PREDICTION OF EXPECTED GLOBAL CLIMATE CHANGE BY FORECASTING OF GALACTIC COSMIC RAY INTENSITY TIME VARIATION IN NEAR FUTURE BASED ON SOLAR MAGNETIC FIELD DATA

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ABSTRACT

A method of prediction of expected part of global climate change caused by cosmic ray (CR) by forecasting of galactic cosmic ray intensity time variation in near future based on solar activity data prediction and determined parameters of convection-diffusion and drift mechanisms is presented. This gave possibility to made prediction of expected part of global climate change, caused by long-term cosmic ray intensity variation. In this paper we use the model of cosmic ray modulation in the heliosphere, which considers a relation between long-term cosmic ray variations with parameters of the solar magnetic field. The later now can be predicted with good accuracy. By using this prediction, the expected cosmic ray variations in the near Earth space also can be estimated with a good accuracy. It is shown that there are two possibilities: 1) to predict cosmic ray intensity for 1-6 months by using a delay of long-term cosmic ray variations relatively to effects of the solar activity and 2) to predict cosmic ray intensity for the next solar cycle. For the second case the prediction of the global solar magnetic field characteristics is crucial. For both cases reliable long-term cosmic ray and solar activity data as well as solar magnetic field are necessary. For solar magnetic field we used results of two magnetographs (from Stanford and Kitt Peak Observatories). The obtained by described method prediction on long-term cosmic ray intensity variation we used for estimation of expected part of global climate change caused by cosmic rays.

SOLAR-HELIOSPHERIC PARAMETERS FOR MULTI-PARAMETRIC MODEL OF COSMIC RAY MODULATION

Long-term variations of galactic cosmic rays were compared with the behavior of various solar-activity indices and heliospheric parameters many times. A close relation of this parameter to the behavior of cosmic rays in the past decades was substantiated theoretically by (see e.g. *Jokipii and Thomas*, 1981; *Kota and Jokipii,* 1983) and proved experimentally by (see e.g. *Simpson,* 1963, *Dorman and Dorman,* 1967, *Smith and Thomas,* 1986; *Webber and Lockwood*, 1988; *Smith* 1990; *Belov et al.,* 1995, 1999a,b, 2003; *Mavromichalaki et al., 1995, 1998, Bazilevskaya and Svirzhevskaya,* 1998, *McCracken and McDonald, 2001, Usoskin et al., 2001*).

In this paper a model of long-term modulation of cosmic rays has been constructed using a set of parameters of the global solar magnetic field. A reliable model of CR modulation should incorporate at least several solar-heliospheric parameters. The choice of the parameters is explained in detail by Belov et al. (2002). We obtain the best results by using the heliospheric current sheet tilt η, the intensity of the magnetic field radial component B_r averaged over the entire source surface - B_{SS} of the source surface magnetic field (SSMF), the polarity p (qA>0, qA<0) of the general solar magnetic field.

Expected CR variations were calculated basing on characteristics of the solar wind source surface field determined from observations on the Stanford and Kitt Peak Observatories. An existing difference between characteristics and observational results of the two magnetographs didn't allow choosing the best one among them for prediction purpose. These magnetographs register fields of different spatial scale. Mean intensity B_{ss} of the source surface magnetic field and HCS tilt η are successfully complement to each other. By the polarity of the large-scale solar magnetic field *p*, we mean the polarity of its dipole component at the north pole of the Sun.

We suppose that CR intensity long-term variation may be determined as following (taking into account direct action of polarity effect on CR as well as actions with different times-lag for other parameters):

$$\delta = a + \frac{b_\eta}{\tau_{u\eta}+1}\sum_{\tau=0}^{\tau_{u\eta}}(1+b_{\eta p}p_f(t-\tau))\eta(t-\tau) + \frac{b_B}{\tau_{uB}+1}\sum_{\tau=0}^{\tau_{uB}} B_{ss}(t-\tau) + \frac{b_p}{\tau_{up}+1}\sum_{\tau=0}^{\tau_{up}} p_s(t-\tau), \tag{1}$$

where $p_s(t-\tau)$ and $p_f(t-\tau)$ are the periods of inversion of the solar magnetic field were determined on the source surface from optical observations and magnetic observations. We have applied this model to describe CR variations (10 GV rigidity) during a rather long period, when reliable information on solar magnetic field is available. The calculations were performed for parameters: a = 10.9±0.6, b_η= – 0.205±0.001 %/°, $b_{\eta p}$ = – 0.65±0.08, b_B= – 1.42±0.09 %/nT, b_p= – 3.2±0.2 %. Were determined also $\tau_{u\eta}$= 7 months, τ_{uB} = 10 months, τ_{up}= 3 months. The obtained correlation coefficient is 0.94. Results are shown in Fig. 1.

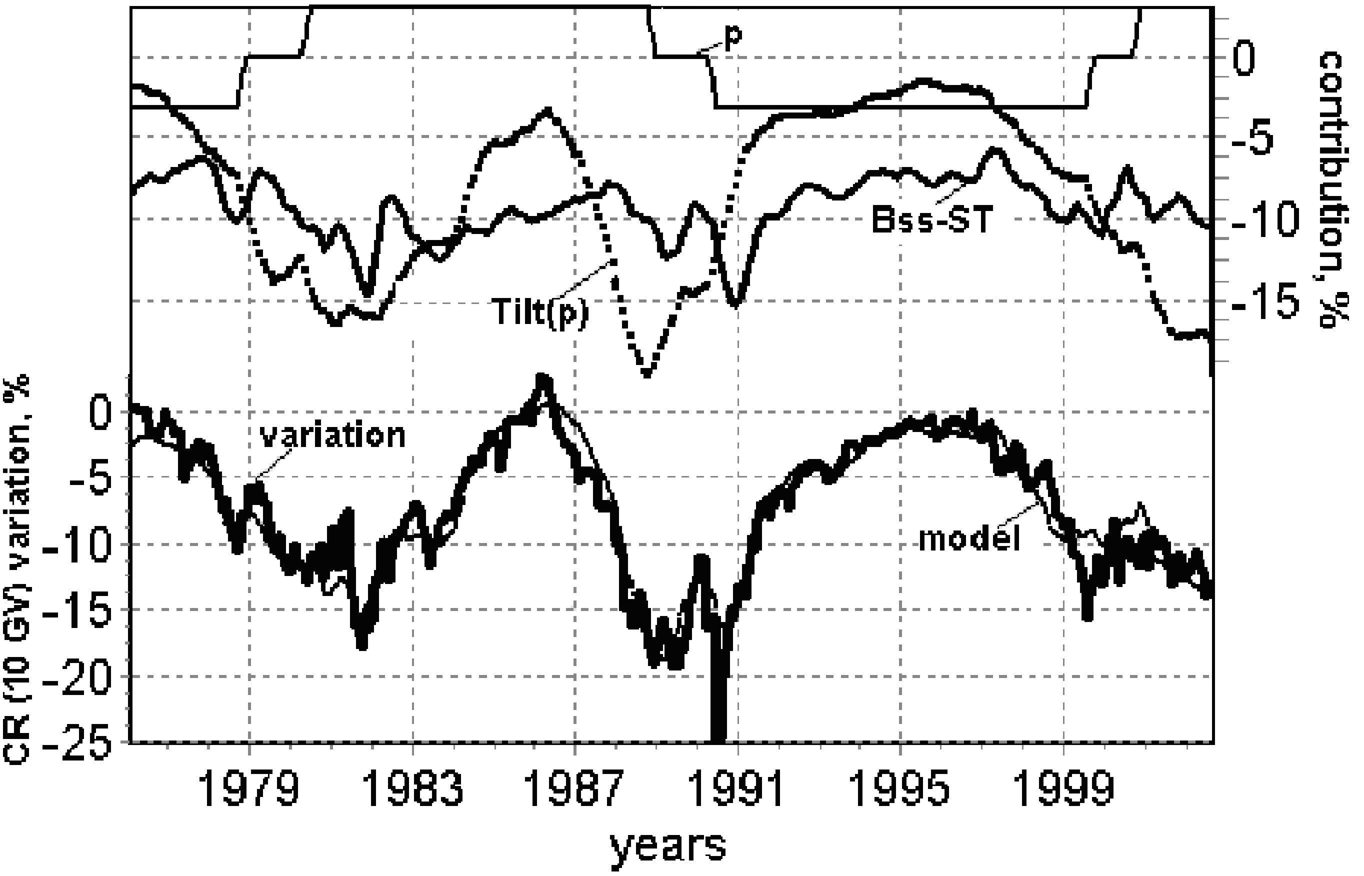

Fig. 1. Observed and simulated CR variations for 1976-2003 years (lower curves). Contributions to simulated CR variation from of mean source surface magnetic field intensity B_{SS}, the heliospheric current sheet tilt η, heliomagnetic polarity changes p are shown as upper curves.

The analysis of results shown in Fig. 2, leads to following conclusions. Two characteristics of the source surface magnetic field – the structural (HCS tilt angle) and quantitative (mean field B_{SS}) ones – well supplement each other in describing CR variations. The changing of HCS tilt angle controls long-term variations (11-year cycles and their basic features), while B_{SS} is responsible mainly for shorter period variations. Correspondingly, the HCS tilt angle plays the leading part in the periods of low and moderate solar activity, yielding to B_{SS} in the vicinity of the cycle maxima. Results of modeling have revealed differences of CR modulation during periods with different direction of the solar global magnetic field that is described by influence of cyclic changes of local and large scale fields of the Sun registered by the observatories mentioned above on long-term CR variations. Both the Stanford and Kitt Peak observations could be used for CR forecasting

Calculations performed by Obridko and Shelting (2001) show that the magnetic field at the source surface changes its sign much earlier than in the photosphere. The time boundaries in the photosphere and at the source surface were determined using both the line-of-sight observations of the polar field and the field calculated in radial direction. The behavior of CR correlated with the polarity changes at the source surface much better than in the photosphere. The CR variation is most closely related to the sign of magnetic fields obtained from H_α observations for the solar wind source surface- p_{HBss}. The obtained boundaries are as follows: 09.1979–03.1981, 10.1989–03.1991, and 04.1999-06.2001.

THE COSMIC RAY FORECASTING MODEL

As the source of the CR variation data, we are using the Moscow neutron monitor. Since 1997, these data have been available through Internet in real time. The delay of CR variations reflects complicated individual features of the activity cycles and is related to the solar magnetic cycle. We suggest using this particularity of CR variations to predict the CR flux in the near-Earth space. In Fig. 2 are shown results of CR intensity forecasting bases on the method described in the previous Section for several months ahead (up to 12 months). The results (the correlation coefficient ρ and standard r.m.s. deviation σ as a function of time) were obtained for three periods: 1977-2003 – all time with 3 reversals of the global solar magnetic field; 1981–1989 – negative polarity of the global solar magnetic field (qA<0); 1991–2000 – positive polarity of the global solar magnetic field period (qA>0).

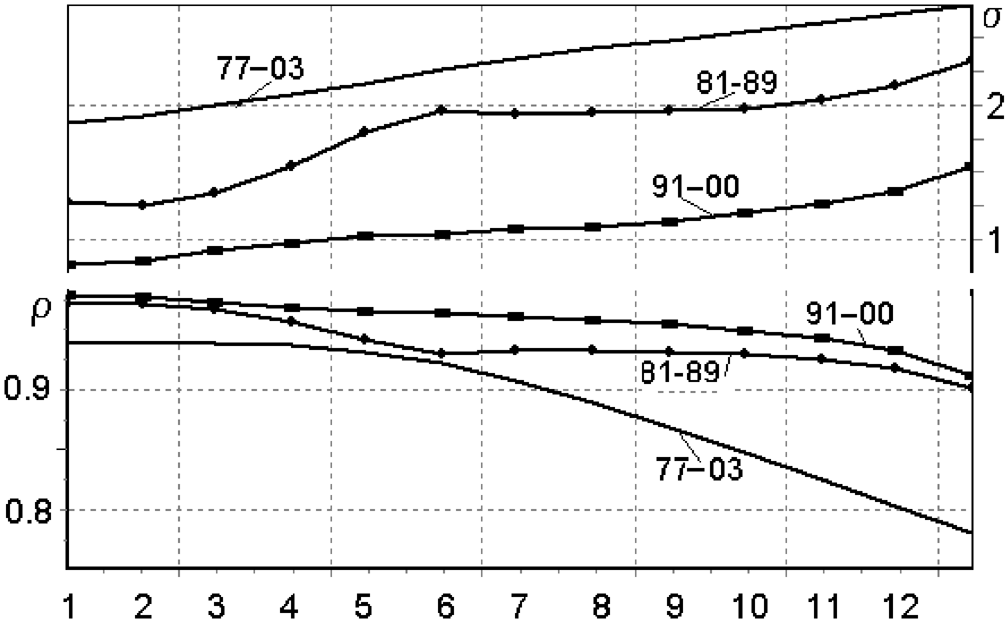

Fig. 2. The correlation coefficient ρ (three low curves, the left ordinate) and the standard r.m.s. deviation σ (upper three curves, the right ordinate) between the observed CR variations (Moscow neutron monitor) and the predicted CR variations with **η**, **B_{ss}** and **p** as modulating parameters for different time of the forecast (in months).

From Fig. 3 can be seen that the analysis of data for 1977–2003 has revealed a good correlation ($\rho = 0.82 \div 0.94$) between the simulated CR variations with η, B_{ss} and p as modulating parameters of the multi-parameter model and galactic CR intensity behavior during long period, spanning several cycles of solar activity. The model gives the good prediction for 1-5 months in advance. Beginning from ~ 6 months forecasting time the quality of forecasting is not so good. Fig. 2 shows also that the using data for the period with one polarity ($qA < 0$ or $qA > 0$) gives much better results (higher correlation coefficient), and for longer number of months ahead (up to about 10 months).

FORECAST OF COSMIC RAY INTENSITY MODULATION FOR 1 AND 12 MONTHS

In Fig. 3 are shown results of CR intensity forecasting for 1 month ahead (the upper panel) in comparison with observed CR intensity variation. In the bottom panel are shown the same but for CR intensity forecasting for 12 months ahead.

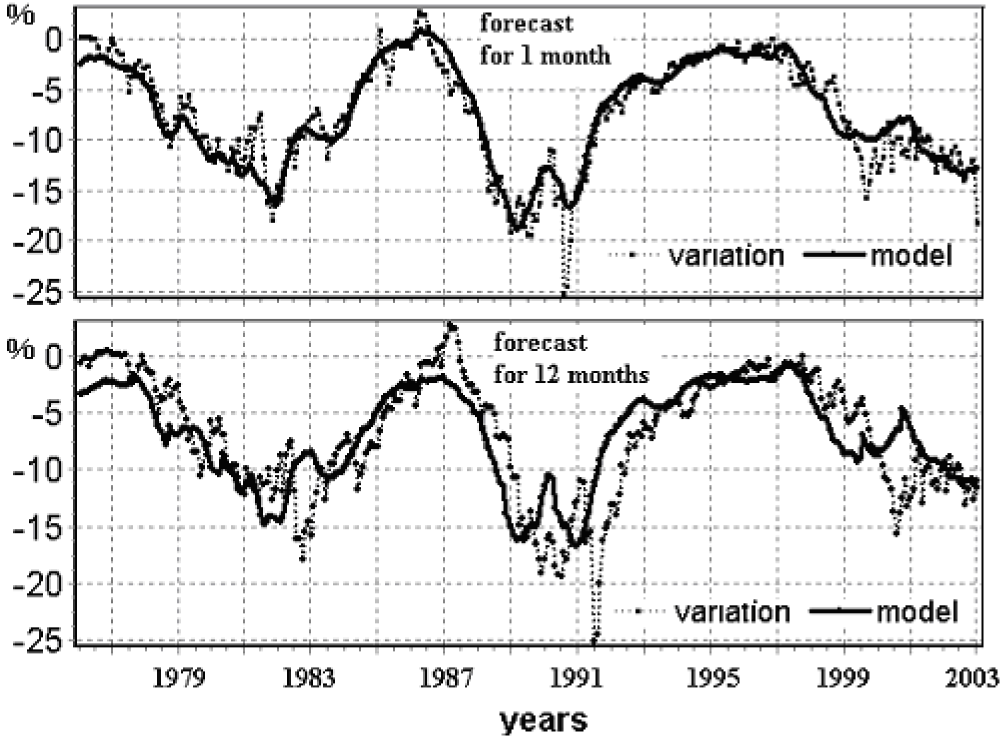

Fig. 3. Observed on Moscow neutron monitor and predicted for 1 and 12 months ahead - the long-term CR variations.

We must admit that the model applied herein meets difficulties when forecasting for half a year or more. The longer the term of the forecast, the larger the fraction of the inner heliosphere excluded from consideration. More promising seems the approach that involves prediction of the main parameters of the solar magnetic field. Then, the forecast of CR variations would be based both on the measured solar indices and on their expected future behavior.

THE PREDICTION OF COSMIC RAY INTENSITY VARIATION FOR THE NEXT SOLAR CYCLE

Predictions of global solar magnetic field characteristics are crucial for predictions long-term CR variations. CR variations for the next solar cycle are predicted by solar magnetic field data of two magnetographs (Stanford and Kitt Peak) using the statistical method. According to our predictions of CR behavior till 2013 the next CR maximum should be between the end of 2006 and the beginning of 2007 by observations in the Kitt Peak observatory, but it should be in the middle of 2006 by data of the Stanford observatory (see Fig. 4).

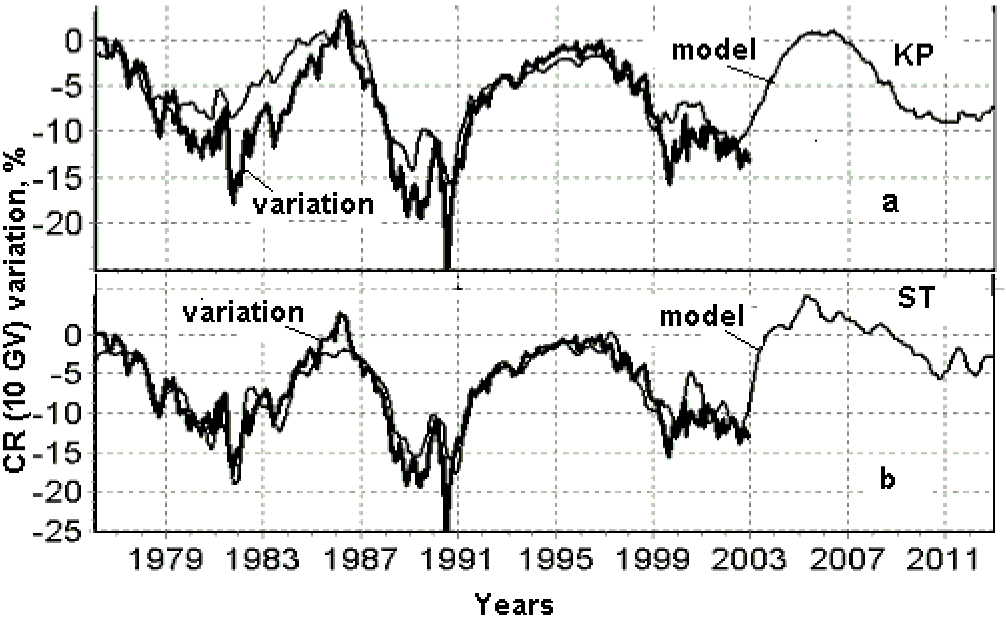

Fig. 4. The forecast of the CR behavior based on the predicted values of the global characteristics of the solar magnetic field, thick line – data of CR intensity observations (Moscow NM), thin line – the predicted CR variation up to 2013 based on data of Kitt Peak Observatory (upper panel) and based on data of Stanford Observatory (bottom panel).

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 (*Svensmark and Friis-Christensen*, 1997; Svensmark, 1998, 2000; *Marsh and Svensmark,* 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.

It was shown that low clouds give a cooling of about $17\ \mathrm{W.m^{-2}}$, 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 $0.3\ \mathrm{W.m^{-2}}$).

Fig. 5 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.5 it can be seen that the correlation of global cloud coverage with CR intensity is much better than with solar activity. Marsh and Svensmark (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. 5), 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.

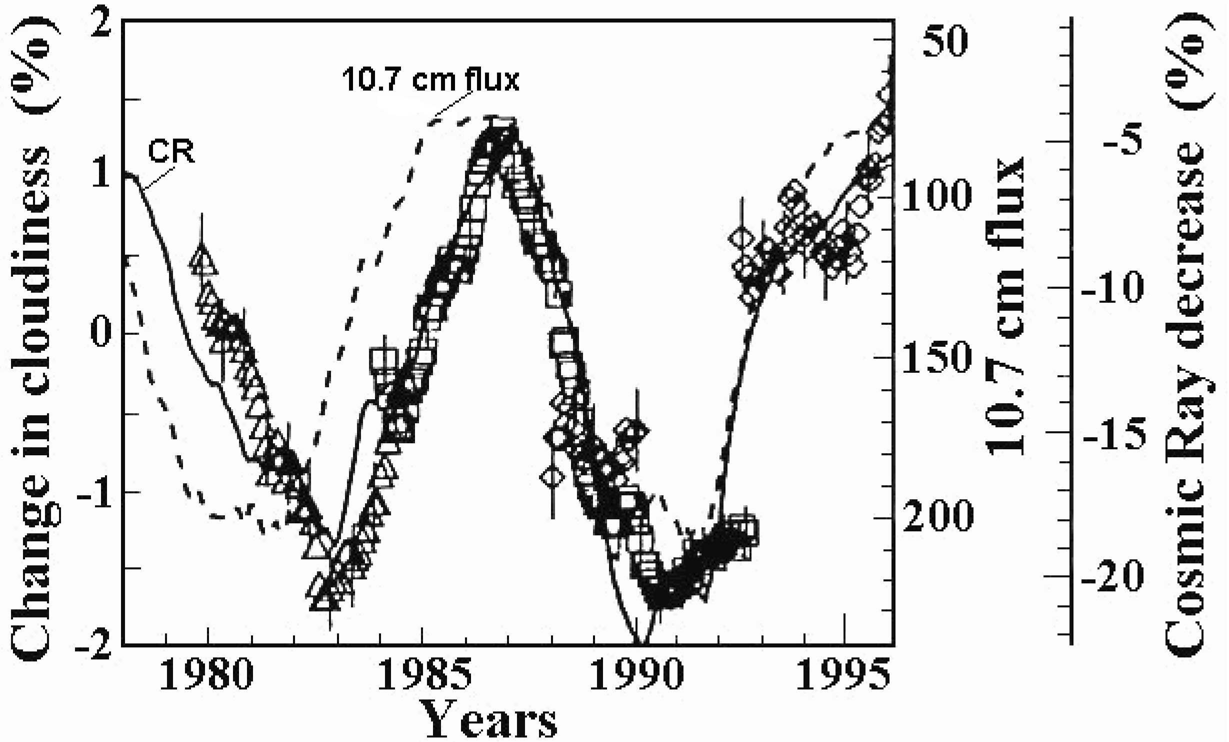

Fig. 5. Changes in the Earth's cloud coverage: triangles - from satellite Nimbus 7, CMATRIX project, (Stowe et al., 1988); squares - from the International Satellite Cloud Climatology Project, ISCCP, (Rossow and Shiffer, 1991); diamonds – from the Defense Meteorological Satellite Program, DMSP (Weng 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 $10^{-22}\,\mathrm{W.m^{-2}.Hz^{-1}}$). All data are smoothed using 12 months running mean. According to Svensmark (2000).

EXPECTED PART OF CLIMATE CHANGE CAUSED BY CR INTENSITY VARIATION

From Fig. 5 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 can give sufficient change in radiation balance influenced on climate change. From other side, from Fig.4 can be seen that the accounting of data on general solar magnetic field give a possibility to predict with a good accuracy expected CR intensity variation. For example, for the period of few years (up to about 2006) the CR intensity expected to be increase on about 10%, so it is expected some global climate cooling and increasing of precipitation corresponded to increase of the global cloud covering on about 2-2.5%. 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

Our conclusions are as follows:

1. On the basis of solar magnetic field data by taking into account tilt angle data and data on reversals periods, can be made very good determination of CR intensity change and made prediction for the future with correlation coefficient between observed and predicted intensities about 0.97 for 1 month prediction, 0.91 for 6 months prediction, and 0.80 for 12 months prediction (see Fig. 2 and 3).

2. For the period of about 2 years ahead (up to 2006) the CR intensity expected to be increase on about 10%, so it is expected some global climate cooling and increasing of precipitation corresponded to increase of the global cloud covering on about 2.0-2.5% during these two years.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

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