FLARE INDEX DURING THE RISING PHASE OF SOLAR CYCLE 23

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Abstract. A brief description and results of the flare index (FI) as a measure of solar activity for cycle 23 are given. The calculation of the daily flare index was determined using the final solar flare tables from the National Geophysical Data Center A. The final data of FI are presented in graphical form over the rising activity phase of solar cycle 23. Daily calculated values are available for general use in Kandilli observatory's and NGDC's anonymous ftp servers. The pattern of similar activity indices that arise under different physical conditions during the rising activity phase are compared with the flare index. The north-south asymmetry in the daily flare index data was studied.

1. Introduction

Solar activity variations are manifest themselves not only in electromagnetic radiation from radio frequencies of a few kHz to powerful gamma rays but also in particle flux. In broad physical terms, solar activity may be understood in terms of the properties and the behaviour of the magnetised solar plasma. Solar structures and phenomena all arise from magnetic fields embedded in dynamic plasma. Various forms appear at all latitudes from the poles to the equator and at all space scales from several hundred to many hundred thousand km. Some of these structures are remarkably long-lived, and a variety of structures are observed over the entire electromagnetic spectrum from radio, through visible, to X-rays and gamma rays. Continuous observations are required to catch short-lived but infrequent phenomena. One important example is solar flares. Images of the Sun show that solar flares are one of the most powerful and explosive of all forms of solar activity. Many studies in the solar-terrestrial field classified solar flares as one of the most important solar events affecting the Earth.

Kleczek (1952) introduced the quantity $FI = it$ to quantify the daily flare activity over a 24-hour period. He assumed that this relationship roughly gave the total energy emitted by the flare and named it 'flare index' (FI). In this relation, i represents the intensity scale of importance of a flare in Hα and t the duration of the flare in minutes. Catalogues of flare activity using Kleczek's method are given for each day from 1936 to 1986 by Kleczek (1952), Knoška and Petrásek (1984), Ataç (1987), and Ataç and Özgüç (1998).

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The flare index is an interesting parameter and is of value as a measure of the short-lived activity on the Sun. Therefore the authors will continue to compile this index in the future. In this paper the results of the determination of the flare index for the ascending branch of solar cycle 23 are presented. Its relation with other solar activity indices is shown in Section 2. Its comparison with the similar solar indices is given in Section 3. The north-south asymmetry of the flare index is described in Section 4, and concluding remarks are presented in Section 5.

2. Flare Index on the Ascending Branch of Solar Cycle 23 and Its Relation with Other Solar Activity Indices

The authors continue to compile the daily flare index for solar cycle 23 using the tables of solar flares from the National Geophysical Data Center (NGDC). The daily sums of the index for the northern and southern hemispheres and for the total surface are divided by the total time of observations for that day. This division takes days into account which have incomplete observations and places the index on a common temporal scale of one hour. The daily total time of observation is calculated from *Solar Geophysical Data Comprehensive Reports*. Calculated values are published by NOAA in *Solar-Geophysical Data Comprehensive Reports* No. 665, Part II and are available for general use in our observatory's and NGDC's anonymous ftp servers: *ftp://ftp.koeri.boun.edu.tr/pub/astronomy/flare_index* and *ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_FLARES/INDEX*. They are shown in Figure 1 as daily plots of northern and southern hemispheres and together with daily plots of sunspot number, total area of sunspot groups, and Wilcox Solar Observatory's net magnetic field intensity summed over the solar disk.

The idea of comparing the pattern of similar activity indices that arise under different physical conditions led us to investigate how FI agrees with other full-disk solar indices. The indices which are to be compared:

(1) Stanford University, Wilcox Solar Observatory's measurement of the net magnetic field intensity in micro Teslas summed over the disk. Such integrated light measurements of the mean solar magnetic field have been made daily since May 1975 (Scherrer *et al.*, 1977).

(2) Daily corrected total areas of sunspot groups. These are observed, measured and compiled by USAF/NOAA (D. H. Hathaway, private communication).

(3) The relative sunspot number. This is an index of the activity of the entire visible disk of the Sun calculated by the Sunspot Index Data Center (SIDC)

(4) Two active-cavity radiometers are part of VIRGO on SOHO to investigate the total solar irradiance. A description of the instruments can be found in Fröhlich *et al.* (1995). The determination of the total solar irradiance is made by first correcting the time series for all *a priori* known influences and second, to correct the data for instrumental sensitivity changes, using the back-up instruments (Fröhlich *et al.*, 1997).

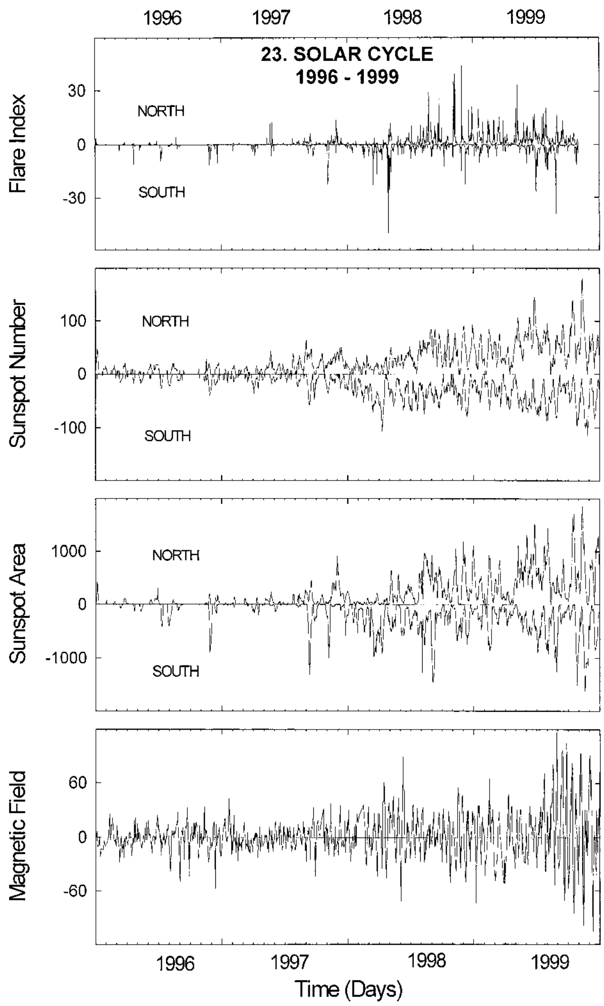

Figure 1. Comparison of daily plots of the northern and the southern hemisphere flare index, sunspot number, sunspot area with daily plots of Stanford University, Wilcox Solar Observatory's net magnetic field intensity summed over the solar disk.

As can be seen from Figure 1, FI is of value as a measure of the short-lived activity on the Sun. This feature makes the flare index a suitable full-disk solar index, which reflects different physical conditions from a layer of the solar atmosphere.

3. Comparison of Similar Solar Indices

Similar activity indices for the previous and the current cycles are shown in Figure 3. Two time intervals of 48 months, each starting from the beginning of their minimum years were compared. We can see that this cycle rises much more slowly

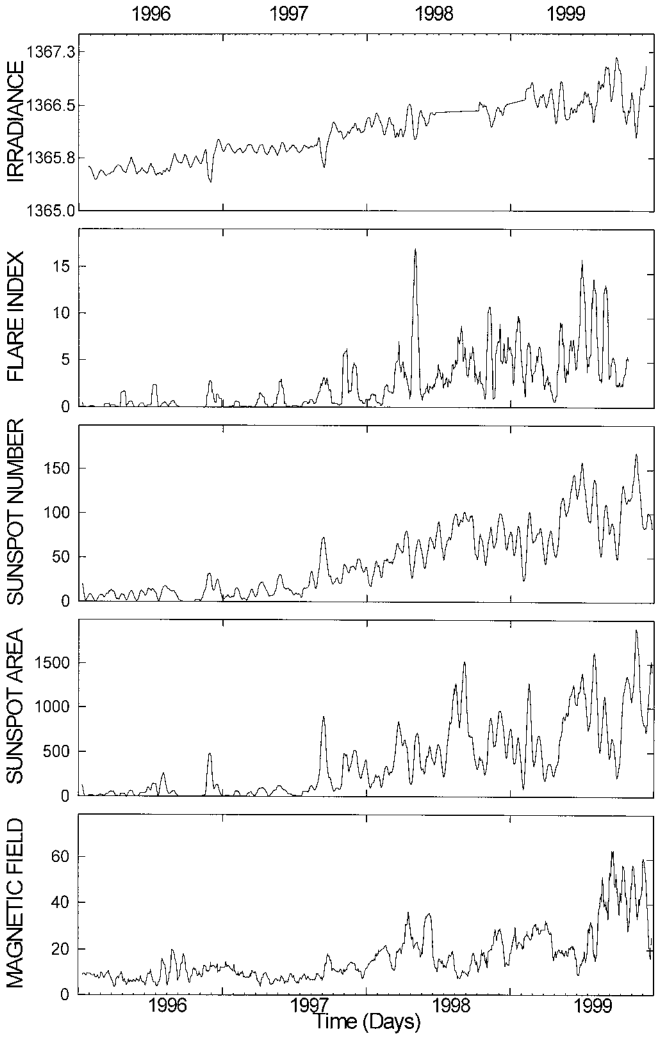

Figure 2. Plots of the 13-day running means of the similar solar activity indices.

than the last one, except the total solar irradiance in the same time interval. We observe that the flare activity remains at a lower level during the ascending phase of the current cycle. This behaviour is also clear from the major flare events of the two consecutive cycles as shown in Figure 4. In addition, this observation is reinforced by the Ca II K data from the San Fernando Solar Observatory (*http://davinci.csun.edu/∼astro/sfopics.cgi*). The K-line excess, which is the change of the emission from the Sun in the K line image due to the presence of faculae, also shows how much more slowly this cycle is rising than the last one did.

The first important increase of flare activity, due to the active region NOAA 8210, was seen in April 1998 in the southern hemisphere. A similar increase for

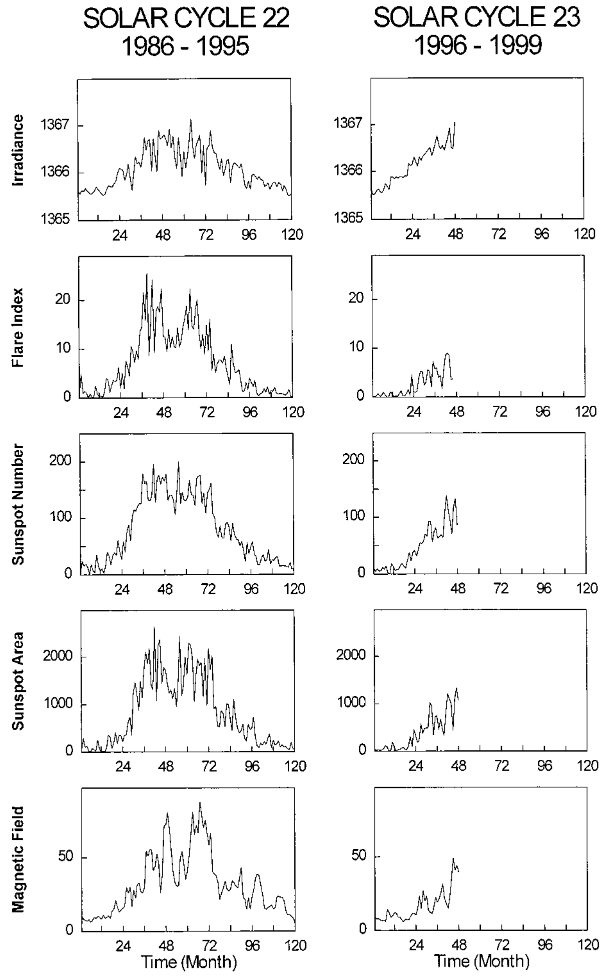

Figure 3. Comparison of the monthly means of the similar activity indices for the previous and the current cycles.

the ascending branch of the previous cycle was observed again in the southern hemisphere.

The rate of increase in the magnetic field has slowed down remarkably toward the middle of 1998. However, sunspot and flare activity continued to increase during the same time interval; the irradiance activity could not be followed because of SOHO's malfunction. A similar trend in all indices is repeated between April 1999 and mid-August 1999. A sharp increase in the magnetic field starting in August 1999 is accompanied by increasing sunspot and flare activity. On the contrary, total solar irradiance activity has shown a remarkable decrease during the same time period as seen in Figure 2. Solanki and Unruh (1998) suggested that practically the whole of the solar irradiance variation is produced in the lower photospheric

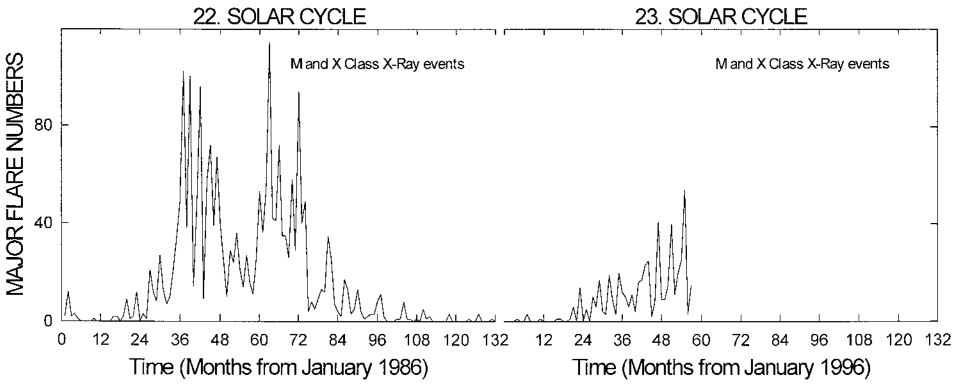

Figure 4. Comparison of monthly counts of the major flare event number for the previous and the current cycles.

layers and provides improved estimates of the contributions to the total irradiance variation of different heights and wavelengths.

4. North-South Asymmetry of the Similar Solar Indices during the Ascending Phase of the Solar Cycle 23

It is well known for a long time that the occurrence of different features on the northern and southern part of the solar disk is not uniform. Many types of solar phenomena exhibit the same N–S asymmetry distributions (Roy, 1977; Knoška, 1985; Swinson, Kyoma, and Saito, 1986; Verma, 1987; Vizoso and Ballester, 1990; Carbonell, Oliver, and Ballester, 1993; Olivier and Ballester, 1994; Joshi, 1995; Watari, 1996; Ataç and Özgüç, 1996; Li, Schmieder, and Li, 1998; Li and Gu, 2000).

Joshi (1995) and Li, Schmieder, and Li (1998) show that the asymmetry is real and not due to random fluctuations. To show the statistical significance of the asymmetry series, a sign test introduced by Gleissberg (1947) was performed. According to this test, the probability, p, that the variations in a time series are due to chance can be calculated from

$$p = 1 - \mathrm{erf}(x),$$

where 'erf' denotes the error function. If $p \simeq 1$, than we can say that variations in the time series are due to chance; alternatively, if $p \ll 1$, the asymmetry time series can be considered significant. The method of calculating erf (x) is given by Balli (1955). Following Balli, we have determined that $p \ll 1$, which shows that the distribution of the asymmetry index is highly significant during the ascending phase of the solar cycle 23 for the flare index, sunspot number, and sunspot area.

Plot of asymmetry for the monthly mean is given for each index in Figure 5. The first curve (a) represents the flare index, where the shift of flare activity from

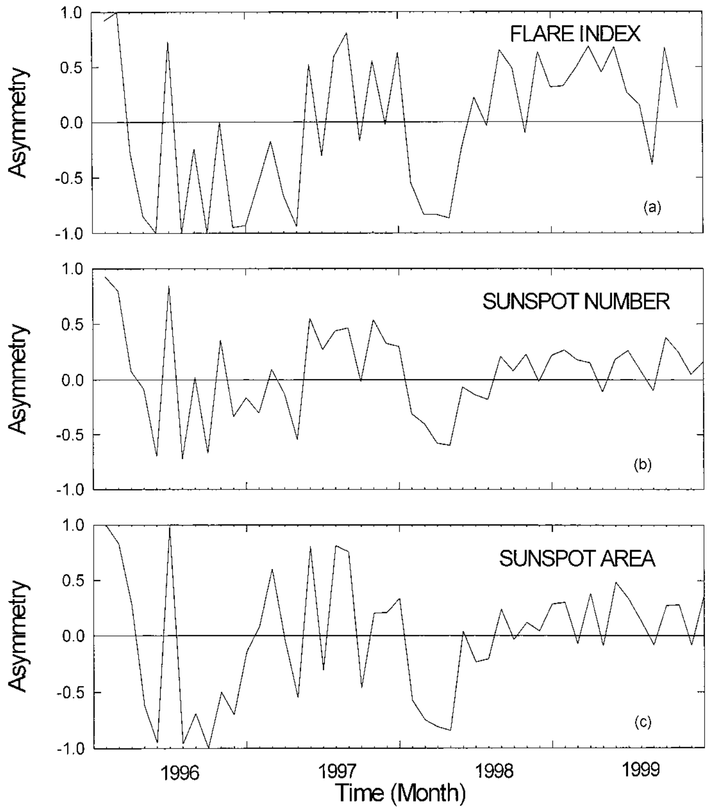

Figure 5. Monthly plots of the north – south asymmetry of the similar activity indices.

one hemisphere to the other is easily seen. The N – S asymmetry showed similar behaviour for the total areas of sunspot groups and sunspot number. It varied nearly in parallel for both indices. From this curve the dominance of the activity for the southern hemisphere throughout 1996 turns to the northern dominance beginning by April 1997. Solar activity shifts to the southern hemisphere around mid-1998, then shifts again to the northern hemisphere. The dominance of activity for the northern hemisphere throughout 1999 is easily seen in Figure 5.

5. Conclusion

Comparison of the monthly mean plots of the similar activity indices with the previous cycle shows that the current cycle rises at a lower level of activity during the ascending phase. This is confirmed by comparison of the major flare events of the two consecutive cycles. On the other hand, the low level of the major flare activity during the ascending phase of this cycle increases the monthly number of

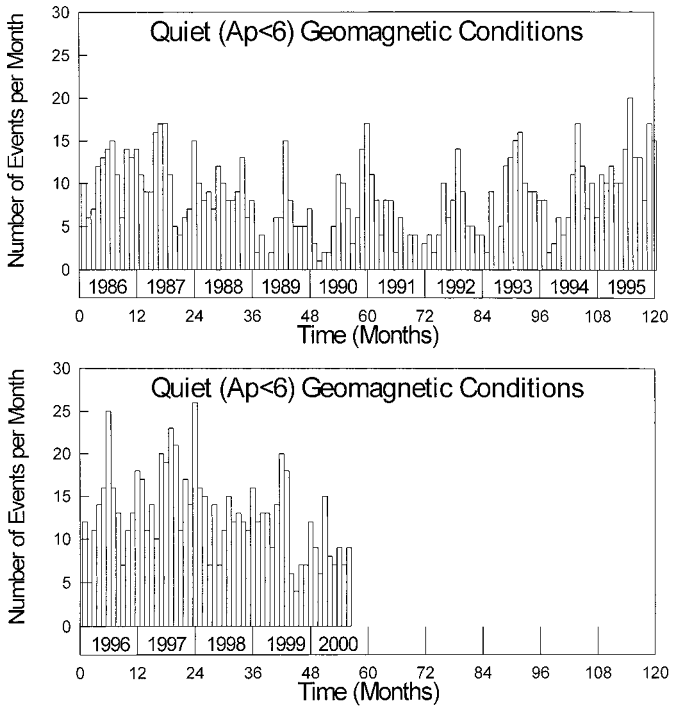

Figure 6. Comparison of the monthly number of the geomagnetically quiet days ($Ap < 6$) for the previous and the current cycles.

the geomagnetically quiet days ($Ap < 6$). Figure 6 shows that quiet geomagnetic conditions are remarkably high during the rising phase of the current cycle.

Hathaway, Wilson, and Reichmann (1994) suggested that during the cycle progresses, the activity amplitude of the cycle could better be determined at 42 months into the cycle. Therefore we can conclude from the rising phase of this cycle that the flare production will be lower then the previous one for the rest of the current cycle.

The N – S asymmetries of the similar activity indices show similar behaviour. The activity prefers the northern hemisphere in general during the rising phase of cycle 23.

The solar activity is increasing in the period which we studied. However, all the indices fluctuate while the activity cycle rises. The levels of their peaks are not necessarily at the same levels at the same time. These differences come from the different physical conditions required by each index, and a time shift (Altrock *et al.*, 1999)

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