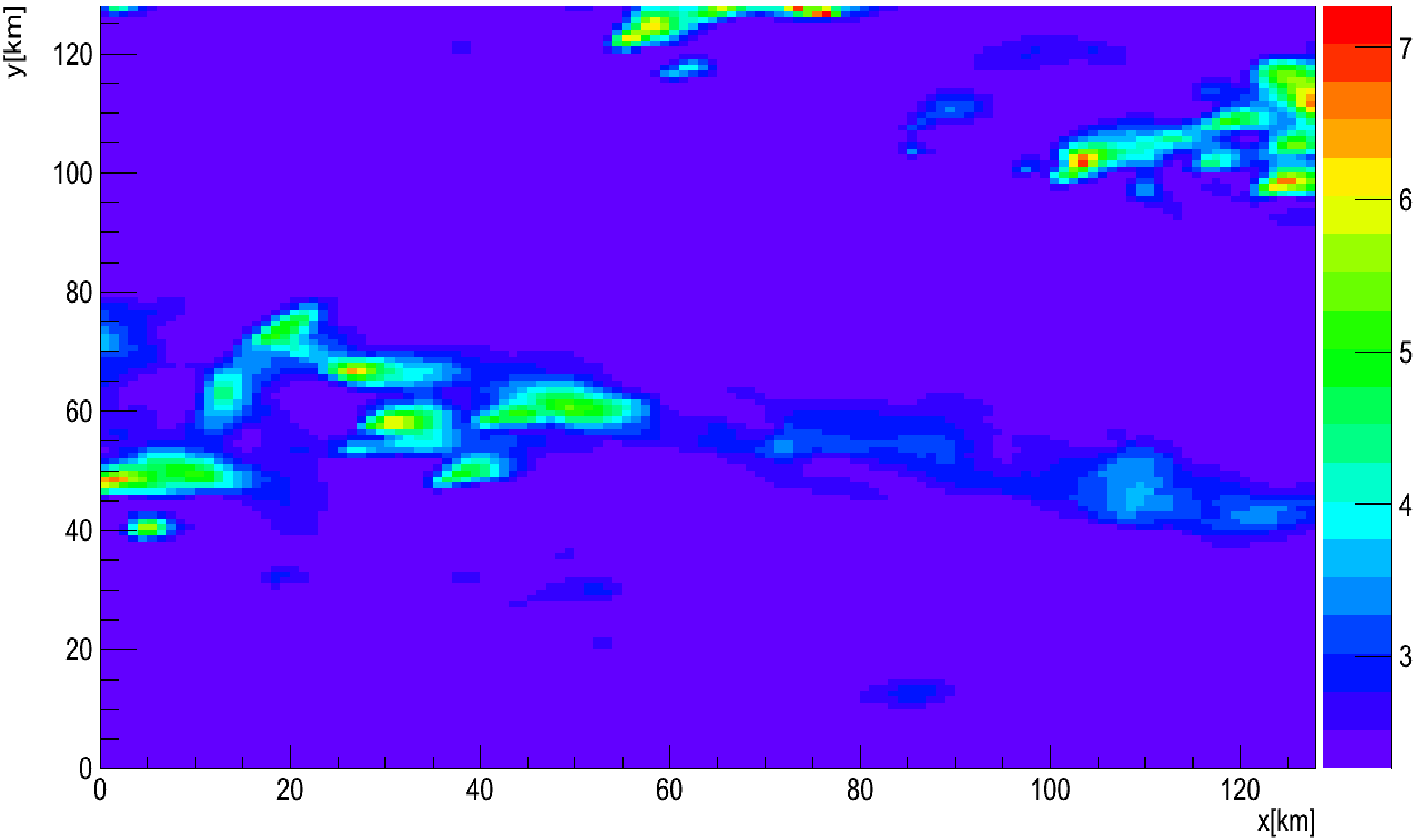
Morales de los Ríos et al.
ICRC, 2013.

Simulated cloud from the South China Sea Monsoon experiment

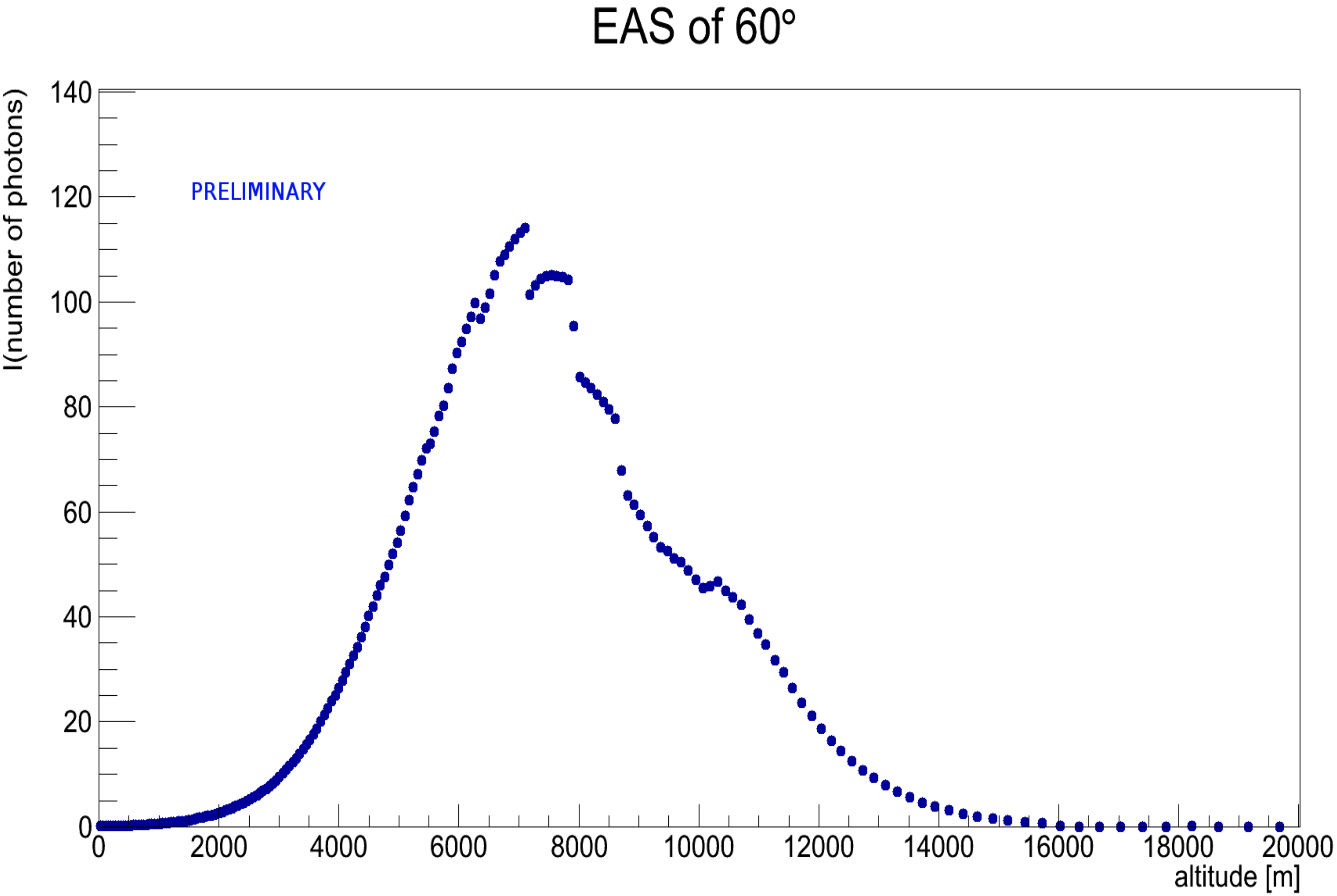


Thick and thin cloud 3D UV simulation

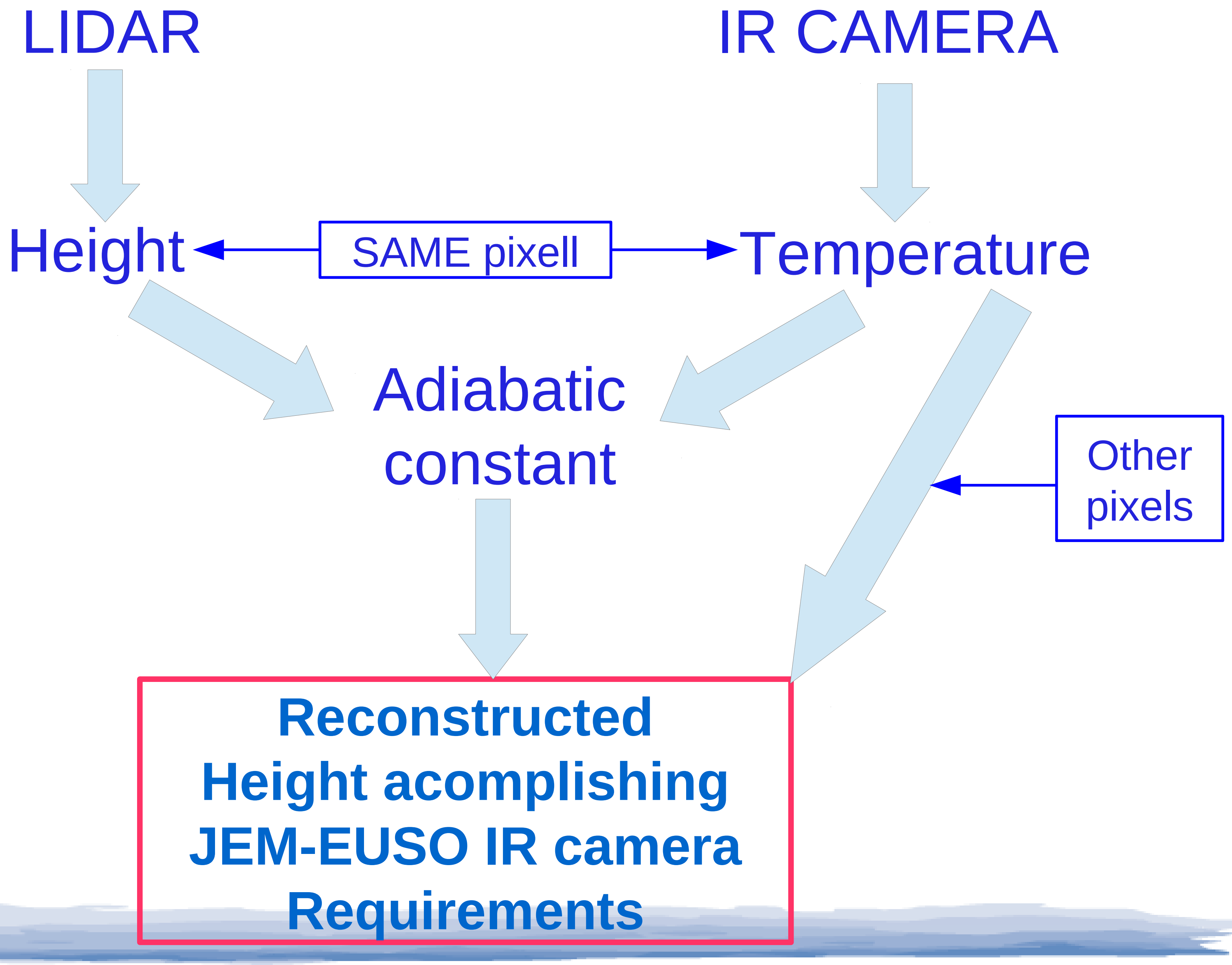
But which is the cloud top altitude?



EAS fluorescence photons progations in a 3D cloud



HEIGHT RECONSTRUCTION ALGORITHM



LIDAR

IR CAMERA

Height

SAME pixell

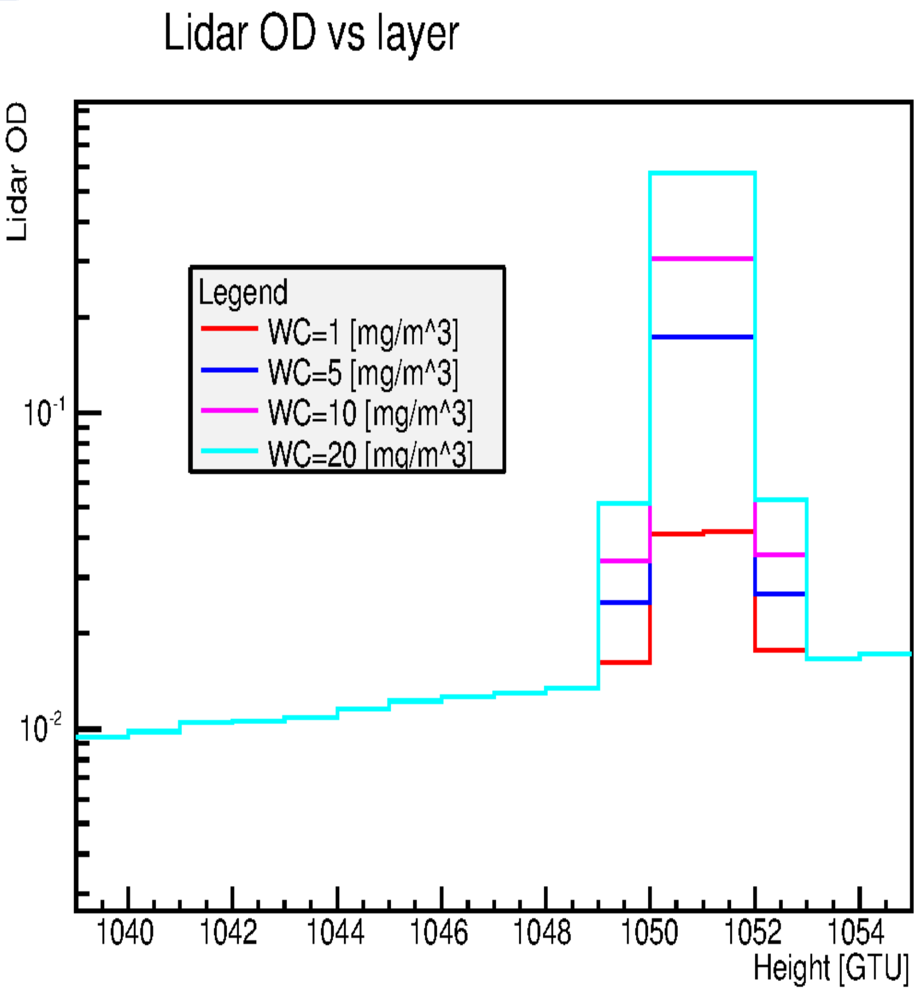
Temperature

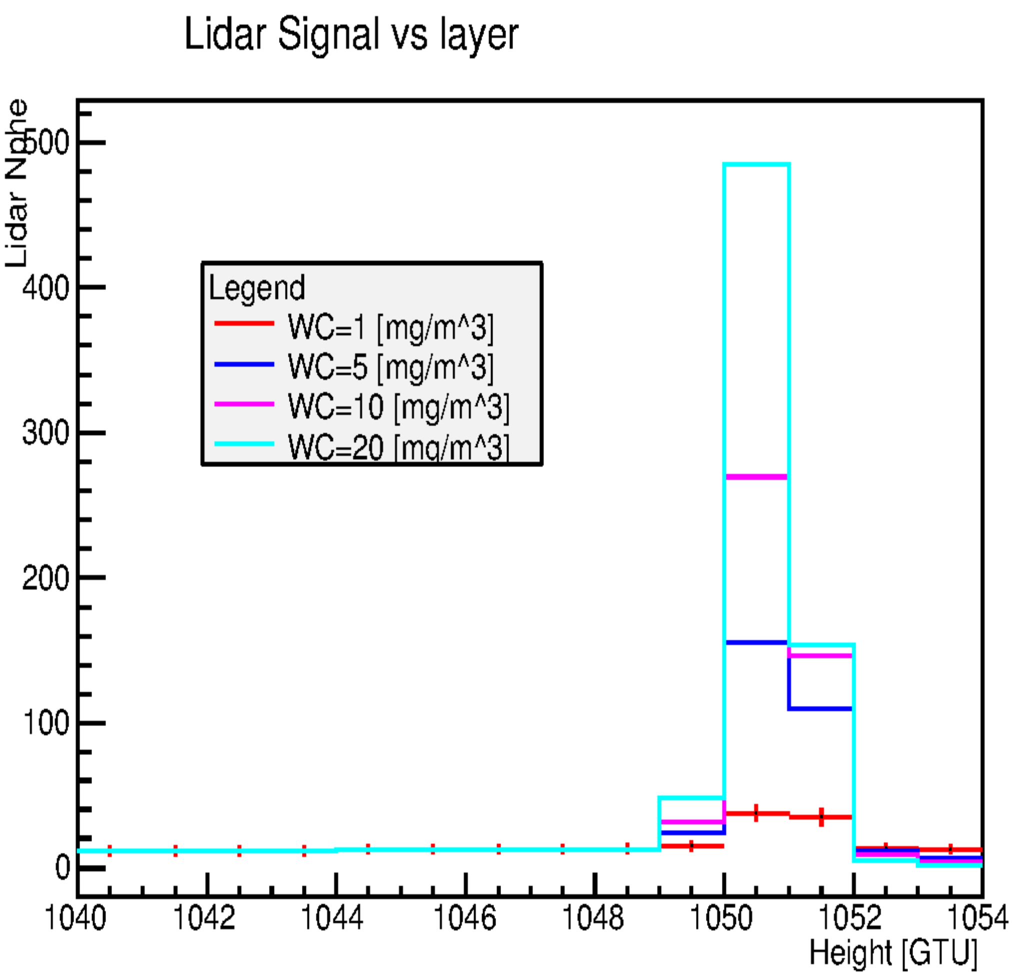
Adiabatic constant

Other pixels

Reconstructed Height acomplishing JEM-EUSO IR camera Requirements

LIDAR SIMULATION



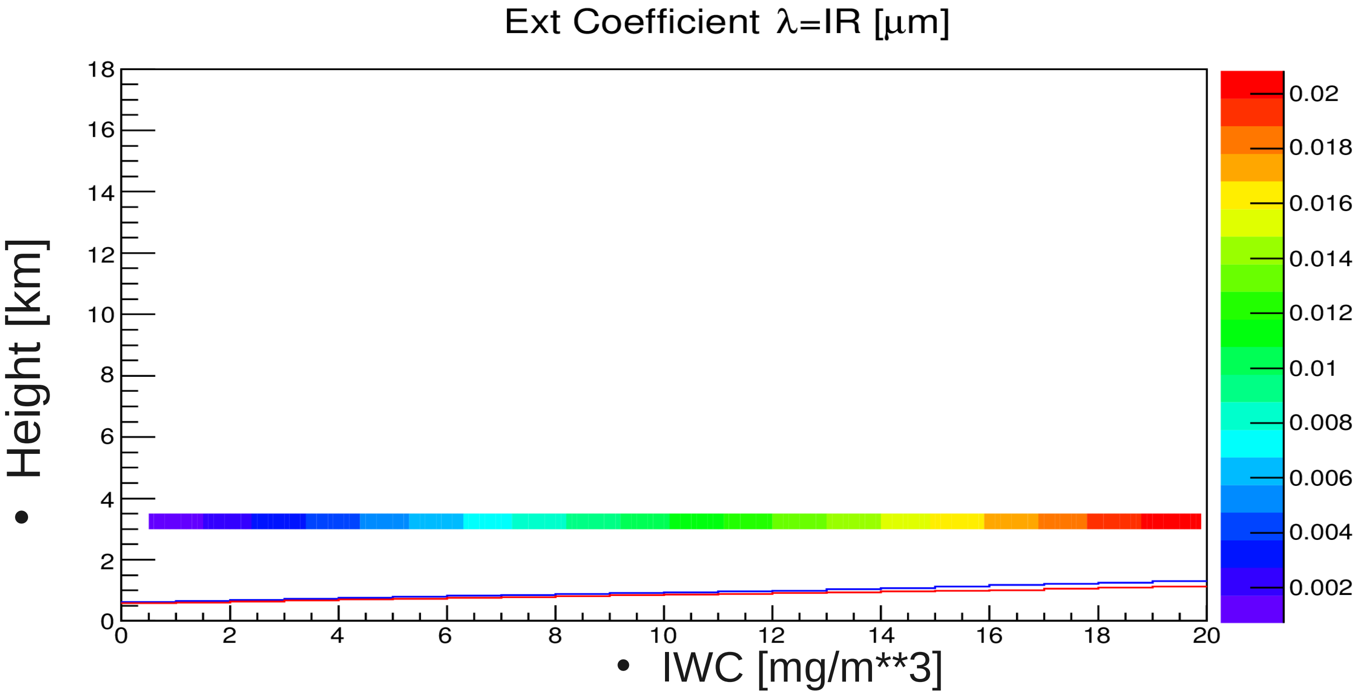


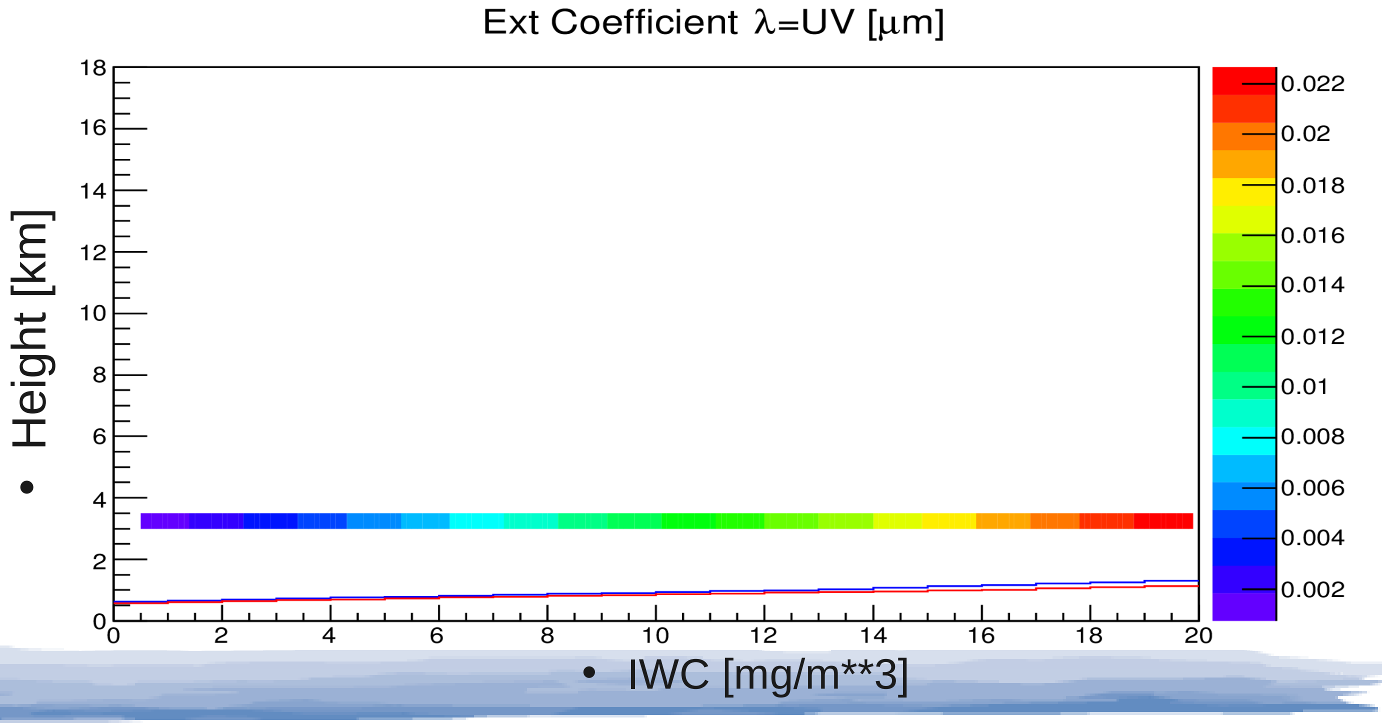
J.A. MORALES DE LOS RÍOS, JEM-EUSO INTERNATIONAL MEETING, TENERIFE 2013

Reconstructed height

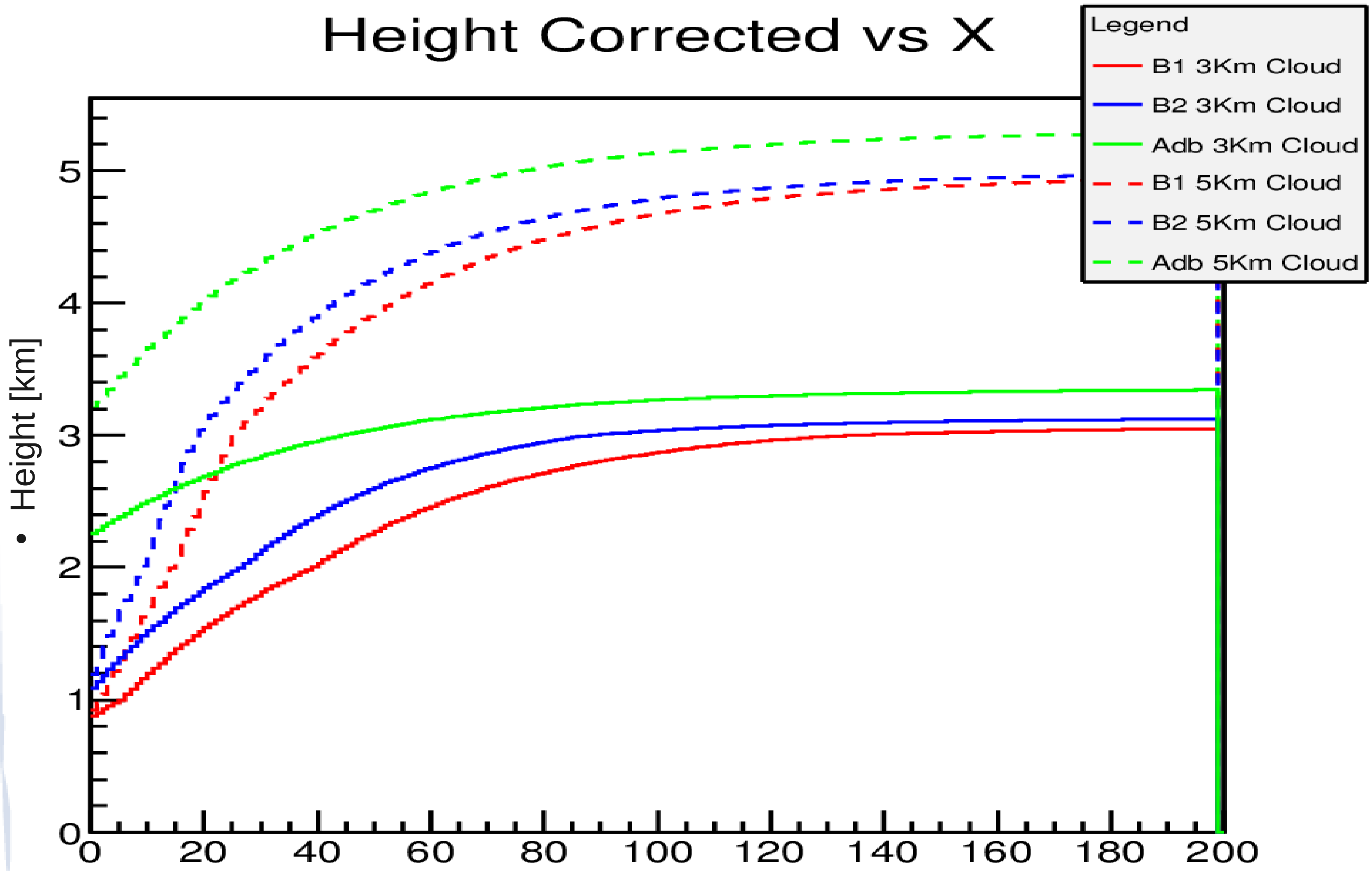
Water droplets

$OD_{UV} \simeq OD_{IR}$





Reconstructed Height



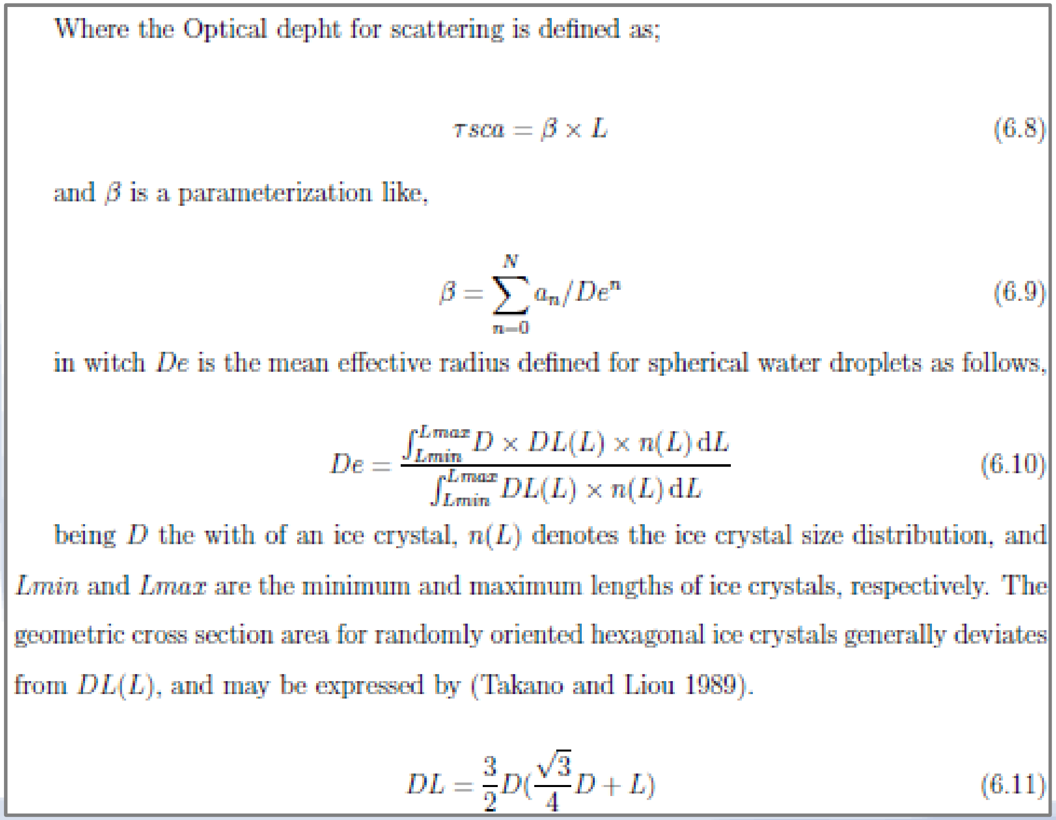
- IWC [mg/m**3]

Thin Ice-Cloud Optical Depth Study.

$$\beta = \beta_{ground} \times (1 - \tau) + \beta_{cloud} \times (\tau)$$

$$\tau = \tau abs + \tau sca$$

OD calculates using parametrization from Qiang Fu and K.N. Liou, in the paper titlet Parametrization of the Radiative Properties of Cirrus Clouds.



Where the Optical depht for scattering is defined as;

$$\tau sca = \beta \times L \qquad (6.8)$$

and β is a parameterization like,

$$\beta = \sum_{n=0}^{N} a_n / De^n \qquad (6.9)$$

in witch De is the mean effective radius defined for spherical water droplets as follows,

$$De = \frac{\int_{Lmin}^{Lmax} D \times DL(L) \times n(L)\,\mathrm{d}L}{\int_{Lmin}^{Lmax} DL(L) \times n(L)\,\mathrm{d}L} \qquad (6.10)$$

being D the with of an ice crystal, $n(L)$ denotes the ice crystal size distribution, and $Lmin$ and $Lmax$ are the minimum and maximum lengths of ice crystals, respectively. The geometric cross section area for randomly oriented hexagonal ice crystals generally deviates from $DL(L)$, and may be expressed by (Takano and Liou 1989).

$$DL = \frac{3}{2} D(\frac{\sqrt{3}}{4} D + L) \qquad (6.11)$$

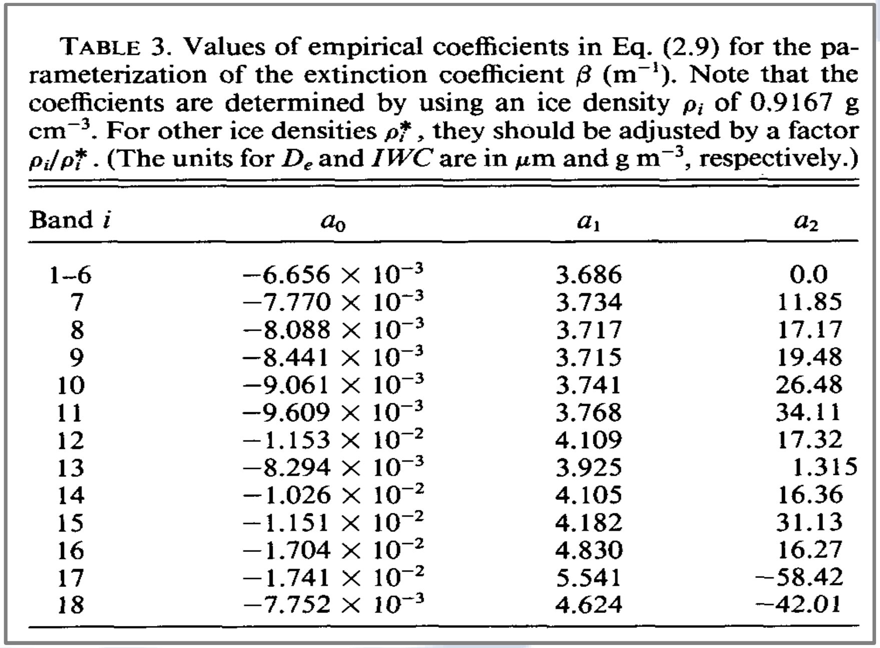
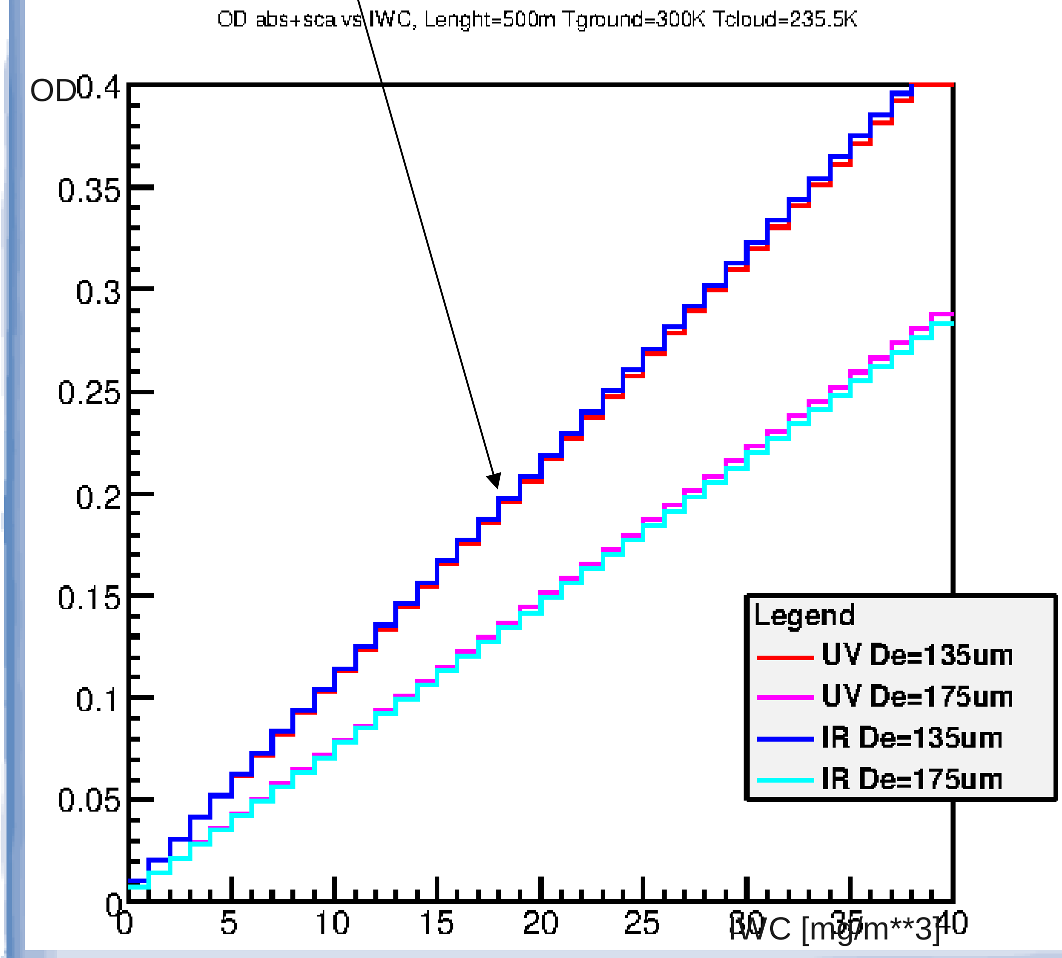
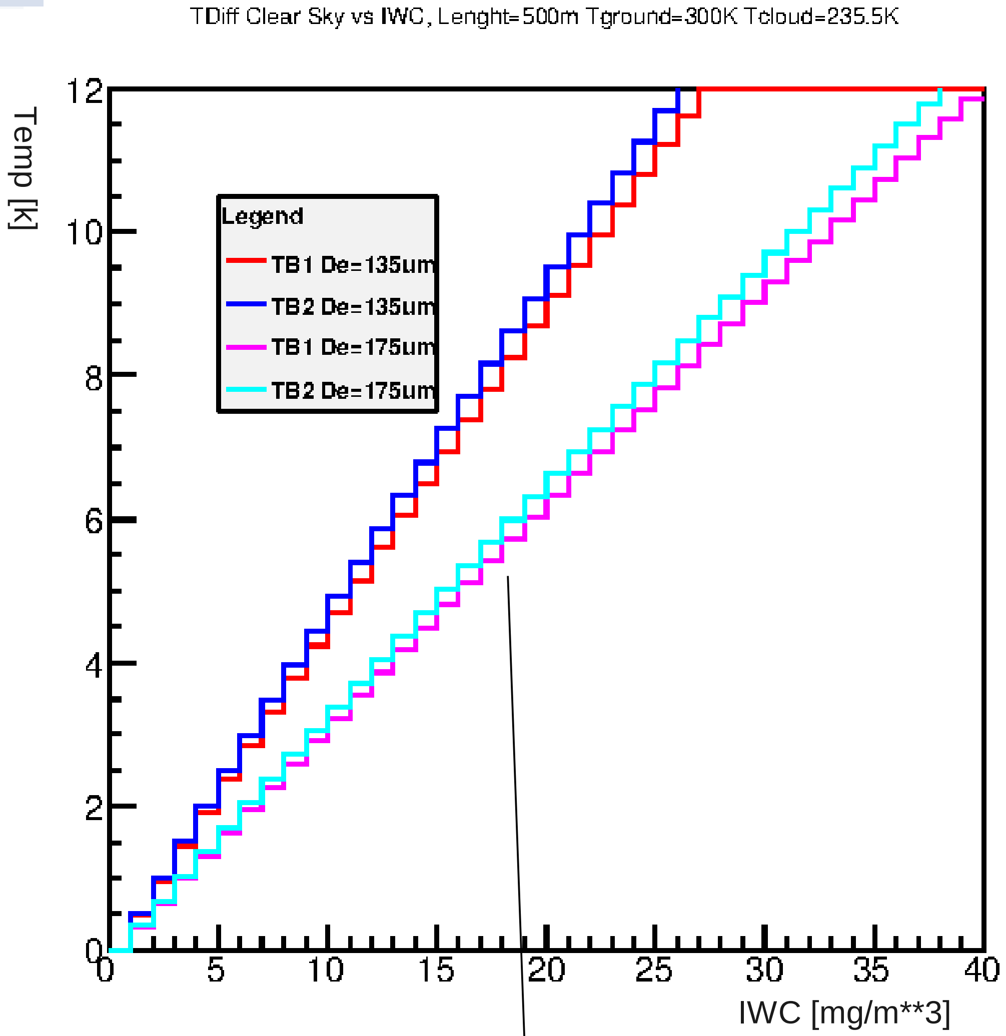


TABLE 3. Values of empirical coefficients in Eq. (2.9) for the parameterization of the extinction coefficient β (m^{-1}). Note that the coefficients are determined by using an ice density ρ_i of 0.9167 g cm^{-3}. For other ice densities ρ_i^*, they should be adjusted by a factor ρ_i/ρ_i^*. (The units for D_e and IWC are in μm and g m^{-3}, respectively.)

Band i	a_0	a_1	a_2
1–6	-6.656×10^{-3}	3.686	0.0
7	-7.770×10^{-3}	3.734	11.85
8	-8.088×10^{-3}	3.717	17.17
9	-8.441×10^{-3}	3.715	19.48
10	-9.061×10^{-3}	3.741	26.48
11	-9.609×10^{-3}	3.768	34.11
12	-1.153×10^{-2}	4.109	17.32
13	-8.294×10^{-3}	3.925	1.315
14	-1.026×10^{-2}	4.105	16.36
15	-1.151×10^{-2}	4.182	31.13
16	-1.704×10^{-2}	4.830	16.27
17	-1.741×10^{-2}	5.541	−58.42
18	-7.752×10^{-3}	4.624	−42.01

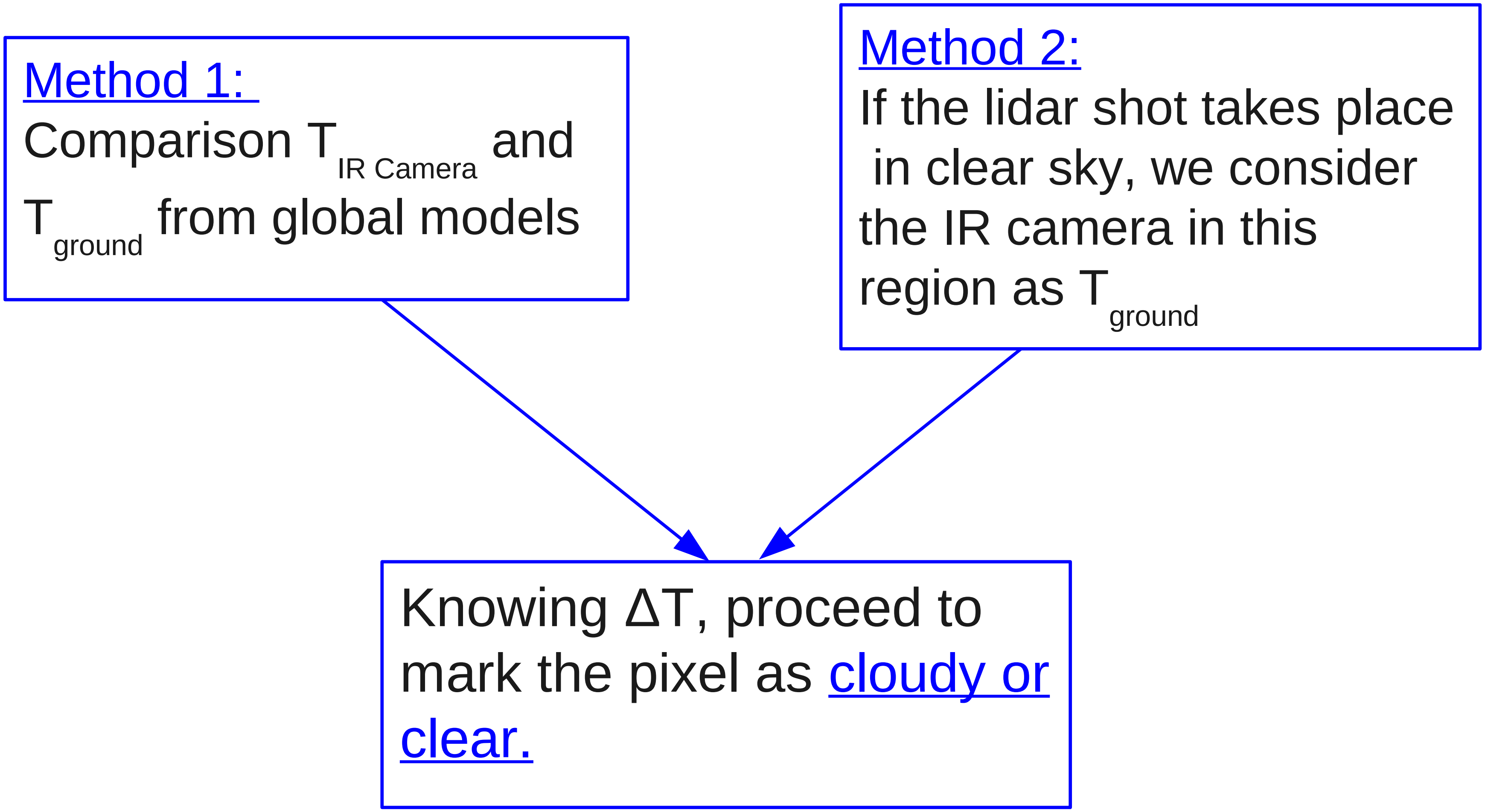
An Ice cloud of OD=0.2 in UV could have an IWC=18 [mg/m**3] (very low)





This same cloudy pixel has more than 4K when compared to a clear sky pixel, allowing us to seek pixels with lower temperature and mark them as cloudy pixels.

Cloud Mask Strategy under development



Method 1:

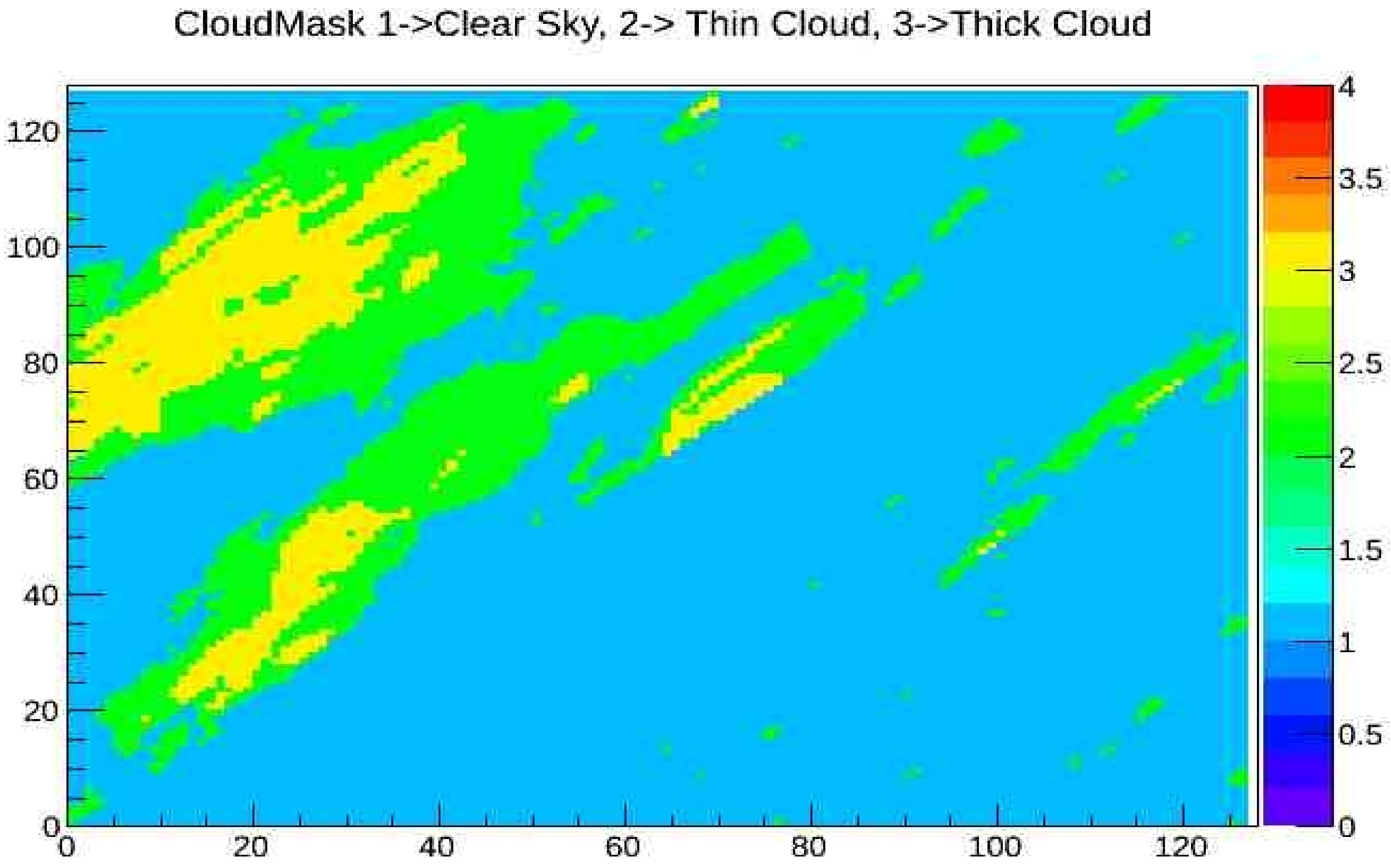
Comparison $T_{\text{IR Camera}}$ and T_{ground} from global models

Method 2:

If the lidar shot takes place in clear sky, we consider the IR camera in this region as T_{ground}

Knowing ΔT, proceed to mark the pixel as cloudy or clear.

Cloud Mask Real Simulation (Preliminary).



Final results to come: Morales de los Ríos PhD Thesis 2014

Summary and conclusions

- UHECRs can be observed in certain cloudy conditions by space based telescopes with a proper AMS (IR camera +LIDAR)
  - Depending on clouds and showers properties
- For JEM-EUSO, an atmospheric monitoring system is needed
- For JEM-EUSO, around 72% of events in cloudy cases can be used for analysis
- A module to simulate 3D clouds in UV has been performed
- A module to propagate EAS photons in 3D clouds is being performed

Summary and conclusions

- To fulfill IR camera requirements, the cloud algorithm has to properly retrieve the height of the clouds in the whole FoV.
    - Overall NETD Budget < 3K (500 m)

- This CLOUD TOP HEIGHT RETRIEVAL ALGORITHM retrieve the cloud top heights of thin and thick clouds without any intermedia steps that innecesarily increases the NETD budget.

- The HEIGHT RETRIEVAL ALGORITHM of JEM-EUSO is based on SDSU simulation and considers a LIDAR shot in the IR camera image.

- Cloud mask to distinghuish between clear sky, thin clouds and thick clouds is also successfully under development

BACKUP SLIDES

• Cloud Top Height Reconstruction

• Adiabatic atmosphere aproach, with Lidar signal.

- First we have an Hydrostatic equation:

$$\frac{d\rho}{dz} = -\frac{\rho}{g_n}$$

- ...where rho=density, z= height, gn=Std gravity.
  - Integrating...
  - If liquiq:

$$p = \rho \times g_n \times z + p_0$$

  - If gas:

$$p = p_0 * e^{\frac{-M \times g_n \times z}{R \times t}}$$

- Using...

$$p = \rho \times \frac{R}{M} \times t$$

- And then, defining the atmosphere pressure with this adiabatic aproximation:

$$p \times t^{\frac{-\alpha}{(\alpha-1)}} = Ctte$$

- … where:
- gn=std gravity= 9.80665 m/s^2.
- M=Air molar mass= 0.02897 kg/mol
- R= gast ctte= 8.3144621 J/(mol*k)
- alpha = heat cap ratio=7/5
- P0= pressure at sea level= 101325 Pa.

- Using one reference height position got by the Lidar, and the cloud temperature in the same position, we can calculate the adiabatic constant, and then reconstruct height of other pixels.

Photon propagation module for 3D clouds: How we treat light from EAS

FLUORESCENCE:

Only directly emitted light to the telescope is considered

CHERENKOV:

Only first order of scattering is considered

Cherenkov bunches:

Considerations:

- No emitted photons in the direction of the telescope.
- Rayleigh scattering has been considered.

- How we proceed:

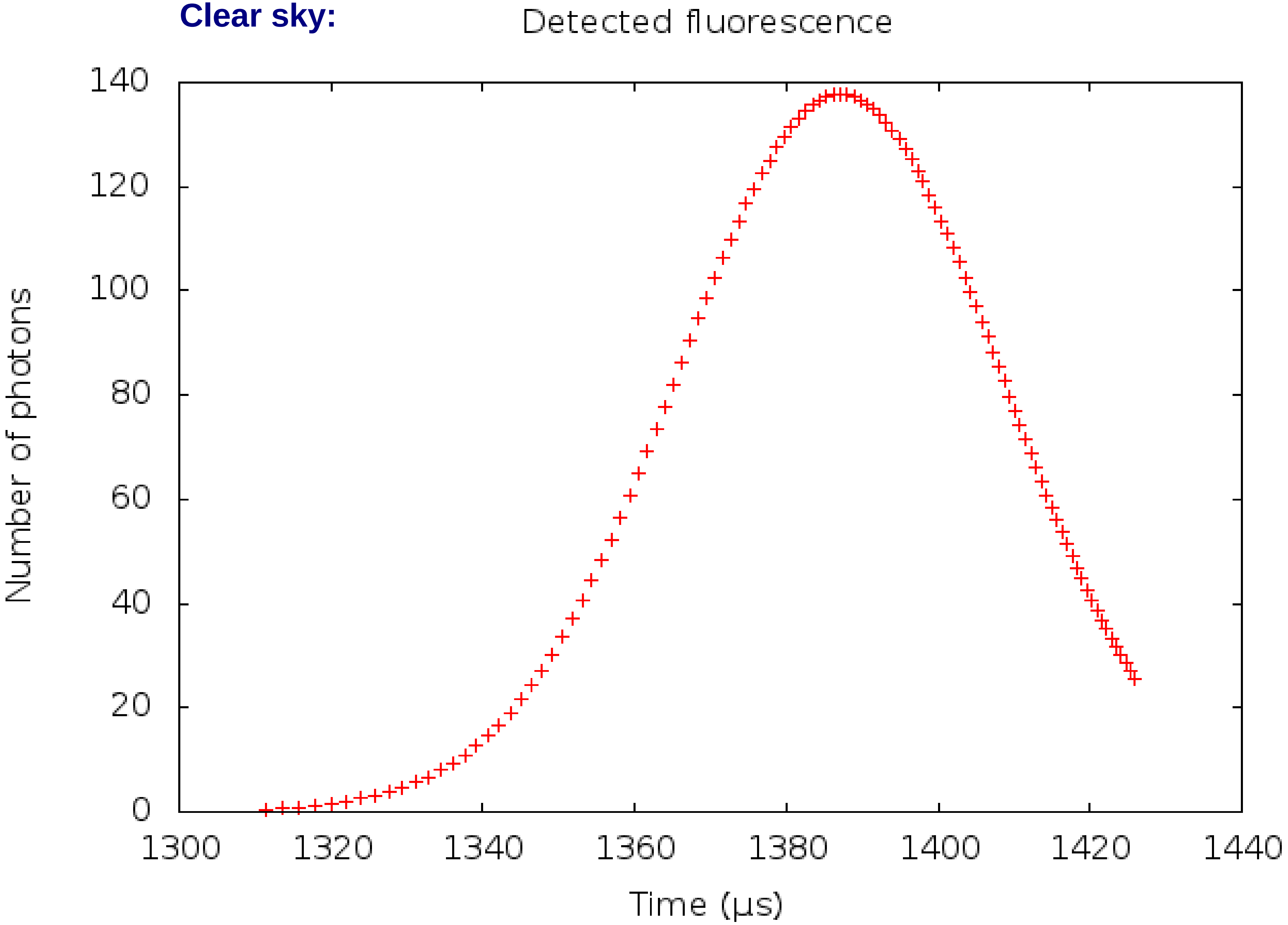
1) We calculate the cell of the atmosphere where the bunch is located, and the number of photons in the bunch

For each Cherenkov sample:

2) We propagate this bunch in the direction of the shower in different steps. For each step, we calculate the probability to have scattering in the direction of the telescope, and the Number of scattered photons.

3)We propagate each “scattered bunch” till the telescope, Considering attenuation coefficient of the different cells the bunch pass through

Clear sky:


Detected fluorescence
Number of photons
0
20
40
60
80
100
120
140
1300
1320
1340
1360
1380
1400
1420
1440
Time (µs)

Clear sky:

Detected Cherenkov