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Fast Analysis of the Solar Wind Energy

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Abstract

The solar wind energy injected into the magnetosphere may be evaluated by means of the AE-index of the geomagnetic activity. However, these indexes are underestimated for the disturbed periods and available too late to be efficiently used. For a fast analysis, daily sums of the differences between the mean hourly values of horizontal component and the corresponding mean hourly values of H on five international quiet days have been used instead of the AE-index.

These sums were calculated from the data of mid-latitude observatories. They have a high correlation with the corrected AE-indexes for the quiet and disturbed periods. Using these sums, the solar wind energy injected into the magnetosphere was estimated for the years 1953-2001 as the daily, monthly and yearly values. It is shown that the energy increased with increasing solar and magnetic activity. At some cycles of the solar activity, the increase of the injected energy continued for several years on the descending phases of cycles and at some cycles the injected energy and solar activity have changed their phase.

Key words: solar wind, magnetic activity indices, injected energy, magnetosphere.

Solar wind carries the energy of 10^{13} joule per second on the disk of magnetosphere with radius $15R_E$ (R_E is the Earth's radius). The main part of the energy is the kinetic energy of plasma. The heat, electric and magnetic energies are ten times smaller (or even more). The main mechanisms of the solar wind energy access into the magnetosphere are the penetration of plasma through the cusps and side surfaces of the magnetosphere, and also the hydromagnetic mechanisms such as viscous interaction and reconnection of the magnetic field lines on the magnetopause.

The above-mentioned mechanisms inject into the magnetosphere the energy of 10^{11}–10^{12} J/sec and it is enough to generate magnetic storms and sub-storms. However, one cannot judge which mechanism prevails because the experimental materials are not sufficient for making final conclusion. Most probably, all the mechanisms act, but their effectiveness changes with changing solar wind parameters and state of the magnetosphere.

The value of the energy injected into the magnetosphere is controlled by interplanetary medium parameters (Atkinson 1978). The main flow down of injected energy is Joule heating of high latitude atmosphere (Banks 1981, Stern 1984). The Joule heating is connected with the existence of electric current systems in the ionosphere. Some part of injected energy is pilled up into the magnetosphere and another one penetrated to the ionosphere and generates electric current systems. Akasofu (1982) distinguished three kinds of the expenditure of solar wind energy in the magnetosphere: energization of auroral particles (U_A), energy of dissipation in the ionosphere (U_J), and energization of the ring current ions (U_{DR}). According to Spiro *et al.* (1982) and Feldstein (1992):

$$U_A = (1.75\ AE/100 + 1.6)\bullet 10^{10};$$

$$U_J = 0.32AE\bullet 10^{9};$$

$$U_{DR} = 0.74[\partial R/\partial t + DR(\tau)]\bullet 10^{10}.$$

Here τ is in hours, AE and DR in nT, and U in J/sec. Thus, the value of the energy stored in the magnetosphere and ionosphere can may be estimated by means of AE indices.

It is well known that during magnetic storms, when D_{st}-index is smaller than 150 nT, auroral electrojets move down to the sub-auroral latitudes. It means that standard AE-index is underestimated. To obtain the correct AE indices one must use also data of sub-auroral latitude observatories. To avoid it, we have used data of middle latitude observatories Lviv (LVV) and Fredericksburg (FRD) to receive an index adequate to AE.

Figure 1 shows dependence of the corrected mean daily indices AE on the daily sum of $(H - S_q)$ values for the year 1980 at magnetic observatory LVV. Here H is mean hourly value of horizontal component at observatory Lviv, and S_q are the mean hourly values the same component on five international quiet days for the same month. The correlation coefficient between the values is $r = 0.86 \pm 0.02$. A similar high correlation coefficient was received for observatory Fredericksburg. This means that it is possible to use daily sum $\Sigma(H - S_q)$ instead of AE. By substituting in the above formulas AE by $\Sigma(H - S_q)$ and taking into account the transition coefficient, we calculated the energy injected to the magnetosphere. Daily, monthly, yearly values of energy were determined.

Figure 2 shows the monthly total energy (E) and its dispersion for the years 1953-2001. The line without bars shows the mean yearly Wolf numbers. It is seen that the increase of solar activity leads to an increase in the stored energy in the magnetosphere. In the nineteenth solar cycle, such an increase started in 1954 and continued till 1959, although the solar maximum passed in 1957. The maximum mean monthly value of energy for 1959 is $7549 \bullet 10^{14}$ J. Since this year, a sudden decrease of energy

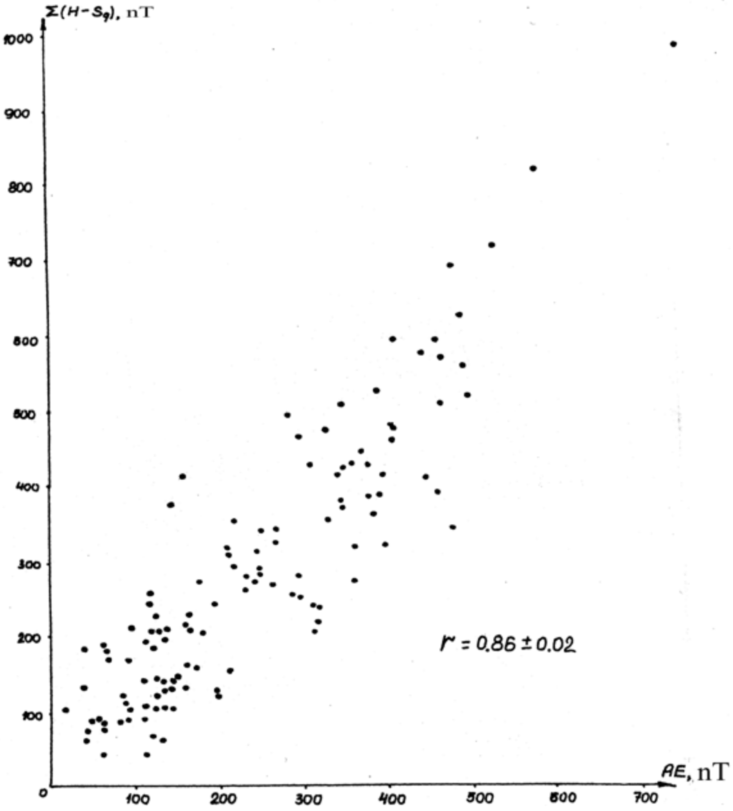

Fig. 1. Dependence between Σ(H-Sq) and AE for the year 1980 at magnetic observatory LVV.

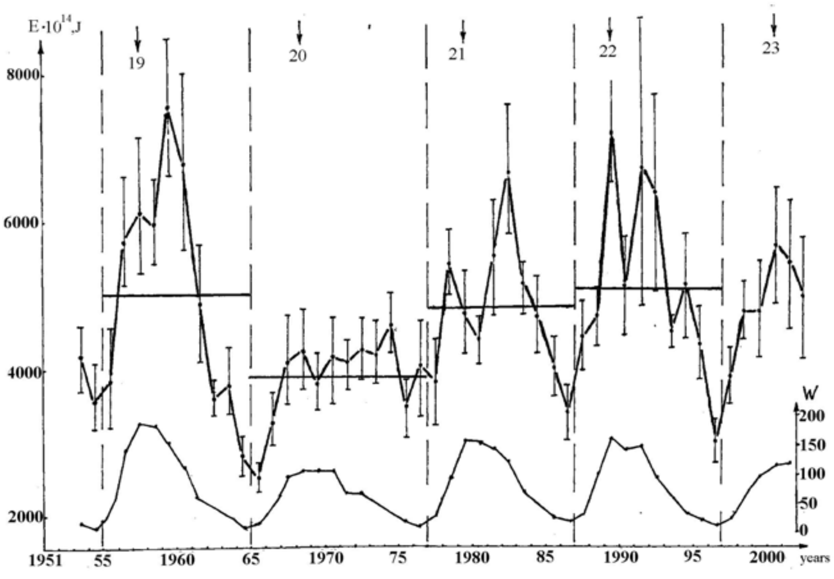

Fig. 2. The monthly total energy injected into the magnetosphere for the years 1953-2001. The lower curve is the yearly Wolf number.

was observed. A particularly deep decrease was observed in 1961. The deep minimum of energy at the end of nineteenth cycle is the deepest one for examined time interval ($E = 2576 \bullet 10^{14}$J). The twentieth cycle (1964-1976) was unusual. First of all, the solar maximum was low and blurred. The difference between maximum and minimum was small. The changes of injected energy were also small. The ratio of the maxima of injected energy in nineteenth and twentieth cycles was one and a half. Characteristic features of the twenty-first and twenty-second cycles were the two maxima of energy. In the twenty-first cycle, the second maximum appeared at the decreasing stage of solar cycle, but in the twenty-second cycle both maxima of energy appeared correspondently to the maxima of Wolf number. The mean-per-cycle energy values are shown in Fig. 2 by thick horizontal lines.

Figure 3 shows dispersion of energy, i.e., the deviation of the monthly energy from its mean value. It is seen that the dispersion increased with the growth of the injected energy. This means that an increase of solar activity leads to growth of the seasonal amplitude of the magnetic activity and, consequently, the injected energy.

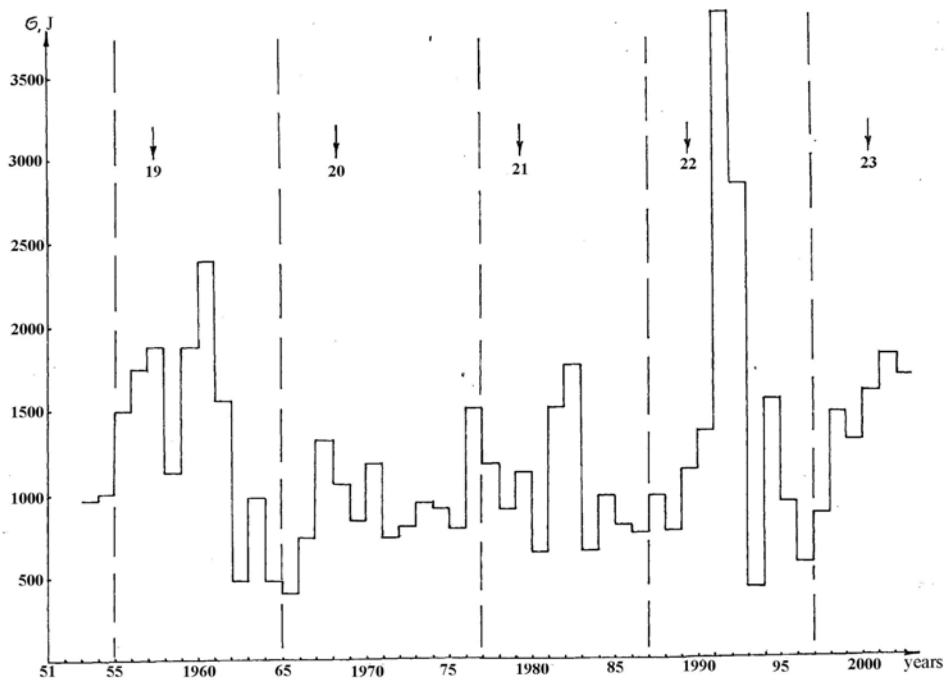

Fig. 3. The dispersion of the energy injected into the magnetosphere in 1953-2001.

Conclusions

The value of the solar wind energy injected into the magnetosphere is increasing (decreasing) along with increasing (decreasing) solar and magnetic activities. In 19-21 solar cycles, the increase of the injected energy continues through the next several years further, on the decreasing phase of solar activity. The solar activity and values of the injected energy change their phase in 22 and 23 solar cycles. Seasonal changes of the amplitude of injected energy and its yearly dispersion have been increasing with growth of the solar and magnetic activities.

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