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THE INFLUENCE OF THE COSMIC RAY FORBUSH DECREASE ON THE LOW IONOSPHERE IN THE POLAR REGION

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Abstract Used the ionization theory of the cosmic ray charged particles in the polar ionosphere, the influence of the cosmic ray Forbush decrease on the low ionosphere in the polar region is studied in this paper. The relationship between the Forbush decrease and the cosmic noise absorption during the polar night is analysed based on the data recorded by a Riometer at Antarctic Zhongshan Station (69°22′24″S, 76°22′40″E). The relation of between the cosmic ray Forbush decrease and the cosmic noise absorption is well interpreted by means of the ionizaiotn theory.

Key words cosmic ray Forbush decrease, precipitation particles, polar ionosphere, cosmic noise absorption

1. Introduction

Galactic cosmic rays are generally considered as the dominant source of the ionization in the lower part of D-region during geomagnetic quiet periods, The part of the ionosphere below the height of about 70 km has been called 'cosmic ray layer'. Forbush decrease (below FD for short) events are very important phenomenon of the intensity variation of the galactic cosmic ray. A FD event can cause ionization deficit in the ionosphere D region, especially, in polar region (Antarctic and Arctic regions). We have studied the change of VLF phase caused by FD events of galactic cosmic ray (Ye and Deng, 1985), and Satori (Satori *et al.*, 1987; Satori, 1991) has shown the relation between the ELF, VLF, atmospheric radio noise level, LF absorption on FD events based on 1975—1985 the neutron monitor data of the Moscow galactic cosmic ray station (50.9°N geomagnetic latitude) and atmospheric radio noise data in the VLF bands (5 kHz and 27 kHz) from the observation of Panska Ves (Czechoslovakia, 50.4°N), which shows that exists a important relation between a FD event and a radio wave propagation. However, until to now, the influence of cosmic ray FD events on the low ionosphere in the polar region, and the relation between the galactic cosmic ray FD events and the absorption of the cosmic noise, there is very few people to study. Galactic cosmic ray FD events have a obvious latitude dependence of the amplitude of the decrease (also, the geomagnetic cut-off rigidity dependence of the amplitude of the decrease). Based on both observed data (neutron monitor data) and the computed results in theory, we found easily a FD event's the amplitude of the decrease in lower or mid-latitude is times smaller than that in polar region. For example, a FD event occurred in August 4, 1972, which amplitude of the decrease was only 3% that was recorded by Beijing cosmic ray station (chamber, its geomagnetic cut-off rigidity is 9.56 GV), and 26% that was recorded by high latitude station Alert neutron monitor station (its regidity is 0 GV), even, 35% that was recorded by the South Pole Amenson-Scott Station. So a FD event disturbance for lower ionosphere is not ignorable, especially for the ionosphere in high latitude regions, even especially for the ionosphere in Arctic and Antarctic region during polar night. The reason is that, during polar night, the ionization sources of the ionospheric which from solar are almost vanished (for example: photoionization source and solar X ray ionization source *et. al.*). Until then, cosmic ray becomes a dominant ionization source. About the ionization of galactic cosmic ray in the ionospheric D-region, many authors have given their study results (Ye, 1980; Ye and Zong, 1989; Velinov, 1968; Argo, 1970), those results have showed the importance of the galactic cosmic ray ionization for lower ionospheric, especially for polar lower ionospheric (Ye and Zong, 1989). It should be noticed that not only the FD event can cause an ionization deficit in D-region, but also the high energy particle (HEP) precipitation followed with the geomagnetic storm from the magnetosphere can result in an extra ionization in the D-region. These two opposite ionization mechanisms determine the final ionization pattern in the whole D-region because a Forbush decrease event and a geomagnetic storm occur almost simultaneously. It is the purpose of the present paper that simulation the effects of a galactic cosmic ray FD event in high latitude D-region electron density especially in Arctic and Antarctic regions. The results are compared with the value of the riometer absorption measurements at Zhongshan Station.

2. Formula and Analysis

The ionization caused by galactic cosmic ray particles and high energy precipitation particles may be computed by means of the following formula (Ye ang Zong, 1989)

$$q(h) = \sum_i \int_E \int_\Omega \frac{1}{Q_0}\left(-\frac{\mathrm{d}E}{\mathrm{d}h}\right)_i \varphi_i(E,\Omega)\,\mathrm{d}E\,\mathrm{d}\Omega \qquad (2.1)$$

where $q(h)$ is the total electron production rate at a height h, due to particles of type i, Q_o is the energy required for the formation of an electron-ion pair, which quantity is 35eV in atmostphere; $-\frac{\mathrm{d}E}{\mathrm{d}h_i}$ is the ionization losses of the particles, it can be obtained from the Beth-

Bloch ionization losss formula; $\varphi_i(E, \Omega)$ is differential flux spectra, dE and $d\Omega$ are the energy interval and the spatial angle respectively. Because of $-\frac{dE}{dh} = \frac{dE}{dR} \cdot \frac{dR}{dh}$, we can get the relation (Ye and Zong, 1989):

$$-\frac{dR}{dh} = 0.3\,\rho(h)\,AZ[\,ln(\frac{ZR}{AE_0}) + 4.2] \tag{2.2}$$

where R is the geomagnetic cut-off rigidity, $\rho(h)$ is the atmosphere density, A and Z are atomic amount and charge numbers respectiviely, E is particles static energy. So we get the electron production rate $q(h)$ caused by galactic cosmic ray at height h. Now, we suppose the total electron production rate is q_0, during quiet time, ignoring transport processes, the electron density is given by the equilibrium condition:

$$N_0 = (\frac{q_0}{\alpha_{eff}})^{\frac{1}{2}} \tag{2.3}$$

where α_{eff} is the effective recombination coefficient. Because a FD event or a high energy particle precipitation event can cause the disturbance of the electron density. Supposed that the change of electron production rate caused by FD event is Δq_f and the change of the electron production rate caused by high energy precipitation particles is Δq_e, correspondingly, the change of the electron density are ΔN_f and ΔN_e. We consider three case, one is only FD event existance case, one is only a high energy precipitation particles existance case, and the other is both them existance case.

1. *Only a FD event existance case*

From Eq. (2.2), we can get the relation between the electron production rate change Δq_f caused by FD events and the electron density change ΔN_f

$$q_0 - \Delta q_f = \alpha_{eff}(N_0 - \Delta N_f)^2 \tag{2.4}$$

we have:

$$\frac{\Delta N_f}{N_0} = [1 - (1 - \frac{\Delta q_f}{q_0})^{\frac{1}{2}} \tag{2.5}$$

So, if we get $\Delta q_F/q_0$, we can get $\Delta N_F/N_0$ easily. During quiet time, the electron production rate q_0 may divide three parts, $q_0 = q_{10} + q_{20} + q_{30}$ (Ye and Zong, 1989), where q_{10} is the electron production rate caused by the cosmic ray particles which energy above 200 MeV; q_{20} is the electron production rate casused by the cosmic ray particles which energy below 200 MeV; and q_{30} is the electron production rate caused by the other sources, we assumed that q_{30} is not changable during a FD event or a high energy particle precipitation existance.

$$q_{10} = 5.4 \times 10^4 \rho(h) \sum_{i=p}^{VH} (Di(> R_c) Z_i^2 [\ln \frac{Z_i R_c}{Ai} + \frac{1}{r_i - 1} + 4.26]$$

$$+ 0.88 \frac{r_i - 1}{r_i + 1} (\frac{A_i}{Z_i R_c}) [\ln \frac{Z_i R_c}{Ai} + \frac{1}{r_i + 1} + 4.26] \qquad (2.6)$$

$$q_{20} = 5.4 \times 10^4 \rho(h) \sum_{i=p}^{VH} (Di(> Rc) Z_i^2 [\ln \frac{Z_i R_c}{Ai} - \frac{1}{b + 1} + 4.26]$$

$$+ 0.88 \frac{b + 1}{b - 1} (\frac{A_i}{Z_i R_c}) [\ln \frac{Z_i R_c}{Ai} - \frac{1}{b - 1} + 4.76] \qquad (2.7)$$

where $i=p$, α, V_H are components of the galactic cosmic ray, respective proton particle, α particle, V_H heavy particle. $\rho(h)$ is atmosphere density at height h; Ai and Zi are atomic amount and charge numbers respectively; Rc is Geomagnetic cut-off rigidity ($R_c = 0.06\ GV$ for Zhongshan Station); $D_i(c > R_c)$ is the integration spectra of galactic cosmic ray; r_i and b are the spectra indexes. Because the cut-off rigidity of the galactic cosmic ray for a certain position is changed during a FD event and a geomagnetic storm exist, but in high latitude region, the variation of the cut-off rigidity (Rc) is much smaller than that in lower and mid-latitude, and in the polar region, the cut-off rigidity almostly does not change (Dorman, 1987). So during a FD event, the reason of the variation of the electron production rate is caused dominantly by the variation of the cosmic ray integration flux $D_i(R_c)$, so we can rewrite Eq. (2.6) and (2.7) as:

$$q_{10} = 5.4 \times 10^4 \rho(h) \sum_{i=p}^{VH} D_i(> R_c) C_{i1} \qquad (2.8)$$

$$q_{20} = 5.4 \times 10^4 \rho(h) \sum_{i=p}^{VH} D_i(> R_c) C_{i2} \qquad (2.9)$$

then we have

$$q_{10} + q_{20} = 5.4 \times 10^4 \rho(h) \sum_{i=p}^{VH} D_i(> R_c)(C_{i1} + C_{i2}) \qquad (2.10)$$

where C_{i1} and C_{i2} are the constant coefficients, which can be got from Eq. (2.6) and (2.7). During a FD event and a geomagnetic storm existence, because the cosmic ray energy spectra is still the function of the particles energy or the cut-off rigidity (Velinov, 1971; Lockwood, 1991), but the flux of cosmic ray integration is changed. Now we define the modification function of the flux variation of the cosmic ray:

$$F(Rc) = \frac{D_f(> R_c)}{D_o(> R_c)} \qquad (2.11)$$

Where D_f is the cosmic ray rigidity integration spectra during a FD event existence, $D_0(> Rc)$ is the rigidity integration spectra of the cosmic ray during quiet time, FD events modification function usually can be rewritten as: $F(R)=\alpha R^{-\beta}$ where α, β are the spectra constant coefficients that determined by the amplitude of the FD event decrease and the geomagnetic cut-off rigidity R_c. So, $F(R_c)$ can be determinined by means of the FD event observed data of the whole world net cosmic ray stations (neutron monitors) (Lockwood, 1991). If we have determined the express formula $F(R)$, then we can easily get the variation of electron production rat during FD event Δq_f.

$$\begin{aligned}\Delta q_f &= q_0 - q_f + q_{30} = q_{10} + q_{20} + q_{30} - (q_f + q_{30}) \\ &= 5.4\times 10^4\,\rho(h)\sum_{i=p}^{VH}(D_i(>R_c)(C_{i1}+C_{i2}) - D_f(>R_c)(C_{i1}'+C_{i2}')) \\ &= 5.4\times 10^4\,\rho(h)\sum_{i=p}^{VH}(D_i(>R_c)((C_{i1}+C_{i2}) - F(R)(C_{i1}'+C_{i2}')))\end{aligned} \tag{2.12}$$

$$\frac{\Delta N_f}{N_o} = 1 - \left(1 - \frac{\sum_{i=p}^{VH}\{D_i(>R_c)[(C_{i1}+C_{i2}) - F(R)(C_{i1}'+C_{i2}')]\}}{q_0}\right)^{\frac{1}{2}} \tag{2.13}$$

where C_{i1}', C_{i2}' are constant coefficients that determined by the cosmic ray spectra parameters and various components parameters during a FD events existence. This is a general express formula of the variations of the electron production rate and the electron density by a FD event effects on low ionosphere.

2. Only an event of the high energy electrons precipitation existence case

Supposed that an event of the only high energy electron precipitation existence without a FD event existence, so there is a extra ionization source in the polar ionosphere which the electron production rate is $\triangle q_e$, similar to (2.4) and (2.5), we have

$$\frac{\Delta N_e}{N_0} = (1 + \frac{\Delta N_e}{N_0})^{\frac{1}{2}} - 1 \tag{2.14a}$$

$$\frac{\Delta q_e}{q_0} = (1 + \frac{\Delta q_e}{q_0})^{\frac{1}{2}} - 1 \tag{2.14b}$$

Considered that the energy range of the precipitation electrons is from several keV, we may ignore the particle's relative effective, similar to (2.1), we can obtain the electron production rate caused by the high energy precipitation electrons.

$$\Delta q_e = \frac{1}{Q_0}(-\frac{\mathrm{d}E}{\mathrm{d}h})_e \varphi_e(E,\Omega)\mathrm{d}E\mathrm{d}\Omega \tag{2.15}$$

Q_0 is the energy required for the formation of an electron ion pair, is the differential energy spectra, Ω is spatial angle, $-(\frac{\mathrm{d}E}{\mathrm{d}h})_e$ can be obtained from the Beth-Block ionization losses formula (Zong and Ye)*.

$$\Delta q_e = 2.12 \times 10^6 \rho(h) \frac{1}{Q_0}\left(-\frac{\mathrm{d}E}{\mathrm{d}h}\right)_e \varphi_e(E,\Omega)\mathrm{d}E\mathrm{d}\Omega \tag{2.16}$$

For the precipitation electron spectra, we may apply the Hardy's statistics model (Hardy, 1985), so the ionosphere extra production rate of electron Δq_e can be easily got.

3. Both a FD event and a precipitation electron event existence case

When both a FD event and a precipitation electron event exist, the disturbance of the electron production rate and electron density of the ionosphere can be easily got from above section (1) and (2).

$$\Delta N_t = \Delta N_e - \Delta N_f \tag{2.17a}$$

$$q_0 + \Delta q_e - \Delta q_f = \alpha(N_0 + \Delta N_e - \Delta N_f)^2 \tag{2.17b}$$

$$\frac{\Delta N_t}{N_0} = \left(1 + \frac{\Delta q_e}{q_0} - \frac{\Delta q_f}{q_0}\right)^{\frac{1}{2}} - 1 \tag{2.17c}$$

3. The Variation of the Cosmic Noise Absorption

It is well know that the variation of the ionospheric electron density can cause the change of the cosmic noise absorption, and the relation exists between the cosmic noise absorption and the ionosphere electron density. The total absorption of cosmic noise of angular frequency ω sec^{-1} passing vertically through the ionosphere is:

$$A(h) = 0.46 \int_h \frac{N_0(h)\gamma_e(h)}{\gamma_e^2(h) + \omega^2}\mathrm{d}h \tag{3.1}$$

Where $A(h)$ is the absorption in decibels, $N_o(h)$ is the number density of electrons per-cubic centimeter, $\gamma e(h)$ is the electron-neutral collision frequency per second, and h is height in centimeters (van Allen, 1984; Belogalzov, 1990). The relation of the electron-neutral collision frequency $\gamma_e(h)$ and height h can be written as (Beloglazov, 1990)

$$\gamma_e(h) = 1.5 \times 10^5 \exp[0.154(90 - h)] \tag{3.2}$$

based on Eq. (3—1), we get the variation of the cosmic noise absorption at a certain height h aproxmately.

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* Zong and Ye, the Monte Carlo simulation of the solar X bursts effect on ionosphere. (to be published).

$$\frac{\Delta A}{A_0} \cong \frac{\Delta N}{N_0} \tag{3.3}$$

For the case of the only a FD event existence, the variation of the cosmic noise absorption can be written as:

$$\frac{\Delta A}{A_o} = 1 - (1 - \frac{\sum_{i=p}^{VH} \{D_i(> R_c)[(C_{i1} + C_{i2}) - F(R)(C_{i1}' + C_{i2}')]\}}{q_0})^{\frac{1}{2}} \tag{3.4}$$

During a polarnight, because the ionization sources that from solar (for example solar x ray and solar photoionization *et al.*) are almost vanish, the galactic cosmic ray is the most dominant ionization source. If the effect of variation of the galactic cosmic x ray is ignored, the Eq. (3.4) can be deduced as:

$$\frac{\Delta A}{A_o} = 1 - (\frac{\sum_{i=p}^{VH} (D_i(> R_c)(C_{i1} + C_{i2})}{\sum_{i=p}^{VH} (D_i(> R_c)(C_{i1} + C_{i2})})^{\frac{1}{2}} \tag{3.5}$$

For the case of the only a high energy precipitation electron existence, we have

$$\frac{\Delta A}{A_o} = (1 + \frac{\Delta q_e}{q_0})^{\frac{1}{2}} - 1 \tag{3.6}$$

During a polar night, Eq. (3.6) changes into

$$\frac{\Delta A}{A_o} = (1 + \frac{\Delta q_e}{\sum_{i=p}^{VH} (D_i(> R_c)(C_{i1} + C_{i2})})^{\frac{1}{2}} - 1 \tag{3.7}$$

For the case of the both a FD event and a high energy precipitation electron existence, we have:

$$\frac{\Delta A}{A_o} = (1 + \frac{\Delta q_e}{q_o} - \frac{\sum_{i=p}^{VH} D_i(> R_c)[(C_{i1} + C_{i2}) - F(R)(C_{i1}' + C_{i2}')]}{q_0)})^{\frac{1}{2}} - 1 \tag{3.8}$$

During a polar night, Eq. (3.8) change into:

$$\frac{\Delta A}{A_o} = [\frac{\Delta q_e + \sum_{i=p}^{VH} D_i(> R_c)F(R_c)(C_{i1}' + C_{i2}')}{\sum_{i=p}^{VH} D_i(> R_c)(C_{i1} + C_{i2})}]^{\frac{1}{2}} - 1 \tag{3.9}$$

4. Application and Results

When we overwintered in Zhongshan Station in 1990—1991, during polarnight, a FD event had been observed luckily. The variation of the FD event amplitude and the value of the Riometer absorption and geomagnetic K_p index during 12—18 June, 1990, are shown in Fig. 1.

The Superposed epoch analyses have been carried out using the date of maximum depression of FD event as key days. In the Fig. 1, the cosmic ray FD variation data was obtained by Thule cosmic ray station (neutron monitor station), and the geomagnetic K_p index was got from Solar Geophysics Data report (S. G. D). In the Fig. 1, the cosmic ray intensity began to decreases from 1200 UT in June 12, and continuly decrease to the maximum value of the FD event in June 15. And the maximum value of the FD event amplitude is 6%, recorded by Thule cosmic ray station, then recovered gradually, until to June 18, the cosmic ray intensity recovered to quiet time level. From Fig. 1a we know, from June 14 to June 18, that geomagnetic K_p index is always less than 4, no a magnetic

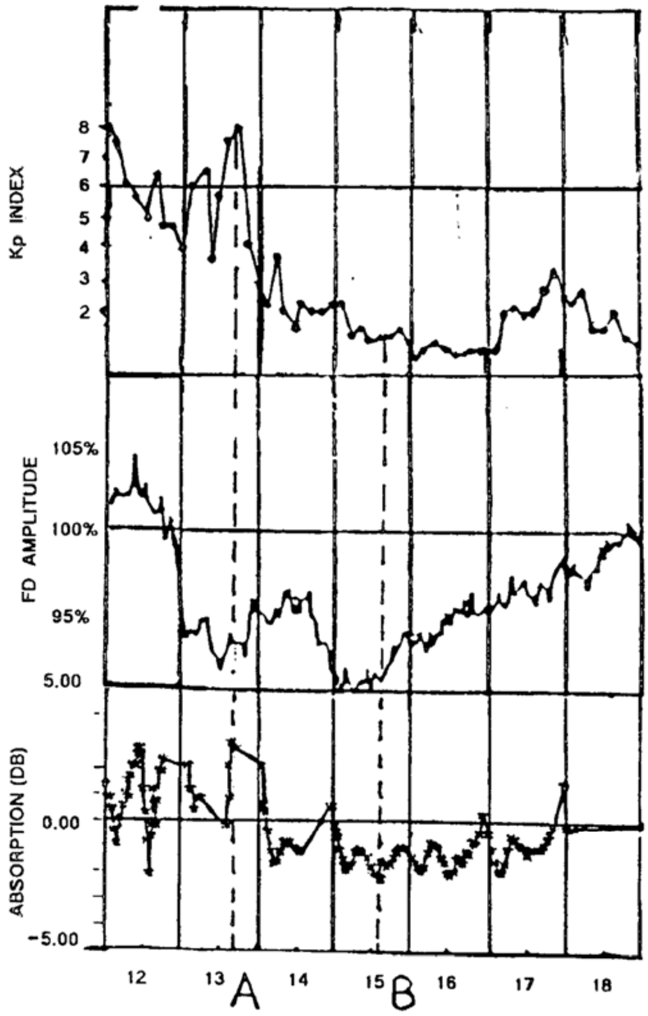

Fig. 1. The variation of the June, 12 — 19, 1990 FD event amplitude and the Riometer absorption value and the geomagnetic K_p index.

storm happed, that means there was not the existence of the intense precipitation electron event. the absorption value of the cosmic noise, correspondingly, is shown in Fig. 1. c. and which decrease with the variation of the FD event's intensity. And meanwhile, the riometer maximum minus absorption is approaxmately −1. 1dB. Because the FD event's duration time was rather long, and from June 14 to June 18, no a magnetic storm happened. So the reason of the disturbance of the cosmic noise absorption was dominantly caused by the FD event. The Fig 1. also shows that the geomagnetic disturbance's time was earlier than the FD evnet beginning decrease's and there was a mid-strong magnetic storm (SC) at 0812UT, June 12 which the main phase began at 1000UT, June 12 and the cosmic noise riometer absorption began to increase at 1800UT. During the geomagnetic disturbance period from June 12 to June 13, the high energy precipation disturbance period from June 12 to June 13, the high energy precipitation electron events were frequently induced by the geomagnetic activity, and caused the riometer value of the cosmic noise absorption to increases. However the FD event began at 1200UT, June 12 leaded to decrease of the riometer absorption value. The increase of the cosmic noise absorption level was a signature of the geomagnetic storm activity, and the cosmic noise absorption level turned to a sudden decrease when the ionospheric affect of FD becomes stronger. Of course, we should have a combination of the two opposite ionization influences.

Table 1. The position of the cosmic ray stations.

Stations	Rigidities	Latitude	Lagitude
Thule	0. 00GV	76. 50°N	68. 70°W
Deep River	1. 07GV	46. 10°N	77. 50°W
Keil	2. 32GV	54. 34°N	10. 120°E
Rome	6. 27GV	41. 90°N	12. 52°E
Beijing	9. 56GV	40. 80°N	116. 26°E
Tokyo	11. 50GV	35. 75°N	139. 72°E

Now, equations described in section 2 and section 3 are applied to explain the variation of the absorption value of the cosmic noise. In order to calculate the maximum riometer absorption value caused by the FD event. First, we must deduce the primary variation of the cosmic ray intensity $\frac{\Delta D_0(>R)}{D_0(>R)}$ from the amplitudes of the FD events decrease that were recorded by the world cosmic ray net stations. The cosmic ray modulation function may be written as (Lockwood, 1991): $F(R) = \alpha R^{-\beta}$, where α, β are constant coefficeint, which varies as different FD events. Now, we determine the constant coeffeicient α, β of the FD event, June 13, 1990 by means of the data of the world cosmic ray (neutron monitors) net stations. The stations data, see Table. Then we can deduce the decrease amplitutde of the FD event, June 12, 1990 change with the Geomagnetic cut-off rigidities. The primary variation of the cosmic ray intensity with $\frac{\Delta D_0(>R)}{D_0(>R)}$ was shown in Fig. 2. The modulation functions of the geomagnetic cut-off rigidity of the June 12, 1990 FD event is written as

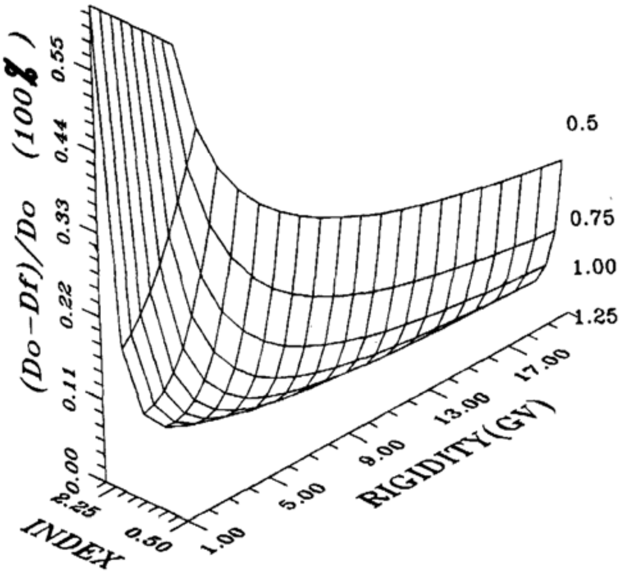

Fig. 2. The variation of the June, 12—19 1990 FD event amplitude and the Riometer absorption value and the geomagnetic K_p index.

(Lockwood, 1991) $F(R)=0.9R^{-0.96}$

So, we can calculate the riometer absorption value of the cosmic noise of two important time based on the formulae above. The first time (A) is 2000UT June 13, 1990 at that time, the FD decrease amplitude that recorded by Thule station was 4%, geomagnetic K_p index 8^-, this is the case that both a FD event and a precipitation electron event exists. We obtain the maximum value of the cosmic noise absorption is 2.77 dB, by means of the statistics relation of the geomagnetic K_p index and the flux of the energetic electrons precipitation, and the variation of the cosmic noise absorption Eq. (3.9) and the relation of the absorption value and the electron flux of the high energy percipitation that was given by Penman (Penman, 1979). The second time (B) is 1200UT June 15, 1990, at that time, the intensity of the FD event decreased to minimum value (decrease amplitude was approximately 6%), and meanwhile geomagnetic K_p index is 1, that showed the level of the geomagnetic activity was rather quiet without a event of the high energy precipitation electron. We calculate the minus absorption value caused by the June, 12 FD event is −1.8dB, and the value of the cosmic noise absorption were recorded by a riometer system in the Antarctic Zhongshan Station were 2.9 dB and −2.10dB, that errors are 4.5% and 14.3%. Those results show that the analysis what we described above can explain essentially the June 12, 1990 minus absorption of the cosmic noise recorded by a riometer system in Zhongshan Station.

5. Discussion

In the analysis what we decribed above，we have only calculated the maximum absorption value of the cosmic noise that caused by the June 12，1990 cosmic ray FD event and particles precipitation events. It is noticed that the variation of the cosmic noise absorption are determined by varies factors. In our analysis，we have removed the effect of solar proton events，solar X ray events and the energetic particles of interplanetary，but ignored the effect of the variation of the ionospheric itself，such as the ionosphere irregular structures and their motion. In order to study the effect of the FD events for the ionosphere，more observed data，such as auroral data；the data of the precipitation electron spectra and local geomagnetic activity data，are required in the future.

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