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CALCIUM FLOCCULI AS AN INDEX OF SOLAR ACTIVITY

By

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Abstract

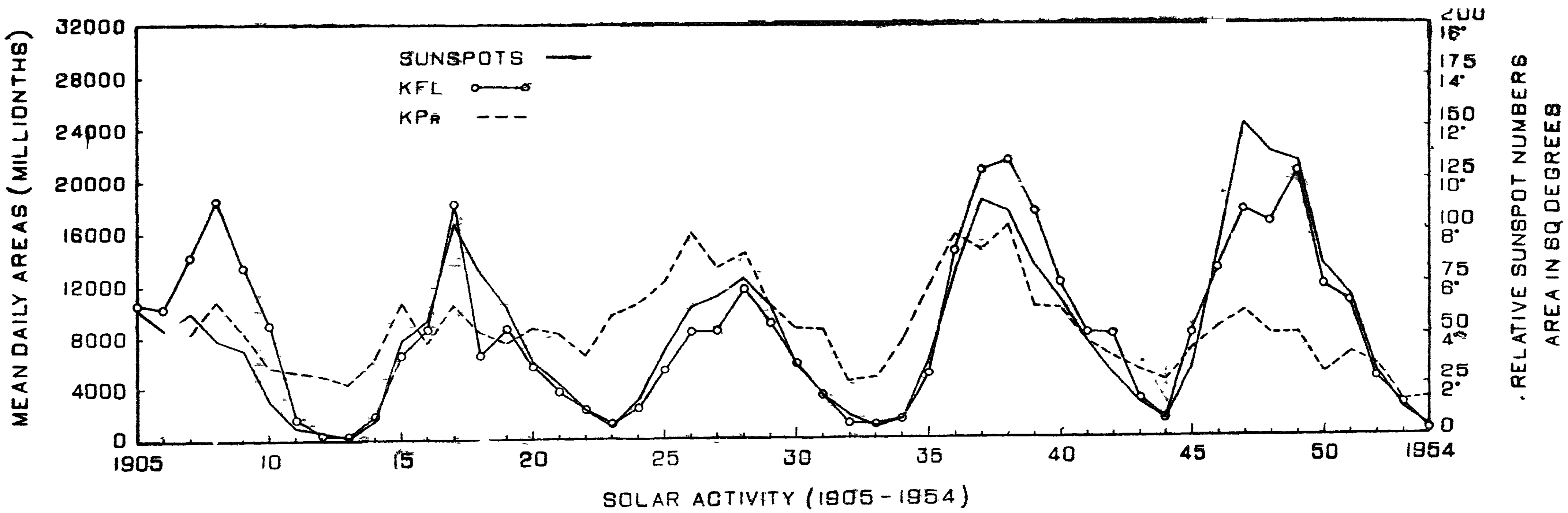
Areas of calcium flocculi (plages) were measured from the Kodaikanal calcium spectroheliograms for the period 1905-1954. Yearly mean daily areas and areas in each quadrant have been tabulated. The mean daily areas show a high correlation with the relative sunspot number and the mean daily areas of sunspot. The east-west asymmetry of the calcium flocculi has been discussed.

Introduction.—Calcium flocculi (plages) are chromospheric features associated with sunspots or disturbed regions. Since Hale obtained the first calcium spectroheliogram in 1889, it has been well established that calcium plages are an important aspect of solar activity. It has often been proposed to use them as an index of solar activity since they are more long-lived and extensive in area than the associated sunspots. Since 1955, Kodaikanal Observatory publishes regularly the total and mean daily area of calcium flocculi. Mount Wilson and Tokyo Observatories publish a K-index which is an estimate of calcium plage activity. Calcium spectroheliograms are available in the Kodaikanal plate collection since 1905 and hence it was considered worthwhile to extend the plage area measurement back as far as possible.

Calcium spectroheliograms consist of a regular surface mottling extending all over the disc with concentrated masses of flocculi following the sunspot activity distribution zones. The areas given in this paper refer to these latter concentrated masses. For each day, when an observation was available, one calcium spectroheliogram was taken and was projected over the appropriate Stonyhurst's disc and areas of calcium plages were read out from it. The area given here is a measure of the plage coverage of the solar ~~disc~~ hemisphere and is uncorrected for foreshortening. Since the calcium plages have irregular boundaries the estimation errors are inevitable.

Table I gives the yearly summaries of the mean plage area, quadrantwise, in the two hemispheres bothways i. e. north-south and east-west and the total plage activity. For a ready reference the corresponding year's mean daily values of sunspot area and the relative sunspot numbers for the whole period have also been tabulated. The values have been extracted from the Royal Greenwich Observatory publications and from Waldmeier's Sunspot Activity 1610-1960.

The mean daily areas of calcium flocculi when plotted against the corresponding years (Fig. 1) show very closely the 11-year pattern of solar activity. Figure 1 also contains a plot of relative sunspot numbers and the mean daily areas of prominence. The data for the latter have been taken from the Kodaikanal bulletins.



MEAN DAILY AREAS (MILLIONTHS)
32000
28000
24000
20000
16000
12000
8000
4000
0
1905
10
15
20
25
30
35
40
45
50
1954
SOLAR ACTIVITY (1905 - 1954)
SUNSPOTS
KFL
KPR
175
14°
150
12°
125
10°
100
8°
75
6°
50
4°
25
2°
0
, RELATIVE SUNSPOT NUMBERS
AREA IN SQ DEGREES

Fig 1

The plage activity is more closely associated with sunspot activity than prominence activity The close association of the former is further evident from the scatter diagrams in Figures 2 and 3.

The linear regression equation of plage area versus the two indices of sunspot activity and the corresponding correlation coefficients are

1. Area plage $(10^{-6}_{\odot})$ = 145 × Relative Sunspot Number + 460;
   r = 0 95

2. Area plage $(10^{-6}_{\odot})$ = 8 5 × Area Sunspot $(10^{-6}_{\odot})$ + 773;
   r = 0 95

For the 1957 maximum which is the highest maximum on record, the corresponding Zurich relative sunspot number is 190 2. The regression equation gives an area of plage equal to 28039 which compares well with the corresponding Kodaikanal figure of 27992.

Numerous efforts have been made in the past to investigate the east-west asymmetry in the distribution of sunspots and prominences. Maunders, and Minnaert have stated that the eastern half of sun is more active than the west.

Table I tabulates the yearly differences and accumulated differences over each cycle The yearly differences have been plotted in Figure 4(a) and accumulated differences over each cycle in Figure 4 (b).

There are 28 years of eastern excess, 21 years of western excess and one year of equal area. The total value over 50 years shows an eastern excess of 707 $(10^{-6}_{\odot})$ which is 0 17%. Archenhold (1940) in a study of sunspots over the years 1888–1915 obtained,

$\frac{W}{E} = 0{\cdot}95 \pm 0\ 017$ i e. E–W = 1.3%

Figure 4 (b) shows that in the case of calcium flocculi, the E–W excess over successive solar cycles appears to experience a change in sign over 22 years .

The sunspot (E–W) asymmetry has been explained in terms of the following The spots have their axes tilted westward (Mrs Maunder 1907, Gleissberg 1940 and Minnaert 1946), which makes the sec θ corrections unsymmetrical in the two halves of the hemisphere Secondly, the spot groups, in general, have an asymmetry in their shape in that the preceding part is more compact and hence better visible than the following counterpart (Kiepenheuer 1953) If any similar logical explanation is to be sought for the calcium plage area asymmetry, this would not show any 22-year cycle. The change in the sign of the accumulated E–W differences after 2 cycles thus seems to be a coincidence The fortuitous character of this reversal is further evident from the yearly difference (Figure 4a) which has a random distribution but does not show any such systematic trend It is of interest to note Bruzek's (1954) results which show that the E–W excess when established in terms of sunspot areas shows a change in sign after two eleven-year cycles, whereas the relative sunspot number always gives an eastern exceess over the period of his investigation (1889–1943)

In Figure 5 the north-south plage activity (Table I) is plotted separately. At the start of a cycle the southern activity lags behind the northern one in cycles 14, 15 and 16 and leads the cycles 17 and 18. The cycle 14 which is the last of the 4 cycles Maunder (1913) has discussed shows that the cycles start with northern activity, but later the southern activity becomes more pronounced The change in the lag of starting a cycle between northern and southern hemispheres at the 17th cycle is similar to that found by Kopecky who from an analysis of Waldmeier's sunspot data finds that the lag follows a 80-year pattern.

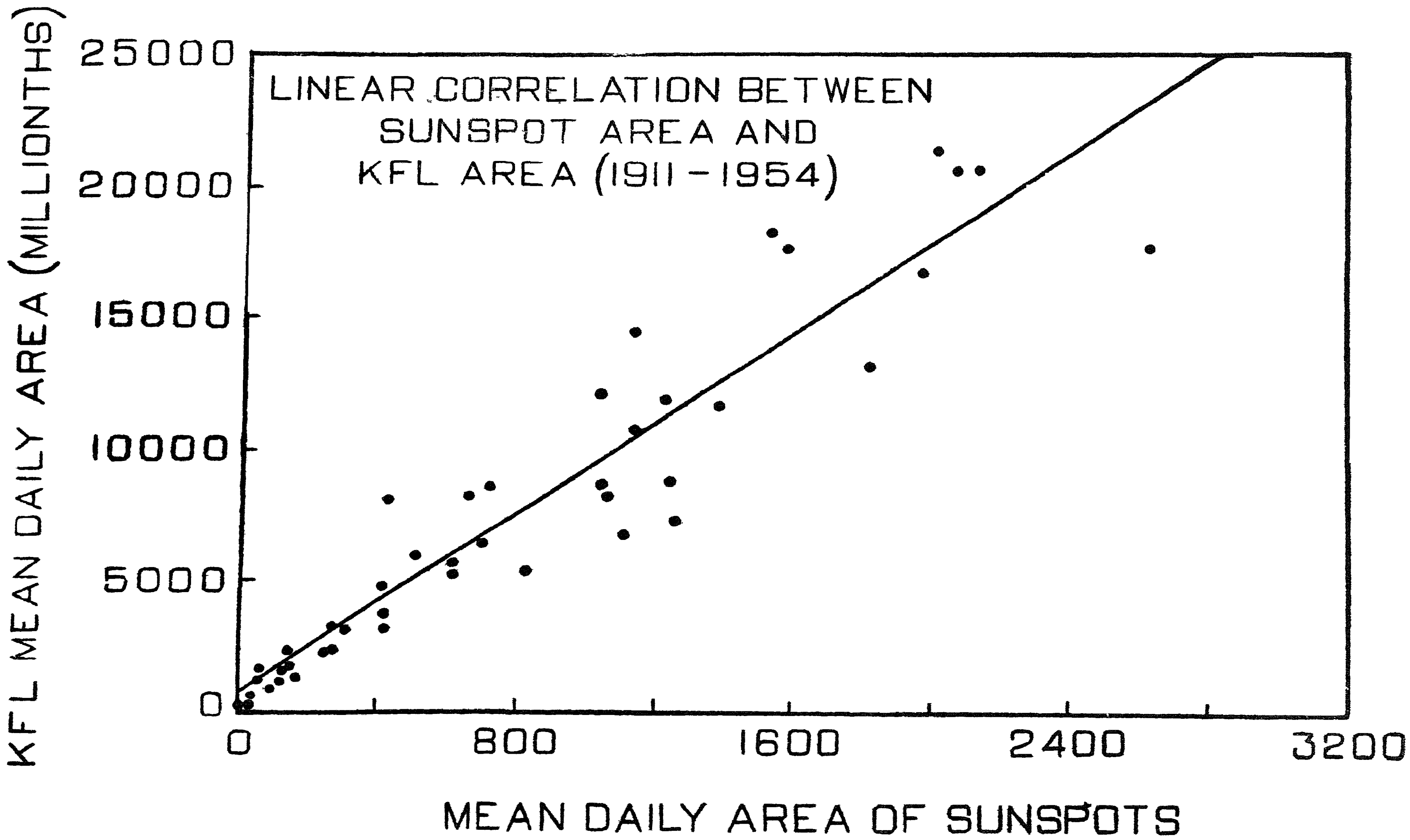

LINEAR CORRELATION BETWEEN
SUNSPOT AREA AND
KFL AREA (1911 - 1954)
KFL MEAN DAILY AREA (MILLIONTHS)
25000
20000
15000
10000
5000
0
0
800
1600
2400
3200
MEAN DAILY AREA OF SUNSPOTS

Fig. 2

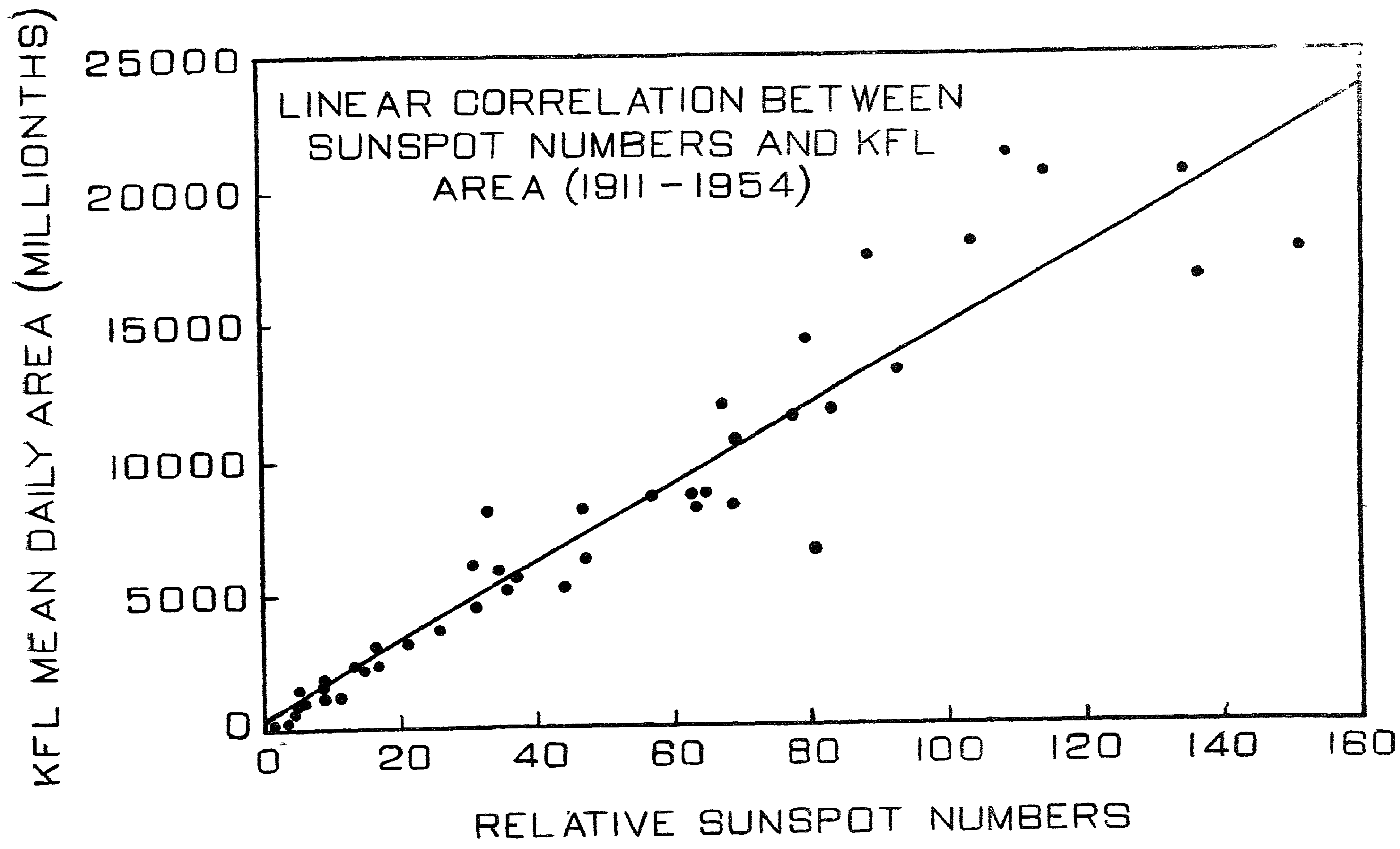

LINEAR CORRELATION BETWEEN
SUNSPOT NUMBERS AND KFL
AREA (1911 - 1954)
KFL MEAN DAILY AREA (MILLIONTHS)
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
120
140
160
RELATIVE SUNSPOT NUMBERS

Fig. 3

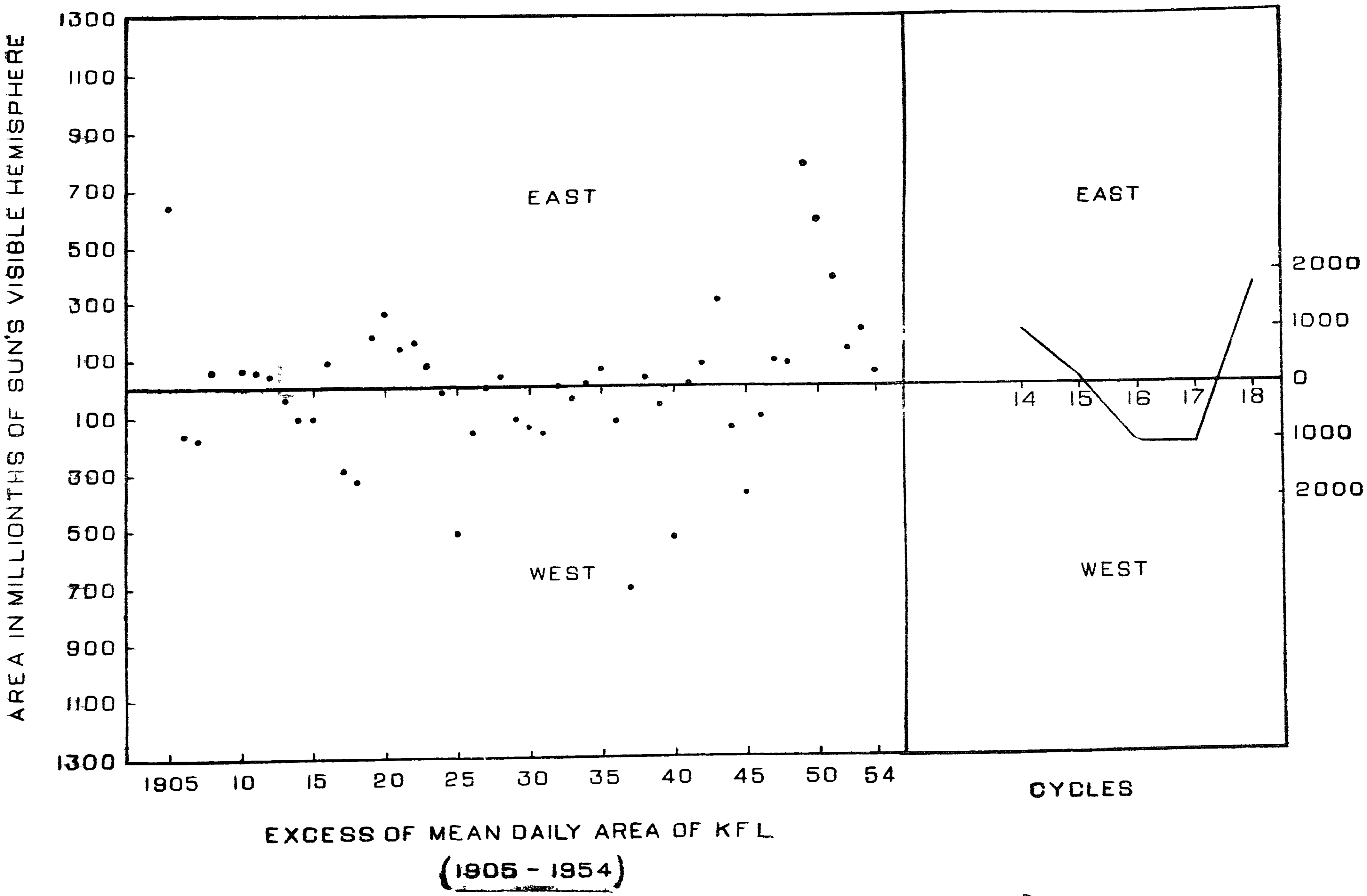

AREA IN MILLIONTHS OF SUN'S VISIBLE HEMISPHERE
1300
1100
900
700
500
300
100
100
300
500
700
900
1100
1300
EAST
WEST
1905
10
15
20
25
30
35
40
45
50
54
EXCESS OF MEAN DAILY AREA OF KFL
(1905 - 1954)
EAST
WEST
2000
1000
0
1000
2000
14
15
16
17
18
CYCLES

Fig 4a

Fig 4b

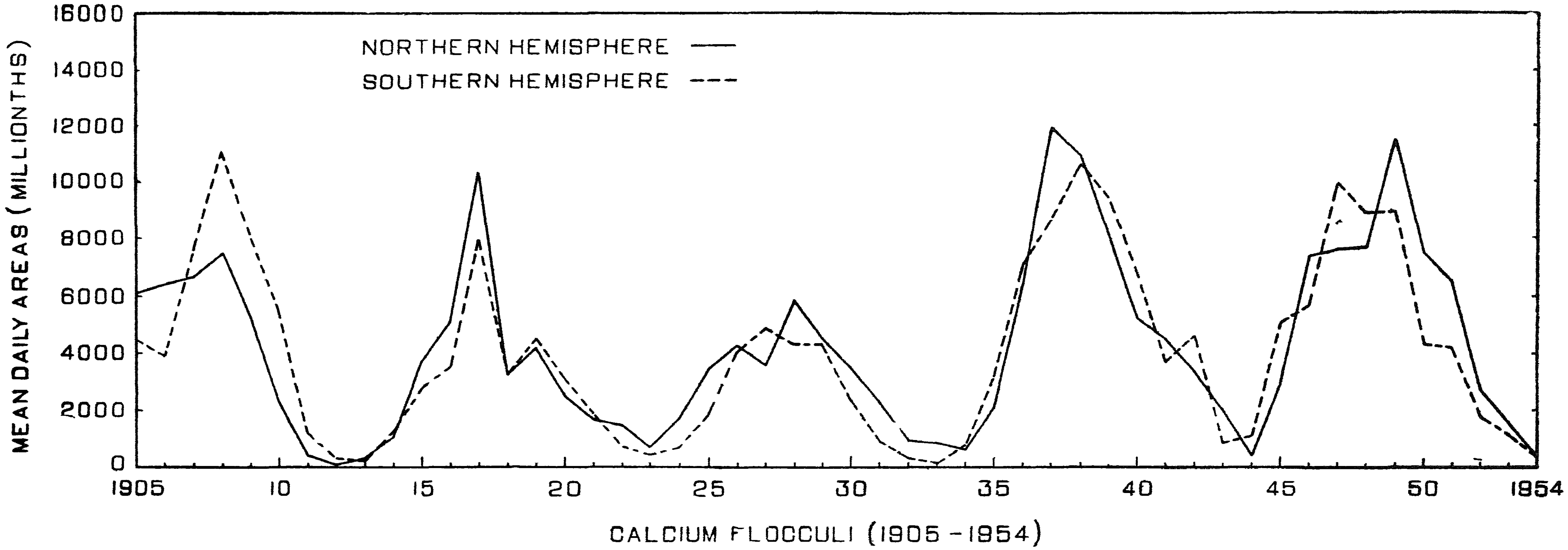

NORTHERN HEMISPHERE
SOUTHERN HEMISPHERE
MEAN DAILY AREAS (MILLIONTHS)
16000
14000
12000
10000
8000
6000
4000
2000
0
1905
10
15
20
25
30
35
40
45
50
1954
CALCIUM FLOCCULI (1905 - 1954)

Fig 5

From the close relationship of plage and sunspot activity one may expect the plage data also to show the same pattern

Acknowledgement

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TABLE 1

Cycle	Year	Sun-spot area	Relative sunspot number	Mean daily area of calcium flocculi: Total	NE	NW	SE	SW	N	S	E	W	E-W	Excess: E-W Cycle wise	Excess: Percentage
14	1905	1191	63 5	10604	3295	2831	2327	2151	6126	4478	5622	4982	+640		
	1906	778	53 8	10347	3348	3069	1749	2181	6417	3930	5097	5250	−153		
	1907	1082	62 0	14227	3339	3305	3634	3899	6644	7583	7023	7204	−181		
	1903	697	48 5	18540	3941	3571	5359	5669	7512	11023	9300	9240	+ 60		
	1909	692	43 9	13433	2892	2441	4050	4050	5333	8100	6942	6491	+451		
	1910	264	18 6	7876	1180	1115	2790	2731	2295	5581	3970	3906	+ 64		
	1911	64	5 7	1607	198	211	636	562	409	1198	834	773	+ 61		
	1912	37	3 6	425	45	14	192	174	59	366	237	188	+ 49		
	1913	7	1 4	297	86	88	47	76	174	123	133	164	− 31	+960	+1·23%
15	1914	152	9 6	1700	475	577	323	325	1052	648	798	902	−104		
	1915	697	47 4	6485	1851	1832	1339	1463	3633	2302	3190	3295	−105		
	1916	724	57 1	8610	2615	2481	1738	1776	5096	3514	4353	4257	+ 96		
	1917	1537	103 9	18149	5127	5136	3806	4080	10263	7886	8933	9216	−283		
	1918	1118	80 6	6562	1540	1764	1577	1681	3304	3258	3117	3445	−328		
	1919	1052	63 6	8684	2044	2171	2390	2079	4215	4469	4434	4250	+184		
	1920	618	37 6	5661	1272	1231	1694	1464	2503	3158	2966	2695	+271		
	1921	420	26 1	3570	875	858	975	862	1733	1837	1850	1720	+130		
	1922	252	14 2	2280	804	686	417	373	1490	790	1221	1059	+162		
	1923	55	5 8	1179	367	335	260	217	702	477	627	552	+ 75	+ 98	+0·16%
16	1924	276	16 7	2415	871	917	330	297	1788	627	1201	1214	− 13		
	1925	830	44 3	5329	1541	1967	864	957	3508	1821	2405	2924	−519		
	1926	1262	63 9	8385	2032	2242	2033	2028	4274	4111	4115	4270	−155		
	1927	1058	69 0	8392	1765	1772	2431	2424	3537	4855	4196	4196	0		
	1928	1390	77 8	11521	2907	2919	2876	2819	5326	5695	5783	5738	+ 45		
	1929	1242	64 9	8872	2215	2267	2169	2221	4482	4390	4384	4488	−104		
	1930	516	35 7	5903	1765	1790	1120	1228	3555	2348	2885	3018	−133		
	1931	275	21 2	3134	1036	1207	450	441	2243	891	1486	1648	− 62		
	1932	163	11 1	1282	484	460	160	178	944	338	644	638	+ 6		
	1933	88	5 7	922	393	428	47	54	821	101	440	482	− 42	−1077	−1·92%
17	1934	119	8 7	1331	296	302	379	354	598	733	675	656	+ 19		
	1935	624	36 1	5139	1065	998	1541	1535	2063	3076	2606	2533	+ 73		
	1936	1141	79 7	14462	3160	3239	4014	4049	6399	8063	7174	7288	−114		
	1937	2074	114 4	20605	5865	6060	4036	4594	11925	8680	9951	10654	−703		
	1938	2019	109 6	21472	5387	5516	5365	5204	10903	10569	10752	10720	+ 32		
	1939	1579	88 8	17547	4079	4064	4665	4739	8143	9404	8744	8803	− 59		
	1940	1039	67 8	12006	2611	2675	3123	3597	5286	6720	5734	6272	−538		
	1941	658	47 5	8211	2272	2303	1835	1801	4575	3636	4107	4104	+ 3		
	1942	423	30 6	6080	1809	1624	1275	1372	3433	2647	3034	2996	+ 88		
	1943	295	16 3	3012	1142	974	516	380	2116	896	1658	1354	+304		
	1944	126	9·6	1591	172	226	549	644	398	1193	721	870	−149	−1044	−0 94%
18	1945	429	33 2	8050	1300	1619	2534	2597	2919	5131	3834	4216	−382		
	1946	1817	92 6	13106	3832	3571	2664	3039	7403	5703	6496	66.0	−114		
	1947	2637	151 6	17573	3963	3641	4871	5098	7604	9969	8834	8739	+ 95		
	1948	1977	136·3	16604	3978	3658	4366	4602	7636	8968	8344	8260	+ 84		
	1949	2129	134 7	20513	6086	5490	4558	4379	11576	8937	10644	9869	+775		
	1950	1222	83 9	11869	4011	3534	2222	2102	7545	4324	6233	5636	+597		
	1951	1136	69 4	10714	3280	3236	2251	1947	6516	4198	5531	5183	+348		
	1952	404	31 5	4509	1466	1278	849	916	2744	1765	2315	2194	+121		
	1953	146	13 9	2493	802	684	546	461	1488	1007	1348	1145	+203		
	1954	35	4 4	593	184	146	134	129	330	263	318	275	+ 43	+1770	+1·67%