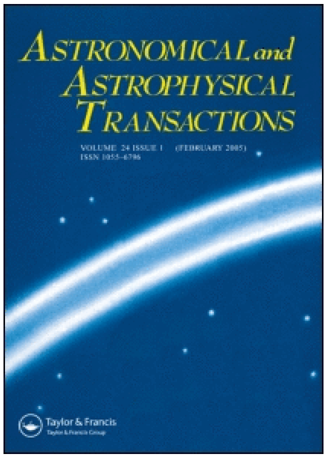

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EVOLUTION AND FORECAST OF FLARE ACTIVITY IN THE CURRENT SOLAR CYCLE 23 (MEDIUM AND SHORT-TERM PREDICTION)

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The prediction of the current solar cycle characteristics is a very interesting and important task for the solar-terrestrial physics. An effective 'method of similar cycles' for the prediction of the current 23rd cycle history and characteristics is presented. Furthermore a method for utilizing solar observational data to predict geoeffective solar flare events, that is, a large solar flare and solar filament ejection, is presented. The process of new magnetic flux emergence, its evolution and its interaction with already existing magnetic flux is sufficiently determined to allow us to predict the period of flare energy release (PFER). All large solar flares are always accompanied by a series of weaker events. They form together with the PFER confined within a time interval of 55 ± 20 hours, when the bulk of the middle and large solar flares occur.

KEY WORDS Solar activity, solar cycles, solar flare events, magnetic flux, forecast

1 INTRODUCTION

In this paper, medium-term solar activity is defined as a period longer than one solar rotation but shorter than the 11-year solar cycle. Prediction includes the forecast of current solar cycle evolution after its beginning. The forms of prediction include the estimation of: amplitude of the current cycle; the variation of sunspot number within the cycle; the length of the cycle; and the timing of critical points such as maximum and minimum.

We define short-term solar activity as a period longer then one day but shorter than five days for solar flare phenomena like solar flare and solar filament eruptions and up to one solar rotation for solar coronal holes.

Prediction of solar cycle evolution is a very interesting and important task for the solar-terrestrial forecaster. Its significance arises from the utilization of predictions in such areas as planning for scientific research, for satellite and spacecraft operations, and for communications. But attempts at prediction of the solar cycle

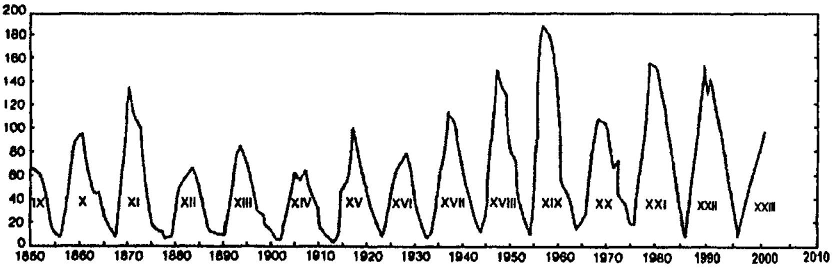

Figure 1 150-year plot of solar cycles with hard observational data (cycles 9 to 23).

characteristics prior to its onset have usually not been successful. Maybe we do not have a physical model by which prediction can be made. Maybe the statistics of those observations are very small. But we are optimistic of an effective method for the prediction of the some parameters of the current solar cycle after the cycle's onset.

In Figure 1 we can see those solar cycles which have hard observational data. These solar cycles can be separated into following classes: low, medium (10, 13, 15, 17, 20), high (11, 18, 21, 22) and super-high (19) solar cycles.

2 EVOLUTION AND SOME CHARACTERISTICS OF CURRENT SOLAR CYCLE

Solar cycle 23 began in June 1996 and its evolution has shown that our knowledge of long-duration active processes in the Sun is insufficient to confidently predict the next 11-year cycle. August 2000 was month 51 of Cycle 23. The principal features of the current solar cycle are:

- The current cycle has been began in June 1996 and the starting smoothed sunspot number was $W_0^* = 8.6$.
- The first active region (AR) of the current cycle appeared at the minimum – May 1996, and from February 1997 the structures of new cycle have been dominant. According K. Harvey *et al.* (1997), the first sunspot region of a new solar cycle is observed prior to sunspot minimum. Cycle membership is based on two characteristics of AR: new cycle regions first appear at high latitudes, typically poleward of 25–35° with the old cycle sunspot regions at lower latitudes; the magnetic polarity leader and follower sunspots in new-cycle regions are reversed from those observed in the lower latitude old-cycle sunspot regions.
- The ascending phase began in September 1997: $W = 51.3$, $F10.7 = 96.2$,

Table 1. Number of active regions (ar) and coronal holes (ch) in cycles 21–23 (48 months).

Structures	*Cycle 21*	*Cycle 22*	*Cycle 23*
AR	1771	1490	1049
CH	> 142	165	298

- The total number of active regions is considerably smaller when compared with the AR number at the same point in previous cycles;
  Conceivably the new rules might represent the fact that there is an excess of coronal holes in solar cycles with a deficit of active regions.

- Sunspot groups are smaller than normal, less complex than usual, slower to evolve, and longer-lived than normal. These properties are signs of stable active regions. A solar cycle with more stable sunspot groups may indicate a weaker circulation in the solar convection zone.

- Flare activity is dramatically less than in cycle 18, 20–22, according to the data published recently in the NOAA SEC weekly report. This is consistent with the average qualities of the sunspot groups. The total number of optical, X-ray and large solar flares over the same period in previous solar cycles (19–22) is considerably smaller.

The activity has been unremarkable when compared with the same point in five previous cycles.

There have been five episodes of major solar – geophysical activity during Cycle 23. The first one occurred in early November 1997 (associated with a relatively rare ground-level energetic particle event – GLE), the second, in April–May 1998, the third, in August 1998, the fourth, in November 1998, and the most resent, in July 2000 (GLE). Solar proton events were associated with all five episodes, while severe geomagnetic storms were associated with the three latest.

Our medium-term prediction is the finding of the Solar Cycle Forecast Technique (method of similar cycles). Referring to Figure 2 it is possible to estimate the minimal time of current cycle evolution after which we can determine the height and the time of the current cycle maximum. This time is 18–24 months after the beginning of the current solar cycle. We expect Cycle 23 to be a moderate solar cycle with a smoothed sunspot maximum of $W = 110 \pm 10$, forecast to occur between December 1999–March 2000.

This peak is comparable with the peaks of Cycle 17 and 20, but is not expected to exceed the peaks of the last two Cycles 21 and 22.

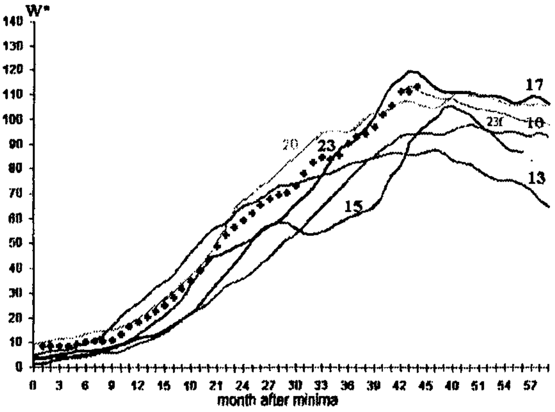

Figure 2 The current 23rd cycle of solar activity in a family of similar solar cycles (medium-size solar cycles).

3 THE TECHNIQUE OF SHORT TERM FLARE EVENT FORECASTING

Short-term large flare event forecasting is presently based on observations of:

- the process of new magnetic flux emergence,
- their evolution: the magnitude growth and rate of emergence,
- their localization and interaction with already existing magnetic fields of the active regions or outside them.

Such an approach enables classification of these phenomena depending on size and characteristics of magnetic fields, in which the new magnetic fluxes emerge. Golovko (1986, 1988) made the most successful attempt at EFR phenomena classification in relation to the flare activity.

In accordance with EFR magnitudes and the time of their existence the author revealed three branches reflecting the presence of three main different magnetic structures on the Sun and, significantly, marked out a special category of EFR with rapid evolution.

These papers provide sufficient reasons to consider the process of solar flare occurrence as an *original process* within the common evolution of the active region.

This physical process has a concrete *beginning* – the emergence of a new magnetic flux reaching the stage of interaction between new and old magnetic structures (1.5–3 days); *maximum* – the time interval when middle and large flares occur, caused by interaction between these magnetic structures (2–3 days), and *end* – when the energy of the EFR is fully realized.

The emergences of new magnetic fluxes may occur in all phases of active region evolution. Their interactions with overlying magnetic fields will *always* cause a flare activity increase.

For a normal active region: the magnitude is $\geq 10^{12}$–10^{13} Wb , and the rate of emergence is $V = 10^7$–10^8 Wb s^{-1}.

For flare EFR: the magnitude is $\Phi \geq 10^{13}$ Wb and the rate of emergence is $V \geq 10^9$ Wb s^{-1}.

The observational evidence for large EFR manifestations:

- rapid growth of sunspot areas, usually by more than a factor 2 or more on the first day for sunspot groups with areas up to 300 m.v.h. and greater than a factor of 1.5 on the second and third days (time of evolution is about 1–3 days);
- appearance of new large umbrae within the same penumbra for large and complex sunspot groups with an area ¿1000 m.v.h. (time of evolution is about 1–3 days);
- fast complication of the magnetic structure of a sunspot group at the expense of the appearance of new spots and umbrae with gamma and delta-configurations (time of evolution is from several hours to 1.5 days);
- rapid evolution of the sunspot groups to D, E, F (ki, kc) McIntosh classes (time of evolution is from several hours to 1.5 days);
- appearance of compact arch filament systems (AFS) which visualize EFR within active regions; observations in the wings of the Hα spectral line (±1Å) indicate a large number of microflares in the arch footpoints;
- rapid increase of soft X-ray background (1-12.5 keV) – essential for the minimum solar activity phase.

The consequences of large new magnetic flux emergences are:

- rapid proper motions of one or more spots, umbrae or pores Dejo *et al.* (1980);
- appearance of sheared magnetic configuration ('shear') in regions immediately adjacent to the line of polarity reversal in the active region, Tanaka, (1980), etc.

The some essential observational peculiarities of solar flare realization:

- all large flares are necessarily accompanied by middle importance flares;
- solar flares of large and middle importance are distributed randomly in time, but forming successions; Obashev *et al.* (1973), Ishkov (1989);
- in most cases they occur within a certain limited temporal interval, Ishkov (1998, 1999).

The temporal interval during which the bulk of large and moderate solar flares occur we call '*the period of flare energy release*' (PFER);

Table 2. The main characteristics of the solar flare event in accordance with magnetic fields magnitudes.

B (GS)	*1*	*2*	*The greatest value*			*3*	γ	*CME*	*AFFS*	*4*
			$H\alpha$	*R (cm)*	*Imp*					
< 50	–	DSF	Brightness	< 50 s.f.u.	<C5	–	–	+	+	–
< 500	–	4N	Fl	< 300	<M9	–	–	+	+	A
≥ 2000	γ, δ	3B	Fl	> 10000	>X12	+	+	+	+	B, C
> 2000	Δ	1B	Fl	< 10000	<X2	+	+	$< 0.1\%$	–	C

Note: 1, MF configuration; 2, phenomena; 3, X-ray hard; 4, Flare classification.

- PFER occurs on the 2nd–3rd day after the first evidence of the emergence of a new sufficiently powerful magnetic flux;

- PFER may last from 16 to 80 hours (the average duration is 55 ± 20 hours or 5–25% of whole the time of AR passage across the solar disk) depending on the degree of AR evolution, the parameters of its magnetic field and the characteristics of a new emerging flux.

It is most important to notice that ALL large flares and the most moderate flares of a given active region occur in this temporal interval if the given sunspot group area is no more than $\sim$ 1000 m.v.h.

Other large solar flares to occur in a given active region a new large magnetic flux emergence must take place.

From this standpoint it is possible to consider the solar filament eruption as a flare process in a weak magnetic field (up to several tens of gauss). In this case a new emergence magnetic flux interacts with the overlying background solar magnetic field and can emerge in the vicinity of the polarity inversion line, where a filament is located.

Table 2 presents some maximal characteristics of solar flare production according to the magnitude of the already existing magnetic field in which the new magnetic fluxes emerge. The first column presents typical values of the magnetic field magnitudes. The second presents the type of magnetic configuration, which depends on the magnetic field magnitude. The third column defines the type of solar flare event. Columns 4–8 present the maximum event intensity in different ranges of electromagnetic spectra. Columns 9–10 present the possibility of coronal mass ejection and the formation of arch filament flare systems (post flare loops).

Filament eruptions or 'disparition brusque' are two-ribbon 'flare-like brightening' events with slower rise times (about 1 hour), and considerably longer lifetimes (up to 3 hours) than solar sunspot groups. There is no evidence of any impulsive phase microwave or hard X-ray emissions. These events are accompanied by weak gradual thermal soft X-rays ($\leq$C7), microwave flux ($\leq$ 50 s.f.u.), and cool loop arcades in the last stage of event evolution.

If flare knots occur in the fairly weak magnetic fields (< 50 Gs), outside the penumbra (so-called 'spotless' flares), the soft X-ray importance should not be more than M9; the hard X-rays will be very slight. This is reflected in cm radio bursts more accessible to observations. Its maximum intensity will be not more than 300 s.f.u.

The third line is related to flares with the maximal energetic input within the whole spectral range.

The last line is connected with impulsive non-thermal flares. They are clearly visible in hard X-rays and gamma radiation but are weakly distinguished in Hα ($\leq$1B) and soft X-rays.

Filament eruption prediction is worse than flare forecasting. At the moment the only reliable observational indicator of imminent filament eruption is an occurrence of weak soft X-ray emission within the filament localization region 2–4 days before the processes begin. This emission can be observed only on images with good spatial resolution (YOHKOH and SOHO data only).

The estimates show that the total value of the emerging magnetic flux cannot be less than 1.5×10^{11} Wb, and the emergence rate should be over 2×10^{7} Wb s^{-1}. These are characteristic values of unstable, constantly emerging ephemeral regions in quiet areas of the Sun. For this reason, the forecast of the solar filament eruptions is possible today only with a large degree of uncertainty.

Taking into account physical and geometrical parameters of the flare, the flare active region and solar filament permits us to predict the parameters of a solar proton event, the characteristics of geomagnetic activity and other things. The method of solar flare prediction for large and proton solar flares has been put to test on Russian scientific satellites such as GRANAT, GAMMA, KORONAS-I.

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