Radar Echo Detection System of EAS Ionization Columns as Part of a LAAS Detector Array

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Abstract

Extensive air shower (EAS) resulting from ultra high energy cosmic rays have been observed by means of compact arrays of scintillation detectors in order to study large-scale correlations of cosmic rays, by the Large Area Air Shower (LAAS) group. The possibility to detect the radar echoes produced by scattering from ionization columns in an EAS were proposed on the basis of the theoretical and phenomenological calculation on the analogy to the observation of meteor ionization tails at radar frequencies of the low VHF range. Four EAS arrays are operated in Okayama as part of LAAS experiments, and some of them are equipped with the observation systems of radar meteor echoes. The prototype of EAS radar echo detection system synchronized with EAS trigger signals have been constructed. In the early results on coincident radar echoes with EAS trigger signals, we could not find any significant correlation during this period.

1. Introduction

The understanding of extremely high energy cosmic rays represents one of the most important problems of high energy astrophysics. EASs produced by extremely high energy cosmic ray have been observed so that the primary cosmic ray spectrum extends in energy beyond Greisen-Zatsepin-Kuzumin cutoff expected if the particle is hadronic in nature and due to source at distance greater than 50Mpc. To study the origin of these particles, higher statistics are needed. The higher collection areas of present detection techniques are required.

The recent theoretical study[1] of ionization trails produced by EAS suggests that radar techniques would give the new parameters of EAS like that of

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meteor ionization trails. A meteor ionization trail typically occurs at heights of about 100km, of which speed is about 50$\sim$70km/s. The incident meteor has a mass of 0.1 to 10g. The expected line density of electrons is about 10^{14}/m. And the typical length of meteor trails ranges 10 to 15 km, of which radius is several ten cm to several ten meter. Radar observation of meteor echoes has commonly been applied for both atmospheric parameter measurement for aeronomy and meteor characteristics for planetary science.[2] Two types of meteor echoes are used for the radar measurement. At first, meteor trail echo is a strong Frenel scattering from the ionization trails lasting for 0.1 to 1 second in usual case. This scattering highly depends on the trail aspect from a radar transmit site and an observation site. On the other hand, meteor head echo is a backward scattering from high density ionization region. In this case, the radar transmit site and echo detection site is almost located in the same area.

The ionization in an EAS has lateral distribution due to the spread of the shower electrons and positrons, and all high energy particles are collectively moving like the pancake of particles at almost the speed of light. The possibility of radar observation of EAS ionization columns and highly ionized pancakes depend on the diffusion effect of ionization columns and their life time. High power radar system should also be utilized to obtain enough echo powers.

In this paper, the status of radar observation of EAS tail echo, synchronized with LAAS EAS arrays[3,4] is reported.

2. Experimental Setup

The LAAS project[3,4] have been operating GPS-synchronized compact EAS arrays in large part of Japan. In Okayama area, 4 arrays are located on the top of building in the campus of both Okayama University (OU) and Okayama University of Science(OUS1, OUS2, OUS3). Each array consists of 5-8 plastic scintillation counters within 20m$\times$30m area, and of 1μs accuracy GPS system which allow us to measure an EAS arrival time in UT.

We have installed the meteor ionization trail detection system on LAAS's EAS sites in March 2003. The profiles of these systems are summarized in Table 1, as well as the number of scintillation counters at each site. The stable observations at each site were just started in the end of March. Each yagi antenna is pointing in the source direction, because the distance between the transmitter and the receiving sites in Okayama city should is so long that the transmitted radio wave have never been detected directly.

To optimize the S/N ration to detect the echoes of ionization column, it was suggested by Gorham[1] that the system should be operated at the lowest frequency. Typical plasma frequency of ionospheric layers is less than several ten MHz even in daytime environment. The available source of VHF radio wave in Japan, have been maintained at Fukui National Colleage of Technology in Sabae-

Table 1. Radar echo receiving systems in LAAS at Okayama sites. Nc represents the number of scintillation counters in each EAS array.

Array Name	yagi antenna		Receiver	Nc
	elements	Gain(dBi)		
OU	2	6.3	IC-R75(ICOM corp.)	8
OUS1	5	10.1	IC-R75(ICOM corp.)	8
OUS3	2	6.2	HRO-RX(AITEC)	5

city, Fukui pref., of which specification are shown in Table 2.

Each receiver provide detected signals from an audio output, and this audio data are acquired by analog to digital converter (ADC) in using PC sound card system. We use the HROFFT software to aquire and store observed data. The sampling frequency and frequency resolution of this software are 8192Hz and 2Hz, respectively. The observed radio signals were finally converted to spectrum data by fast Fourier transform method. The advantages to use this system is to achieve high cost performance in order to construct the prototype system of EAS signal detections.

3. Results and Conclusions

We have seeked the coincident radio signals with EAS events observed in LAAS at Okayama area. The LAAS data were selected under the condition that EAS events were simultaneously detected in more than 3 arrays, since higher energy EAS should have made high ionization line density along the track. The spectrograms of radar echo radio signals obtained by HROFFT software were scanned at each EAS arrival time. In daytime, noise levels are still high due to human activity and some meteorological effects were obviously seen in them. In this analysis, therefore, an eye-scan method was applied.

Figure 1 displays one of typical spectrogram of radar observation of meteor

Table 2. The summary of HRO radio wave source transmitted from Fukui National Colleage of Technology.

Transmit power	50W
Frequency	53.75000 MHz
Geographical location	136˚10’28”
Transmit mode	continuous wave(CW)
Transmitter	IC-706 with a stabilized clock generator(ICOM corp.)
Transmit antenna	2 ele. crossed yagi.

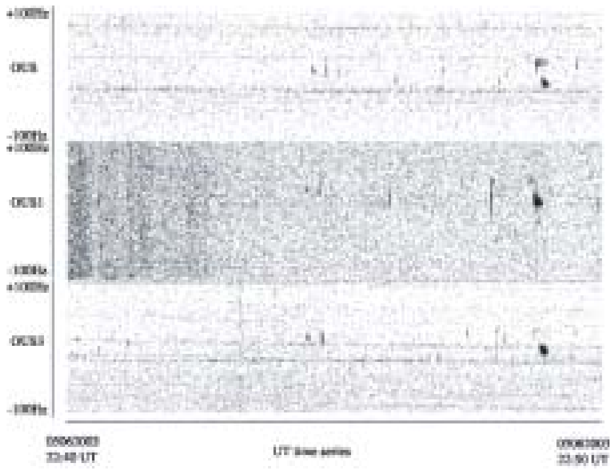

Fig. 1. Radar echo spectrogram at OU, OUS1 and OUS3.

echoes at OU, OUS1 and OUS3. Clear signals were shown in both spectrograms, and they were observed at the same time in the other distant observatory. We have searched the correlation of those signals, but have not detected any correlation between them in this analysis yet. In conclusion, the protype system to observe VHF radio waves from EAS ionization columns were operated by using meteor trail observation systems. There is no clear signals correlated with EAS trigger signals. We are now going to install high gain antennas and precise VHF receivers, and also to extend to the capability of radar pulse transmitting/receiving to detect the signals like meteor head echoes.

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4. References

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