Potential of the Atmospheric Monitoring System of JEM-EUSO Mission

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Abstract: The existance of high energy particles with energies >10^{20} eV in the space is a basic problem in fundermental physics, because it means a violation of the GZK theoretical limitation. JEM-EUSO will try to detect such high energy particles in the space by the oprical fluorescence from the high energy paticles incident to the atmosphere. For caliblation of the optical background an atmospheric monitoring system consisting of a spaceborne lidar with an ultraviolet pulsed laser and an IR camera will be used. The IR camera takes images at suitable time intervals, monitoring the cloud cover in the whole field of view (FoV) of the telescope. Moreover stereo images are also taken to retrieve pixel by pixel the height of the cloud-top. The ultraviolet lidar measures the height of surface of clouds with the 30 m resolution. From these measuremnts we obtain a 3 dimentional map of clouds. The laser specifications are 20mJ/pulses at 355nm 20Hz rate, single longitudinal mode, and M_2<1 with conduction cooling.

Introduction

JEM-EUSO will have a Atmospheric Monitor system. The aim of the Atmospheric Monitor system is to observe the condition of the atmosphere in the field of view of the telescope. The strength of the fluorescent light and Cherenkov light emitted from EAS and their transmission process depend on the transparency of the atmosphere, cloud coverage and the height of cloud top. These must be determined by the Atmospheric Monitor system of the JEM-EUSO telescope.
In the case of events above 10^{20} eV, the existence of the cloud can be detected by the signals from the EAS [1]. The monitoring of the cloud coverage by JEM-EUSO Atmospheric Monitor, however, is important to estimate the effective observing time with a high accuracy and to increase the confidence level in the events just above the energy threshold of the telescope. The JEM-EUSO mission, therefore, requires an Atmospheric Monitor subsyste, but its impact on the mass and power budget is insignificant. It consists of 1) infrared camera, 2) Lidar, and 3) the slow data mode of the JEM-EUSO telescope. The plan is to measure the height of cloud top with an accuracy of better than 500 m. We have determined the basic specifications of the instruments and developed a conceptual design for them.

The sensors for the atmospheric monitoring will provide the inputs necessary to determine the effective aperture of EUSO telescope by correcting for losses due to opaque clouds. They will also determine the attenuation of the EECR's optical signal due to subvisible clouds and aerosol.. In addition, these sensors will provide useful observations of the Earth's atmosphere.
The present concept for atmospheric monitoring is based on the use of a complex of sensors in synergy with each other, which have a small impact on the overall budget. These sensors are:

(A) Infrared Camera for precise 2D mapping of clouds and evaluation of the cloud top altitude by means of strereo methods for computer vision. ; The accuracy of the retrieved heights depends on several parameters such as cloud configuration, features of the final setting of the acquiring system, temporal distance between pairs of frames etc. Some cases have shown accuracies better than 500m.

(B) Elastic backscatter Lidar, for direct measurements of the opaque cloud top with accuracy of 30m, as well as the optical depth and altitude distribution of subvisible clouds and aerosol layers;

(C) UV background detection using PDM rate meters allowing implementation a stereoscopic evaluation of the opaque cloud top.

The Infrared Camera

The Infrared camera consists of refractive optics made by Gelium material and an uncooled micro bolometer array detector. Interferometer filters are used that transmit in the 10-12 μm band. The field of view of the telescope is 60°, which matched to that of the main telescope. The angular resolution, which corresponds to one pixel, is about 0.25° at the center of the field of view. The temperature controlled shutter in the camera and mirrors are used to calibrate background noise and gains of the detector to achieve the absolute temperature accuracy of 3K. The sea temperature, observed by the other satellites, can also be used for calibration. Although the infrared camera takes images continuously at a frame rate (= 1/30 sec), transfer of the images takes place every 30 seconds during which ISS moves half of the field of view of JEM-EUSO telescope. Table 1 summarizes the requirement of the infrared camera.

Table 1 Specification of the IR camera

Specification	***Value***
Temperature range	220 – 300 K
Wavelength	10 – 12 µm
Field of View	60º
Spatial resolution	0.25 º @ FOV center (= 4.4 mrad) 0.22 º @ FOV edge (= 3.8 mrad)
Absolute Temperature accuracy	3 K
Optics	Ge Refractive Optics
Detector	Unclooled Microbolometer array
Digitizing resolution	12 bit
Integration Time	33 msec / image (= video frame rate)

The uncooled bolometer array can be small, light weight, and low power, since it does not use semiconductor detectors such as HgCdTe, GaAs, InGaAs, which require the cooling system. In recent years, the performance of bolometes has dramatically improved. They are used in space environment in Mars Odyssey and space shuttle mission, STS-85. Planet-C/VCO□Venus Climate Orbiter □, scheduled launch in 2010, is also adopted an infrared camera in mid-infrared (LIR) with a uncooled micro bolometer array detector. A wide field has been achieved by the Germanium refraction optics was developed in JAXA for the stratosphere platform mission. Also EADS/SODERN has developed an infrared camera with an uncooled micro bolometer array for METOP1 satellite and CALIPSO satellite. In JEM-EUSO mission will take advantage of this heritage.

Stereo vision for cloud–top evaluation

The IR camera will be used to obtain information on the cloud coverage and maps of the cloud-top heights for each pixel in the FoV of the JEM-EUSO telescope and in particular when an event occurs. The acquired images will be analyzed by methods used in computer vision and stereo vision as described in [2]. This is in agreement with some recent studies [Moroney'02] showing that it is possible to achieve reliable height estimations from the color temperature of the clouds, but also by methods that rely only on geometrical features. Temporal sequences of pairs of different infrared views of the atmosphere below the ISS, will be recorded along the flight direction, within a suitable temporal range thereby the same scene is mostly in the field of view of the pair of images at the two different times.

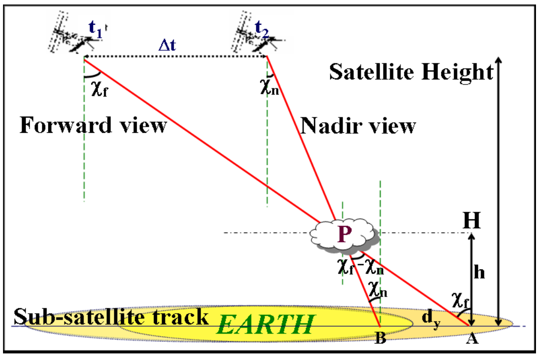

Fig.1. Two views of the same scene (stereo vision) obtained by moving the camera respect to the observed scene.

The parallax effect from the stereo approach is treated as an apparent motion (disparity) of the cloud from the first image to the next one. So from an evaluation of the disparity combined with the geometry of the system the cloud height can be determined. A reliable cloudiness mask detection can improve the precision of the cloud height maps. Studies for a reliable cloud detection method are currently ongoing and in Fig.2 an example of a cloudy infrared image from ground and its cloudiness mask overlapped to the original one, is shown. Black pixels in the right image are detected as cloud free. [4].

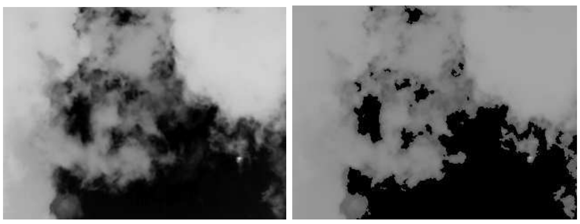

Fig.2. Left: IR image of clouds. Right: cloudiness mask overlapped to the original one; black pixels are cloud free.UV background image detection is currently foreseen using the PDM rate meters [5] (photo-electron counts/sec). Work is in progress to evaluate the feasibility both from a point of view of telemetry resources and resolution capability for cloud coverage detection. Also in this case the stereo approach can be used for cloud top height evaluation.

The Backscatter lidar

The proposed Lidar will be a backscatter type using wavelength in the UV spectral range, *i.e.*, coinciding with the wavelength of the atmospheric fluorescence from the EECR. In this way it is possible to use the JEM-EUSO telescope as Lidar receiver. The operation with the telescope of EUSO decreases the requirements for the laser power, mass, volume and complexity. A preliminary view of this concept is shown in Fig. 3. In this concept, the beam from the laser is directed into the atmosphere in the directions to be investigated. It covers, in succession, several sections in the FOV of the JEM-EUSO telescope that are necessary for calibration and correction of the results from the evaluation of the cloud top altitude the IR camera and stereo-imaging from the "slow-mode" background detection.

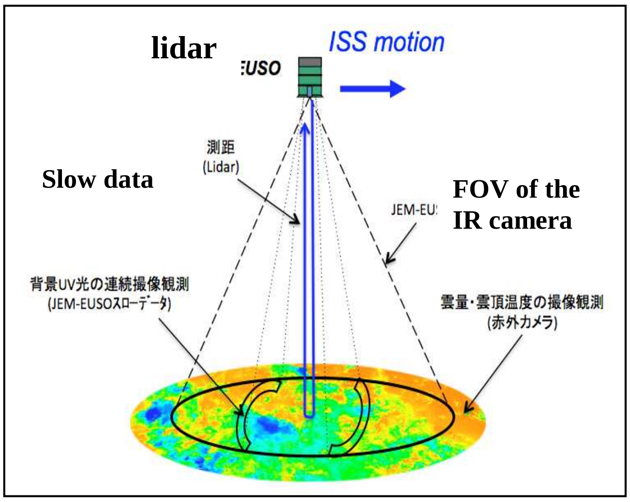

Fig. 3 Concept of the Atmospheric Monitor

The compliance of the proposed lidar concept to JEM-EUSO measurement objectives was shown by a series of end-to-end lidar signal numerical simulations. The instrument specifications used as inputs to the simulations are given in Table 2. The estimated mass, dimensions and power consumption of the used laser are given in Table 2..

Table 2. Specifications of the subsystems of the JEM-EUSO Lidar concept

Specification	***Value***
Wavelength	355 nm
Pulse repetition rate/Energy	10 Hz/10mJ
Divergence of the laser beam	1.2 mrad
Filter FWHM / transmission	2 nm / 60 %
Lidar telescope, diameter	JEM-EUSO, 2.5m
Detector, quantum efficiency	MAPMT, 35%
Range resolution	30 m
Mass (total, only laser)	17 kg / 15 kg
Dimensions of the laser	450 × 350 × 250 mm
Power consumption, laser only	< 75 W (operative) 100 W (start phase)

The divergence of the laser beam will be 1.2 mrad. In this way, the laser footprint will almost coincides with a single pixel observed on the Earth's surface by the JEM-EUSO detector (750 m diameter). Considering a pulse repetition rate of the laser of 10.053 Hz and the orbital velocity of ISS, the successive laser pulses will come to successive pixels on the surface. We note that the detection concept of the proposed instrument is similar to other space-borne backscatter lidars [6,7]

It is important to determine whether one laser shot will besufficient to detect the opaque cloud top. Fig. 4 shows the results of numerical simulation when the single pixel on ground is entirely covered by opaque clouds (case study #1), while Fig. 5 is when 50% od the single pixel is covered by opaque cloud (case study #2). The cloud is assumed to have an optical depth OF=4.8 (in visible) with a geometrical thickness of 500m and an altitude of the center of 3500 m. On the figures, the horizontal axis is the altitude above sea level, while three values are presented on the vertical axis: the aerosol scattering ratio of the atmosphere, the detected signal in photon counts and the signal-to-noise ration for signal detection.

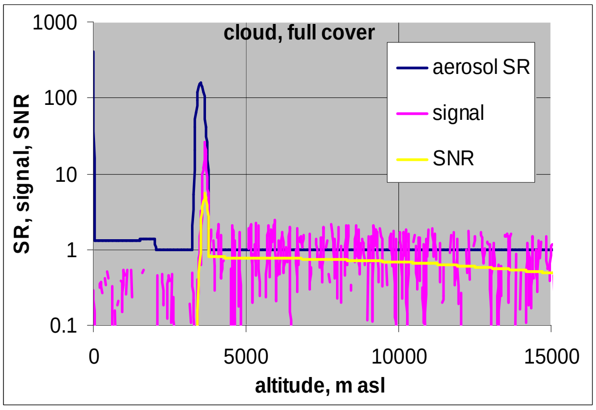

Fig. 4. Backscatter Signal and Signal-to-noise ratio for the proposed lidar, with one laser shot. See the text for explanation of the aerosol Scattering Ratio. Cloud coverage of the single pixel is 100%.

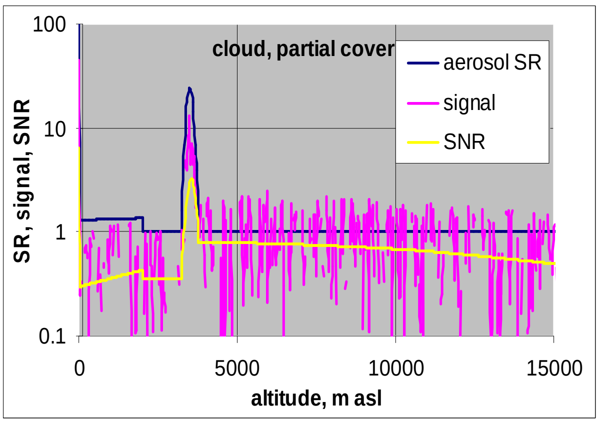

Fig. 5. Backscatter Signal and Signal-to-noise ratio for the proposed lidar, with one laser shot. See the text for explanation of the aerosol Scattering Ratio. Cloud coverage of the single pixel is 50%

In both cases, the SNR is well above 2, allowing the probability of detection more than 2σ. Comparing the results from Figs. 4 and 5, we may see that the SNR for cloud detection in the case of partial coverage of the pixel is still high enough for the cloud top detection. The difference is the appearance of signal scattered from the Earth surface in the case in Fig. 5, indicating that some parts of the surface are not obscured, i.e., the partial cloud coverage.

The possibility to measure the optical depth of the subvisible cloud at altitude higher than the altitudes for development of the shower trace, is illustrated in Fig. 6. The axis present the same values as in Figs. 4 and 5. The aerosol scattering ratio is representative for a subvisible cloud at altitude of 9 km with geometrical thickness of 600 m. The cloud has an OD=0.1 so the transmission factor is 0.9. Such a transmission factor causes an under estimation of the optical yield from the shower of 10%. We may consider this to be representative of the maximum tolerable under estimation. The altitude resolution considered is again 30 m. The signal is integrated over 10 lasers shots. As we may see from the figure, the backscatter signal has a SNR above 2 not only for the subvisible cloud but also for the atmospheric molecular backscatter (Rayleigh) above and below the cloud. This allows a precise evaluation of the cloud backscatter, optical depth and the transmission factor. The fact that integration of 10 shots is necessary for such precision (i.e, a line over 10 pixels or 7.9km on the surface) is not an obstacle for probing of such clouds. In addition, the detection of the molecular (Rayleigh) backscatter may be used also for evaluation of the atmospheric density. Such evaluation will improve the precision of the determination optical yield from EECR. For such evaluation, the backscatter signal integration may proceed over a longer line on the surface and with altitude resolution bin width up to 150m or even 300m.

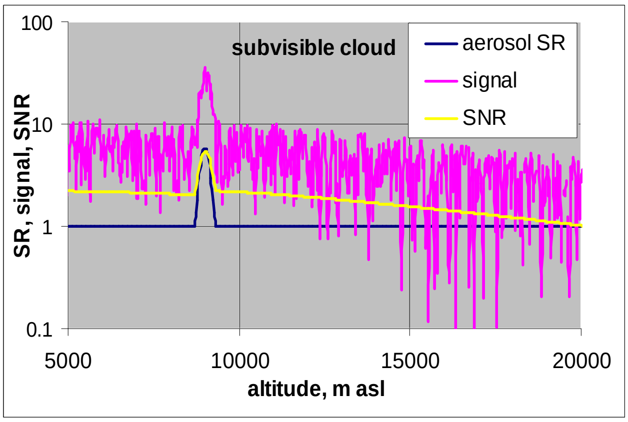

Fig. 6. Backscatter Signal and Signal-to-noise ratio for detection of the signal from high-altitude subvisible clouds and atmospheric molecular backscatter above and below the cloud. See the text for explanations for the aerosol Scattering Ratio.

Laser system and beam steering of laser beams

Using simulations, the specification of the laser system was decided. Detailed parameters is as same as those in Table 1. However, considering loss of beam, we request the pulse energy of laser to be 20 mJ with several ns pulsewidth. For steering of laser, we will try to introduce MEMS mirrors developed by Ewha University in Korea.

Summary

In this paper, present status of the atmospheric monitoring system of JEM-EUSO was described.

References

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