Chinese Journal of Polar Science, Vol. 10, No. 1, 33 - 40, June 1999

Preliminary result of imaging riometer at Zhongshan Station, Antarctica

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Received December 23, 1998

Abstract An imaging riometer with 8×8 antenna array was installed successfully at Zhongshan Station, Antarctica in January 1997. The structure and working principle of the instrument are described. The first set of observation data is analyzed and the quiet day curve(QDC) are deduced. Preliminary results show that cosmic noise absorption is very different between night side and magnetic noon. In night side, there are often short-duration impulsive absorption events with a large absorption area in the northern side of the station, stretching in an east-west direction. In magnetic noon the absorption event is continuous, which lasts for more than 1 h with the absorption area strengthening in the northern and southern sides and weakening in the middle. It is thought that the absorption is caused by aurora particle precipitation in night side and by soft particle precipitation or convection in cusp at magnetic noon.
Key words cosmic noise, absorption, QDC, Zhongshan Station, Antarctica.

1 Introduction

Zhongshan Station(76°22′E, 69°22′S) of Antarctica is located in an idea place for observing solar-terrestrial phenomena. At Zhongshan Station several instruments such as ionosonde DPS-4, magnetometers, aurora optical recording system have been installed and in operation. These instruments are running coordinately. The data could be compared with the correspondent observation in Svalbard, the magnetic conjugate area of Zhongshan Station, and conformed each other with the HF radar observation in Syowa Station (Japan) and the similar observation in Davis Station, Australia (Liu and Liu 1994). An imaging riometer was installed at Zhongshan Station during the austral summer, 1997 under the cooperation between Polar Research Institute of China and National Institute of Polar research, Japan.

The imaging riometer consists of two parts: the antenna array and the data recording system.

The antenna array is composed by 64 (8×8) dipole elements with semi-wavelength separation between two neighboring elements and a quarter wavelength above the ground net. The ground net is woven by copper lines and used to strengthen the reflecting capacity of the ground to radio wave. Then a mirroring image of the dipole elements could be formed with respect to the ground net and the antenna array could receive cosmic noise more effective. The array produces 64 beam signals with different direction. The averaged horizontal width of one beam is 25 km therefore the array can monitor an area of about 200 km×200 km in 90 km height.

The data recording system has three parts: a butler matrix, an interface box and a personal computer. The 64 signals received by dipole antennas are linked to butler matrix through 64 coaxial cables respectively. The butler matrix shifts their phase and overlays them to produces 64 beams signals which are transmitted into the interface box through a 300 m length coaxial cable and then to the computer. Last, they are digitized and recorded in magnetic optical disk. Meanwhile, the computer monitors and controls the whole of the instrument, and displays the data on screen in real-time.

The imaging riometer operates on 38.2 MHz with wavelength of 7.86 m. Its antennas array towards invariant magnetic north in one side.

The working principle of the instrument could be described in the following: the cosmic rays are attenuated as they penetrate into the earth's magnetosphere and ionosphere. There are electrons and ions that would absorb cosmic ray through wave-particle interaction and collisions. The attenuating magnitude is dependent on local electron density and the collision frequency between electron and the other particle along the propagating path, and can be calculated by following formula (Stauning 1996):

$$A = 4.58 \times 10^{-5} \int_S \frac{N\nu}{(\omega \pm \omega_L)^2} \mathrm{d}s$$

Where, A is the attenuating magnitude or absorption along the propagating path. N and ν are local electron density and collision frequency respectively, ω is angular frequency of the wave, ds denotes a differential element of the path. $\omega_L = \omega_c \cos\theta$ is the longitudinal component of the electron gyro frequency ω_c, θ is the propagating angle which is the angle between the geomagnetic field line and the wave path. The signs, + or −, depend on polarization of the signal.

The relative variation of the cosmic ray received on the ground can indicate the change in the upper atmosphere. Therefore, the imaging riometer can be used to monitor the physical phenomena occurring in the upper atmosphere in real time and independent to the weather.

2 Quiet day curve of cosmic noise

The quiet day curve of cosmic noise (QDC) is based on the observing data. The absorption values of the cosmic ray can be obtained when we reduce observing values by their QDC value.

For making the quiet day curve, it is needed to weight smooth the observing data and to transform the data from universal time system into sidereal time system. Then the probability distribution curve of the strength in any special time can be deduced from the data. It is thought that the value of the inflection point of the distribution curve is the quiet day value in that time. The quiet day curve is formed when all of the quiet day values are ordered along time series.

It is impossible to unattenuate for cosmic ray propagating towards ground because the ionization always exists in and above the ionosphere, then some amount of electrons and ions would be contained there, which will absorb the cosmic ray. In fact, the quiet day curve reflects the time variation of the strength of cosmic ray in quiet days (Xue and Ye 1994).

It is shown that the strength of cosmic ray changes apparently at different time of the day. Curve (1) in Fig. 1 shows the QDC of the central beam ($x=4$, $y=4$, x denotes east-west direction, $x=1$ corresponds most eastern beam; y denotes south-north direction, $y=1$ corresponds most northern beam). The maximum value occurs during 1:00 – 2:00UT, the minimum value occurs during 13:00 – 15:00UT, and the former is 3.73 times higher than the latter.

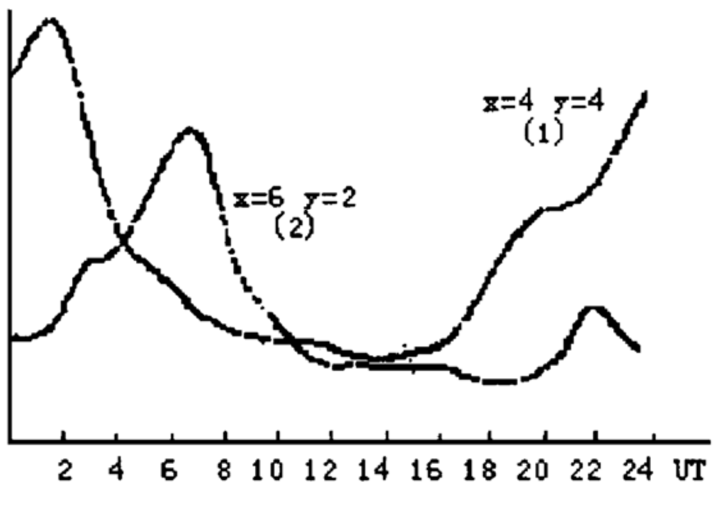

Fig. 1. Comparison between central beam QDC and edge beam's.

Curve (2) in Fig. 1 shows the QDC of one edge beam ($x=6$, $y=2$, the meaning of x/y is the same as above). It has two apparent peaks, one occurs during 6:00 – 8:00UT and the other occurs during 21:00 – 23:00UT. Its minimum value occurs during 17:00 – 19:00UT, and the maximum value is 3.67 times higher than the minimum value and 1.12 times higher than the second maximum. Fig. 1 indicates that the QDC is variable with the direction in space.

3 Absorption events

A QDC can be made for each beam of the imaging riometer. Absorption value is obtained when we reduce the observing value by its QDC value. Here we adopt this absorption value to discuss the events, and select the absorption events with criteria of absorption value greater than 0.5 dB and the duration larger than 1 min. Two dimensions image of the absorption is got when we display the values of beams according to their positions and orientations in a plane.

Analyzing the data of the imaging riometer at Zhongshan Station, it is shown that apparent cosmic ray absorption events occur frequently there every day. In night side, there are often short-duration impulsive absorption events with large absorption area in the northern side of the station, stretching in an east-west direction. For example, three typical cosmic ray absorption events were recorded at 15:39UT, 17:00UT, 23:28UT, Feb. 10, 1997, respectively.

Fig. 2(1) shows the absorption event in 15:39UT in which the absorption began in the east-northern area. The absorption did not appear at 15:37:03UT but increased to 2 dB at 15:39:11UT and lasted to 15:43:27UT for 6 min. Here W, E, N and S denote west, east, north and south of the view field, respectively. At the top of each small picture, the digits such as 15:37:03UT is universal time, so as in Fig. 3.

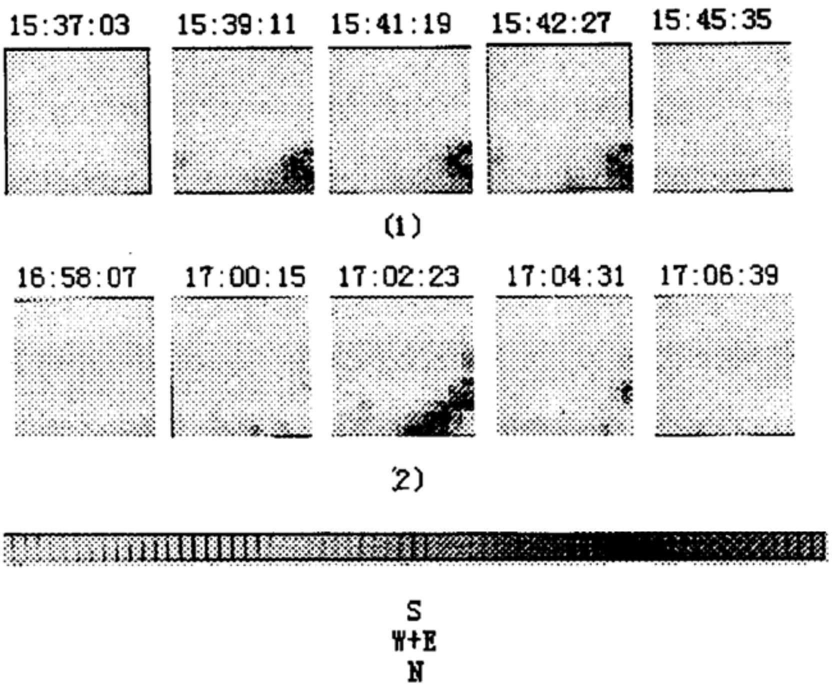

Fig. 2. Absorption events in 15:39UT and 17:02UT, Feb. 10, 1997.

Fig. 2(2) shows the event occurring at 17:00UT, in which the absorption did not appear at 16:58:07UT and occurred weakly in the east-north part of the field at 17:00:15UT, and reached 2 dB at 17:02:23UT. The absorption area looks like a belt along east-south to west-north direction, and of which two ends were outside of the view field.

Comparing with Fig. 2(1), it is seen that the absorption area shifted towards to the center of the view field and occurred weakly in the northwest part. Up to 17:06:39UT, absorption disappeared. The absorption events were still impulsive.

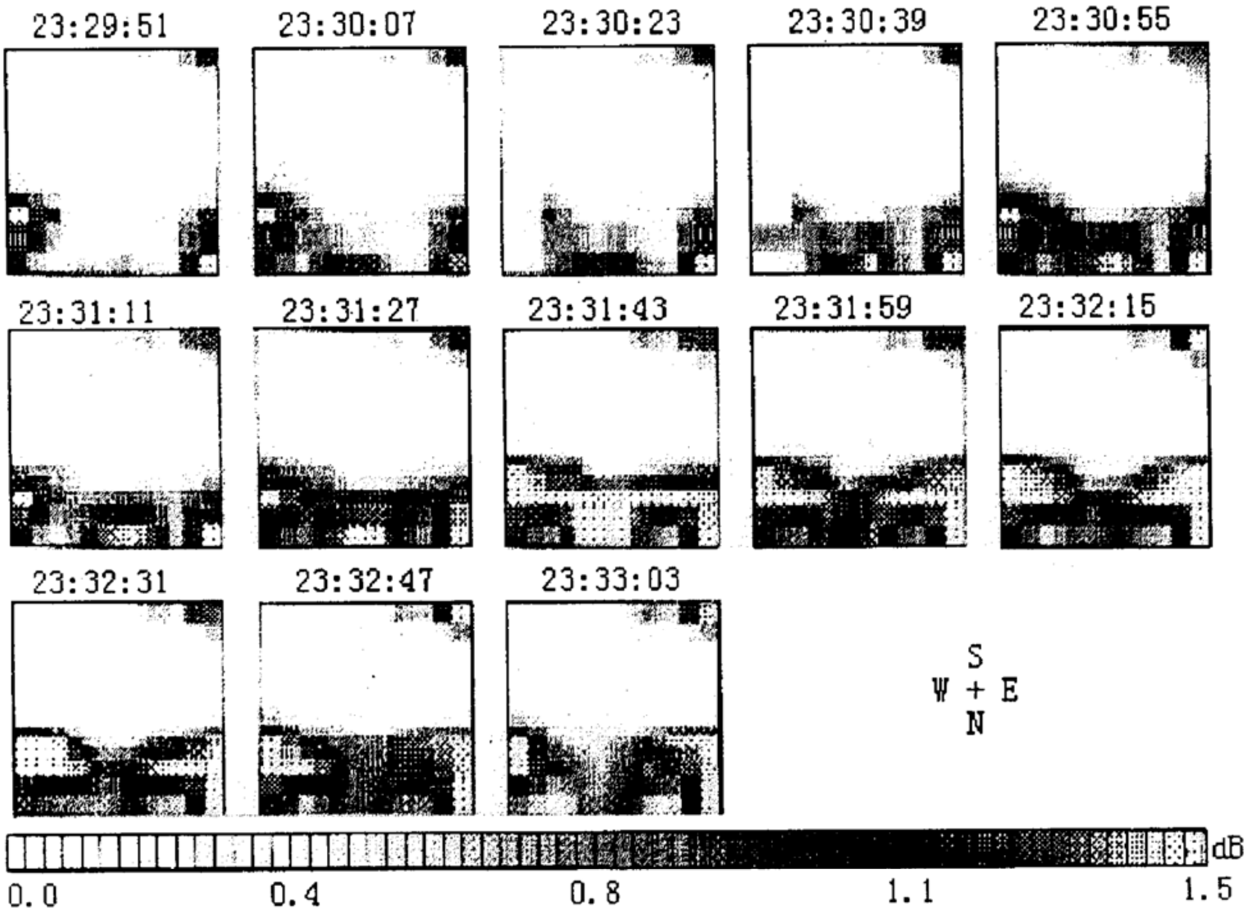

Fig. 3. Absorption events of 23:29UT, Feb. 10, 1997.

A large absorption event is shown in Fig. 3 in the same day. Beginning at 23:29:51UT, the absorption appeared in the northern side of the field with the edge paralleling to east-west direction (according to invariant magnetic north), of which the east/west ends were outside the field. The absorption area could separate into west, middle, east parts, and the absorption strength did not decline but stretched east-west direction. Up to 23:31:43UT, the three parts gradually jointed each other as a whole. Later, the absorption area divided into west, middle, and east parts again and disappeared at last.

In dayside, the absorption events often appeared in magnetic noon and postnoon with high strength and wide area. It is worth to noticed that the absorption were apparent weaker in S5 column beams than the other beams so that a "trough" formed along S5 column beams. Fig. 4 shows such an example, where S denotes south-north direction and S1 the most southern one, E denotes east-west direction and E1 the most eastern one. In each small frame, the horizontal axis indicates time while vertical axis indicates absorption. It is shown that the absorption increased during 10:00 – 14:00UT in this case. In other days, several absorption events occurred, though their strength was weak relatively.

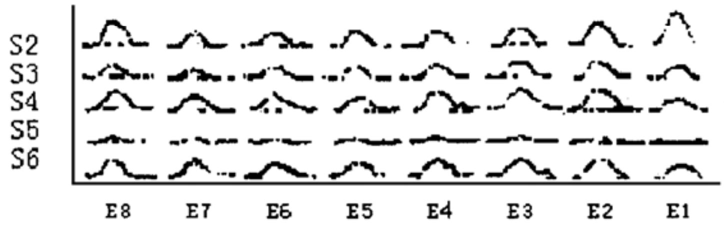

Fig. 4. Absorption of magnetic local noon, Feb. 12, 1997.

4 Analysis and discussion

Zhongshan Station is located under the ionospheric projection of the magnetospheric cusp in dayside and at the polar cap in night side, crossing the auroral belt twice every day (Liu *et al*. 1997). There are many geophysical phenomena happening frequently in the cusp and the auroral belt. An extra absorption would be created during the course of these phenomena. For these reasons, there are a lot of cosmic ray absorption events being recorded at Zhongshan Station.

In night side, Zhongshan Station is situated in the polar cap and on the southern side of the auroral belt (Liu *et al*. 1997). The absorption caused by precipitating auroral particles often occurs on northern side of the Station, which is consistent with the observations such as the cases shown in Fig. 2 and Fig. 3. It is thought that the absorption is caused by precipitating auroral particles. It is also demonstrated that Zhongshan Station is located on the southern side of the auroral belt.

The $\sum K_p$ value on Feb. 10 reaches 29, which is the third largest one in the month. Especially, the geomagnetic field changed a lot at that night as shown in Fig. 5, which is consistent temporally with the absorption shown in Fig. 2 and Fig. 3. The strength of cosmic ray received on the ground declines when electron density increases, which is caused by precipitating auroral particles ionizing the upper atmosphere. The observations show that absorption event lasted for a short time and appeared frequently, which imply that the auroral particles precipitate impulsively.

Fig. 6 shows variation of foEs, the critical frequency of ionospheric Es layer based on the data measured by DPS-4 simultaneously at Zhongshan Station. It is seen that the foEs have 4 peaks during that night which is consistent temporally with the appearance of the cosmic ray absorption. It is quite often that the appearance of the cosmic ray absorption occurred at the leading edge time of the ionospheric Es layer strengthening. The absorption still exist but became weaker after the Es layer strengthening. As mentioned in the first section of this paper, cosmic ray absorption depends on the product of the electron density to its collision frequency. The absorption is mainly caused by ionospheric D layer since the electron collision frequency in the D layer is much larger than in the E layer. While the strengthening Es layer is the results of extra ionization caused by the precipitating auroral particles at the height of E layer.

Cosmic ray absorption, geomagnetic fluctuating and the Es layer strengthening are consistent temporally with each other very well, indicating that they are result of the

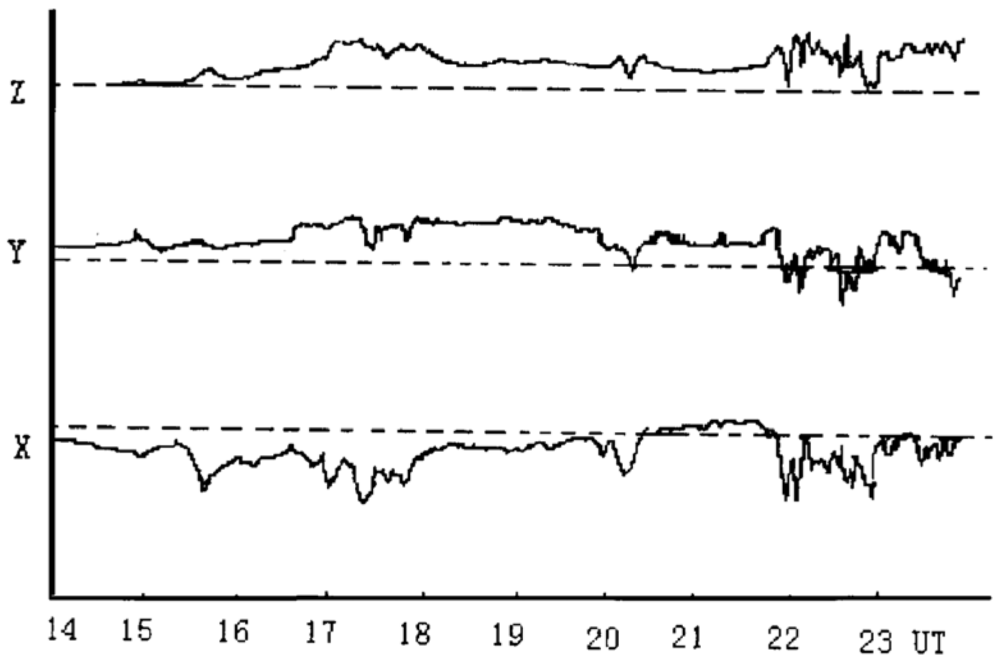

Fig. 5. Geomagnetic variation from 14:00UT to 23:59UT, Feb. 10, 1997.

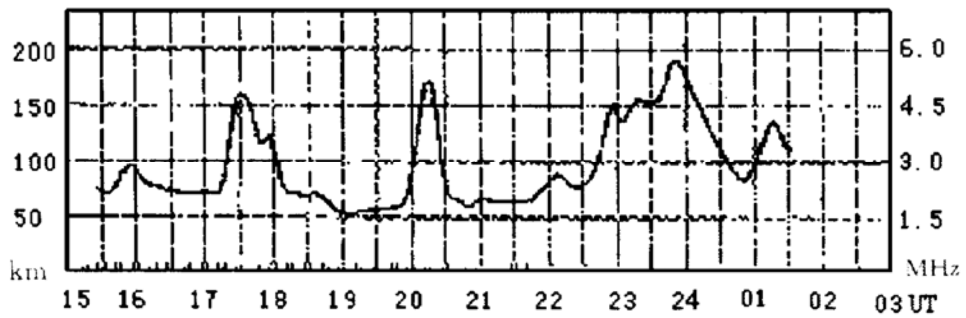

Fig. 6. Variation of foEs, the critical frequency of ionospheric Es layer at Zhongshan Station.

same physical phenomena that is auroral particle precipitation. The two-dimension image of the data of imaging riometer shows that the auroral particle precipitation often appeared at lower latitudes in comparison with that of Zhongshan Station (on the northern side of the Station) with narrow range in south-north direction and stretching in east-west direction.

At magnetic noon, it is rather complicated that the absorption is much weaker in the middle column beam than in the both sides as shown in Fig. 4. This feature could be explained if we suppose that the ionization is stronger in the middle than in two sides of the view field due to the precipitation and/or convection stronger in the middle than in the two sides of the view field. Since this absorption occurred at magnetic noon and lasted for about 4 h and Zhongshan Station is situated in 74.5° latitude, therefore it might reflect the case of cosmic ray absorption in the magnetospheric cusp, and the precipitating particles might come from magnetosheath (Shargeaves *et al*. 1994).

It needs further study to understand the absorption at magnetic noon due to the complex of magnetospheric configuration and precipitation.

5 Summary

An Imaging riometer with 8×8 antenna array was installed successfully at Chinese Zhongshan station, Antarctica in January 1997. The structure and working principle of the instrument are described. The first set of observation data is analyzed and the QDC are deduced. Preliminary results show that cosmic noise absorption events are very different between night side and magnetic noon during the measurement over Zhongshan Station. In night side, there are often short-duration impulsive absorption events with large absorption area on the northern side of the station, stretching in an east-west direction. In magnetic noon the absorption events is continuous, which lasted for more than 1 h and with absorption area strengthening at the northern and southern sides and weakening in the middle. It is thought that the absorption is caused by aurora particle precipitation in night side and by other particle precipitation or convection in cusp at magnetic noon. Cosmic ray absorption, geomagnetic fluctuating and the Es layer strengthening are consistent temporally with each other very well, indicating that they are results of the same physical phenomena that is auroral particle precipitation.

The imaging riomeuer is a useful tool to investigate and study the polar ionosphere / magnetosphere. Preliminary results of the imaging riometer have shown some features of the polar upper atmosphere, it is expected that some new characteristics of the polar upper atmosphere could be realized with further studies.

Acknowledgement This project is supported by the National Natural Scientific Foundation of China(No. 49634160).

References

Liu RY, Liu SL (1994): Observation of solar-terrestrial physics in Antarctica. Antarctic Research(Chinese Edition), 6(4): 43 - 58(Chinese edition).

Liu SL, He LS, Liu RY (1997): Mean ionospheric properties in winter at Zhongshan Station, Antarctica. Chinese Journal of Polar Science, 8(2):133 - 138.

Shargreaves JK, Rosenberg TJ, Detrik DL (1994): Dynamics of auroral precipitation in the morning sector observed with the imaging riometer at South Pole Station: evidence of co-rotating precipitation regions. Journal of Atmospheric and Terrestrial Physics, 56(6): 783 - 793.

Stauning P (1996): Investigation of ionospheric radio wave absorption processes using imaging riometer techniques. Journal of Atmospheric and Terrestrial Physics, 58(6):753 - 764.

Xue BS, Ye ZH(1994): Study of Antarctic cosmic noise absorption daily variation. The seventh solar-terrestrial physics academic meeting (Guilin, Guangxi), 71.