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Comparison of heliospheric conditions near the earth during four recent solar maxima

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Abstract

Statistical properties of the daily averaged values of the solar activity (sunspot numbers, total solar irradiance and 10.7 cm radio emission indices), the solar wind plasma and the interplanetary magnetic field parameters near the Earth's orbit are investigated for a period from 1964 to 2002 covering the maxima of four solar cycles from 20th to 23rd. Running half-year averages show significant solar cycle variations in the solar activity indices but only marginal and insignificant changes in comparison with background fluctuations for heliospheric bulk plasma and magnetic field parameters. The current 23rd cycle maximum is weaker than 21st and 22nd maxima, but slightly stronger than 20th cycle in most of solar and heliospheric manifestations.

Keywords: Space weather; Earth heliospheric conditions; Solar maxima; Solar activity; Solar wind; Interplanetary magnetic field

1. Introduction

Heliospheric conditions near the Earth are important controlling factors for the geomagnetic activity level (see, e.g., Burton et al., 1975; Keating et al., 2001). The corresponding dynamical predictions based on the solar observations are not always possible. The most serious problem consists in a poor knowledge of the solar interiors where the energy, momentum and mass fluxes exist providing the needed time-dependent boundary conditions for the observed solar atmosphere and heliosphere changes. The dynamical predictability limits and horizons are not established for solar and heliospheric processes. Because of this we concentrate our attention on the statistical analysis of the available data for the past 40 years. The purpose of this paper is to compare the solar activity and its heliospheric manifestations during the four past maxima of solar activity in the solar cycles 20–23.

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2. Data

The data base SWDB (http://decl.sinp.msu.ru/~dalex/swdb) is used in this study. The daily averaged sunspot numbers (*W*), the radio emission flux of the Sun at the wave length 10.7 cm (index *F10.7)* in units 10^{-22} W m^{-2} Hz^{-1} and the average magnetic field of the Sun (*SF*) in microTeslas are taken from ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA. The average magnetic field of the Sun data for 1968–1975 was added according to the Crimean Astrophysical Observatory measurements (http://www.crao.crimea.ua/). The total solar irradiance (*SI*) in units W/m^2 is constructed as described by Fröhlich and Lean (1998) for 1979–2001 at the web site http://www.pmodwrc.ch/solar_const/solar_const.html. The hourly averaged values of the solar wind velocity V (km/s), the solar wind number density n (cm^{-3}), the interplanetary magnetic field intensity B (nT) and its vector components Bx, By, Bz (nT) are taken from OMNI (ftp://nssdcftp.gsfc.nasa.gov/pub/spacecraft_data/omni/) for 1963–1998 and from ACE

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spacecraft measurements in 1998–2002 (http://www.srl.caltech.edu/ACE/ASC/view_browse_data.html).

This information was used in this paper to construct the following heliospheric parameters: the induced electric field $E = 1/c{*}B_tV$ (mV/m), where B_t is the transversal magnetic field perpendicular to the solar wind velocity, $B_t = (By^2 + Bz^2)^{1/2}$, the parameter BV^2 (nT km^2/s^2) which is assumed to be one of important factors for auroral activity (Gleisner and Lundstedt, 2001), the solar wind flux density nV (cm^{-3} km/s), and the solar wind dynamical pressure Pd (nPa).

Induced electric fields and the north–south Bz component of the magnetic field are known to be well correlated with geomagnetic storms (see, e.g., Burton et al., 1975). The dynamical pressure and Bz are known to be of the influence on the size of the magnetosphere.

3. Running histogram analysis

Figs. 1–3 show running histograms for the distributions of different solar, heliospheric and geomagnetic parameters, correspondingly. These figures are constructed as follows. Step in time for each histogram is equal to 27 days. Each histogram contains the occurrence statistics of daily averaged values (indicated as an ordinate) in the bins containing totally 189 days around the middle of the interval which is sufficient for representation in 30 bins coded as gray and black tones in a logarithmic scale with maximal values as black. The white tone shows also no data cases. The thick and thin dotted white curves represent the running half-a-year medians and the corresponding RMSDs. The thin dotted curves in black show the three RMSD levels. The horizontal white thick line shows the medians over the whole interval, when the horizontal dotted white and black lines demonstrate the level of respectively one and three RMSDs during the same interval.

Let us discuss briefly the obtained running histograms. Fig. 1(a) and (b) demonstrates a nearly log-normal distributions for sunspot numbers W and the $F10.7$ index. This character of distributions is clearly seen in the logarithmic scale: the most probable values (black bins in the histograms) coincide with the running averages (thick dotted white curves). In addition, the upper and lower RMSDs (thin dotted white curves) are situated practically symmetric against the running average values. Contrary to this, the total solar irradiance SI and the solar magnetic field SF in Fig. 1(c) and (d), correspondingly, show practically normal distributions (linear scale). Large statistically significant variations during the cycle are seen in W, $F10.7$ and SI. For example, in the 21st solar maximum during 1980–1981 the running mean value $F10.7$ is equal to ~200, which is higher than the overall RMSD ~174 or the current RMSD in 1980 which was about 100. The solar magnetic field SF fluctuates around zero values with the maximal amplitudes near the solar maximum. The running RMSD at the solar maximum (minimum) is higher (lower) than the RMSD for the entire period. We note this behavior in the WSO data (1976–2002). For the period 1968–1975 we used the data from Crimean Astrophysical Observatory (CrAO). They show different behavior with larger amplitudes of variations. The calibration problem of absolute values obviously exists between these two observatories, which makes the comparison of the 21–23 cycles with the 20th cycle difficult. The same can be said about the interplanetary magnetic field measurements onboard various satellites before and after 1974 (Fig. 2). The comparison with the galactic cosmic ray variations measured

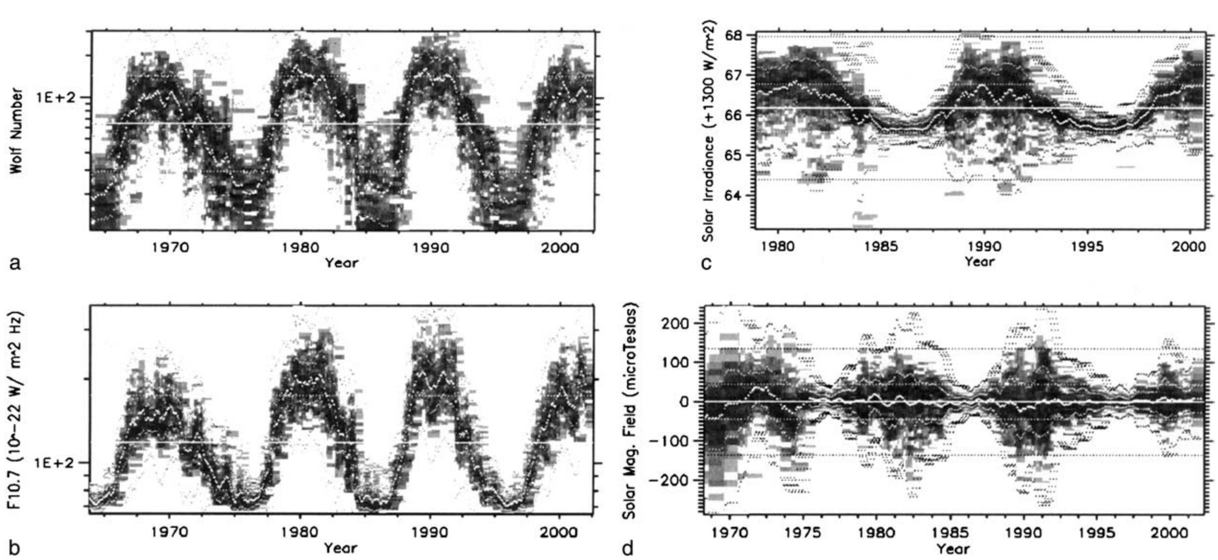

Fig. 1. Running histograms for the distributions of the solar activity indices: (a) sunspot number W; (b) solar radio flux $F10.7$; (c) total solar irradiance SI; (d) average magnetic field of the Sun SF vs. time during four recent solar cycles with numbers 20–23.