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HIGH ENERGY PROTONS IN AURORAL REGIONS

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Abstract. The role of energetic protons in physical processes occurring in the auroral regions of near-Earth's space is being discussed. Measurements of the fluxes of protons with energies higher than 1 MeV in experiments, made by various spacecrafts in the 21st–23^{d} solar cycles are considered. Proton fluences for the time intervals from half a year to ten years are studied. It is shown that energy distribution of proton fluences could be well fitted by a power function. Variations of the exponent of the power function essentially decrease with the increase of time for which fluences are calculated. A conclusion is made that the data obtained could be put in the basis of developing a model of proton fluxes in the auroral regions.

Introduction

Energetic particles coming from interplanetary space into the auroral regions of near-Earth's space in many respects determine the nature of physical processes in it. As distinct from other regions of near-Earth's space, charged particles in the auroral regions almost do not encounter a deflecting force of geomagnetic field. This fact allows one to use measurements performed on the orbit outside the Earth's magnetosphere for estimations. Energetic proton fluxes by several orders exceed the fluxes of other particles. The main purpose of this paper is studying energetic proton fluences calculated over long time periods. These data are helpful for understanding conditions and physical processes in the environment as well as charged particle influence on objects located in the auroral regions.

Method

The choice of the method follows from the field of application of the results, capability and quality of the initial data available. From that point of view analysis of total fluxes of solar and galactic protons coming into the auroral regions from interplanetary space appears to be most expedient. One of the important parameters of space climate in the auroral regions are fluences of protons of various energies integrated over long periods of time. The knowledge about them is being also used for applied purposes, such as estimation of the impact on spacecrafts. These parameters could be found from analysis of long-term satellite measurements on Earth's orbit outside the magnetosphere. Suggested approach permits to avoid a lot of laborious operations and to eliminate the faults connected with dividing the results of measurements into solar and galactic cosmic rays, calculating solar proton event parameters, developing and applying solar cosmic ray and galactic cosmic ray models separately.

There are two most effective ways of analysis. The first one suggests the total fluence over long period of time (e.g. for 1, 2, 5 years, etc.) to be a variate. The estimated fluence value is found by interpolation of the results of calculations according to the probabilistic model based on these data. After that, for a given time interval and probability, energy spectra can be drawn. Another way is to study energy spectra variations and changing of their parameters for various time intervals.

Initial Data

For the implementation of the suggested method the results of continuous long-term various energy proton flux observations out of the Earth's magnetosphere should be used. From this point of view, observations being made from 1973 by IMP series satellites (http://nssdc.gsfc.nasa.gov/omniweb/) are of major interest.

Observations of charged particle fluxes in near-earth space began in 1957 when the second Earth's artificial satellite with the equipment of the Institute of Nuclear Physics of Moscow State University had been launched. For the first time solar particles were registered, using a spacecraft, in July 1958 during the 3-rd artificial satellite mission. Fluxes of protons of energies >100 MeV amounted to 104 cm^{-2} sec^{-1}, radiation dose amounted to 100 rad (Gorchakov and Basilevskaya, 1961). Later on, measurements were conducted by many spacecrafts, but the data were uncoordinated. In the 80s, on the basis of analysis and processing of numerous observations nearly permanent from 1963, a database on averaged daily fluxes of protons of energies >10, 30 and 60 MeV has been compiled (Armstrong et al., 1983). Nevertheless, in the present study we only use the data from IMP series satellites obtained with identical equipment. These data also include fluxes of protons of energies lower than 10 MeV, that may be a serious hazard to the outside elements and material of the spacecraft surface.

In Fig. 1 fluxes of protons of energies >30 MeV integrated over every six month (half-year fluences, cm^{-2}) are shown. From the Figure one can see the contribution of solar proton fluence (shaded) to the total fluence.

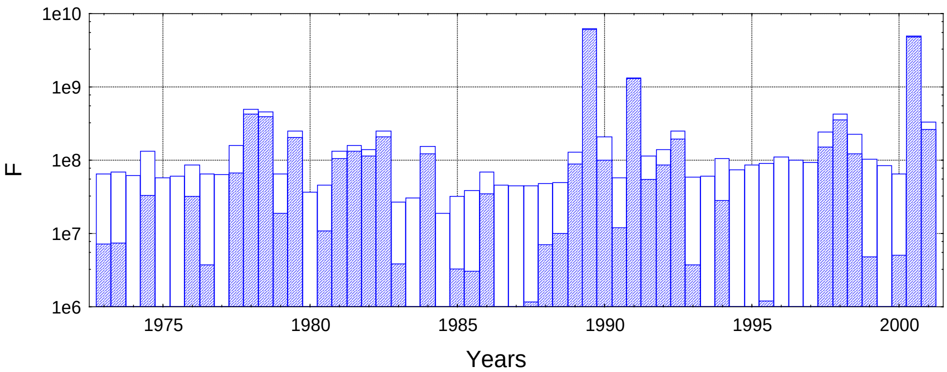

Fig. 1 Half-year fluences of protons of energies >30 MeV from 1973 to 2002.

Analysis

The measurements of the fluxes of protons of energies higher than 1, 2, 4, 10, 30 and 60 MeV from 1973 to 2002 have been considered. Fluences of protons of these energies were calculated for the time intervals from half a year to 10 years, the time shifts from 24 hours to 3 months being used. The results of calculations were tested against various distribution laws. Logarithms of proton fluences well satisfy the normal law.

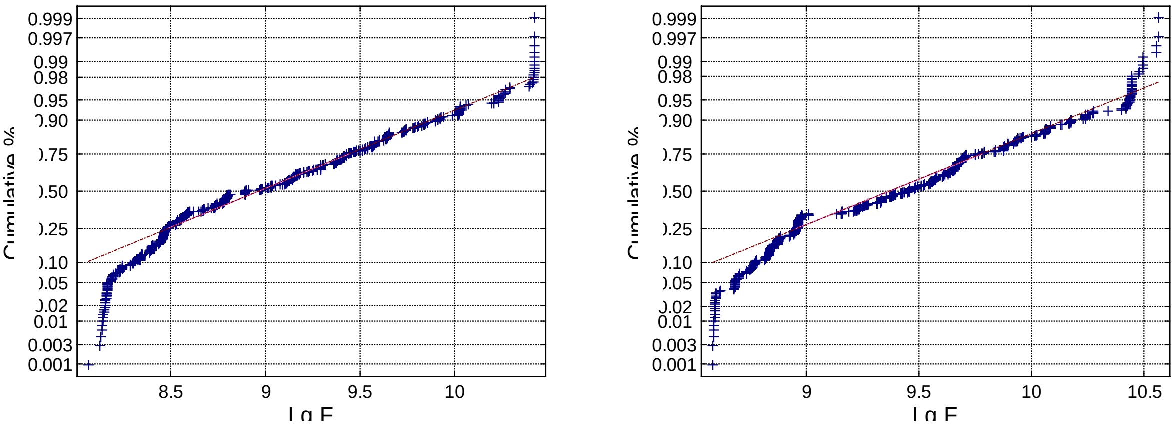

Fig. 2 Distribution of 1-year (left) and 2-year (right) fluences of protons of energies >10 MeV.

In Fig. 2 distribution of logarithms of the fluences of protons of energies >10 MeV for several time intervals is shown. The plot is ruled in such a way that the normal distribution is presented as a straight line. The calculated points are mostly well fitted by the normal curve. Spaces at the edges of the plot seem more noticeable due to the chosen scale.

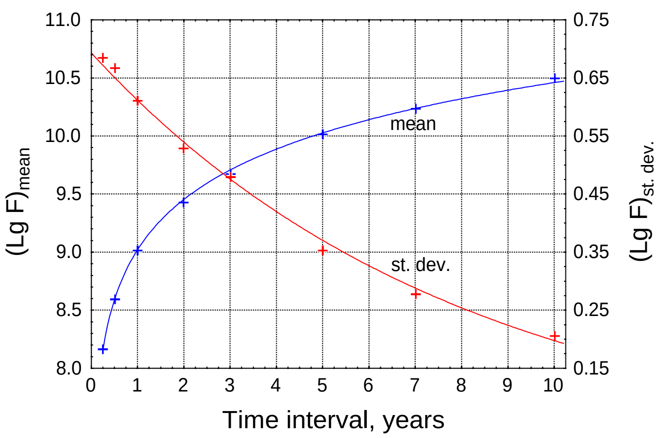

Fig. 3 Parameters of distribution of proton fluences of energies >10 MeV for various time intervals.

In Fig. 3 the curves of mathematical expectation and standard deviation of logarithms of the fluences of protons of energies >10 MeV versus the period of observation are given. Standard deviation decreases when the time interval grows.

Results of Calculations

Probabilistic model. Using the calculated values, probabilities of proton fluence not exceeding various threshold levels for the time intervals from half a year to 10 years have been estimated (see Fig. 4). As we mentioned above, mean-square deviation decreases exponentially with the increase of the time interval, thus we do not expect an increase of the fault for long time intervals.

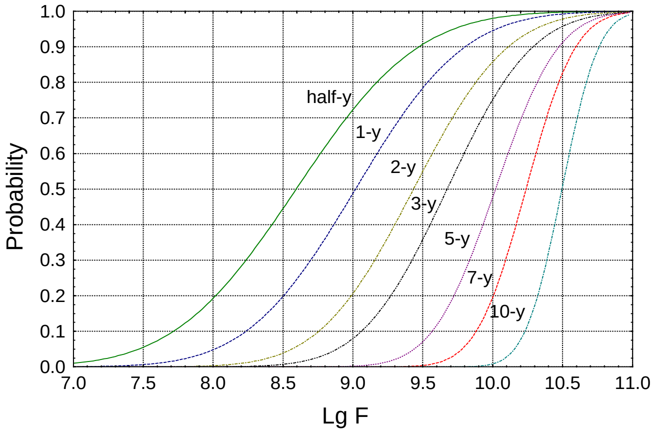

Fig. 4 Probability charts for the fluences of protons of energies >10 MeV for various time intervals.

Energy spectra. Energy spectra of proton fluences for all the periods mentioned above have been considered. They can be quite well fitted by a power function $y = Cx^{\alpha}$. In Fig. 5 energy spectra of the mean of proton fluences are shown for various time intervals, the coefficient of the fit determination R^2 being ~0.99. The exponent of the power function remains constant, $\alpha \sim -1$.

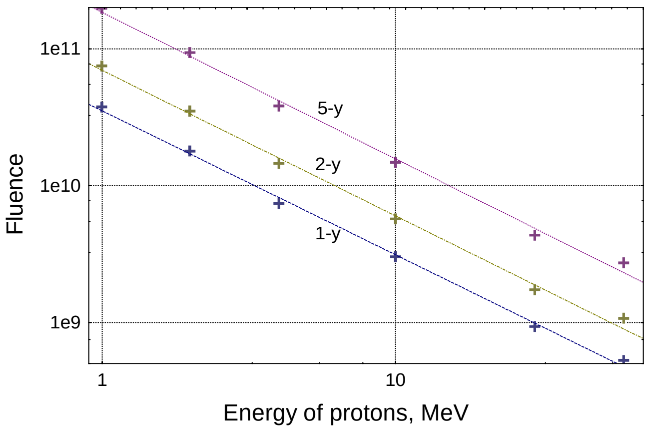

Fig. 5. Energy spectra of the mean of proton fluences for various time intervals.

Parameters of energy spectra approximation of the mean over 1-year proton fluences, depending on probability of the fluence not exceeding a certain level, are shown in Figure 6.

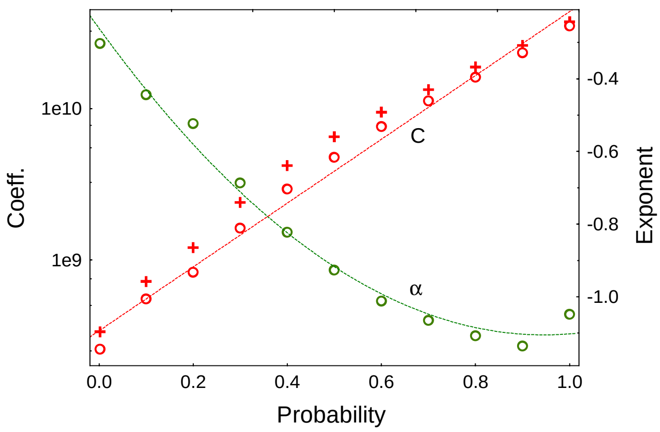

Fig. 6. Parameters of energy spectra of the 1-year mean proton fluences depending on the probability of the fluence not exceeding a certain level.

With time period increasing, the range of the exponent variations decreases down to 0.15 for 10-year fluences.

The coefficient of approximation of proton fluence energy spectra versus time interval is presented by a linear function.

Conclusion

Based on the most reliable data on energetic interplanetary proton fluxes, a statistical model has been worked out. It permits to estimate the probability of fluence of protons of energies 1–60 MeV and higher, not exceeding a given level, for the time intervals from half a year to 10 years. The results of the study are recommended for being used when designing a spacecraft, for ensuring radiation security of the flight. Spacecraft and onboard equipment developers setting the degree of risk, which is determined as a probability of proton fluence over a period of the mission not exceeding a certain level, by using the above results, can estimate the energy spectra of the fluences outside the Earth's magnetosphere. With applying known methods of estimation of the charged particle penetration into the magnetosphere, the data on energy spectra of protons impacting a spacecraft on its orbit can be evaluated. These data enable calculations of the radiation dose on the surface and inside a spacecraft.

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