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The Atmospheric Monitoring System of the JEM-EUSO space mission

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Abstract. An Atmospheric Monitoring System (AMS) is mandatory and a key element of a space-based mission which aims to detect Ultra-High Energy Cosmic Rays (UHECR). JEM-EUSO has a dedicated atmospheric monitoring system that plays a fundamental role in our understanding of the atmospheric conditions in the Field of View (FoV) of the telescope. Our AMS consists of an infrared camera and a LIDAR device that are being fully designed with space qualification to fulfil the scientific requirements of this space mission. This AMS will provide information of the cloud cover in the FoV of JEM-EUSO, as well as measurements of the cloud top altitudes with an accuracy of 500 m and the optical depth profile of the atmosphere transmittance in the direction of each air shower with an accuracy of 0.15 degree and a resolution of 500 m. This will ensure that the energy of the primary UHECR and the depth of maximum development of the EAS (Extensive Air Shower) are measured with an accuracy better than 30% and 120 g/cm^2, for EAS occurring either in the clear sky or with the EAS depth of maximum development above optically thick cloud layers. Moreover novel stereoscopic and radiometric retrieval techniques are under development to infer the Cloud Top Height (CTH) from the brightness temperature patterns obtained from the infrared camera.

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[a] For the full authorlist see Appendix "Collaborations" in this volume

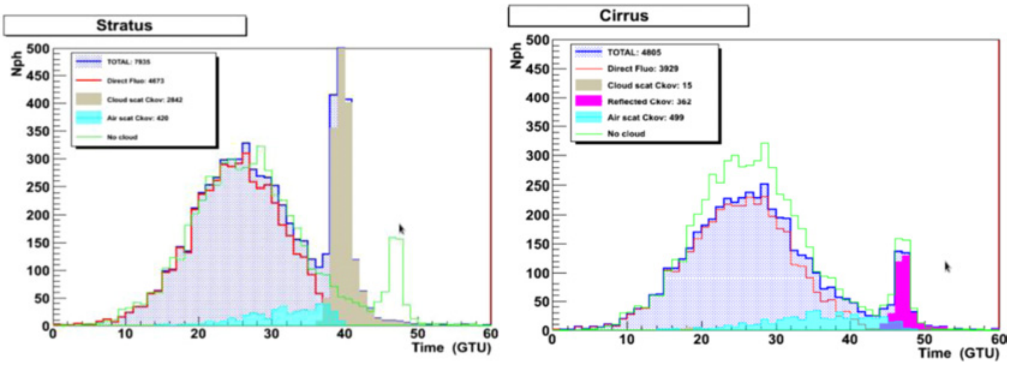

Figure 1. The panel on the left shows the clear sky signal (green line) compared to a low and optically thick ($H = 2.5$ km, $OD = 5$) cloud signal (blue line). On the top of the cloud, a very high Cherenkov peak is produced and most of the fluorescence radiation develops before the cloud. Therefore this Stratus-case is similar to the clear sky one. The panel on the right shows a high and optically thin ($H = 10$ km, $OD = 0.5$) cloud signal (blue line) is compared to that of clear sky signal (green line). Now the fluorescence radiation suffers absorption but the Cherenkov peak takes place on ground due to the fact that the cirrus clouds are thin clouds.

1. INTRODUCTION

JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) is the space-based observatory to detect EAS induced by UHECR from the International Space Station (ISS). The UHECR observation will take place within different atmospheric conditions, including scenarios with the presence of clouds at different altitudes and with different optical depths of transmission conditions. The AMS of JEM-EUSO is aimed to obtain detailed information of atmospheric conditions when an UHECR is detected in the FoV of the main instrument. It will consist of a dedicated Infrared Camera and a LIght Detection And Ranging device (LIDAR).

2. SIMULATION OF THE EAS PROFILE IN CLOUDY CONDITIONS

ESAF (Euso Simulation and Analysis Framework) is currently widely used in JEM-EUSO and is explored in this work to analyze expected signals of EAS as detected by JEM-EUSO. Since the main telescope is using the atmosphere as a detector, the presence of clouds in the atmosphere may affect the signal observed. Therefore, EAS have been simulated in scenarios with different types of clouds and its absorption and scattering behavior are implemented into ESAF. These clouds are simulated as uniform layers, which characteristics are Optical Depth (OD) τ and Cloud Top Height (CTH) H_c. The resulting effect of clouds is also dependent on the arrival direction of the shower, i.e., more horizontal showers will be affected only by higher clouds, since these showers typically develop higher in the atmosphere. In Figure 1 is shown the EAS development under stratus (left panel) and cirrus (right panel) clouds. In this last case an AMS is crucial to distinguish this scenario from the one of clear sky with lower primary energy [1].

3. CLOUD TOP TEMPERATURE RADIOMETRIC RETRIEVAL ALGORITHMS

The main aim of the IR camera is to provide information of the cloud cover and CTH in the FoV of the JEM-EUSO main instrument. The CTH can be inferred from the cloud top temperature. The radiation emitted by clouds is measured by the IR camera and the cloud temperature is calculated from the radiance measured by the camera (brightness temperature). However, the atmosphere between the cloud and the sensor absorbs and emits energy as well. Consequently, the radiance measured by the IR

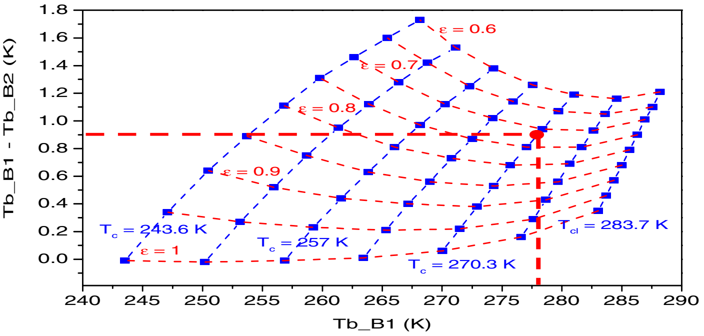

Figure 2. Example of LUT used to retrieve the temperature and emissivity of the cloud from brightness temperatures in two spectral bands.

camera is not exactly the radiance emitted by the cloud and therefore the temperature retrieved from the radiance (brightness temperature) is not the real temperature of the cloud.

In order to correct the effects of the atmosphere some radiometric algorithms can be applied. The Split Window Algorithm (SWA) is a linear algorithm with coefficients that depend on the atmospheric transmittance. This algorithm retrieves the cloud top temperature of thick water clouds, i.e. clouds that can be assumed as black bodies. The accuracy of the algorithm accomplishes with the scientific requirement of 3 K on the accuracy of the temperatures provided by the IR camera. However, this methodology is not able to retrieve the cloud top temperature with enough accuracy for thin clouds (emissivity < 1). Nevertheless, the difference between Brightness Temperatures (BT) of two bands centered at 10.8 μm and 12 μm, in a bi-spectral IR camera allows us to retrieve cloud temperature and the cloud emissivity. A method based on Look-Up Tables (LUT) can be applied to retrieve the cloud top temperature of thin clouds. In Figure 2 this methodology is shown. The blue squares correspond to the matrix values (Tb_B1, BTD) for different clouds and different emissivities, where BTD stands for Brightness Temperature Difference. Blue dashed lines correspond to clouds with the same temperature and different emissivities. Red dashed lines represent clouds with same emissivity and different temperatures. The coordinates of the red point are calculated from the brightness temperatures that the infrared camera would measure in both bands. The cloud temperature is obtained from the interpolation between the two nearest blue lines. The cloud emissivity is interpolated from the closest red dotted lines. The simulated cloud used in Figure 2 was located at 4.5 km, which correspond to 270.2 K and the emissivity was 0.72. As can be seen in Figure 2 the values retrieved from the LUT are very close to those of the simulated cloud.

4. CLOUD TOP HEIGHT RETRIEVAL BY STEREO TECHNIQUE

CTH estimation in the JEM-EUSO AMS will be approached based on the stereo vision technique as well. This stereo vision algorithm mainly exploits the parallax effect of the binocular vision. The evaluation of the apparent displacement of the observed point allows the reconstruction of its distance from the sensor by triangulation. One sensor can also be used to obtain the same effect of the stereo vision by moving the device towards a selected direction while a static object is observed. This is the main approach used in our case: the ISS displacement provides the movement of the infrared camera along track, during the imaging of the underlying scene. A suitable time interval between consecutive acquisitions is chosen to obtain a sufficient overlap between the images of the scene, in such a way the common parts are observed by two different view angles.

According to the IR camera bi-spectral baseline design, bi-band stereo views are obtained firstly by observing a scene in one band, then acquiring the intersection part of the next observed scene in the

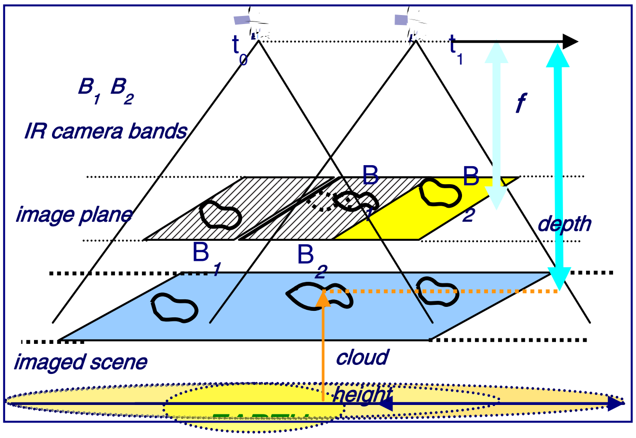

Figure 3. Schematic drawing of the “Stereo System” and the bi-band acquisition of the stereo pair of a cloudy scène.

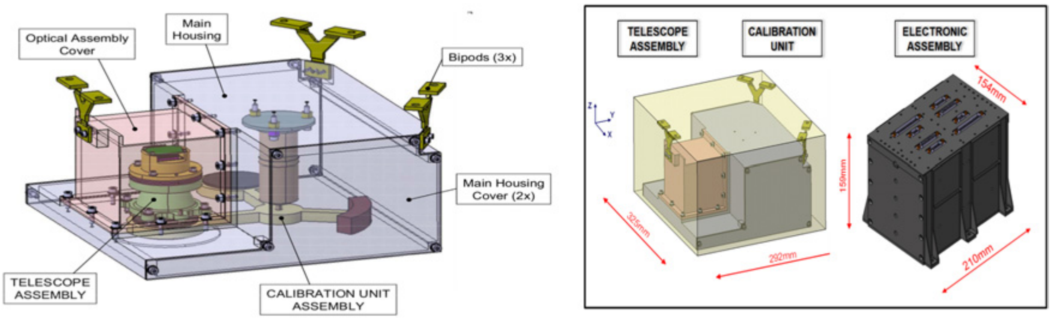

Figure 4. Telescope Assembly and Calibration Unit of the Infrared Camera on the left and the housing on the right.

other band. In Figure 3, a schematic drawing of the system is shown. The CTH reconstruction depends strongly on the disparity evaluation, i.e., on the estimation of the apparent displacement of the pixels in the two images due to the parallax effect. Corresponding points are searched in the stereo pair by an image matching process that could be affected by the differences in brightness temperature values present in the bi-band stereo case because of the differences in emissivity of the scene elements at different wavelengths. Therefore, the methods normally used for mono-band are not straightforward applicable to a multi-band stereo. Different methods need to be compared and optimized to meet the mission requirements and also a study on how the set of different approaches for CTH estimation can be combined to complement each other is in progress [3].

5. INFRARED CAMERA

The IR camera will detect the presence of clouds in the FoV of JEM-EUSO and from its radiometric measurements of the cloud temperature, the cloud cover and cloud top altitude during the observation period of the JEM-EUSO main instrument will be inferred. The IR camera will cover the whole FoV of the main JEM-EUSO instrument and it will operate within a range of 220 K – 320 K. Moreover, it will acquire images in two different spectral bands centered at 10.8 μm and 12.0 μm. In Figure 4, a preliminary design to fulfill all the scientific requirements of this space mission is shown where the telescope assembly and a dedicated calibration unit assembly are plotted.

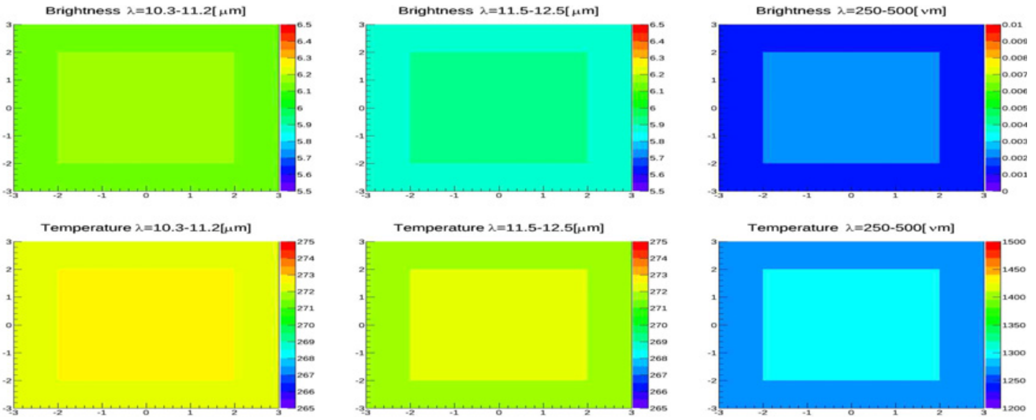

Figure 5. Image of a scenario simulated with the SDSU code showing radiated brightness (W/(m^2 str μm)) on top and brilliance temperature (K) at bottom in two bands IR (2 columns on the left) and UV (right column). Using as input a test scenario of one single layer of cloud at 4 km, with values of 3, 1 and 0.5 g/m^3 of Cloud Water Content, we can realize that using 2 IR bands (2 left columns) the differences in the scenario are bigger in the IR band (second column) compared to the other (first column). Moreover we have compared the IR images with the UV ones to find out if small changes in the scenario have any effect in the UV band of the main telescope.

The infrared radiation emitted by the ground and the atmosphere is simulated using a modified version of the Satellite Data Simulation Unit (SDSU) code developed in the Hydrospheric Atmospheric Research Center, Nagoya University, to fully simulate the infrared response of the infrared camera. Moreover, thanks to the capabilities of this code we are simulating the UV range of the JEM-EUSO main instrument (250–500 μm) as well, to get an approach of the slow data in the UV range of JEM-EUSO. Once the end-to-end simulation of the infrared camera will be completed it will be implemented in the AMS detector simulation module of the ESAF software. The simulation of the optics has been done using a dedicated Module Transfer Function (MTF) with CodeV for the simulation of the diffraction effect. Moreover the distortion of the detector is being simulated based on the data taken from the calibration test of an INO IRXCAM-640 with the same ULIS microbolometer that will be implemented in the JEM-EUSO IR camera. At the end, the output from this end to end simulation will be images similar to what we expect from the infrared camera that would allow us to test the temperature retrieval algorithms and obtain correction factors for the IR camera. A preliminary example of the IR simulations with the SDSU software is shown in Figure 5.

6. IDAR

The LIDAR onboard JEM-EUSO will operates in UV and will provide information about the absorption and scattering properties of clouds and aerosols. It will measure the optical depth profiles of the atmosphere with a sensitivity of $\Delta\tau < 0.15$. The code for the simulation of LIDAR events has been implemented in ESAF and therefore specific methods have been developed to simulate photons at 355 nm emitted by the onboard LIDAR laser source. The simulated LIDAR events will be useful to develop analysis tools for measuring the atmospheric conditions (Fig. 6 and Fig. 7).

7. METEORS

A simulator of meteor phenomena has been developed at INAF-Astronomical Observatory of Torino as a necessary pre-requisite for a systematic study of the expected performances of JEM-EUSO in detecting meteors. It can be used to design a suitable observation strategy and triggering procedure

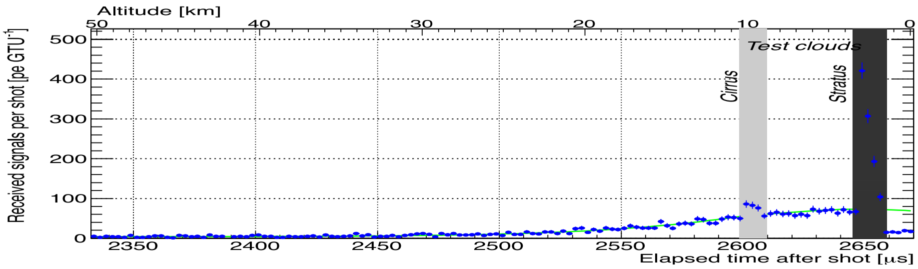

Figure 6. Simulated LIDAR backscatter signal in presence of optically thin clouds (cirrus) and optically thick clouds (stratus).

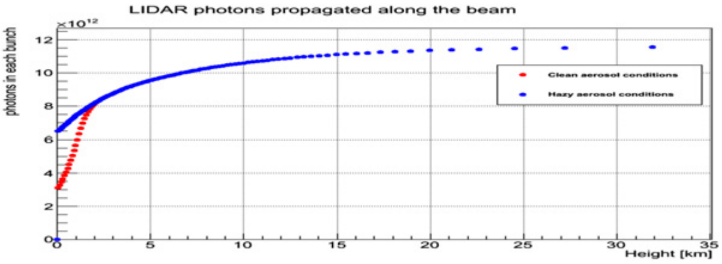

Figure 7. Number of LIDAR photons along the simulated beam at 0.65 mJ in two different attenuation conditions for aerosols (clean, Visibility = 23 km and hazy, Visibility = 5 km).

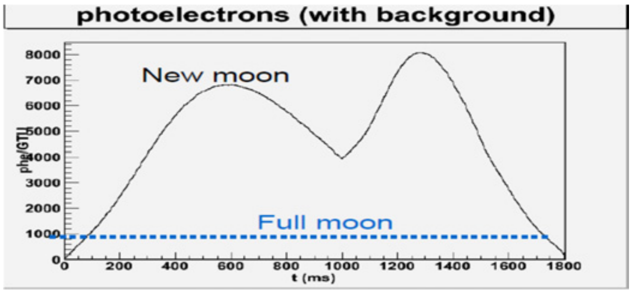

Figure 8. An example of a simulated meteor signal (solid line), where “new moon” stands for standard nightglow background without moon (500 ph/m^2/ns/sr). The light curve morphology includes a secondary burst in this particular case, and the intensity is given in photo-electrons per GTU, the standard Gate Time Unit of JEM-EUSO (2.5 μs). In terms of apparent magnitude, the first maximum corresponds to mag = 0 in UV light, while the secondary burst is slightly brighter. An average background level expected in conditions of full Moon is also shown as a reference. It is assumed that the meteor signal is recorded every 1 ms.

for these events very slow compared to those involving cosmic rays. In its current version, the meteor simulator is fairly simple. It allows simulating the occurrence of meteor events in a wide variety of possible observing circumstances including initial height and horizontal coordinates of the meteor with respect to the detector, meteor speed vector, duration of the phenomenon, and light curve. The simulated light curve morphology includes a large variety of possible single signals as well as an option to add a secondary luminosity burst, as observed in many practical cases (Fig. 8).

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