PROCEEDINGS OF SCIENCE

Cloud Optical Depth obtained from the Infrared Camera data and the UV Flashers mounted on a helicopter flying under the EUSO-Balloon during its flight

G. Sáez Cano[1], L. del Peral[1,2], M. Mustafa[3], J. F. Soriano[1], J.H. Adams Jr.[3], L. Wiencke[4], L. López[5], A. Merino[5], M. Reyes[6], E. Joven[6], Y. Martín[6], E. Roibas[7], A. Sanz[7], J. L. Sánchez*[5], S. Franchini[7], J. Licandro[6] and M. D. Rodríguez Frías[1,2,8] for the JEM-EUSO Collaboration

E-mail: `lupe.saez@uah.es, luis.delperal@uah.es`

[1] *SPace and AStroparticle (SPAS) Group, UAH, Ctra. Madrid-Barcelona, km. 33.7, Madrid, Spain.*
[2] *ISDC, Astronomy Dept. University of Geneva, Switzerland.*
[3] *University of Alabama in Huntsville (UAH), Huntsville, USA.*
[4] *Colorado School of Mines, Golden, USA.*
[5] *GFA. IMA. University of León, León, Spain.*
[6] *Instituto de Astrofísica de Canarias (IAC), Vía Lactea S/N, Tenerife, Spain.*
[7] *IDR/UPM, E. T. S. I. Aeronáutica y del Espacio, Universidad Politécnica de Madrid, Spain.*
[8] *IFIC, CSIC, U. de València. Dpto. Física Atómica, Molecular y Nuclear, U. de València, Spain.*

The EUSO-Balloon (CNES) campaign was conducted during the summer of 2014, when the EUSO-Balloon was launched at the night of August 24. A completely isolated Infrared Camera was mounted on the side of the gondola carrying the EUSO-Balloon instrument. We have obtained the optical depth of the cloudy part of the atmosphere by mean of the cloud coverage and the cloud top altitude given by the IR camera. During part of the balloon flight a helicopter carrying UV flashers was flown below the balloon. We have retrieved cloud coverage and Cloud Top Height from the IR camera images during time that the flashers were operated under the balloon. The optical depth in UV during times when the atmosphere was not clear will be inferred by comparing the luminosity of the flashers with the signal recorded by EUSO-Balloon, both in clear and in partially cloudy conditions.

The 34th International Cosmic Ray Conference,
30 July- 6 August, 2015
The Hague, The Netherlands

PoS(ICRC2015)658

---

*Speaker.

1. Introduction

The EUSO-Balloon is a balloon-borne experiment performed in collaboration with the French Space Agency (CNES). It is a pathfinder mission for the EUSO (Extreme Universe Space Observatory) Mission. EUSO-Balloon consists of a telescope of smaller dimensions than the main EUSO Mission, designed for the ISS, mounted in an unpressurized gondola of a stratospheric CNES balloon. Its main objective is to perform a full scale end-to-end test of all the key technologies and instrumentation of JEM-EUSO detectors and to prove the whole detection process. Also, a very important objective for the EUSO-Balloon is to measure the atmospheric and terrestrial UV background components in different observational modes. This is fundamental for the development of realistic simulations.

Due to its Fresnel Optics and a Photo-Detector Module (PDM), the EUSO-Balloon monitors a $12^\circ \times 12^\circ$ wide field of view in a wavelength range between 290 and 430 nm, at a rate of 400000 frames/sec. Its PDM, similar to the one designed for the main mission, has 2304 pixels .The pixel size corresponds to 145m × 145m on the ground for a float level of 40 km. This balloon has been built thanks to the joint work between various institutes of the JEM-EUSO collaboration. The first EUSO-Balloon flight was successfully launched from the Timmins Stratospheric Balloon Launch Facility in Ontario, Canada, in the night of August 24, 2014, and the flight duration at a constant altitude lasted for 4 hours. In order to monitor the atmospheric properties during the flight, as well as the cloud coverage, the EUSO-Balloon also carried a co-aligned IR camera, which covered a wider field of view than the PDM at flight. Also, a helicopter with a laser and flashers was flying in circles along the flight track for more than two hours.

2. EUSO-Balloon IR camera

The IR Camera of the EUSO-Balloon is a stand-alone payload within the balloon, which provides images centered at 10.8 μm and 12 μm (medium infrared), thanks to a ULIS UL 04171 μbolometer and two filters centered in these two wavelengths with 0.85 μm of bandwidth. The imaging system is similar to the JEM-EUSO IR Camera in its BreadBoard Model (BBM) that has been accomplished by the Spanish EUSO consortium [1]. The system has a field of view of 45°, almost 4 times higher than the area studied by the UV telescope installed in the balloon. During its first flight, the EUSO-Balloon IR Camera took one picture every 80 s. All the data taken by the IR camera was stored in two Solid State Disks (SSD), and analyzed on ground, after the balloon was recovered after the flight.

We only consider for our study the images taken during the proper flight (from around 03:30 to 8:20 UTC), where the flight conditions were stable. Therefore, $\sim$220 images need to be analyzed. Once the analysis of the images is completed, the Cloud Top Height (CTH) is retrieved using a Weather Research and Forecasting model. Vertical profiles of temperature and humidity are obtained for different locations and at different times covering the full track of the EUSO-Balloon. Thus, an algorithm is built to retrieve the CTH in each pixel of the IR-Camera. We have developed two different methods to obtain the optical depth of the cloudy part of the atmosphere: using only the IR-camera, where we can obtain the optical depth in the infrared, and using the IR camera and the signal from the Xenon flasher shot by the helicopter and detected by the PDM.

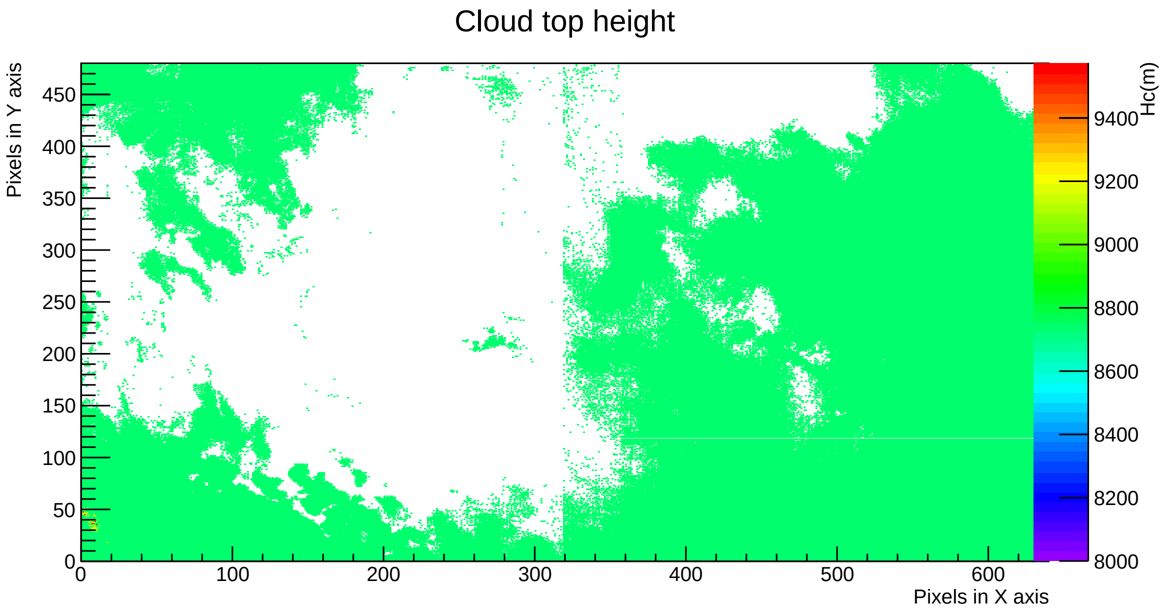

Figure 1: Cloud coverage and Cloud Top Height (CTH) in the Infrared at 04:42:25 UTC. White colour means an area without clouds.

3. Optical Depth with the IR camera

The radiance measured by the infrared camera located at the EUSO-Balloon corresponds to various contributions:

- the radiance which is emitted by the Earth (I_s) and survives until the detector after suffering a certain attenuation produced by the atmosphere located between the ground and the cloud ($\simeq e^{-\tau_{sn}}$), an attenuation inside the cloud ($\simeq e^{-\tau_n}$) and an attenuation produced by the atmosphere located between the cloud and the telescope ($\simeq e^{-\tau_{nj}}$).
- the radiance emitted by the cloud layer (I_n) and arriving to the telescope after suffering absorption due to the atmosphere between the cloud and the detector ($\simeq e^{-\tau_{nj}}$).

This total radiance can be expressed as:

$$I_t = I_s \times e^{-\tau_{sn}} \times e^{-\tau_n} \times e^{-\tau_{nj}} + I_n \times e^{-\tau_{nj}} \tag{3.1}$$

which is also equivalent to the radiance emitted by a black body located at the altitude of the cloud layer (I_{bb}), after suffering an attenuation due to the atmosphere located between the cloud and the detector ($\simeq e^{-\tau_{nj}}$), that can be written as:

$$I_t = I_{bb} \times e^{-\tau_{nj}} \tag{3.2}$$

We have obtained the CTH for each image taken by the IR camera. Figures 1 and 2 represent the altitude of the clouds observed by each pixel of the IR camera at 03:44:52 and at 05:15:51 UTC.

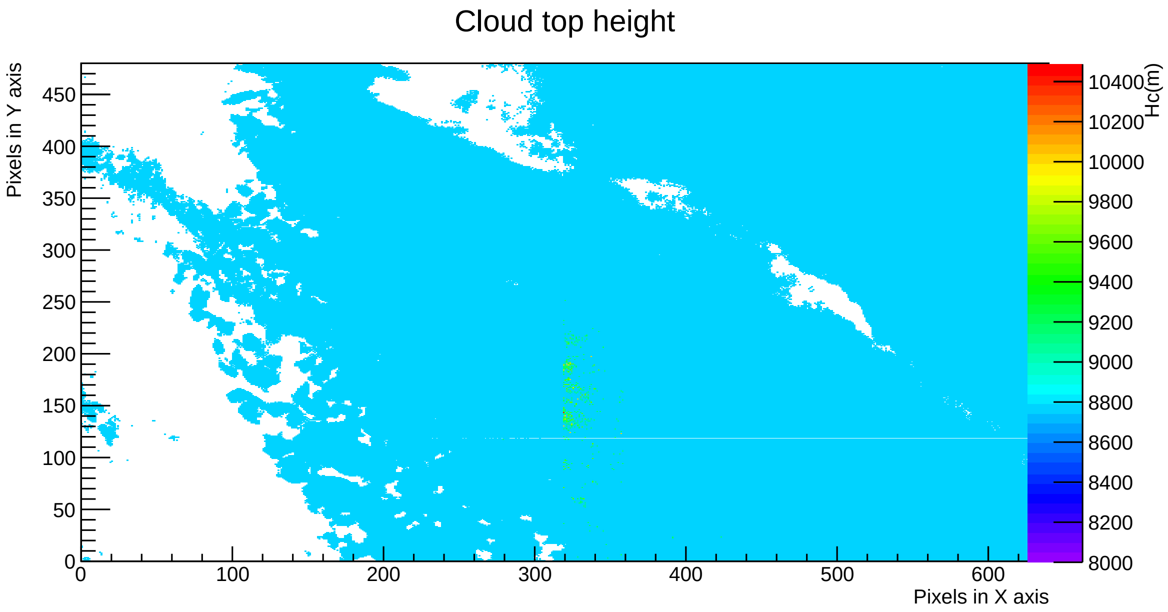

Figure 2: Cloud coverage and Cloud Top Height (CTH) in the Infrared at 05:15:51 UTC. White colour means an area without clouds

If we compare 3.1 and 3.2 for each pixel [i][j] of the IR camera, the optical depth of the cloud measured by each pixel would correspond to:

$$\tau_n[i][j] = ln\left(\frac{I_s[i][j] \times e^{-\tau_{sn}[i][j]}}{I_{bb}[i][j] - I_n[i][j]}\right) \tag{3.3}$$

We have performed this study for each image taken by the IR camera during the EUSO-Balloon flight to get the cloud coverage and optical depth in the Infrared of the atmosphere for each case. Figure 3 and Figure 4 are the obtained results for the images taken at 03:44:52 and at 05:15:51 UTC. The black square represents the field of view of the PDM. It can be seen that the field of view of the camera is much higher than the FoV of the UV PDM. Moreover, we observe that there is a row of pixels ([i][120]) that did not work perfectly and the obtained image is not coherent with the ones from the surroundings. Also we can observe in the obtained image the transition between the two filters of the camera ([320][j]). For the rest of the pixels this method works properly and smoothly.

4. OD with the IR camera and the EUSO-Balloon

Below the EUSO-Balloon, at an altitude of around 3 km from ground, a helicopter from the NASA Space Agency was flying during two hours (between 3:45 and 5:54 UTC). The helicopter was shooting Xenon flashers, LED flashers and a laser. This operation consisted of 12 LED flashes, each 2.5 μs long, occurring one right after the other. Each flash increased in brightness so there were 12 brightness levels. Following the LED flashes, the laser was fired. Then, $\simeq$10 μs after the laser fired, the Xe flasher fired. The light output of the Xe flasher followed a temporal pattern extending over several GTUs (1GTU is the time frame of the PDM data acquisition, and corresponds

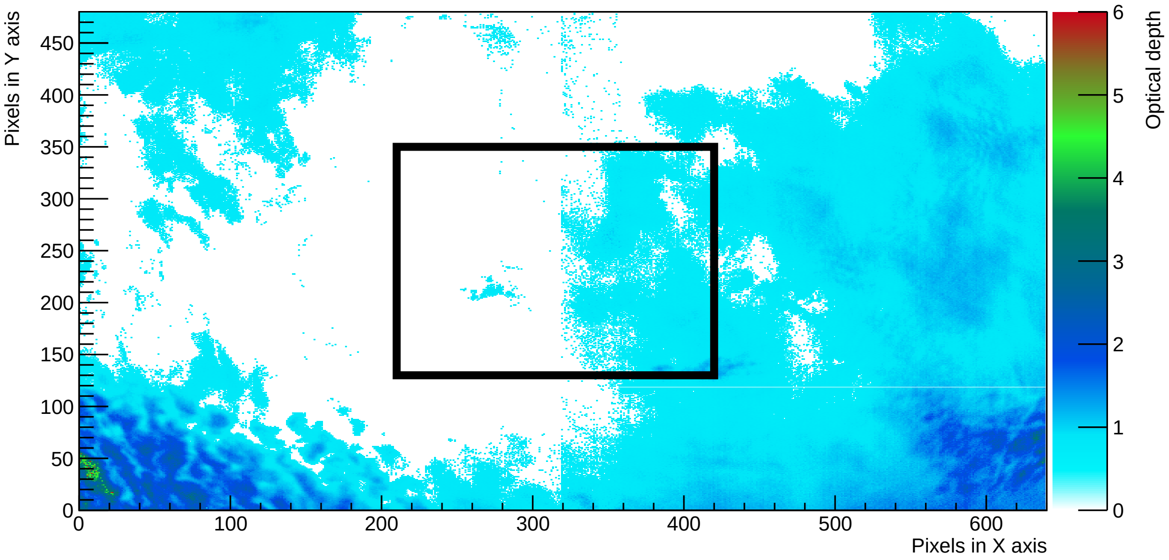

Figure 3: Cloud coverage and optical depth in the Infrared at 04:42:25 UTC. The intersection of both filters can be observed at x=320.

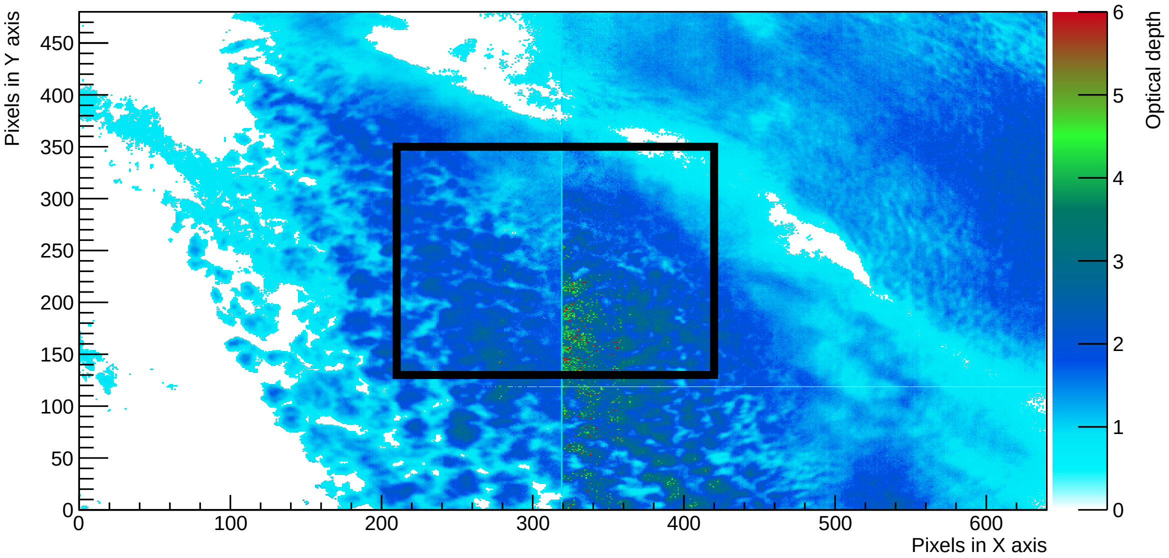

Figure 4: Cloud coverage and optical depth in the Infrared at 05:15:51 UTC. The intersection of both filters can be observed at x=320.

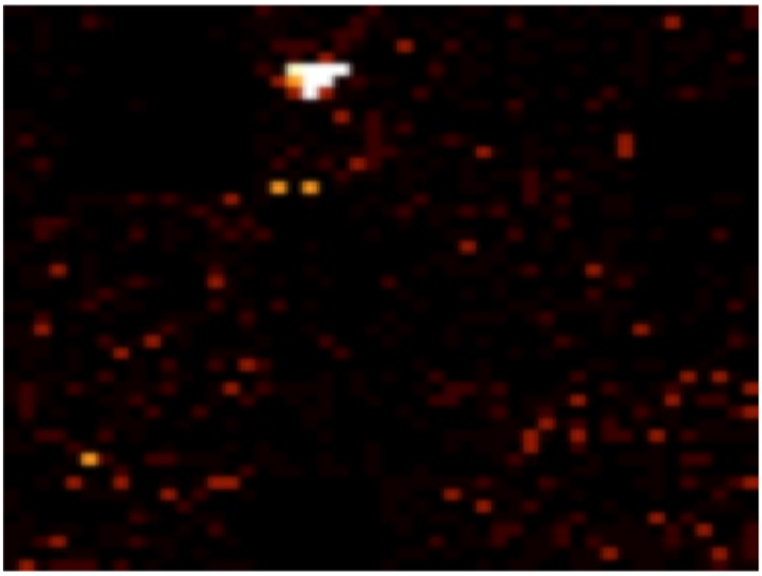

Figure 5: PDM detection of one of the helicopter lasers.

to 2.5 μs). The Xe flasher operated always at one of four voltage settings (the voltage settings determine the brightness of the temporal pattern of light emission by the Xe flasher).

For the laser shots, the signal in each pixel is a combination of the intrinsic luminosity of the flasher, the attenuation due to distance and scattering loss in the atmosphere (Rayleigh scattering mainly for the clear atmosphere part, and MIE scattering mainly for clouds), losses in the optics of the experiment and the point spread function of the focal spot. The point spread function of the lenses needs to be determined in order to understand how the total amount of light that makes it through the lenses gets divided among the pixels in the focal spot. While the optical power in the beam is known, the amount of light that reaches the balloon depends on scattering. One must calculate the scattering at each point along the laser track to account both for the light emitted isotropically from each point and for the light lost from the laser beam between the helicopter and the point of interest along the beam. In principle, this cannot be done because the aerosol-cloud content of the air is not known. In Figure 5 we observe the signal of one of the laser shots detected by the EUSO-Balloon. On the other hand, we can use the data from the flashers. Their intrinsic light output is known exactly, so the light reaching the helicopter is attenuated only by the aerosol-cloud layer scattering loss along the path from the flasher to the balloon, which is estimated by the IR camera. Therefore, the intrinsic luminosity can be presented as the photoelectron signal corresponding to the number of photons striking the entrance aperture of EUSO Balloon, excluding the losses in the atmosphere.

We have used the dark sky background to measure the relative sensitivity of the pixels. With this, we can correct the pixels to a common sensitivity reference point. Then we compare flashes at different times and in different places in the field of view, and we assume that the attenuation produced in the flasher signal is due to the aerosol-cloud layer. And with these assumptions we calculate the optical depth in UV of this layer.

To get an estimation of the optical depth in UV, we have used the signal of the Xenon flasher

Time (UTC)	H_c (m)	τ_c
04:32:02	8500	0.7
05:21:52	9500	0.9
05:23:58	9000	0.4
05:27:53	8500	0.6

Table 1: Estimated UV optical depth at four different shots and the CTH, for the pixels where the flasher light was detected.

detected by the PDM. We know the intrinsec brigthness of each shot of the Xe flasher. Assuming a isothermal atmospheric model without clouds, its density $\rho(h_i)$ at a certain altitude h_i can be expressed as:

$$\rho(h_i) \simeq \rho_0 \cdot e^{(-h_i/h_0)} \tag{4.1}$$

Being ρ_0 the density at a given altitude h_0, and h_i the altitude of the photon measured perpendicular to the Earth's surface. Then, we can calculate which is the attenuation due to the propagation through an atmosphere without clouds, and how many photons should arrive to the detector in a clear atmosphere. Considering the number of photons which actually arrive to the detector, the difference with the photons that would arrive in clear sky would be related with the optical depth of the cloudy zone. To calculate this optical depth, we locate the pixels of the PDM where the signal arrives, and we localize these pixels in the IR image, so we identify whether these pixels of the PDM have detected the signal in cloudy conditions, and if so, the altitude of the cloud for each pixel. Finally, we consider the sum of the counts over the spot and over the duration of the flash, corrected from background. Table 1 represents preliminary results of the optical depth obtained by this method for four different instants (4:32:02, 05:21:52, 05:23:58 and 05:27:53 UTC). This optical depth is less accurate than the one obtained only by the IR camera, because the delay between the IR camera images and the flasher signal detected by the PDM is in some cases of several seconds.

Acknowledgment: This work was partially supported by Basic Science Interdisciplinary Research Projects of RIKEN and JSPS KAKENHI Grant (22340063, 23340081, and 24244042), by the Italian Ministry of Foreign Affairs, General Direction for the Cultural Promotion and Cooperation, by the 'Helmholtz Alliance for Astroparticle Physics HAP' funded by the Initiative and Networking Fund of the Helmholtz Association, Germany, and by Slovak Academy of Sciences MVTS JEM-EUSO as well as VEGA grant agency project 2/0076/13. Russia is supported by the Russian Foundation for Basic Research Grant No 13-02-12175-ofi-m. The Spanish Consortium involved in the JEM-EUSO Space Mission is funded by MICINN & MINECO under the Space Program projects: AYA2009-06037-E/AYA, AYA-ESP2010-19082, AYA2011-29489-C03-01 and AYA2011-29489-C03-02 , AYA-ESP2012-39115-C03-01 and AYA-ESP2012-39115-C03-03, AYA-ESP2013-47816-C4, MINECO/FEDER-UNAH13-4E-2741, CSD2009-00064 (Consolider MULTIDARK) and by Comunidad de Madrid (CAM) under projects S2009/ESP-1496 & S2013/ICE-2822. M.D. Rodríguez Frías acknowledges a grant under the "Atraccio de Talent" program from the Vicerrectorado de Investigación de la Universidad de Valencia (Spain).

References

[1] Rodríguez- Frías, M.D. et al. (JEM-EUSO Collaboration). Towards the Preliminary Design Review of the Infrared Camera of the JEMEUSO Space Mission. Proc. of 33rd International Cosmic Ray

Conference (ICRC), Rio de Janeiro, Brazil. ArXiv:1307.7071, (2013).

[2] Adams, J.H. et al. (JEM-EUSO Collaboration). An evaluation of the exposure in nadir observation of the JEM- EUSO mission. Astropart.Phys., 44, pg 76-90, http://dx.doi.org/10.1016/j.astropartphys.2013.01.008, (2013).

[3] The JEM-EUSO Collaboration, The JEM-EUSO Mission: Contributions to the ICRC 2013, Proc. of 33rd International Cosmic Ray Conference (ICRC), Rio de Janeiro, Brazil. ArXiv:1307.7071, (2013).

[4] Rodríguez Frías, M.D., Toscano, S., Bozzo, E., del Peral, L., Neronov, A., and Wada, S. and for the JEM-EUSO Collaboration., The Atmospheric Monitoring System of the JEM-EUSO Space Mission, Proceedings of the 2^{nd} AtmoHEAD Conference, Padova (Italy), ArXiv:1501.0482 [astro-ph.IM] (2014).

[5] Rodríguez Frías, M. D. et al. for the JEM-EUSO Collaboration., The JEM-EUSO Space Mission: Frontier Astroparticle Physics at ZeV range from Space., Homage to the Discovery of Cosmic Rays. Nova Science Publishers, New York, ISBN: 978-1-62618-998-0, Inc, pg 201-212, (2013).

[6] Rodríguez Frías, M. D. et al. for the JEM-EUSO Collaboration., The Atmospheric Monitoring System of the JEM-EUSO Space Mission., Proc. International Symposium on Future Directions in UHECR Physics, The European Physical Journal, 53, 10005-pg1-7, (2013), http://dx.doi.org/10.1051/epjconf/20135310005.

[7] The JEM-EUSO Collaboration (corresponding authors: Toscano, S., Morales de los Ríos, J. A., Neronov, A., Rodríguez Frías M. D., & Wada, S.)., The Atmospheric Monitoring System of the JEM-EUSO instrument., Experimental Astronomy, 37, (2014), doi=10.1007/s10686-014-9378-1.

[8] Rodríguez Frías, M. D. et al. for the JEM-EUSO Collaboration., Towards the Preliminary Design Review of the Infrared Camera of the JEM-EUSO Space Mission., Proc. International Cosmic Rays Conference, Rio de Janeiro, Brazil, arXiv:1307.7071v1 [astro-ph.IM], (2013).

[9] The JEM-EUSO Collaboration (corresponding authors Morales de los Rios, J. A. & Rodríguez Frías, M. D.), The infrared camera onboard JEM-EUSO, Experimental Astronomy, 37, doi=10.1007/s10686-014-9402-5, (2014).

[10] Morales de los Ríos, J. A., Joven, E., del Peral, L., Reyes, M., Licandro, J., and Rodríguez Frías, M. D., The Infrared Camera Prototype Characterization for the JEM-EUSO Space Mission., Nuclear Instruments and Methods NIMA, 749, 74-83, ISSN 0168-9002 (2014).

[11] Sáez-Cano, G., del Peral, L., Fernández Soriano, J., Adams, J. H., Wiencke, L., López -Campano, L., Merino, A., Reyes M., Jóven E., Martín, Y., Sánchez, J. L., Franchini, S., Licandro J., and Rodríguez-Frías, M.D. for the JEM-EUSO Collaboration. Cloud Optical Depth obtained from the Spanish Infrared Camera data and the Laser shots of the USA helicopter during the EUSO-BALLOON (CNES) flight. In this proceedings.

[12] Fernández Soriano, J., del Peral, L., Jóven E., Martín, Y., Licandro J., and Rodríguez-Frías, M.D. for the JEM-EUSO Collaboration. Performances of the Spanish Infrared Camera onboard the EUSO-BALLOON (CNES) flight on August 24, 2014. In this proceedings.

[13] Merino, A., Fernández-Soriano, J., Sánchez, J.L., López, L., Del Peral, L., Fernández-González, S., Gascón, E., García-Ortega E., Reyes, M., Joven, E., Martín, Y., Sáez-Cano G., Franchini, S., Licandro, J. and Rodríguez Frías, M. D. for the JEM-EUSO Collaboration. Cloud Top Height estimation from WRF model: Application to the IR camera onboard the EUSO-Balloon (CNES). In this proceedings.

[14] V. Scotti and G. Osteria.-The EUSO-Balloon Instrument, *Proceedings of Science* **TIPP2014** (2014) 137