1989SoPh..119...45M

DO POLAR FACULAE ON THE SUN PREDICT A SUNSPOT CYCLE?

V. I. MAKAROV and V. V. MAKAROVA
Kislovodsk Station of the Pulkovo Observatory, Kislovodsk 357741, U.S.S.R.

and

K. R. SIVARAMAN
Indian Institute of Astrophysics, Bangalore 560034, India

(Received 1 January, 1988; in revised form 21 June, 1988)

Abstract. The paper reports the results of the analysis of the data on polar faculae for three solar cycles (1960–1986) at the Kislovodsk Station of the Pulkovo Observatory and on polar bright points in Ca II K line for two solar cycles (1940–1957) at the Kodaikanal Station of the Indian Institute of Astrophysics. We have noticed that the monthly numbers of polar faculae and polar bright points in Ca II K line and monthly sunspot areas in each hemisphere of the following solar cycle have a correlation with each other. A new cycle of polar faculae and polar bright points in the Ca II K line begins after the polar magnetic field reversal. We find that the smaller the period between the ending of the polar field reversal and the beginning of a new sunspot cycle is, the more intense is the cycle itself. The intensity of the forthcoming solar cycle (cycle 22) and the periods of strong fluctuations in activity expected in this cycle are also discussed.

1. Introduction

Solar activity is usually associated with an 11-year sunspot cycle and other solar events that are observed at latitudes from + 40° to − 40°. However, observations of the polar faculae, shapes of the corona, prominences, evolution of the large-scale and polar magnetic fields show that solar activity should be considered as a global process (Makarov, Makarova, and Koutchmy, 1985; Makarov, 1986; Makarov and Makarova, 1986, 1987). It is known that the solar activity at latitudes greater than 40°–50° manifests as polar faculae which appear as small bright emission points of sizes $\sim 10^3$ km and lifetimes ranging from an hour to a day (Weber, 1865; Waldmeier, 1955; Sheeley, 1976). Polar faculae cycles last from 7 to 12 years and are in the antiphase with sunspot cycles (Waldmeier, 1955; Sheeley, 1976; Makarov, Makarova, and Sivaraman, 1987). The first polar faculae emerge at latitudes from 40° to 70° north and south of the solar equator immediately after the polar magnetic field reversal. The zone of polar faculae emergence migrates poleward with the mean velocity 0.5 m s^{-1} and the last polar faculae emerge at latitudes from 70° to 80° (Makarov and Makarova, 1986; Makarov and Sivaraman, 1986a). A study of the photoheliograms, spectroheliograms in the Ca II K line and magnetograms pertaining to the last 3 solar minima of 1964, 1975, and 1985 shows that the bright emission points similar to polar faculae, although distributed over the entire Sun, are seen to be concentrated at about 60°. Makarov and Makarova (1987) calculated that about 10^3 of these features are simultaneously seen on the entire Sun at any time. Sheeley (1976) from a comparison of the solar activity in

Solar Physics **119** (1989) 45–54.

polar zones with the emergence of sunspots, has shown that the polar faculae result from the decay of active regions of the preceding solar cycle. It was suspected that half a cycle delay in the progress of activity in the polar zones with respect to sunspots is connected with the migration of the magnetic field from the equatorial zone to the polar zone (Bumba and Howard, 1965).

In this paper, we report new results on the correlation of the polar zone activity with the sunspot activity in the following cycle. We have noticed a high correlation between the frequency of emergence of polar faculae and sunspot areas of the preceding cycle on the scheme of the evolution of the zonal structure of the large-scale magnetic field of the Sun (Makarov, Makarova, and Koutchmy, 1985) which conforms with the above mentioned results. But circa $\frac{1}{2}$ of polar faculae and polar bright points in the Ca II K line are in the form of bipolar magnetic structures, others are monopolar. The leading polarity of the magnetic field in bipolar structure as well as in monopolar structures has the same sign as that of the background magnetic field at latitudes 40°–50° in the current cycle and has the same sign as that of the leader sunspot of the succeeding cycle.

2. Observational Data

We have used monthly numbers of polar faculae and monthly sunspot areas for 1960–1986 in each solar hemisphere from the white light images of the Sun (diameter ~ 80 mm) that are obtained daily at the Kislovodsk Station of the Pulkovo Observatory. For the two earlier cycles 1940–1948 and 1950–1958, we used Ca II K_{232} spectroheliograms of Kodaikanal Station of the Indian Institute of Astrophysics, which are obtained on a daily basis. The solar image in the spectroheliograms has a diameter of ~ 60 mm. We have made the number counts of the high latitude bright facular points from these spectroheliograms, for these two cycles. The monthly numbers of the polar faculae for the period covered in this investigation are listed in Tables I and II. The observed number of polar faculae in the course of a year was corrected by the experimental visibility functions F_N and F_S. Data on the epochs of the reversal of the polar magnetic field of the Sun during 1870–1982 used for this investigation are from Makarov and Sivaraman (1986b).

3. Results

3.1. From the polar faculae data and the epochs of polar field reversal, we find that a new polar faculae cycle begins immediately after the polar magnetic field reversal has taken place (Makarov, Ruzmaikin, and Starchenko, 1987) and a new sunspot cycle begins 4 to 7.5 years later. We determined the epoch of the polarity reversal of the magnetic field of the Sun from the synoptic charts of the large-scale magnetic field prepared from the Kodaikanal observations covering the period 1904–1982 (Makarov and Sivaraman, 1983). These data were later supplemented with Secchi's observations of prominences (Makarov, 1983a, b). Thus, at present we have with us information on the epochs of the polar magnetic field reversal for the past 100 years (Makarov and

TABLE I

The observed numbers of bright points from the Ca II K line spectroheliograms (latitude $\varphi > 50°$) and smoothed experimental visibility function

Northern hemisphere													Southern hemisphere												
Years	Months												Years	Months											
	1	2	3	4	5	6	7	8	9	10	11	12		1	2	3	4	5	6	7	8	9	10	11	12
1940	14	14	13	17	28	34	36	40	38	38	38	35	1940	18	28	34	35	32	25	16	14	15	20	28	34
1941	27	18	15	19	33	50	59	60	55	57	45	35	1941	40	48	48	49	47	40	39	24	21	26	30	38
1942	28	27	25	35	41	29	33	39	51	43	38	30	1942	44	57	54	65	60	33	23	23	25	21	28	29
1943	20	23	24	31	37	32	42	48	50	49	40	34	1943	37	43	45	45	48	27	24	18	17	23	39	41
1944	34	21	26	29	34	43	47	62	53	52	60	44	1944	29	46	49	49	47	35	28	26	23	27	37	46
1945	29	20	18	18	23	28	34	40	36	37	28	23	1945	41	42	43	26	21	24	17	13	11	13	13	14
1946	21	20	15	16	14	16	18	17	20	30	26	16	1946	26	34	30	25	21	6	4	2	3	11	9	11
F_N smoothed	0.53	0.43	0.41	0.50	0.63	0.72	0.83	1.0	1.0	0.98	0.90	0.67	F_S smoothed	0.83	1.0	1.0	0.98	0.90	0.67	0.53	0.43	0.41	0.50	0.63	0.72
1949	4	4	4	5	6	7	8	8	10	13	9	7	1949	4	4	4	5	5	4	4	4	6	7	9	6
1950	5	7	6	9	8	13	19	29	44	41	37	32	1950	4	6	8	8	6	8	7	10	15	17	21	24
1951	29	23	24	22	37	41	48	52	51	45	45	38	1951	29	34	39	32	37	34	24	23	21	20	20	29
1952	40	35	31	46	69	74	86	96	80	83	80	54	1952	41	56	58	78	84	64	49	42	35	40	52	49
1953	58	35	46	47	51	65	83	86	101	107	89	66	1953	66	81	103	100	75	60	49	39	48	52	71	67
1954	62	41	37	38	58	71	76	110	126	119	105	103	1954	84	80	75	81	93	73	54	50	56	56	75	81
1955	82	52	60	75	96	80	94	122	107	106	93	52	1955	67	61	74	94	82	78	59	46	40	46	53	49
1956						40	52	60	61	55	60	54	1956						29	27	26	25	22	35	34
1957	31	19	15	18	17	14	15	9	9	8	7	5	1957	47	36	38	41	24	12	8	4	5	5	12	11
F_N smoothed	0.56	0.44	0.46	0.52	0.64	0.71	0.80	0.92	1.0	0.98	0.90	0.72	F_S smoothed	0.80	0.92	1.0	0.98	0.90	0.72	0.56	0.44	0.46	0.52	0.64	0.71

TABLE II

The observed monthly numbers of polar faculae in the northern and southern hemisphere from white light images

Northern hemisphere													Southern hemisphere												
Years	Months												Years	Months											
	1	2	3	4	5	6	7	8	9	10	11	12		1	2	3	4	5	6	7	8	9	10	11	12
1960							8	14	24	22	13	10	1960							1	3	2	1	0	2
1961	8	10	8	13	13	22	47	52	42	31	20	8	1961	2	3	2	4	4	5	6	4	4	5	8	4
1962	11	6	4	7	7	13	24	30	28	15	13	6	1962	8	6	8	13	6	8	8	7	8	0	2	2
1963	2	5	12	9	7	11	14	20	22	18	20	2	1963	0	5	12	15	6	8	4	6	3	6	8	11
1964	3	2	1	6	10	18	22	30	28	22	13	8	1964	4	5	2	5	5	6	7	11	8	6	9	8
1965	6	3	6	3	12	5	14	10	16	12	7	4	1965	3	3	8	4	20	9	3	1	2	4	2	2
1966	5	6	4	6	9	10	4	16	16	10	10	5	1966	10	13	18	20	15	7	11	10	5	2	2	4
1967	2	3	2	3	3	4	5	8	10	8	3	1	1967	4	6	5	8	5	5	6	7	2			
1968	2	2	3	1		1	1	2	0			1	1968												
1969													1969												
1970													1970												
1971	3	2	4	4	3	4	2	2	8	8	11	4	1971							1	2	2	2	1	2
1972	4	4	7	8	13	19	22	26	50	21	6	6	1972	2	4	5	7	2	6	5	9	4	7	1	2
1973	5	7	6	5	14	21	17	24	24	16	11	4	1973	2	5	7	10	14	8	16	14	12	8	4	3
1974	9	14	11	4	10	26	10	16	44	21	18	14	1974	10	16	20	15	15	30	21	8	9	6	9	9
1975	13	15	5	7	17	16	20	70	44	12	15	12	1975	18	20	23	28	38	25	11	8	9	6	6	12
1976	15	8	10	12	9	18	28	40	28	28	31	15	1976	21	18	63	27	18	21	15	5	9	7	9	9
1977	7	1	3	7	8	12	20	20	24	15	13	4	1977	13	8	23	22	18	10	9	9	5	4	7	3
1978	1	3	2	4	9	10	16	20	12	6	4	6	1978	2	8	8	10	2	8	4	2	2	1	1	2
1979													1979												
1980													1980												
1981													1981												
1982						13	13	13	14	10	14	12	1982						2	3	4	4	2	3	4
1983	24	11	20	14	18	26	53	37	50	36	41	28	1983	14	9	15	10	11	18	25	14	24	15	14	16
1984	22	14	12	32	24	32	36	34	33	28	36	25	1984	22	22	27	40	29	28	25	15	7	8	20	22
1985	20	23	19	18	22	31	48	52	55	48	44	38	1985	52	43	47	44	30	25	26	17	19	17	20	40
1986	26	30	27	23	24	38	56	29	20	19	23	24	1986	53	54	53	54	33	38	37	12	10	4	11	14
1987	16	19	18	18									1987	25	44	38									
F_N smoothed	0.37	0.33	0.33	0.37	0.44	0.63	0.81	0.96	1.0	0.80	0.55	0.41	F_S smoothed	0.55	0.75	1.0	1.0	0.85	0.70	0.55	0.40	0.35	0.30	0.35	0.40

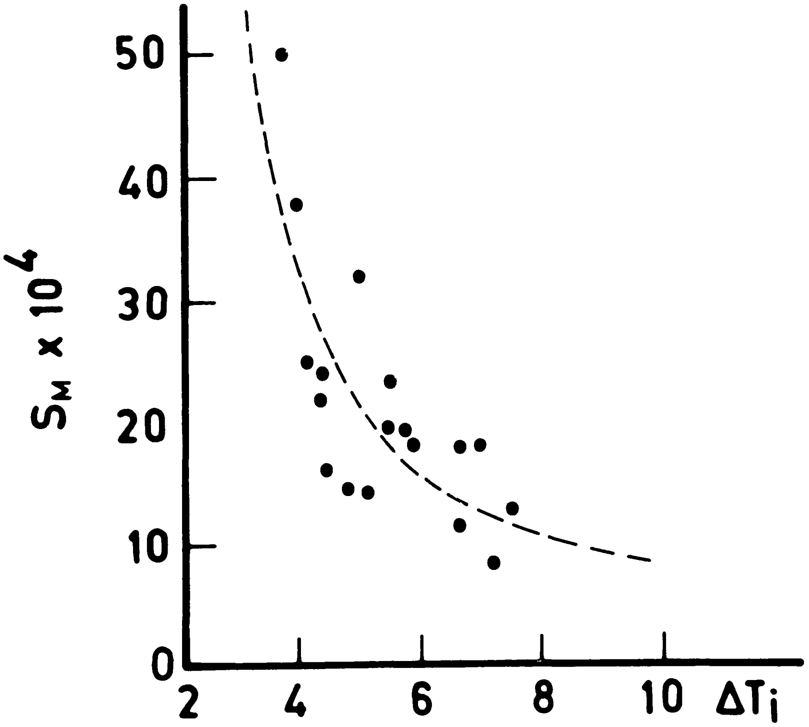

Fig. 1. Dependence of the maximum semiannual sunspot areas S_M derived separately for the N and S hemispheres on ΔT_i which is a time interval between the epoch of the polar field reversal and the beginning of the sunspot cycle.

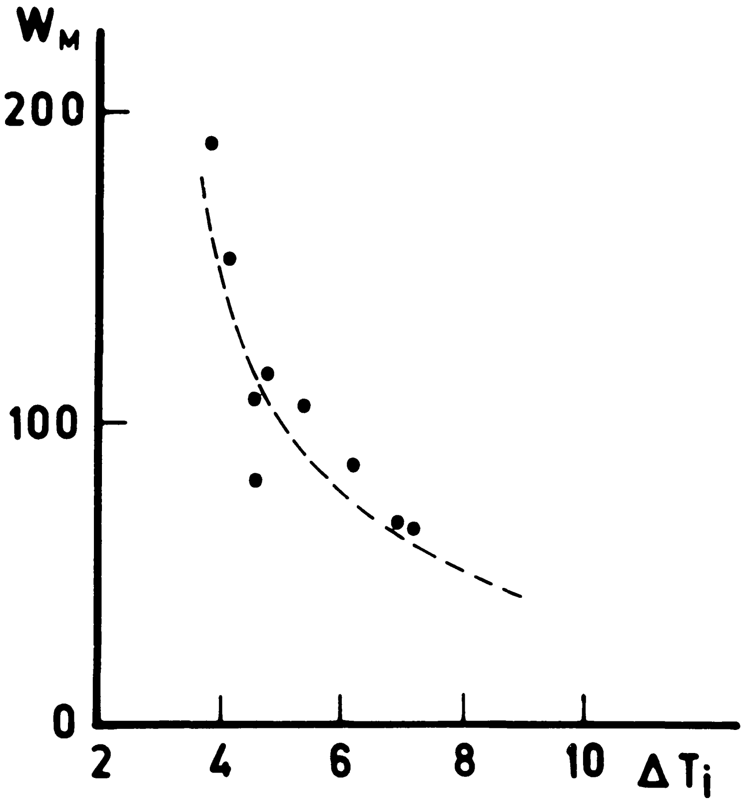

Fig. 2. Smoothed Wolf numbers (W_M) at the maximum of the next cycle versus ΔT_i. (ΔT_i same as in Figure 1.)

Sivaraman, 1986b). We find that, the smaller the interval ΔT_i between the ending of the polar magnetic field reversal T_{i-l}^r and the beginning of a new sunspot cycle T_i is, the more intense is the ith sunspot cycle (Figures 1 and 2).

If

$$\Delta T_i = T_i - T_{i-l}^r ,$$

then, approximately this dependence can be written as:

$$S_M \simeq \frac{65}{\Delta T_i - 2} , \qquad W_M \simeq \frac{300}{\Delta T_i - 2} ,$$

where S_M is a sunspot area expressed in 10^{-2} times the area of the solar hemisphere, W_M is the Wolf number at the maximum of the cycle. The last solar minimum occurred at about 1986.2 and the last polar magnetic field reversals occurred in 1981.0 and 1981.6

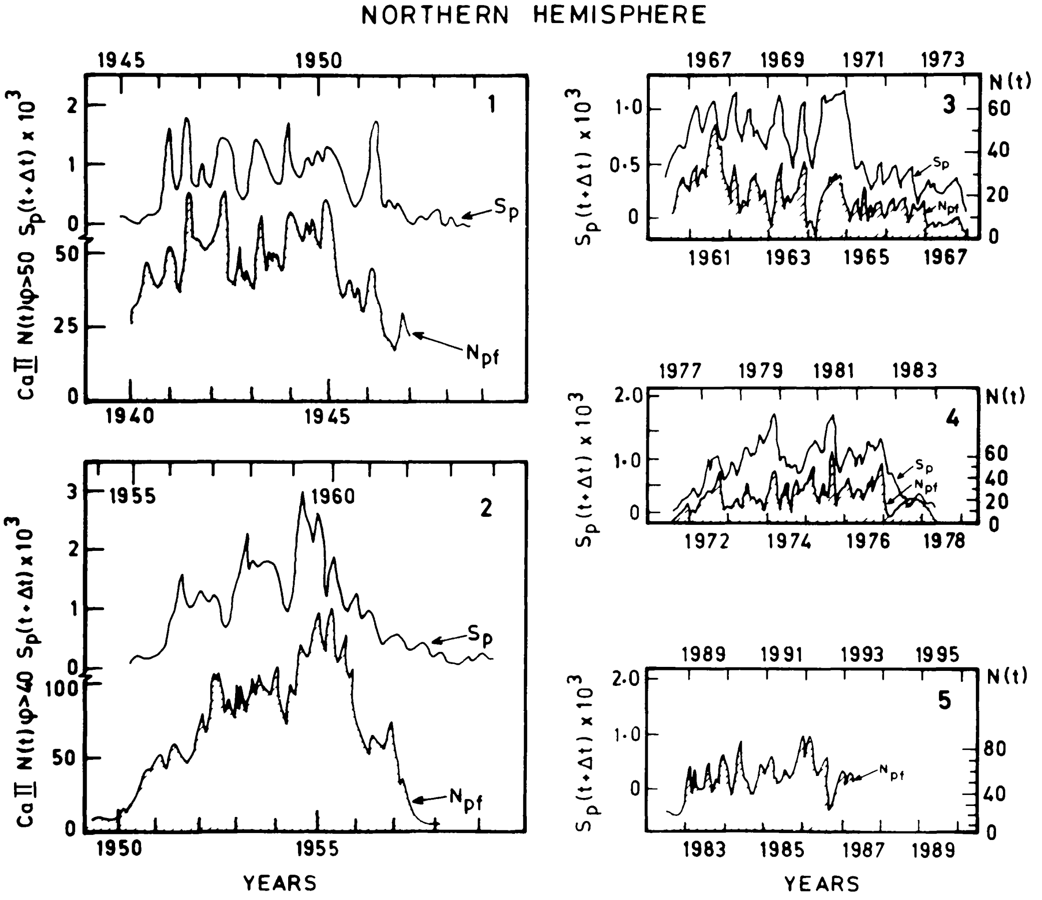

Fig. 3. The hatched (lower) curve is a plot of the monthly numbers of polar faculae $N(t)$ with time in years for the northern hemisphere. The corresponding years for the polar faculae are marked at the bottom of each box. The thick curve immediately above the hatched curve in each box is a plot of the monthly sunspot areas $S_p(t + \Delta t)$. The time-scale in years for the spot areas are marked on the top of each box. Δt is the time in years by which the polar faculae counts have to be lagged for maximum correlation with spot areas. Boxes 1 and 2: the faculae counts are from the Ca II K_{232} spectroheliograms. Boxes 3, 4, and 5: the faculae counts are from white light images. Notice that Δt = 5.8 yr for the 20th sunspot cycle (Box 3) and Δt = 5.6 yr for the 21st sunspot cycle (Box 4). Box 5: the faculae counts are from white light images for 1982–1987 (hatched) for the northern hemisphere.

for the northern and southern hemispheres, respectively. Thus, we have $\Delta T_i(N) \simeq 5.2$ and $\Delta T_i(S) \simeq 4.6$ years and expect that the next solar cycle (cycle 22) will have $W_M \simeq 100$ to 110, and $S_M(N) \simeq 20 \times 10^{-2}$ and $S_M(S) \simeq 28 \times 10^{-2}$ of the area of the solar hemisphere. A similar forecast $W_M = 109 \pm 20$ for the twenty second cycle was made on the basis of measurements of the polar magnetic field of the Sun during the sunspot minimum (Schatten and Hedin, 1984). A few more authors using different methods have arrived at similar results (Chistjakov, 1982; Robbins, 1983; Vitinsky, 1986; Wang-Tai-long, 1985). Ohl's (1987) forecast for W_{22} is 150. This figure is somewhat higher than all other predictions.

The commencement epochs of a polar faculae cycle and a sunspot cycle correspond to the onset of the first and second waves of the global solar cycle activity, respectively (Makarov, Ruzmaikin, and Starchenko, 1987). But the length of the interval between the starting points of these two waves is related to the intensity of the second wave. Thus, the properties of the new sunspot cycle gets to be formed immediately after the polar magnetic field reversal.

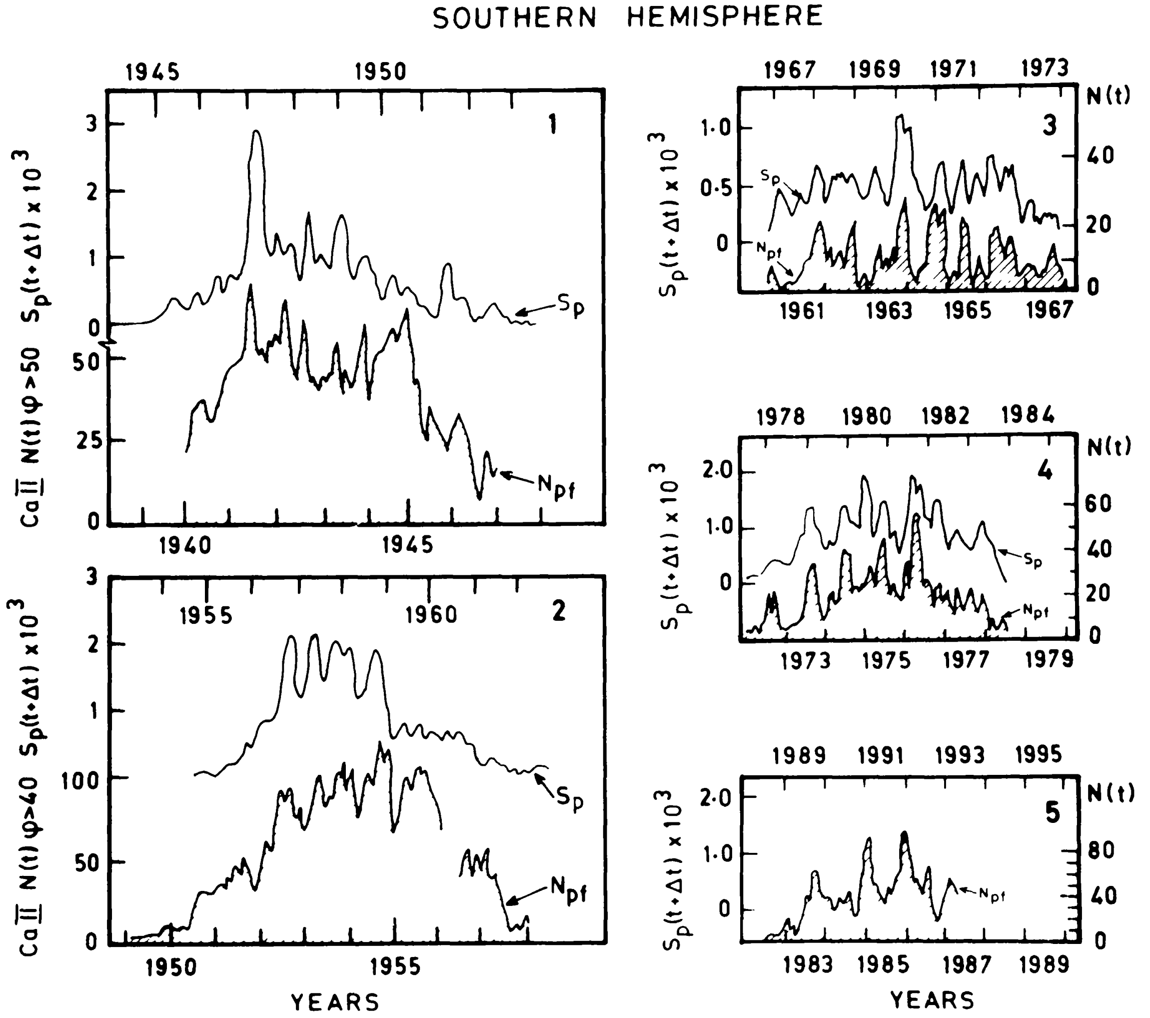

Fig. 4. Same as Figure 3 for the southern hemisphere. $\Delta t = 6.2$ yr for the 20th sunspot cycle (Box 3) and $\Delta t = 5.4$ yr for the 21st sunspot cycle (Box 4). Box 5: the faculae counts are from white light images for 1982–1987 (hatched) for the southern hemisphere.

3.2. The idea on a relation between the number of polar faculae and the sunspot number during the next sunspot cycle has been used by Schatten and his colleagues for predictions of future sunspot numbers (Schatten *et al.*, 1978; Schatten, 1986). We have also noticed a high degree of correlation (0.76 to 0.86) between the variations of monthly numbers of polar faculae $N(t)$ in any cycle and the sunspot areas, $S_p(t + \Delta t)$ for each hemisphere of the following cycle (Figures 3 and 4). For the last two sunspot cycles 1966–1985, the correlation was maximum for a value Δt that ranged from 5.8 to 6.2 years.

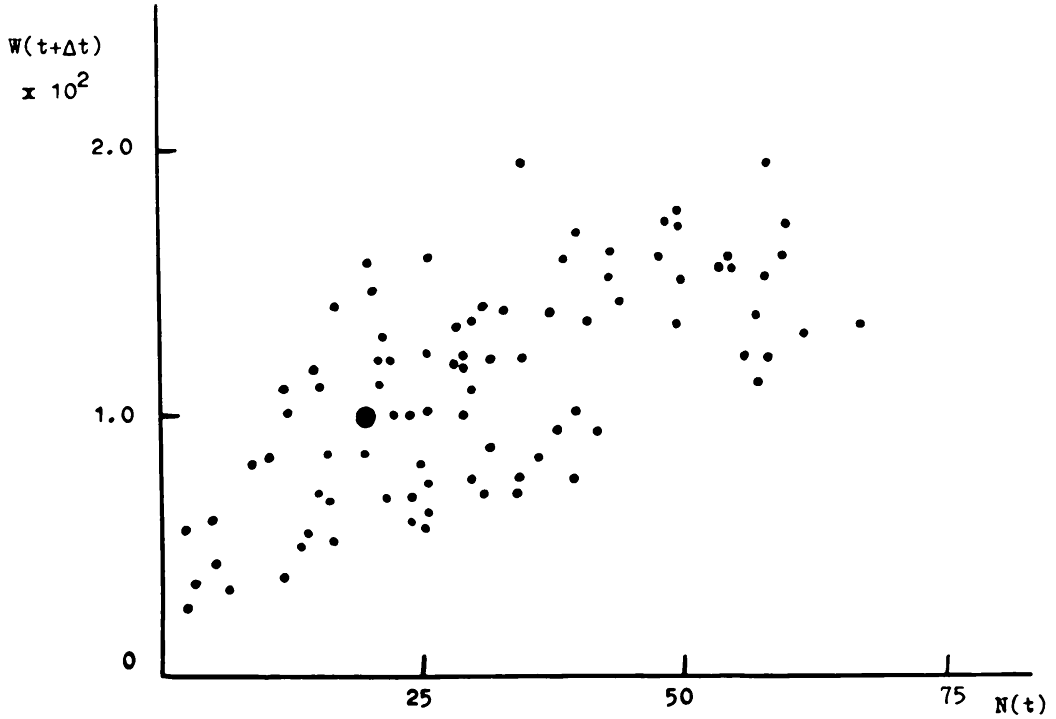

Fig. 5. Dependence of the polar faculae monthly numbers in both polar zones $N(t)$ in the period 1972–1978 on monthly Wolf number $W(t + \Delta t)$ in the period 1978–1983. Timeshift between the beginning of the polar and sunspot activity Δt has been taken as equal to the mean value ΔT_i for both hemispheres.

Thus, the observations show that a sunspot cycle is modulated by the frequency of emergence of polar faculae. This modulation shows up even in the structure and duration of activity bursts (Figure 3, boxes 1 and 4 and Figure 4, boxes 1 to 4). Thus, it may be possible to predict strong fluctuations of sunspot emergence almost 4–7 year in advance through a knowledge of the polar zone activity.

The results obtained emphasize the dualism of the connection of activity in polar zones with that of the sunspots. Indeed, on the one hand, polar faculae are a result of the poleward migration of most sunspot magnetic fields of the preceding cycle. On the other hand, the same polar faculae possess information on the properties of the succeeding cycle too. The dependence obtained, perhaps, may be interpreted in terms of the theory of the global solar activity. According to Makarov, Ruzmaikin, and

Starchenko (1987), this process shows up as two approximately 11-yr dynamo-waves of the solar magnetic field, shifted relative to each other by half a period. It is possible, there is a third shorter-period wave (Makarov, Ruzmaikin, and Starchenko, 1987) whose source is at the bottom of the convective zone and which may show up in the activity variations of the first two waves.

The results obtained (Figure 3, box 5 and Figure 4, box 5 for $\Delta t = 6.0$ yr) can be used for prediction of powerful fluctuations lasting for 2–3 months in sunspot activity in the forthcoming solar cycle (cycle 22). Although as it has been noted above the interval between the ending of the polar magnetic field reversal and the beginning of a new sunspot cycle is 5.2 yr and 4.6 yr for the northern and southern hemispheres respectively. Now we do not insist on the forecast, since we do not know the exact epoch of the beginning of the twenty-second cycle. Time variations of sunspot areas can be determined more precisely when the ascending phase of cycle 22 is definite.

3.3. We have also compared the sunspot activity for the entire Sun (Wolf numbers) with that of polar faculae in both polar zones (for cycle 21, Figure 5). A high degree of correlation $\rho = 0.70$ has been noted between monthly number of polar faculae of the northern and southern hemisphere $N(t)$ in the period 1972–1978 and monthly Wolf number $W(t + \Delta t)$ in the period 1978–1983. The time-shift between the beginning of polar and sunspot activity Δt has been taken as equal to the mean value ΔT_i for both hemispheres.

Acknowledgements

Both of us (V.I.M. and K.R.S.) wish to express our thanks to Prof. J. C. Bhattacharyya, Director, Indian Institute of Astrophysics, for his kind encouragement. Part of the work was carried out during the visit of V. I. Makarov to the Indian Institute of Astrophysics, Bangalore and Kodaikanal under the Scientific Exchange Programme between the USSR Academy of Sciences and the Indian National Science Academy.

The authors are grateful to the unknown referee whose advice helped to improve the paper.

References

Bumba, V. and Howard, R.: 1965, *Astrophys. J.* **141**, 1492.
Chistjakov, V. F.: 1982, *Soln. Dann.* No. 4, 97.
Makarov, V. I.: 1983a, *Soln. Dann.* No. 1, 86.
Makarov, V. I.: 1983b, *Soln. Dann.* No. 7, 87.
Makarov, V. I.: 1986, *Soln. Dann.* No. 8, 57.
Makarov, V. I. and Makarova, V. V.: 1986, *J. Astrophys. Astron.* **7**, 113.
Makarov, V. I. and Makarova, V. V.: 1987, *Soln. Dann.* No. 3, 62.
Makarov, V. I. and Sivaraman, K. R.: 1983, *Solar Phys.* **85**, 227.
Makarov, V. I. and Sivaraman, K. R.: 1986a, *Soln. Dann.* No. 9, 64.
Makarov, V. I. and Sivaraman, K. R.: 1986b, *Bull. Astron. Soc. India* **14**, 163.
Makarov, V. I., Makarova, V. V., and Koutchmy, S.: 1985, *Soln. Dann.* No. 8, 53.
Makarov, V. I., Makarova, V. V., and Sivaraman, K. R.: 1987, *Soln. Dann.* No. 4, 62.

Makarov, V. I., Ruzmaikin, A. A., and Starchenko, S. V.: 1987, *Solar Phys.* **111**, 267.
Ohl, A. I.: 1987, *Soln. Dann.* No. 2, 58.
Robbins, R. W.: 1983, *Cycles* **34**, 187.
Schatten, K. N.: 1986, in P. A. Simon, G. Heckman, and M. A. Shea (eds.), *Solar-Terr. Predict.-Proc. Workshop*, Meudon, June 18–22, 1984, NOAA, pp. 92–96.
Schatten, K. N. and Hedin, A. E.: 1984, *Geophys. Res. Letters* **11**, 873.
Schatten, K. N., Scherrer, P. H., Svalgaard, L., and Wilcox, J. M.: 1978, *Geophys. Res. Letters* **5**, 411.
Sheeley, N. R., Jr.: 1976, *J. Geophys. Res.* **81**, 3462.
Vitinsky, Yu. I.: 1986, *Soln. Dann.* No. 8, 64.
Waldmeier, M.: 1955, *Z. Astrophys.* **38**, 37.
Wang Tai-long: 1985, *Acta Geophys. Sinica* **28**, 641.
Weber, F.: 1865, *Wochenschrift Astron. Meteorol. Geogr.* **8**, 38.