The magnetic reversal of the Sun and manifestations of solar activity

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Abstract. The affinity of the LDE-type flare locations to the reversed coronal magnetic sectors (and their boundaries) is studied. The Sun's gradual magnetic reversal (as described by computed coronal field structures) is compared with the occurrence of a flare activity in the solar unipolar coronal magnetic sectors. It is shown that the active regions of the 21st and 22nd cycles, giving rise to the LDE-type flares, are concentrated in the sectors of reversed magnetic polarity.

Key words: Sun – global magnetic reversal

1. Introduction

A number of the properties of the large-scale solar magnetic field, such as long-term recurrence patterns, cyclic latitudinal distribution of prominences and coronal holes (CHs), reversal of polar fields, may be used as reliable indicators of the global magnetic field reversal process.

The principal aim of this paper is to introduce some reasons favouring the fact that a gradual process of the reversal of the Sun's coronal magnetic field (as computed at the Wilcox Solar Observatory at Stanford University by Hoeksema 1989, 1992) starts at *the same* time as the new sunspot cycle, as illustrated for the ascending phase of the 22nd cycle in figures 3 - 6. Moreover, the coronal unipolar sectors of reversed polarity are, as a rule, the sites of complex sunspot groups and, consequently, also the sites of largest flares.

2. Stanford computed coronal magnetic field and magnetic reversal of Sun

The large-scale magnetic field of the Sun evolves slowly during the 11-year cycle and its large-scale changes are seen on the modelled source surface field (in fact, the computed coronal magnetic field) better than directly on photospheric and chromospheric magnetic network. The source surface fields have now been published for the last two cycles (Hoeksema and Scherrer 1986; Hoeksema 1991, 1992). If we assume that the change in the pattern of coronal unipolar magnetic

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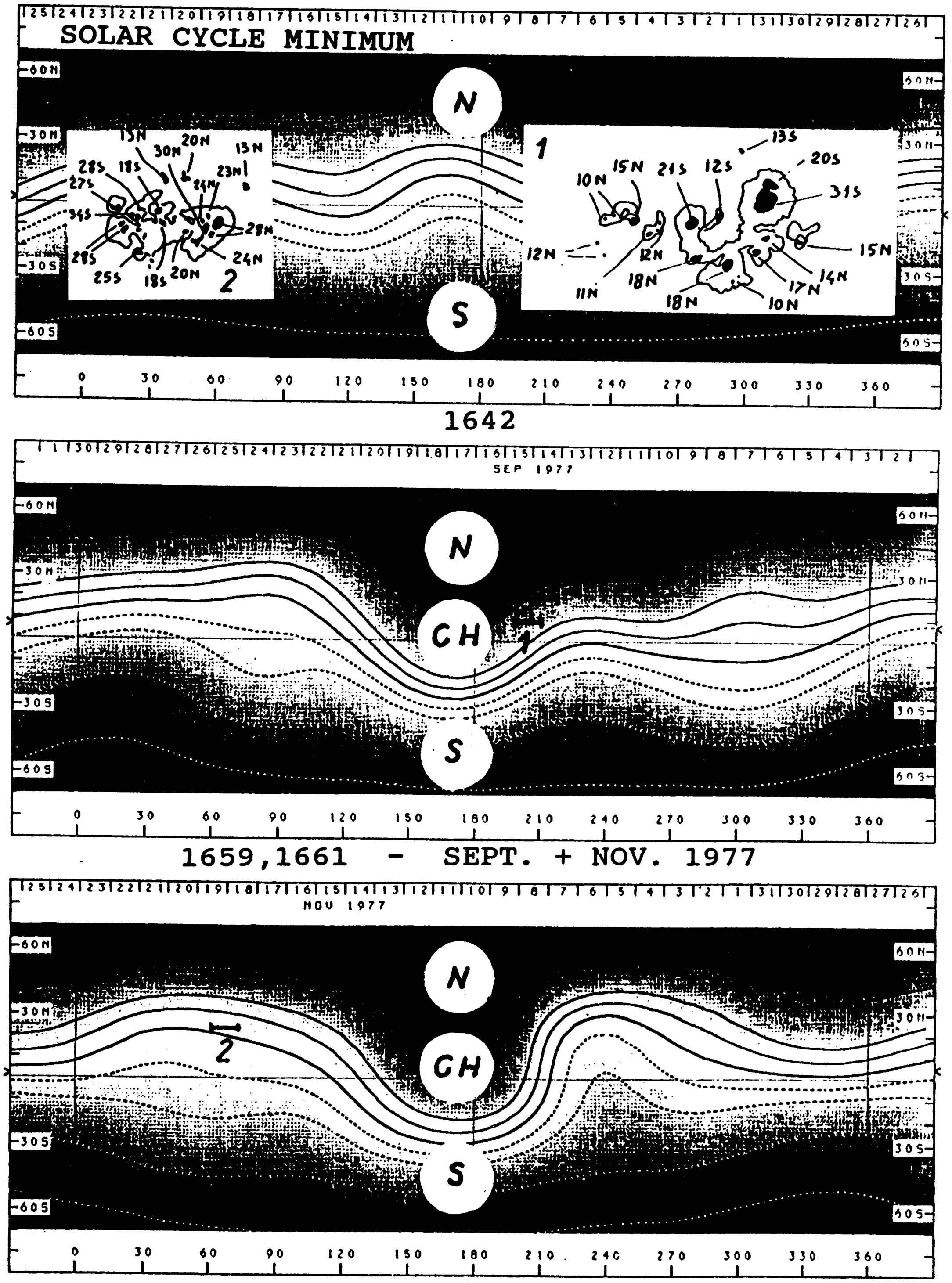

Figure 1. Gradual phases of the field reversal characterizing the onset of the 21st cycle; in both cases (September 1977 and November 1977) it is the northern hemisphere that is involved in the process. The polar CH of the 20th cycle (of the positive magnetic polarity) can be seen at L = 180°, as well as the two large complex spots.

Table 1. The occurrence of magnetically complex spots in 1977 and their distribution in magnetic sectors . The sunspot data were taken from the Debrecen Heliographic Results. September 1977 and November 1977 complex spots are illustrated in Fig. 1

CR	CMP	Area	B^o	L^o	Sector	FI
1656	Jun 29.74	677	+14.5	145.8	boundary	003
1659	Sep 15.49	863	+08.0	197.8	rev+old CH	320
1660	Oct 12.13	198	+06.7	206.3	rev+old CH	001
1661	Nov 19.39	251	+23.8	061.8	reversed	101

sectors reflects strong solar magnetic sources in some way, it is possible to take sector changes to be one of the symptoms of the global Sun's magnetic reversal.

2.1. Relationship between magnetic sectors, ARs and prominences

The origin of large-scale fields is still an open question (Svalgaard and Wilcox 1975, Howard 1979, Snodgrass 1983). The large-scale sectors may well in fact be the only diffuse surface relicts of strong field fluxes in conformity with Babcock (1961) and Leighton's original flux-transport model (1964) and its modifications (Sheeley, Jr. 1992). Significant difficulties connected with such explanation was pointed out by Severny (1969, 1971). Stepanyan (1983) came to the conclusion that large-scale magnetic fields are independent phenomena and diffused fields of active regions did not significantly affect the space occupied by a large-scale field of either sign. The latitudinal distribution of the prominence polar zones reflects the clear relations to*the polar field reversal*, which is observed at sunspot maximum. The existence of the prominence polar zones (shifting steadily from middle latitudes toward the poles) is well documented. (Ananthakrishnan 1952, 1954, Waldmeier 1955, Makarov and Sivaraman 1989, Bumba 1990, 1991, Bumba et al. 1990) and it is important part of the sunspot cycle reversal.

2.2. Does Complex Sunspot groups relate to reversed sectors?

One of the possible ways of how to tackle this problem is to consider magnetically complex spots and their relation to reversed sectors. The fact of nonrandom longitudinal distribution of solar active regions has been known for a long time (the so-called active longitudes and sunspot nests). Hence, a question naturally emerges what the relation between the latter and the sectors of unipolar field is. From current theories we would expect that sunspot bipoles form near the boundaries of the above-mentioned sectors, as schematically illustrated in Akasofu (1984). However, the observations indicate that the forming of sunspots is found in the areas of strong magnetic field rather than near the sector boundaries. It would be of considerable interest to see whether there exists the relation between locations of complex sunspots and field reversal process. The

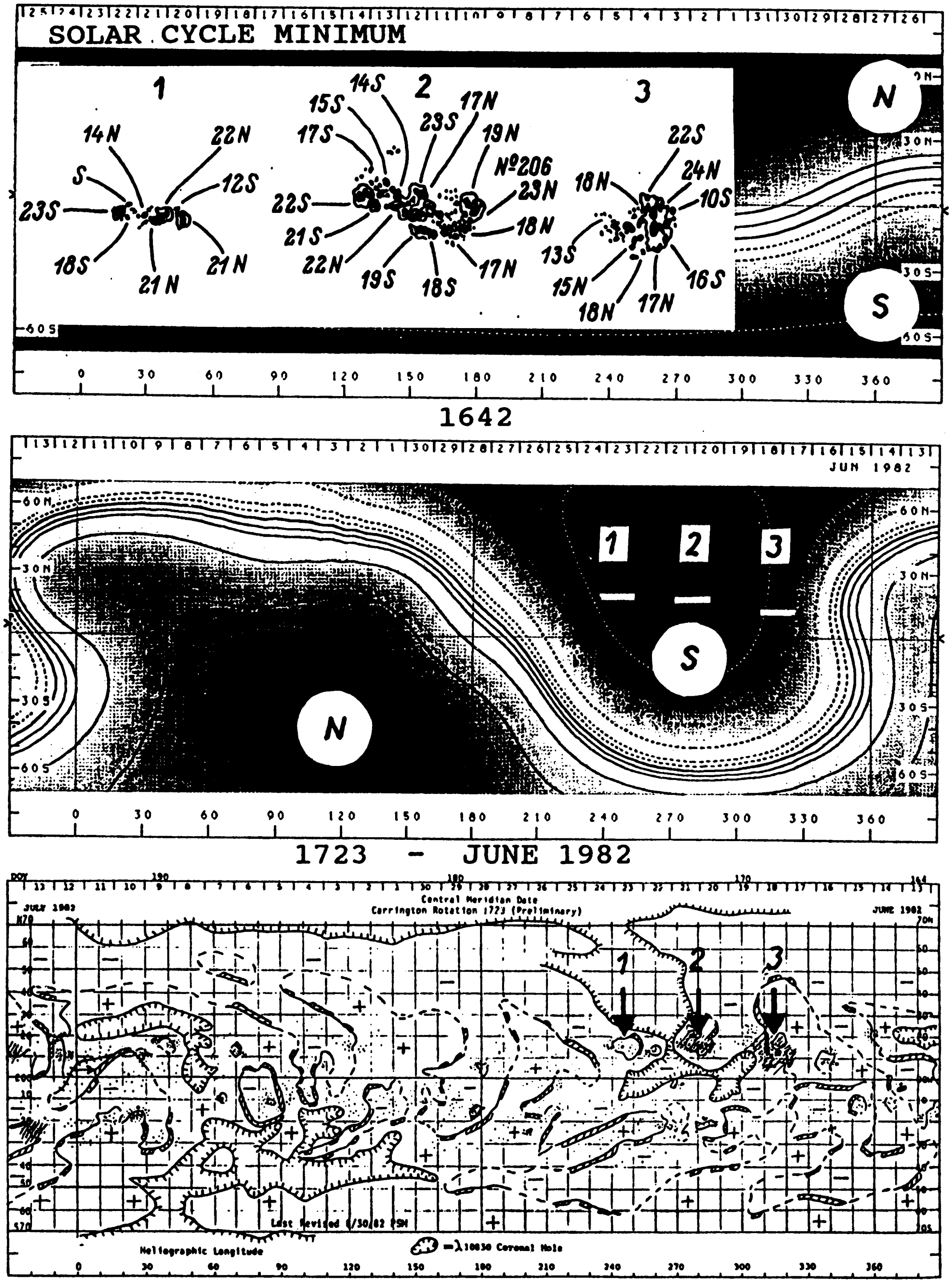

Figure 2. Well known June-July 1982 reversed magnetic sector. Three 'super-active' regions (Yazev and Banin 1991) are located close to the northern polar CH of negative polarity and are the indicators of an extreme degree of field reversal. Also this case was characterized by a large number of relativistic proton flare events (McIntosh 1992).

Table 2. The 1979 - 1985 list of large sunspot groups, published by Gnevysheva (1987) and their distribution to unipolar magnetic sectors. The occurrence of LDE-type flares in these large groups is presented by FI/N - mean LDE flare index for one group

year	N	N_{rev}	N_{boun}	N_{old}	FI_{rev}	FI_{boun}	FI_{old}
1979	34	15	08	11	398	874	085
1980	42	15	16	11	458	830	205
1981	39	23	09	07	1453	211	046
1982	34	22	04	08	2308	000	286
1983	13	05	02	06	001	132	239
1984	12	13	03	04	013	384	052
1985	03	01	01	01	205	132	001
Sum	177	94	43	48	4836	2563	914
FI/N	47	–	–	–	51	60	19

corresponding preliminary analysis for 1977 year is given in Table 1 . Taking the Debrecen Heliographic Results as a source we found only four complex groups. All spots were found to be located inside the reversed coronal magnetic sectors and their boundaries (in fact the third spot is the same as the second one, but one rotation later). LDE-type flare index (FI) was defined earlier (Antalová and Viktorínová 1991). September 1977 and November 1977 complex spots are illustrated in Figure 1.

The next step is to consider a large group formation during a solar cycle. Here it is important to know in what manner the location of large sunspot groups depends on the sector distribution. A preliminary analysis in this respect is given in Table 2 which presents the statistics of 177 large spots observed during 1979 - 1985 years (Gnevysheva 1987). The distribution of large groups between sectors seems to be uniform at the early onset of the 21st cycle (1979-1980). In 1981 and 1982 large groups were mainly located in reversed sectors. And it is namely this fact which, in our view, contributes substantially to the process of global field reversal of the 21st cycle. Hence, another question is at hand, namely, whether the appearance of large spots within the field reversal sectors is somehow linked with enhanced production of LDE-type flares. There are some indication that this may really be the case. It follows from the comparison of large group FI/N values of different magnetic sectors. From Table 2 yields that the strong LDE-type flares are concentrated in large groups of reversed sectors (their value FI/N = 51) and along the sector boundaries (value FI/N = 60). The large spots located in old polarity sectors have FI/N = 19. These results agree with the Banin and Yazev (1991) data of *the 21st cycle complexes of activity.* The active sunspot longitude (Fig. 2, 300° - 360°) is the equatorial part of the extended negative sector (from the north pole to about southern latitude 60°) of reversed polarity). The June 1982 CH formation was the final stage of the

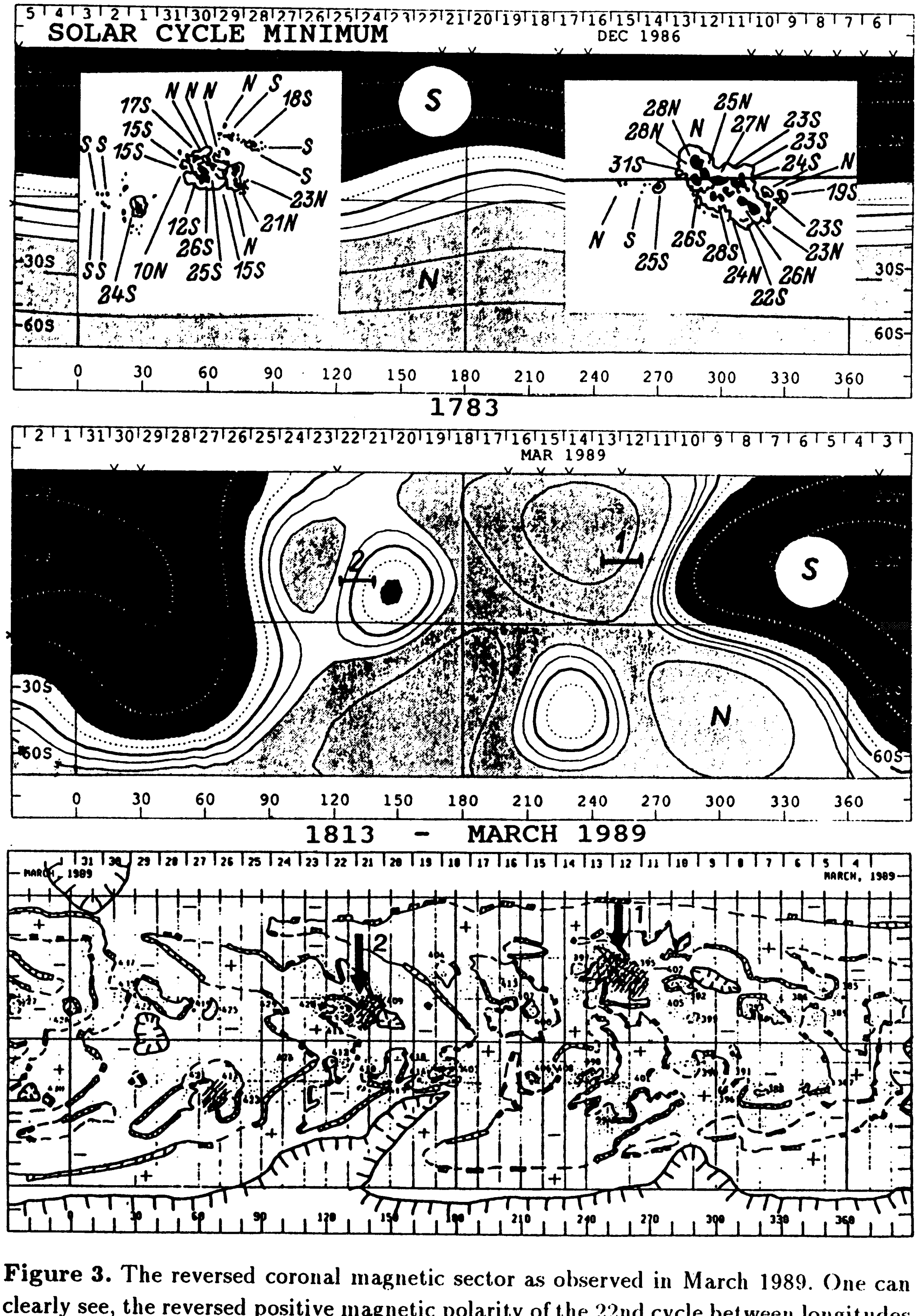

Figure 3. The reversed coronal magnetic sector as observed in March 1989. One can clearly see, the reversed positive magnetic polarity of the 22nd cycle between longitudes ranging from 90° to 300°. In reversed sector, two complex sunspot groups can be found. The large polar CH in the southern hemisphere is a remnant of the 21st cycle.

Table 3. The mean group value of the LDE-type flare index (FI/N) computed from LDE flare's active regions observed from January 1976 till December 1979. The active regions are distributed to polarity sector classes

Sector polarity	Old	Sector's border	Reversed
Number of ARs with LDE flares	76	26	48
Sum of LDE FI in all ARs	3087	3575	7394
FI/N	40	137	154

developoment of this extended reversed magnetic sector (McIntosh 1992).

2.3. Sector boundaries and flare locations

Outstanding flaring centers tend to be members of long-lived activity complexes, or "nests" of sunspot groups (Švestka 1968). The relationship between occurence of solar flares and interplanetary sector boundaries was found by Bumba and Obridko (1969) and Dittmer (1975) and their results are in agreement with here discussed idea of coronal reversed solar sectors.

From the Catalogue of LDE-type flares (Antalová 1991, 1993) it is possible to distribute all observed LDE-type flares to magnetic sectors. The 1976-1979 data (Table 3) show that the LDE flare productive nests of the ascending phase of the 21st cycle were mainly located inside reversed sector (FI/N = 137) and along the sector boundaries (FI/N = 154). The FI/N values of Table 3 are larger comparing to Table 2; there are the large groups (simetimes magnetically simple) considered.

3. The field reversal process

The computed coronal magnetic field of the Sun (Hoeksema and Scherrer 1986; Hoeksema 1991, 1992) evolves slowly during the cycle. The sector development of the last two cycles can be seen on Hoeksema's modelled source surface field maps and is documented in Figures 1 - 6.

3.1. Variation with the solar cycle

At cycle minimum, the large-scale magnetic distribution is very stable and the neutral line of the global field is not far from the equatorial plane. The whole northern and the whole southern hemisphere are unipolar (Hoeksema 1992). The gradual development of the new-cycle magnetic reversal is indicated by the formation of the small new-cycle polarity CHs in middle heliographic latitude zones 50°. Polar CHs extend equatorward from the poles approximately to latitude 30°. The polar field reversal is observed around sunspot maximum, together with the prominence polar crown disruption. It should be stressed that

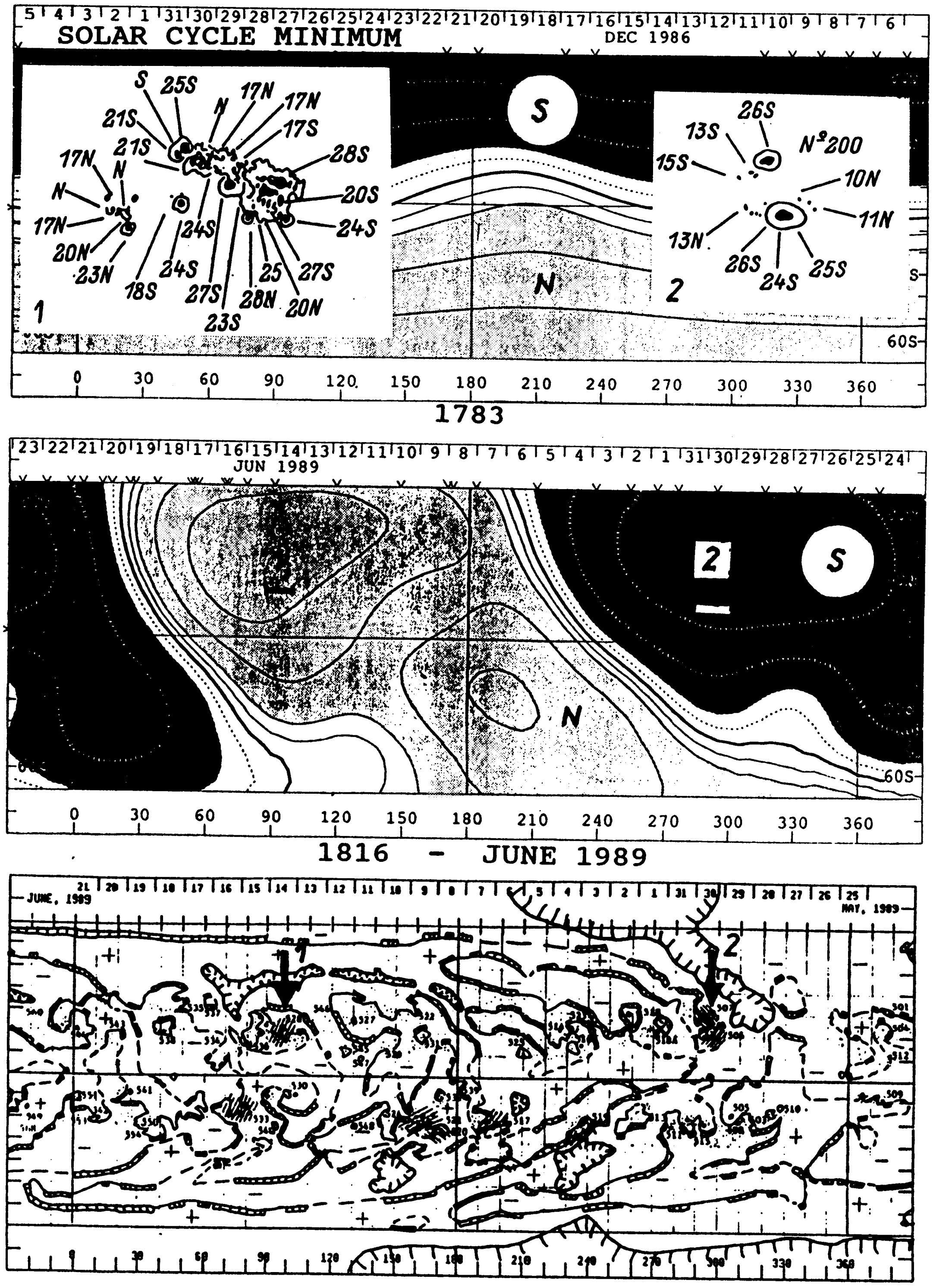

Figure 4. The reversed magnetic sector, observed in the northern hemisphere in June 1989. A middle-latitude coronal hole belonging to the 22nd cycle is observed at L = 90°. This CH is close to the site of a complex group (No. 1). On the other hand, a couple of large spots close to a old polarity polar CH show very little flare activity.

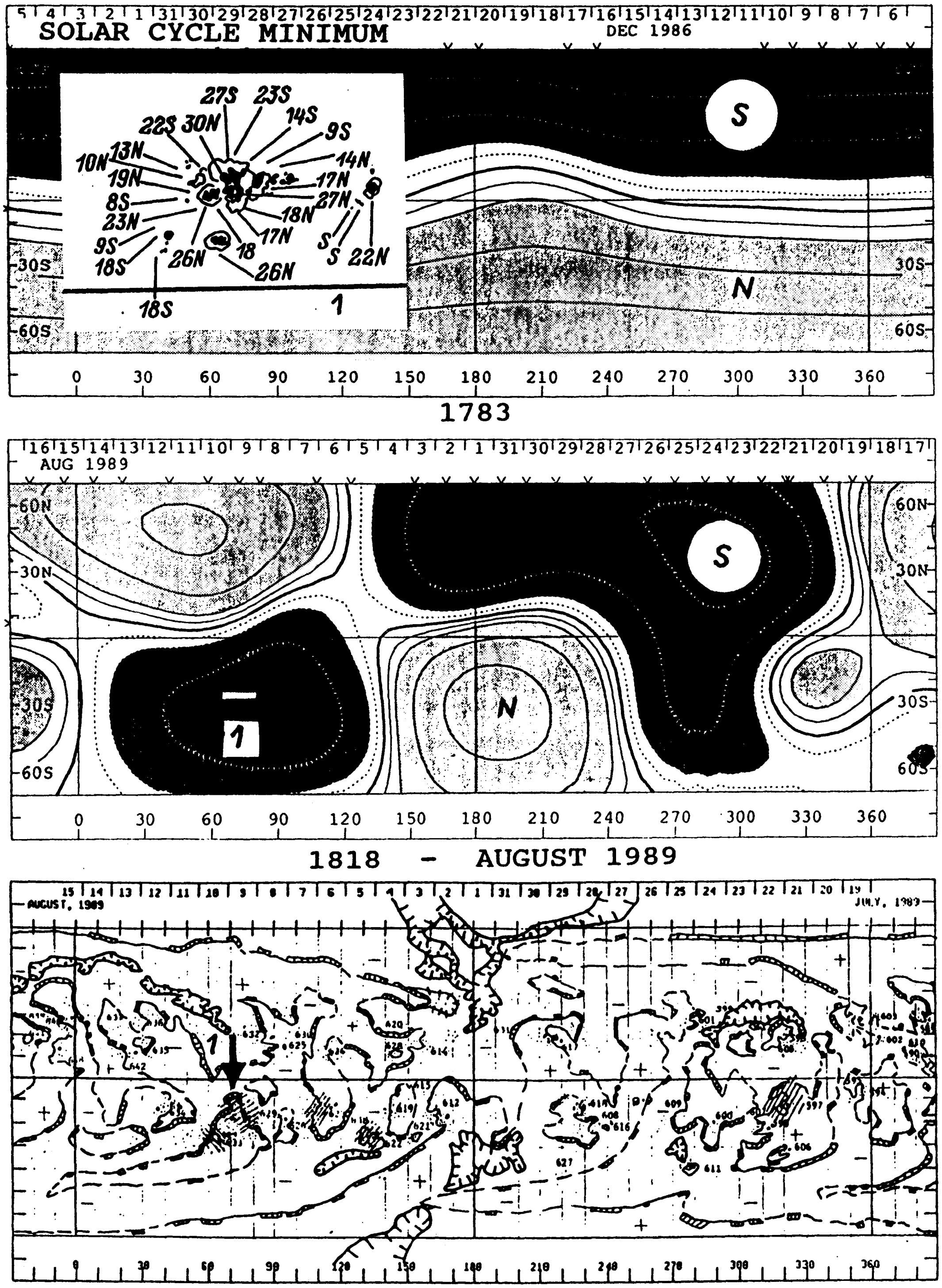

Figure 5. The southern hemisphere reversed magnetic sector, as observed in August 1989; one can identify characteristic symptoms, i.e., the presence of a composite spot group (No. 1, Korobova and Saidalieva, 1992). The northern hemisphere's middle-latitude small CH has the new 22nd cycle polarity. It is worth noticing that the both polar CHs are the remnants of the old 21st cycle.

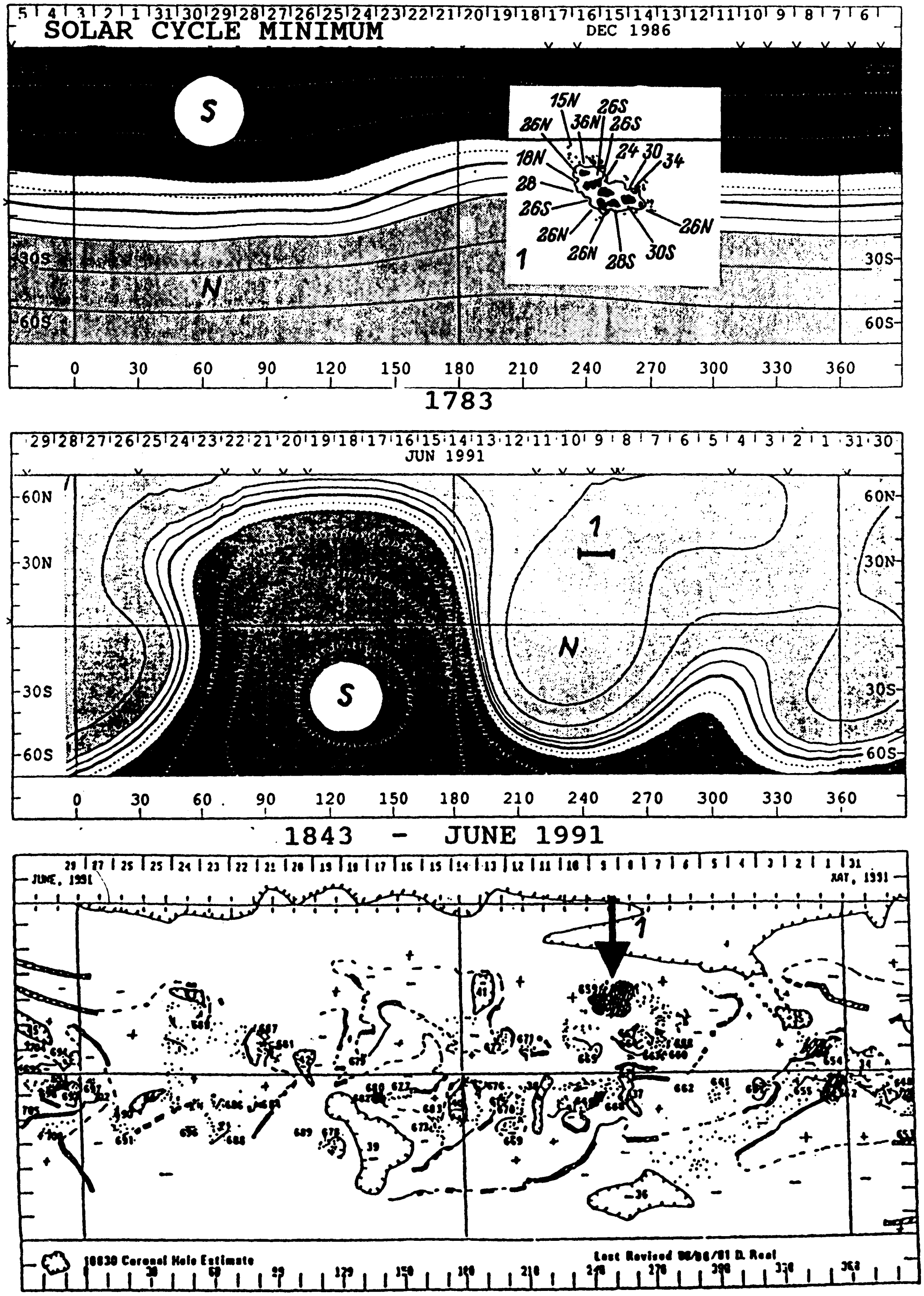

Figure 6. The magnetic positive, northern-hemisphere polar CH of June 1991 indicating a high degree of field reversal and polar field reversal. A 'super-active' region (of complex type - No. 1) is located near polar CH (McIntosh 1992) and it is characterized by a large number of proton flares.

at sunspot cycle maximum both poles already possess well-developed regions with reversed polarities of the magnetic field, and in the literature it is namely this stage that is usually termed as the 'polar or poloidal field reversal'. This may prove rather misleading, because this represents only a certain polar phase of the 'true' reversal process.

The gradual process of magnetic reversal of the Sun during the rising phase of solar cycle 22 is illustrated in Figs. 3 - 6. Each figure consists of two Carrington rotation maps of the computed coronal magnetic field (Hoeksema 1991, 1992). The upper part of the figures shows the polarity structure, as observed at the onset of the 22nd cycle (CR 1783) and the middle one represents the computed coronal magnetic field for a particular Carrington rotation. The synoptic maps, taken (*from SGD*), showing the positions of CHs and active regions, are illustrated at the bottom of each figure. One can easily identify *the polar field reversal* (see figure 6) of the 22nd cycle at the beginning of 1991.

3.2. The 22nd cycle reversed magnetic sectors - unique September 29, 1989 flare

The middle part of figure 5 represents the computed coronal magnetic field for Carrington rotation 1818 (August 1989). The extended negative magnetic sector is observed in the southern hemisphere. Active region NOAA 5629 (B = S16° , L = 80°) was located in this reversed sector and its sunspot proper motions were studied by Korobova and Saidalieva (1992). The largest observed flare (2N/X20.0) of August 16, 1989 occured in NOAA 5629. One rotation later, along the western border of the reversed sector, in active region NOAA 5698 (B = S32°, L = 230°), the famous September 29, 1989 X9.8 flare was observed.It was connected with the largest the ground level solar cosmic ray enhancement (its amplitude was about 178%, Kudela et al., 1993). The distance of NOAA 5698 from the nearest CH was about 30°.

4. Conclusions

The comparison of the distribution of the computed long-lasting Stanford magnetic unipolar sectors in the corona with the sites of energetic LDE-type flares yields the following results:
1) the sites of LDE-type flares (as well as the magnetic complex sunspot groups) are mainly concentrated inside and along the boundaries of unipolar sectors having "correct" polarity of the cycle, i.e., of the sectors showing a reverse polarity when the latter are compared with the polarity characterizing the minimum phase of the previous cycle. It, therefore, seems to be very probable that the cause of flares might have something to do with the global field reversal process.
2) the process of gradual magnetic reversal of the large-scale magnetic field of the Sun is synchronous with the sunspot activity cycle in contrary to the usually adopted view of a considerable phase shift between these two processes.

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