AN EXAMINATION OF THE SUNSPOT AREAL DATASET, 1875–2023: PAPER III, THE MAGNETIC COMPLEXITY OF SUNSPOTS

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ABSTRACT

This is the third paper in a three-part study of the sunspot areal dataset, 1875–present. Paper I (Wilson 2020) provided an overview of the areal dataset and gave some predictions for annual minimum and maximum amplitudes of specific parameters, noting that the minimum between solar cycles (SCs) 24 and 25 would likely be prolonged. Paper II (Wilson 2021) examined areal hemispheric differences, noting that SC12 had the smallest northern hemispheric annual maximum sunspot area (SSA(N)), while SC19 had the largest SSA(N), and that SC14 had the smallest southern hemispheric annual maximum sunspot area (SSA(S)), while SC18 had the largest SSA(S). Furthermore, the average time from minimum to maximum SSA was found to be about 3.8 years for SSA(N) and about 4.8 years for SSA(S). In Paper III, the magnetic complexity of sunspot groups is examined in terms of the: (1) Zurich visual classes (1875–1976), (2) Mount Wilson magnetic classes (MWC, 1982–2023), and (3) McIntosh modified Zurich visual classes (MMZ, 1982–2023). (No visual or magnetic classification of sunspot groups is available for the interval 1977–1981 in the solar areal dataset.)

INTRODUCTION

As noted in the Abstract, this is the third part of a three-part study of the sunspot areal dataset, 1875–present (http://solarcyclescience.com/activeregions.html). It will examine the variation of simple and complex spot groups over the sunspot cycle and the relationship between the MWC and MMZ for sunspot groups. Also examined are: (1) the number of single spots (N(SS)) in comparison to the number of types A and A+H spots, where A and H refer to the magnetic classification using MWC and MMZ, and (2) the annual area of simple and complex spot groups and the mean yearly area per spot group of simple and complex spots over the sunspot cycle (1982–2023).

A sunspot first appears as a tiny pore measuring only a few arc seconds in diameter (Kiepenheuer 1953). Rapid growth usually follows, increasing both in size (to several square degrees) and number (of individual spots forming the spot group). Many spots last no more than a day, while others continue to grow and develop into more complex entities. Waldmeier (1947) developed a classification scheme used to describe the development process of sunspot groups called the Zurich classification system for sunspot groups, consisting of nine classes, A–J (with no type I), numbered 1–9 in the solar areal dataset. (The areal dataset also includes a class 0, which is similar in areal size to class A spot groups, although the exact meaning of class 0 is uncertain; Hathaway 2023).

Based on the Zurich classification system (Kiepenheuer 1953), as well as the MMZ classification system (McIntosh 1990), a spot group classified as type A (i.e., 1) is one consisting of one or more tiny spots of unipolar magnetic field with no penumbra (the shadowy part outside the darker umbral region of a sunspot). A spot group classified as type B (i.e., 2) is one that has bipolar magnetic field and no penumbra. A spot group classified as type C is a bipolar spot group of two or more individual spots with one of the spots having penumbra. Type D spot groups are bipolar spots with both the leading and following spots having penumbra and the spots spread out <10 degrees of solar longitude. Type E spot groups are like type D spot groups but are spread over a longer solar longitude (10–15 degrees). Type F spot groups are like types D and E except they are spread out >15 degrees of solar longitude. A type G spot group is a large bipolar group spread out >10 degrees in solar longitude, but without small spots between the two major spots. A type H spot group is a unipolar spot with penumbra and sometimes with complicated structure and a diameter >2.5 degrees. A type J spot group is like a type H spot, but it is round in shape with a diameter <2.5 degrees. (The MMZ scheme is the same as the Zurich scheme, but omits types G and J, incorporating them instead into other Zurich types. The MMZ system also uses additional descriptors regarding the largest spot and the degree of spottiness within the group interior and is based on the spot group's appearance in white light (McIntosh 1990).)

In contrast, the MWC is a system based on the magnetic polarities of individual sunspots in the group and the distribution of the surrounding plage (the bright region around active regions observed in strong chromospheric lines, such as Hα (Martres and Bruzek 1977), rather than the visual appearance of the spot group (Hale, Ellerman, Nicholson, and Joy 1919; Greatrix and Curtis 1973; Jaeggli and Norton 2016). Three major classes form the MWC, including alpha (a unipolar spot group, identified as A in the solar areal dataset), beta (a bipolar spot group, identified as B, and gamma (a complex spot group, identified as G). The complex group is further divided into several sub-classifications, including BG, BD, GD, and BGD, where D indicates a delta configuration which exists when an inversion line separates umbrae of opposite polarity within the same penumbral area. (In the solar areal dataset, the MWC is identified using A, B, G, BG, BD, GD, and BGD. Spot groups identified as types A and B are considered simple spot groups, while those identified as types G, BG, BD, GD, and BGD are considered complex spot groups (Martres and Bruzek 1977).)

The description of spot groups in the sunspot areal dataset uses the Zurich classification system during the Royal Greenwich Observatory (RGO) portion, May 1874–December 1976. For the interval January 1977–December 1981, the sunspot areal dataset has no magnetic or visual classifications given for spot groups. For the interval starting in January 1982 through the present, the classification of spot groups in the sunspot areal dataset uses both the MWC and the MMZ magnetic/visual classification systems. (A discussion of the errors associated with the RGO dataset can be found in Willis, Coffey, Henwood, Erwin et al. 2013; Willis, Henwood, Wild, Coffey et al. 2013; Foukal 2013; and by David Hathaway in http://solarcyclescience.com/activeregions.html.)

METHODS AND MATERIALS

Annual sunspot number (SSN) is taken from https://www.sidc.be/SILSO/datafiles, while all other parameters are determined from http://solarcyclescience.com/activeregions.html. In this study, complex spot groups are taken to be Zurich types 4–7 during the RGO timeframe 1875–1976 (i.e., D, E, F, and G), while they are taken to be G, BG, BD, GD, and BGD based on MWC and D, E, and F based on MMZ during the interval 1982–2023. No determination of magnetic or visual complexity for sunspot groups is included in the sunspot areal dataset for the interval 1977–1981.

RESULTS AND DISCUSSION

Table 1 displays yearly values and counts for: (1) SSN, (2) SSA (corrected sunspot area in millionths of a solar hemisphere), (3) NARE (number of active region entries where each entry in the solar areal dataset indicates the daily occurrence of an individual spot group), (4) Zurich group types 1–9 (corresponding to Waldmeier's A, B, C, etc.) and 0, and (5) N(S) and N(C), where N(S) is the number of simple spot groups, types 0–3, 8, and 9, and N(C) is the number of complex spot groups, types 4–7 for the interval 1875–1976. Cyclic means are given for each sunspot cycle SC12–20, as well as for the overall interval 1875–1976. (The meaning of type 0 is uncertain (Hathaway 2023).)

Table 1. Royal Greenwich Observatory (RGO) Zurich Group Type distribution, 1875–1976.

				Zurich Group Type											
Year	**SSN**	**SSA**	**NARE**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**N(S)**	**N(C)**
SC11															
1875	28.3	213.1	394	144	51	90	8	44	0	0	44	13	0	306	88
1876	18.9	109.3	265	117	22	34	16	9	0	0	65	0	2	191	74
1877	20.7	92.9	229	70	53	53	9	7	0	0	37	0	0	185	44
SC12															
1878m	5.7	22.2	81	45	8	15	2	11	0	0	0	0	0	70	11
1879	10.0	36.3	117	41	26	8	2	30	0	0	8	2	0	79	38
1880	53.7	446.8	775	256	172	48	49	147	30	18	47	8	0	533	242
1881	90.5	679.5	1423	541	202	161	28	100	128	54	175	34	0	966	457
1882	99.0	968.0	1622	545	268	236	107	102	82	18	220	16	28	1200	422
1883M	106.1	1148.9	1792	604	387	199	84	58	66	15	304	33	42	1349	443
1884	105.8	1034.1	2039	813	268	222	159	60	88	30	337	38	24	1524	515
1885	86.3	810.2	1522	492	248	187	110	49	83	13	297	30	13	1080	442
1886	42.4	379.4	750	284	85	103	46	32	98	12	57	19	14	551	199
1887	21.8	177.3	452	158	54	91	55	24	27	1	25	17	0	375	77

				Zurich Group Type											
Year	**SSN**	**SSA**	**NARE**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**N(S)**	**N(C)**
1888	11.2	87.9	265	86	44	32	38	34	20	0	6	5	0	205	60
mean	57.5	526.4	985	351	160	118	62	59	57	15	134	18	11	721	264
sd	41.2	422.0	716	261	125	86	49	41	43	16	135	14	15	524	196
sum	-	-	10838	3865	1762	1302	680	647	622	161	1476	202	121	7932	2906
SC13															
1889m	10.4	76.7	191	84	24	12	19	6	10	2	10	11	13	163	28
1890	11.8	98.8	258	72	27	63	27	8	16	10	3	12	20	221	37
1891	59.5	566.4	1252	363	200	121	79	129	56	78	61	21	144	928	324
1892	121.7	1211.3	2321	723	271	174	130	284	279	95	142	9	214	1521	800
1893M	142.0	1460.6	3071	850	338	284	86	240	423	236	142	11	461	2030	1041
1894	130.0	1281.5	2740	840	399	228	93	152	371	218	105	10	324	1894	846
1895	106.6	973.4	2134	448	240	199	54	131	326	265	109	48	314	1303	831
1896	69.4	547.4	1182	259	154	135	11	157	96	122	38	52	158	769	413
1897	43.8	511.7	903	165	233	64	0	34	51	46	104	4	202	668	235
1898	44.4	374.7	777	174	93	74	7	69	85	87	69	14	105	467	310
1899	20.2	110.0	384	100	79	38	0	44	60	29	2	3	29	249	135
1900	15.7	74.3	273	86	39	21	7	4	8	0	33	0	75	228	45
mean	63.5	607.2	1291	347	175	118	43	87	148	99	68	16	172	870	420
sd	50.3	506.5	1227	300	126	88	44	86	154	94	52	17	139	670	364
sum	-	-	15486	4164	2097	1413	513	1258	1781	1188	818	195	2059	10441	5045
SC14															
1901m	4.6	27.9	78	40	13	10	0	0	0	0	15	0	0	63	15
1902	8.5	59.5	134	31	13	24	0	12	30	7	7	0	10	78	56
1903	40.8	338.6	760	201	94	76	2	110	94	52	46	7	78	458	302
1904	70.1	488.2	1374	242	163	84	11	263	195	100	135	10	171	681	693
1905M	105.5	1195.9	1937	237	251	115	10	341	182	191	227	34	349	996	941
1906	90.1	775.0	1859	207	285	116	36	246	257	135	189	12	376	1032	827
1907	102.8	1092.1	1951	248	356	90	47	278	136	124	191	47	434	1222	729
1908	80.9	697.5	1686	359	247	92	15	209	51	85	150	10	468	1191	495

				Zurich Group Type											
Year	**SSN**	**SSA**	**NARE**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**N(S)**	**N(C)**
1909	73.2	691.5	1442	268	201	58	55	185	125	127	168	25	230	837	605
1910	30.9	266.0	766	114	103	54	19	90	34	83	86	5	178	473	293
1911	9.5	64.4	279	82	40	27	2	14	5	14	16	13	66	230	49
1912	6.0	37.3	154	33	20	8	0	22	2	9	32	9	19	89	65
mean	51.9	477.8	1035	172	149	63	16	148	93	77	105	14	198	613	423
sd	39.5	413.6	754	108	119	39	19	121	86	62	80	14	172	441	335
sum	-	-	12420	2062	1786	754	197	1770	1111	927	1262	172	2379	7350	5070
SC15															
1913m	2.4	7.5	60	5	14	7	0	9	0	0	9	3	13	42	18
1914	16.1	152.4	436	93	42	43	0	38	25	41	15	9	130	317	119
1915	79.0	697.8	1864	512	414	130	62	89	91	182	89	96	199	1413	451
1916	95.0	725.5	2290	647	363	162	86	252	103	105	251	72	249	1579	711
1917M	173.6	1533.9	3510	929	404	274	103	524	123	280	350	63	460	2233	1277
1918	134.6	1112.6	2904	939	341	190	38	403	116	218	264	57	338	1903	1001
1919	105.7	1054.7	2249	758	315	152	80	306	60	184	162	53	179	1537	712
1920	62.7	617.3	1396	475	155	95	29	178	101	94	92	56	121	931	465
1921	43.5	419.6	943	281	120	63	14	174	73	51	86	9	72	559	384
1922	23.7	252.0	543	218	47	37	10	105	10	28	46	13	29	354	189
mean	73.6	657.3	1620	486	222	115	42	208	70	118	136	43	179	1087	533
sd	54.9	476.0	1137	334	161	82	38	165	45	93	116	32	140	749	398
sum	-	-	16195	4857	2215	1153	422	2078	702	1183	1364	431	1790	10868	5327
SC16															
1923m	9.7	54.7	244	103	32	10	1	21	24	4	20	15	14	175	69
1924	27.9	278.0	589	174	40	62	6	68	36	123	7	16	57	355	234
1925	74.0	825.1	1718	487	252	134	30	218	108	136	30	27	296	1226	492
1926	106.5	1263.2	2210	719	219	114	65	424	86	187	131	5	260	1392	828
1927	114.7	1060.8	2369	714	224	140	19	420	154	140	141	42	375	1514	855
1928M	129.7	1388.9	2613	773	218	121	67	482	164	237	167	69	315	1563	1050
1929	108.2	1238.9	2413	763	276	155	27	367	187	189	127	13	309	1543	870

				Zurich Group Type											
Year	**SSN**	**SSA**	**NARE**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**N(S)**	**N(C)**
1930	59.4	516.6	1394	431	144	78	38	297	115	76	76	6	133	830	564
1931	35.1	279.1	781	230	81	89	7	143	14	122	17	8	70	485	296
1932	18.6	163.2	471	222	43	29	10	55	20	42	13	0	37	341	130
mean	68.4	706.9	1480	462	153	93	27	250	91	126	73	20	187	942	539
sd	44.4	597.8	905	267	96	48	24	172	65	71	63	21	137	565	349
sum	-	-	14802	4616	1529	932	270	2495	908	1256	729	201	1866	9414	5388
SC17															
1933m	9.2	91.3	225	93	19	4	0	50	20	17	6	0	16	132	93
1934	14.6	118.2	337	138	32	13	5	67	9	46	0	0	27	215	122
1935	60.2	622.1	1290	439	75	79	11	301	109	134	19	0	123	727	563
1936	132.8	1140.8	2706	763	131	197	92	465	164	397	107	4	386	1573	1133
1937M	190.6	2072.8	3705	1075	266	279	126	620	111	569	150	3	506	2255	1450
1938	182.6	2015.2	3401	1143	166	357	196	441	99	391	102	14	492	2368	1033
1939	148.0	1576.8	2892	1047	236	145	128	345	100	381	156	14	340	1910	982
1940	113.0	1037.2	2118	619	166	223	7	401	54	327	151	3	167	1185	933
1941	79.2	658.1	1473	445	110	111	20	258	39	223	71	33	163	882	591
1942	50.8	427.3	1014	355	43	125	15	141	45	80	102	12	96	646	368
1943	27.1	296.8	495	186	71	31	0	33	10	83	13	5	63	356	139
mean	91.6	914.2	1787	573	120	142	55	284	69	241	80	8	216	1114	673
sd	65.7	716.9	1250	386	82	113	69	193	50	182	61	10	182	806	463
sum	-	-	19656	6303	1315	1564	600	3122	760	2648	877	88	2379	12249	7407
SC18															
1944m	16.1	124.7	370	142	21	25	0	89	0	7	16	7	63	258	112
1945	55.3	426.5	1103	405	44	150	18	163	74	47	80	11	111	739	364
1946	154.3	1823.9	2838	906	92	300	52	338	252	328	290	24	256	1630	1208
1947M	214.7	2634.1	4298	1353	315	452	111	525	362	225	205	160	590	2981	1317
1948	193.0	1974.6	3892	1295	417	418	105	367	311	121	273	27	558	2820	1072
1949	190.7	2140.0	3903	1321	344	397	107	322	310	116	291	67	628	2864	1039
1950	118.9	1227.3	2333	830	190	228	73	133	195	141	125	29	389	1739	594

				Zurich Group Type											
Year	**SSN**	**SSA**	**NARE**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**N(S)**	**N(C)**
1951	98.3	1135.3	1861	592	174	200	49	143	133	136	54	10	370	1395	466
1952	45.0	402.9	963	336	86	152	41	54	67	28	26	4	169	788	175
1953	20.1	145.1	431	178	11	80	10	34	14	22	11	7	64	350	81
mean	110.6	1203.4	2199	736	169	240	57	217	172	117	137	35	320	1556	643
sd	75.0	909.0	1488	475	145	147	41	162	133	101	117	48	220	1044	476
sum	-	-	21992	7358	1694	2402	566	2168	1718	1171	1371	346	3198	15564	6428
SC19															
1954m	6.6	34.6	166	73	7	28	0	12	0	15	0	0	31	139	27
1955	54.2	552.4	1183	326	86	147	50	139	76	40	22	5	292	906	277
1956	200.7	2394.7	3820	1008	363	273	83	373	329	254	134	37	966	2730	1090
1957M	269.3	3048.5	4855	1252	357	336	114	441	331	278	337	65	1344	3468	1387
1958	261.7	3011.3	5016	1300	385	259	197	766	688	160	413	0	848	2989	2027
1959	225.1	2872.9	4514	943	586	190	203	549	371	251	392	12	1017	2951	1563
1960	159.0	1641.2	3259	742	438	88	82	427	329	27	483	17	526	1993	1266
1961	76.4	613.5	1586	499	143	62	49	198	151	39	216	8	221	982	604
1962	53.4	463.5	1027	306	59	33	38	147	95	43	91	8	207	651	376
1963	39.9	287.8	819	284	77	15	45	65	136	0	70	0	127	548	271
mean	134.6	1492.0	2625	673	250	140	86	312	251	121	216	15	558	1736	889
sd	99.6	1236.6	1859	437	198	116	67	240	201	109	178	21	454	1225	669
sum	-	-	26245	6733	2501	1431	861	3117	2506	1207	2158	152	5579	17357	8888
SC20															
1964m	15.0	53.9	390	138	29	41	18	56	15	0	26	0	67	293	97
1965	22.0	113.3	506	126	66	56	0	73	3	0	182	0	0	248	258
1966	66.8	592.6	1498	382	106	219	9	199	45	0	512	12	14	742	756
1967	132.9	1519.1	3390	1198	355	408	92	275	129	51	820	37	25	2115	1275
1968M	150.0	1569.8	2963	975	394	206	120	452	85	26	641	55	9	1759	1204
1969	149.4	1450.1	2932	572	695	105	48	662	81	47	659	9	54	1483	1449
1970	148.0	1601.3	3379	720	588	152	85	953	90	27	761	3	0	1548	1831
1971	94.4	990.2	2229	632	327	134	29	507	66	0	498	13	23	1158	1071

				Zurich Group Type											
Year	**SSN**	**SSA**	**NARE**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**N(S)**	**N(C)**
1972	97.6	916.7	2263	550	305	187	14	535	29	18	605	20	0	1076	1187
1973	54.1	457.6	1203	274	247	69	35	246	13	9	310	0	0	625	578
1974	49.2	398.9	1096	391	119	73	18	204	29	4	243	7	8	616	480
1975	22.5	166.4	473	117	112	14	3	119	17	12	79	0	0	246	227
mean	83.5	819.2	1860	506	279	139	39	357	50	16	445	13	17	992	868
sd	52.4	600.8	1143	341	210	108	39	271	39	18	269	17	22	630	549
sum	-	-	22322	6075	3343	1664	471	4281	602	194	5336	156	200	11979	10413
SC21 (incomplete)															
1976m	18.4	169.8	426	82	151	10	7	56	22	0	98	0	0	250	176
1875-1976															
mean	78.4	780.7	1581	455	182	126	45	206	105	97	153	19	191	1020	561
sd	62.3	721.2	1235	361	148	102	48	192	118	111	173	25	242	807	465

Notes: m denotes year of SSN minimum
M denotes year of SSN maximum
SSN means annual sunspot number
SSA means annual sunspot area
NARE means number of active region entries
N(S) means number of simple regions (i.e., 0+1+2+3+8+9)
N(C) means number of complex regions (i.e., 4+5+6+7)

Similarly, Table 2 displays yearly values, counts, cyclic means, and overall interval means for SSN, SSA, NARE, and the MWC types A, B, G, BG, BD, GD, and BGD for the interval 1977–2023, where types A and B are considered simple spot groups and types G, BG, BD, GD, and BGD are considered complex spot groups. Table 3 gives the yearly values, counts, cyclic means, and overall means for the interval 1977–2023 for the MMZ classes, where simple spot groups are considered to be types A, B, C, and H, and complex spot groups are considered to be types D, E, and F. (As stated earlier, no magnetic classification values are given for MWC and MMZ for the interval 1977–1981.)

Table 2. Distribution of USAF/NOAA MWC magnetic classes, 1977–2023.

					USAF/NOAA Group Type								
Year	**SSN**	**SSA**	**NARE**	**NC**	**A**	**B**	**G**	**BG**	**BD**	**GD**	**BGD**	**N(S)**	**N(C)**
SC21 (continued)													
1977	39.3	347.0	926	926	-	-	-	-	-	-	-	-	-
1978	131.0	1368.5	4035	4035	-	-	-	-	-	-	-	-	-

					USAF/NOAA Group Type								
Year	**SSN**	**SSA**	**NARE**	**NC**	**A**	**B**	**G**	**BG**	**BD**	**GD**	**BGD**	**N(S)**	**N(C)**
1979M	220.1	2194.5	5439	5439	-	-	-	-	-	-	-	-	-
1980	218.9	2160.7	3965	3965	-	-	-	-	-	-	-	-	-
1981	198.9	2270.2	3920	3920	-	-	-	-	-	-	-	-	-
1982	162.4	2220.1	3686	88	1386	1836	1	181	51	19	124	3222	376
1983	91.0	919.5	2371	37	941	1219	0	101	30	1	42	2160	174
1984	60.5	811.7	1474	14	532	812	5	36	26	0	49	1344	116
1985	20.6	179.0	604	7	244	327	0	7	5	0	14	571	26
mean	116.1*	1182.1*	2685*	2048	776	1049	2	81	28	5	57	1824	173
sd	80.9*	961.3*	1753*	2238	497	639	2	77	19	9	47	1135	148
sum	-	-	26846*	18431	3103	4194	6	325	112	20	229	7297	692
SC22													
1986m	14.8	124.7	394	2	185	188	1	11	6	0	1	373	19
1987	33.9	296.8	938	0	402	520	0	12	4	0	0	922	16
1988	123.0	1345.3	2900	0	1135	1617	0	94	12	2	40	2752	148
1989M	211.1	2579.2	4734	1	1716	2738	0	143	39	1	96	4454	279
1990	191.8	2048.7	4751	1	1943	2630	0	114	23	1	39	4573	177
1991	203.3	2470.2#	4715	3	1836	2578	2	150	66	2	78	4414	297
1992	133.0	1349.2	3314	0	1387	1759	1	95	29	2	41	3146	168
1993	76.1	696.2	1886	0	858	959	0	48	11	0	10	1817	69
1994	44.9	340.4	1205	0	519	652	0	22	7	0	5	1171	34
1995	25.1	159.6	707	4	297	384	2	13	2	0	5	681	22
mean	105.7	1141.0	2554	1	1028	1403	1	70	20	1	32	2430	123
sd	77.2	959.8	1761	1	669	994	1	56	20	1	34	1659	108
sum	-	-	25544	11	10278	14025	6	702	199	8	315	24303	1229
SC23													
1996m	11.6	81.9	306	0	126	162	0	13	2	0	3	288	18
1997	28.9	210.2	686	0	233	400	0	39	0	0	14	633	53
1998	88.3	763.1	1937	0	587	1206	0	113	11	1	19	1793	144
1999	136.3	1162.0	2733	0	751	1754	2	176	5	0	45	2505	228

					USAF/NOAA Group Type								
Year	**SSN**	**SSA**	**NARE**	**NC**	**A**	**B**	**G**	**BG**	**BD**	**GD**	**BGD**	**N(S)**	**N(C)**
2000M	173.9	1614.2	3587	0	1043	2263	0	226	14	4	37	3306	281
2001	170.4	1704.1	3476	0	1043	2000	1	306	7	0	119	3043	433
2002	163.6	1828.7	3528	0	1023	2030	0	317	16	0	142	3053	475
2003	99.3	1099.2	2145	0	600	1243	0	211	5	2	84	1843	302
2004	65.3	683.8	1311	0	403	680	1	139	8	0	80	1083	228
2005	45.8	542.6	973	0	287	517	0	116	19	0	34	804	169
2006	24.7	245.1	600	0	212	308	0	61	1	0	18	520	80
2007	12.6	133.3	308	0	123	162	0	12	1	0	10	285	23
mean	85.1	839.0	1799	0	536	1061	0	144	7	1	50	1596	203
sd	62.9	635.2	1281	-	359	790	1	105	6	1	46	1147	151
sum	-	-	21590	0	6431	12725	4	1728	89	7	605	19156	2434
SC24													
2008m	4.2	22.8	122	0	40	82	0	0	0	0	0	122	0
2009	4.8	26.6	123	0	29	89	0	4	1	0	0	118	5
2010	24.9	214.3	623	0	247	347	0	26	1	0	2	594	29
2011	80.8	751.2	1788	0	536	1036	0	154	8	0	54	1572	216
2012	84.5	796.9	1848	1	571	1089	0	137	6	0	44	1660	187
2013	94.0	860.8	2121	0	694	1078	0	249	15	0	85	1772	349
2014M	113.3	1252.2	2442	0	703	1217	0	364	22	0	136	1920	522
2015	69.8	618.8	1544	0	474	824	0	177	18	0	51	1298	246
2016	39.9	225.2	910	0	302	561	0	33	5	0	9	863	47
2017	21.7	217.5	477	0	223	208	0	33	1	0	12	431	46
2018	7.0	24.4	161	0	55	99	0	6	1	0	0	154	7
mean	49.5	455.5	1105	0	352	603	0	108	7	0	36	973	150
sd	40.0	418.9	867	0	256	457	-	120	8	-	44	730	171
sum	-	-	12159	1	3874	6630	0	1184	78	0	393	10704	1654
SC25 (incomplete)													
2019m	3.6	37.9	97	0	50	43	0	1	2	0	1	93	4
2020	8.8	85.1	224	0	116	100	0	8	0	0	0	216	8

					USAF/NOAA Group Type								
Year	**SSN**	**SSA**	**NARE**	**NC**	**A**	**B**	**G**	**BG**	**BD**	**GD**	**BGD**	**N(S)**	**N(C)**
2021	29.6	249.2	729	0	287	383	0	47	8	0	4	670	59
2022	83.2	863.3	1788	0	577	1050	0	106	22	0	33	1627	161
2023	125.3	1143.6	2703	0	950	1388	0	229	68	0	61	2345	358
1982-2023													
mean@	85.4	879.6	1942	-	611	965	0	105	14	1	39	1577	157
sd@	68.0	767.5	1507	-	501	776	1	96	17	3	41	1263	144

Notes: m denotes year of SSN minimum
M denotes year of SSN maximum
SSN means annual sunspot number
SSA means annual sunspot area
NARE means number of active region entries
means one entry (11/19/1991, region 6924B) had an erroneous areal measurement, which has been excluded
NC means number with no USAF/NOAA Group Type classification
* means it includes 1976 values (SSN, SSA, and NARE)
N(S) means number of simple regions (i.e., A+B)
N(C) means number of complex regions (i.e., G+BG+BD+GD+BGD)
@ denotes that mean/sd for SSN, SSA, and NARE are for 1977−2023

Table 3. Distribution of MMZ magnetic classes, 1982–2023.

Year	**A**	**B**	**C**	**D**	**E**	**F**	**H**	**NARE**	**N(S)**	**N(C)**
SC21 (incomplete)										
1982	658	583	649	652	347	91	706	3686	2596	1090
1983	586	426	466	359	137	47	350	2371	1828	543
1984	335	308	275	222	104	53	177	1474	1095	379
1985	173	109	141	84	24	1	72	604	495	109
mean	225	357	383	329	153	48	326	2034	1504	530
sd	271	200	222	243	138	37	278	1317	910	414
sum	1752	1426	1531	1317	612	192	1305	8135	6014	2121
SC22										
1986m	114	53	80	60	10	4	73	394	320	74
1987	246	205	165	95	84	2	141	938	757	181
1988	692	524	483	375	270	119	437	2900	2136	764
1989M	1047	946	891	617	398	223	612	4734	3496	1238
1990	1155	926	804	644	356	140	726	4751	3611	1140

Year	A	B	C	D	E	F	H	NARE	N(S)	N(C)
1991	1155#	856#	825	721	336	197	625	4715#	3461	1254
1992	852	531	571	497	238	85	540	3314	2494	820
1993	520	276	287	300	131	37	335	1886	1418	468
1994	296	232	215	171	69	12	210	1205	953	252
1995	215	147	135	83	37	0	90	707	587	120
mean	629	470	446	356	193	82	379	2554	1904	647
sd	407	339	312	252	144	84	242	1761	1307	457
sum	6292	4696	4336	3563	1929	819	3789	25424	19113	6311
SC23										
1996m	88	74	52	34	20	0	38	306	252	54
1997	149	152	138	89	56	16	86	686	525	161
1998	293	436	408	279	154	67	300	1937	1437	500
1999	313	488	584	443	305	159	441	2733	1826	907
2000M	320	460	787	779	392	122	727	3587	2294	1293
2001	267	275	709	877	376	191	781	3476	2032	1444
2002	268	258	717	1006	380	138	761	3528	2004	1524
2003	171	161	479	647	185	68	434	2145	1245	900
2004	106	122	230	323	164	63	303	1311	761	550
2005	65	53	189	325	99	20	222	973	529	444
2006	90	52	161	124	50	4	119	600	422	178
2007	38	45	57	66	14	3	85	308	225	83
mean	181	215	376	416	183	71	326	1799	1129	670
sd	105	167	273	336	145	67	287	1281	767	535
sum	2168	2576	4511	4992	2047	851	3594	21590	13552	8038
SC24										
2008m	23	36	22	23	2	0	16	122	97	25
2009	25	49	13	21	10	1	4	123	91	32
2010	98	106	112	102	40	15	150	623	466	157
2011	162	254	361	429	181	29	372	1788	1149	639
2012	150	165	402	513	160	36	422	1848	1139	709

Year	A	B	C	D	E	F	H	NARE	N(S)	N(C)
2013	176	208	498	526	166	29	518	2121	1400	721
2014M	208	235	551	622	260	68	498	2442	1492	950
2015	168	180	400	277	142	70	307	1544	1055	489
2016	87	132	236	192	46	0	217	910	672	238
2017	52	44	83	68	36	23	171	477	350	127
2018	47	44	35	27	0	0	8	161	134	27
mean	109	132	247	255	95	25	244	1105	731	374
sd	67	82	203	230	89	26	193	867	535	337
sum	1196	1453	2713	2800	1043	238	2683	12159	8045	4114
SC25 (incomplete)										
2019m	18	15	21	9	2	0	32	97	86	11
2020	32	33	51	12	7	5	84	224	200	24
2021	105	102	161	157	22	0	182	729	550	179
2022	159	199	420	352	204	37	417	1788	1195	593
2023	278	250	622	576	263	44	670	2703	1820	883
1982-2023										
mean	286	256	345	308	149	53	320	1737	1207	530
sd	302	239	260	268	130	61	240	1371	962	447

Notes: # means includes 3 Xs, 2 counted as As (1991–01–24 and 1991–01–26) and 1 counted as a B (1991–01–29)
1 B was ignored due to bad areal entry (1991–11–19)
N(S) means number of simple regions (i.e., A+B+C+H)
N(C) means number of complex regions (i.e., D+E+F)

Figure 1 displays the yearly variation of SSN, SSA, and NARE for the overall interval 1875–2023 (late SC11 to early SC25). The unfilled triangles across the top display the occurrence of SSN maximum for SC12–24. Plainly, the parameters are highly correlated, although subtle differences exist. For example, comparison of SSN and SSA reveals that all minimum yearly values occurred simultaneously for SC12–25, while maximum yearly values of SSA were delayed by two years for SC20, 21, and 23. Similarly, comparison of SSN and NARE reveals that all minimum yearly values occurred simultaneously for SC12–25, while maximum yearly values of NARE were delayed by one year for SC12, 19, and 22, and by two years for SC14 and 20. Between SC12 and 19, values of SSN, SSA, and NARE trended upward, while they trended downward in value after SC19. Also, SC25, the current ongoing SC, is now known to be of larger SSN and NARE yearly values in comparison to the maximum values for SC24. (SSA for SC25 has not as yet exceeded the maximum observed yearly value for SC24, although it is expected to do so in 2024.)

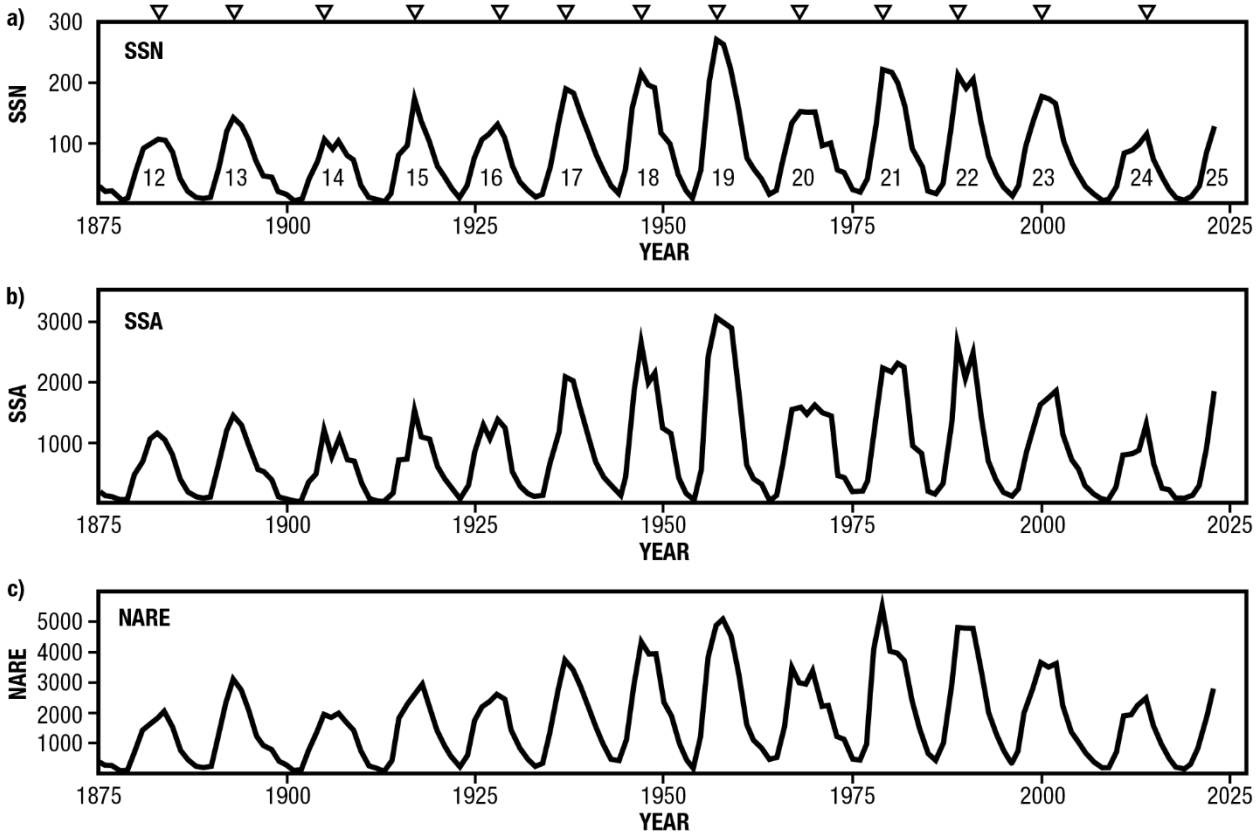

Figure 1. Yearly variation of (a) SSN, (b) SSA, and (c) NARE, 1875–2023.

From Figure 1 (and Tables 1 and 2), one finds the mean maximum value for SSN for SC12–24 to be 153.8, with a standard deviation (sd) equal to 62.8. For SSA, its mean maximum value and sd are 1,847.3 millionths of a solar hemisphere and 620 millionths of a solar hemisphere, respectively, and for NARE to be 3,280 and 1,421, respectively.

Figure 2 shows the annual variation of N(S) and N(C) for the overall interval of 1875–2023 based on the combined Zurich and MMZ determinations. Recall that N(S) for the RGO interval (1875–1976) includes types 0–3 plus 8 and 9, while for the MMZ interval (1982-2023) N(S) includes types A–C plus H, and N(C) includes types 4–7 for the RGO interval and types D–F for the MMZ interval. No determination of N(S) and N(C) appears in the sunspot areal dataset for the interval 1977–1981. Plainly, N(S) and N(C) increase between SC12 and 19 and decrease after SC19 (like that found for SSN, SSA, and NARE). Interestingly, SC23 is found to have had more complex spot groups than SC22, an SC of much larger SSN maximum yearly value (211.1 vs. 173.9, respectively). Minimum yearly values of N(S) and N(C) almost always occur simultaneously with SSN minimum occurrence (only SC21 had its N(S) minimum value one year earlier). On the other hand, the maximum yearly value of N(S) appears one year later for SC12, 17, and 22, and the maximum value of N(C) occurs one year later than SSN maximum for SC12 and 19 and two years later for SC20, 22, and 23. Also, N(C) for SC25, the current ongoing SC, has not as yet had a yearly value larger than was seen for SC24, although it is a larger cycle in comparison (125.3 in 2023 for SC25 as compared to 113.3 in 2014 for SC24). The mean

maximum value and sd for N(S) for SC12–24 are 2,442 and 969, respectively (excluding SC21), and the maximum value and sd for N(C) for SC12–24 are 1,062 and 549, respectively.

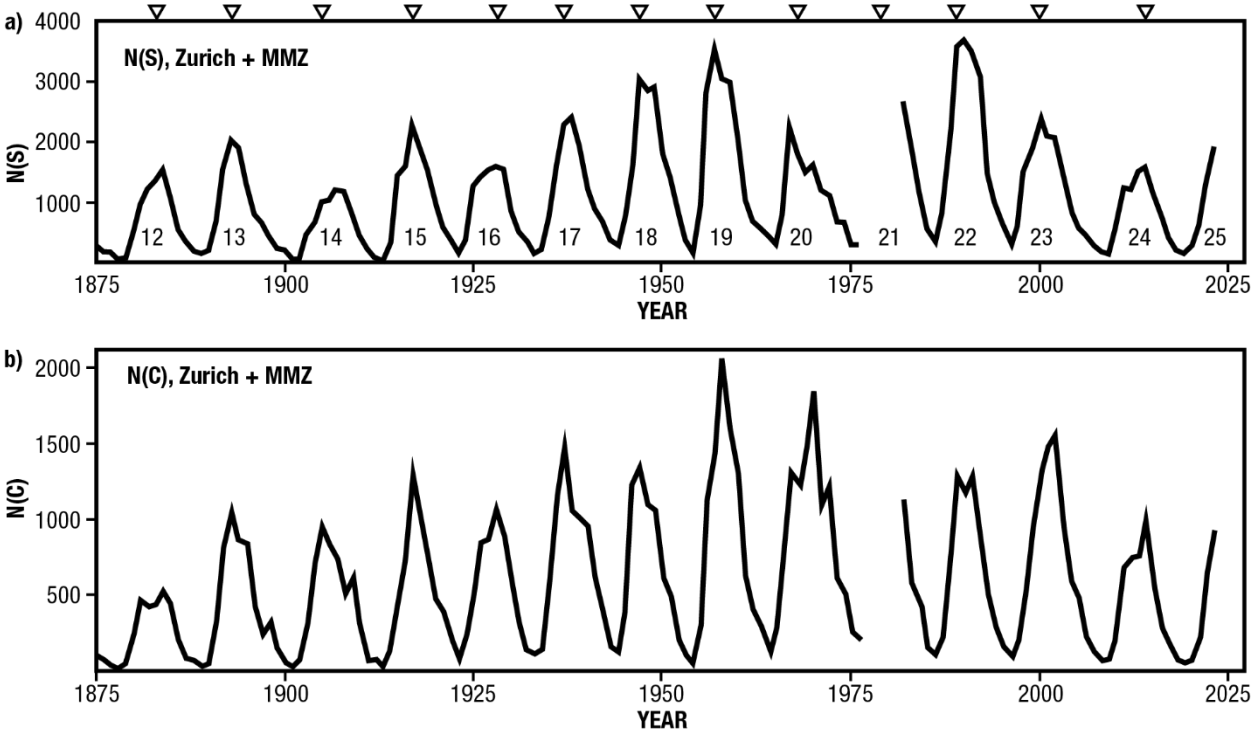

Figure 2. Yearly variation of (a) N(S) and (b) N(C) based on Zurich and MMZ, 1875–2023.

Figure 3 depicts the yearly variation of N(S) and N(C) for the interval 1982–2023 based on the MWC. Interestingly, complex spot groups increased in number between SC22 and 24, while simple spot groups decreased in number. Minimum yearly values of N(S) and N(C) usually occur simultaneously with SSN minimum occurrence (the exception being N(S) for SC21, which occurred one year earlier), while the maximum yearly value for N(S) occurs one year later for SC22, and the maximum value for N(C) occurs two years later for SC22 and 23. In contrast with MMZ N(C) values, SC24 had the larger N(C) yearly value as compared with SC23 (based on the MWC, 522 vs. 475) and was considerably larger than the SC22 N(C) maximum yearly value (298). (SC25 had N(C) = 358 in 2023 and measured 258 between January and June 2024, suggesting that N(C) for SC25 likely will exceed its 2023 value.)

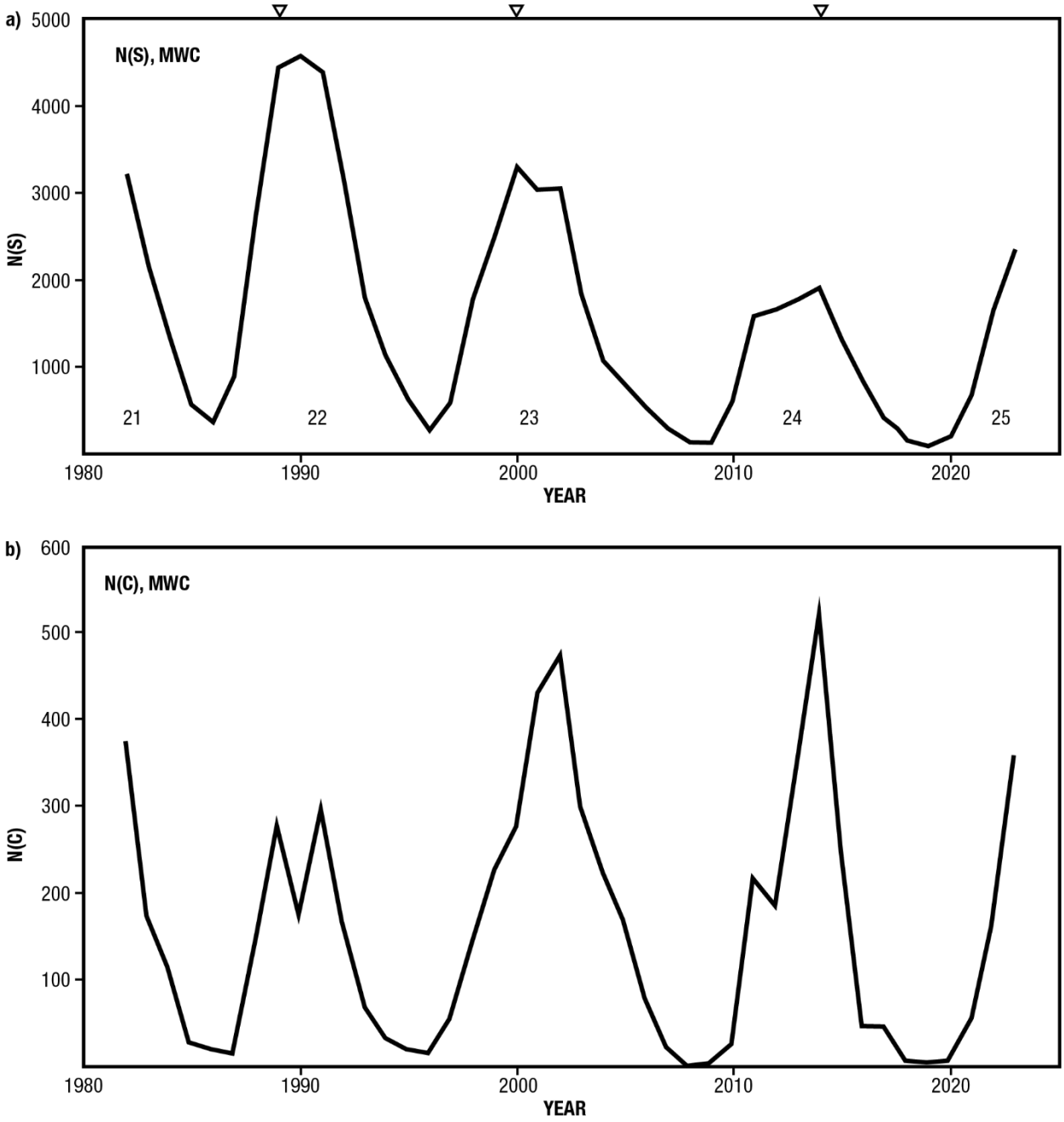

Figure 3. Yearly variation of (a) N(S) and (b) N(C) based on MWC, 1982–2023.

Table 4 gives the yearly parametric values and means and sds for SSN, SSA, NARE, N(S), and N(C) for SC12–24 for elapsed times t = 0–9 years, where t = 0 is the year of SSN minimum occurrence. Figure 4 compares SC25 values (the filled circles) against the means for each of the parameters. From Figure 4, one sees that SC25 values are below the mean values for all parameters (except N(C)) based on MWC at t = 4 years. The elapsed time of occurrence for SSN maximum is shown for SC12–24, where SC16, 18, 19, 21, and 22 had SSN maximum at t = three years; SC13, 14, 15, 17, 20, and 23 had SSN maximum at t = 4 years; SC12 had SSN maximum at t = 5 years; and SC24 had SSN maximum at t = 6 years. (SSN for SC25 measures

125.3 at t = 4 years. SSN maximum for SC25 is expected to occur in 2024 or 2025 at t = 5 or 6, respectively (Wilson 2019 a, b, 2022 and 2023).)

Table 4. Yearly parametric values for t = 0–9.

SSN

t	SC12	SC13	SC14	SC15	SC16	SC17	SC18	SC19	SC20	SC21	SC22	SC23	SC24	<SSN>/sd	SC25
0	5.7	10.4	4.6	2.4	9.7	9.2	16.1	6.6	15.0	18.4	14.8	11.6	4.2	9.9/5.1	3.6
1	10.0	11.8	8.5	16.1	27.9	14.6	55.3	54.2	22.0	39.3	33.9	28.9	4.8	25.2/16.7	8.8
2	53.7	59.5	40.8	79.0	74.0	60.2	154.3	200.7	66.8	131.0	123.0	88.3	24.9	88.9/49.9	29.6
3	90.5	121.7	70.1	95.0	106.5	132.8	214.7	269.3	132.9	220.1	211.1	136.3	80.8	144.8/63.2	83.2
4	99.0	142.0	105.5	173.6	114.7	190.6	193.0	261.7	150.0	218.9	191.8	173.9	84.5	161.5/51.7	125.3
5	106.1	130.0	90.1	134.6	129.7	182.6	190.7	225.1	149.4	198.9	203.3	170.4	94.0	154.2/44.2	
6	105.8	106.6	102.8	105.7	108.2	148.0	118.9	159.0	148.0	162.4	133.0	163.6	113.3	128.9/24.2	
7	86.3	69.4	80.9	62.7	59.4	113.0	98.3	76.4	94.4	91.0	76.1	99.3	69.8	82.8/15.9	
8	42.4	43.8	73.2	43.5	35.1	79.2	45.0	53.4	97.6	60.5	44.9	65.3	39.9	55.7/18.5	
9	21.8	44.4	30.9	23.7	18.6	50.8	20.1	39.9	54.1	20.6	25.1	45.8	21.7	32.1/13.0	

SSA

t	SC12	SC13	SC14	SC15	SC16	SC17	SC18	SC19	SC20	SC21	SC22	SC23	SC24	<SSA>/sd	SC25
0	22.2	76.7	27.9	7.5	54.7	91.3	124.7	34.6	53.9	169.8	124.7	81.9	22.8	68.7/48.7	37.9
1	36.3	98.8	59.5	152.4	278.0	118.2	426.5	552.4	113.3	347.0	296.8	210.2	26.6	208.9/162.0	85.1
2	446.8	566.4	338.6	697.8	825.1	622.1	1823.9	2394.7	592.6	1368.5	1345.3	763.1	214.3	923.0/634.9	249.2
3	679.5	1211.3	488.2	725.5	1263.2	1140.8	2634.1	3048.5	1519.1	2194.5	2579.2	1162.0	751.2	1492.1/845.1	863.3
4	968.0	1460.6	1195.9	1533.9	1060.8	2072.8	1974.6	3011.3	1569.8	2160.7	2048.7	1614.2	796.9	1651.4/602.8	1143.6
5	1148.9	1281.5	775.0	1112.6	1388.9	2015.2	2140.0	2872.9	1450.1	2270.2	2470.2	1704.1	860.8	1653.1/652.0	
6	1034.1	973.4	1092.1	1054.7	1238.9	1576.8	1227.3	1641.2	1601.3	2220.1	1349.2	1828.7	1252.2	1391.5/364.6	
7	810.2	547.4	697.5	617.3	516.6	1037.2	1135.3	613.5	990.2	919.5	696.2	1099.2	618.8	792.2/218.8	
8	379.4	511.7	691.5	419.6	279.1	658.1	402.9	463.5	916.7	811.7	340.4	683.8	225.2	521.8/212.5	
9	177.3	374.7	266.0	252.0	163.2	427.3	145.1	287.8	457.6	179.0	159.6	542.6	217.5	280.7/130.1	

NARE

t	SC12	SC13	SC14	SC15	SC16	SC17	SC18	SC19	SC20	SC21	SC22	SC23	SC24	<NARE>/sd	SC25
0	81	191	78	60	244	225	370	166	390	426	394	306	122	235/132	97
1	117	258	134	436	589	337	1103	1183	506	926	938	686	123	564/377	224
2	775	1252	760	1864	1718	1290	2838	3820	1498	4035	2900	1937	623	1947/1128	729
3	1423	2321	1374	2290	2210	2706	4298	4855	3390	5439	4734	2733	1788	3043/1371	1788
4	1622	3071	1937	3510	2369	3705	3892	5016	2963	3965	4751	3587	1848	3249/1077	2703

5	1792	2740	1859	2904	2613	3401	3903	4514	2932	3920	4715	3476	2121	3145/947
6	2039	2134	1951	2249	2413	2892	2333	3259	3379	3686	3314	3528	2442	2740/621
7	1522	1182	1686	1396	1394	2118	1861	1586	2229	2371	1886	2145	1544	1763/369
8	750	903	1442	943	781	1473	963	1027	2263	1474	1205	1311	910	1188/413
9	452	777	766	543	471	1014	431	819	1203	604	707	973	477	711/245

N(S), Zurich and MMZ

t	SC12	SC13	SC14	SC15	SC16	SC17	SC18	SC19	SC20	SC21	SC22	SC23	SC24	<N(S)>/sd	SC25
0	70	163	63	42	175	132	258	139	293	250	320	252	97	173/93	86
1	79	221	78	317	355	215	739	906	248	-	757	525	91	378/287	200
2	533	928	458	1413	1226	727	1630	2730	742	-	2136	1437	466	1202/710	550
3	960	1521	681	1579	1392	1573	2981	3468	2115	-	3496	1826	1149	1895/942	1195
4	1200	2030	996	2233	1514	2255	2820	2989	1759	-	3611	2294	1139	2069/803	1820
5	1349	1894	1032	1903	1563	2368	2864	2951	1483	-	3461	2032	1400	2025/746	
6	1524	1303	1222	1537	1543	1910	1739	1993	1548	2596	2494	2004	1492	1762/422	
7	1080	769	1191	931	830	1185	1395	982	1158	1828	1418	1245	1055	1159/280	
8	551	668	837	559	485	882	788	651	1076	1095	953	761	672	768/195	
9	375	467	473	354	341	646	350	548	625	495	587	529	350	472/111	

N(C), Zurich and MMZ

t	SC12	SC13	SC14	SC15	SC16	SC17	SC18	SC19	SC20	SC21	SC22	SC23	SC24	<N(C)>/sd	SC25
0	11	28	15	18	69	93	112	27	97	176	74	54	25	61/49	11
1	38	37	56	119	234	122	364	277	258	-	181	161	32	157/109	24
2	242	324	302	451	492	563	1208	1090	756	-	764	500	157	571/328	179
3	457	800	693	711	828	1133	1317	1387	1275	-	1238	907	639	949/309	593
4	422	1041	941	1277	855	1450	1072	2027	1204	-	1140	1293	709	1119/400	883
5	443	846	827	1001	1050	1033	1039	1563	1449	-	1254	1444	721	1056/329	
6	515	831	729	712	870	982	594	1266	1831	1090	820	1524	950	978/374	
7	442	413	495	465	564	933	466	604	1071	543	468	900	489	604/217	
8	199	235	605	384	296	591	175	376	1187	379	252	550	238	421/273	
9	77	310	293	189	130	368	81	271	578	109	120	444	127	238/156	

Note: For SC12-21, N(S), and N(C) are based on RGO; for SC21-25, N(S) and N(C) are based on MMZ.

N(S), MWC

t	SC21	SC22	SC23	SC24	<N(S)>/sd	SC25
0	-	373	288	122	261/128	93

1	-	922	633	118	558/407	216
2	-	2752	1793	594	1713/1081	670
3	-	4454	2505	1572	2844/1471	1627
4	-	4573	3306	1660	3180/1461	2345
5	-	4414	3044	1772	3077/1321	
6	3222	3146	3053	1920	2835/614	
7	2160	1817	1843	1298	2307/731	
8	1344	1171	1083	863	1115/200	
9	571	682	804	431	622/159	

N(C),	**MWC**					
t	**SC21**	**SC22**	**SC23**	**SC24**	**<N(C)>/sd**	**SC25**
0	-	19	18	0	12/11	4
1	-	16	53	5	25/25	8
2	-	148	144	29	107/68	59
3	-	279	228	216	241/33	161
4	-	177	281	187	215/57	358
5	-	298	432	349	360/68	
6	376	168	475	522	385/157	
7	174	69	302	246	198/101	
8	116	34	228	47	106/89	
9	26	21	169	46	66/70	

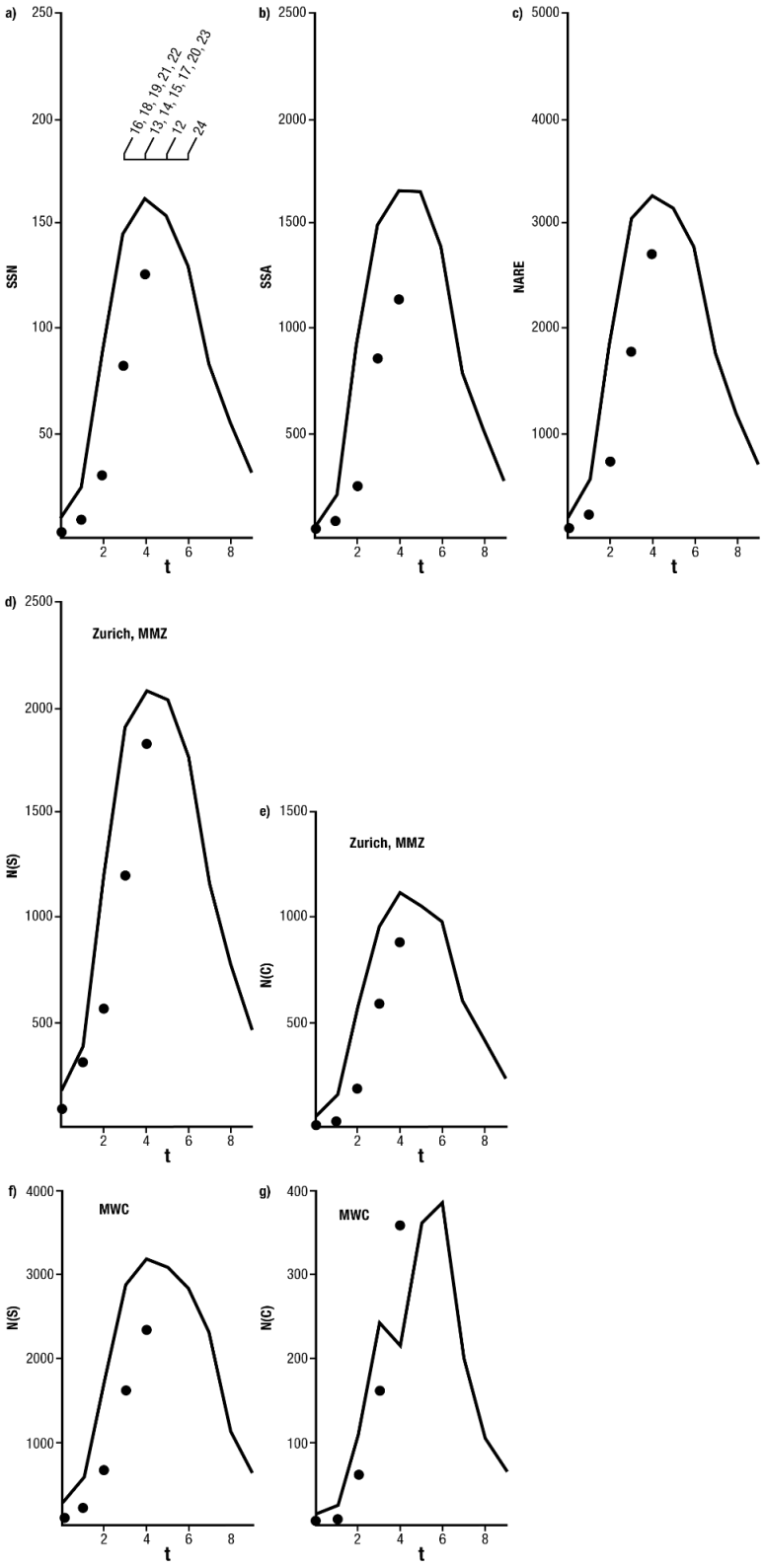

Figure 4. Comparison of SC25 parametric values (a) SSN, (b) SSA, (c) NARE, (d) N(S) based on Zurich and MMZ, (e) N(C) based on Zurich and MMZ, (f) N(S) based on MWC and (g) N(C) based on MWC for elapsed time t = 0–9 years.

Table 5 compares N(S), N(C), and N(D) values based on MWC during the interval 1982–2023, where N(D) is the number of delta spot groups (delta spots are strongly associated with great flares; Zirin and Liggett 1987; Zhongxian and Jingxiu 1994; and Sammis, Tang, and Zirin 2000. Interestingly, N(S), as a percentage of NARE, has decreased slightly between SC22 and SC24, from 95% to 86%, and the percentage of N(C) has increased from 5% to 14%. N(D) has remained fairly constant (about 3% of NARE). For SC22, 42% of the N(C) were delta configurations, with only about 29% and 28%, respectively, for SC23 and 24. For SC22 and 23, the largest yearly N(D) occurred two years after SSN maximum occurrence during the decline of the solar cycle. For SC24, yearly N(D) maximum coincided with yearly SSN maximum (at t = 6 years). (For the interval 1982–2023, N(D) comprises about 34% of the N(C).)

Table 5. Numbers and percentages of simple, complex, and delta spots based on MWC, 1982–2023.

Year	NARE	N(S)	N(C)	N(D)	P1	P2	P3	P4
SC21								
1982	3686	3222	376	194	87.4	10.2	5.3	51.6
1983	2371	2160	174	73	91.1	7.3	3.1	42.0
1984	1474	1344	116	75	91.2	7.9	5.1	64.7
1985	604	571	26	19	95.7	4.3	3.2	73.1
mean	2034	1824	173	90				
sd	1317	1135	148	74				
sum	8135	6087	692	361				
SC22								
1986m	394	373	19	7	94.7	4.8	1.8	36.8
1987	938	922	16	4	98.3	1.7	0.4	25.0
1988	2900	2752	148	54	94.9	5.1	1.9	36.5
1989M	4734	4454	279	136	94.1	5.9	2.9	48.8
1990	4751	4573	177	63	96.3	3.7	1.3	35.6
1991	4715	4414	298	146	93.6	6.3	3.1	49.0
1992	3314	3146	168	72	94.9	5.1	2.2	42.9
1993	1886	1817	69	21	96.3	3.7	1.1	30.0
1994	1205	1171	34	12	97.2	2.8	1.0	35.3
1995	707	681	22	6	96.3	3.0	0.9	28.6
mean	2554	2430	123	52				

Year	NARE	N(S)	N(C)	N(D)	P1	P2	P3	P4
sd	1761	1659	108	53				
sum	25544	24303	1230	521				
SC23								
1996m	306	288	18	5	94.1	5.9	1.6	27.8
1997	686	633	53	14	92.3	7.7	2.0	26.4
1998	1937	1793	144	31	92.6	7.4	1.6	21.5
1999	2733	2505	228	50	91.6	8.3	1.8	21.9
2000M	3587	3306	281	55	92.2	7.8	1.5	19.6
2001	3476	3043	433	126	87.6	12.4	3.6	29.2
2002	3528	3053	475	158	86.5	13.5	4.5	33.3
2003	2145	1843	302	91	85.9	14.1	4.2	30.1
2004	1311	1083	228	88	82.6	17.4	6.7	38.6
2005	973	804	169	53	82.6	17.4	5.5	31.4
2006	600	520	80	19	86.7	13.3	3.2	23.8
2007	308	285	23	11	92.5	7.5	3.6	47.8
mean	1799	1596	203	58				
sd	1281	1147	151	49				
sum	21590	19156	2434	701				
SC24								
2008m	122	122	0	0	100.0	0.0	0.0	
2009	123	118	5	1	95.9	4.1	0.8	20.0
2010	623	594	29	3	95.4	4.6	0.5	10.3
2011	1788	1572	216	62	87.9	12.1	3.5	28.7
2012	1848	1660	187	50	89.8	10.1	2.7	26.7
2013	2121	1772	349	100	83.6	16.5	4.7	28.7
2014M	2442	1920	522	158	78.6	21.4	6.5	30.3
2015	1544	1298	246	69	84.1	15.9	4.5	28.1
2016	910	863	47	14	94.8	5.2	1.5	29.8
2017	477	431	46	13	90.4	9.6	2.7	28.3
2018	161	154	7	1	95.7	4.3	0.6	14.3
mean	1105	955	150	43				

Year	NARE	N(S)	N(C)	N(D)	P1	P2	P3	P4
sd	867	710	171	51				
sum	12159	10504	1654	471				
SC25								
2019m	97	93	4	3	95.9	4.1	3.1	75.0
2020	224	216	8	0	96.4	3.6	0.0	0.0
2021	729	670	59	12	91.9	8.1	1.7	20.3
2022	1788	1627	161	55	91.0	9.0	3.1	34.2
2023	2703	2345	358	129	86.8	13.2	5.0	36.0
1982-2023								
mean	1737	1577	157	54				
sd	1371	1263	144	53				

Notes: NARE means the number of active region entries
N(S) means the number of simple spots (A+B)
N(C) means the number of complex spots (G+BG+BD+GD+BGD)
N(D) means the number of delta spots (BD+GD+BGD)
P1 is the percentage N(S)/NARE
P2 is the percentage N(C)/NARE
P3 is the percentage N(D)/NARE
P4 is the percentage N(D)/N(C)
m means minimum sunspot number occurrence
M means maximum sunspot number occurrence

Table 6 compares MMZ visual classes with MWC magnetic classes for N(C) and N(D). For the interval of 1982–2023, there were 6,600 N(C) based on MWC and 22,274 N(C) based on MMZ (from Table 3), of which 6,289 were also N(C) as determined using MWC; as stated earlier, types D–F are considered N(C) spots based on MMZ. Hence, 95.3% of the N(C) as determined using MWC were also N(C) as determined using MMZ (i.e., 6,289/6,600). Of the 22,274 N(C) as determined using MMZ, only 28.2% were also N(C) as determined using MWC (i.e., 6,289/22,274). Of the 6,600 N(C) as determined using MWC, 34.1% were also N(D) (i.e., 2,253/6,600). Of the 2,253 N(D), 97.3% were N(C) using MMZ (i.e., 2,191/2,253), while only 9.8% of the N(C) using MMZ were N(D) based on MWC (i.e., 2,191/22,274).

Table 6. Distribution of number of complex and delta spots based on MWC for MMZ, 1982–2023.

Year	class	A	B	C	D	E	F	H	total
SC21 (incomplete)									
1982	complex	1	3	15	98	190	67	2	376
	delta	1	0	6	39	94	53	1	194
1983	complex	1	2	10	65	61	35	0	174

Year	class	A	B	C	D	E	F	H	total
	delta	0	0	2	33	23	15	0	73
1984	complex	0	0	1	32	34	49	0	116
	delta	0	0	1	19	19	36	0	75
1985	complex	0	0	4	10	11	1	0	26
	delta	0	0	0	10	9	0	0	19
sum	complex	2	5	30	205	296	152	2	692
	delta	1	0	9	101	145	104	1	361
SC22									
1986	complex	0	1	3	9	5	1	0	19
	delta	0	0	0	4	2	1	0	7
1987	complex	0	0	2	8	6	0	0	16
	delta	0	0	0	2	2	0	0	4
1988	complex	1	0	5	33	55	54	0	148
	delta	1	0	1	9	15	28	0	54
1989	complex	1	1	9	33	102	133	0	279
	delta	1	0	3	14	53	65	0	136
1990	complex	1	0	5	38	72	61	0	177
	delta	0	0	3	12	24	24	0	63
1991	complex	2	1	15	77	92	109	2	298
	delta	1	1	8	42	37	57	0	146
1992	complex	1	1	16	45	68	37	0	168
	delta	1	0	3	24	36	8	0	72
1993	complex	1	0	4	22	23	19	0	69
	delta	1	0	1	11	6	2	0	21
1994	complex	0	0	4	11	11	8	0	34
	delta	0	0	0	7	5	0	0	12
1995	complex	0	1	2	11	8	0	0	22
	delta	0	0	0	3	4	0	0	7
sum	complex	7	5	65	287	442	422	2	1230
	delta	5	1	19	128	184	185	0	522

Year	class	A	B	C	D	E	F	H	total
SC23									
1996	complex	0	0	5	4	9	0	0	18
	delta	0	0	2	1	2	0	0	5
1997	complex	0	0	4	5	33	10	1	53
	delta	0	0	0	1	9	4	0	14
1998	complex	0	1	16	38	45	44	0	144
	delta	0	0	6	14	9	2	0	31
1999	complex	0	0	5	35	99	89	0	228
	delta	0	0	0	7	21	22	0	50
2000	complex	0	0	3	67	127	84	0	281
	delta	0	0	0	13	20	22	0	55
2001	complex	0	0	8	102	181	142	0	433
	delta	0	0	0	32	44	49	0	125
2002	complex	0	0	8	125	216	126	0	475
	delta	0	0	3	32	62	61	0	158
2003	complex	0	0	7	118	122	55	0	302
	delta	0	0	0	34	33	24	0	91
2004	complex	0	0	7	66	95	59	1	228
	delta	0	0	3	13	32	39	1	88
2005	complex	0	0	5	87	62	15	0	169
	delta	0	0	0	27	23	3	0	53
2006	complex	0	0	10	32	35	3	0	80
	delta	0	0	2	12	5	0	0	19
2007	complex	0	0	1	13	6	3	0	23
	delta	0	0	0	7	1	3	0	11
sum	complex	0	1	79	692	1030	630	2	2434
	delta	0	0	16	193	261	229	1	700
SC24									
2008	complex	0	0	0	0	0	0	0	0
	delta	0	0	0	0	0	0	0	0
2009	complex	0	0	0	4	1	0	0	5
	delta	0	0	0	0	1	0	0	1

Year	class	A	B	C	D	E	F	H	total
2010	complex	0	0	2	10	13	4	0	29
	delta	0	0	0	1	0	2	0	3
2011	complex	0	1	7	67	119	22	0	216
	delta	0	0	2	8	38	14	0	62
2012	complex	0	1	12	63	86	25	0	187
	delta	0	0	0	13	21	16	0	50
2013	complex	0	0	16	174	133	26	0	349
	delta	0	0	2	37	54	7	0	100
2014	complex	0	0	21	244	191	66	0	522
	delta	0	0	2	60	46	50	0	158
2015	complex	0	0	14	75	100	57	0	246
	delta	0	0	0	14	33	22	0	69
2016	complex	0	0	3	25	19	0	0	47
	delta	0	0	0	5	9	0	0	14
2017	complex	0	0	1	12	18	15	0	46
	delta	0	0	0	4	7	2	0	13
2018	complex	0	0	2	5	0	0	0	7
	delta	0	0	0	1	0	0	0	1
sum	complex	0	2	78	679	680	215	0	1654
	delta	0	0	6	143	209	113	0	471
SC25 (incomplete)									
2019	complex	0	0	1	2	1	0	0	4
	delta	0	0	1	2	0	0	0	3
2020	complex	0	0	0	3	1	4	0	8
	delta	0	0	0	0	0	0	0	0
2021	complex	0	0	8	38	13	0	0	59
	delta	0	0	1	8	3	0	0	12
2022	complex	0	0	7	48	83	23	0	161
	delta	0	0	1	21	25	8	0	55
2023	complex	0	0	15	145	165	33	0	358
	delta	0	0	0	58	59	12	0	129

Year	class	A	B	C	D	E	F	H	total
sum	complex	0	0	31	236	263	60	0	590
	delta	0	0	3	89	87	20	0	199
1982-2023									
	complex	9	13	283	2099	2711	1479	6	6600
	delta	6	1	53	654	886	651	2	2253

Note: Complex includes G, BG, BD, GD, and BGD
Delta includes BD, GD, and BGD only

Figure 5 displays the yearly variation of N(D) during the interval 1982–2023. Noticeable is that for SC22 and 23, the peak yearly N(D) followed SSN maximum by two years (i.e., during the declining phase of the solar cycle), while for SC24, yearly N(D) peaked simultaneously with SSN maximum (at t = 6). Also, SC21 had a larger N(D) (≥194) than SC22–24, and N(D) for both SC23 and 24 measured the same (N(D) = 158), even though SC23 was the larger SC (173.9 vs. 113.3). Yearly N(D) for SC25 is presently below that of SC21–24 but seems destined to be larger, reaching a maximum possibly in 2024–2026. (N(D) measures 110 for the interval January–June 2024.)

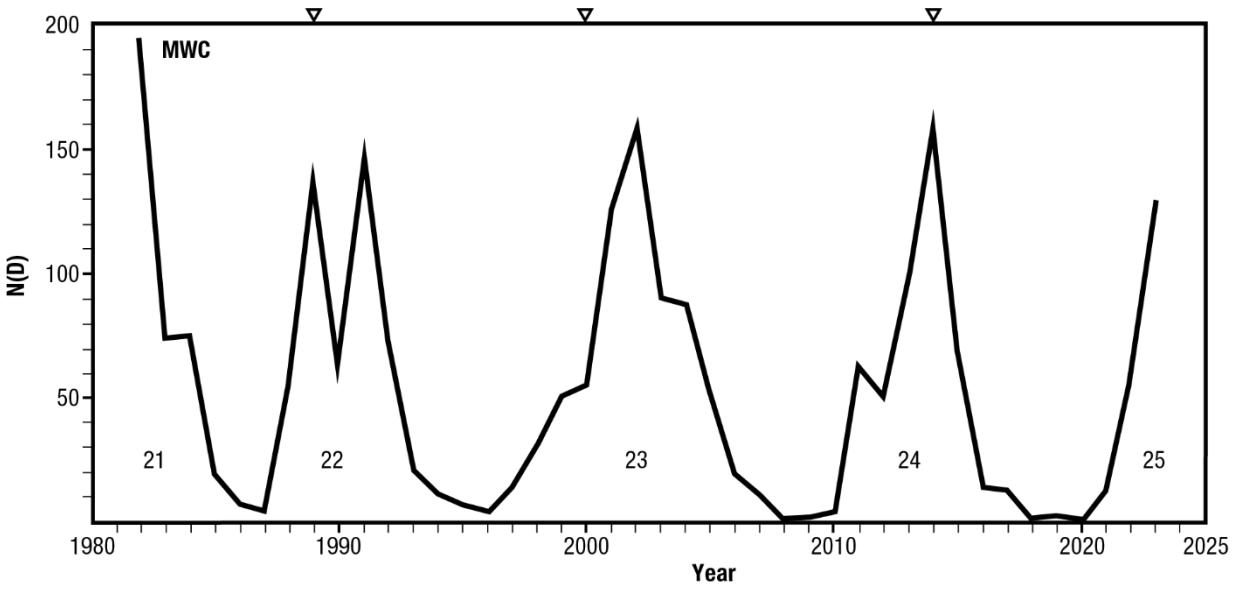

Figure 5. Yearly variation of N(D) based on MWC, 1982–2023.

Table 7 compares the number of single spots (N(SS)) against the number of type A spots (N(A)) as determined from MWC and the number of type A+H spots (N(A+H)) as determined from MMZ for the interval 1982–2023. Also given is the NARE and various percentages. During the interval 1982–2023, N(SS) totaled 16,276, which was about 22% of the NARE (16,276/72,969).

Table 7. Single spots (SS) 1982–2023.

Year	NARE	N(A)#	N(A+H)^	N(SS)	P1	P2	P3	P4	P5
SC21 (incomplete)									
1982	3686	1386	1364	879	37.6	23.9	63.4	37.0	64.4
1983	2371	941	936	572	39.7	24.1	60.8	39.5	61.1
1984	1474	532	512	337	36.1	22.9	63.4	34.7	65.8
1985	604	244	245	152	40.4	25.2	62.3	40.6	62.0
mean	2034	776	764	485					
sd	1317	497	491	314					
sum	8135	3103	3057	1940					
SC22									
1986m	394	185	187	110	47.0	27.9	59.5	47.5	58.8
1987	938	402	387	258	42.9	27.5	64.2	41.3	66.7
1988	2900	1134	1129	618	39.1	21.3	54.5	38.9	54.7
1989M	4734	1716	1659	854	36.3	18.0	49.8	35.0	51.5
1990	4751	1943	1881	905	40.9	19.0	46.6	39.6	48.1
1991	4715	1836	1780	893	38.9	18.9	48.6	37.8	50.2
1992	3314	1388	1392	695	41.9	21.0	50.1	42.0	49.9
1993	1886	859	855	468	45.6	24.8	54.5	45.3	54.7
1994	1205	519	506	301	43.1	25.0	58.0	42.0	59.5
1995	707	297	305	165	42.0	23.3	55.6	43.1	54.1
mean	2554	1028	1008	526					
sd	1761	669	648	307					
sum	25544	10279	10081	5266					
SC23									
1996m	306	126	126	82	41.2	26.8	65.1	41.2	65.1
1997	686	233	235	168	34.0	24.5	72.1	34.3	71.5
1998	1937	588	593	449	30.4	23.2	76.4	30.6	75.7
1999	2733	754	754	554	27.6	20.3	73.5	27.6	73.5

Year	NARE	N(A)#	N(A+H)^	N(SS)	P1	P2	P3	P4	P5
2000M	3587	1044	1047	799	29.1	22.3	76.5	29.2	76.3
2001	3476	1046	1048	809	30.1	23.3	77.3	30.2	77.2
2002	3528	1023	1029	765	29.0	21.7	74.8	29.2	74.3
2003	2145	602	605	413	28.1	19.3	68.6	28.2	68.3
2004	1311	404	409	275	30.8	21.0	68.1	31.2	67.2
2005	973	287	287	204	29.5	21.0	71.1	29.5	71.1
2006	600	212	209	135	35.3	22.5	63.7	34.8	64.6
2007	308	123	123	84	39.9	27.3	68.3	39.9	68.3
mean	1799	537	539	395					
sd	1281	360	361	280					
sum	21590	6442	15465	4737					
SC24									
2008m	122	40	39	27	32.8	22.1	67.5	32.0	69.2
2009	123	29	29	22	23.6	17.9	75.9	23.6	75.9
2010	623	247	248	174	39.7	27.9	70.5	39.8	70.2
2011	1788	536	534	438	30.0	24.5	81.7	29.9	82.0
2012	1848	571	572	434	30.9	23.5	76.0	31.0	75.9
2013	2121	694	694	507	32.7	23.9	73.1	32.7	73.1
2014M	2442	706	706	515	28.9	21.1	73.0	28.9	73.0
2015	1544	475	475	349	30.8	22.6	73.5	30.8	73.5
2016	910	304	304	207	33.4	22.8	68.1	33.4	68.1
2017	477	223	223	145	46.8	30.4	65.0	46.8	65.0
2018	161	55	55	41	34.2	25.5	74.6	34.2	74.6
mean	1105	353	353	260					
sd	867	257	257	194					
sum	12159	3880	3879	2859					
SC25 (incomplete)									
2019m	97	50	50	33	51.6	34.0	66.0	51.6	66.0
2020	224	116	116	97	51.8	43.3	83.6	51.8	83.6
2021	729	287	287	227	39.4	31.1	79.1	39.4	79.1

Year	NARE	N(A)#	N(A+H)^	N(SS)	P1	P2	P3	P4	P5
2022	1788	577	576	434	32.3	24.3	75.2	32.2	75.4
2023	2703	950	948	686	35.2	25.4	72.2	35.1	72.4
1982-2023									
mean	1714	603	606	388					
sd	1380	504	490	276					

Note: NARE means number of active region entries
N(A) is the number of Group A spots from MWC
N(A+H) is the number of Group A and H spots from MMZ
N(SS) is the number of single spots
P1 is the percentage N(A)/NARE
P2 is the percentage N(SS)/NARE
P3 is the percentage N(SS)/N(A)
P4 is the percentage N(A+H)/NARE
P5 is the percentage N(SS)/N(A+H)
m means sunspot minimum occurrence
M means sunspot maximum occurrence
means based on MWC
^ means based on MMZ

Figure 6 plots the yearly values of type 0 spot groups and N(SS) for the interval 1875–2023. Presuming type 0 spots are, perhaps, similar to single spot groups, one finds that they increased in number over time between SC12 and SC18–19, with SC14 being extremely low in number. Type 0 and N(SS) are observed to have trended downward from SC18–19, with SC24 having the smallest number of single spot groups since SC14, perhaps marking the recurrence of another Dalton-like minimum, a reflection of the Centennial Gleissberg Cycle (Gleissberg 1965; Feynman and Fougere 1984; Feynman and Ruzmaikin 2011, 2014; Wilson 2023).

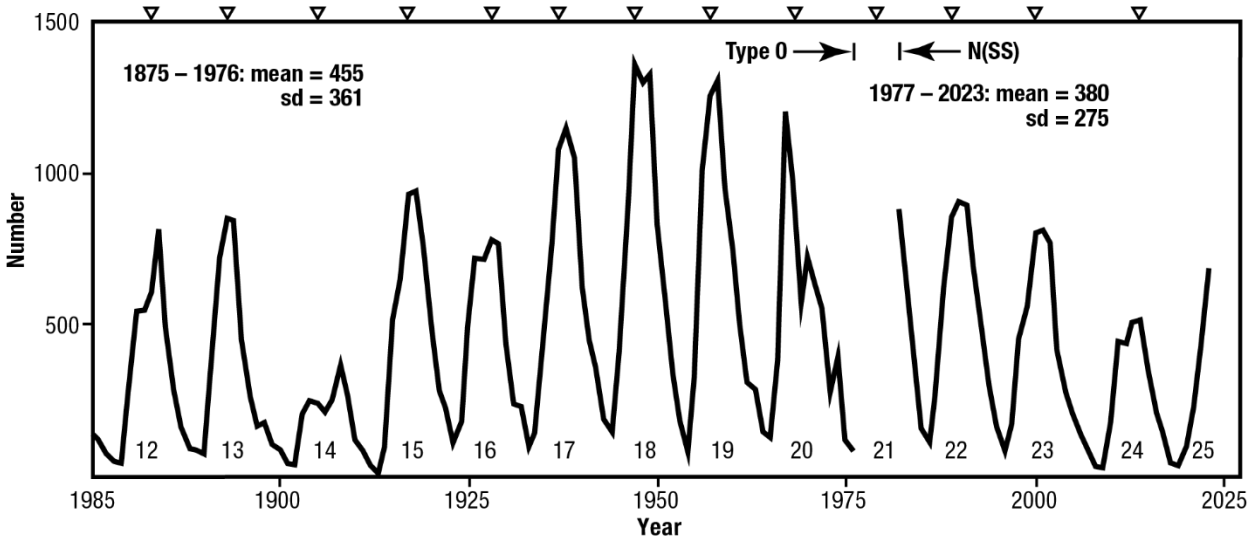

Figure 6. Yearly variation of type 0 spot groups and N(SS), 1875–2023.

During the RGO interval (1875–1976), type 0 spot groups averaged about 455 per year, with an sd of 361. During the interval 1982–2023, N(SS) averaged 380 single spots per year,

with an sd of 275. The *t* statistic for independent samples is computed to be $t = 1.21$, a result suggestive that the difference in means for the two samples is not statistically significant. Hence, type 0 spot groups appear to be consistent with the hypothesis that they might possibly be related to single spot groups; strictly speaking, it remains uncertain as to whether type 0 spots are, indeed, related to single spot groups. (Close inspection of Figure 6 (seen also in Tables 1 and 7) reveals that type 0 spots and single spots behave quite similarly, with the maximum number of each typically coinciding with the maximum in SSN or the year after SSN maximum, exceptions being SC14, which peaked three years after SSN maximum and SC20, which peaked one year before SSN maximum.)

Table 8 shows the yearly variation (1982–2023) of SSA, A(C), A(S), P(C), P(S), <A(C)>, and <A(S)>, where A(C) and A(S) are the yearly mean areas of complex and simple spot groups, respectively, based on MWC; P(C) and P(S) are the percentages of complex and simple spot groups as compared to SSA; and <A(C)> and <A(S)> are the mean areas of complex and simple spot groups. Thus, on average, complex and simple spot groups contribute, respectively, about 27% and 73% each to the total yearly SSA. Also, on average, complex spot groups measure about 414.5 millionths of a solar hemisphere in size as compared to about 123.8 millionths of a solar hemisphere for simple spot groups.

Table 8. Area and percentages of simple and complex spots based on MWC, 1982–2023.

Year	SSA	A(C)	A(S)	P(C)	P(S)	<A(C)>	<A(S)>
SC21 (incomplete)							
1982	2220.1	697.2	1522.9	0.314	0.686	676.8	172.5
1983	919.5	229.7	689.8	0.250	0.750	481.8	116.6
1984	811.7	285.2	526.5	0.351	0.649	899.9	143.4
1985	179.0	30.9	148.1	0.173	0.827	433.8	94.7
mean	1032.6	310.8	721.8			623.1	131.8
sd	856.4	279.8	580.2			212.4	33.7
SC22							
1986m	124.7	18.6	106.1	0.149	0.851	357.3	103.8
1987	296.8	12.4	284.4	0.042	0.958	282.9	112.6
1988	1345.3	241.9	1103.4	0.180	0.820	598.2	146.7
1989M	2579.2	714.0	1865.2	0.277	0.723	930.8	152.9
1990	2048.7	320.4	1728.3	0.156	0.844	660.7	137.9
1991#	2470.2	670.2	1800.0	0.271	0.729	820.9	148.8
1992	1349.2	227.9	1121.3	0.169	0.831	496.5	130.5
1993	696.2	90.4	605.8	0.130	0.870	478.2	121.7

Year	**SSA**	**A(C)**	**A(S)**	**P(C)**	**P(S)**	**<A(C)>**	**<A(S)>**
1994	340.4	40.5	299.9	0.119	0.881	448.0	93.4
1995	159.6	9.4	150.2	0.059	0.941	156.0	80.5
mean	1141.0	234.6	906.5			523.0	122.9
sd	959.8	265.0	709.9			237.5	24.9
SC23							
1996m	81.9	12.5	69.4	0.153	0.847	191.1	190.9
1997	210.2	52.5	157.7	0.250	0.750	361.6	90.9
1998	763.1	161.5	601.6	0.212	0.788	409.4	122.5
1999	1162.0	278.1	883.9	0.239	0.761	445.2	128.8
2000M	1614.2	379.8	1234.4	0.235	0.765	498.2	136.6
2001	1704.1	561.1	1143.0	0.329	0.671	467.6	137.3
2002	1828.7	625.4	1203.3	0.342	0.658	480.6	143.9
2003	1099.2	534.3	564.9	0.486	0.514	645.8	111.9
2004	683.8	251.4	432.4	0.368	0.632	403.6	146.1
2005	542.6	199.3	343.3	0.367	0.633	430.4	155.9
2006	245.1	70.3	174.8	0.287	0.713	320.7	122.7
2007	133.3	21.8	111.5	0.164	0.837	346.0	142.8
mean	839.0	262.3	576.7			416.7	135.9
sd	635.2	218.4	439.7			110.9	24.6
SC24							
2008m	22.8	0.0	22.8	0.000	1.000	0.0	68.4
2009	26.6	2.9	23.7	0.109	0.891	211.7	73.3
2010	214.3	13.4	200.9	0.063	0.938	168.7	123.4
2011	751.2	214.8	536.4	0.286	0.714	363.0	110.5
2012	796.9	186.3	610.6	0.234	0.766	362.7	134.7
2013	860.8	265.0	595.8	0.308	0.692	277.1	122.7
2014M	1252.2	544.4	707.8	0.435	0.565	380.7	134.6
2015	618.8	225.1	393.7	0.364	0.636	334.0	110.5
2016	225.2	33.6	191.6	0.149	0.851	261.7	81.3
2017	217.5	49.4	168.1	0.227	0.773	392.0	142.4

Year	SSA	A(C)	A(S)	P(C)	P(S)	<A(C)>	<A(S)>
2018	24.4	1.9	22.5	0.078	0.922	99.1	53.3
mean	455.5	139.7	315.8			259.2	105.0
sd	418.9	169.5	261.0			127.7	30.7
SC25 (incomplete)							
2019m	37.9	3.0	34.9	0.079	0.921	237.8	137.0
2020	85.1	11.6	73.5	0.136	0.864	530.7	124.5
2021	249.2	41.3	207.9	0.166	0.834	255.5	113.3
2022	863.3	174.9	688.4	0.203	0.797	396.5	154.4
2023	1143.6	310.3	833.3	0.271	0.729	316.4	129.7
1982-2023							
mean	785.7	209.9	575.8			414.5	123.8
sd	713.9	217.2	518.8			197.6	28.0

Note: SSA is sunspot area in millionths of a solar hemisphere
A(C) is the area of complex spots (G+BG+BD+GD+BGD)
A(S) is the area of simple spots (A+B)
P(C) is the percentage A(C)/SSA
P(S) is the percentage A(S)/SSA
<A(C)> is the mean size of a complex spot group
<A(S)> is the mean size of a simple spot group
m means SSN minimum occurrence
M means SSN maximum occurrence
means one entry considered bad data and is not included in tally: region 6924B on 19 November 1991, a beta region, listed as having a corrected area of 8020, up from 10 on 17 November 1991

Figure 7 shows plots A(S) and A(C) during the interval 1982–2023. Noticeable is that A(S) appears to have trended downward since SC21–22, at least through SC24. Likewise, A(C) appears to have trended downward slightly. As yet, SC25 has not had a yearly A(C) that has exceeded that of SC24, although its A(S) is now greater than that observed for SC24.

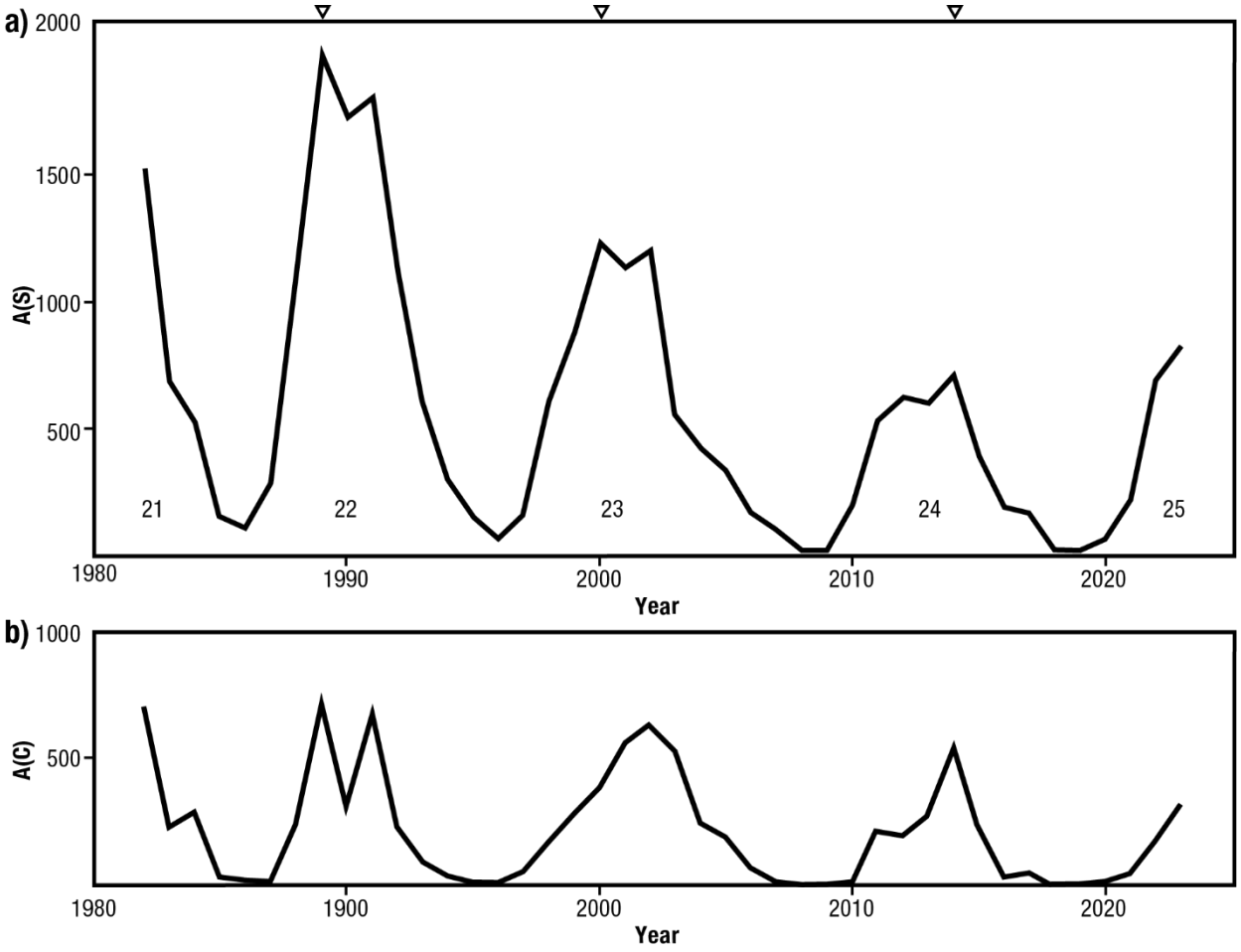

Figure 7. Yearly variation of (a) A(S) and (b) A(C), 1982–2023.

Figure 8 depicts the yearly variation of <A(S)> and <A(C)> for the interval 1982–2023. Both <A(S)> and <A(C)> appear to have trended downward, at least through SC24. (The filled triangle across the top of the chart shows the occurrences of SSN minimum for SC22–25.)

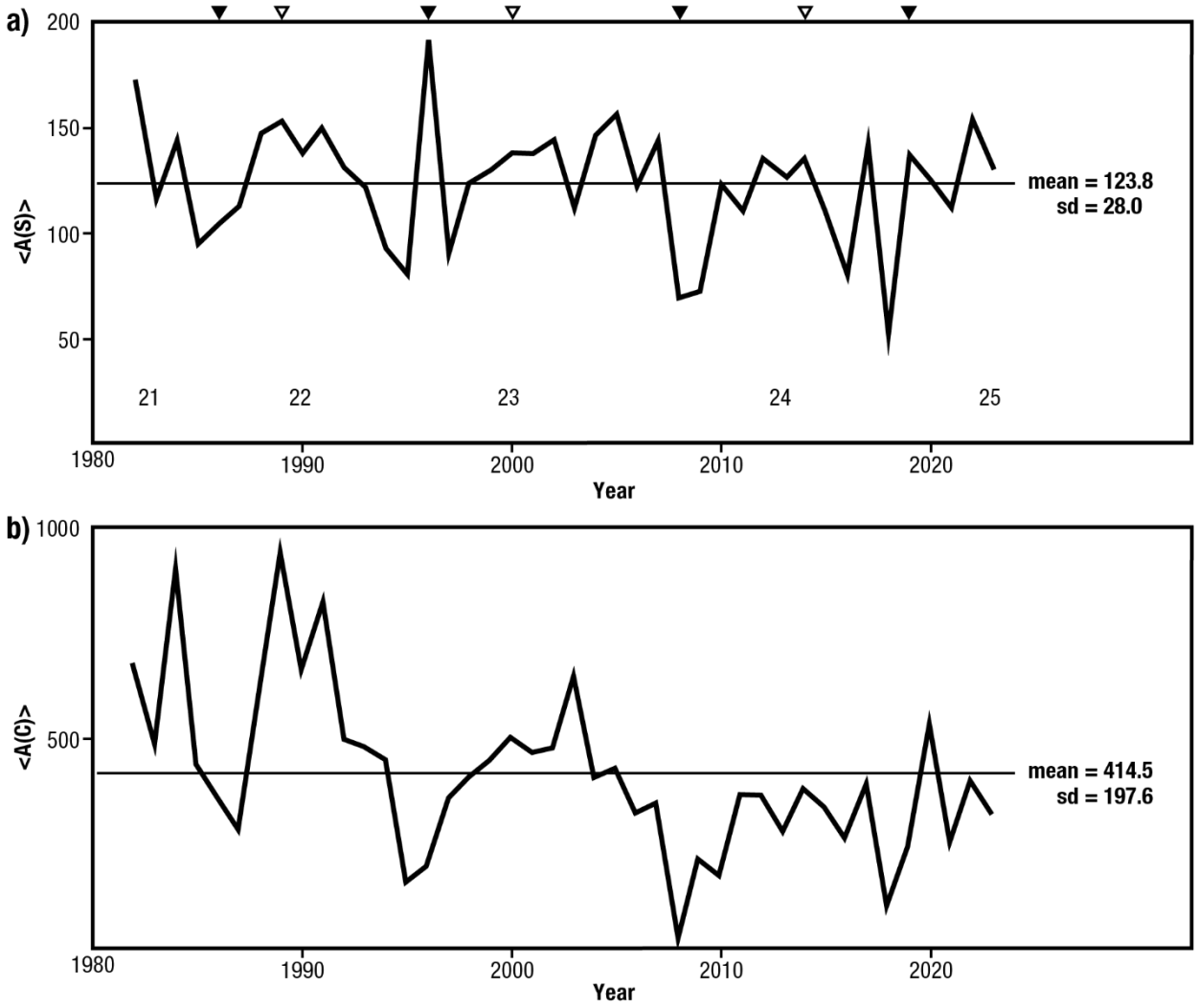

Figure 8. Yearly variation of (a) <A(S)> and (b) <A(C)>, 1982–2023.

Figure 9 shows the scatterplot of yearly N(S) vs. yearly SSN based on the MWC, 1982–2023. One finds a very strong correlation to exist between the two parameters, one having a coefficient of correlation $r = 0.9653$, a coefficient of determination $r^2 = 0.9317$ (meaning that about 93% of the variance in yearly N(S) can be explained by the inferred correlation, or vice versa), a standard error of estimate $S_{yx} = 334.1$, and a t statistic equal to 23.3650. Plainly, small (large) yearly SSN is associated with small (large) yearly N(S), and vice versa. Based on the observed 2x2 contingency table (determined by the vertical and horizontal lines), 20 of 21 small yearly N(S) are associated with small yearly SSN, and 20 of 21 large yearly N(S) are associated with large yearly SSN, yielding a probability $P << 0.001$ (i.e., the probability of obtaining the observed result, or one more suggestive of a departure from independence is $P << 0.001$). Because SC25 will have a yearly SSN maximum ≥125.3 (marked by the downward pointing arrow), its yearly N(S) will lie in the upper-right quadrant of Figure 9 (the value for the year 2023 is shown). Based on the regression equation, $y = 67.1 + 19.76x$, yearly N(S) at cycle maximum for SC25 will be ≥2,543 ± 334. Assuming a yearly SSN maximum equal to 148.5 for SC25 (Wilson 2023), its yearly N(S) based on MWC should measure about 3,000.

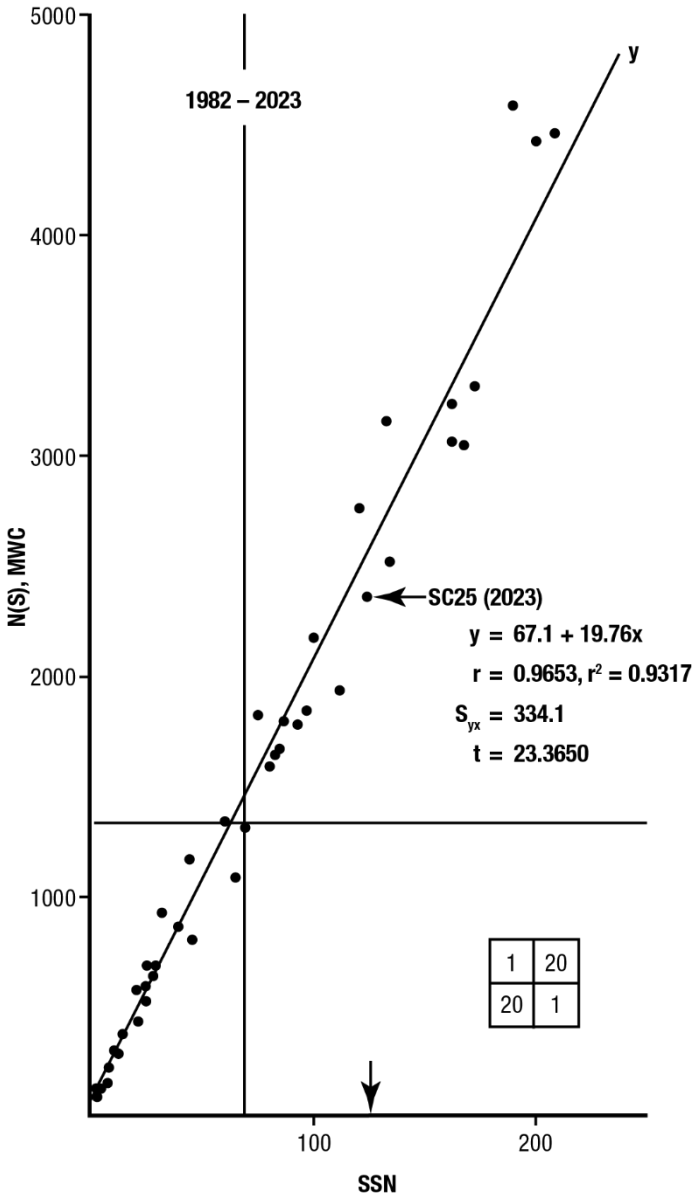

Figure 9. Scatterplot N(S), MWC vs. SSN, 1982–2023.

Similarly, Figure 10 depicts the scatterplot of yearly N(C) vs. yearly SSN based on the MWC, 1982–2023. The inferred linear regression is statistically important, having $r = 0.8052$, $r^2 = 0.6483$, $S_{yx} = 201.0$, and $t = 3.6451$. Again, small (large) yearly SSN is associated with small (large) yearly N(C), and vice versa. Based on the observed 2x2 contingency table, 19 of 21 small yearly N(S) are associated with small yearly SSN, and 19 of 21 large yearly N(S) are associated with large yearly SSN. Because SC25 will have a yearly SSN maximum ≥125.3 (marked by the downward pointing arrow), its yearly N(C) will lie in the upper-right quadrant of Figure 10 (the value for the year 2023 is likewise shown). Based on the regression equation, $y = 15.5 + 1.86x$, yearly N(C) at cycle maximum for SC25 will be ≥ 249 ± 201. Assuming yearly SSN maximum equal to 148.5 for SC25, its yearly N(C) based on MWC should measure about 292.

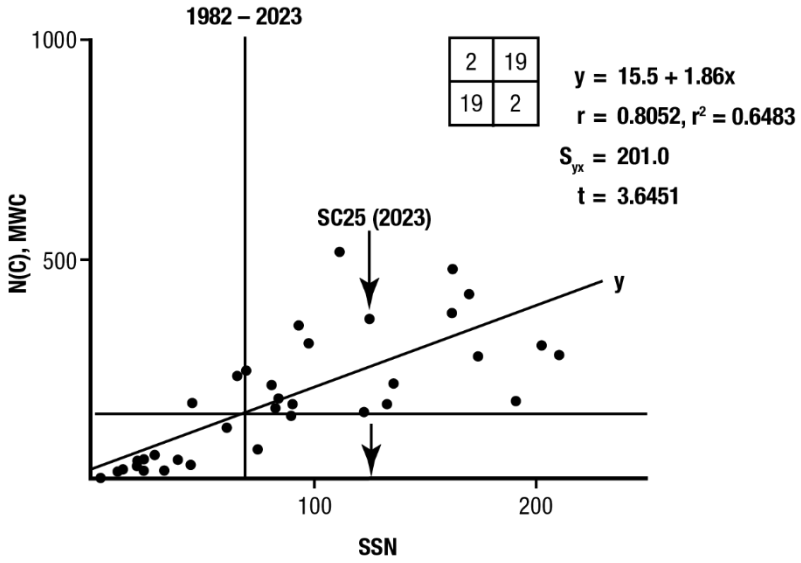

Figure 10. Scatterplot N(C), MWC vs. SSN, 1982–2023.

Figure 11 displays scatterplots of (a) yearly N(SS) vs. yearly SSN and (b) yearly N(D) vs. yearly SSN. Both inferred regressions are statistically important. For SC25, its yearly N(SS) at cycle maximum will be ≥ 603 ± 52, and its yearly N(D) will be ≥ 87 ± 31. (Yearly N(D) measured 129 in 2023.)

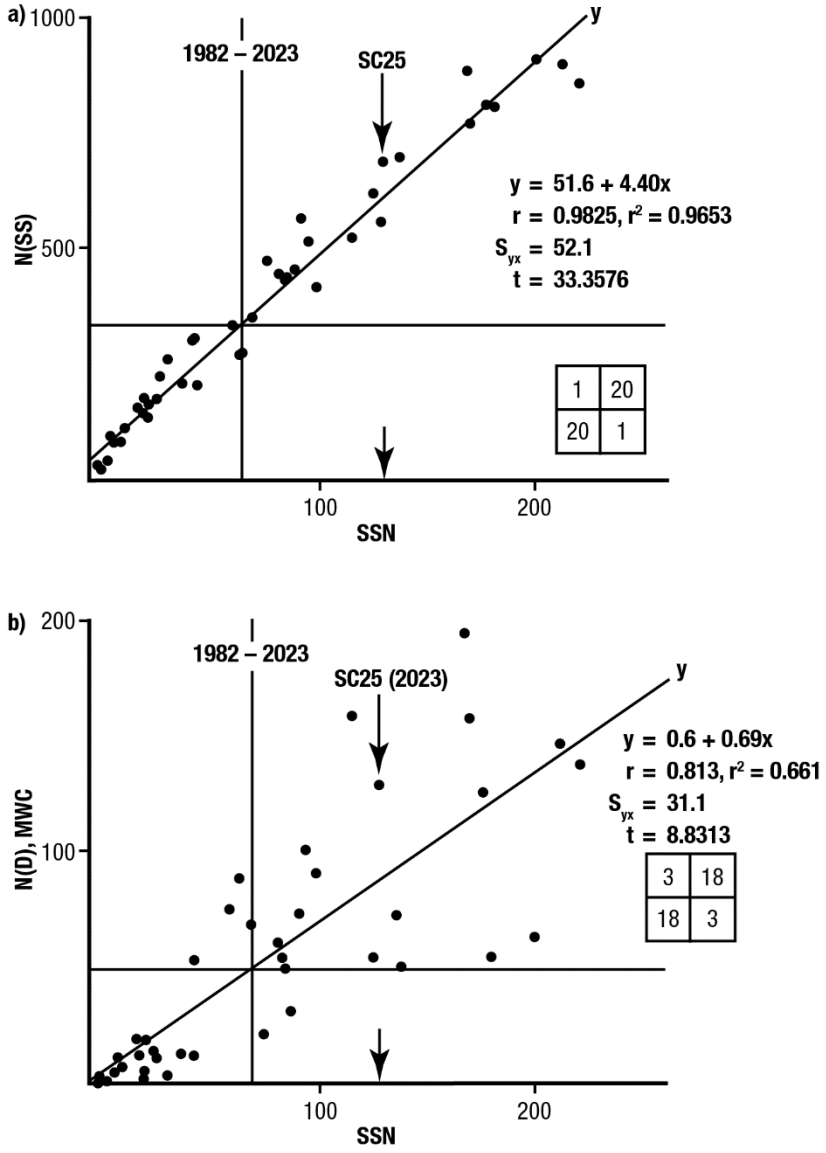

Figure 11. Scatterplots (a) N(SS) vs. SSN and (b) N(D) vs. SSN.

Figure 12 shows scatterplots of (a) yearly A(S) vs. yearly SSN, (b) yearly A(C) vs. yearly SSN, (c) yearly <A(S)> vs. yearly SSN and (d) yearly <(A(C)> vs. yearly SSN based on MWC. Of the four scatterplots, the weakest (although statistically significant at the 5% level of significance, or 95% level of confidence) is the one associating yearly <A(S)> vs. yearly SSN. All plots suggest that SC25 will have yearly values in the upper-right quadrant of the scatterplots. Interestingly, the yearly value of <A(C)> for 2023 is in the lower-right quadrant of its scatterplot. Presuming SC25 to have SSN maximum ≥125.3, one expects the A(S) maximum to be ≥ 985 ± 109 millionths of a solar hemisphere, A(C) maximum to be ≥363 ± 101 millionths of a solar hemisphere, <A(S)> maximum to be ≥134 ± 25 millionths of a solar hemisphere, and <A(C)> maximum to be ≥519 ± 145 millionths of a solar hemisphere. Assuming SSN maximum is equal to 148.5, A(S) maximum should be about 1,170 millionths of a solar hemisphere, A(C)

maximum about 436 millionths of a solar hemisphere, <A(S)> maximum about 138 millionths of a solar hemisphere, and <A(C)> maximum about 569 millionths of a solar hemisphere.

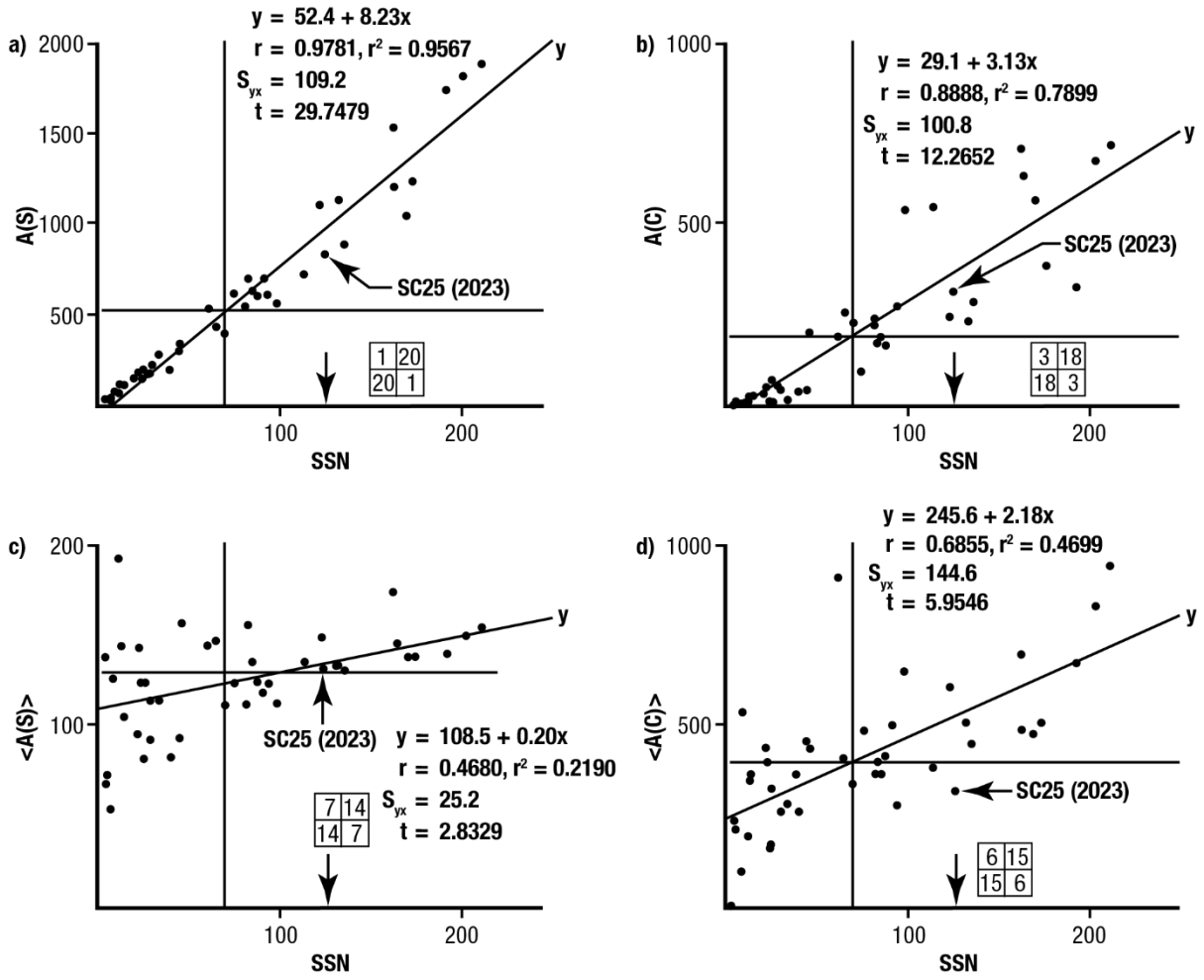

Figure 12. Scatterplots of (a) A(S) vs. SSN, (b) A(C) vs. SSN, (c) <A(S)> vs. SSN and (d) <A(C)> vs. SSN.

Table 9 provides a summary of the parametric maximum values for SC12–24 and their occurrence relative to SSN minimum occurrence. For the RGO-MMZ (and MWC) interval, N(S) and N(C) tend to occur on or after SSN maximum occurrence (i.e., during the declining phase of the solar cycle; only SC20 had N(S) maximum prior to its SSN maximum occurrence).

Table 9. Summary of parametric maximum values, SC12–24.

				RGO,MMZ				MWC				
SC	SSN	SSA	NARE	N(S)	N(C)	N(S)	N(C)	N(D)	A(S)	A(C)	<A(S)>	<A(C)>
12	106.1(5)	1148.9(5)	2039(6)	1524(6)	515(6)	-	-	-	-	-	-	-
13	142.0(4)	1460.6(4)	3071(4)	2030(4)	1041(4)	-	-	-	-	-	-	-

				RGO,MMZ				MWC				
SC	SSN	SSA	NARE	N(S)	N(C)	N(S)	N(C)	N(D)	A(S)	A(C)	<A(S)>	<A(C)>
14	105.5(4)	1195.9(4)	1959(6)	1222(6)	941(4)	-	-	-	-	-	-	-
15	173.6(4)	1533.9(4)	3510(4)	2233(4)	1277(4)	-	-	-	-	-	-	-
16	129.7(5)	1388.9(5)	2613(5)	1563(5)	1050(5)	-	-	-	-	-	-	-
17	190.6(4)	2072.8(4)	3705(4)	2368(5)	1450(4)	-	-	-	-	-	-	-
18	214.7(3)	2634.1(3)	4298(3)	2981(3)	1317(3)	-	-	-	-	-	-	-
19	269.3(3)	3048.5(3)	5016(4)	3468(3)	2027(4)	-	-	-	-	-	-	-
20	150.0(4)	1601.3(6)	3379(6)	2185(3)	1831(6)	-	-	-	-	-	-	-
21	220.1(4)	2220.1(6)	5439(4)	-	-	-	-	-	-	-	-	-
22	211.1(3)	2579.2(3)	4751(4)	3611(4)	1254(5)	4573(4)	297(5)	146(5)	1865.2(3)	714.0(3)	152.9(3)	930.8(3)
23	173.9(4)	1828.7(6)	3587(4)	2294(4)	1524(6)	3306(4)	475(6)	158(6)	1234.4(4)	625.4(6)	190.9(0)	645.8(7)
24	113.3(6)	1252.2(6)	2442(6)	1492(6)	950(6)	1920(6)	522(6)	158(6)	707.8(6)	544.4(6)	142.4(9)	392.0(9)

Note: The number in the parentheses is the elapsed time in years from SSN minimum year occurrence

In summary, this paper has presented the results of a study of the complexity of sunspot groups based on the solar areal dataset (http://solarcyclescience.com/activeregions.html). Sunspot groups can be simply divided into two groups—those with a simple visual or magnetic appearance and those with a more complicated visual or magnetic appearance. For the RGO/Zurich interval (1875–1976), simple spot groups (as defined in this study) accounted for about 64.5% of the daily observations, and complex spot groups accounted for about 35.5%. For the more recent MMZ interval (1982–2023), simple spots accounted for about 69.5% of the daily observations, and complex spot groups accounted for about 30.5%. Based on the MWC interval (1982–2023), simple spot groups accounted for about 90.8% of the daily observations, and complex spot groups accounted for only about 9.0% (0.2% of the observations during the interval had no MWC determinations). For the combined RGO/Zurich and MMZ intervals, simple spot groups accounted for about 66.1% of the combined daily observations, and complex spot groups accounted for 33.9%. (As stated earlier, the interval 1977–1981 has no MMZ or MWC spot group determinations of simplicity and complexity.)

For the most part, the current ongoing SC25 has tracked below mean values (SC12–24) of SSN, SSA, NARE, N(S), and N(C) for elapsed time t = 0–4 years. SC25 likely will attain maximum values in 2024 or 2025 (at t = 5 or 6 years). Based on MWC, N(D) appears to average about 3% of the daily observations (i.e., NARE) and has more often tended to peak in number during the declining phase of the solar cycle. For the interval 1982–2023, there were 6,600 complex spot groups based on MWC and 22,274 based on MMZ. 6,289 complex spot groups based on MMZ were also complex spot groups based on MWC (28.2%), but 95.3% of the complex spot groups as determined using MWC were also complex spot groups based on MMZ (i.e., types D, E, and F). Of the 6,600 complex spot groups, 34.1% were delta spots. Single spot groups accounted for about 64% of type A or type A+H spot groups and 22.6% of the daily entries. Simple spot group area accounted for about 73.3% of the SSA, while complex spot group area accounted for about 26.7%. During the 1982–2023 interval, simple spot groups averaged about 123.8 millionths of a solar hemisphere in size, while complex spot groups averaged about

414.5 millionths of a solar hemisphere. Interestingly, simply on the basis of N(S) or N(SS), one can predict SSN for an ongoing SC, or given the expected size of an ongoing SC, one can predict its N(S) or N(SS). As an example, Wilson (2023) predicted SC25 to have a maximum SSN of about 148.5 ± 21.1, based on the average of several techniques for predicting the size of an SC. Such a value predicts N(S) = 3,001 ± 334, N(C) = 292 ± 201, N(SS) = 705 ± 52, N(D) = 103 ± 31, A(S) = 1,170 ± 109 millionths of a solar hemisphere, A(C) = 436 ± 101 millionths of a solar hemisphere, <A(S)> = 138.2 ± 25.2 millionths of a solar hemisphere, and <A(C)> = 569.3 ± 144.6 millionths of a solar hemisphere (all predictions being +/– 1 sd prediction intervals).

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