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Теория Форбуш-понижения и предшествующих эффектов в космических лучах

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Суть проблемы

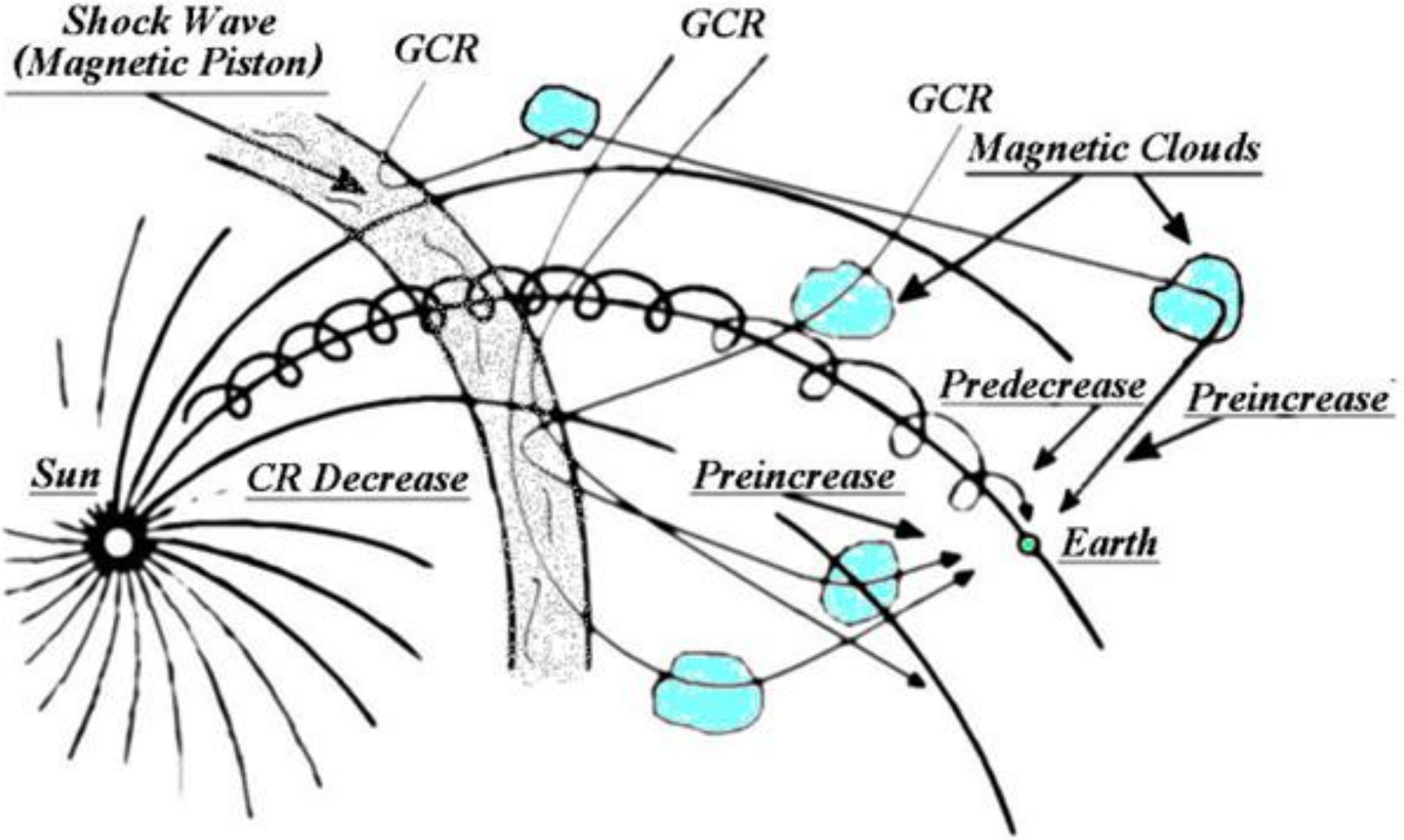
Понимание механизма Форбуш-понижения КЛ и прекурсорных эффектов в КЛ очень важно для разработки методов прогнозирования больших магнитных бурь с помощью одно-часовых данных интенсивности КЛ на многих станциях, полученных в реальном масштабе времени. Прежде всего рассматривается ситуация с распределением КЛ внутри СМЕ и как оно изменяется со временем. Предполагается, что ударная волна перед СМЕ и границы СМЕ полупрозрачны для КЛ, причем коэффициент просачиваемости зависит от жёсткости частиц. Одно дифференциональное ур-ие определяет изменение со временем распределения интенсивности КЛ внутри СМЕ с учетом уменьшения энергии частиц в расширяющемся объеме СМЕ и постоянного обмена с частицами КЛ вне СМЕ (за счёт полупрозрачности границ СМЕ). Другое дифференциональное ур-ие определяет ситуацию вне СМЕ с учетом дрейфового ускорения частиц КЛ ударной волной перед СМЕ (это объясняет небольшое предвозрастание интенсивности КЛ перед началом магнитной бури), а также обмен с частицами КЛ внутри СМЕ.

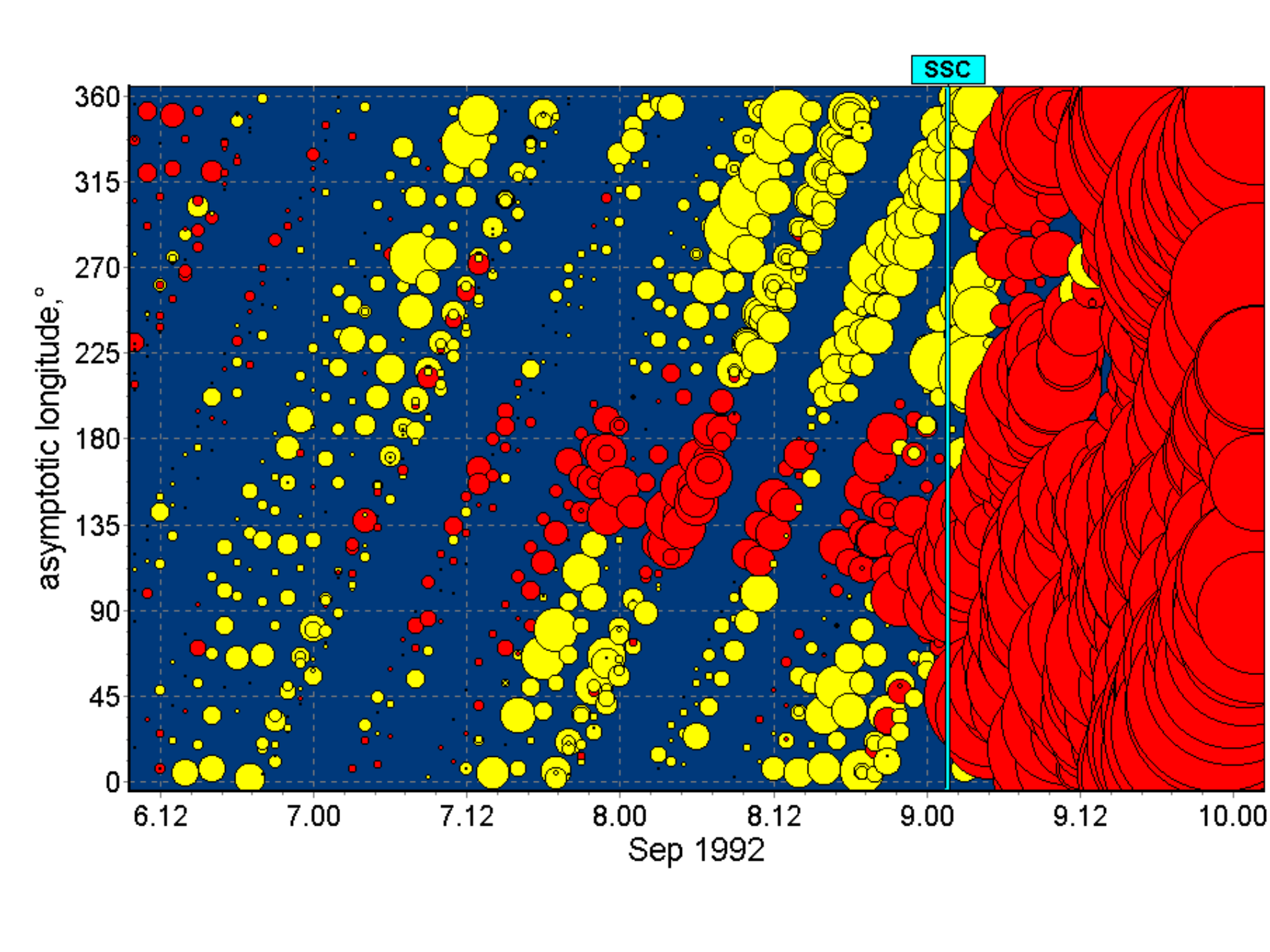
Суть проблемы (продолжение)

Особенно сильный обмен идет вдоль магнитных силовых линий (с коэффициентом просачиваемости близким к единице). Этим объясняется эффект предпонижения интенсивности КЛ вдоль спиральных линий межпланетного магнитного поля, соединяющих СМЕ с планетой Земля. Показано, что сравнение модельных расчётов с начальными данными наблюдений интенсивности КЛ позволяет получить важную информацию о свойствах СМЕ и ударной волны, существенную для предсказания ожидаемой магнитной бури и предварительной оценки её опасности для спутников, самолётов на регулярных авиалиниях, наземных технологий, и здоровья людей.

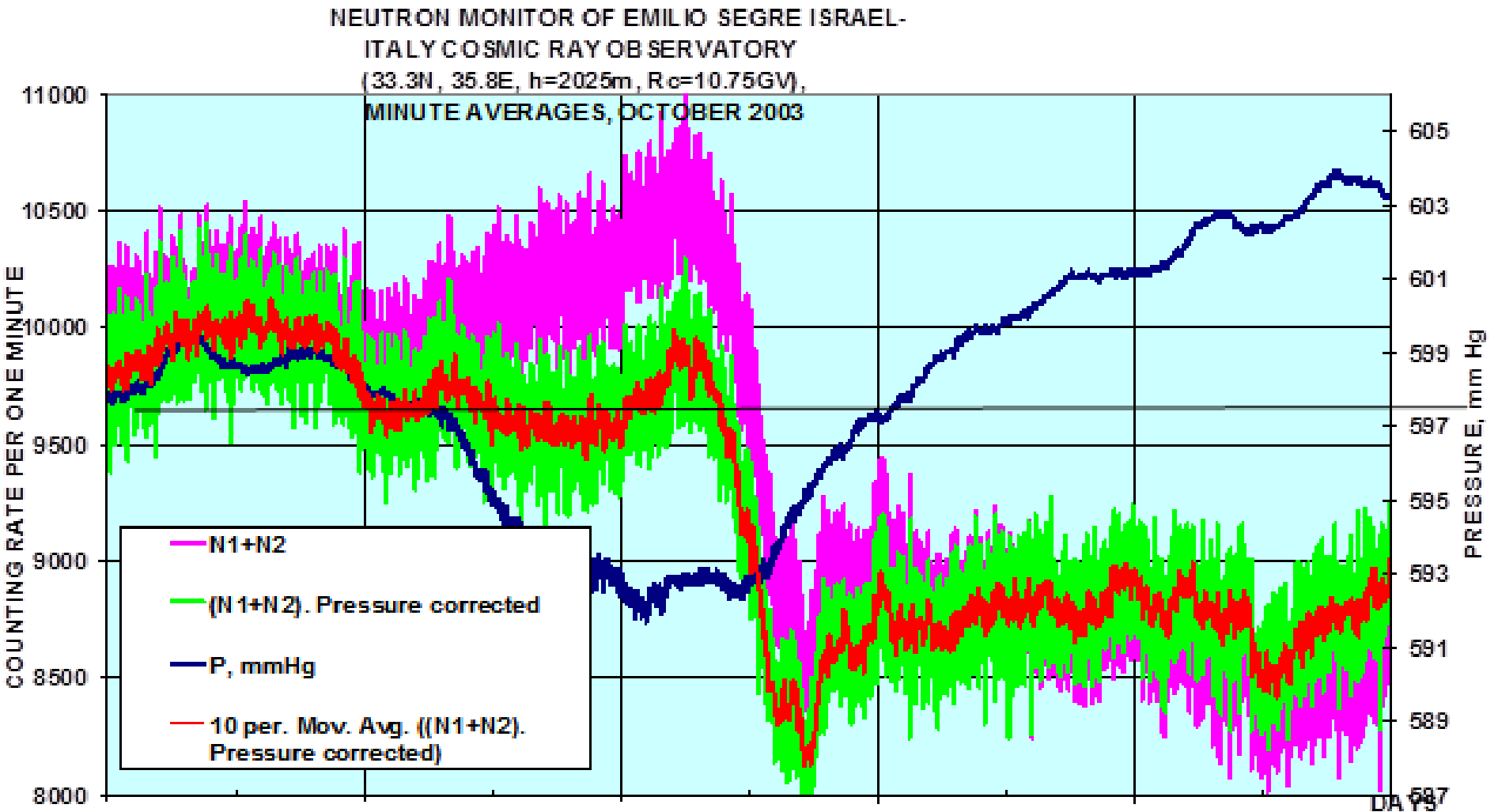
1. Introduction

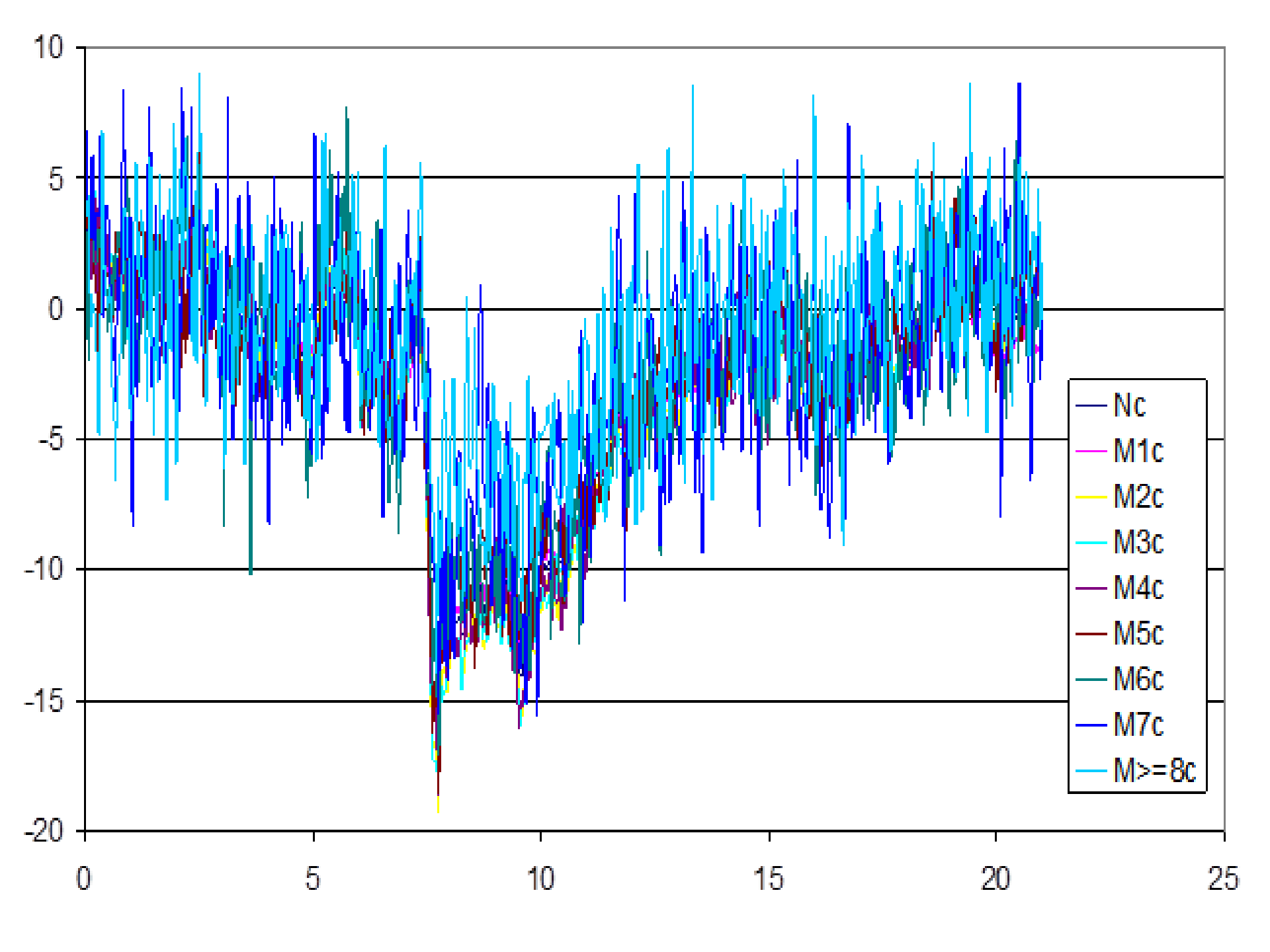
For about 80 years it was obtained a great information on the very complicated phenomenon connected with major geomagnetic storms: cosmic ray Forbush-decrease (Fenton et al., 1959) with effects of cosmic ray preincrease (Blokh et al, 1959; Dorman et al, 1967-1969) and predecrease (McCracken & Parsons, 1958; Fenton et al, 1959; Blokh et al, 1961; Nagashima et al., 1992) as well as effects of sufficient changes of cosmic ray anisotropy before and during Forbush-decrease (see review in Krimsky, M1969; Dorman, 1973, M1975). Cosmic ray distribution function before sudden commencements of magnetic storms was considered by Belov et al (1995). It was developed different models for explanation of these effects: magnetic mirror and shock wave model for preincrease effect (Dorman, 1959), semitransparent magnetic piston model for Forbush-decrease (Dorman, M1963), the model of Forbush-decrease formation by interplanetary shock wave (Parker, M1963; Krimsky et al, 1974a,b), diffusion model of cosmic ray Forbush-decrease and preincrease effect (Belov et al, 1973; Dorman, 1973; Nishida, 1982; Kadokura & Nishida, 1986), kinetic model of the preincrease effect (Dorman & Shogenov , 1974, 1980, 1986) and possible quality model for predecrease effect (Blokh et al, 1961; Nagashima et al, 1992; Dorman et al, 1995). Meanwhile until now there are no full understanding of Forbush-decrease and precursory effects; here we will step by step consider this problem with some rough estimations to understand main features of this complicated phenomenon.


Shock Wave
(Magnetic Piston)
GCR
GCR
GCR
Magnetic Clouds
Predecrease
Preincrease
Sun
CR Decrease
Preincrease
Earth


SSC
360
315
270
225
180
135
90
45
0
asymptotic longitude, °
6.12
7.00
7.12
8.00
8.12
9.00
9.12
10.00
Sep 1992

Examples of Forbush effects observed by neutron monitor on Mt. Hermon




10
5
0
-5
-10
-15
-20
0
5
10
15
20
25
Nc
M1c
M2c
M3c
M4c
M5c
M6c
M7c
M>=8c

2. Main Parameters Determined the Fall Phase of Forbush-decrease

- Independent of the concrete model (moving from the Sun magnetic mirror, magnetic piston, CME, interplanetary shock wave, magnetized diffusion region) the fall phase of Forbush decrease will be determine mainly by two processes: 1) by particle exchange between inside and outside through the moved from the Sun magnetized region and 2) particle energy change during interaction with moved region. To estimate the role of these two processes we will consider in the beginning only the first process and then both processes. For our problem the following few parameters are important: the velocity u and dimensions Ω, L of moving region (space angle from the Sun and thickness), factors of semi-transparent (from inside to outside in dependence of particle energy) and (from outside to inside).

Case 1: only expanding of CME

$$2d\left(N(t,E)\Omega r^3\right)/dt = -N(t,E)\Omega r^2(v-u)F_{\mathrm{I}0}(E)$$

$$+ N_0(E)\Omega r^2(v+u)F_{0\mathrm{I}}(E)$$

$$dr/dt = u \quad t = 0$$

$$dN(t,E)/dt = -N(t,E)f_2(E)/2(a+ut) + N_0(E)f_1(E)/2(a+ut)$$

$$f_1(E) = (v+u)F_{0\mathrm{I}}(E); \quad f_2(E) = 6u + (v-u)F_{\mathrm{I}0}(E)$$

Case 1 (continue)

$$f_1(E) = (v+u)F_{0\mathrm{I}}(E); \quad f_2(E) = 6u + (v-u)F_{\mathrm{I}0}(E)$$

$$\frac{N(t,E)}{N_0(E)} = \frac{f_1(E)}{f_2(E)} + \left(\frac{N_{\mathrm{I}}(E)}{N_0(E)} - \frac{f_1(E)}{f_2(E)}\right)\left(\frac{a}{a+ut}\right)^{f_2(E)/2u}$$

$$F_{\mathrm{I}0} = F_{0\mathrm{I}} = F$$

Case 2: expanding of CME + change of energy

$$< \Delta E / \Delta t >= -E\gamma u(v-u)(1-F_{I0}(E))/2rc^2$$

$$\frac{N(t,E)}{N_0(E)} = \frac{f_1^*(E)}{f_2^*(E)} + \left(\frac{N_I(E)}{N_0(E)} - \frac{f_1^*(E)}{f_2^*(E)}\right)\left(\frac{a}{a+ut}\right)^{f_2^*(E)/2u}$$

$$f_1^*(E) = f_1(E); \qquad f_2^*(E) = f_2(E) + \gamma u(v-u)(1-F_{I0}(E))/c^2$$

Main results for cases 1 and 2

E, GeV	$\Delta N/N$, %	F	$(\Delta N/N)^*$, %
3	33.3	0.040	41.4
10	10.0	0.169	13.4
30	3.3	0.489	4.2
3	16.7	0.096	22.2
10	5.0	0.336	6.6
30	1.7	0.843	2.2

3. Main Parameters Determined the Recovery Phase of Forbush-decrease

- 1. With expanding CME the magnetic field at the front boundary decreased and F for corresponding energy has tendency to increase with time up to 1: corresponds recovery to the level before Forbush effect
- 2. When the Earth came inside CME in time when CR intensity decreased, we will see double decrease and then recovery phase
- 3. When the Earth came inside CME in time when CR intensity recovered, we will see sharp recovery phase

4. Main Parameters Determined the Preincrease Effect

$$N_0(E)\Omega r^2(v+u)(1-F_{0\mathrm{I}}(E))/6$$

$$K(E)\approx(1+(N(t,E)(v-u)F_{\mathrm{I}0}(E))/(N_0(E)(v+u)(1-F_{0\mathrm{I}})))^{-1}$$

$$<\Delta E>=+\left(Evu/c^2\right)K(E) \qquad N_0(E)\propto E^{-\gamma}$$

$$\Delta N(E)/N(E)\approx\left(\gamma\, vu/c^2\right)K(E)$$

5. Main Parameters Determined the Predecrease Effect

- The cosmic ray predecrease effect according to qualitative model discussed in Blokh et al, 1961; Nagashima et al, 1992; Dorman et al, 1995 is caused by the flux of particles transperented from inside to outside through moved magnetized region. From Eq. 1 we see that in the unit of time the number of particles escaped from inside to outside through the moved region will be

$$N(t,E)\Sigma\Delta r^2(v-u)F_{10}(E),/6$$

5. Main Parameters Determined the Predecrease Effect (continue)

- The flux of these particles is determined by the intensity inside , what is smaller than intensity outside , but in general this difference will be compensated by the reflected particles and moreover, in the solid angle the sum of these fluxes we expect bigger than background (considered above preincrease effect). Only in some special cases when there are formatted channels in the moved magnetized region it can be realized the predecrease effect. We can see in the Table that for big Forbush-decrease the coefficient of particle transparent for 10 GeV is 0.17 and 0.34 for 13.4 % and 6.6 % amplitude of the Forbush-decrease (with taking into account the energy change); this transparence can be formatted by homogeneous diffusion and in this case the predecrease effect can not be realized.

conclusion

- 1. Processes of CR Forbush-decreases and precursory effects (preincrease and predecrease) can be explain by transperancy of CR through boundary of CME (magnetic cloud), expanding CME and CR particle energy decrease inside CME.
- 2. Preincrease effect must be in all cases, but

predecrease effect only when the magnetic channels through the boundary of CME front is formatted.