



## The IR-Camera of the JEM-EUSO Space Observatory

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**Abstract:** The JEM-EUSO space observatory will be launched and attached to the Japanese module of the International Space Station (ISS) in 2016. Its aims is to observe UV photon tracks produced by Ultra High Energy Cosmic Rays (UHECR) and Extremely High Energy Cosmic Rays (EHECR) developing in the atmosphere and producing Extensive Air Showers (EAS). JEM-EUSO will use our atmosphere as a huge calorimeter, to detect the electromagnetic and hadronic components of the EAS. The Atmospheric Monitoring System plays a fundamental role in our understanding of the atmospheric conditions in the Field of View (FoV) of the telescope and it will include an IR-Camera for cloud coverage and cloud top height detection.

**Keywords:** JEM-EUSO, Ultra High Energy Cosmic Rays, Atmospheric Monitoring, Infrared Camera, Clouds Temperature Retrieval, End to End Simulation.

## 1 Introduction

JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) [1] is an advanced observatory onboard the International Space Station (ISS) that uses the Earth's atmosphere as a calorimeter detector. The instrument is a super wide-Field Of View (FOV) telescope that detects UHECRs and Extremely High Energy Cosmic Rays (EHECRs) with energy above  $10^{19}$  eV. This instrument orbits around the earth every  $\approx 90$  minutes on board of the International Space Station (ISS) at an altitude of  $\approx 430$  km.

An extreme energy cosmic ray particle collides with a nucleus in the Earth's atmosphere and produces an Extensive Air Shower (EAS) that consists of a huge amount of secondary particles generating fluorescence light of atmospheric  $N_2$ . JEM-EUSO captures the moving track of the fluorescence UV photons and reproduces the calorimetric development of the EAS [2], [3]. At the energies observed by JEM-EUSO, above  $10^{19}$  eV, the existence of clouds will blur the observation of UHECRs. Therefore, the moni-

toring of the cloud coverage by JEM-EUSO Atmospheric Monitor System (AMS), is crucial to estimate the effective exposure with high accuracy and to increase the confidence level in the UHECRs and EHECRs events just above the threshold energy of the telescope. Therefore, the JEM-EUSO mission have implemented the AMS as far as the impact onto mass and power budget is insignificant. It consists of 1) Infrared (IR) camera, 2) LIDAR, 3) slow data of the JEM-EUSO telescope.

The Atmospheric Monitoring System (AMS) IR Camera is an infrared imaging system used to detect the presence of clouds and to obtain the cloud coverage and cloud top altitude during the observation period of the JEM-EUSO main instrument. Cloud top height retrieval can be performed using either stereo vision algorithms (therefore, two different views of the same scene are needed) or accurate radiometric information, since the measured radiance is basically related to the target temperature and therefore, according to standard atmospheric models, to its altitude [4].

Parameter	Target value	Comments
Measurement range	200 K - 320 K	Annual variation of cloud temperature plus 20 K margin
Wavelength	10-12 $\mu\text{m}$	Two atmospheric windows available: 10.3-11.3 $\mu\text{m}$ and 11.5-12.5 $\mu\text{m}$
FoV	60°	Same as main instrument
Spatial resolution	0.25°@FOV center 0.22°@FOV edge	Threshold values.
Absolute temperature accuracy	3 K	500 m in cloud top altitude
Mass	$\leq 7$ kg	Inc 30% margin.
Dimensions	200 $\times$ 280 $\times$ 320 mm.	300 $\times$ 300 $\times$ 500 mm. Max
Power	$\leq 11$ W	Inc 30% margin.

Table 1: Requirements for the IR camera.

## 2 Requirements for the infrared camera measurements

The Atmospheric Monitoring System (AMS) IR Camera is an infrared imaging system used to detect the presence of clouds and to obtain the cloud coverage and cloud top altitude during the observation period of the JEM-EUSO main instrument. Moreover, since measurements shall be performed at night, it shall be based on cloud IR emission. The observed radiation is basically related to the target temperature and emissivity and, in this particular case, it can be used to get an estimate of how high clouds are, since their temperatures decrease linearly with height at 6 K/km in the Troposphere. Table 1 summarizes the current scientific and mission requirements for the JEM-EUSO AMS IR camera.

Although there are no formal requirements for data retrieval, it has been assumed that the IR camera retrieval of the cloud top altitude could be performed on-ground by using stereo vision techniques or radiometric algorithms based on the radiance measured in one or several spectral channels (i.e. split-window techniques). Therefore, the IR camera preliminary design should be compliant with both types of data processing. Moreover, in this work, we have considered two methods for the data retrieval based on the use of one or two IR bands.

## 3 The infrared camera preliminary design

The IR-Camera can be divided into two main subsystems: a) Opto-mechanical unit, including the components necessary for the manipulation of the optical signal (magnification, spectral filtering), the detection of light (sensor)

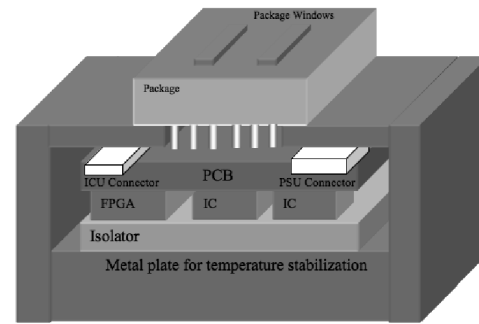


Figure 1: Detail view of the temperature stabilizer and the arrangement of the different components.

and the calibration of the sensor. b) Electronic subsystem, providing the instrument control and HouseKeeping (HK) functions, scientific data processing, redistribution of the power supply to IR camera components and electronic interfaces with the JEM-EUSO Instrument.

The optical system will be a refractive objective based on a modified IR Cooke triplet, with an aperture of 15mm, made of composed materials to save weight. This type of lens is especially interesting because has enough available degrees of freedom to allow the designer the correction of primary aberrations. For the detector, the baseline is an uncooled microbolometer pixel array, with a size of 640 x 480 pixels, and a Read Out Integrated Circuit (ROIC) as well, that is in charge of reading the values of the photo-detector array. The ROIC has on-chip programmable gain for optimization of the performance over a wide range of operating conditions. The system is uncooled, although a temperature stabilizer is required with a thermistor close to the detector array for accurate temperature measurements, and a Peltier cooling system, as is show in figure 1.

In the Electronic subsystem, we can find the image channel wich is formed by an optic element, used to focus the image, and the IR detection unit (detector plus video electronics). The data generated by the image channel is processed by the Data Processing Unit (DPU) within the Instrument Control Unit (ICU), which is in charge of controlling several aspects of the system management such as the electrical system, the thermal control, the calibration subsystem and the communication with the platform computer. The actuators of the instrument are managed by the ICU through an interface with the Centralized Control Unit (CCU). The Power Supply Unit (PSU) provides the required power regulation to the system. The management of the PSU is controlled by the ICU as well.

Most of the digital circuit implementation is based on FPGAs. The design contains two FPGAs which are located inside the ICU and inside the CCU respectively. Both FPGAs offer a control interface to the microprocessor to deal with basic functions such as actuator manipulations and data processing functions. All the commands are transmitted through a common data interface.

Therefore, the system architecture can be split into four different blocks: the optic with the detector and video electronics, the CCU with the power drivers and the mechanisms controller FPGA, the PSU which is in charge of provide the power supply to the instrument, and the ICU that controls and manages the overall system behavior. A cold redundancy scheme has been selected for the design.

## 4 Infrared data retrieval

The radiation emitted by the Earth's surface and the atmospheric clouds is measured by the IR sensor and the system retrieves the temperature of the emitter from this measurement. However the radiation collected by the IR sensor is not emitted by one single source. On the contrary, the atmosphere between the emitter and the sensor absorbs and emits energy. Therefore, the temperature obtained directly is not exactly the temperature of the emitter. These effects involve some uncertainties in the emitter temperature obtained from the direct radiation measurements. The objective of this part is the estimation of the errors associated to several factors: temperature and water vapor profiles deviations and cirrus effect. For this purpose some retrievals simulations have been carried out.

The simulations are based in a radiative model that consists of an atmospheric model, with the Earth surface emitting at 300K and a cloud at a certain height. In order to define the atmospheric model, the atmosphere is split into layers and values of temperature, pressure and gases concentrations have to be assigned. In this study, the atmosphere has been divided in 0.5 km thick layers from the bottom to the top of the atmosphere assumed at 150 km. Far away from this altitude, it is assumed that there is not physical effects on the IR radiation transport through the medium. In this way, the atmospheric model is described by vertical profiles of temperature, pressure and density. As a good approximation, clouds can be considered as blackbody emitters. For this reason, the clouds would absorb the energy emitted by the Earth surface and by the atmosphere beneath the clouds. For the same reason, the cloud can be modeled by a thin layer located at the top of the cloud that behaves as a blackbody at the temperature of the atmospheric layer at the same level. Figure 2 shows the vertical profiles describing the atmosphere model used.

### 4.1 Results of the one-band analysis

The main conclusions can be summarized as follow: a)The effect of the temperature vertical profiles is not significant (errors  $< 3$  K). b)The effect of water vapor vertical profile is significant for low-level clouds and atmospheres with high water vapor concentrations. c)The effect of thin clouds (cirrus) cannot be neglected since errors in retrieved temperatures are higher than 3 K for low and medium-level clouds. d)The temperatures retrieved by only one band are not accurate enough due to the effect of water vapor profiles and thin clouds.

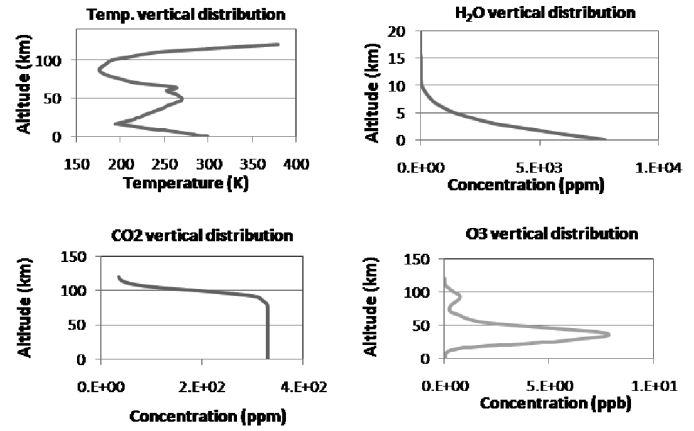


Figure 2: Examples of vertical profiles that describe the atmosphere model used in radiance calculations.

Cloud Height	$T_{cloud}(K)$	$T_{band-1}(K)$	$T_{band-2}(K)$	$T_{SWA}(K)$
0.5 km	296.7	293.6	292.0	297.4
1 km	293.7	291.5	290.3	294.0
2 km	287.7	286.7	286.1	287.7

Table 2: Comparison between retrieved temperatures by the one-band algorithm and the SWA. Although clouds have been studied from top heights of 0.5 km to 12 km in 0.5 km steps, in this table only the worst cases are shown

### 4.2 Results of the two-band analysis

In order to take advantage of the two-bands, a Split-Window Algorithm (SWA) has to be applied to the brightness temperatures retrieved from B1 and B2 bands. These algorithms have been used since latest 70s to measure the Earth's surface temperature from satellites to minimize the effect of the atmosphere. There are plenty of SWA that have been developed to retrieve the surface temperature from satellite measurements [5] [6]. All these algorithms are based on linearization of Planck's law and on the Radiative Transfer Equation (RTE). They have been applied to radiances obtained in two spectral bands and all of them consist of linear or quadratic functions of the temperatures retrieved in two bands. A comparison between retrieved temperatures by the one-band option and the SWA is shown in table 2. For blackbody clouds, the coefficients only depend on the atmospheric transmittance and they can be calculated because atmospheric profiles are known in simulations studies.

For real cases, the transmittance is not always known and, for this reason, different algorithms have been developed by different authors. The differences between algorithms lies in the SWA parameters and different authors propose different parameters to retrieve the surface temperatures in different conditions [7]. The algorithms have to be validated for different examples and environmental conditions but there is not an universal algorithm that can be applied

to any problem with enough accuracy. The same methodology can be applied to measure clouds temperatures, especially to low-level and thick clouds. In fact, there are also some SWAs devoted to retrieve clouds temperatures from satellites such as AVHRR, MODIS, etc. [8]. These algorithms are able to retrieve top-cloud temperature (Niemann, 1993), cloud emissivity and type of clouds (Pavolonis, 1985 and Inoue, 1987) and cloud microphysics (Inoue 1985). However the results attained when semitransparent cirrus are found in the FOV are not so accurate [8]. Therefore still open points remain to be addressed in order to retrieve top-cloud temperatures accurately.

Summarizing the results of this SWA preliminary study we can state: a) SWA is as accurate as the transmittances calculated with specific known atmospheric profiles. b) In order to study the effect of a cirrus (semitransparent cloud) in the temperature retrieval of a blackbody cloud, some simulations have been performed considering a cirrus between the cloud top and the IR camera. The examples show that the one-band option temperature retrievals have stronger uncertainties than SWA option, although SWA error is still above 3K. c) Not all SWAs from the bibliography always give good results. d) For higher clouds the coefficients of SWA have to be checked because the distance between the cloud top and the sensor decreases. These are only preliminary results, other factors like partially-covered pixels, semitransparent clouds, and some other issues will be studied in the future.

## 5 End to end simulation of the IR-camera

End to end simulation of the infrared camera will give us simulated images of those we expect to obtain with the instrument. Therefore this simulation together with the data analysis will be included in the AMS detector simulation module of the JEM-EUSO analysis software. First the simulated radiation produced by the Earth's surface and atmosphere have been considered, taking in account the effect of the optics and the detector, and finalizing in the electronics and image compression algorithm. A data analysis module is foreseen to take the data from simulator, and real data from the IR-Camera to perform the analysis tasks with the algorithms for data retrieval. The output from this analysis module will be used as an input in the official codes for the event reconstruction of the main telescope.

So far we have just started with the IR simulations, emitted by the ground and the atmosphere, using a modified version of the SDSU [9] software developed in the Hydrospheric Atmospheric Research Center, Nagoya University, to simulate the wavelength of our detector, and thanks to the capabilities of this code we are simulating the UV(Ultraviolet) range of our main instrument (250-500  $\mu\text{m}$ ) to get an approach for the slow data of JEM-EUSO. At the end, the output from this work will be images similar to what we expect from our camera, that would allow us to test the data retrieval algorithms and calculate correction factors for the

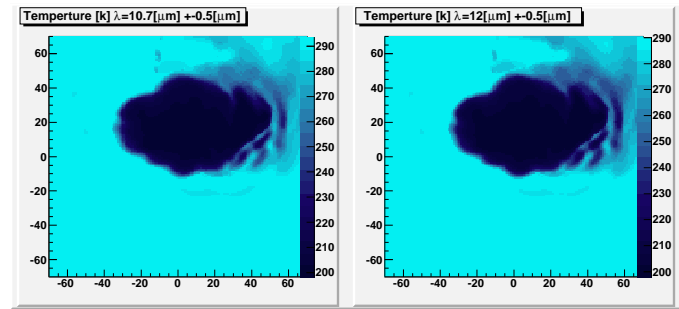


Figure 3: Examples of simulated cloud with SDSU modified for the IR-Camera bands.

IR-Camera. A preliminary example of the IR simulations done by the SDSU software is shown in the figure 3.

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