ESWW-2

Forecasting of the part of global climate change caused by the influence of long-term cosmic ray intensity variation on the planetary cloudiness

L.I. Dorman (a, b)

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

(b) Cosmic Ray Department of IZMIRAN Russian Academy of Science, RUSSIA;

E-mail: lid@physics.technion.ac.il, Fax: 972-4-6964952

Abstract

On the basis of results obtained in our papers on hysteresis effects we determine the dimension of Heliosphere (modulation region), radial diffusion coefficient and other parameters of convection-diffusion and drift mechanisms of cosmic ray (CR) long term variation in dependence of particles energy, level of solar activity (SA) and general solar magnetic field. This important information we obtain on the basis of CR and SA data in the past taking into account the theory of convection-diffusion and drift global modulation of galactic CR in the Heliosphere. By using these results and published regularly elsewhere predictions of expected SA variation in near future and prediction of future next SA cycle we may made prediction of expected in near future (up to 10-12 years) long-term cosmic ray intensity variation. From other hand, from hysteresis effects were estimated properties of connection between CR intensity long-term variation and some part of global climate change,

controlled by solar activity through CR. We show that by this way we may made prediction of expected in near future (up to 10-12 years, and may be more, in dependence for what period can be made definite prediction of SA) some part of global climate change, controlled by solar activity through CR. In this case become important also estimation of expected long-term changes in the planetary distribution of cutoff rigidities which also influenced on CR intensity, and through CR – influenced on global climate variation.
This research is in the frame of COST- 724.

CONVECTION-DIFFUSION MODULATION

According to Dorman et al. (2001a,b) the expected value of the natural logarithm of CR intensity global modulation at the Earth's orbit, taking into account time-lag in the Heliosphere relative to the processes on the Sun, will be

$$\ln\left(n\left(R, X_o, \beta, r_E, t\right)_{\exp}\right) = A - B \times F\left(t, X_o, \beta, W\left(t-X\right)\Big|_{X_E}^{X_o}\right), \qquad (1)$$

where

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

$X = r/u$, $X_E = 1AU/u$, $X_o = r_o/u$, and $n\left(R, X_o, \beta, r_E, t\right)_{\exp}$ is the expected galactic CR density at the Earth's orbit in dependence of the values of parameters X_o and β. Regression coefficients $A\left(R, X_o, \beta, t_1, t_2\right)$ and $B\left(R, X_o, \beta, t_1, t_2\right)$ can be determined by correlation between observed values $\ln\left(n\left(R, r_E, t\right)\right)_{\text{obs}}$ and the values of $F\left(t, X_o, \beta, W\left(t-X\right)\Big|_{X_E}^{X_o}\right)$, calculated according to Eq. (2) for different values of X_o and β. In Dorman et al. (1997) three values of $\beta = 0;\ 0.5;\ 1$ have been considered; it was shown that $\beta = 1$ strongly contradicts CR and SA observation data, and that $\beta = 0$ is the most reliable value. Therefore, we will consider here only this value.

INFLUENCE OF DRIFT EFFECTS ON THE TIME-LAG IN ODD AND EVEN CYCLES

We suppose that observed long-term cosmic ray modulation is caused by two processes: convection-diffusion mechanism (e.g. Parker, 1958; Dorman, 1959; Dorman, 1965) what does not depend from the sign of solar magnetic field, and drift mechanism (e.g. Jokipii and Davila, 1981; Jokipii and Thomas, 1981; Lee and Fisk, 1981, Kota and Jokipii, 1999, Burger and Potgieter, 1999; Ferreira et al., 1999) what gave opposite effects with changing sign of solar magnetic field. For convection-diffusion mechanism we will use model described in details in Dorman et al. (2001) and shortly above. We will consider three approaches of drift effects. Two of them are shown schematically in Fig. 1.

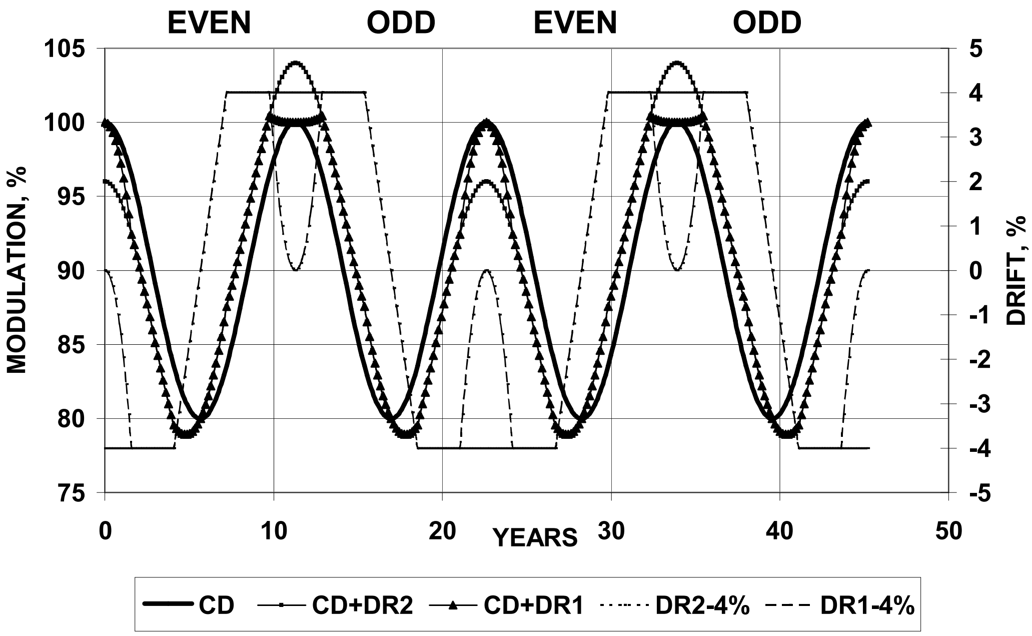

Fig.1. The 1-st and 2-nd approaches of the different influence of drift effects on the observed time-lag in odd and even cycles: **CD** is convection-diffusion modulation with total change 20% (as about in Climax NM data), **CD+DR2** and **CD+DR1** are "observed", included convection-diffusion and drift modulations; **DR2-4%** and **DR1-4%** are supposed drift effects with amplitude $A_{dr} = 4\%$ (right ordinate).

It can be seen from Fig. 1 that in both approaches drift effects in even cycles lead to decrease time-lag and in odd cycles to increase time lag in comparison with expected in convection-diffusion modulation. The 1-st approach leads also to increase the width of CR maximum from even to odd cycle but not changed the value of CR maximums. The 2-nd approach not changed the width of CR maximums but leads to relative increase of CR maximum from even to odd cycle and decrease from odd to even cycle (see Fig. 1).

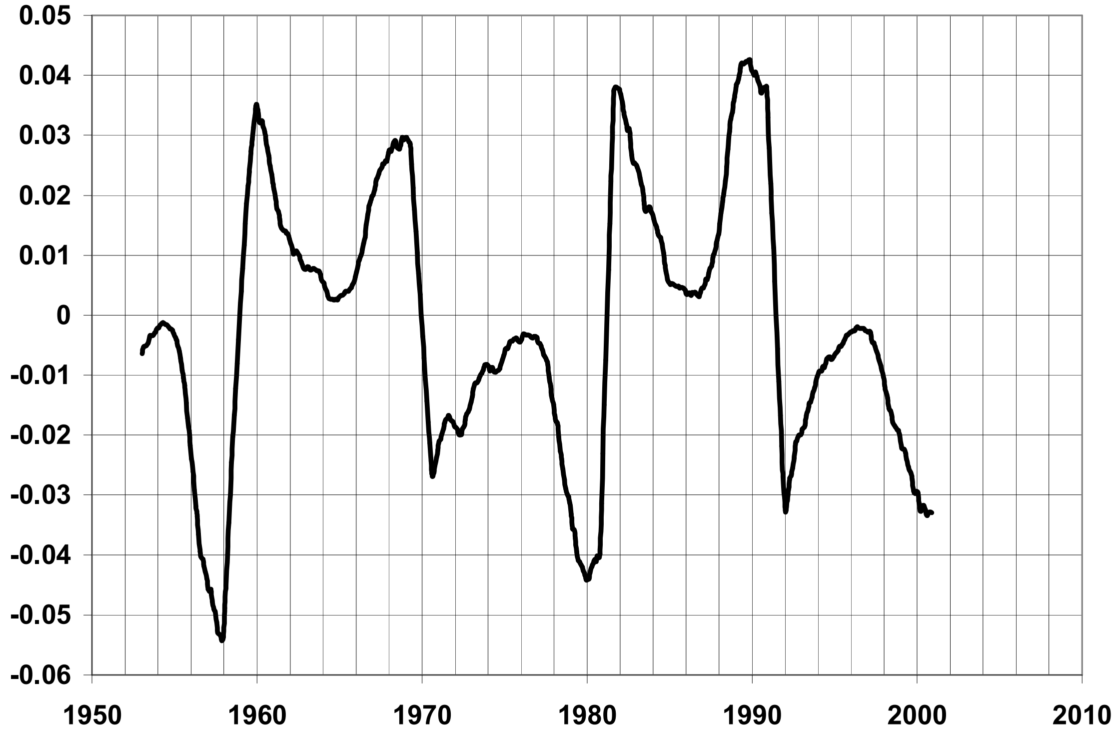

Fig. 2. Drift effect according to 3-rd approach for A_{dr}=2% (at W=75).

This result contradicts supposition that CR intensity out of the modulation region is constant in time. But we cannot exclude this model from consideration and discussion: it can be some additional modulation out of the Heliosphere in periods of solar magnetic field A>0, and no modulation in periods A<0 (e.g. only at A<0 can be good direct connection of IMF with interstellar magnetic field, see Ahluwalia, 1997). In the 3-rd approach we suppose that the drift effect is proportional to the value of tilt-angle T (see references above on drift effects in galactic CR). For us available were data on tilt-angle only for the period May 1976- September 1993. On the basis of these data it was found that there are very good connection between T and W: for yearly data T=0.363W+13.06° with correlation coefficient 0.973, for monthly data T=0.316W+16.42° with correlation coefficient 0.882, and for 11 months smoothed data T=0.349W+13.52° with correlation coefficient 0.955. We used 11 months smoothed data of W and the amplitude A_{dr} of drift effects normalized to W=75 (average value of W for the period January 1953-November 2000). Information on reversal periods we used as following (according to site in Internet): August 1949±9 months, December 1958±12 months, December 1969±8 months, March 1981±5 months, and June 1991±7 months. The drift effect according to the 3-rd approach for the period January 1953-November 2000 is shown in Fig. 2 for A_{dr}=2% (at W=75). We calculated correlation coefficients between expected integrals F determined by Eq. 2 with observed **LNCL11M** and **LNHU/HAL11M** as well as for these integrals corrected on drift effects according to 1-st, 2-nd and 3-rd models with different amplitude of drift effect from 0.15% up to 4%. As example, in Table 1 are shown results of determination of $X_{o\max}$ and correlation coefficients for the 3-rd model for solar cycles 19, 20, 21, and 22.

Table 1. Values of $X_{o\max}$ (in Av. Months, Bold) and Correlation Coefficients for Observed Data (0%) and Corrected on Drift Effects with Different Amplitudes According to the 3-rd Model.

CLIMAX NEUTRON MONITOR, LN(CL11M)								
CYCLE	0%	0.5%	1%	1.5%	2%	2.5%	3%	4%
19	**21**,0.989	**18.5**,0.987	**16.5**,0.982	**14.5**,0.976	**12.5**,0.968	**11**,0.958	**9**,0.948	**6**,0.924
20	**6.5**,0.904	**8**,0.911	**9.5**,0.912	**12**,0.908	**16.5**,0.901	**20**,0.895	**27**,0.893	**34**,0.895
21	**31**,0.979	**27**,0.976	**23**,0.972	**20**,0.967	**16.5**,0.963	**15**,0.946	**12**,0.928	**9**,0.887
22	**8**,0.955	**10**,0.960	**11**,0.964	**12**,0.965	**14**,0.964	**16.5**,0.961	**18**,0.955	**24**,0.941

HUANCAYO/HALEAKALA NEUTRON MONITOR, LN(HU/HAL11M)							
CYCLE	0%	0.15%	0.25%	0.35%	0.5%	0.75%	1.0%
19	**20**,0.971	**18**,0.969	**16.5**,0.966	**14**,0.963	**12**,0.958	**9**,0.945	**6**,0.929
20	**10.5**,0.881	**15**,0.883	**18**,0.880	**25**,0.916	**31**,0.887	**39**,0.899	**46**,0.912
21	**34**,0.929	**23**,0.923	**18**,0.923	**15**,0.922	**12**,0.915	**9**,0.884	**7**,0.833
22	**9**,0.978	**12**,0.978	**11**,0.978	**12**,0.976	**14**,0.971	**16.5**,0.955	**22**,0.934

ESTIMATION OF ROLE OF DRIFT EFFECTS IN LONG-TERM MODULATION

It can be seen from Table 1 that for odd cycles increasing of drift effects leads to decrease of $X_{o\max}$ but for even cycles situation is inverse: with increasing of drift effects $X_{o\max}$ increases. In Fig. 3 and Fig. 4 are shown dependences $X_{o\max}(A_{dr})$ for Climax NM (sensitive to primary particles with rigidity 10-15 GV) and for Huancayo/Haleakala NM (sensitive to 35-40 GV).

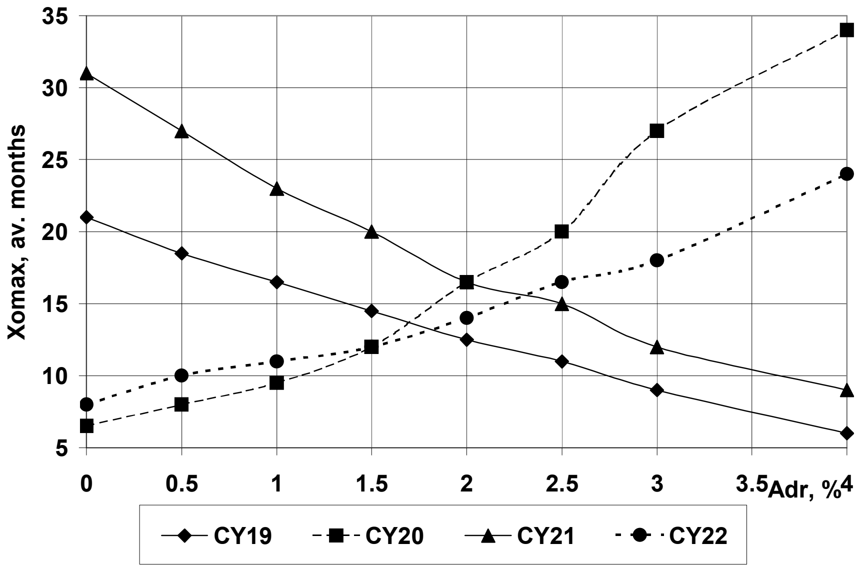

Fig. 3. Dependences $X_{o\max}(A_{dr})$ for Climax NM in the frame of the 3-rd drift model.

From Fig. 3 can be seen that for Climax NM the region of crossings of dependences $X_{o\max}(A_{dr})$ for odd cycles with dependences for even cycles is very small: $13 \le X_{o\max} \le 16.5,\ 1.7\% \le A_{dr} \le 2.3\%$. For Huancayo/Haleakala NM this region is also very small: $13 \le X_{o\max} \le 18,\ 0.23\% \le A_{dr} \le 0.43\%$ (see Fig. 4). Let us note that for 1-st and 2-nd approaches the regions of crossings are much bigger than for 3-rd drift approach. That we came to conclusion that more reliable is 3-rd drift approach and amplitude of drift effects is about 2% for Climax NM and about 0.25-0.3% for Huancayo/Haleakala NM.

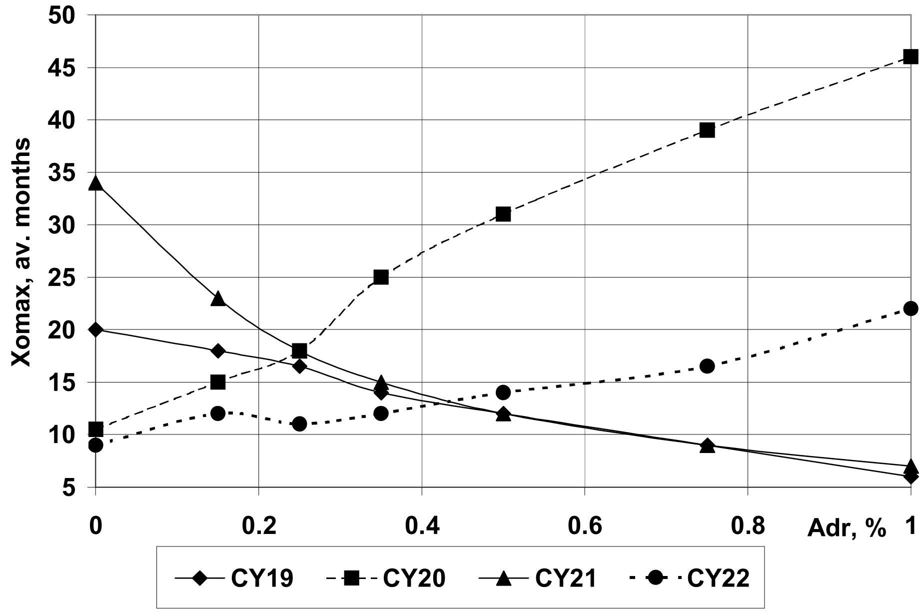

Fig. 4. Dependences $X_{o\max}(A_{dr})$ for Huancayo/Haleakala NM

DETERMINATION AND PREDICTION OF CR INTENSITY ON THE BASIS OF SA DATA

In Fig. 5 is shown comparison of observed long-term CR variation and corrected on drift effects according to 3-rd approach with amplitude 2% (at W=75) for Climax NM (the long-term variation of drift effects for this case was shown in Fig. 2). That we came to conclusion that for primary CR with rigidity 10-15 GV the relative role of drift effects is about 20% in periods of high solar activity and negligible near solar minimums. For CR with rigidity 35-40 GV the relative role of drift effects is about 3 times smaller.

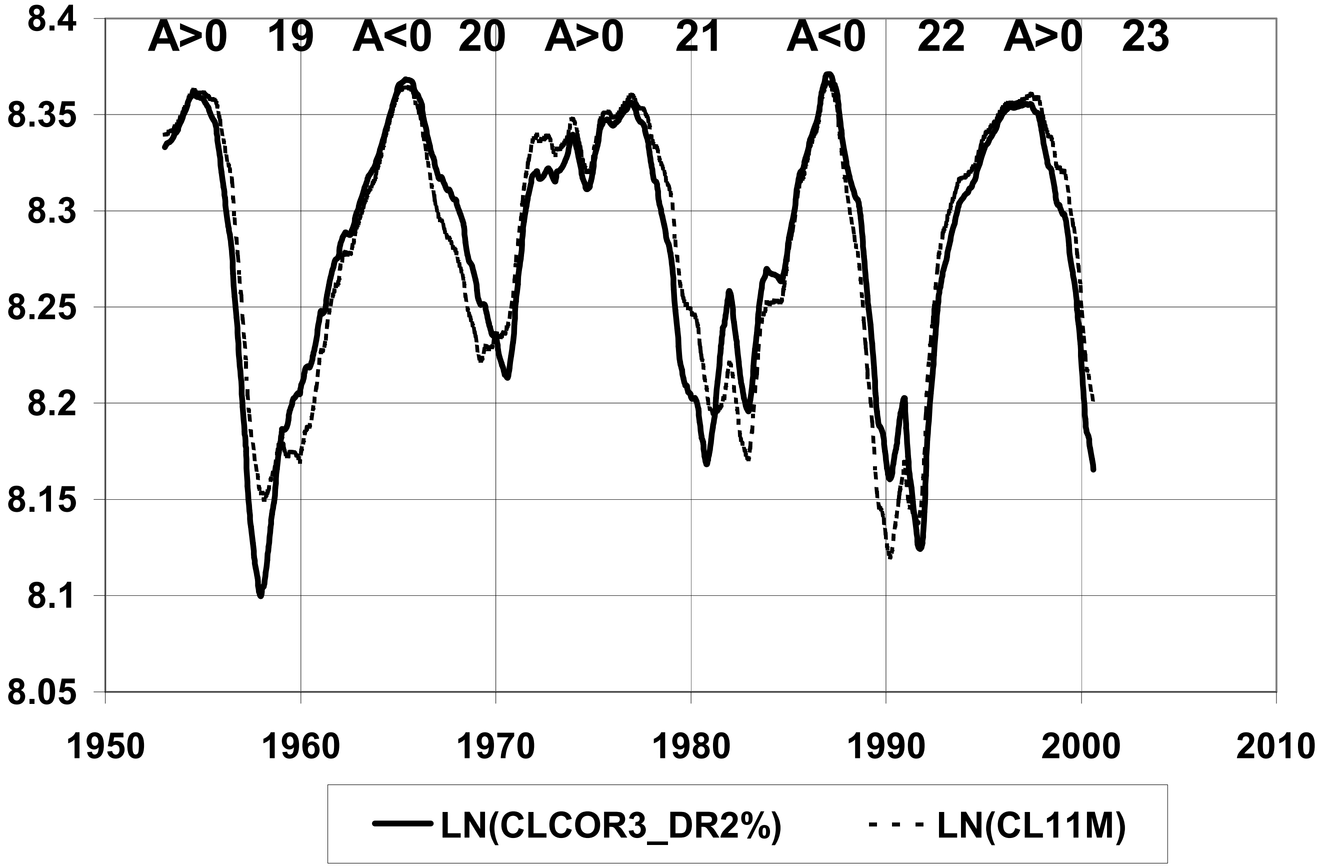

Fig. 5. Climax NM data: comparison of observed LN(CL11M) with expected from convection-diffusion modulation, corrected on drift effects according to the 3-rd approach with A_{dr}=2% (at W=75).

From Fig. 5 can be seen that on the basis of SA data by taking into account convection-diffusion and drift modulations can be made very good determination of CR intensity change in the past and prediction for the future with correlation coefficient between observed and predicted intensities about 0.97.

ON THE CONNECTION OF CR SOLAR CYCLE VARIATION WITH VARIATION OF PLANETARY CLOUD COVERAGE

A very important result for an understanding of the mechanism of the influence of solar activity cycle on the Earth's climate has recently been obtained: it was found that the Earth's cloud coverage (observed by satellites) is strongly correlated with CR intensity (Swensmark and Friis-Christensen, 1997; Swensmark, 1998, 2000; Marsh and Swensmark, 2000a,b). Clouds influence irradiative properties of the atmosphere by both cooling through reflection of incoming short wave solar radiation, and heating through trapping of outgoing long wave radiation. The total result depends mostly on the height of the clouds. According to Hartmann (1993), high optically thin clouds tend to heat while low optically thick clouds tend to cool (see Table 2).

Table 2. Global annual mean forcing owed to various types of clouds, from the Earth Radiation Budget Experiment (ERBE), according to Hartmann (1993). The positive forcing increases the net radiation budget of the Earth and leads to a warming; negative forcing decreases the net radiation and causes a cooling.

Parameter		High clouds		Middle clouds		Low clouds	Total
		Thin	Thick	Thin	Thick	All	
Global fraction	(%)	10.1	8.6	10.7	7.3	26.6	63.3
Forcing (relative to clear sky):							
Albedo (SW radiation)	(Wm^{-2})	-4.1	-15.6	-3.7	-9.9	-20.2	-53.5
Outgoing LW radiation	(Wm^{-2})	6.5	8.6	4.8	2.4	3.5	25.8
Net forcing	(Wm^{-2})	2.4	-7.0	1.1	-7.5	-16.7	-27.7

From Table 2 it can be seen that low clouds give a cooling of about $17\ W.m^{-2}$, so they play an important role in the Earth's radiation budget (Ohring and Clapp, 1980; Ramanathan et al., 1989; Ardanuy et al., 1991). So even small changes in the lower cloud coverage can give important changes in the radiation budget and considerably influence the Earth's climate (let us remember that the solar irradiance changes during solar cycle by only about $0.3\ W.m^{-2}$). Fig. 6 shows the composite of satellite observations of the Earth's total cloud coverage in comparison with CR intensity (according to Climax NM) and solar activity data (intensity of 10.7 cm solar radio flux).

From Fig. 6 it can be seen that the correlation of global cloud coverage with CR intensity is much better than with solar activity. Marsh and Swensmark

(2000a) came to conclusion that CR intensity connects very well with low global cloud coverage, but not with high and middle clouds.

It is important to note that low clouds lead, as rule, to the cooling of the atmosphere. It means that with increasing CR intensity and cloud coverage (see Fig. 6), the surface temperature is expected to decrease. It is in good agreement with the situation for the last 1000 years, and with direct measurements of the surface temperature for the last four solar cycles.

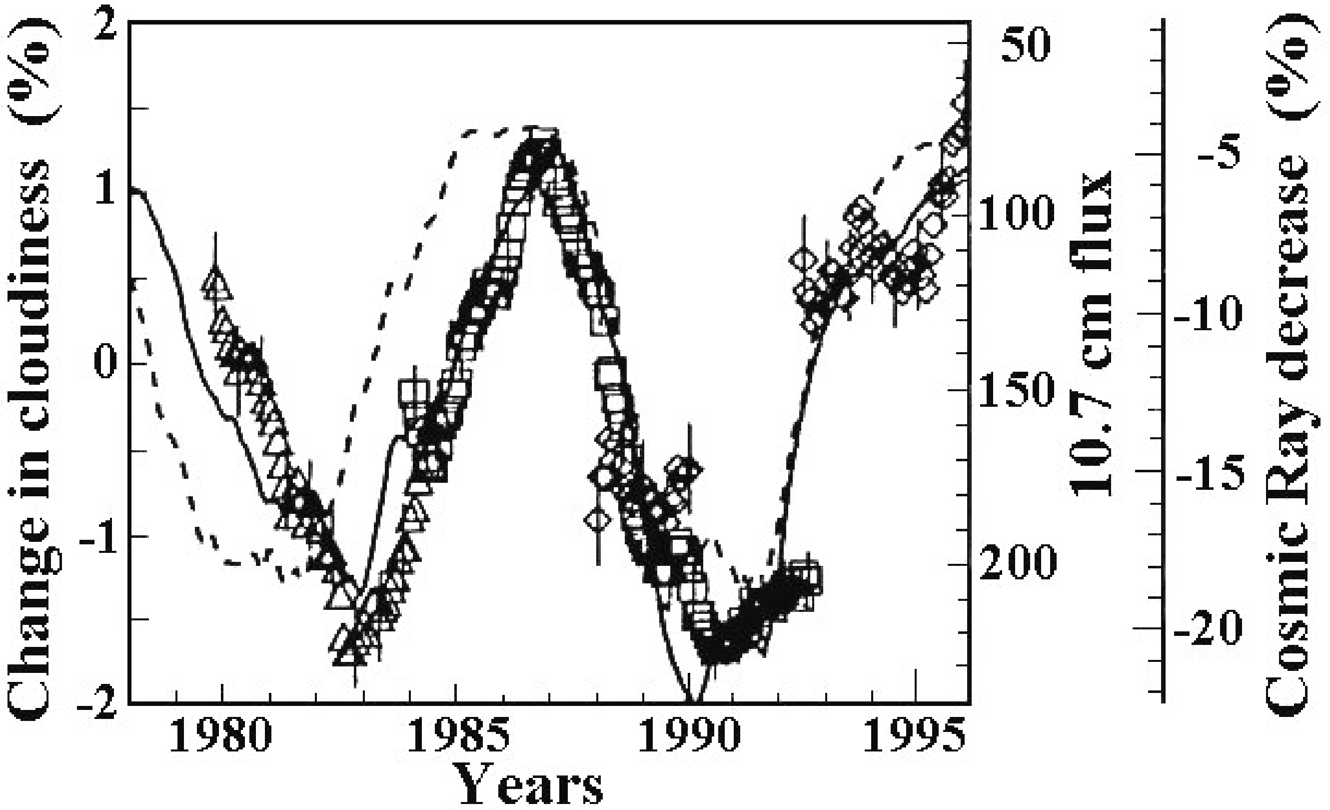

Fig. 6. Changes in the Earth's cloud coverage: triangles - from satellite Nimbus 7, CMATRIX project, (Stowe et al., 1988); squares - from the International Satellite Cloud Climatology Project, ISCCP, (Rossow and Shiffer, 1991); diamonds – from the Defense Meteorological Satellite Program, DMSP (Weng and Grody, 1994, Ferraro et al., 1996). Solid curve – CR intensity variation according to Climax NM, normalized to May 1965. Broken curve – solar radio flux at 10.7 cm (in units 10^{-22} W.m^{-2}.Hz^{-1}). All data are smoothed using 12 months running mean. According to Swensmark (2000).

EXPECTED PART OF CLIMATE CHANGE CAUSED BY CR INTENSITY VARIATION

From Fig. 6 can be seen that about 20% of CR intensity increase in Climax NM for solar cycle corresponds to about 4% increase of global cloud covering, what according to Table 2 give sufficient change in radiation balance influenced on climate change. From other side, from Fig. 5 can be seen that the accounting of convection-diffusion and drift modulations through sunspot numbers and data on general solar magnetic field reversals give a possibility to predict with a good accuracy expected CR intensity variation. For example, for the period of 5-6 years (half solar cycle) the CR intensity expected to be increase on about 20-25% (in good agreement with observations), so it is expected some global climate cooling and increasing of precipitation corresponded to increase of the global cloud covering on about 5-6%. Of course, this cooling can be compensated with the process of global warming caused by increasing of green gases, but in any case it is necessary to take into account all processes influenced on global climate change.

CONCLUSIONS

1. On the basis of SA data (monthly sunspot numbers) by taking into account convection-diffusion and drift modulations can be made very good determination of CR intensity change in the past and prediction for the future with correlation coefficient between observed and predicted intensities about 0.97 (see Fig. 5).

2. For the period of 5-6 years (half solar cycle) the CR intensity expected to be increase on about 20-25% (in good agreement with observations), so it is expected some global climate cooling and increasing of precipitation corresponded to increase of the global cloud covering on about 5-6% during solar cycle.

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