33-я Всероссийская конференция по космическим лучам, г. Дубна, 15 августа 2014 г., 11.00-13.00

Long-term CR variations according to NM Mt. Hermon and other CR stations: effects in total intensity and different multiplicities

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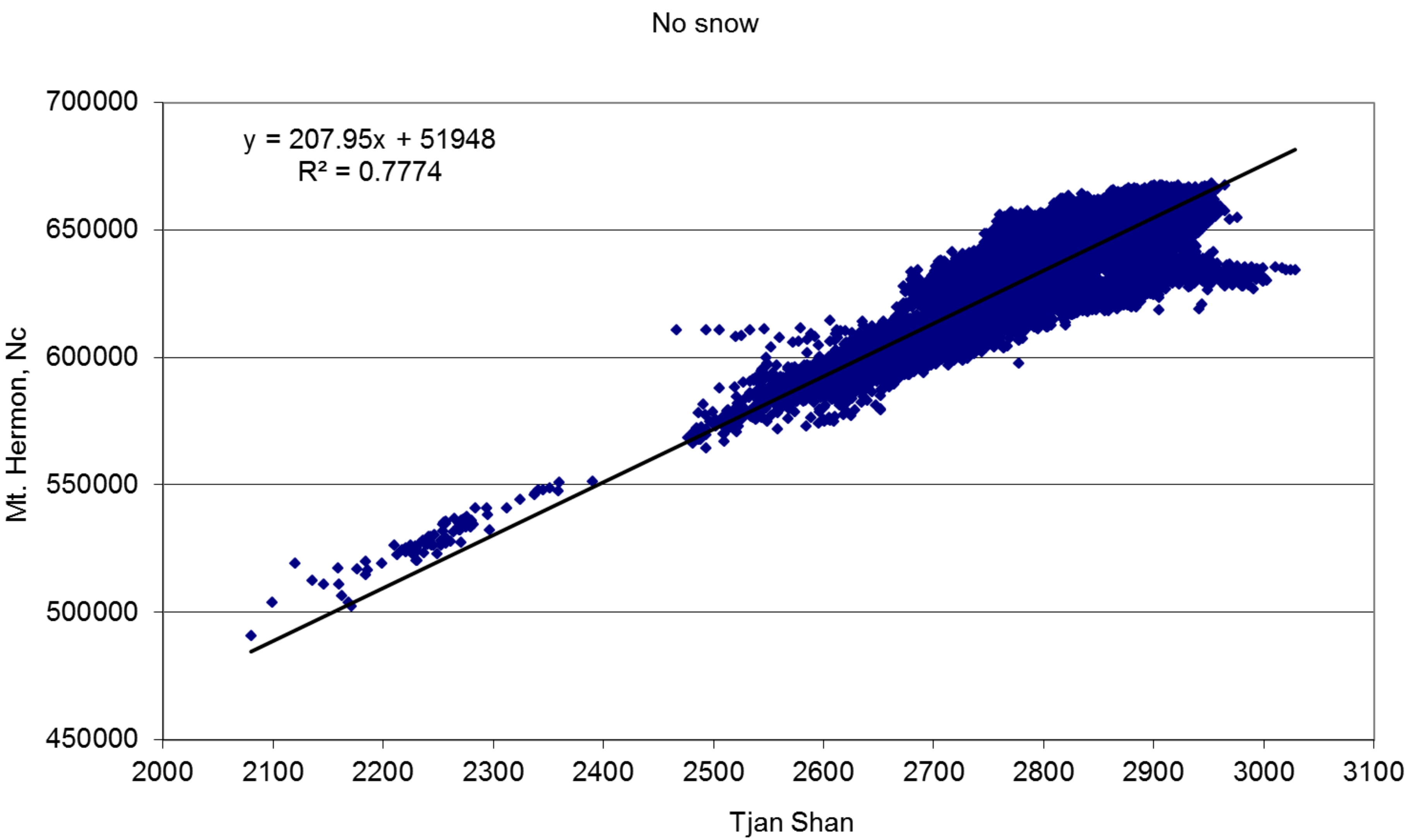
The matter of the problem

- After correction NM data on snow effect according to our work presented for Moscow COSPAR Assembly (Dorman et al. “Snow effect for total NM intensity and different multiplicities on Mt. Hermon during 1998 – 2013”) we determined long-term CR variations according to NM Mt. Hermon in total neutron intensity and different multiplicities. Obtained results for total neutron intensity we compare with results on other CR stations in dependence of altitude and cut-off rigidity. Results for different multiplicities we use for estimation of long-term CR rigidity spectrum. We estimate also the hysteresis effect and the effective size of the modulation region and expected size of the Heliosphere.

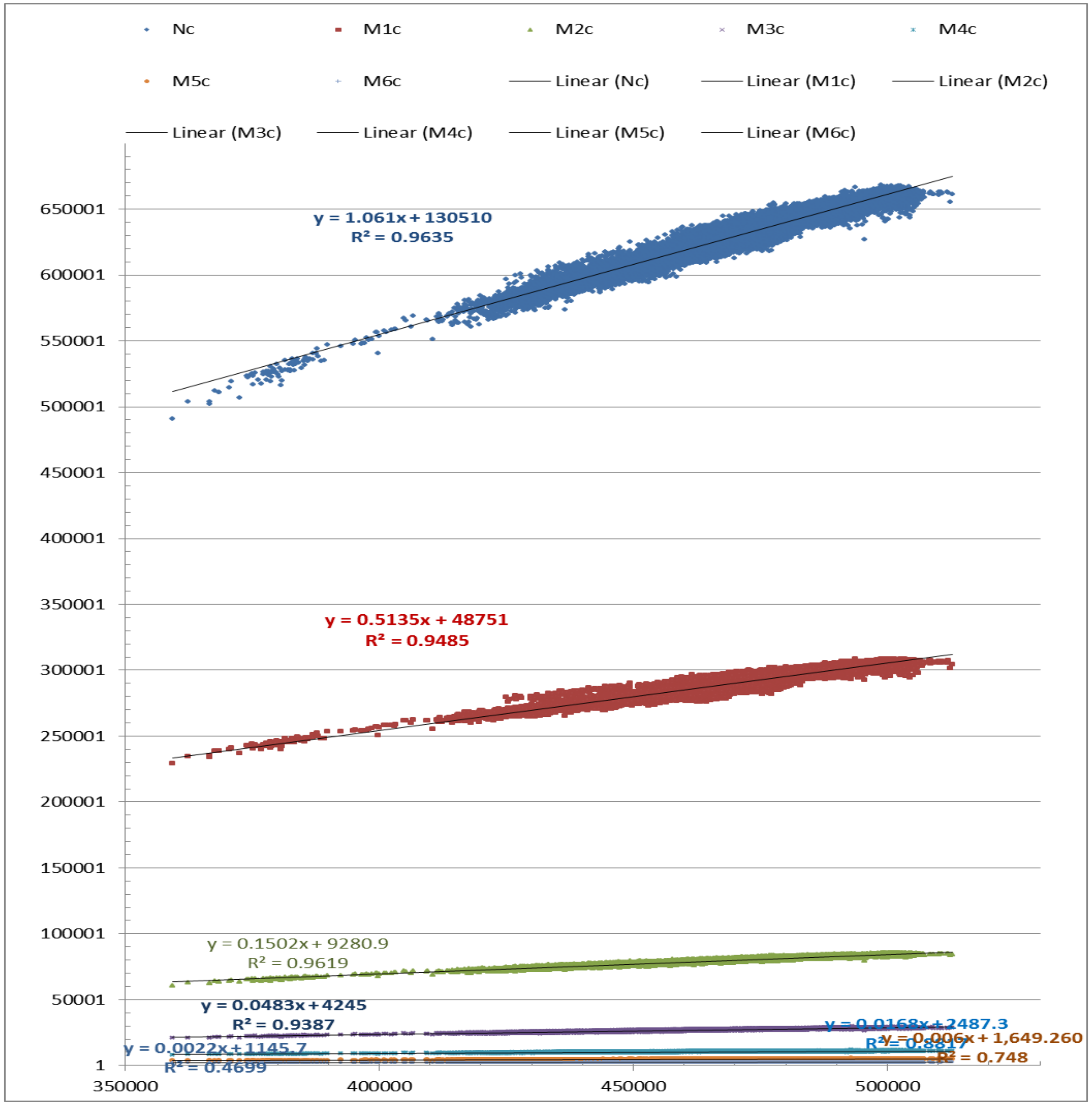
Introduction

- The propagation and modulation of galactic CR (generated mostly during Supernova explosions and in Supernova remnants in our Galaxy) in the Heliosphere are determined by their interactions with magnetic fields frozen in solar wind and in coronal mass ejections (CME) with accompanied shock waves (produced big magnetic storms during their interactions with the Earth's Magnetosphere). The most difficult problem of monitoring and forecasting the modulation of galactic CR in the Heliosphere is that the CR intensity in some space-time 4D-point is determined not by the level of solar activity at this time-point of observations and electro-magnetic conditions in this space-point but by electromagnetic conditions in total Heliosphere. These conditions in total Heliosphere are determined by development of solar activity during many months before the time-point of observations. It is main cause of so called hysteresis phenomenon in connection galactic CR – solar activity. From other hand, detail investigations of this phenomenon give important possibility to estimate conditions in and dimension of Heliosphere. To solve described above problem of CR modulation in the Heliosphere, we considered as the first step behavior of high energy particles (more than several GeV, for which the diffusion time of propagation in Heliosphere is very small in comparison with characteristic time of modulation) on the basis of neutron monitor data in the frame of convection diffusion theory, and then take into account drift effects. For small energy galactic CR detected on satellites and space probes we need to take into account also additional time lag caused by diffusion in the Heliosphere. Then we consider the problem of CR modulation forecasting for several months and years ahead.

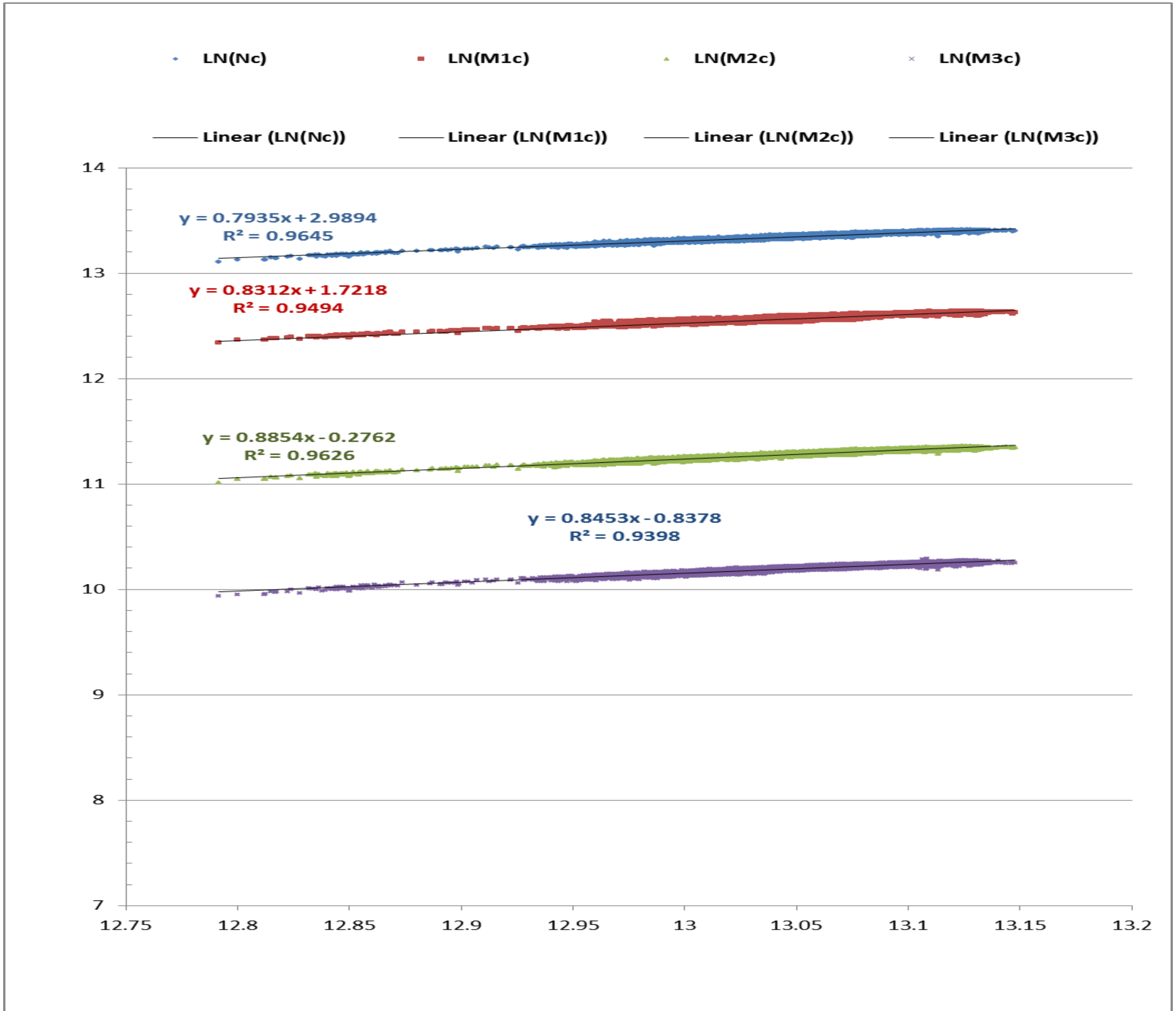
Mt. Hermon, Nc / Tjan Shan



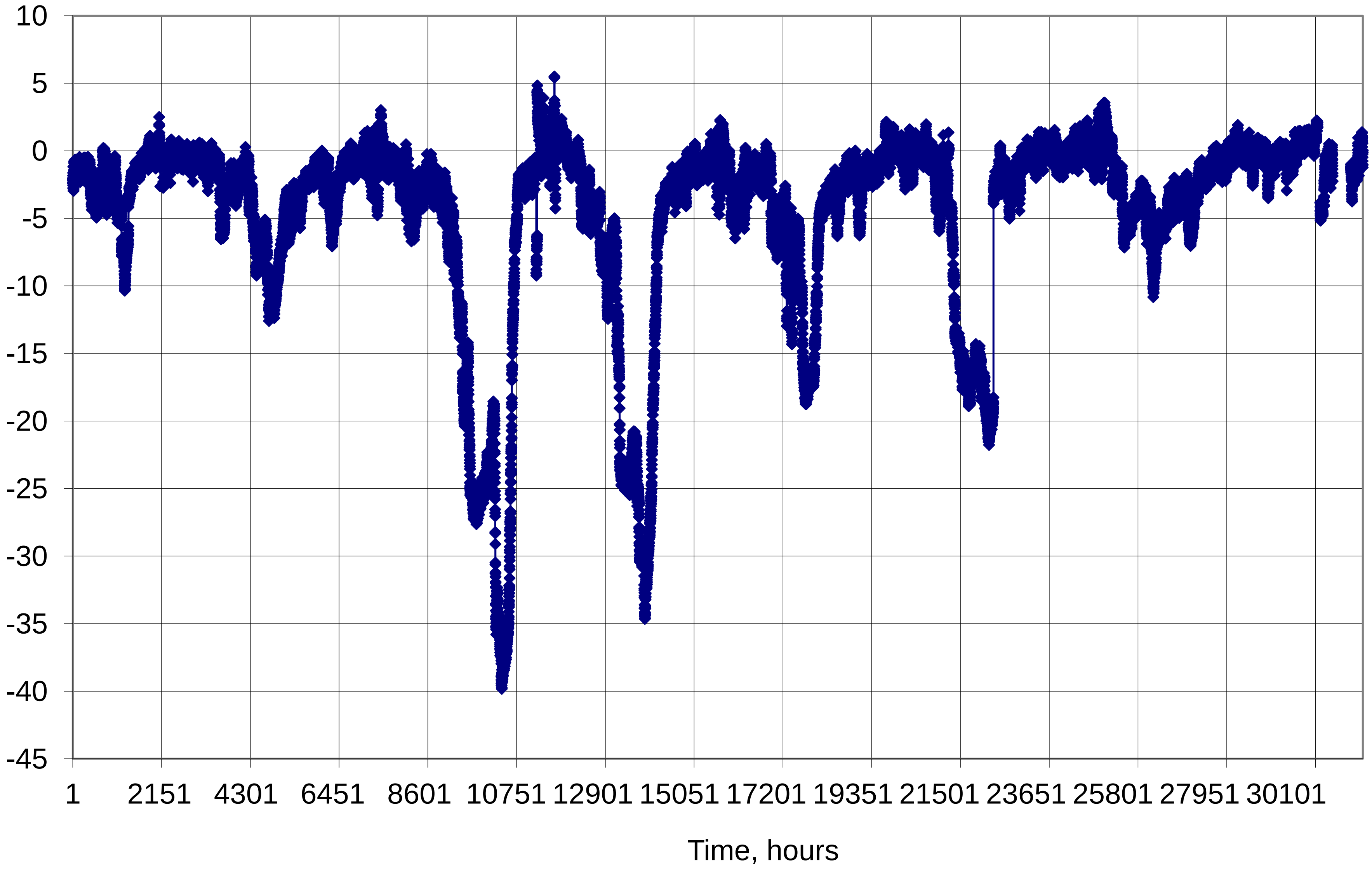
Mt. Hermon Nc,M1-M6 / Rome Nc



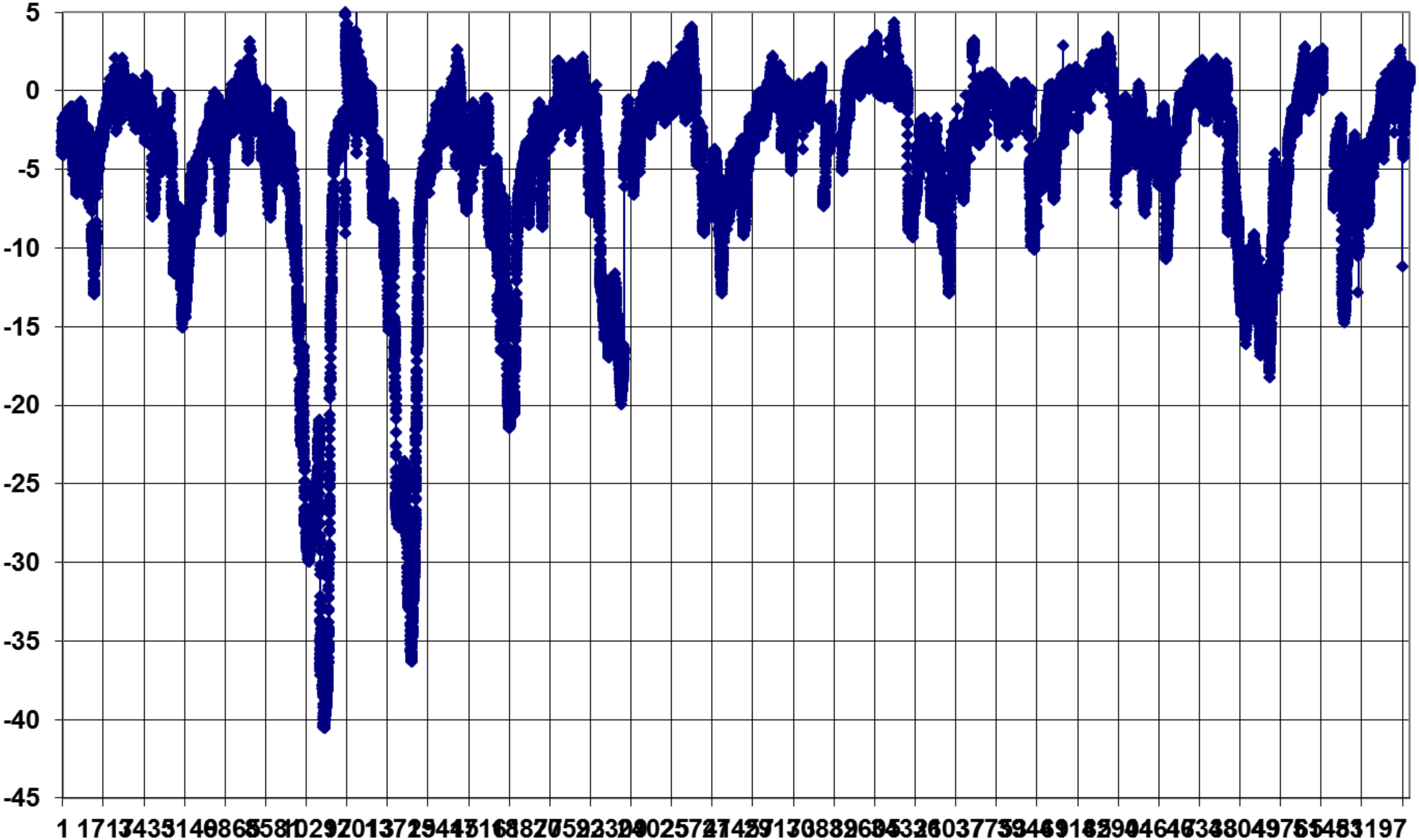
Mt. Hermon, ln(Nc),ln(M1),ln(M2),ln(m3)/Rome ln(Nc)



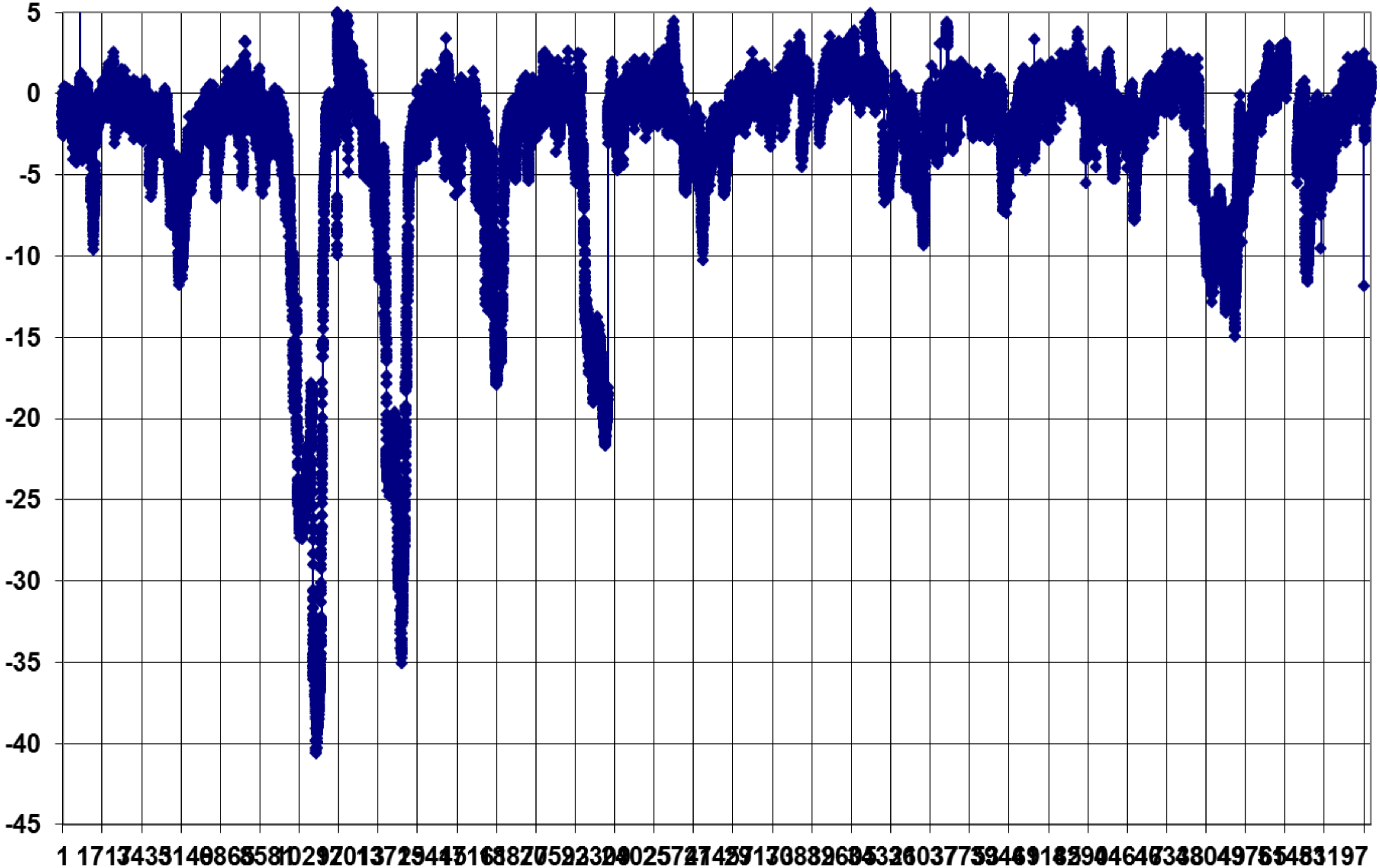
SNOW EFFECT IN CR, % Nc-snow



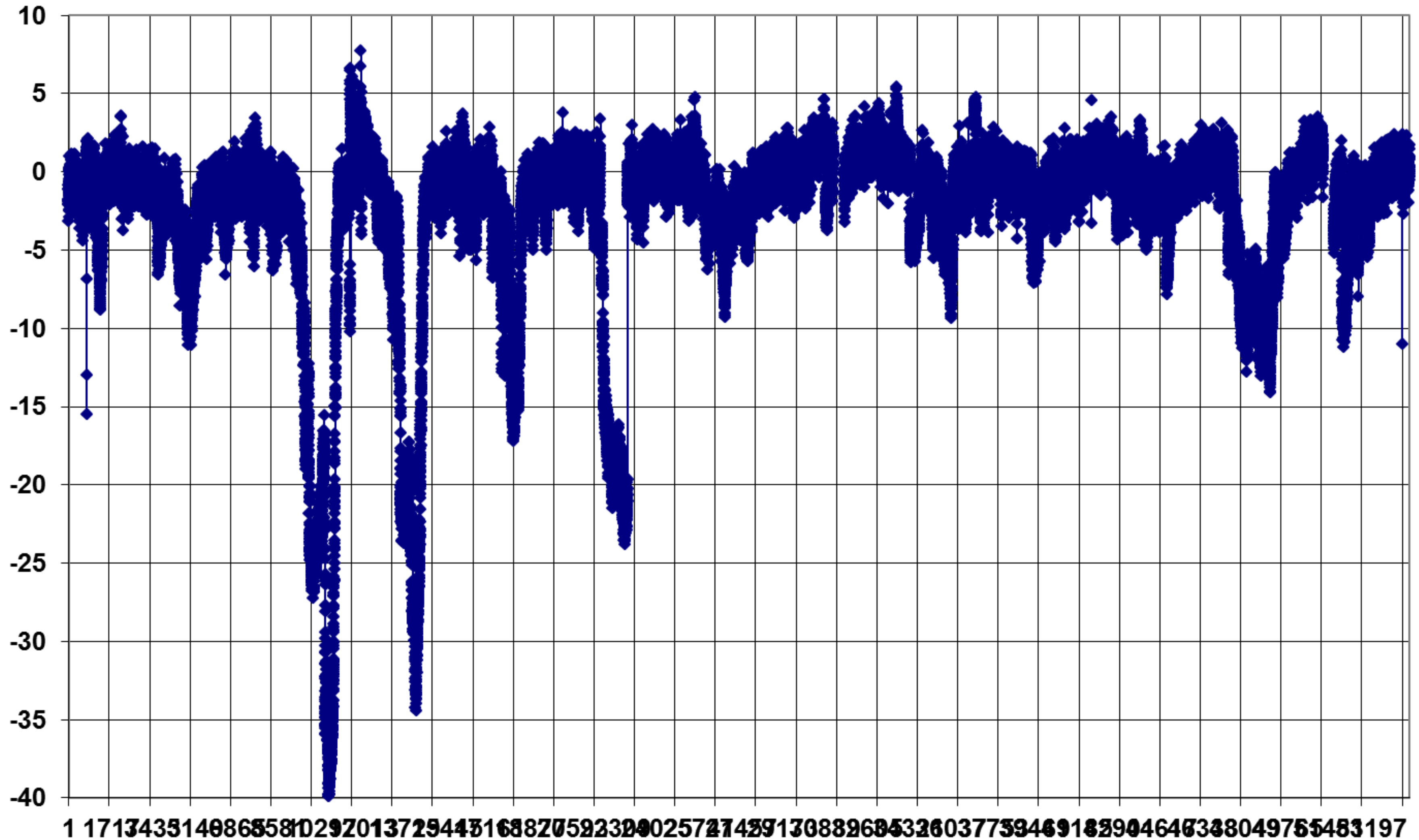
SNOW EFFECT IN CR, % M1-snow



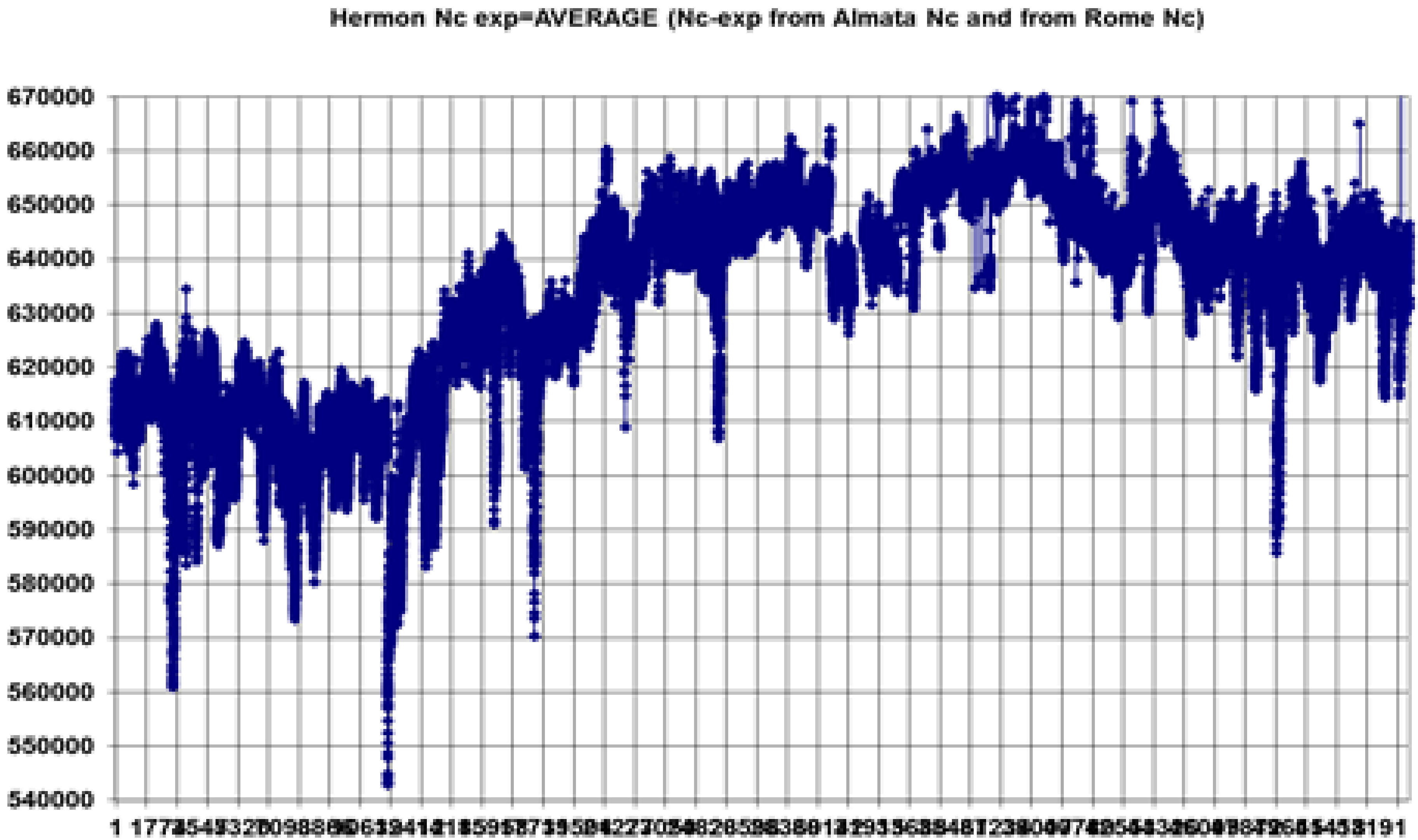
SNOW EFFECT IN CR, % M2-snow



SNOW EFFECT IN CR, % M3-snow



Hermon Nc exp=AVERAGE (Nc-exp from TjanShan Nc and from Rome Nc)



2. Hysteresis phenomenon and the model of CR global modulation in the frame of convection-diffusion mechanism

$$n(R, r_{obs}, t)/n_o(R) \approx \exp\left(-a \int_{r_{obs}}^{r_o} \frac{u(r,t)dr}{\kappa_r(R,r,t)} \right) \qquad a \approx 1.5$$

$$\kappa_r(R,r,t) \propto r^{\beta}\left(W(t - r/u)\right)^{-\alpha} \qquad \alpha(t) = 1/3 + (2/3)(1 - W(t)/W_{\max})$$

$$\ln\left(n(R, r_E, t)_{obs}\right) = A(R, X_o, \beta) - B(R, X_o, \beta) F\left(t, X_o, \beta, W(t - X)\Big|_{X_E}^{X_o} \right)$$

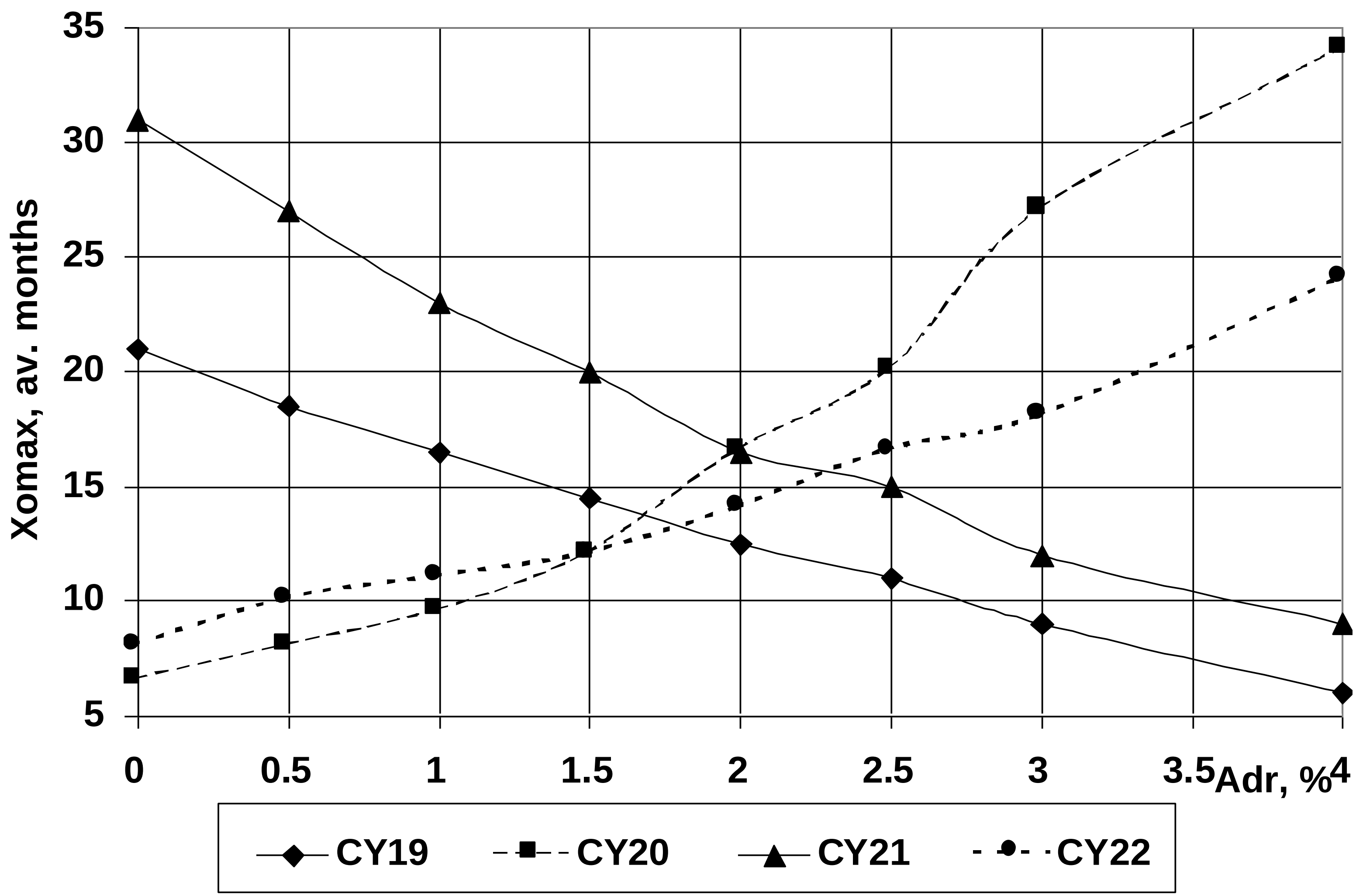
$$F\left(t, X_o, \beta, W(t - X)\Big|_{X_E}^{X_o} \right) = \int_{X_E}^{X_o} \left(\frac{W(t - X)}{W_{\max}} \right)^{\frac{1}{3} + \frac{2}{3}(1 - W(t - X)/W_{\max})} X^{-\beta} dX$$

$$X = r/u\ ,\ X_E = 1AU/u,\ X_o = r_o/u$$

are in units of average month = (365.25/12) days

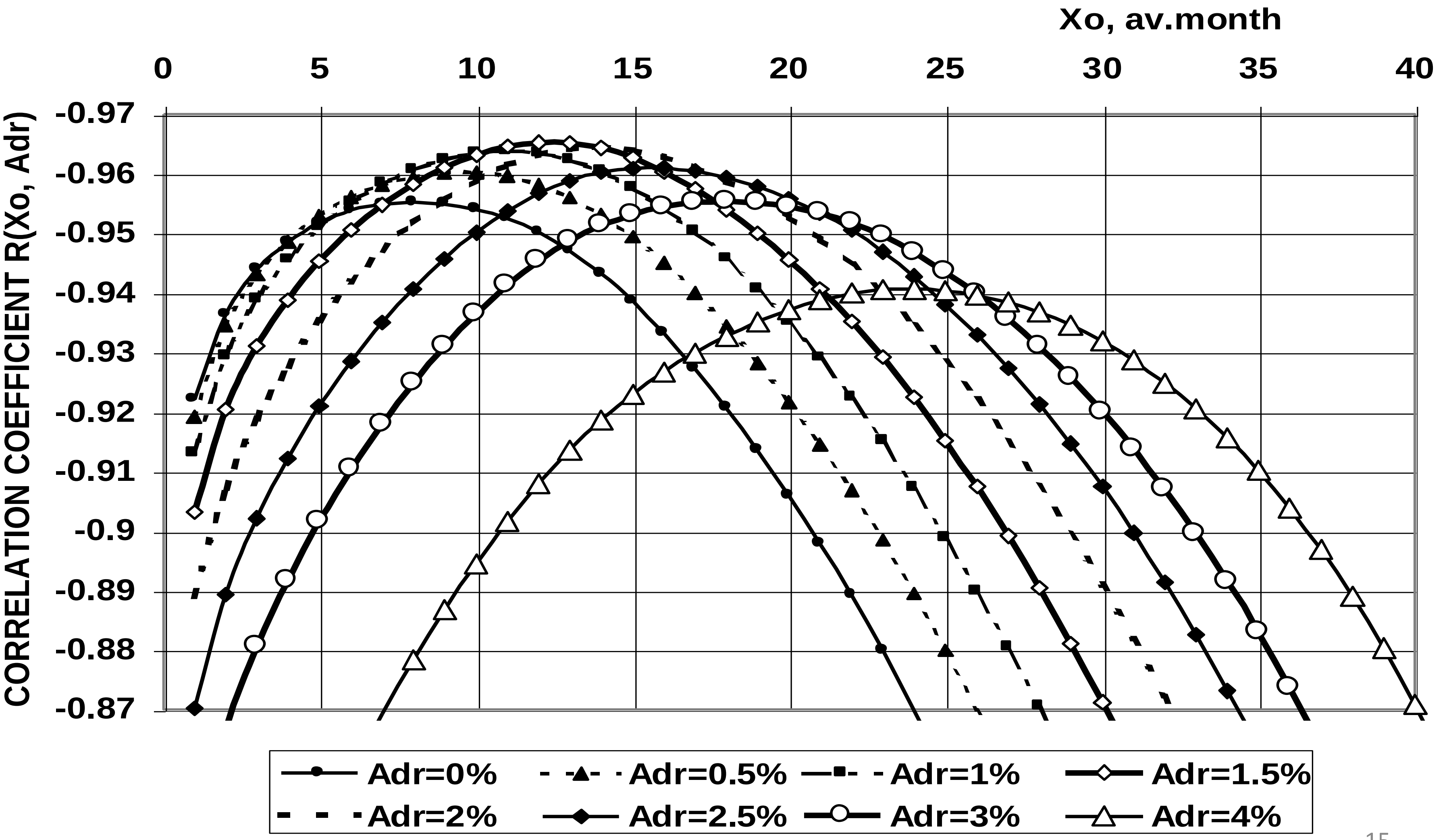
3. Even-odd cycle effect in CR and role of drifts for NM energies

- We assume that observed long-term CR modulation is caused by two processes: the convection-diffusion mechanism (e.g., Parker, 1958, Dorman, 1959), which is independent of the sign of the solar magnetic field; and the drift mechanism (e.g., Jokipii and Davila, 1981; Burger and Potgieter, 1999; Ferreira et al., 1999), what gave opposite effects with changing sign of solar magnetic field. For the convection-diffusion mechanism we use the model described in detail in Dorman (2001), for drift effects we use results of Burger and Potgieter (1999), and assume that the drift effect is proportional to the value of the tilt angle with negative sign at $A > 0$ and positive sign at $A < 0$, and in the period of reversal we suppose linear transition through 0 from one polarity cycle to other



- Dependences $X_{o\max}\left(A_{dr}\right)$ for Climax NM. The drift effect is about 2.0% for Climax NM and about 0.33% for Huancayo/Haleakala NM

4. The inverse problem for CR propagation and modulation during solar cycle 22 on the basis of NM data



5. Diffusion time lag for small energy particles

$$T_{dif}\left(R,t,r_{obs},r,r_o\right)\approx\frac{\left(r_o-r_{obs}\right)^2-\left(r_o-r\right)^2}{6D_{r,ef}\left(R,t\right)}\approx C\left(R,t\right)\times\frac{\left(r-r_{obs}\right)\left(2r_o-r-r_{obs}\right)}{u_{ef}\left(t\right)\left(r_o-r_{obs}\right)}$$

$$C\left(R,t\right)=-\frac{\ln\left(n\left(R,r_{obs},t\right)/n_o\left(R\right)\right)}{6a}$$

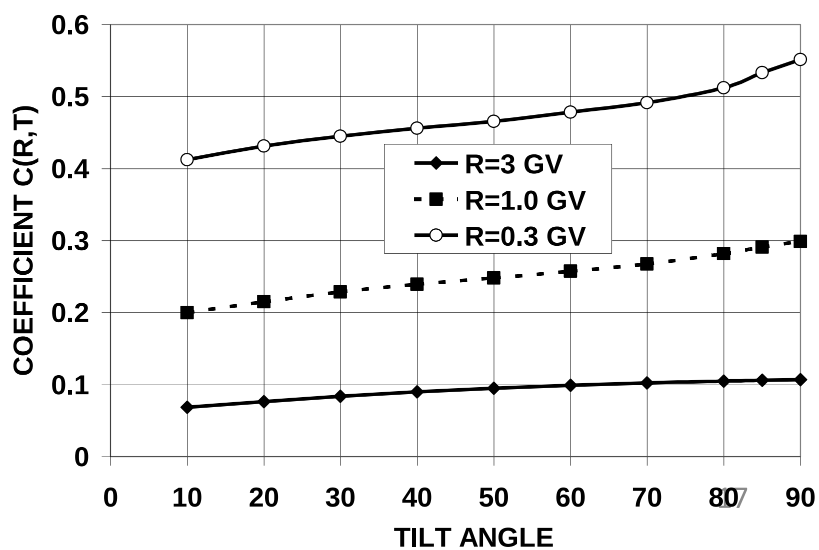
$$T_{dif}\left(R,t,X_{obs},X,X_o\right)\approx C\left(R,t\right)\times\frac{\left(X-X_{obs}\right)\left(2X_o-X-X_{obs}\right)}{X_o-X_{obs}}$$

6. Convection-diffusion modulation for small energy galactic CR particles

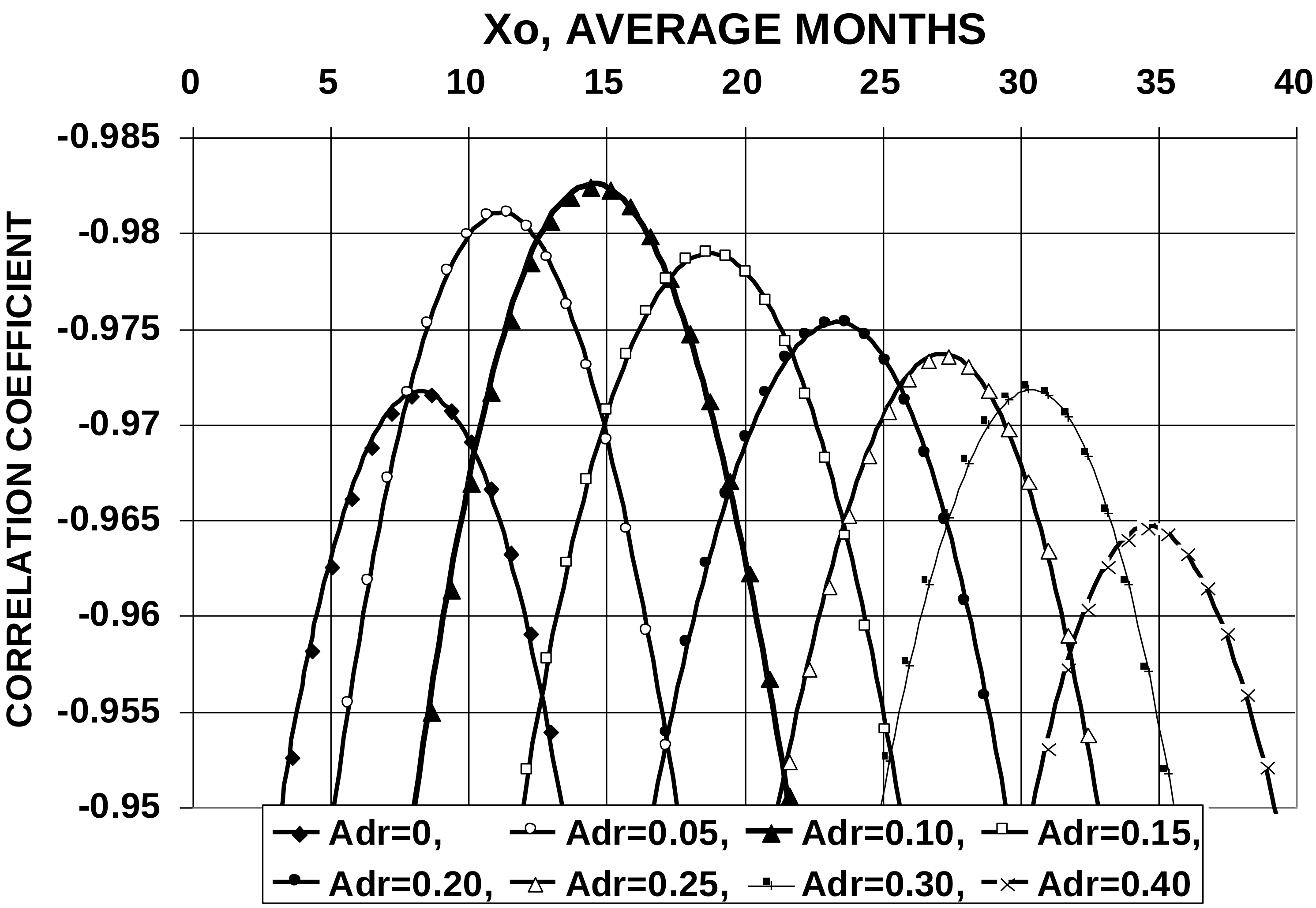
$$\ln\left(n\left(R,r_{obs},t\right)\right)=A\left(X_o,\beta,t_1,t_2\right)-B\left(X_o,\beta,t_1,t_2\right)\times F\left(t,X_o,\beta,W\left(t-X^*\right)\Big|_{X_{obs}}^{X_o}\right)$$

$$F\left(t,X_o,\beta,W\left(t-X^*\right)\Big|_{X_{obs}}^{X_o}\right)=\int_{X_{obs}}^{X_o}\left(\frac{W\left(t-X^*\right)}{W_{\max}}\right)^{\frac{1}{3}+\frac{2}{3}\left(1-W\left(t-X^*\right)/W_{\max}\right)}X^{-\beta}dX$$

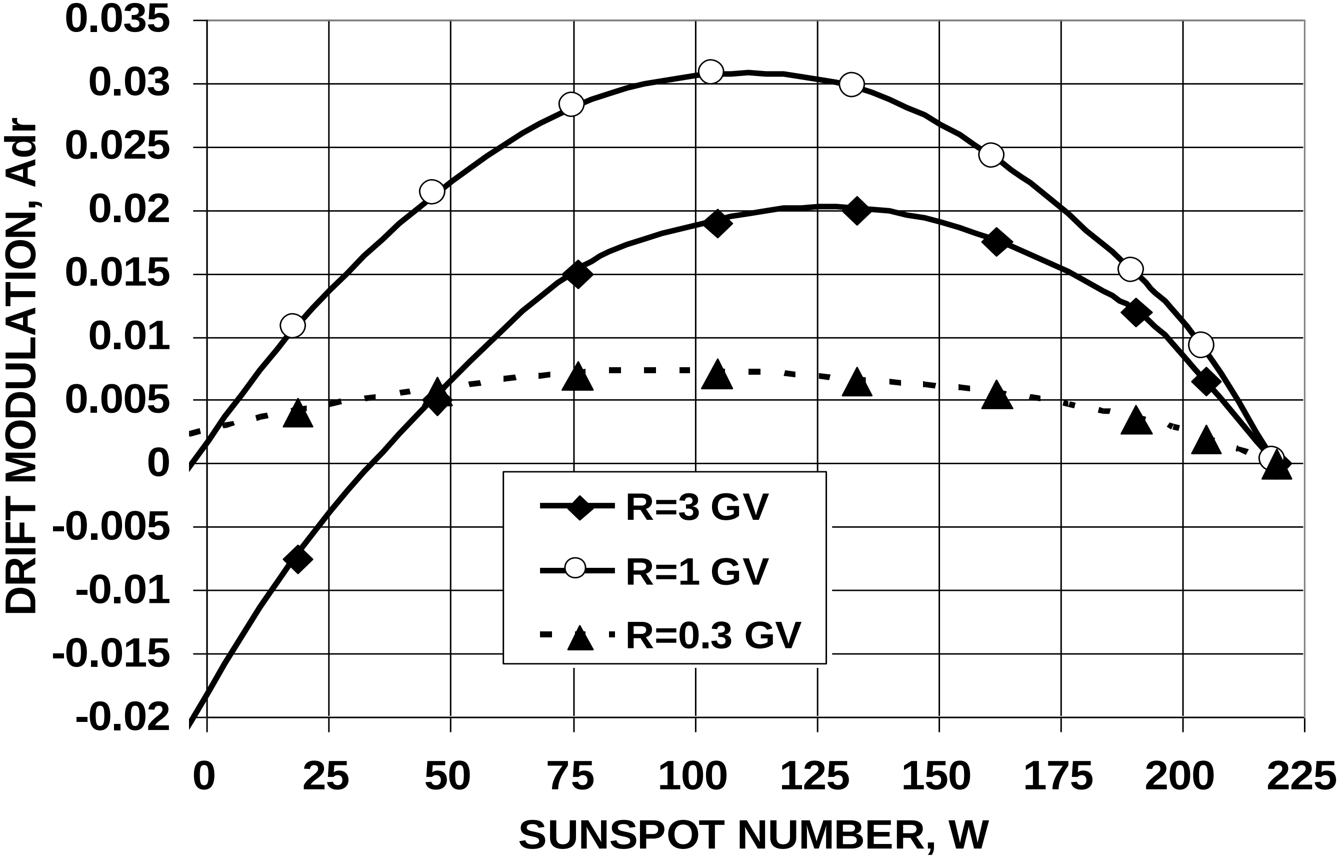
$$X^*=X+C\left(R,t\right)\times\frac{\left(X-X_{obs}\right)\left(2X_o-X-X_{obs}\right)}{X_o-X_{obs}}$$



9. Results for alpha-particles in the energy interval 330–500 MeV

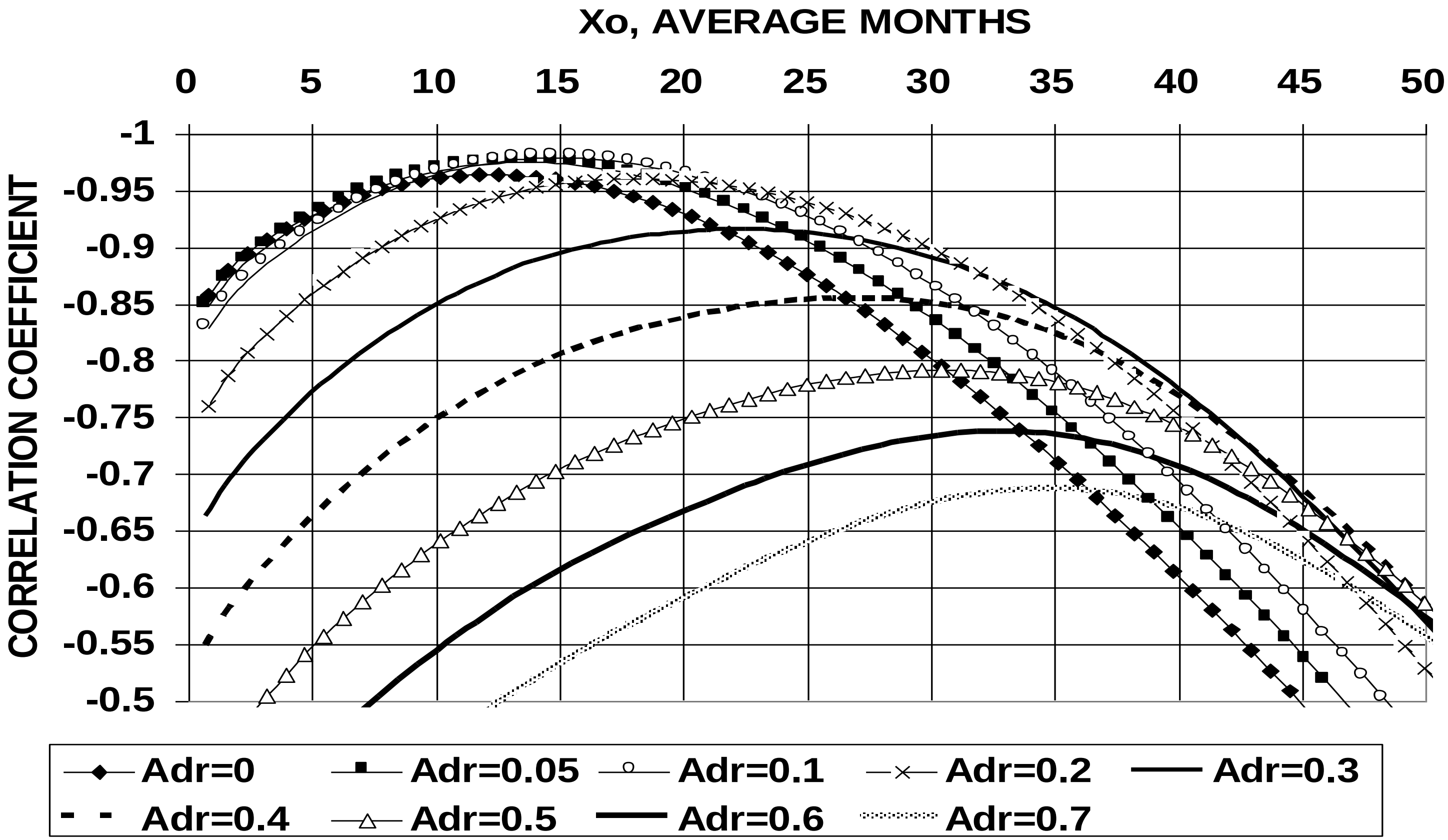


7. Small energy CR long-term variation caused by drifts



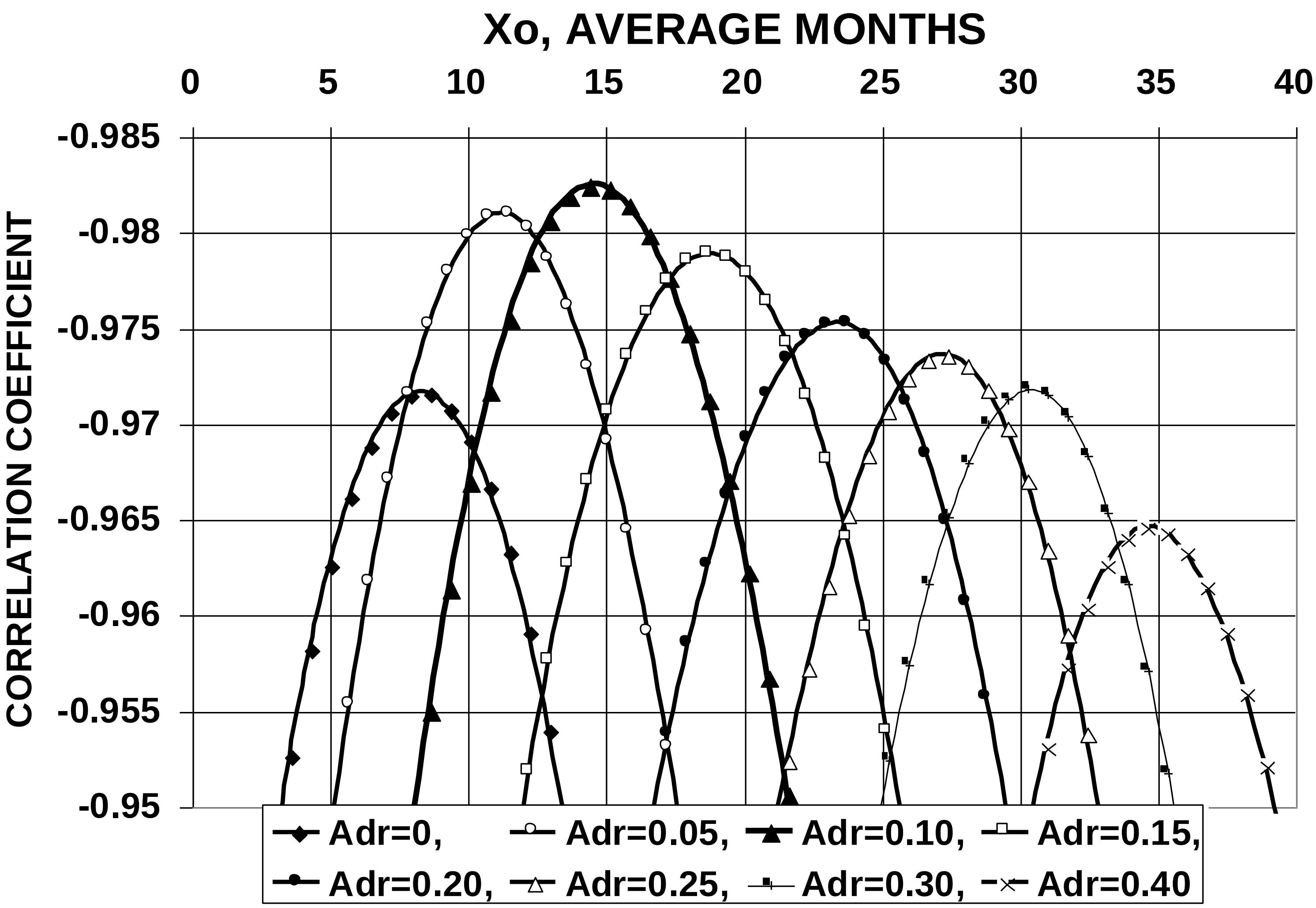
- Expected drift modulations for *R* = 3, 1, and 0.3 GV relative to the intensity out of the Heliosphere, in dependence of sunspot number W and derived from Burger and Potgieter (1999)

8. The satellite proton data and their corrections on solar CR increases



for GOES data of protons with energy $E_k \geq 100$ MeV from Jan 1986 to Dec 1999

9. Results for alpha-particles in the energy interval 330–500 MeV



Gonclusion

The taking into account drift effects gives an important possibility, using data only for solar cycle 22, to determine the most reliable drift amplitude (at W = 75) and the effective time of the solar wind moving with frozen magnetic fields from the Sun to the boundary of the modulation region). We found that with an increasing effective CR primary particle rigidity from 10–15 GV (Climax NM and Kiel NM) up to 35–40 GV (Huancayo/Haleakala /Mt Hermon NM) are decreased both the amplitude of drift effect (from about 1.5% to about 0.15%) and time-lag (from about 13 av. months to about 10 av. months). It means that in cycle 22, for the total long term modulation of CR with rigidity 10-15 GV, the relative role of the drift mechanism was $\approx$ 1/4 and the convection-diffusion mechanism about 3/4 (we take into account that observed total 11-year variation in Climax and Kiel NM is 25%, and the total change of CR intensity owed to drift effects is about 4 times more than the amplitude); for rigidity 35-40 GV these values were $\approx$ 1/10 for the drift mechanism, and about 9/10 for the convection-diffusion mechanism. If we assume that the average velocity of the solar wind in the modulation region was about the same as the observed average velocity near the Earth's orbit in 1965-1990: u = 7.73 AU/(average month), the estimated dimension of modulation region in cycle 22 will be ~ 100 AU for CR with rigidity of 10-15 GV and about 80 AU for CR with rigidity of 35-40 GV. It means that at distances more than 80 AU the magnetic fields in solar wind and in inhomogeneities are too weak to influence intensity of 35-40 GV **CR** particles. For small energies according to satellite data radius of modulation is about equal to the radius of Heliospher (about 100 AU) and drift effect about 30% From total modulation