Analysing sunspot activity: A qualitative and quantitative approach

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The two methods currently used for monitoring solar activity in white light, the sunspot count and the active area count, provide consistent measures of the extent of solar activity but both ignore its quality. This paper addresses the question of whether the quality of sunspot activity changes during a cycle. Solar activity since 1979 is analysed in order to check whether any change in quality could be detected during this period. Furthermore it illustrates how observations of both the number and type of active areas can be used to monitor both the quality and the extent of solar activity reliably.

Introduction

The most often quoted method for measuring solar activity is the sunspot count, which takes into consideration the number of spot groups, g, and the number of individual spots in each group, f, combining them through the relationship: $R = k(10g + f)$, where R is the relative sunspot number, k is a constant depending on the telescope used and the observer's ability, and 10 is an arbitrarily chosen constant.[1] This method, however, does not distinguish between spots of various sizes. In fact, a small spot counts as much as a larger spot with penumbra.

On the other hand, the active area count simply adds the number of active areas (AAs) on the Sun's disk.[2] Each area counts as one irrespective of whether it consists of a single spot or of a multitude of spots and penumbral areas.

Thus, an observer of the Sun's disk as shown in Figure 1 would estimate the solar activity as having a relative sunspot number, $R = 50$, assuming $k = 1$, since $g = 4$, and $f = 10$, or an active are count, AA, of 4. Both methods ignore the type of activity and the fact that one can arrive at the same values of R and AA with a completely different set of sunspots. Therefore, though both methods are good indicators of the rise and fall of sunspot activity during a solar cycle, they give no indication of any change in the type of spot groups. In other words, these methods disregard the quality of sunspot activity, that is, the mix of small and large single spots, with or without penumbra, and spot groups of different size, structure and complexity.

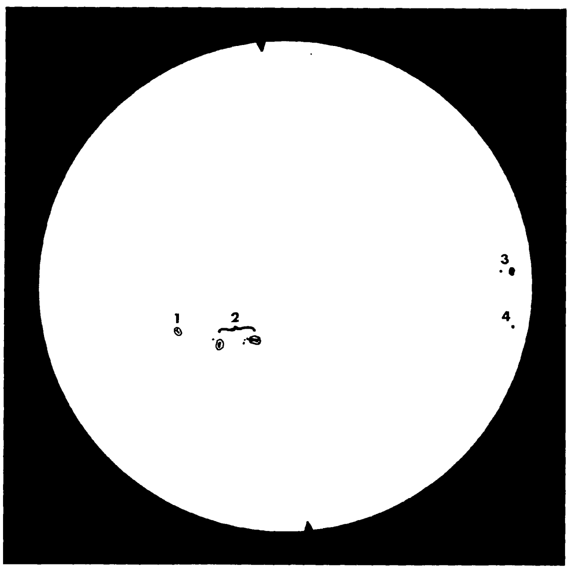

Figure 1. 80-mm, f/15 refractor, by projection, Tony Tanti. The Sun's disk in white light, 1984 January 17 at 12h 05m UT. $P = 5.5°$, $B_0 = -4.8°$, $L_0 = 244.4°$. North is up and East is to the right. The spot-groups west of the central meridian are counted as two separate active areas since area no.1 is 10° of heliocentric longitude away from the leading spot of group no. 2 which, in turn, is less than 10° away from the other centre of activity in the same group.

Because of the predominant use of the sunspot count and the active area count, references to the quality of solar activity are virtually non-existent, at least in the current literature available to amateurs. Some books on observational astronomy[3,4] give the Zurich classification of sunspot groups as revised by Waldmeier (see Figure 2), but they do not present any data regarding its use. In the semi-popular literature, Abetti[5,6] simply describes the Zurich classification without any reference to its application in solar research. However, when discussing the nineteenth solar cycle, which reached an all-time record maximum relative sunspot number of 355 on 1957 December 24 and 25, he notes that the activity was of a different quality from that of previously recorded maxima. In fact, the 19th cycle was remarkable because it had no spots of large dimensions as had been observed in all earlier cycles. The high relative number was due to the occurrence of a large number of small spots.[7]

In his classical review of solar research, Kiepenhauer[8] uses the Zurich classification to describe the development of some types of active areas, which, as he notes, do not merely change their number of spots and surface area but apparently also pass through a sequence of classes. However, he neither mentions any attempt to monitor general sunspot activity for change in quality nor any check whether the sunspot activity of one cycle is significantly different from that of another.[9]

Apparently, neither has the problem of quality attracted any attention from members of the BAA, at least these last thirty five years, since none of the papers related to solar observations published in this *Journal*

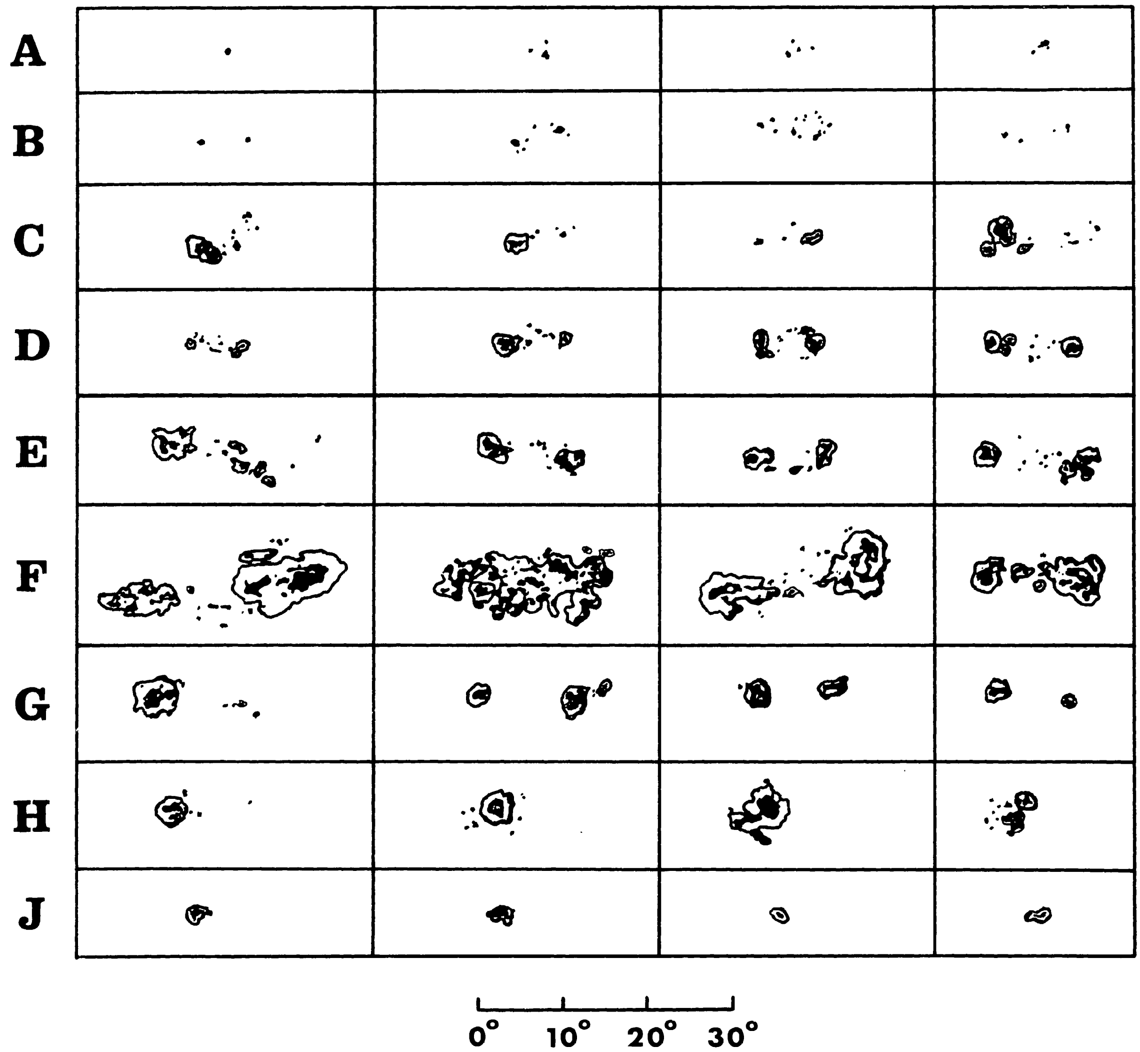

Figure 2. The Zurich Classification of Sunspots. Type A: Small single spot or very small group of spots, mostly of short duration and concentrated in a region of two to three square degrees. No systematic structure of the group; spots without penumbra. Type B: Bipolar group without penumbrae, long axis roughly East-West with concentration of spots at the east and west ends. Type C: Bipolar like B, but at least one main spot with penumbra. Type D: Bipolar with largest spots showing penumbrae. Type E: Large bipolar with complicated structure. Numerous small spots between the two major spots which both have penumbrae. At least 10° in longitude. Type F: Very large bipolar or complex group. At least 15° in longitude. Type G: Large bipolar without small spots between the major two. At least 10° long. Type H: Unipolar with penumbra. Diameter at least 2.5°. Type J: As H, diameter less than 2.5°.

since 1951 and indexed by Perry and Dougherty[10] seem to tackle it.

Observations

For some years we have been making observations of the Sun in such a way as to permit us to attempt an answer to the question of possible change in the quality of sunspot activity. Both authors have sketches of the solar disk at least since 1979, as well as both disk drawings and a classification of active areas since 1984 for each observing day. Although the sketches do not show the exact position and size of each sunspot, they are intentionally detailed enough to permit the classification of each active area according to the Zurich types. The observations were made using a 50-mm refractor by direct vision (FV) and an 80-mm refractor by the projection method (TT).

The assignment of an active area to a particular class is fairly straightforward in the majority of cases provided that careful attention is paid to the descriptive notes and to the illustrative examples of the Zurich classification. Occasionally an active area may not fit any one class exactly in which case either the spot is considered as a member of the class which most nearly fits its description, or a double classification may be made. If the latter procedure is adopted the total number of active areas per class could contain fractions.

Table 1 presents our combined data for each year from 1979, when sunspot maximum was reached, to 1986, when sunspot activity had decreased drastically. The table shows the number of spots per class, N, the mean daily frequency (MDF) of each class obtained by dividing the number of spots by the number of observ-

Table 1. Number (N) and mean daily frequency (MDF) of sunspots in each Zurich class (A – J) for the years 1979–86.

Class		*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*Tot.*
	N	948	596	542	283	197	56	145	399	764	3930
1979	MDF	2.10	1.32	1.20	0.63	0.44	0.12	0.32	0.88	1.69	8.70
(452 d)	%	24.12	15.17	13.79	7.20	5.01	1.42	3.69	10.15	19.44	
	N	1026	540	495	335	114	21	110	258	585	3484
1980	MDF	2.48	1.30	1.20	0.81	0.28	0.05	0.27	0.62	1.41	8.42
(414 d)	%	29.44	15.50	14.21	9.62	3.27	0.60	3.16	7.41	16.79	
	N	721	507	435	265.5	195.5	31.5	86	295.5	330	2867
1981	MDF	2.04	1.44	1.23	0.75	0.55	0.09	0.24	0.84	0.93	8.11
(353 d)	%	25.15	17.68	15.17	9.26	6.82	1.10	3.00	10.31	11.51	
	N	383	256	232	155	84	30	25	205	244	1614
1982	MDF	1.56	1.04	0.95	0.63	0.34	0.12	0.10	0.84	1.00	6.58
(245 d)	%	23.73	15.86	14.37	9.60	5.20	1.86	1.55	12.70	15.11	
	N	363	238.5	206	106	53.5	4	24	103	195	1293
1983	MDF	1.03	0.68	0.59	0.30	0.15	0.01	0.07	0.29	0.56	3.68
(351 d)	%	28.07	18.45	15.93	8.20	4.14	0.31	1.86	7.97	15.08	
	N	337	159	147.3	111.3	45	16.5	17.3	61.5	219	1114
1984	MDF	0.73	0.35	0.32	0.24	0.10	0.04	0.04	0.13	0.48	2.43
(459 d)	%	30.27	14.25	13.22	9.99	4.06	1.48	1.55	5.52	19.66	
	N	113.3	67	85	27	27	0	10.3	66.3	96	492
1985	MDF	0.23	0.14	0.17	0.06	0.06	0.00	0.02	0.14	0.20	1.02
(490 d)	%	23.02	13.62	17.28	5.49	5.49	0.00	2.08	13.49	19.54	
	N	94	57	61	29	17	0	10	53	58	379
1986	MDF	0.19	0.11	0.12	0.06	0.03	0.00	0.02	0.11	0.12	0.76
(496 d)	%	24.80	15.04	16.09	7.65	4.49	0.00	2.64	14.00	15.30	
Mean	%	26.08	15.70	15.01	8.38	4.81	0.85	2.44	10.19	16.55	

ing days, which are shown in brackets, and the relative percentage of each class of spot obtained by dividing the number of spots in each class by the total number of spots for that year and converting the fraction to a percentage.

Quality control

A cursory look at Table 1 shows that solar activity decreases considerably from a high mean daily frequency of 8.7 active areas per day in 1979 to a low of 0.76 in 1986. For each year, the majority of active areas are of class A followed by a preponderance of areas of classes J, B and C. Large, complex areas of class E or F are found every year irrespective of the extent of sunspot activity. The MDF values of each class for each year can be interpreted as the probability of the occurrence of a spot of that type. Thus the probability of observing a class E active area decreases from 44 out of 100 observing days in 1979 to only 3 out of 100 observing days in 1986.

When considering the changes in the percentage of active areas in each class from year to year, no discernible pattern emerges. This suggests that there is no consistent change in the quality of sunspot activity for the years under consideration and that the general distribution of active areas among classes is as shown in Figure 3.

Two statistical methods can be used to check whether there was any change in the quality of sunspot activity, namely (a) χ^2 tests for differences between the percentage distribution of active areas among classes for each year and the average distribution over the whole period, and (b) tests of significance on the slopes of regression lines of graphs of percentage against time for each of the classes.[11]

A χ^2 test gives reliable results without need of a correction as long as each entry is above a certain value. In our case the value of the percentage of each class is expected to be at least 5%. However some values, notably those of classes F and G, fall well below this level. The normal procedure of combining some of the values so that the aggregate exceeds the 5% level is adopted. Thus the percentages of classes D and G, and classes E and F have been combined in the calculation

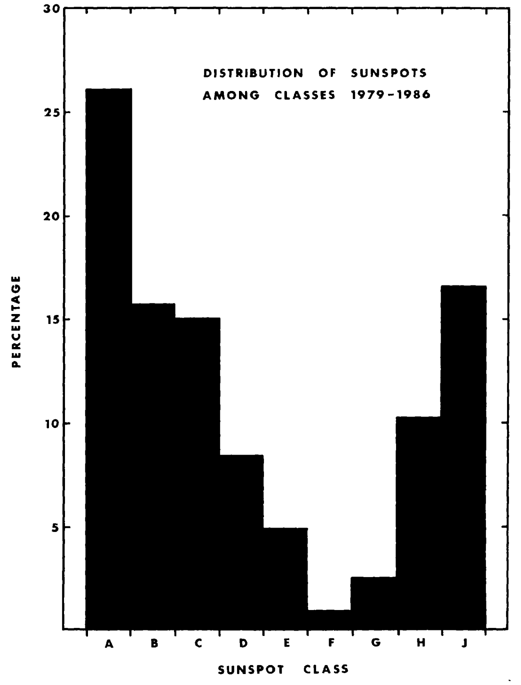

Figure 3. Distribution of sunspots among classes based on the average percentage values in each class for the years 1979–1986.

of χ^2 values. The criterion for combining classes depends on their likeness and on the possibility that they may be exchanged by an observer especially if observing conditions are unfavourable. Additionally, the values of classes H and J have been combined since our observations indicate that at times these had been exchanged and small class H areas for one observer had been recorded as large class J areas by the other and vice versa.

Thus χ^2 tests were used to check whether the percentage distribution of spots for each year was any different from the following:

Class	*A*	*B*	*C*	*D+G*	*E+F*	*H+J*
%	26.08	15.70	15.01	10.82	5.66	26.74

For the second method graphs of percentage against year are plotted and the line of best fit determined by means of regression equations for each class. Now, if there is no significant change in the percentage distribution from one year to another, the slopes of these graphs are expected to be zero, or nearly so. Otherwise the slopes would have values significantly different from zero: positive if there is a consistent increase in the percentage of a certain type of spot, or negative if there is a decrease. A *t*-test can be used to check whether the slopes are any different from zero by estimating the standard error of the slope, calculating the value of *t* and determining its statistical significance.

Results

The values of χ^2 obtained by the first method range between 0.511 and 3.439, which, at five degrees of freedom, fail to reach statistical significance of the required magnitude. In other words, this test shows that the percentage distribution of sunspots among classes in any one year is not particularly different from the average distribution over the whole period.

The slopes of the graphs of each class of active area, the standard errors and the *t* values are given in Table 2 below. When the *t* values are compared to the appropriate table of significance, it is found that the value of the slopes are not significantly different from zero. From this result, it can only be concluded that none of the different classes of active areas has shown an increase or a decrease in its percentage distribution since 1979.

The general conclusion is that both methods of analysis show that the quality of sunspot activity did not change significantly from year to year between 1979 and 1986. In other words the Sun churned out practically the same pattern of sunspots, but in decreasing amount, as solar activity abated from the maximum of 1979 to 1986.

Valuing quality

While this result is interesting in its own right, it would be even more interesting to find out whether such a pattern changes over a whole cycle or from one cycle to another. Persons with access to past records could look back and compare the present cycle with previous ones. On the other hand, active observers could take advantage of the new cycle that is beginning and start monitoring the Sun for the quality of sunspot activity. For this purpose we recommend that, rather than just noting the number of active areas on the solar disk, observers should also classify these areas according to the Zurich types. Such observations would enable analysts to estimate both the extent of the activity by means of the active area (AA) count method, and the quality of the activity as outlined above.

Table 2. Results of plotting percentage in each sunspot class against year and determining the significance of the slope of the line of best fit by the regression method.

Class	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*
Slope	−0.091	−0.214	0.323	−0.199	−0.022	−0.159	−0.200	0.455	0.109
SE	0.400	0.223	0.159	0.212	0.156	0.087	0.091	0.414	0.414
t	−0.227	−0.960	2.031	−0.939	−0.141	−1.828	−2.198	1.099	0.263

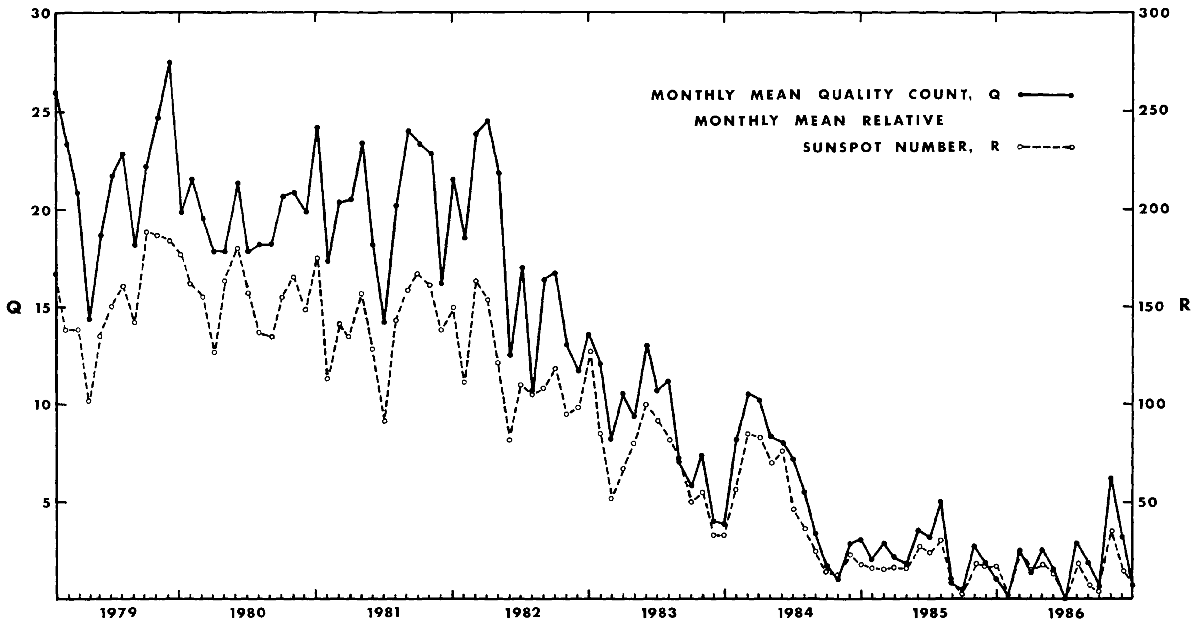

Figure 4. Plot of Quality count, Q, and Relative Sunspot Number, R, against date 1979 to 1986.

Furthermore by a simple method of reduction, the data can be converted into a count that correlates with the relative sunspot number, R, to a higher degree than the AA count does. The method involves the assignment of arbitrary values to the various classes of active areas such that class A areas are given a value of 1, and the other classes are given the values B = 2, C = 3, D = 4, E = 5, F = 6, G = 4, H = 3, and J = 2.[12] Thus, referring back to Figure 1, in which the Sun is shown with one area each of classes A, C, G and H, the count, which can be called the quality count, would be 11. The aggregate of similar daily quality counts over a whole month divided by the number of observing days in that month gives a monthly mean, Q, which can be compared directly to the monthly mean relative sunspot number, R, although the scales are different.

When our observational data from 1979 to 1986 are reduced in this way and plotted along with the definitive monthly mean sunspot number obtained from Zurich, up to 1980, and from the Sunspot Index Data Centre, Bruxelles thereafter, the graph shown in Figure 4 is obtained. This graph shows how closely the reduced data reflect the sunspot number obtained by the standard method. The correlation coefficient, r, of the two measures is 0.977, which confirms their comparability and the validity of the reduction method as proposed. Similarly, the correlations between our individual monthly means is very high ($r = 0.987$), which indicates the high reliability of this method.

Finally we are sure that solar observers would agree that adding a measure of quality to that of quantity provides us with further information that can help us understand better the processes that cause the phenomenon we call solar activity. Hopefully, this paper will stimulate observers to carry out observations in such a way as to permit analysis of the quality of sunspot activity. Moreover, if the results outlined above are accepted, it should inspire theoreticians to suggest feasible explanations for the apparent consistency of the quality of sunspot activity throughout a cycle. The ultimate aim is to shed more light on the, as yet, unresolved problem of what causes the solar cycle.[13]

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Notes and References

1 This method was first suggested by Wolf in 1849. It is the method that has been used to determine solar activity internationally at the Federal Observatory, Zurich back to 1749 and up to 1980, and at the Sunspot Index Data Centre, Bruxelles since then.

2 A single spot is counted as an active area if it is at least 10° from its nearest neighbour. If two unconnected spots or groups of spots are 10° or more apart, they are counted as two active areas.

3 Clay Sherrod, P., *A complete manual of amateur astronomy*, 99, Englewod Cliffs, N. J., 1981.

4 Muller, R., in *Astronomy: A handbook* (ed. Roth, G. D., transl. and rev. Beer, A.), 228, Berlin, 1975.

5 Abetti, G., *The Sun*, 82, London, 1957.

6 Abetti, G., *Solar Research*, London, 1962.

7 Abetti, G., *op. cit.*, 45 (1962).

8 Kiepenhauer, K. O., in *The Sun* (ed. Kuiper, G.), 340–344, Chicago, 1953.

9 Other classifications of sunspot types exist but they are not known widely. Sidgwick, J. B., *Observational Astronomy for Amateurs*, 4th ed., 49, London, 1982, gives a classification by A. L. Cortie, a former Director of the Solar Section of the BAA, but again no reference is made to its application.

10 Perry, A. W. and Dougherty, L. M., *Solar Index 1951–1981*, Ravenstone Observatory, Halifax, 1984.

11 The statistical techniques used can be found in any basic text such as Guilford, J. P. and Fruchter, B., *Fundamental statistics in psychology and education*, 6th ed., Tokyo, 1978.

12 These values give the highest correlation with the international sunspot number. Other values, which make the differences between classes larger, have been investigated but they give lower correlations.

13 Gough, D., *Nature*, **31**, 263 (1986).