SH 3.2.31

# On the Changes with Solar Cycles of Cosmic Ray Propagation Parameters and Dimension of Modulation Region and Heliosphere

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**Abstract**

We continue our investigations of cosmic ray-solar activity hysteresis phenomenon by using data of Climax and Huancayo/Haleakala neutron monitors and Huancayo ionization chamber for about 4 solar cycles. We determine approximately the changes from one cycle to another of the effective dimension of modulation region and Heliosphere and show that there is a great difference between even and odd solar cycles, and appreciable dependence on the effective rigidity of cosmic ray particles for even cycles. It appears that there are at least 3 cycles in cosmic ray modulation: 11, 22 and 44 years.

## 1 Introduction:

In Dorman et al. (1999a) it was given a short historical introduction on CR-SA hysteresis phenomenon investigations (with related references), and it was described the used model. On the basis of 4 solar cycles data for the Climax neutron monitor we estimated also the average dimension of the Heliosphere and average CR propagation parameters. These results allowed us to determine the expected CR long-term variations in the past for about 250 years. In Dorman et al. (1999b) we used data corresponding to remarkably different effective CR rigidities and estimated how the dimension of modulation region (averaged for several solar cycles) is changing with increasing the primary CR energy. In this paper we will investigate if there are appreciable changes in the dimension of modulation region and Heliosphere from one cycle to another (and also how the propagation parameters and the character of modulation are changing). We will also consider the particularly important problem to find possible differences between odd and even solar cycles. It is worthwhile to note that in any case the dimension of Heliosphere cannot be smaller than the dimension of CR modulation region; they have about the same dimension for neutron monitors with small cut-off rigidities (as Climax NM).

## 2 Changes of the Dimension of Modulation Region over Solar Cycles 19-22 According to Climax Neutron Monitor Data:

To determine the dimension of CR modulation region let us correlate, in accordance with our model described in Dorman et al. (1999a, b), the logarithm of CR intensity with the value of parameter $F$ computed on the basis of solar activity data

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

Parameter $F$ depends on time $t$, on $X_o = r_o/u$ , as well as on the time distribution of SA in the interval from

$t - X_o$ to $t - X_E$. Then, we compute the correlation coefficient $\rho(X_o)$ and regression coefficients $A$ and $B$ in the relation

$$\ln(n(R, r_E, t))_{\text{obs}} = A - B \times F\left(t, X_o, W(t - X)\Big|_{X_E}^{X_o}\right) \quad (2)$$

as a function of $X_o$. In Figure 1 we show dependencies of $\rho(X_o)$ on $X_o = r_o/u$ (in the interval $1 \le X_o \le 36$, where $X_o$ is in units of average month (365.25/12) days = $2.628 \times 10^6$ s) for $\beta = 0$, obtained by observations of Climax neutron monitor (USA, Colorado, N39, W106, *H*=3400 *m*, $R_c = 2.99\,GV$) for monthly data and 5-month moving averages in the periods January 1953–December 1965 (covering solar Cycle 19), January 1965–December 1975 (Cycle 20), January 1975–December 1985 (Cycle 21), and January 1985–December 1996 (Cycle 22).

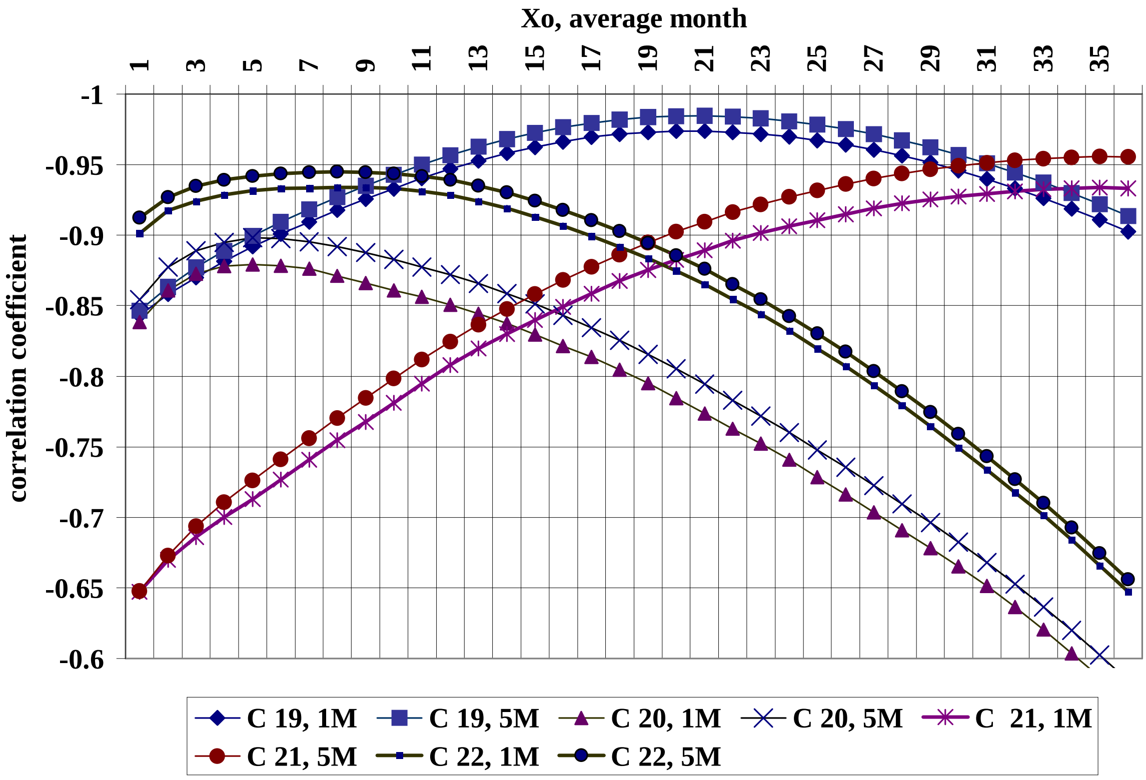


**Figure 1:** Dependencies of $\rho(X_o)$ on $X_o = r_o/u$ (in the interval $1 \le X_o \le 36$ months) by observations of Climax neutron monitor: monthly data (1M) and 5-month moving averages (5M) separately for solar cycles 19, 20, 21 and 22.

From Figure 1 it can be seen a great difference between even and odd solar cycles: $X_o^{\max}$ for even cycles is much bigger than for odd cycles (see also Table 1).

## 3 Changes of the Modulation Region Dimension over Solar Cycles 19-22 According to Huancayo/Haleakala Neutron Monitor Data

The correlation coefficients $\rho(X_o)$ obtained on the basis of Huancayo (Peru, S12, W75, $R_c = 12.92\,GV, H = 3400m$)/Haleakala (Hawaii, N20, W156, $R_c = 12.91\,GV, H = 3030\,m$) neutron monitor data for solar cycles 19-22 are shown in Figure 2. Results will be given in Section 5.

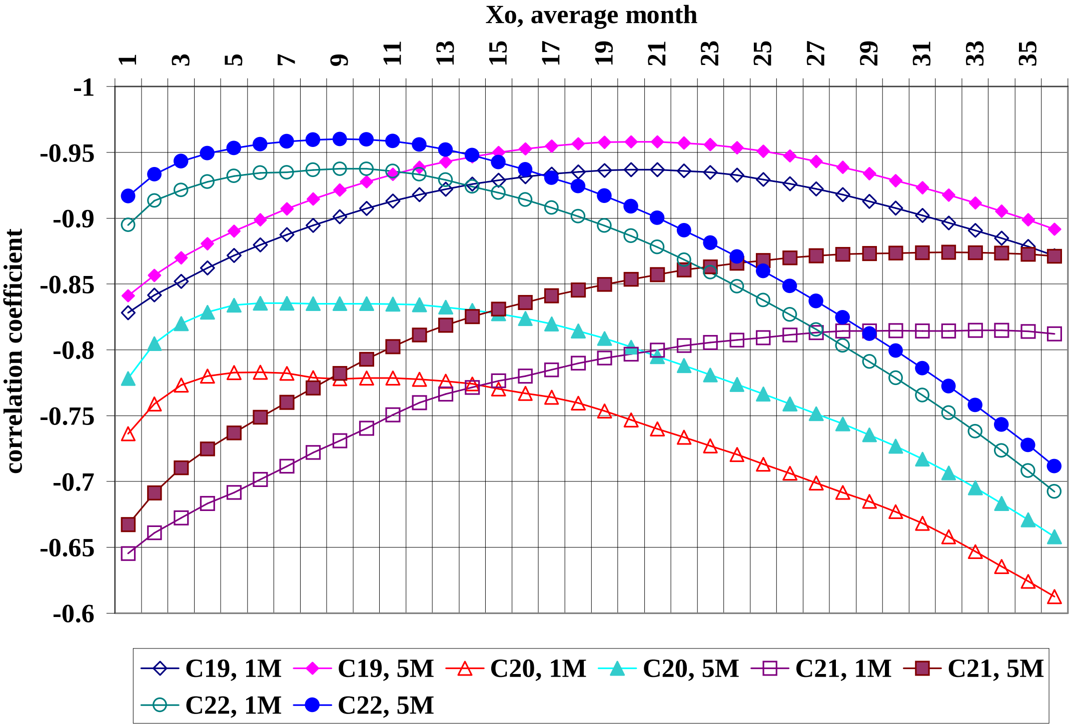


**Figure 2:** The same as in Figure 1, on the basis of Huancayo/Haleakala neutron monitor data.

## 4 Changes with Solar Cycles of Dimension of Modulation Region According to Huancayo Ionization Chamber Data:

Results based on Huancayo ionization chamber data for solar cycles 19-21 are shown in Figure 3 for monthly (1M), 5-month (5M) and 12-month moving averages (12M). We will present the results in Section 5 together with previous ones obtained on the basis of neutron monitor data.

## 5 Conclusions:

The approximate determination of $X_o^{\max}$ (position at which $\rho(X_o)$ reaches the maximum value) and $\rho\left(X_o^{\max}\right)$, obtained on the basis of results of Figures 1-3, are summarized in Table 1. It can be seen that:

- There is great difference between even and odd solar cycles; the value of $X_o^{\max}$ for odd cycles is 3-4 times smaller than for even cycles.
- For even cycles there is a clear tendency of decreasing $X_o^{\max}$ with increasing the effective primary CR rigidity (from 21 for Climax NM to 15-16 for Huancayo IC for cycle 19, and from 35 for Climax NM, to 28-32 for Huancayo NM and to 19-20 for Huancayo IC for cycle 21 (see Dorman et al. 1999b)
- Clear 11 and 22-years CR modulation are observed (even and odd solar cycles separately, and cycle even + odd), as well as 44 years modulation ( $X_o^{\max}$ for cycles 21 and 22 are significantly bigger than for cycles 19 and 20, correspondingly).
- For $X_o^{\max}$ the accuracy of regression coefficients $A$ and $B$ in (2) well agrees with values of correlation coefficient $\rho\left(X_o^{\max}\right)$ (see Table 1): $A$ is the logarithm of galactic CR intensity out of the modulation region, and $B = au^2/D_{\max}(R)$ determines the effective diffusion coefficient for particles with rigidity $R$ in the maximum of SA.

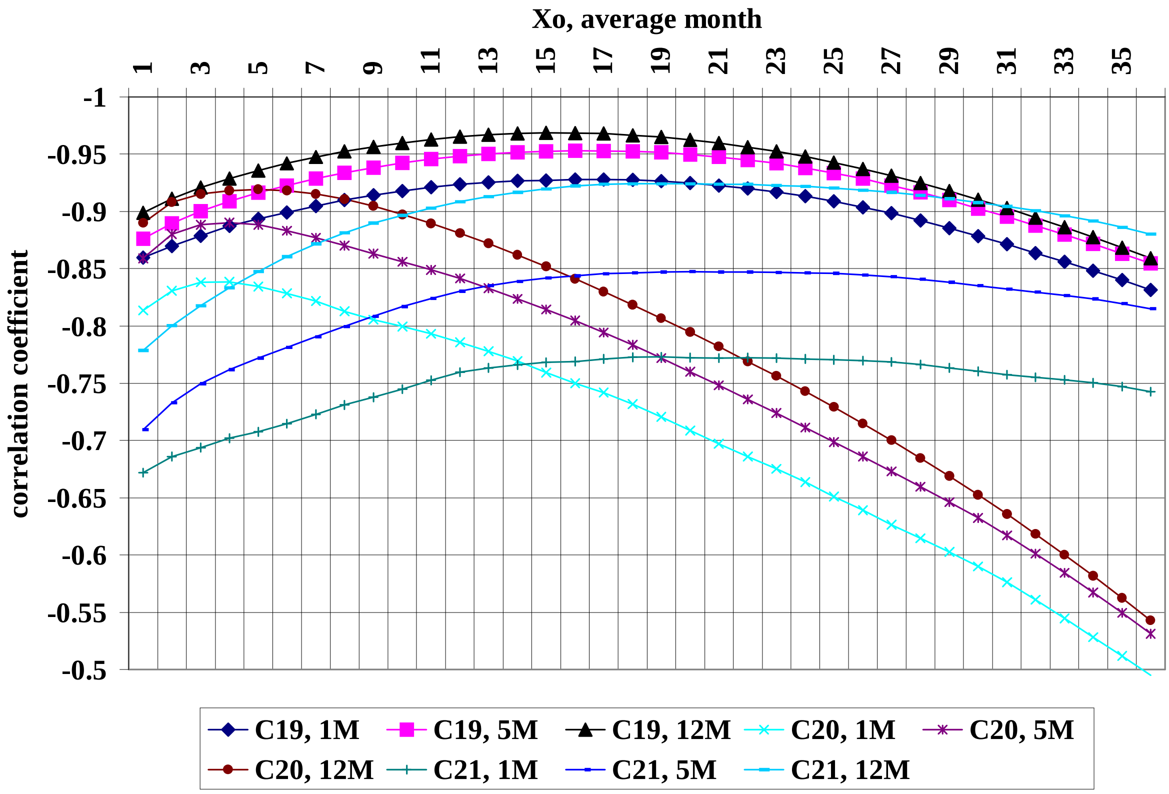


**Figure 3:** As in Figure 1, for Huancayo ionization chamber data for solar cycles 19, 20 and 21.

**Table 1:** Changes of $X_o^{\max}$ and $\rho\left(X_o^{\max}\right)$ with solar cycles

| SOLAR CYCLE | VALUE | CLNM 1M | CLNM 5M | HUNM 1M | HUNM 5M | HUIC 1M | HUIC 5M | HUIC 12M |
|---|---|---|---|---|---|---|---|---|
| 19 | $X_o^{\max}$ | 21 | 21 | 20 | 20 | 17 | 16 | 15 |
| | $\rho\left(X_o^{\max}\right)$ | -0.9739 | -0.9846 | -0.9368 | -0.9581 | -0.9279 | -0.9530 | -0.9686 |
| 20 | $X_o^{\max}$ | 5 | 5 | 6 | 7 | 4 | 4 | 6 |
| | $\rho\left(X_o^{\max}\right)$ | -0.8793 | -0.8982 | -0.7830 | -0.8354 | -0.8387 | -0.8902 | -0.9243 |
| 21 | $X_o^{\max}$ | 35 | 35 | 28 | 32 | 19 | 20 | 19 |
| | $\rho\left(X_o^{\max}\right)$ | -0.9337 | -0.9556 | -0.8142 | -0.8740 | -0.7729 | -0.8473 | -0.9243 |
| 22 | $X_o^{\max}$ | 9 | 8 | 11 | 11 | | | |
| | $\rho\left(X_o^{\max}\right)$ | -0.9338 | -0.9449 | -0.9302 | -0.9539 | | | |

Due to the lack of space, we will discuss these results elsewhere.

# References


Dorman, L.I. et al. 1999a, Proc. 26th ICRC (Salt Lake City) Paper SH 3.2.29
Dorman, L.I. et al. 1999b, Proc. 26th ICRC (Salt Lake City) Paper SH 3.2.30