Athens, 24-28 Sept, 2007

Cosmic rays and space weather effects: methods of forecasting

Lev I. Dorman (1, 2)

(1) Israel Cosmic Ray & Space Weather Center and Emilio Segre' Observatory, affiliated to Tel Aviv University, Technion and Israel Space Agency,

Address: POB 2217, Qazrin 12900, Israel;

(2) Cosmic Ray Department of IZMIRAN, Russian Academy of Science, Troitsk 142092, Moscow Region, Russia;

E-mail: lid@physics.technion.ac.il

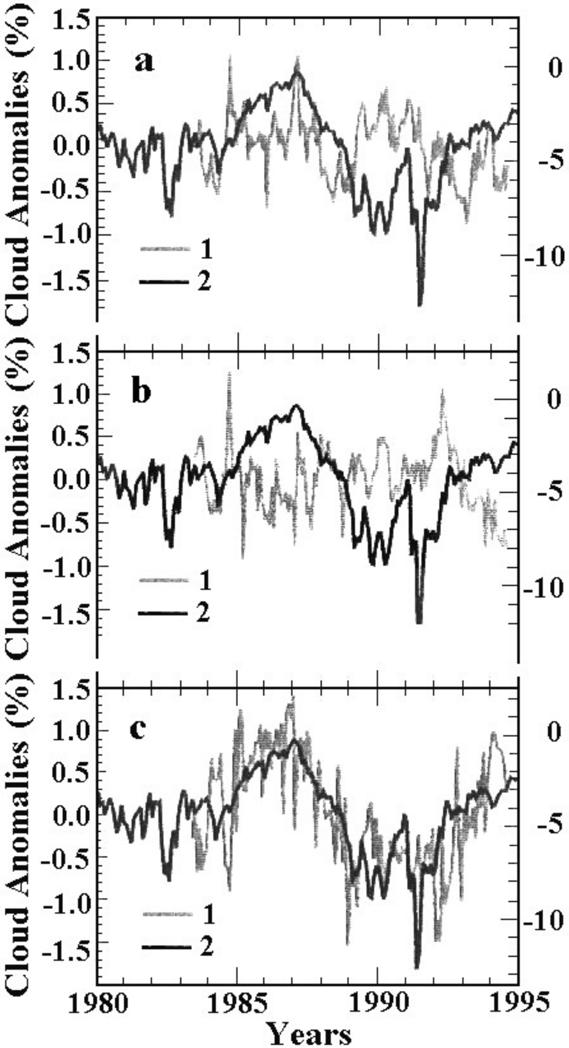
Tel.: 972-4-6964932 (of), 972-546816111 (mob)

Part 1. Cosmic rays and space weather influence on global climate change

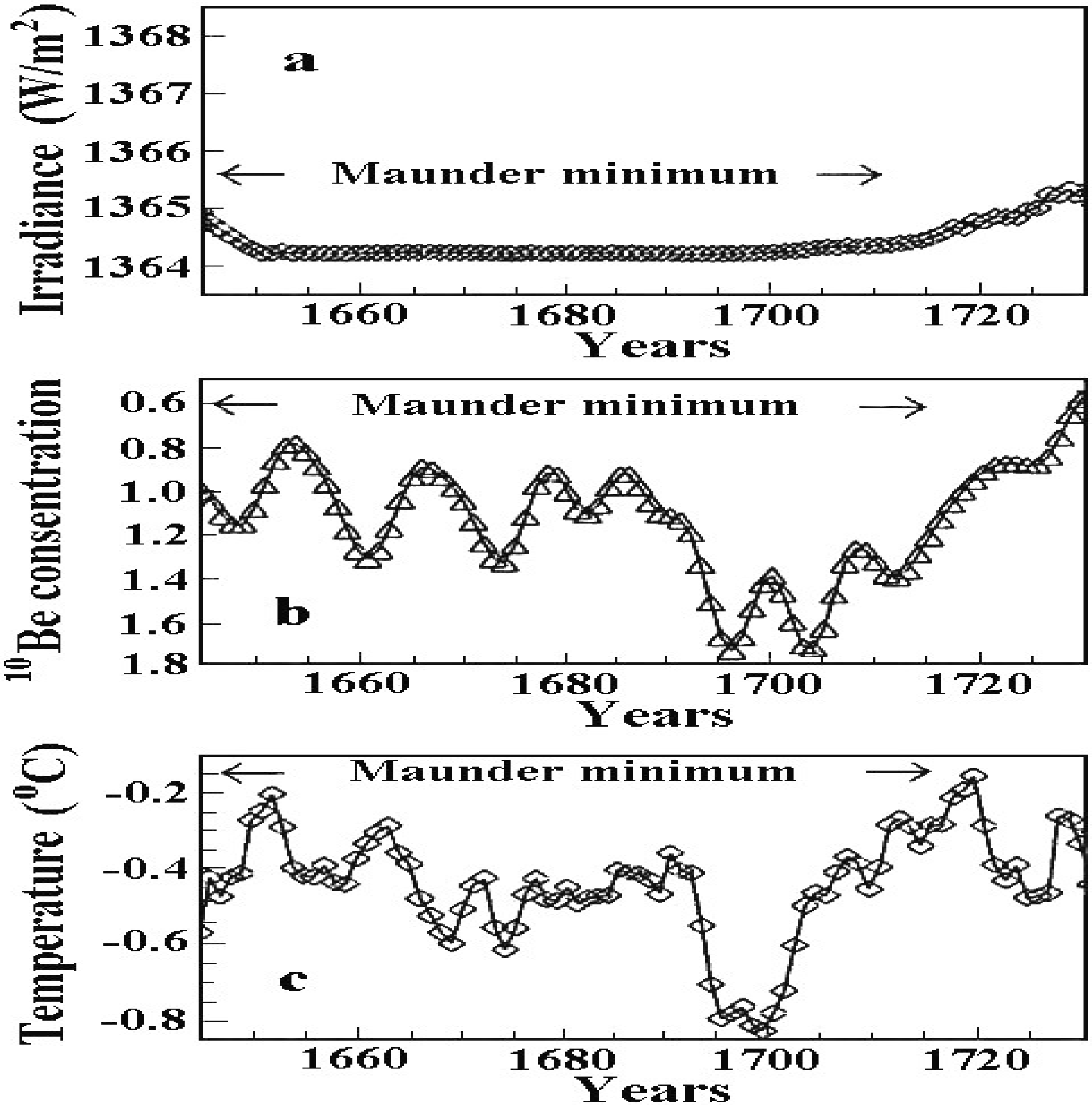
- Determining of the part of global climate change caused by the long-term change of CR intensity through influence on air ionization and planetary clouds formation; examples from the past; method of forecasting of the part of global climate change caused by space weather effects.

CR intensity according to Huancayo/Haleakala NM (cut off rigidity 12.9 GV, normalized to October 1965, curve *2*) in comparison with global average of monthly cloud coverage anomalies (curves *1*) for: ***a*** – high clouds, H > 6.5 km, ***b*** – middle clouds, 6.5 km >H > 3.2 km, and ***c*** – low clouds, H < 3.2 km.

According to Marsh and Swensmark (2000a).

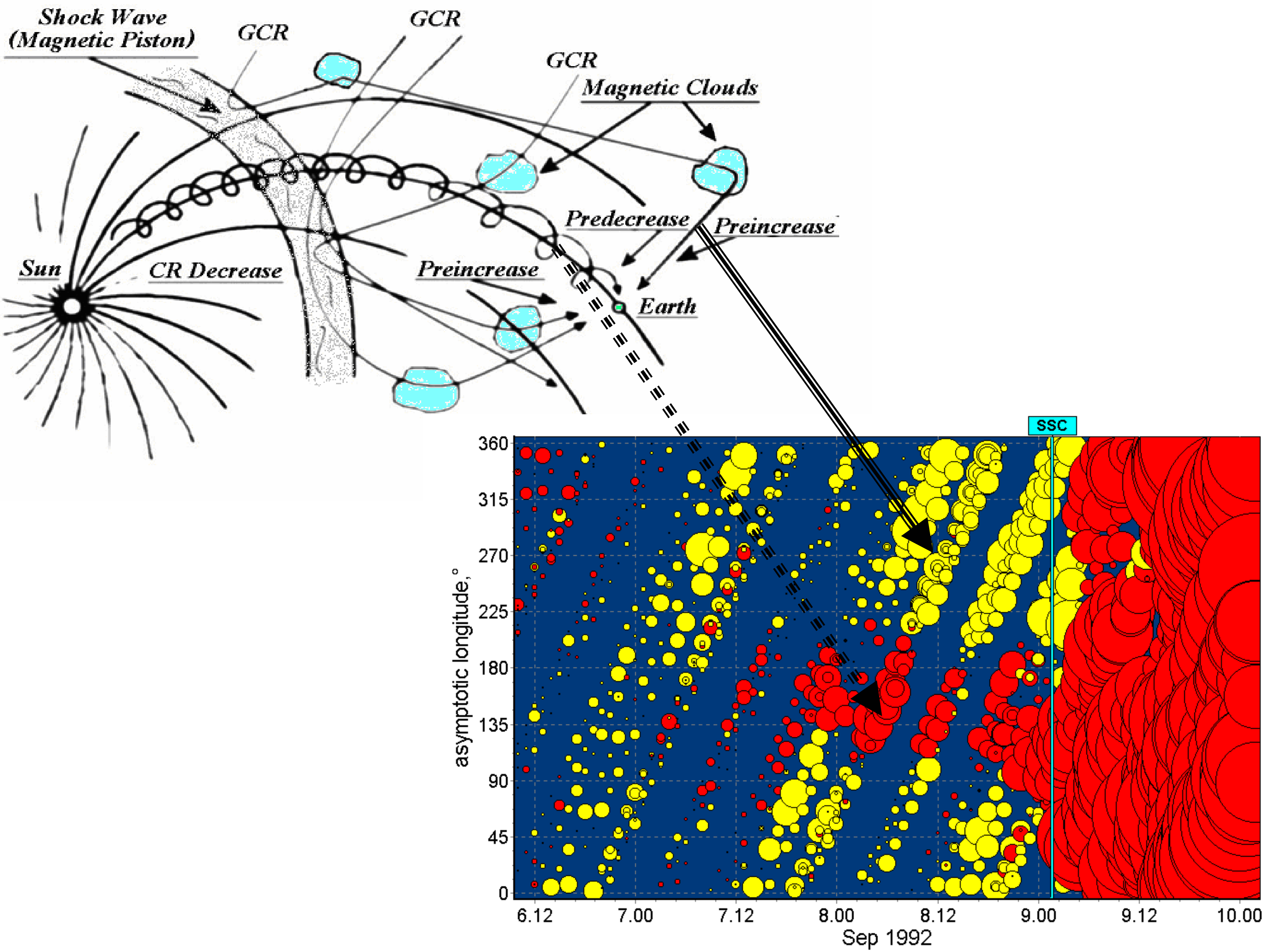


Situation in the Maunder minimum: ***a***) variation in reconstructed solar irradiance from Lean et al. (1995); ***b***) variation in concentration Be10 from Beer et al. (1991); ***c***) reconstructed air surface temperature for the northern hemisphere from Jones et al. (1998). According to Swensmark (2000).



Part 2. Global natural disaster from great magnetic storms connected with big CR Forbush-decreases and their assessment by using world-wide network of CR stations

- Great geomagnetic storms affect adversely global technology systems, high frequency radio communications are disrupted, electric power distribution grids are blacked out when induced currents causes safety devices to trip, and atmospheric warming causes increased drag on satellites and anomalies in their operation, increasing of frequency of infarct myocardial, brain strokes, car and train accidents; examples of electric power and long oil tubes catastrophes in the past in Canada and other countries.
- We show that by using on-line one hour CR data from world-wide network of stations is possible to made exact assessment of this natural hazard for 15-20 hours before of the storm sudden commencement


Shock Wave
(Magnetic Piston)
GCR
GCR
GCR
Magnetic Clouds
Predecrease
Preincrease
Sun
CR Decrease
Preincrease
Earth
SSC
asymptotic longitude, °
360
315
270
225
180
135
90
45
0
6.12
7.00
7.12
8.00
8.12
9.00
9.12
10.00
Sep 1992

Part 3. Global natural disaster from great intense radiation hazards for astronauts, crew and passengers on regular airline flights, for people on the ground due to great solar flare CR events

- Statistical distribution,
- Examples from the past;
- We show that this advertisement, with high occurrence probability, can be given 30-60 minutes before the arrival of the more dangerous particle flux
- This method is based on the well known fact that the main part of radiation hazard in space and in atmosphere is caused by particles with small energy (few hundreds MeV) that reach the Earth 1-2 hours after their acceleration on the Sun
- On the contrary the relatively small flux of high-energy ($\geq$ 2 GeV) particles, which can be detected by super neutron monitors and practically are not involved in the radiation hazard, reach the Earth much more quickly.

- We show that 20-30 minutes of CR observation by neutron monitors on the ground and CR on satellites of the first-coming solar high-energy particles give enough information for automatically determining total flux and energy spectrum on the Sun (source function) as well as transport parameters in the Heliosphere
- This make it possible to predict the time-space distribution for about 48 hours of radiation hazard in interplanetary space and in the Earth’s magnetosphere (for astronauts and space-probe technology) and in the Earth’s atmosphere (for crew, passengers and technology in aircrafts, for people and technology on the ground) as a function of geomagnetic cut-off rigidity and altitude.

FORECAST STEPS

1. AUTOMATICALLY DETERMINATION OF THE FEP EVENT START BY NEUTRON MONITOR DATA

2. DETERMINATION OF ENERGY SPECTRUM OUT OF MAGNETOSPHERE BY THE METHOD OF COUPLING FUNCTIONS

3. DETERMINATION OF TIME OF EJECTION, SOURCE FUNCTION AND PARAMETERS OF PROPAGATION

4. FORECASTING OF EXPECTED FEP FLUXES AND COMPARISON WITH OBSERVATIONS

5. COMBINED FORECASTING ON THE BASIS OF NM DATA AND BEGINNING OF SATELLITE DATA

1. AUTOMATICALLY DETERMINATION OF THE FEP EVENT START BY NEUTRON MONITOR DATA

$$D_{A1Z} = \left[\ln\left(I_{AZ}\right) - \sum_{k=Z-120}^{k=Z-60} \ln\left(I_{Ak}\right) / 60 \right] \Big/ \sigma_1$$

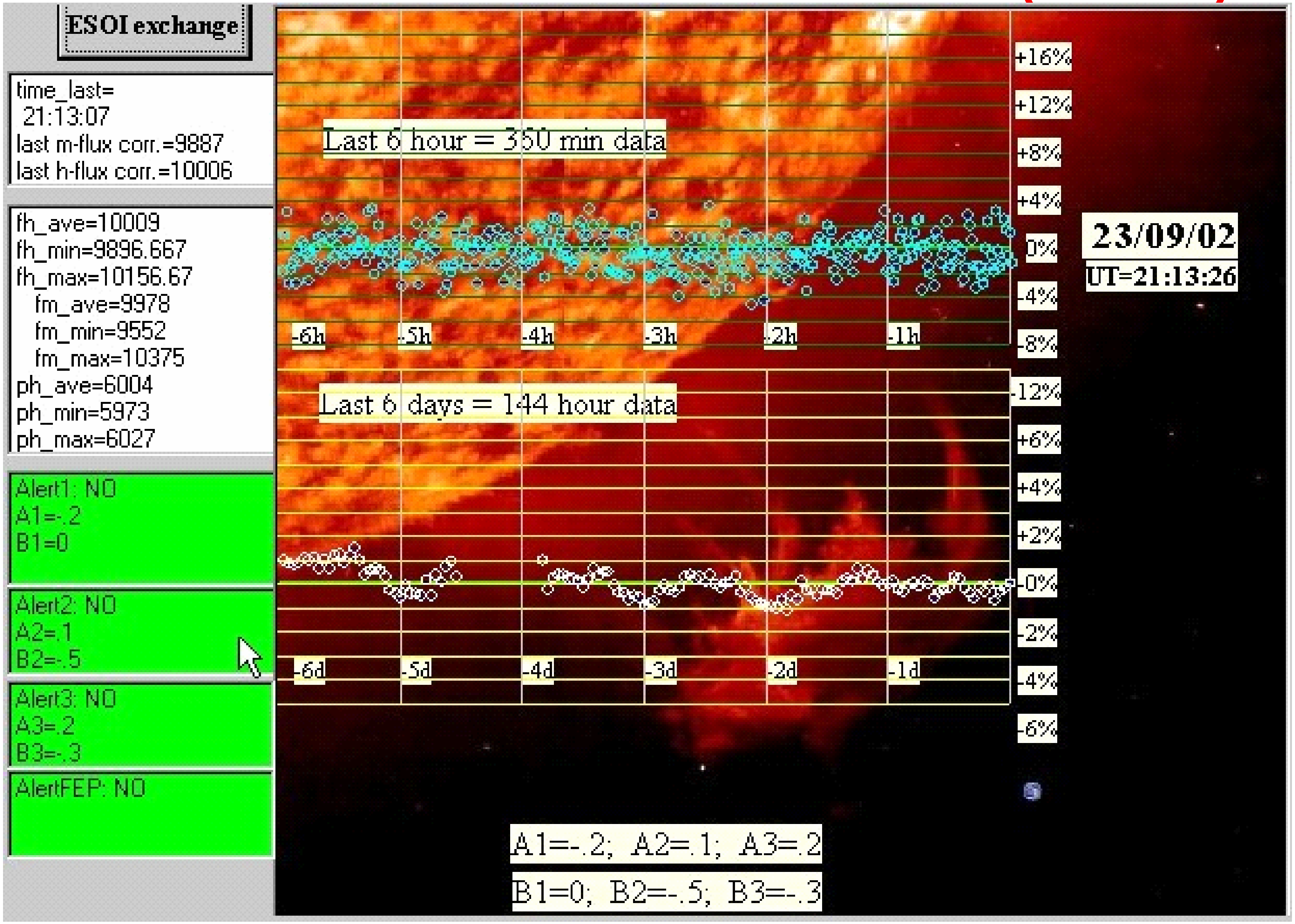
$$D_{B1Z} = \left[\ln\left(I_{BZ}\right) - \sum_{k=Z-120}^{k=Z-60} \ln\left(I_{Bk}\right) / 60 \right] \Big/ \sigma_1$$

$$D_{A1Z} \geq 2.5, \; D_{B1Z} \geq 2.5,$$

THE PROBABILITY OF FALSE ALARMS

THE PROBABILITY OF MISSED TRIGGERS

EXAMPLE OF INTERNET PRESENTATION OF REAL TIME DATA AND FEP ALERT FROM ESO (ISRAEL)



time_last=
21:13:07
last m-flux corr.=9887
last h-flux corr.=10006

fh_ave=10009
fh_min=9896.667
fh_max=10156.67
fm_ave=9978
fm_min=9552
fm_max=10375
ph_ave=6004
ph_min=5973
ph_max=6027

Alert1: NO
A1=-.2
B1=0

Alert2: NO
A2=.1
B2=-.5

Alert3: NO
A3=.2
B3=-.3

AlertFEP: NO

23/09/02
UT=21:13:26

A1=-.2; A2=.1; A3=.2
B1=0; B2=-.5; B3=-.3

2. DETERMINATION OF ENERGY SPECTRUM OUT OF MAGNETOSPHERE BY THE METHOD OF COUPLING FUNCTIONS

$W_m(R_c, R) = a_m k_m R^{-(k_m+1)} \left(1 - a_m R_c^{-k_m}\right)^{-1} \exp\left(-a_m R^{-k_m}\right)$, if $R \geq R_c$,
and $W_m(R_c, R) = 0$, if $R < R_c$

$$\delta I_k(R_c) = -\Delta R_c W_k(R_c, R_c) + bF_k(R_c, \gamma)$$

$$\delta I_m(R_c) \equiv \Delta I_m(R_c) / I_{mo}(R_c) \qquad \Delta D(R) / D_o(R) = bR^{-\gamma}$$

$$F_m(R_c, \gamma) = a_m k_m \left(1 - \exp\left(-a_m R_c^{-k_m}\right)\right)^{-1} \int_{R_c}^{\infty} R^{-(k_m+1+\gamma)} \exp\left(-a_m R^{-k_m}\right) dR$$

$$\Psi_{lmn}(R_c, \gamma) = \frac{W_l(R_c, R_c) F_m(R_c, \gamma) - W_m(R_c, R_c) F_l(R_c, \gamma)}{W_m(R_c, R_c) F_n(R_c, \gamma) - W_n(R_c, R_c) F_m(R_c, \gamma)}$$

$$\Psi_{lmn}\left(R_c,\gamma\right)=\frac{W_l\left(R_c,R_c\right)\delta I_m\left(R_c\right)-W_m\left(R_c,R_c\right)\delta I_l\left(R_c\right)}{W_m\left(R_c,R_c\right)\delta I_n\left(R_c\right)-W_n\left(R_c,R_c\right)\delta I_m\left(R_c\right)}$$

$$\Delta R_c=\frac{F_l\left(R_c,\gamma\right)\delta I_m\left(R_c\right)-F_m\left(R_c,\gamma\right)\delta I_l\left(R_c\right)}{F_m\left(R_c,\gamma\right)\delta I_n\left(R_c\right)-F_n\left(R_c,\gamma\right)\delta I_m\left(R_c\right)}$$

$$b=\frac{W_l\left(R_c,R_c\right)\delta I_m\left(R_c\right)-W_m\left(R_c,R_c\right)\delta I_l\left(R_c\right)}{W_l\left(R_c,R_c\right)F_m\left(R_c,\gamma\right)-W_m\left(R_c,R_c\right)F_l\left(R_c,\gamma\right)}$$

3A. DETERMINATION OF TIME OF EJECTION, SOURCE FUNCTION AND PARAMETERS OF PROPAGATION (1-st CASE: K(R) DOES NOT DEPEND FROM DISTANCE TO SUN)

$$t_1 = T_1 - T_e = x,\ t_2 = T_2 - T_1 + x,\ t_3 = T_3 - T_1 + x$$

$$\frac{T_2 - T_1}{x(T_2 - T_1 + x)} = -\frac{4K(R)}{r_1^2} \times \ln\left\{\frac{b(T_1)}{b(T_2)}\left(x/(T_2 - T_1 + x)\right)^{3/2} R^{-[\gamma(T_1) - \gamma(T_2)]}\right\}$$

$$\frac{T_3 - T_1}{x(T_3 - T_1 + x)} = -\frac{4K(R)}{r_1^2} \times \ln\left\{\frac{b(T_1)}{b(T_3)}\left(x/(T_3 - T_1 + x)\right)^{3/2} R^{-[\gamma(T_1) - \gamma(T_3)]}\right\}$$

$$x = \left[(T_2 - T_1)\Psi - (T_3 - T_1)\right]/(1 - \Psi)$$

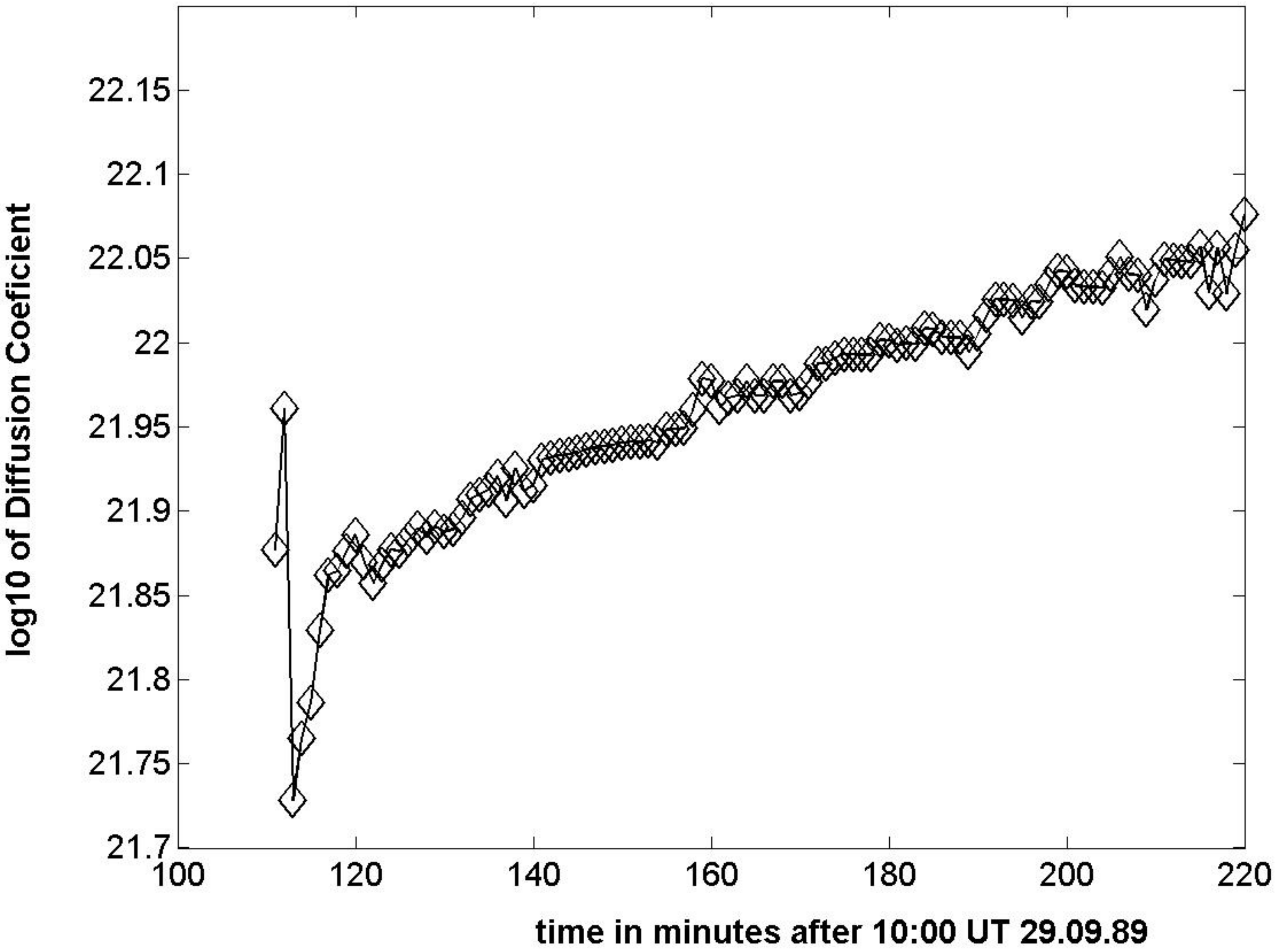
$$\Psi = \frac{T_3 - T_1}{T_2 - T_1} \times \frac{\ln\left\{\frac{b(T_1)}{b(T_2)}\left(x/(T_2 - T_1 + x)\right)^{3/2} R^{\gamma(T_2) - \gamma(T_1)}\right\}}{\ln\left\{\frac{b(T_1)}{b(T_3)}\left(x/(T_3 - T_1 + x)\right)^{3/2} R^{\gamma(T_3) - \gamma(T_1)}\right\}}$$

$$K(R) = -\frac{r_1^2 (T_2 - T_1) \big/ 4x(T_2 - T_1 + x)}{\ln\left\{ \frac{b(T_1)}{b(T_2)} \left(x/(T_2 - T_1 + x) \right)^{3/2} R^{\gamma(T_2) - \gamma(T_1)} \right\}} = -\frac{r_1^2 (T_3 - T_1) \big/ 4x(T_3 - T_1 + x)}{\ln\left\{ \frac{b(T_1)}{b(T_3)} \left(x/(T_3 - T_1 + x) \right)^{3/2} R^{\gamma(T_3) - \gamma(T_1)} \right\}}$$

$$N_o(R) = 2\pi^{1/2} b(t_1) R^{-\gamma(t_1)} D_o(R) \times \left(K(R) t_1\right)^{3/2} \exp\left(r_1^2 / (4K(R) t_1)\right) = 2\pi^{1/2} b(t_2) R^{-\gamma(t_2)} D_o(R) \times$$

$$\times \left(K(R) t_2\right)^{3/2} \exp\left(r_1^2 / (4K(R) t_2)\right) = 2\pi^{1/2} b(t_3) R^{-\gamma(t_3)} D_o(R) \times \left(K(R) t_3\right)^{3/2} \exp\left(r_1^2 / (4K(R) t_3)\right)$$

$$n(R, r, T) = N_o(R) \times \left[2\pi^{1/2} \left(K(R)(T - T_e) \right)^{3/2} \right]^{-1} \times \exp\left(-\frac{r^2}{4K(R)(T - T_e)} \right)$$


log10 of Diffusion Coeficient
22.15
22.1
22.05
22
21.95
21.9
21.85
21.8
21.75
21.7
100
120
140
160
180
200
220
time in minutes after 10:00 UT 29.09.89

3B. DETERMINATION OF TIME OF EJECTION, SOURCE FUNCTION AND PARAMETERS OF PROPAGATION (2-nd CASE: K(R, r) DEPENDS FROM DISTANCE TO THE SUN)

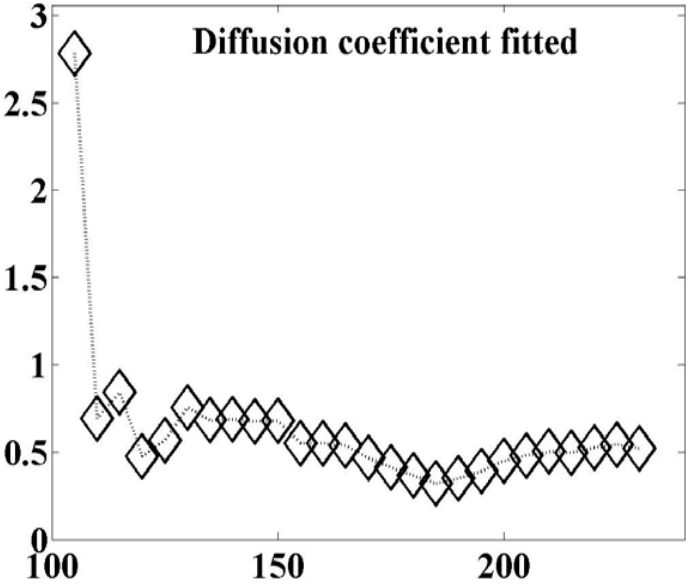
$$K(R,r) = K_1(R) \times (r/r_1)^{\beta} \qquad n_1,\ n_2,\ n_3 \qquad t_1, t_2, t_3$$

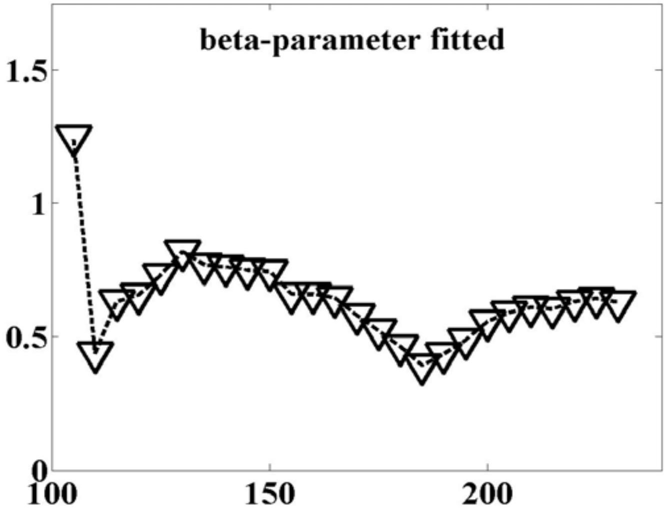
$$n(R,r,t) = \frac{N_o(R) \times r_1^{3\beta/(2-\beta)} \left(K_1(R)t\right)^{-3/(2-\beta)}}{(2-\beta)^{(4+\beta)/(2-\beta)} \Gamma\left(3/(2-\beta)\right)} \times \exp\left(-\frac{r_1^{\beta} r^{2-\beta}}{(2-\beta)^2 K_1(R) t}\right)$$

$$\beta = 2 - 3\left[\left(\ln(t_2/t_1)\right) - \frac{t_3(t_2 - t_1)}{t_2(t_3 - t_1)} \ln(t_3/t_1)\right] \times \left[\left(\ln(n_1/n_2)\right) - \frac{t_3(t_2 - t_1)}{t_2(t_3 - t_1)} \ln(n_1/n_3)\right]^{-1}$$

$$K_1(R) = \frac{r_1^2\left(t_1^{-1} - t_2^{-1}\right)}{3(2-\beta)\ln(t_2/t_1) - (2-\beta)^2 \ln(n_1/n_2)} = \frac{r_1^2\left(t_1^{-1} - t_3^{-1}\right)}{3(2-\beta)\ln(t_3/t_1) - (2-\beta)^2 \ln(n_1/n_3)}$$

$$N_o(R) = n_1 (2-\beta)^{(4+\beta)/(2-\beta)} \Gamma\left(3/(2-\beta)\right) r_1^{-3\beta/(2-\beta)} \left(K_1(R) t_k\right)^{3/(2-\beta)} \times \exp\left(\frac{r_1^2}{(2-\beta)^2 K_1(R) t_k}\right)$$


Diffusion coefficient fitted
3
2.5
2
1.5
1
0.5
0
100
150
200


beta-parameter fitted
1.5
1
0.5
0
100
150
200

4. FORECASTING OF EXPECTED FEP FLUXES AND COMPARISON WITH OBSERVATIONS (2-nd CASE: K(R, r) DEPENDS FROM DISTANCE TO THE SUN)

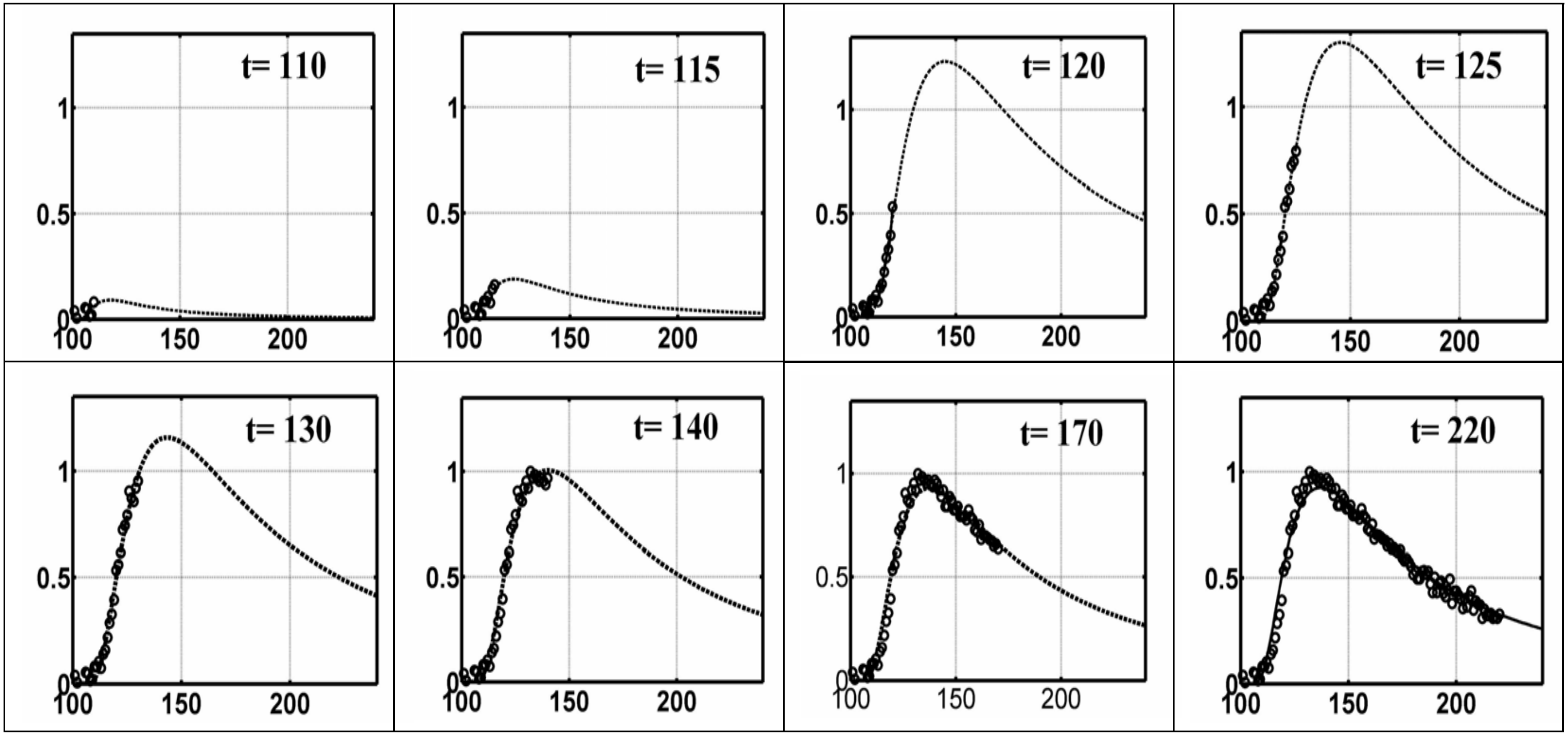


Fig. 2. Calculation on line parameters β, $K_1(R)$, $N_o(R)$ and forecasting of total neutron intensity (time t is in minutes after 10.00 UT of September 29, 1989; curves – forecasting, circles – observed total neutron intensity) .

5. COMBINED FORECASTING ON THE BASIS OF NM DATA AND BEGINNING OF SATELLITE DATA

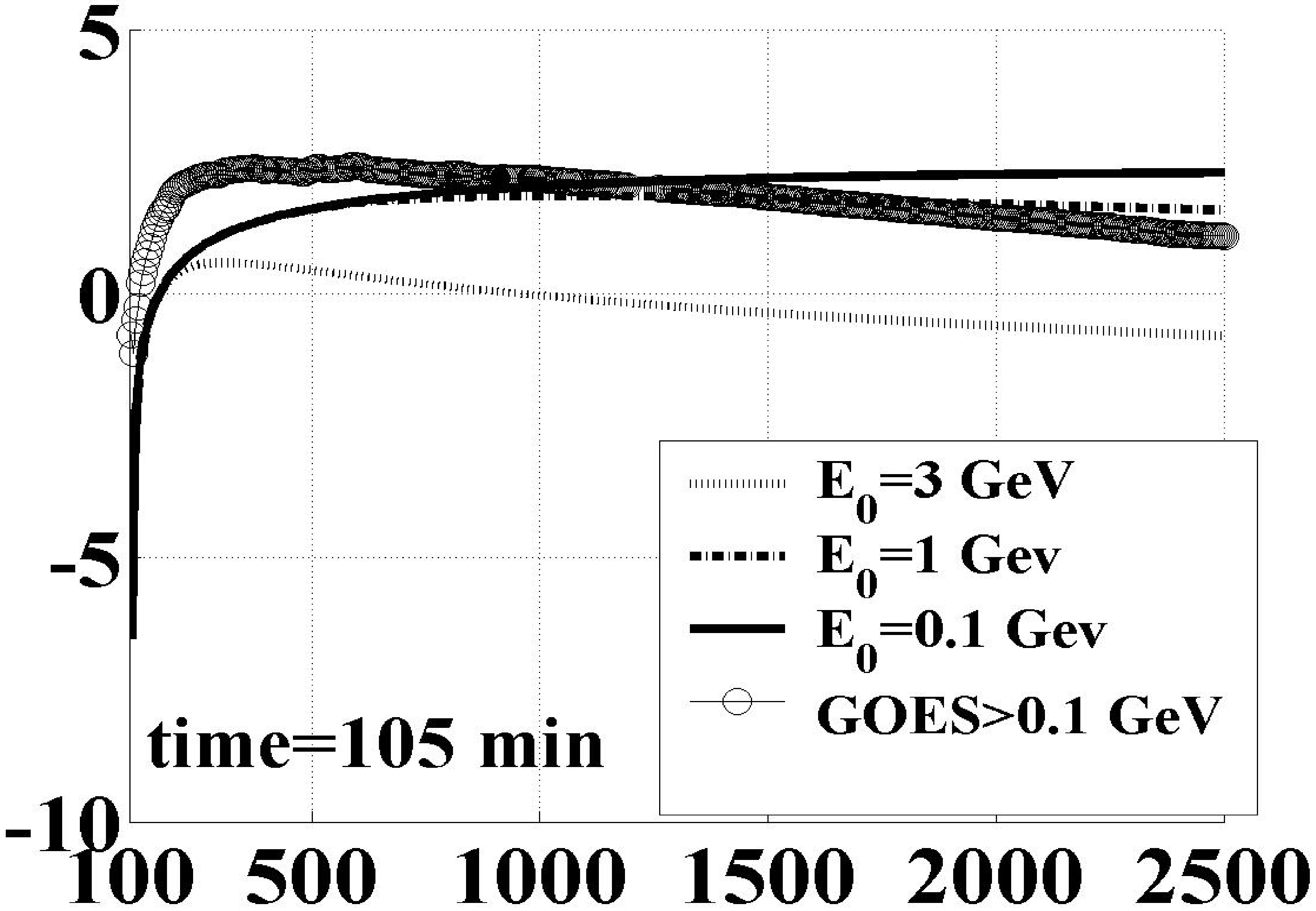
$$N_o(R,T) = N_o(R)\delta(T - T_e) \times R^{-(\gamma_o + a\ln(E_k/E_{k\max}))}$$

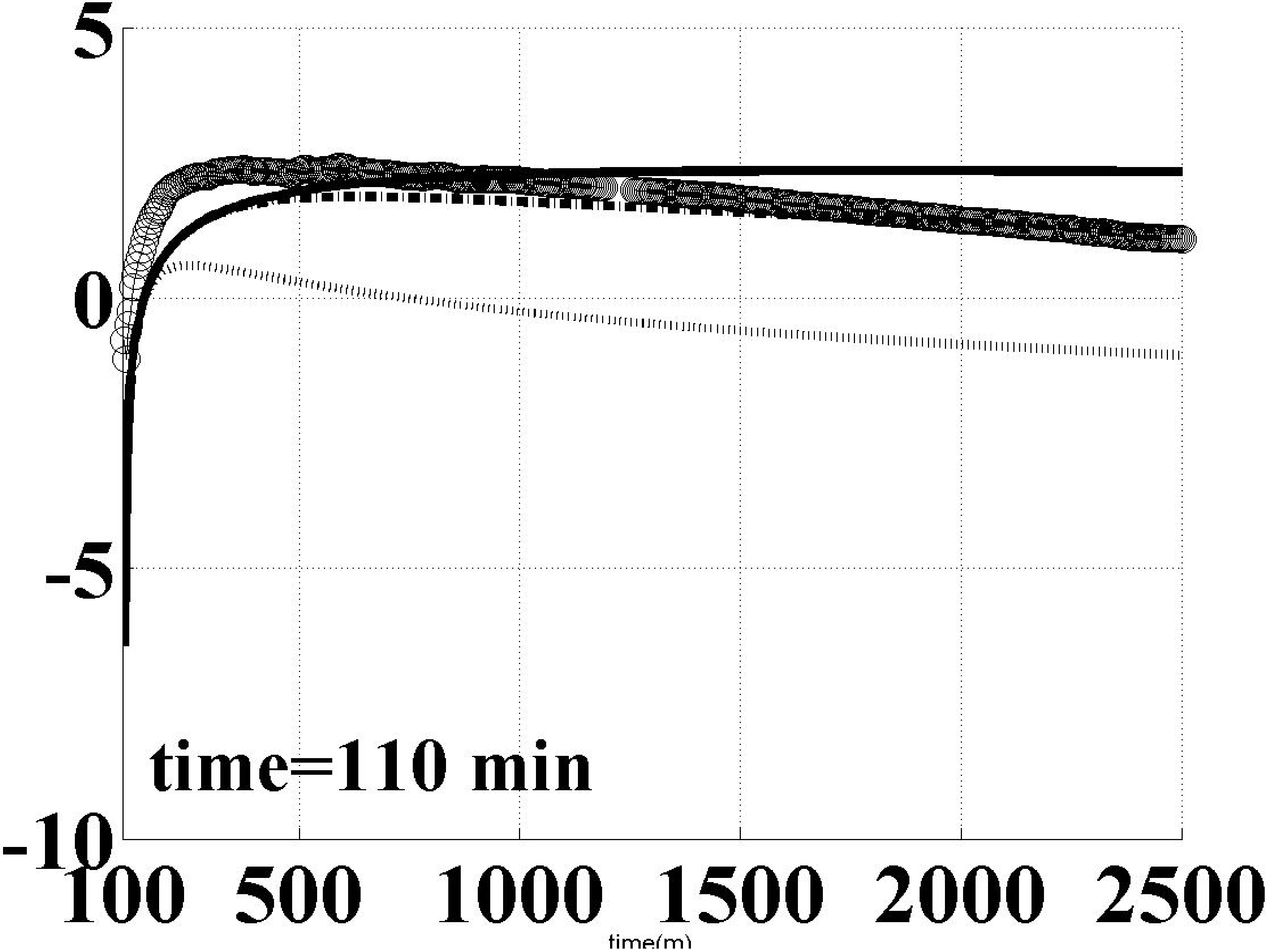
$$K(R,r) = K_1(R) \times (r/r_1)^{\beta}$$

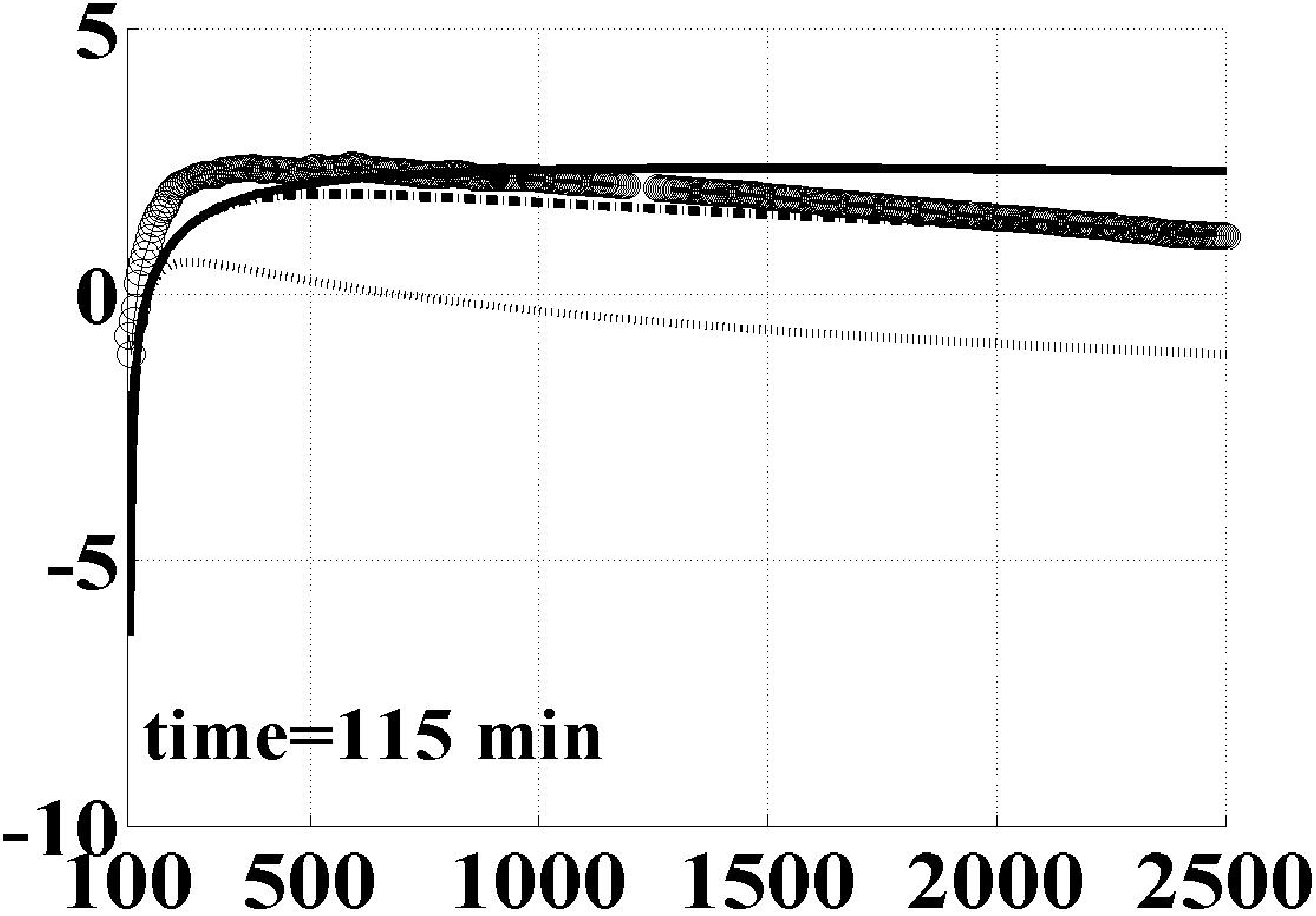
$$K_1(R) = K_1 \times (v/c) \times (R/R_1)^{\delta}$$

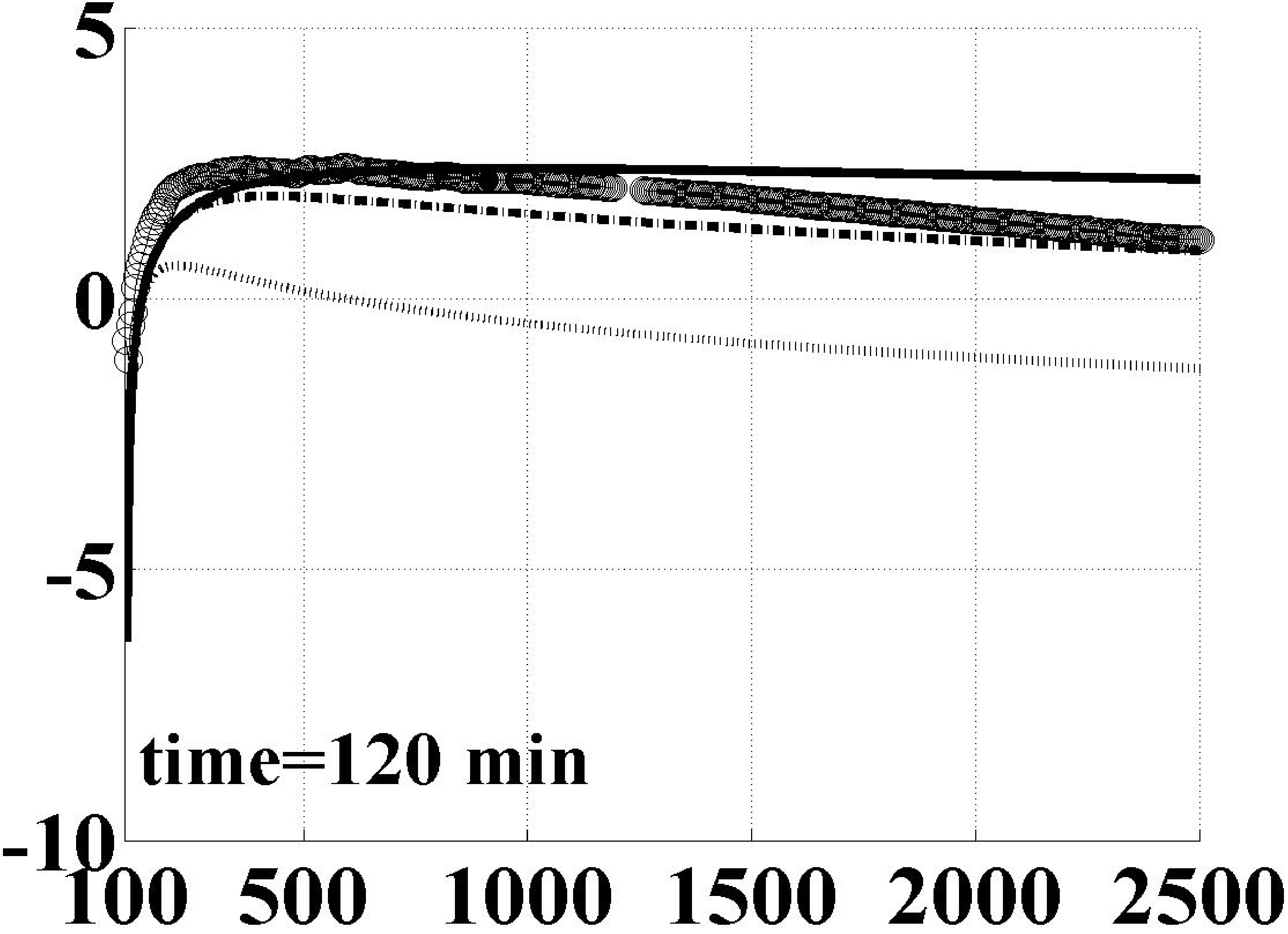
$$n(R,r,T) = \frac{N_o(R) \times r_1^{3\beta/(2-\beta)}((T-T_e)K_1(R))^{-3/(2-\beta)}}{(2-\beta)^{(4+\beta)/(2-\beta)}\Gamma(3/(2-\beta))} \times \exp\left(-\frac{r_1^{\beta} r^{2-\beta}}{(2-\beta)^2(T-T_e)K_1(R)}\right)$$

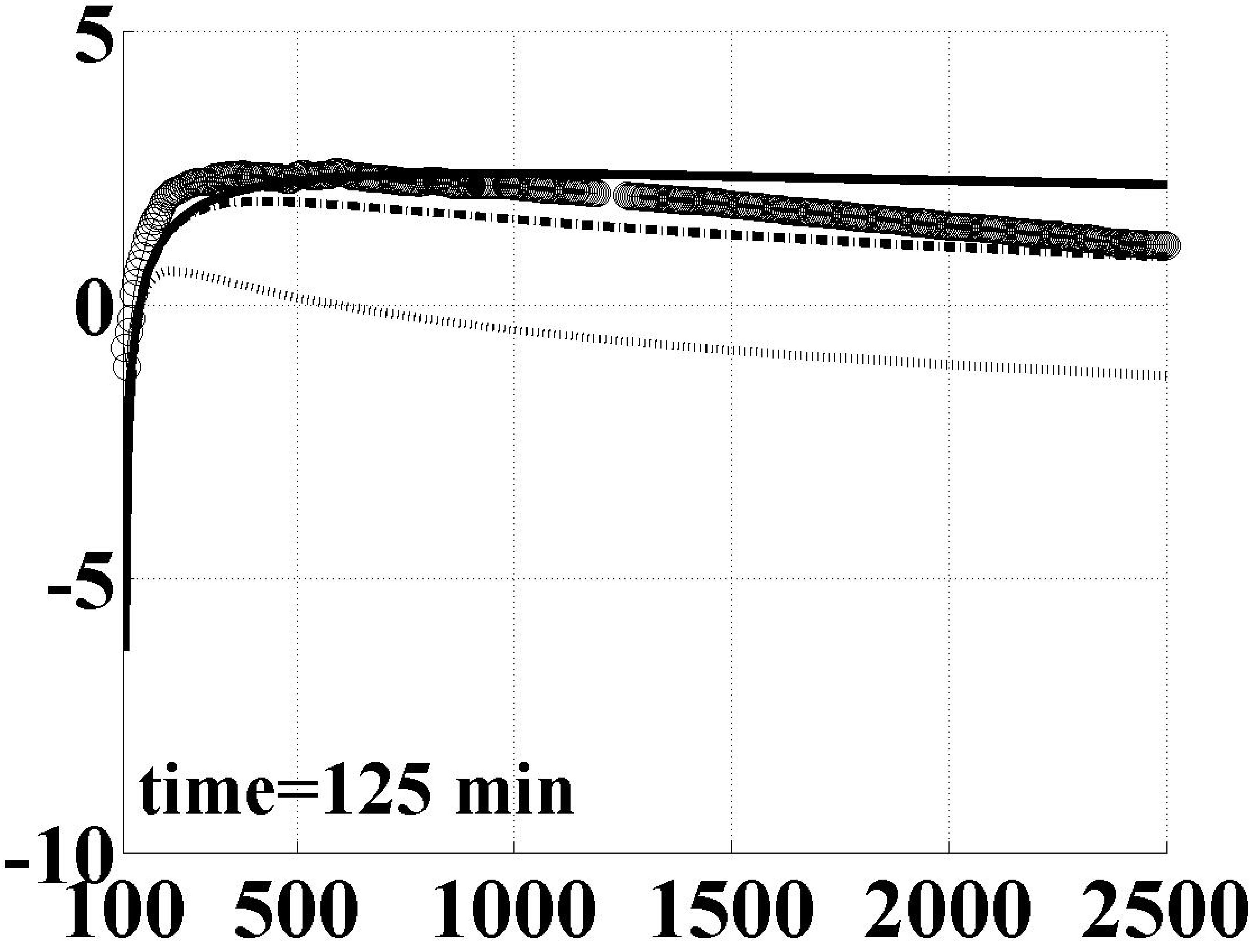
$$F_s(R_c(T)) = \int_{T_e}^{\infty} dT \int_{R_c(T)}^{\infty} N_o(R) \times \frac{r_1^{3\beta/(2-\beta)}((T-T_e)K_1(R))^{-3/(2-\beta)}}{(2-\beta)^{(4+\beta)/(2-\beta)}\Gamma(3/(2-\beta))} \times \exp\left(-\frac{(2-\beta)^{-2} r_1^2}{(T-T_e)K_1(R)}\right) dRc$$

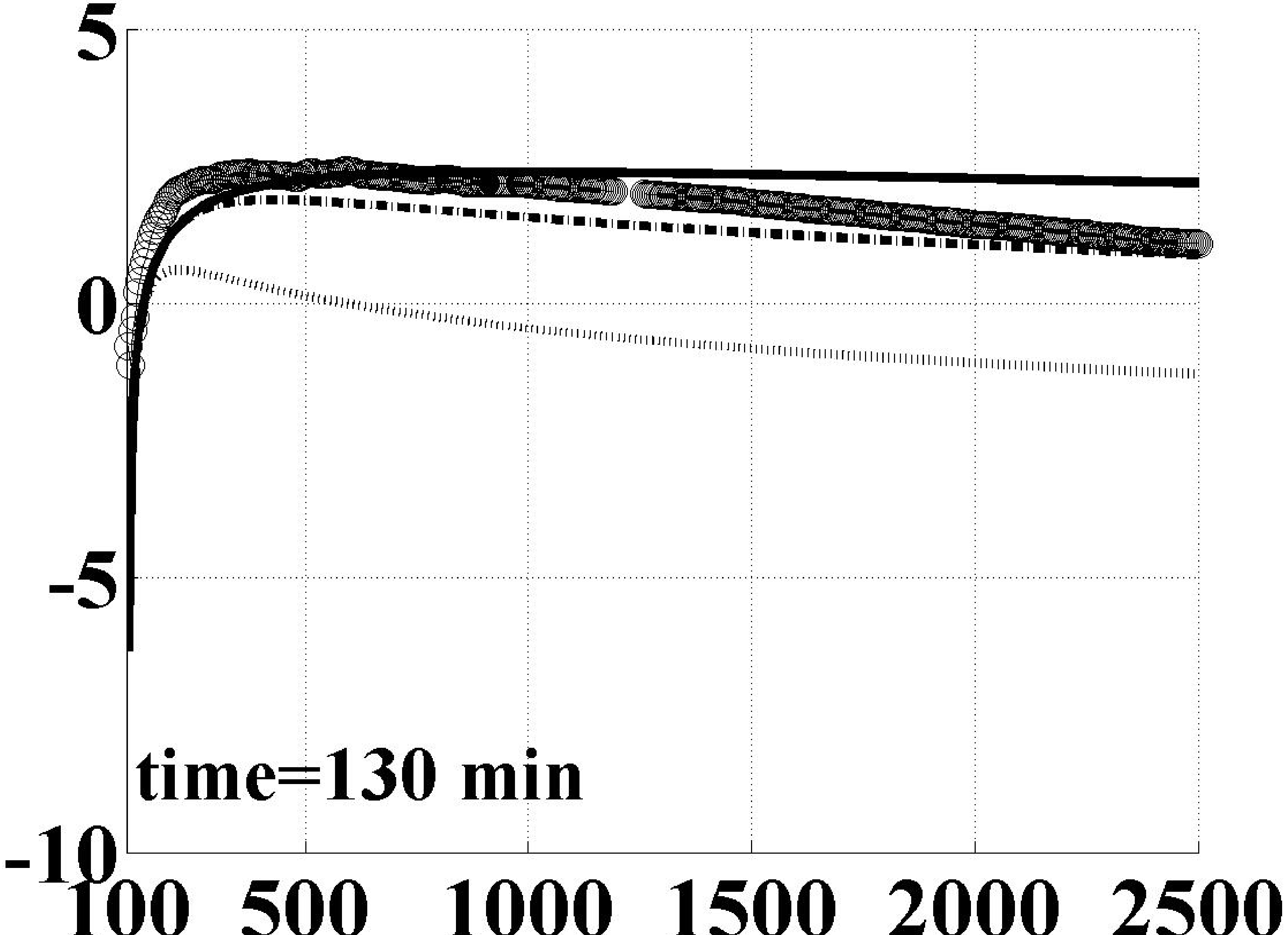

5
0
-5
-10
100
500
1000
1500
2000
2500
E0=3 GeV
E0=1 Gev
E0=0.1 Gev
GOES>0.1 GeV
time=105 min

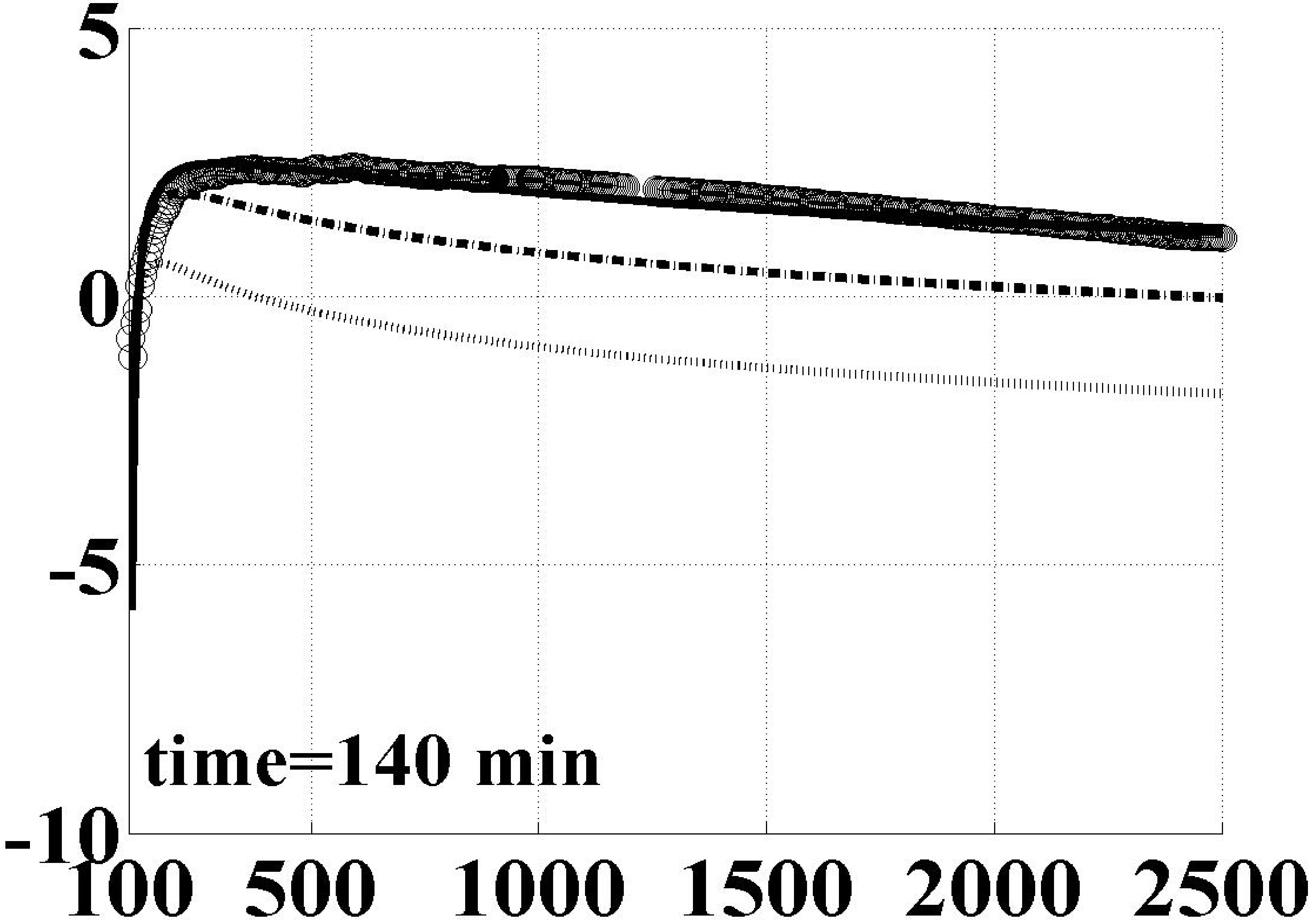

5
0
-5
-10
time=110 min
100
500
1000
1500
2000
2500
time(m)


5
0
-5
-10
100
500
1000
1500
2000
2500
time=115 min


5
0
-5
-10
100
500
1000
1500
2000
2500
time=120 min


5
0
-5
-10
100
500
1000
1500
2000
2500
time=125 min


5
0
-5
-10
time=130 min
100
500
1000
1500
2000
2500


5
0
-5
-10
100
500
1000
1500
2000
2500
time=140 min

CONCLUSION FOR PART 3

BY ONE-MINUTE NEUTRON MONITOR DATA AND ONE-MINUTE AVAILABLE FROM INTERNET COSMIC RAY SATELLITE DATA FOR 20-30 MIN DATA IT IS POSSIBLE TO DETERMINE BY THE METHOD OF COUPLING FUNCTIONS ENERGY SPECTRUM UTSIDE THE ATMOSPHERE, AND THEN THE TIME OF EJECTION, SOURCE FUNCTION, AND DIFFUSION COEFFICIENT IN DEPENDENCE FROM ENERGY AND DISTANCE FROM THE SUN.

THEN IT IS POSSIBLE TO FORECAST OF FEP FLUXES AND FLUENCY IN HIGH AND LOW ENERGY RANGES UP TO ABOUT TWO DAYS.

SEPTEMBER 1989 EVENT IS USED AS A TEST CASE.

IT IS NECESSARY TO DEVELOP MORE COMPLICATED MODEL WITH USING ON LINE DATA FROM MANY NEUTRON MONITORS; IN THIS CASE THE FORECAST MAY BE MADE FOR SUFFICIENTLY SHORTER TIME

Part 4. The great hazard for the Earth’s civilization from the interaction of a dust-molecular cloud with the Solar system

- From the past we know that the dust from clouds between the Sun and the Earth leads to decrease of solar irradiation flux with sufficient decreasing of global planetary temperature (on 5-7° in comparison with 0.8° from green effect for the last hundred years).
- The plasma in a moving molecular dust cloud contains a frozen-in magnetic field; this field could modify the stationary galactic cosmic rays (CR) distribution function outside the Heliosphere.
- The change in the CR distribution function can be significant, and it should be possible to identify these changes when the distance between the cloud and the Sun becomes comparable with the dimension of the cloud.
- The continuous observations of a time variation of the CR distribution function for many years should provide the possibility of determining the direction and the speed of the cloud relative to the Sun, as well as its geometry.
- Therefore by CR measurements we may predict its evolution in space and determine whether the dust-molecular cloud will catch the Sun or not.
- In the case of high probability of capture, we could predict the time of the capture and how long the solar system will be inside the cloud.

Part 5. Great radiation hazard for the Earth’s civilization from CR particles generated in a nearby Supernova Explosion (SE)

- From the energetic balance of CR in the Galaxy it was estimated that the full power for CR production is $W_{CR} \sim 3\times10^{40}$ erg/s.
- Now it is common accepted that the Supernova explosions are the main source of galactic CR.
- At each explosion the average energy transferred to CR is $E_{SE} \sim 10^{50}$ erg.
- From this we can determine the expected frequency of SE in our Galaxy and in vicinity of the Sun.
- We estimate the probability of Supernova explosions inside different distances from the Sun and expected radiation hazard, and its variation with time.
- We show that in some cases the level of radiation may increases about 1000 times in comparison with present level, and it will be very dangerous for the Earth's civilization and biosphere.

- We show that by high energy CR measurements by ground and underground muon telescopes and low-latitude neutron monitors on the Earth will be obtain information on the source function and diffusion coefficient in the interstellar space for many years before when real radiation hazard will be formatted on the Earth.
- We show how on the basis of this information we can made exact forecasting on developing in time of the radiation hazard in space and in the atmosphere on different altitudes and cutoff rigidities (different geomagnetic latitudes) by using method of coupling functions
- On the basis of this information experts must to decide how to prevent the Earth's civilization (in some cases it will be necessary for people to live underground or in special protected buildings for several hundred years, and go out only for very short time).
- It is important that on the basis of obtained forecast the Earth's civilization will have time at least several tens years to prepare the life underground and in special protected buildings.

CONCLUSION

- IT IS NECESSARY TO ORGANIZE STEP BY STEP ICRS - INTERNATIONAL COSMIC RAY SERVICE (LIKE EXIST INTERNATIONAL METEOROLOGICAL SERVICE) ON THE BASIS OF WORLD NETWORK OF NEUTRON MONITORS AND MUON TELESCOPES WITH EXCHANGE DATA IN REAL TIME SCALE AND WITH AVAILABLE FROM INTERNET SATELLITE DATA. I THINK THAT UN AND MANY COUNTRIES WILL SUPPORT THIS PROJECT
- THE FIRST STEP – ACCEPTED NMDB PROJECT OF 12 COUNTRIES FOR 2008-2009 IN THE FRAME OF FP-7

References

- Dorman L.I., 1963. *Geophysical and Astrophysical Aspects of Cosmic Rays*. North-Holland Publ. Co., Amsterdam (In series "Progress in Physics of Cosmic Ray and Elementary Particles", ed. by J.G. Wilson and S.A. Wouthuysen, Vol. 7), pp 320.
- Dorman L.I., 1974. *Cosmic Rays: Variations and Space Exploration*. North-Holland Publ.Co., Amsterdam, pp 675.
- Dorman L.I., 1975. *Experimental and Theoretical Principles of Cosmic Ray Astrophysics*. FIZMATGIZ, Moscow, pp 464.
- Dorman L.I, N. Iucci, and G. Villoresi, 1993. "The use of cosmic rays for continues monitoring and prediction of some dangerous phenomena for the Earth's civilization", *Astrophysics and Space Science*, **208**, 55-68.

- Munakata K., J.W. Bieber, S.-I. Yasue, C. Kato, M. Koyama, S. Akahane, K. Fujimoto, Z. Fujii, J.E. Humble, and M.L. Duldig, 2000 “Precursors of geomagnetic storms observed by the muon detector network”, J. Geophys. Res., **105**, No. A12, 27457-27468.
- Lev I. Dorman, 2002. “Solar Energetic Particle Events and Geomagnetic Storms Influence on People’s Health and Technology: Principles of Monitoring and Forecasting of Space Dangerous Phenomena by Using On-Line Cosmic Ray Data”, in Proc. 22nd ISTC Japan Workshop on Space Weather Forecast (ed. Y. Muraki), Nagoya University, Vol. 2, pp. 133-151.
- Lev I. Dorman, 2004. *Cosmic Rays in the Earth's Atmosphere and Underground*, Kluwer Academic Publishers, Dordrecht/Boston/London.
- Lev I. Dorman, 2006. *Cosmic Ray Interactions, Propagation, and Acceleration in Space Plasmas*, Springer, Netherlands.

THANK YOU VERY MUCH
FOR YOUR ATTENTION