"Physics of Auroral Phenomena", Proc. XXIV Annual Seminar, Apatity, pp. 85-88, 2001

Polar Geophysical Institute

THE RELATION BETWEEN SOLAR ACTIVITY AND SOLAR COSMIC RAY FLUENCE AT THE EARTH'S ORBIT

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Abstract. The study of the relation between the solar activity and solar cosmic ray (SCR) proton annual fluences at the Earth's orbit is very helpful in the analysis of auroral and magnetospheric phenomena and in solving some applied problems of solar-earth relations.

The results of the regression analysis of sunspots and solar cosmic ray proton fluxes measured during solar cycles 19-22 are presented. The poor correlation is noted between the Wolf number and SCR proton annual fluences. A much better agreement is found to exist between the cumulative annual proton fluences and corresponding cumulative annual sunspot numbers.

The method of probabilistic estimation of solar proton fluences on the predicted sunspot number is suggested.

In this paper we try to find a relation between annual proton fluences and sunspot Wolf numbers and to create a model based on statistical analysis of SCR fluences.

Recently we have performed an careful study of the solar cosmic rays (SCR) particle annual fluences, i.e. fluxes integrated over the one year period. It was revealed that the distribution function of the decimal logarithm of this random variable is normal in contrast to the other solar activity indexes [1,2]. So the confident prediction of the SCR particle annual fluences can be developed on the basis of its statistical analysis.

Usually predictions of the SCR fluences are based on the correlation between SCR particle fluences PF and sunspot Wolf numbers R_z. The early papers presupposed the existence of the simple tight (and usually linear) relation between these sets. The regression analysis of the corresponding data obtained during 19-22 solar cycles disproved this idea [1]. In the indicated period the correlation coefficient was found to be 0.35. Fig. 1 illustrates this fact.

A little better correlation was found between the decimal logarithms of annual fluences of protons with an energy equal or higher than 30 MeV ($\lg PF$) and the Wolf numbers R_z [2]. This correlation was considerable only in solar cycle 22 (Table 1).

Below a few cumulative parameters which characterize the proton fluences and solar activity are introduced. Logarithms of cumulative annual proton fluences

$$\lg(PF)_{cum} = \lg \sum_{i=1,n} PF \quad , \tag{1}$$

cumulative logarithms of the annual proton fluences

$$(\lg PF)_{cum} = \sum_{i=1,n} \lg PF \quad , \tag{2}$$

cumulative Wolf numbers

$$Rz_{cum} = \sum_{i=1,n} Rz \quad , \tag{3}$$

where n is the number of year (counted after the beginning of the cycle) for which the cumulative values are calculated. The maximal value of n is the duration of solar activity cycle (in years). PF is the annual value of proton fluence (>30 MeV) and Rz is the annual Wolf number.

The analysis of the cumulative data has revealed a very high correlation. In each cycle the accumulation was held from the year of the beginning of the cycle. In Table 1 one can find the correlation coefficients between decimal logarithms of cumulative annual proton (>30 MeV) fluences $\lg(PF_{cum})$ and cumulative decimal logarithms of the annual proton (>30 MeV) fluences $(\lg PF)_{cum}$ on the one hand and cumulative Wolf numbers $(R_z)_{cum}$ on the other.

Table 1. Correlation coefficients between R_z and $\lg PF$, $(R_z)_{cum}$ and $(\lg PF)_{cum}$, $(R_z)_{cum}$ and $\lg(PF_{cum})$ in solar cycles 19-22.

Solar cycle number Correlation coefficient between variables	19	20	21	22
R_z and $\lg PF$	0.53	0.73	0.10	0.80
$(R_z)_{cum}$ and $(\lg PF)_{cum}$	0.98	0.98	0.98	0.99
$(R_z)_{cum}$ and $\lg(PF_{cum})$	0.99	0.93	0.86	0.92

It was also found that during the active phase of the solar cycle the relation between $(\lg PF)_{cum}$ and $(R_z)_{cum}$ is well approximated by the linear function [3]. Fig. 2-5 represent this approximation for 19-22 solar cycles. This linear approximation during the period of a solar cycle active phase can be used for estimation of the SCR annual fluences. For the prediction purposes it is necessary to estimate the moments of the beginning and the end of the linear dependence between the quantities $(\lg PF)_{cum}$ and $(R_z)_{cum}$. In solar cycles 19-22 this linear dependence was found to begin with a 2-3 year lag after the beginning of the cycle and to end 4-5 years before the end of the cycle.

Having no information about the annual proton fluences at the beginning of the cycle (for example at the stage of the very beginning) the following probabilistic model may be used.

It is easy to see (Fig. 1) that the R_z and $\lg PF$ values roughly correlate. So it is hardly possible to use this correlation for determination of the range of $\lg PF$ values corresponding to a particular range of the R_z values. In our analysis we use the probabilistic estimation. Our goal is to find the distribution function of $\lg PF$ for the particular range of R_z.

The whole scale of solar activity level (the R_z set) was divided into four ranges: LOW (R_z=(0; 40), NORMAL (R_z=40; 70), HIGH (R_z=90; 120) and SUPERHIGH (R_z=140; 200). For each of these ranges (shown in Fig. 1) the MEAN and StDev values of $\lg PF$ were calculated, the density functions of normal probability were derived, and then the normal distribution functions were obtained and their graphs were plotted. The results are shown in Fig. 6-9 by the smooth line . In these graphs the probabilities of the annual proton fluence logarithm values less than that of $\lg PF$ are shown. Here we assumed that the observations are approximated by the normal distribution function. The step line in these figures represent the same probabilities calculated directly from the observations without approximation assumptions. Comparing the smooth and step lines in these graphs one can easily see that the normal distribution function seems to be the good approximating idea. Our selection of the solar activity ranges excluded those with R_z values (70; 90) and (120; 140). The reason is that there were no data in these R_z limits. Surely there may be other particular selection of R_z intervals.

Summary

The linear dependence between the quantities $(\lg PF)_{cum}$ and $(R_z)_{cum}$ was found during the period of the solar cycle active phase in solar cycles 19-22 to begin with a 2-3 year lag after the beginning of a cycle and end 4-5 years before the end of a cycle.

The probabilistic estimation of proton fluences was based on the distribution function of $\lg PF$ for the particular range of R_z. It was shown that the observed proton fluences are well approximated by normal distribution function in the considered 4 range of Wolf numbers.

References

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2. Getselev I., Ivanova T., Krasotkin S. A New Model of Solar Cosmic Rays. *European Geophysical Society Newsletter*, N. 78, Nice, 2001, p. 220.

3. Getselev I.V., Krasotkin S.A., The Solar Cosmic Rays Normative Models. *Abstracts of ISEC-2001 International Conference "Radiation Belt Science and Technology"*, Queenstown, New Zealand, 2001.

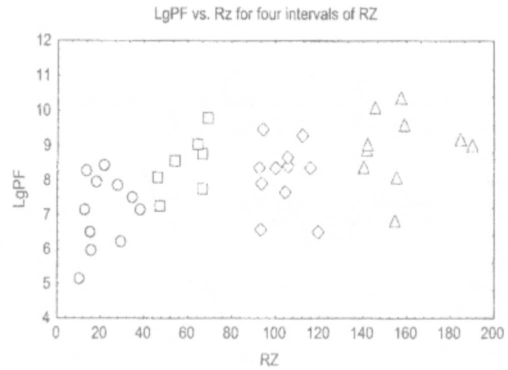

Fig. 1. Annual proton fluence decimal logarithm $\lg PF$ vs. annual averaged Wolf number Rz.

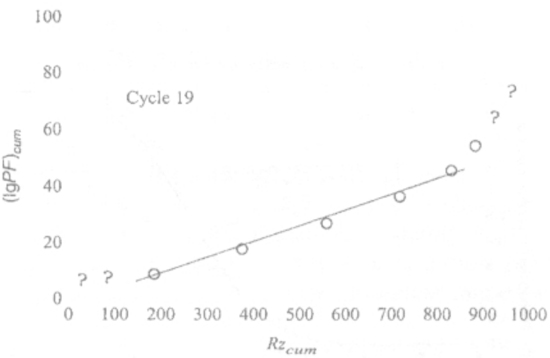

Fig. 2. The relation between cumulative decimal logarithm of the annual proton fluence $(\lg PF)_{cum}$ and cumulative annual sunspot Wolf numbers Rz_{cum} in the solar activity cycle 19 is shown by the round points. The cumulating calculations starts at the beginning of the cycle. The question marks are for the uncertain points. The approximately linear part of the dependence between the parameters under the consideration is shown by linear line.

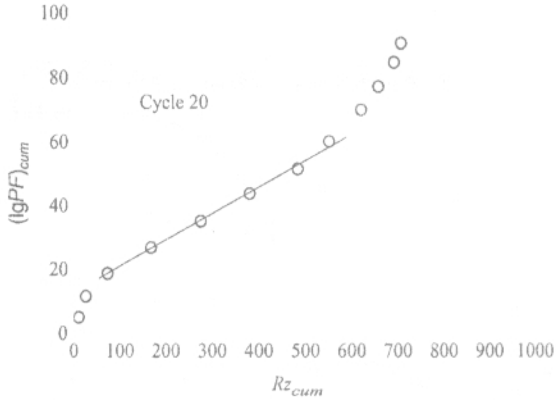

Fig. 3. The same as in Fig. 2 for the solar activity cycle 20.

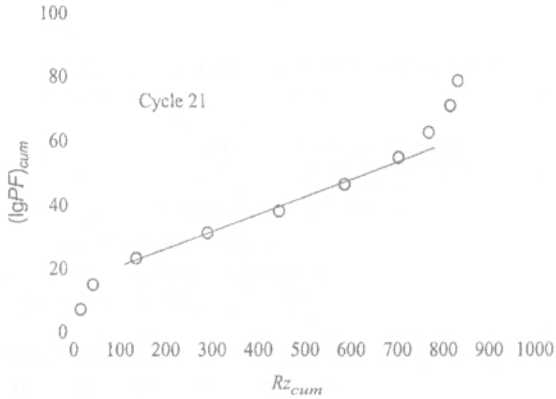

Fig. 4. The same as in Fig. 2 for the solar activity cycle 21.

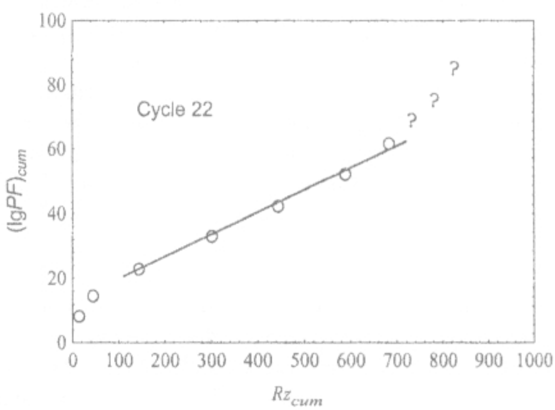

Fig. 5. The same as in Fig. 2 for the solar activity cycle 22.

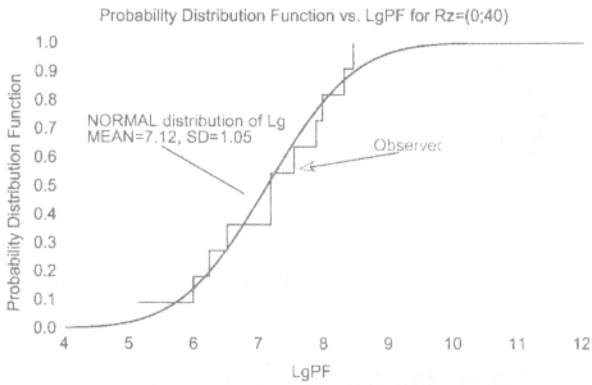

Fig. 6. The probability distribution function of $\lg PF$ calculated (smooth line) and observed (step line) for R_z=(0; 40).

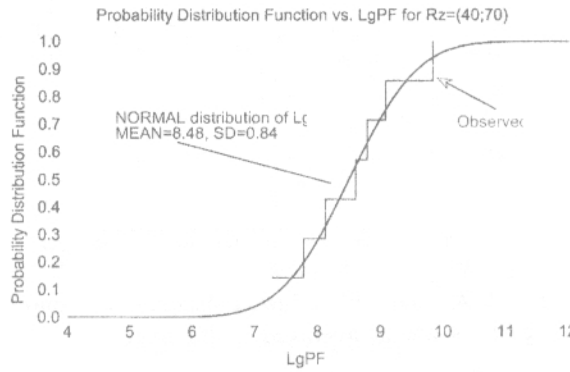

Fig. 7. The probability distribution function of $\lg PF$ calculated (smooth line) and observed (step line) for R_z=(40; 70).

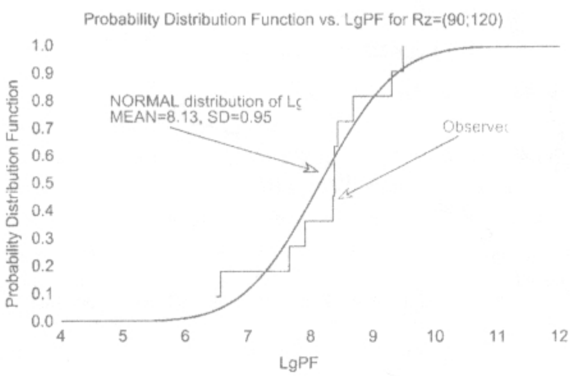

Fig. 8. The probability distribution function of $\lg PF$ calculated (smooth line) and observed (step line) for R_z=(90; 120).

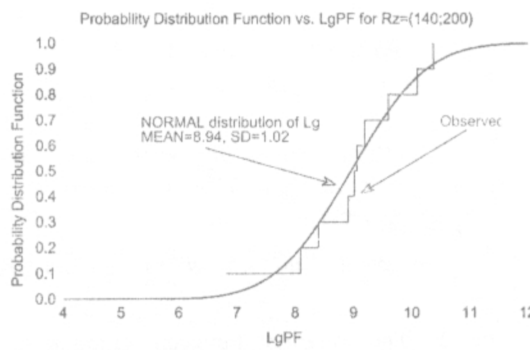

Fig. 9. The probability distribution function of $\lg PF$ calculated (smooth line) and observed (step line) for R_z=(140; 200).