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NORTH-SOUTH ASYMMETRY IN SOLAR SPOTTEDNESS AND IN GREAT-STORM SOURCES

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Contents

A Long-Term North-South Asymmetry in the Location of Solar Sources of Great Geomagnetic Storms

By Barbara Bell[1]

In a previous paper (Bell, 1961), I presented evidence of a striking north-south asymmetry in the number of major solar flares, and an even greater asymmetry in the number of such flares followed by a great geomagnetic storm. During the years 1937 through 1959, about 62 percent of the 580 observed major solar flares occurred in the northern solar hemisphere; about 86 percent of the 74 major flares that were followed within three days by a great geomagnetic storm occurred north of the solar equator. The probability of such large asymmetries occurring by chance is, according to the normal distribution law, about 10^{-8} for the major flares in general, and less than 10^{-9} for the great-storm flares. These surprising asymmetries appeared in each of the three sunspot cycles within the interval studied. These asymmetries thus have no apparent relation either to the 11-year cycle in sunspot numbers or to the 22-year cycle in the magnetic polarities of sunspots. In this paper we shall examine evidence on the preferred location of great-storm sources in earlier sunspot cycles.

Systematic observation of solar flares has been carried out only since about 1936. Although a few bright flares were observed in earlier years, the number of these is much too small for use in any study of the location of great-storm sources. For earlier years one must rely on sunspot data. For the years subsequent to 1874, I obtained such data from *Sunspot and Geomagnetic-Storm Data, 1874–1954*, compiled at the Royal Greenwich Observatory (1955) under the supervision of H. W. Newton. These data include: (1) the annual average spotted area for north and south separately for each year, which I summed to obtain a measure of the "total spotted area" for each cycle; (2) a list of great sunspot groups (area $\geq 500 \times 10^{-6}$ of the visible disk), which includes the heliographic latitude and average area for each spot group; and (3) lists of great and of small geomagnetic storms recorded at Greenwich and/or Abinger from 1874. The last tables include the position and average area of the largest sunspot group in the region -3 to $+5$ days of the solar central meridian at the time of storm onset. If we assume that the listed spot group is the source of the storm, we can readily determine the number of great and of small storms arising from spots in each solar hemisphere in each cycle. In the few cases where the accompanying notes indicated some other spot as the more probable source, the spot listed in the "notes" was used instead of the one in the table.

Figure 1 shows the percentage of spotted area, of great spots, and of great and small storms appearing to arise from northern active centers in each cycle. The Greenwich data cover cycles 12 through 18. Table 1 gives additional information, including the year of sunspot maximum corresponding to each cycle number.

Three sources provide data on four earlier cycles, 8 through 11. A paper by Newcomb (1901) provides data, based on observations by Spörer, whereby the spotted-area curve of figure 1*a* can be extended back for two cycles, 10 and 11. Spörer (1874) published spot frequencies according to hemisphere for 1853 to 1871.

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Newton and Milsom (1955) determined the annual numbers of spot groups in each hemisphere for the years 1832 to 1866 from Schwabe's drawings; these unpublished numbers, which they generously made available to me, provide the points representing cycles 8 and 9 and, together with Spörer's and Newcomb's data, cycle 10.

An estimate for cycle 19 has been added as a broken line to figure 1*a*. Based on the numbers of groups observed at Mount Wilson through 1960, the northern hemisphere has contributed about 56 percent of the spottedness in cycle 19. Although the remaining years of the cycle may alter this percentage, it seems safe to say that cycle 19 will be north-dominant in spottedness.

Figure 1*a* shows that the northern solar hemisphere contributed over 50 percent of the spottedness in cycles 8 and 9 (1833 to 1856) and in cycles 14 through 19 (1901 to 196–); the southern hemisphere contributed over 50 percent of the spottedness in cycles 10 through 13 (1856 to 1901). As a guide to the statistical significance of the deviation of the individual cycles from 50 percent, the expected fluctuation (standard deviation σ) for a random distribution of spottedness is about ± 1.0 percent, ranging from ± 0.9 percent for a strongly spotted cycle like 18 to ± 1.2 percent for a weakly spotted cycle like 12. Cycles 8, 9, 11, 12, 13, 15, 16, and 19 deviate from a symmetrical distribution by more than 3σ. The remaining 4 cycles deviate by less than 2σ (see Wolbach, following paper). The number of large deviations suggests that the relative spottedness of the two hemispheres is a nonrandom phenomenon.

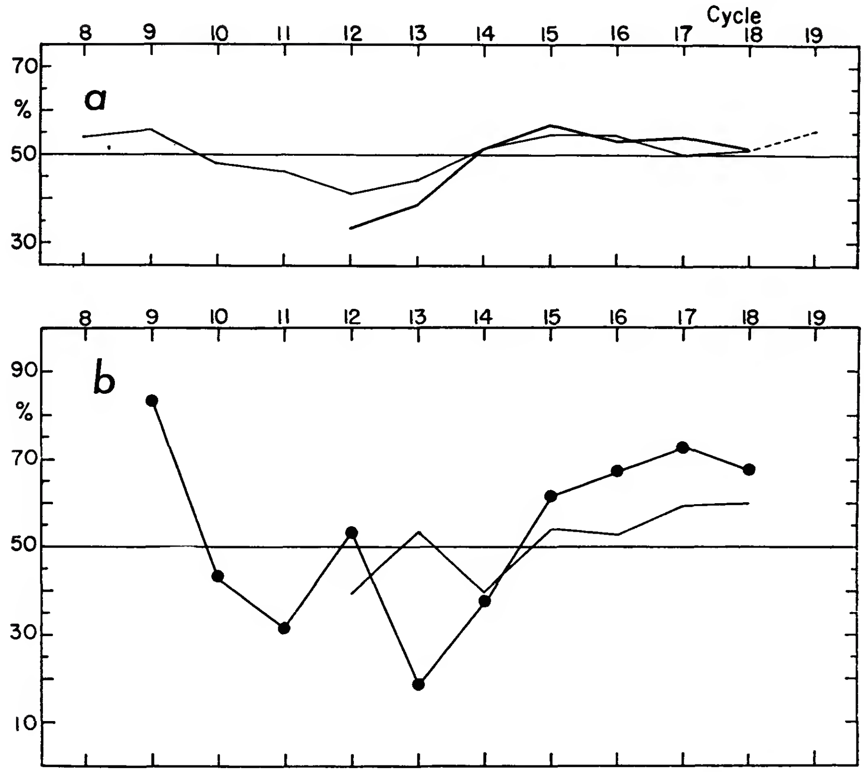
For great spots, because of the smaller sample sizes, only cycles 12 and 13 deviate by as much as 2σ, while cycles 15 and 17 deviate by more than σ. The persistence of the direction of the deviation for several successive cycles is perhaps more impressive than the actual magnitude of the individual deviations.

Great storms recorded at Greenwich from 1840 to 1874 are listed in a supplementary table of the Greenwich (1955) publication. Here the date of central meridian passage and the area of notable relevant sunspots are included, but not the latitude of the spots. Information on the latitude of these spots was obtained from Carrington's (1863) drawings covering the period from November 1853 to March 1861, and Spörer's (1874, 1876) solar maps covering January 1861 to October 1871. Additional data were kindly supplied by A. S. Milsom from his inspection of Kew photographs for 1868 through 1872, and of Schwabe's drawings for 1840 through 1852.

The curve representing the location of great-storm sources (fig. 1*b*) has a larger amplitude, or more pronounced north-south asymmetry, than does the curve of total spottedness or the curve representing total numbers of great spots. This agrees with the earlier finding (see fig. 2) that location of great-storm flares showed a greater hemisphere asymmetry than did that of major flares in general. While the spot and storm-source curves differ in amplitude, a majority of the great storms apparently arose from the more-spotted hemisphere in all but two (nos. 12 and 14) of the 11 cycles available for study.

Because of the small numbers of great storms per cycle, only the points for cycles 9, 11, 13, 17, and 18 represent deviations greater than 2σ from the 50-percent line in figure 1*b*. Here particularly, however, the persistence of the sense of the asymmetry for several cycles appears more significant than the magnitude of the individual deviations. If we consider cycles 10 through 14 as a unit, we find 77 great storms, of which 49 appeared to arise from southern spot groups; for cycles 15 through 18, we find 66 great storms, 45 of them apparently arising from northern spots. According to the normal distribution law, the probability of so large a difference between north and south occurring by change is 0.02 for the first, and 0.003 for the second of these intervals. The addition of cycle 19 would further diminish the second value.

The asymmetry in location of small-storm sources is less systematic and less in amplitude (fig. 1*b*) than that for great-storm sources. While in agreement with the results of Bell (1961) (see also fig. 2), the small-storm curve cannot be considered particularly significant. Many of the small storms must be of the recurrent or M-region type, and Allen (1944) has shown that this type of storm source tends to avoid large sunspots. Thus the procedure of



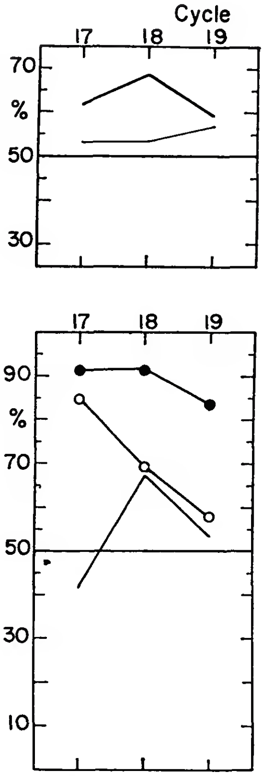


FIGURE 1.—Percentage of spot activity occurring in the northern solar hemisphere in each sunspot cycle from 8 to 19. *a*, Heavy line indicates great ($A \geq 500$) sunspot groups; thin line, total spottedness. *b*, Percentage of great (●——●) and small (——) geomagnetic storms attributed to northern spot groups.

FIGURE 2.—Percentage of observed major flares occurring in the northern solar hemisphere in cycles 17–19. *Top*, Heavy line indicates major flares; thin line, all flares. *Bottom*, flares followed by a great (●——●), moderate (○——○), and small (——) geomagnetic storm. (From Bell, 1961.)

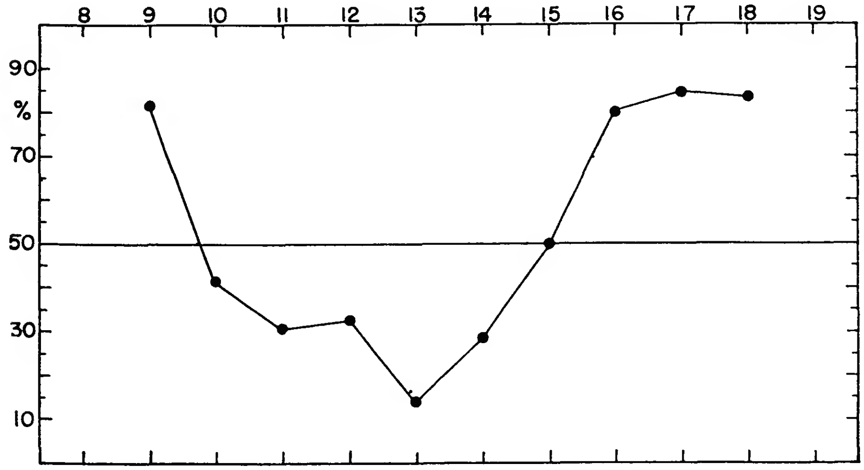


FIGURE 3.—Percentage of extra-great geomagnetic storms attributed to northern spot groups in each cycle, 9 through 18.

ascribing the storm source to the largest centrally located sunspot probably has little consistent validity for small storms, and the curve is included only for completeness.

Figure 1 should be compared with figure 2, reproduced from Bell (1961). The hemispheric inequality in production of major flares appears greater than that in spots, and both are smaller than the inequality in numbers of great-storm flares. Figure 2 shows also that in cycles 17 and 18, when major flares are used to identify the storm-producing region, 91 percent of the great storms appear to arise from northern active centers. This percentage drops to about 70 when spots are used, as in figure 1*b*.

At least two factors contribute to this difference. There is little doubt that observation of a major flare permits a more reliable identification of the storm-producing solar center, which is not always the largest spot group near the central meridian. Thus major flares should be considered to give the more accurate picture of the actual north-south asymmetry in location of great-storm sources. In addition, the criterion of figure 2 for identification of a "great" storm ($Ap \geq 100$ and/or a 3-hr $Kp \geq 9^-$) excludes the lower range of storms listed by Greenwich (1955) as "great"; figure 2 indicates that the asymmetry is more pronounced for great than for moderate-storm sources.

To explore the importance of this second factor, I subdivided the Greenwich "great storms" into greater and lesser great-storms. The Greenwich (1955) criterion for a "great storm" is a deflection of the H or Z component of the earth's field $\geq 300\gamma$ and/or a deflection of at least 60′ in the D component. To select a list of greater great-storms, I raised these limits to H or $Z \geq 400\gamma$ and/or $D \geq 70'$. As figure 3 shows, the greater great-storms have, in most cycles, the larger north-south asymmetry in location of source, particularly from cycle 12 onward. Cycles 17 and 18 are now in better agreement with the flare data. Also cycle 12 becomes south-dominant, as one might expect from the greater spottedness of the south in this cycle. Cycles 14 and 15, however, show a less satisfactory accord with spot asymmetry.

What can we say about a long-period cycle in either aspect of north-south asymmetry? Newcomb (1901) drew attention to a general excess of southern spots from 1856 to 1898. Brunner-Hagger and Liepert (1941) subsequently presented evidence for a long-period variation in relative spottedness of the two hemispheres over the years 1853 to 1938, and inferred a period of about 80 years. The later years of cycle 17, however, did not confirm their inference that this would be a south-dominant cycle; cycle 18 was again slightly north-dominant in total spottedness; and, through 1960, cycle 19 produced 56 percent of its spot groups in the north. Hence if a true cycle does exist, its period appears to be greater than 80 years. Since the available data, from 1832 through 1960, do not appear to define even one possible complete cycle, we cannot draw any conclusions as to whether figure 1 illustrates some long-period cycle of solar behavior, or merely irregular long-period variations in the relative activity of the two hemispheres. We can, however, conclude that the frequency of substantial inequalities is greater than would be expected to occur by chance (see Wolbach, following paper, especially fig. 3), and that the direction of the inequality does not vary in a random manner from cycle to cycle.

Another difference between northern and southern solar hemispheres was pointed out by Bell (1960), who presented evidence suggesting a more systematic structure of the northern than the southern sunspot zone in the years since 1917.

Newton and Milsom (1955) examined the annual values of the spotted areas in the form of the ratio $(N-S)/(N+S)$, where N and S are the annual mean values of the spotted area in the north and in the south. They found that in cycles 12 through 14 this ratio diminished during each cycle; in cycles 17 and 18 the ratio increased, while in cycles 10 and 11, and 15 and 16 it lacked any systematic trend. Waldmeier (1957) suggested that the behavior of the ratio reflects a phase difference in the activity of the two hemispheres, a phase difference that changes slowly with a period of the order of 80 years. The hemisphere that is the more spotted later in the cycle tends to produce a majority of the great storms in that cycle, but from so few cycles we can draw no definite conclusions.

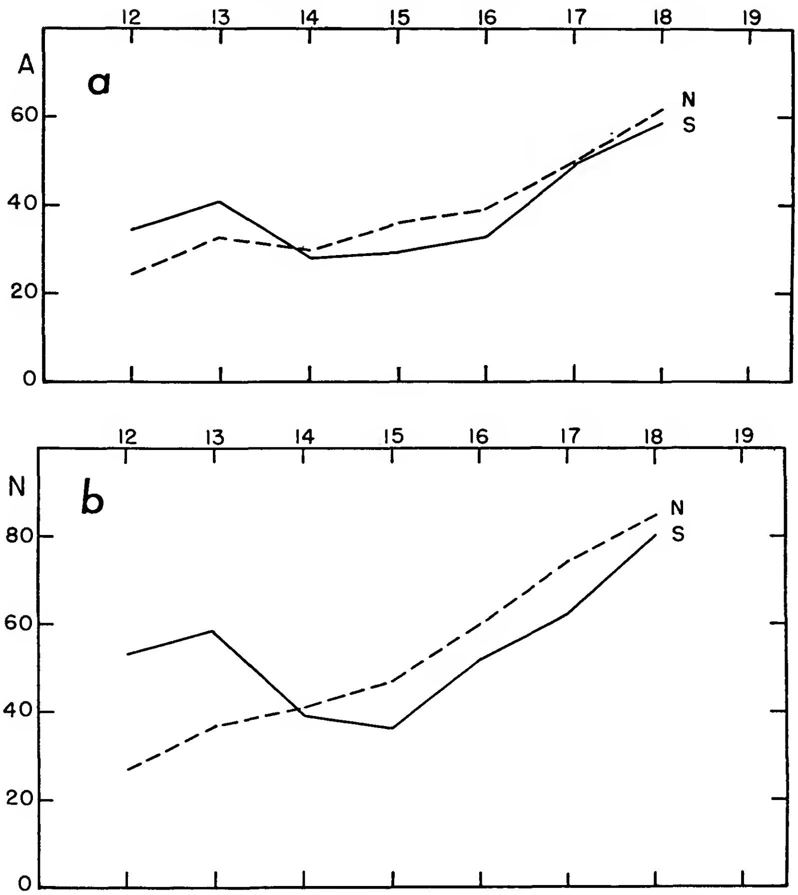


FIGURE 4.—Plot of spottedness of each hemisphere for cycles 12 through 18. *a*, Sum of annual spotted areas per cycle (unit of 10^{-4} of visible disk). *b*, Number of great spot groups. Solid lines indicate southern spots, broken lines, northern.

Wolf, and later Spörer, demonstrated (see Maunder, 1922) that in the latter part of the 17th century and the beginning of the 18th, the northern hemisphere of the sun failed for many years to produce a single recorded spot. The south had some spots, but not many, and for nearly 70 years the sun showed a prolonged sunspot minimum. The failure in spot activity in the north was not compensated by an increase in the south. No aurorae were reported during these years, and from this Maunder reasonably inferred that there were also no great geomagnetic disturbances occurring then on earth.

In connection with the prolonged dearth of spots in both solar hemispheres in the period around 1700, it is interesting to note that for several recent cycles the total spotted area and the numbers of great spot groups have been steadily rising in both hemispheres. The recent dominance of the northern hemisphere does not arise from any particular weakness in the southern. Figure 4 shows, for example, that the south was more spotted in cycle 17 than the north in any previous cycle since 1874; again in cycle 18 the south was more spotted than the north in any previous cycle. Indeed, after the cross-over from south to north dominance between cycles 13 and 14, the spottedness of the two hemispheres increases roughly in parallel, as figure 4 shows.

The relation, if any, of the various solar asymmetries cited above to the asymmetry in the location of major geoactive sources is far

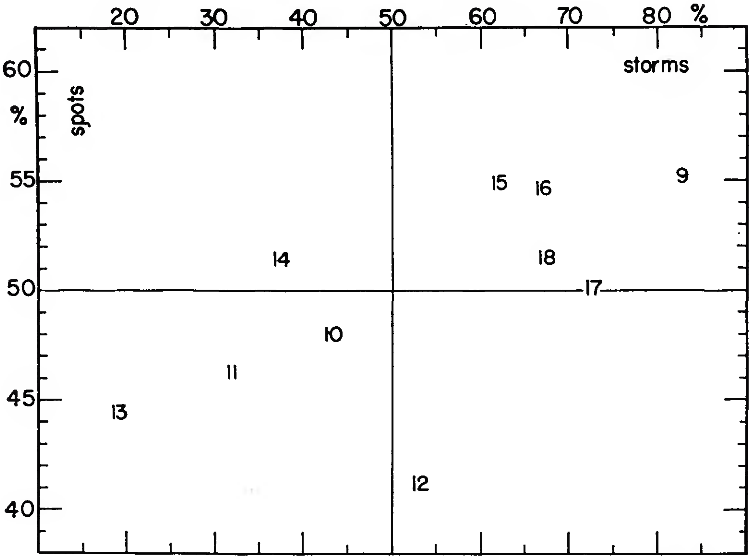


Figure 5.—Percentage of total spotted area in the solar north plotted against percentage of great storms attributed to northern spot groups, for cycles 9 through 18.

from clear. In figure 5 the spot distribution is plotted against storm-source distribution, in terms of percent north of the equator, for each sunspot cycle. In 9 out of 11 cycles (including cycle 19) the more-spotted hemisphere produced more of the great storms. The north-south asymmetry in the location of great-storm sources, however, far exceeds the asymmetry in either the total spotted area or in the frequency of large spot groups. The degree of asymmetry in numbers of major flares appears to be intermediate between the degree of asymmetry in spottedness and that in great-storm sources.

From table 1 we see that some cycles are more effective in producing great storms, not only in the total number of storms produced—as one might expect from the differing heights of the spot maxima—but also in the numbers of storms relative to the various measures of spottedness. For example, the number of great storms per great spot group varies by a factor of two, the minimum value being 0.10 for cycles 14 and 15, and the maximum 0.22 for cycle 13.

The cause of these long-term inequalities in the activity of the two solar hemispheres is completely unknown. The existence of such inequalities would, as Maunder (1922) pointed out, seem to imply a lack of symmetry in the internal structure of the sun, at least with respect to the forces producing sunspots, flares, and corpuscular emission. If, however, sunspots and their associated activity arise from the general dipole field in a manner similar to that proposed by Babcock (1961), the persistence of the direction of the asymmetry for several cycles can perhaps be qualitatively understood. According to Babcock's hypothesis, the residual fields from the follower components of spot groups tend to drift poleward, first neutralizing and then reversing the dipole field. This new dipole field, gradually amplified in lower latitudes by differential rotation, in due course generates the next cycle of spots. The significant point here is that each hemisphere apparently generates its own half of the dipole field, which in turn gives rise to its spots in the next cycle. If such a picture is correct, one might expect that any asymmetry that developed between the hemispheres would tend to persist for several cycles.

In the second following paper evidence for a relation between the asymmetry in spottedness and the asymmetry in location of great-storm sources will be explored on a yearly basis, and compared with the relation on a cycle basis.

TABLE 1.—*Some properties of the sunspot cycles 8 through 19*

Cycle no.	Year of maximum	Maximum smoothed monthly sunspot number	Sum of annual sunspot numbers	Sum of annual spotted areas	Total numbers of			
					Great spot groups	Great storms	Extra-great storms	Small storms
8	1837	147	649	------	------	------	------	------
9	1848	132	692	------	------	18	11	------
10	1860	98	545	------	------	14	12	------
11	1870	140	626	------	------	24	15	------
12	1883	75	383	5845	80	15	6	46
13	1893	84	459	7300	95	21	14	68
14	1905	64	375	5739	80	8	7	68
15	1917	105	456	6577	83	8	4	76
16	1928	78	410	7176	111	12	5	82
17	1937	119	606	9947	137	22	13	128
18	1947	152	754	12029	164	24	18	122
19	1957	201	827*	------	------	29*	------	------

*Through 1960. The great storms of cycle 19 are defined by $Ap \geq 100$; cycles 17 and 18 had 18 and 19 great storms, respectively, by this criterion.

Acknowledgments

The work reported in this paper was supported by the Geophysics Research Directorate of the Air Force Cambridge Research Laboratories, Office of Aerospace Research, under Contract AF19(604)-4962.

I wish to thank A. S. Milsom and H. W. Newton of the Royal Greenwich Observatory for generously making available to me their unpublished data on the spottedness of the two hemispheres from 1832 through 1866. I am indebted to Milsom also for consulting the original sunspot records and determining for me the latitudes of the sunspots most probably associated with the great storms recorded during cycles 9 and 11.

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Abstract

Inequalities in the relative spottedness of the two solar hemispheres and in the location of solar sources of great geomagnetic storms have been investigated for the years 1833 through 1960, with the sunspot cycle as the basic unit of time. It was found that the northern solar hemisphere contributed over 50 percent of the spottedness in cycles 8 and 9 (1833 to 1856) and in cycles 14 through 19 (1901 to 196–); the southern hemisphere contributed over 50 percent of the spottedness in cycles 10 through 13 (1856 to 1901). With eight cycles deviating by more than 3σ from a symmetrical distribution, the frequency of substantial inequalities is much greater than would be expected to occur by chance. The direction of the inequality does not vary in a random manner from cycle to cycle, but the available data are not sufficient to establish whether the variation is periodic.

A majority of great geomagnetic storms appeared to arise from sunspot groups in the more-spotted hemisphere in all but two of the cycles from 9 onward. In most cycles the asymmetry in location of great-storm sources far exceeds the asymmetry in total spottedness, and tends to increase when the lower limit for defining a great storm is raised.

On the Unequal Spottedness of the Two Solar Hemispheres

By John G. Wolbach[1]

The findings of Bell in the preceding paper led me to investigate in more detail the asymmetry in spottedness about the sun's equator for periods of time less than a complete sunspot cycle.

As a working hypothesis, the periods of time in which one hemisphere tends to be more spotted than the other can be divided into three categories: A-periods of several consecutive months; B-periods of several consecutive years; and C-periods of several consecutive sunspot cycles.

During any one of these periods, the prevailing greater spottedness of one solar hemisphere may be reversed for some small fractions of the time. The C-period is the one discussed by Bell in the preceding paper, and elsewhere by Waldmeier (1957).

Study of Greenwich (1955) data on the average spotted area in each hemisphere per rotation, from 1874 to 1954, shows that the A-period may persist for eight to ten rotations. These periods do not appear to be cyclic, and may be largely explained by long-lived centers of spot formation at a particular latitude and longitude (see Kiepenheuer, 1953).

This paper will deal mainly with two questions: First, do B-periods recur in a cyclic manner and with any characteristic cycle length? Second, are the asymmetries in spottedness significantly greater than one might expect them to be by chance when intervals of a year, a half sunspot cycle, and a complete sunspot cycle are considered, and, if so, to what extent?

Newton and Milsom (1955) first studied the regularity in sequences of what I here call B-periods. They examined the annual values of the spotted areas in the form of the ratio $q=(N-S)/(N+S)$, where N and S represent the average yearly spotted areas in the northern and in the southern solar hemispheres. They found that in cycles 12 through 14 this ratio diminished in the course of each cycle; in cycles 17 and 18 the ratio rose toward the end of the cycle; in cycles 15 and 16 the ratio showed no systematic trend. From investigations of cycles 8 through 18 they concluded that the behavior of the ratio showed "changes from cycle to cycle which, although not random, appear to have no definite period. There is the suggestion of a dependence of the pattern of the excess of spottedness, north or south, upon the degree of activity of any particular cycle. The results indicate no dependence upon a 22-year cycle."

Xanthakis (1959a, 1959b, 1959c) attempted to relate the behavior of q to the steepness of rise of the sunspot activity in a number of cycles. Waldmeier (1957) suggested that the behavior of the ratio reflects a phase difference in the activity of the two hemispheres, a phase difference that changes slowly with a period of the order of 80 years.

From an inspection of plots of the data used by Newton and Milsom, I proposed, as a working hypothesis, to attribute the appearance of the curve (see fig. 1*b*) to the alternation of B-periods from one hemisphere to the other, forming a cycle about one year shorter than the sunspot cycle. From cycles 12 through 18, the maximum value of q moved from the waxing part of the cycle to the waning part of the preceding cycle. The critical parts of cycles 15 and 16 would then be around minimum, where

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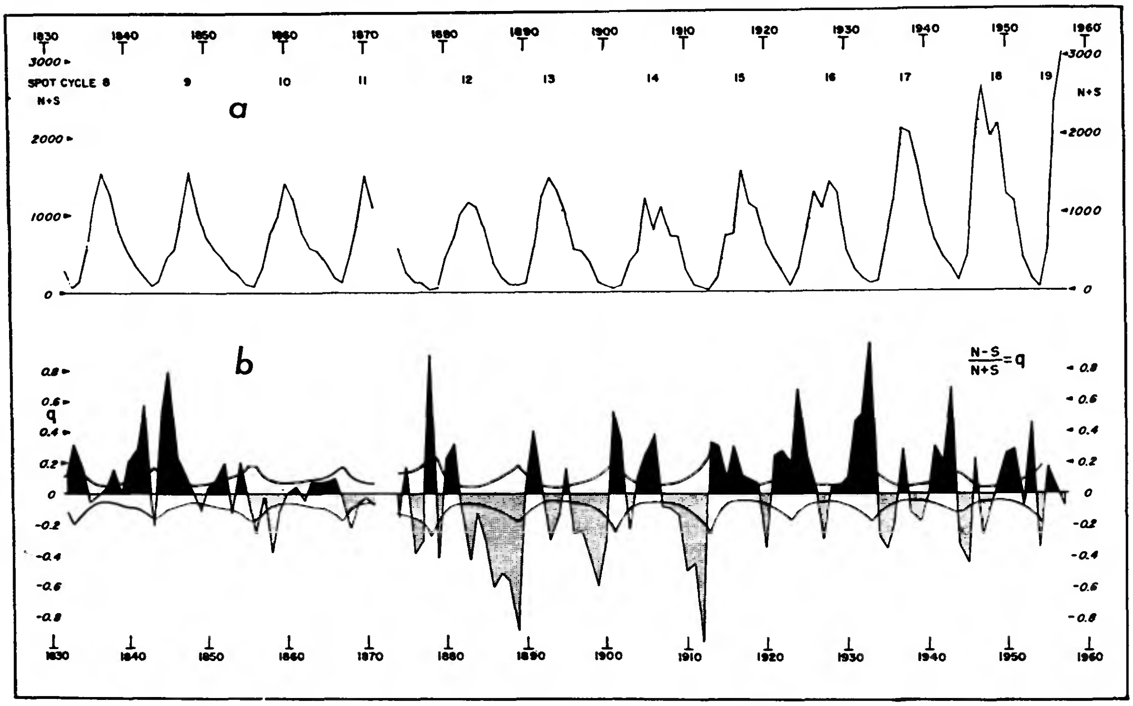

FIGURE 1.—Variation of solar spottedness with time. *a*, Annual average spotted area, $N+S$, of the whole sun. *b*, Relative spotted area of the northern and southern hemispheres, expressed by the ratio $q=(N-S)/(N+S)$. Dark shaded areas indicate the north was more spotted; light areas, the south. The standard deviation of q is shown by the scalloped lines.

the small number of spots precludes a meaningful determination of q. Hence the behavior of the ratio in these cycles would not show any trend.

The observational data available to test this hypothesis are the yearly average areas of spottedness in each hemisphere from 1874 (Greenwich, 1955), the same data employed by previous workers. Data for earlier years consist of numbers of individual spots (not groups) published by Spörer (1874) for 1853 through 1871, and Newton and Milsom's (1955) data on annual group numbers for each hemisphere for the years 1832 through 1866, derived from Schwabe's drawings.

Figure 1*a* shows the total annual average spotted area against time from 1874 onward, and numbers of spot groups from 1832 through 1871 on an arbitrary scale. Figure 1*b* shows the observed annual values of q, from 1832, based on Greenwich areas and the Spörer and Schwabe data. To obtain data as homogeneous as possible, I graphically converted the annual Schwabe-Newton-Milsom group numbers to the Spörer scale, because the latter, which is a count of individual sunspots rather than groups, seemed more closely proportional to the area. The sunspot cycle, shown in figure 1*a*, gives a rough guide to the significance of the various values of q.

To obtain a more precise measure of the significance of each value of q, I determined the standard deviation for each year (the scallop-like curve in figure 1*b*) from the number of spot groups observed each year. These were obtained from the *Greenwich Photoheliographic Results*.

If we denote the number of spot groups in a year in the northern and southern hemispheres by N' and S', then the standard deviation of the number of groups to be expected in the northern or southern hemisphere is

$$\sigma=\frac{1}{2}\sqrt{N'+S'}. \qquad (1)$$

The expected magnitude of fluctuations for $N'/(N'+S')$,

$$\delta\left(\frac{N'}{N'+S'}\right)=\frac{\sigma}{N'+S'}=\frac{1}{2\sqrt{N'+S'}}.$$

For q', the value of q for spot numbers,

$$\delta\left(\frac{N'-S'}{N'+S'}\right)=\sigma_{q'}=\frac{1}{\sqrt{N'+S'}}. \qquad (2)$$

The scalloped lines in figure 1*b* were computed from equation (2).

The standard deviation of q', being inversely proportional to the square root of the number of spot groups, is greatest around spot minima, as figure 1*b* shows. The southern B-periods of cycles 12, 13, and 14, although containing a number of individual years that deviate less than 2σ, gain statistical significance from their duration of five to eight years. The adjoining halves of cycles 8 and 9, and all of cycles 15 and 16, consist of almost unbroken B-periods in the north, with only one year of greater southern spottedness in each interval. While the ratio of observed deviation to standard deviation is not very significant for many individual years, the run of consecutive years and the succession of several B-periods are striking. The frequency of large deviations will be discussed quantitatively in the final section of this paper.

To investigate whether B-periods show a cyclic periodicity, I computed the autocorrelation coefficient for periods of 1 to 26 years. Let q_i be the value of q for a given year, r $(=1, 2, 3, \ldots)$ the length of cycle in years, and n the number of years of observation available. Then the autocorrelation coefficient of r may be expressed by

$$f(r)=\frac{\sum_{i=1}^{n-r} q_i, q_{i+r}}{\sum_{i=1}^{n-r} (q_i)^2}. \qquad (3)$$

Figure 2*a* shows $f(r)$ for $r=1$ to $r=26$. If q varies at random, $f(r)$ should fall to a value close to zero. In figure 2*a*, except for a small rise around $r=10$, $f(r)$ shows no pronounced cyclic tendency.

A further test for any cyclic tendency in the data can be made by using the Fourier transformation, F_j, of σ or power spectrum of the time series q_i. The values of $f(r)$ in equation (3) may be represented as $f(t_i)$, where t is time in years. Then

$$F_j=\sum_{i=1}^{26} f(t_i) \cos 2\pi n_j t_i, \qquad (4)$$

when

$$F_n=f(t_0) \cos\left(\frac{2\pi t_0}{n}\right)+f(t_1) \cos\left(\frac{2\pi t_1}{n}\right)+\ldots$$
$$+f(t_{26}) \cos\left(\frac{2\pi t_{26}}{n}\right),$$

for $1\leq n\leq 26$.

Figure 2*b* shows the variation of F_j for t and $r=1$ to 26. The rise in F_j at $t=8$ through 14 years is the only statistically significant deviation in the diagram. Bisecting the area under this positive deviation yields a period of 11.16 years, a value not differing significantly from the average length of 10.77 years for the 7 sunspot cycles from 1878.9 to 1954.3.

In summary, examination of figures 1*b* and 2 reveals a tendency toward the existence of a cycle of alternation of B-periods of varying length. The evidence for a 10-year cycle, although striking for limited time spans and of some limited statistical significance, is not particularly convincing. With the addition of data prior to 1874 it becomes clear that the statistical significance would be diminished rather than increased. Thus my computations lead to agreement with the conclusion of Newton and Milsom (1955) that the behavior of q shows "changes from cycle to cycle, which, although not random, appear to have no definite period."

I next investigated to what extent the asymmetries in spottedness are significantly greater than one might expect to occur by chance when intervals of a year, a half sunspot cycle, and a complete cycle are considered.

Figure 3 compares the observed and the random distributions of q/σ_q for intervals of (a) a year, (b) a half cycle, and (c) a full cycle. In each section of figure 3, the values are normalized to make equal the areas encom-

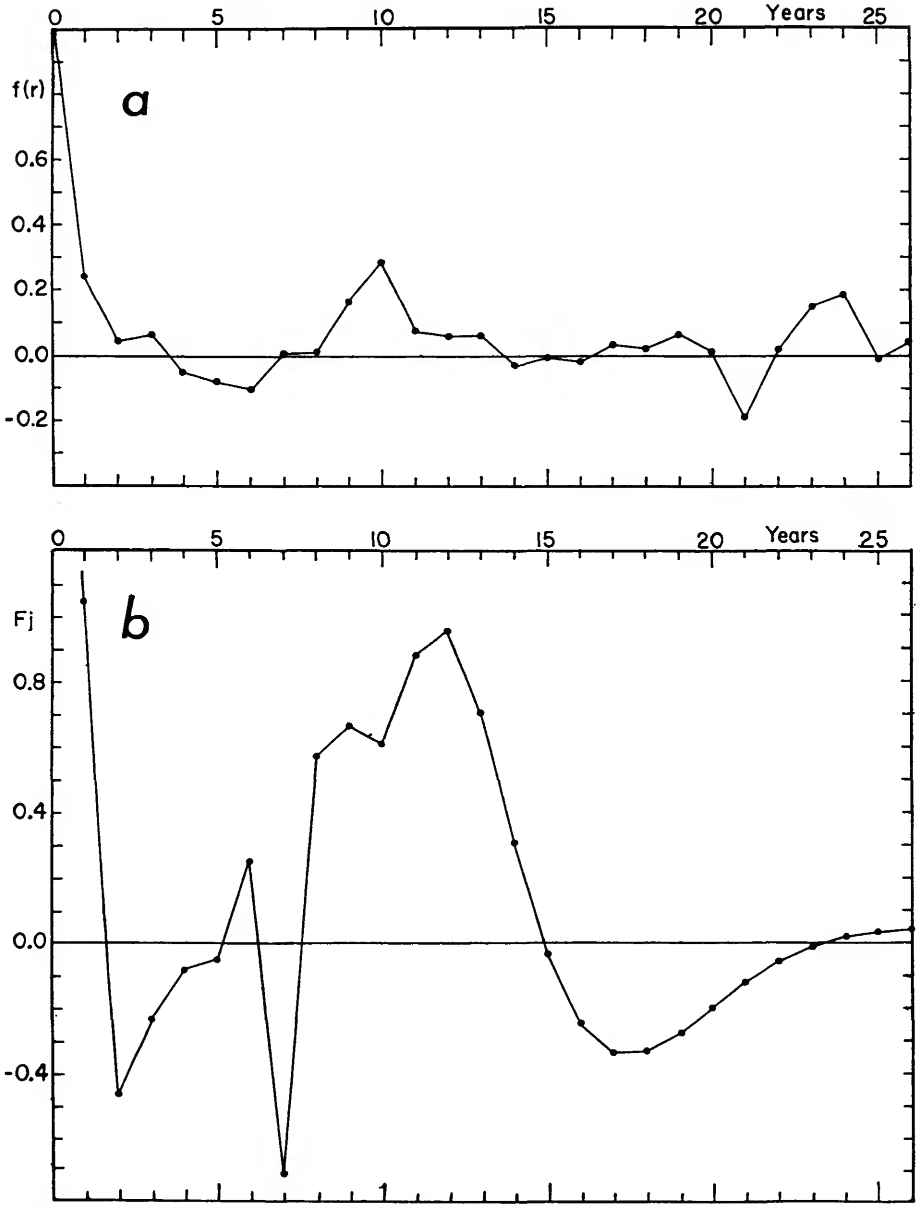

FIGURE 2.—Determination of cyclic tendencies in the unequal spottedness of the hemispheres. *a*, The autocorrelation coefficient, $f(\tau)$, for 1 to 26 years. *b*, Fourier transformation F_i of σ for 1 to 26 years.

passed by the normal curve and the histogram. Table 1 shows that, for each of the three time intervals, less than 50 percent of the area of the observed histogramic distribution falls within the normal curve. The percentages within the normal curve for the year are, however, somewhat higher than those for the half cycle and for the full cycle. Each of these two longer intervals has about one-third of its area within the normal curve. Thus figure 3 and table 1 show that large inequalities in the spottedness of the two hemispheres are much

TABLE 1.—*Proportion of observed distribution of asymmetry in spottedness falling within the normal curve*

Interval	North	South	Total
Year	0.467	0.439	0.454
Half cycle	0.334	0.354	0.343
Full cycle	0.349	0.296	0.330

more frequent than could be expected if these inequalities arose from random fluctuations. They indicate also that the most significant inequalities between the hemispheres are obtained when intervals longer than one year are studied. While the actual deviations tend to be larger for the half than for the whole cycle, in terms of statistical significance the deviations for the two intervals are about equal. The larger deviations for full cycles result when both their halves deviate in the same sense.

To compare further the characteristics of B-periods with other intervals of time, I determined the value of $N/(N+S)$ for each solar rotation from 1880, using the average daily spot areas for each hemisphere published by Greenwich (1955). Let us imagine a histogramic representation in which $N/(N+S)$ is plotted against rotation number. For a given time interval, the area encompassed by the histogram above the 0.5 line may be denoted by N'', and the area below this line by S''. The percent of histogram areas above the 0.5 line is then $N''/(N''+S'')$. The uninterrupted persistence of greater spottedness in a single hemisphere over a given time interval gives $N''/(N''+S'')=0$ or 1, even though the actual difference between the hemispheres may be

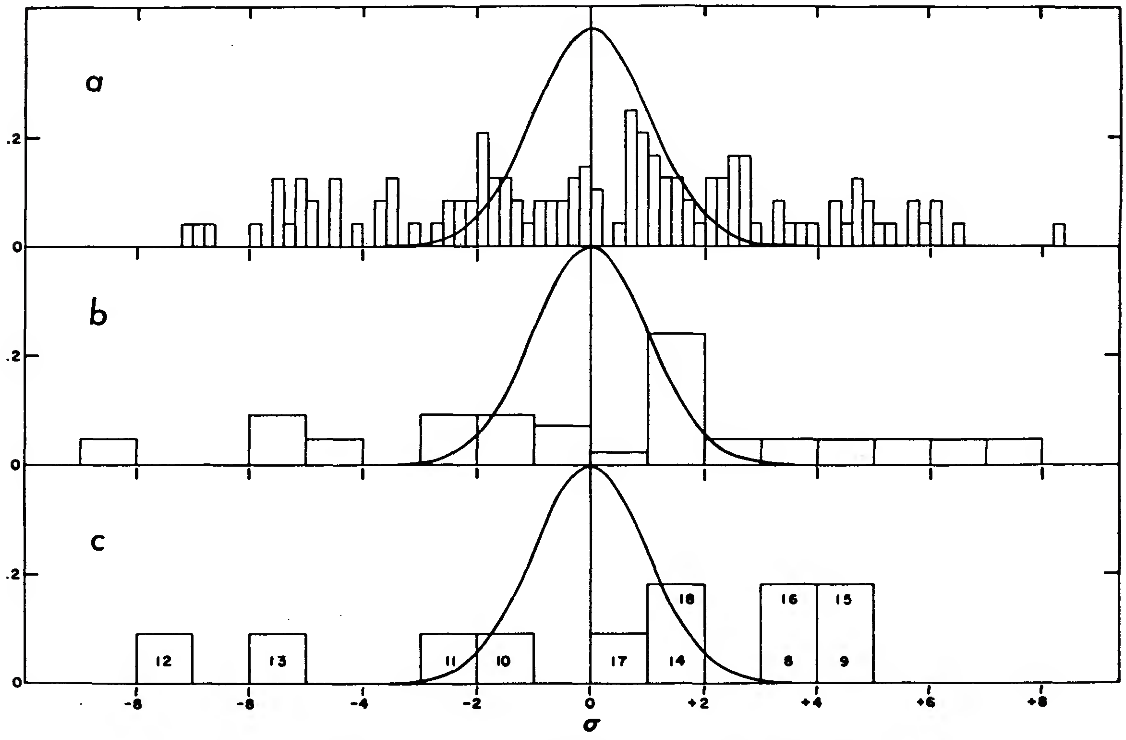

FIGURE 3.—Comparison of the observed distribution of q in units of σ_q, with the normal distribution to be expected under an assumption of random fluctuation of the relative spottedness of the two hemispheres, for intervals of: *a*, the year; *b*, the half cycle; *c*, the full spot-cycle. The areas encompassed by the normal curve and the histogram are equal in each section. Negative values, to the left of the zero line, indicate the south is the more-spotted hemisphere.

slight. Thus $N''/(N''+S'')$ measures consistency as well as magnitude of asymmetry.

I excluded all rotations for which the average daily spotted area for the entire sun is less than 300×10^{-6} of the disk. No yearly determination of $N''/(N''+S'')$ was made unless at least eight usable rotations were available. All sufficiently spotted rotations, however, entered into calculations of $N''/(N''+S'')$ for longer periods.

If we let k represent the average number of spot groups per rotation, and N_0 the number of rotations in a given time interval, then the standard deviation of $\frac{1}{2}|q'|$ is given by

$$\sigma_{|q|} = \frac{1}{2\sqrt{kN_0}}, \tag{5}$$

or in the logarithmic form,

$$\log \sigma_{|q|} = -0.5 \left(\log 4k + \log N_0\right). \tag{6}$$

These equations involve the dubious assumption that all rotations are equally spotted. However, examination of average $N/(N+S)$ and $N''/(N''+S'')$ for each of several years showed no systematic variation with phase of the spot cycle, and seemed to justify the use of equation (6) as a first approximation.

Table 2.—*Absolute values of the average deviation of $N/(N+S)$ and $N''/(N''+S'')$ from 0.5 for various time intervals*

Interval	$N/(N+S)$	$N''/(N''+S'')$
Rotation	0. 198	-----
Year	. 099	0. 239
Half cycle	. 054	. 166
Full cycle	. 038	. 094
Cycles 15–18	. 024	. 083

Table 2 shows the absolute values of the average deviation of $N/(N+S)$ and $N''/(N''+S'')$ from 0.5 for different intervals of time. The southern C-period of cycles 10 through 13 cannot be included because data by rotation are not available prior to cycle 12. The two measures of asymmetry differed in sign for cycle 14, which was accordingly omitted from either C-period. As one would expect, the values of the ratios in table 2 become smaller with longer time intervals, as the short term asymmetries in opposite hemispheres tend to cancel each other out. The rate of the decrease, however, is worth further attention.

The observed rate of decrease for both ratios is shown (broken lines) in figure 4, and compared with the rate to be expected from a random distribution in asymmetry (solid lines) as given by equation (6). The value of k was arbitrarily chosen to make the yearly observed and computed values equal.

The observed quantities decrease less rapidly than the computed ones, with increase of N_0 up to the half cycle. From the half cycle to the full cycle q decreases randomly; q'' decreases faster than random and approaches the computed value. From the full cycle to the C-period both quantities again fail to decrease as rapidly as predicted.

Figure 4 thus illustrates that the yearly asymmetry is greater than one would predict

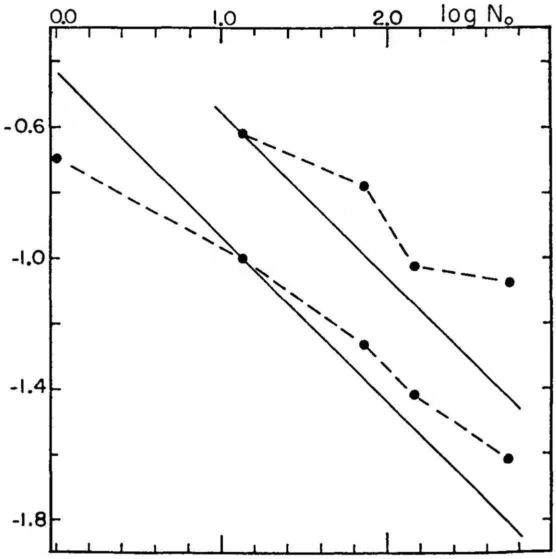

Figure 4.—Plot of the log of the observed values (broken lines) of the asymmetry in spottedness from table 2, against log N_0, where N_0 is the number of solar rotations in the time interval. The solid lines, from eq. (6), indicate the slope to be expected from a random variation in the sense of the asymmetry. Observed and computed lines are arbitrarily set equal for the interval of a year. The upper pair of lines refer to $N''/(N''+S'')$, the lower to $N/(N+S)$.

if the short-term (rotation) asymmetries cancelled out in a random way over a year. A given hemisphere is favored in more rotations than "expected," and this trend continues out to the points representing the half cycle.

From the half cycle to the whole cycle the decrease is random. In the case of q'', where both the persistence in direction and the magnitude of the asymmetry are important, the value of the ratio is more nearly random for the full than for the half cycle. This would imply that the direction of the asymmetry tends to change around spot maximum and minimum, a finding which lends support to Waldmeier's (1957) suggestion that Newton and Milsom's (1955) trends, and B-periods, arise from the two hemispheres being slightly out of phase.

From the whole cycles to the C-period of cycles 15 through 18, the observed ratios again decrease more slowly than at random. If cycle 19 and earlier spot data could be added to give two C-periods, I do not doubt that the slope of the last segment would deviate still more strongly from the random curve. This result gives additional statistical support to the reality of the C-periods found by Bell in the preceding paper.

Table 3 lists the average values of the ratio q/σ_q of the observed deviation to the standard deviation for intervals of a year, a half cycle, and a full cycle. The values of q/σ_q for the southern C-period of cycles 10 through 13 and the northern C-period of cycles 15 through 18 are included. Cycle 19 also evidently belongs to this northern C-period, for 56 percent of its spot groups observed at Mount Wilson through 1960 have occurred in the north. If this trend continues through the remainder of cycle 19, the ratio q/σ_q for the C-period of cycles 14 through 19 will be about 8; in any case, the ratio appears unlikely to fall below 7.

TABLE 3.—*Average value of ratio q/σ_q of observed to standard deviation for various time intervals*

Interval	q/σ_q
Year	2. 7
Half cycle	3. 4
Full cycle	3. 5
Cycles 10–13	8. 1
Cycles 15–18	4. 7*

*If cycle 19 through 1960 were included, this value would become 8.1.

Summary

Although B-periods may alternate between the two hemispheres, perhaps for a few spot cycles, no convincing evidence has been found for a 10-year or any other cycle of B-periods. The alternation of greater spottedness from one hemisphere to the other in a period roughly equal to one sunspot cycle occurs only occasionally, when q shows a trend during the spot cycle. The variation in asymmetry is far less regular than the variation in spot numbers.

However, persistence of unequal spottedness of the two solar hemispheres, as seen in Greenwich spot areas, seems clearly to be a nonrandom phenomenon. The results presented here show that short intervals (a solar rotation) of asymmetry do not alternate in a random manner, but tend to recur in the same hemisphere for as long as a year and, even more strikingly, for as long as a B-period or half cycle. A full spot-cycle is likely to contain two B-periods, often in opposite hemispheres, and the persistence of greater spottedness in one hemisphere appears to end around spot minima and maxima more frequently than one would expect to occur by chance, suggesting that B-periods arise at least in part from a tendency of the two hemispheres to be slightly out of phase.

Finally, the very long-term asymmetries, persisting for several spot cycles, and found by Bell in the preceding paper, are shown to be statistically significant.

Acknowledgments

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Abstract

The unequal spottedness of the two solar hemispheres has been investigated from 1833 through 1954, for time intervals of a year, a half spot-cycle, and whole cycle. For each of these three intervals, large deviations from equality were found to occur much more frequently than a hypothesis of random fluctuations would predict. Large deviations were particularly numerous for the half- and the whole-cycle intervals, where only about one-third of the cases fell within the random curve.

Statistical tests were made for the existence of a periodicity in the alternation of greater spottedness from one hemisphere to the other. Some evidence was found for a period of 8 to 14 years; because of the wide spread, however, this result cannot be considered very meaningful. Evidence is presented which suggests that the sense of the asymmetry tends to change around spot maximum and minimum more often than might be expected by chance.

On Short-Period Relations Between North-South Asymmetry in Spottedness and in Great-Storm Sources

By **Barbara Bell and John G. Wolbach**

The results presented in the two preceding papers led us to examine in more detail relations between the asymmetry in location of great-storm sources and inequalities in spottedness of the two solar hemispheres. Bell, in the first of these papers, found that one hemisphere tends to be more spotted than the other for several consecutive sunspot cycles (the C-period as defined in Wolbach's paper); and that the activity in the more-spotted hemisphere is disproportionately more effective in producing great geomagnetic storms. Wolbach, in the second paper, found that large inequalities in the spottedness of the two hemispheres, for periods of a year, a half cycle, and a whole cycle, were more frequent than a random distribution law would predict. The frequency and persistence of these large inequalities were greater for the half cycle (B-period) than for the year (A-period), and greatest of all for the geomagnetically significant C-period. (For definitions of the A-, B-, and C-periods, see Wolbach's paper, p. 195.)

In this paper we investigate the following questions. Does a great geomagnetic storm usually arise from the hemisphere that is more spotted at the time (i.e., month or year) of the storm? Or does the hemisphere enjoying a long-term or C-period of spot dominance produce most of the great storms even when a shorter-term B- or A-period of spot dominance is present in the opposite hemisphere?

Here, as in the two preceding papers, we used the storm and sunspot data compiled at the Royal Greenwich Observatory for the years 1874 through 1954 (Greenwich, 1955). Some of these data are shown in figure 1, with northern and southern data plotted separately. According to Newton (1949), spot groups with an average area exceeding 1500×10^{-6} of the visible disk (shown in black) are the most likely to be sources of major geomagnetic disturbance, primarily, as Bell and Glazer (1958) showed, because these very large groups contain the highest proportion of sunspots with complex magnetic fields.

Of the 113 great storms plotted in figure 1, 24 appear to arise from spot groups with mean areas exceeding 1500×10^{-6} of the disk; 33 from spots with area exceeding 1000; 35 from spots with areas between 500 and 1000; and 45 from spots smaller than 500×10^{-6}.

The storms were first grouped into four classes: (1) storms from north spots when (a) the northern hemisphere, or (b) the southern hemisphere is the more spotted; and (2) storms from south spots when (a) the northern, or (b) the southern hemisphere is the more spotted. This division provided a two-by-two array whose observed deviation from a random distribution of population could be evaluated by the *chi*-square test.

We studied three intervals of unequal spottedness—the year (A-period), the half cycle (B-period), and the full spot cycle or C-period. (Since neither of the two C-periods observed to date contains any full sunspot cycle at variance with the long-term trend of unequal spottedness, the full cycle and the C-period distributions are identical.) Table 1 gives the values of P, the probability that the observed storm-source distribution occurs by chance, for each of these three intervals of unequal spottedness. Data for the epoch 1840–1874 were obtained from various sources (see Bell's preceding paper). Several years had values of $N/(N+S)=0.500$; these were omitted from the yearly de-

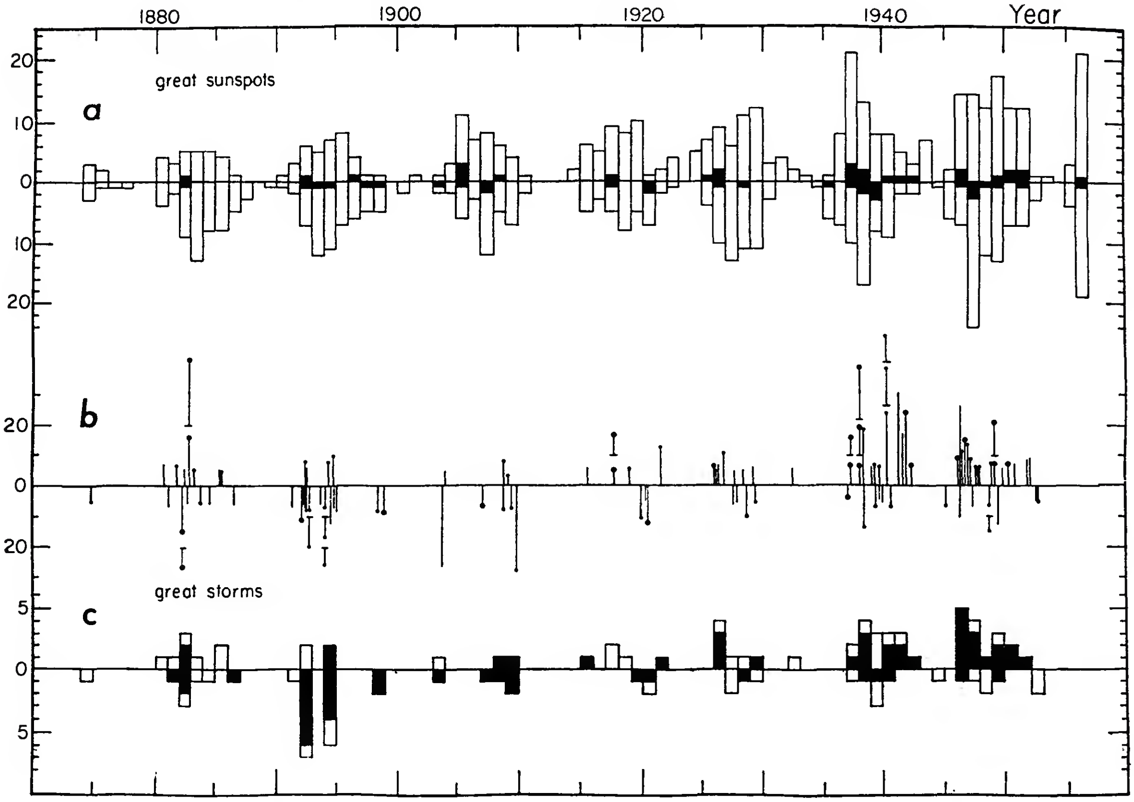

FIGURE 1.—Plot against time of: *a*, Annual numbers of great sunspots, of $A \geq 500$ and (in black) $A \geq 1500 \times 10^{-6}$ of the visible disk. *b*, Individual great storms, with lengths of the individual vertical lines indicating the intensity of the storm as measured by $\Delta(H+Z)$, the sum of the deflections in the H and Z components of the earth's field, in units of 100 γ; two or more storms from a single spot are placed one above the other; the large and small dots indicate storms arising from spots of $A \geq 1500$ and $A \geq 500$, respectively. *c*, Annual numbers of great storms, with greater storms (see Bell, p. 190) in black. In each section northern spots, or storms arising from northern spots, are plotted above the zero line, and southern ones below the zero line.

termination, which accounts for its smaller number of storms.

We also considered various periods in combination. For example, when the direction of the inequality in spottedness for the year agrees with that of the long-term C-period, we have an A- and a C-period in the same hemisphere. The bottom lines of table 1 give the values of P for the A,C and the B,C combinations.

Of the three intervals of unequal spottedness in table 1, the full cycle or C-period gives the smallest probability that the observed distribution in the four-celled array might occur by chance, while the B-period gives the largest probability. Also the A,C combination gives a probability that is smaller by an order of magnitude than that obtained from the B,C combination. None of these probability values is independent of the others, because all of the

TABLE 1.—*Values of* P, *the probability that the observed storm-source distribution arises by chance, for various intervals of unequal spottedness of the solar hemispheres, 1840–1954*

Interval(s) of unequal spottedness	Number of great storms	P
Year, A	152	.00007
Half-cycle, B	166	.00011
Long-term, C	166	.000003
A,C	104	.000001
B,C	126	.000026

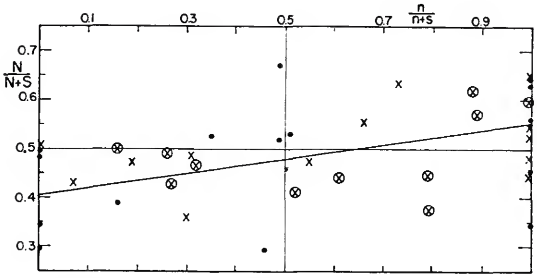

Figure 2.—Yearly average values of the ratio $N/(N+S)$ of spotted area plotted against $n/(n+s)$ of great storms; s and n are the total values of $\Delta(H+Z)$ for great storms attributed to the northern and to the southern hemispheres during the interval. Symbols indicate the weight of the points, according to the number of storms: ●, 2 storms; X, 3 or 4 storms; and ⊗, 5 to 9 storms. Years having only one great storm are omitted.

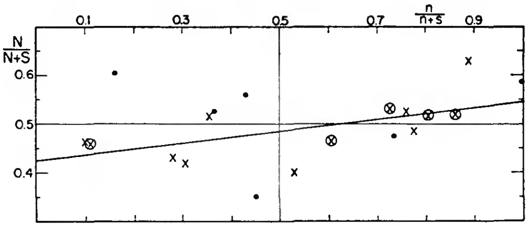

Figure 3.—Half-cycle average values of $N/(N+S)$ plotted against $n/(n+s)$ (see legend for fig. 2). Symbols: ●, 2 to 5 storms; X, 6 to 9 storms; and ⊗, 11 to 19 storms.

full cycles, 80 percent of the half cycles, and 70 percent of the year intervals have greater spottedness in the C-period hemisphere. However, table 1 shows for each of the three time intervals a highly significant tendency for the more-spotted hemisphere to produce a majority of the great geomagnetic storms.

We examine the possibility of linear correlations from the scatter diagrams of figures 2–4, and from table 2. Figure 2 is based on yearly data. For each year having two or more great storms, the ratio $N/(N+S)$ of spot distribution was plotted against the ratio $n/(n+s)$, where n and s are the total values of $\Delta(H+Z)$, the sum of the deflections in the H and Z components of the earth's field, for the northern and the southern storms in the year. Figure 3 shows the average values of these ratios for each half cycle, while figure 4 shows the values for the whole spot cycles. Table 2 gives the parameters of the least-squares lines fitted to the points in figures 2–4, the coefficient of correlation (r), and the standard deviations in the storm (σ_x) and spot (σ_y) directions. In these determinations each point was weighted by the number of storms contributing to it. The value of the intercept was computed for $n/(n+s)=1$.

Figures 2–4 and table 2 show that no significant linear correlation exists between inequalities of spottedness and of storm-source location. The scatter is reduced as longer periods of time are used. Most of this reduction in scatter is in the y or spot direction, and the correlations, though increased, never become large, even for the full spot cycle. The large values of σ_x and σ_y indicate that knowledge of one of the ratios, $N/(N+S)$ or $n/(n+s)$, does not suffice for a meaningful prediction of the other ratio for any of the three time intervals.

Thus while we find strong evidence of a nonrandom distribution in storm-source location, there is only a negligible linear relation between the magnitude of the inequality in spottedness and the magnitude of the inequality in location of storm sources. Tables 1 and 2 both suggest that the C-period is of greater geomagnetic significance than the A- or B-period.

Tables 3 and 4 represent an attempt to evaluate the relative efficiency of the two

Table 2.—*Least-squares parameters of relations between unequal spottedness of the solar hemispheres and location of great-storm sources*

Interval, "Period"	r	r^2	Slope	Intercept	σ_x	σ_y
Year, A	0. 479	0. 229	+0. 148	0. 552	0. 362	0. 094
Half cycle, B	. 505	. 255	. 119	. 545	. 282	. 059
Spot cycle, (C)	. 555	. 308	. 103	. 540	. 255	. 043

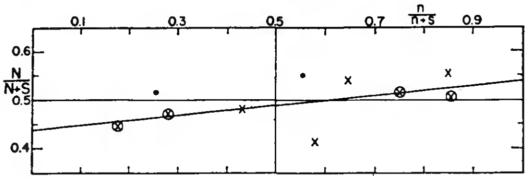

FIGURE 4.—Average values of $N/(N+S)$ for the full sunspot cycle plotted against $n/(n+s)$ of the cycle (see legend for fig. 2). Symbols: ●, 8 storms; X, 10 to 19 storms; and ⊗, $\geq$ 20 storms.

hemispheres in producing great storms for the various periods of time. Table 3 gives the percent of great spot groups and the percent of great-storm sources occurring in the more-spotted hemisphere for various intervals and combinations of intervals of unequal spottedness. We here consider the solar rotation (27 days) as a fourth interval of unequal spottedness. In terms of the four-celled array, the quantity tabulated is the percent occurring on the *Nn–Ss* diagonal. We took the distribution of all great spots ($\geq 500 \times 10^{-6}$) between the two hemispheres as defining the "expected" distribution of great-storm sources, and computed the probability (*P*) of obtaining by chance a distribution of storm sources deviating as much as observed from the expected.

The values of *P* in table 3 indicate that for the three shorter periods, the rotation, the year, and the half cycle, the storm-source distribution does not differ significantly from that of great spots. Only in the C-period does the more-spotted hemisphere produce a significantly higher percentage of great storms than of great spots.

The top section of table 3 shows that the concentration of great spots in the more-spotted hemisphere diminishes as the time interval increases. This is not unexpected, because the shorter the time interval the greater is the contribution that a single large spot group can make toward the inequality of spottedness. The spots with areas exceeding 1000×10^{-6} of the disk have a higher percentage in the more-spotted hemisphere than do the spots with areas of 500 to 1000×10^{-6}.

In striking contrast to this behavior of great spots, the concentration of great-storm sources in the more-spotted hemisphere increases from the year to the C-period.

In the lower section of table 3 another comparison can be made between the behavior of great spots and storm sources. The rotation intervals are divided into those in which the direction of the asymmetry in spottedness agrees with that of the C-period (R,C) and that in which it is opposite (R,–C). Between these two cases the difference in percentage of great spots in the more-spotted hemisphere is minor. In the case of great-storm sources, however, we

TABLE 3.—*Percent of great sunspot groups, and of great-storm sources, occurring in the more-spotted hemisphere; and the probability* (P) *of obtaining by chance a distribution of storm sources deviating by as much as observed from the spot distribution.*

Interval(s) of unequal spottedness	Great sunspot groups, 1874–1954				Great-storm sources				P
	$A \geq 1000$		$1000 > A \geq 500$		1874–1954		1840–1954		
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	
Rotation, R	141	88. 0	621	76. 3	112	72. 3	-----	------	0. 11
Year, A	138	69. 0	611	61. 4	103	61. 2	152	64. 5	. 7
Half-cycle, B	141	61. 0	610	57. 7	112	64. 3	166	65. 1	. 2
Long-term, C	141	59. 6	621	54. 6	112	67. 9	166	68. 7	. 01
A,C	93	71. 0	381	63. 0	61	73. 8	104	74. 0	. 13
A,–C	45	64. 5	230	58. 7	42	42. 9	48	43. 8	. 03
R,C	83	90. 4	357	77. 0	67	83. 6	---	----	. 4
R,–C	58	84. 6	264	75. 4	45	55. 6	---	----	. 0007

TABLE 4.—*Number of great geomagnetic storms per great spot group ($A \geq 500$) in the more-spotted solar hemisphere and in the less-spotted solar hemisphere, 1878–1954, and the probability of obtaining by chance two values deviating from the mean by as much as observed*

Interval(s) of unequal spottedness	The more-spotted hemisphere produced					The less-spotted hemisphere produced					P	P'
	Spots of $A \geq 500$	Great magnetic storms*				Spots of $A \geq 500$	Great magnetic storms*					
		No.	N'o.	No. per spot	N'o. per spot		No.	N'o.	No. per spot	N'o. per spot		
C	424	76	45	0.179	0.106	338	36	22	0.107	0.065	0.002	0.024
B	438	72	41	.164	.094	313	40	26	.128	.083	.10	.5
A, year	470	63	36	.134	.077	279	40	28	.143	.100	.6	.2
R, rotation	598	81	54	.135	.090	164	31	13	.190	.079	.05	.6
A,C	306	45	26	.147	.085	168	16	11	.095	.065	.066	.4
A,–C	164	18	10	.110	.061	111	24	17	.216	.153	.008	.006
R,C	350	56	37	.160	.106	90	11	5	.122	.056	.28	.10
R,–C	248	25	17	.101	.069	74	20	8	.270	.108	.0001	.20
B,C	361	65	36	.180	.100	256	29	17	.113	.066	.012	.09
B,–C	77	7	5	.091	.065	57	11	9	.193	.158	.05	.05

*"No." = the total number of storms attributed to this hemisphere; "N'o." = the number of storms attributed to great spots in this hemisphere. *P* and *P'* are the probabilities corresponding to No. and N'o. respectively.

find a difference of 28 percent. The values of P indicate that in the R,C case each hemisphere produces storms in proportion to the number of great spots it has, but in the R,–C case the C-period hemisphere produces a significantly larger proportion of great storms than of great spots. The great spots in the temporarily more-spotted, non-C-period hemisphere are relatively ineffective storm producers. A similar contrast can be seen in the A,C combination although the statistical significance is less striking. Here however more than 50 percent of the storm sources lie in the C-period hemisphere even when the other is more spotted during the year (A,–C).

Table 4 gives the average number of great geomagnetic storms per great spot group in the more-spotted and in the less-spotted hemispheres, and thus provides a measure of the ability of great spots in each hemisphere to produce great storms. The number of storms per great spot is tabulated for all great storms (No.) and for those (N'o.) specifically attributable to spots with areas exceeding 500×10^{-6} in that hemisphere. The average values of these two ratios are 0.147 and 0.089 respectively. In the intervals involving a combination of two periods, the "more-spotted hemisphere" refers to the one designated by the first symbol. For example, in the case A,–C the "more-spotted hemisphere" was more spotted for the year in direction opposite to the C-period asymmetry; while the "less-spotted hemisphere" (right-hand section of the table) was less spotted for the years in question but more spotted for the C-period.

Of particular interest is the comparison of corresponding columns for the more- and for the less-spotted hemispheres. To evaluate the statistical significance of the differences we determined the mean number of storms per great spot for a given row and computed the probability P (and P' corresponding to N'o.) of obtaining by chance two values deviating from the mean by as much as observed. The values of P and P' are given in table 4. In every line of the table that involves the C-period, the C-period hemisphere produces more great storms per great spot than the non-C hemisphere, regardless of which hemisphere may be temporarily more spotted for a year or a rotation. The values of P show that most of these differences are statistically significant at the 5 percent level or better. Because of the smaller samples only a few of the differences measured by P' attain the 5 percent level of significance.

If we consider the probability that, in the absence of flare data, some of the storms are attributed to a spot that is not the actual source, it seems likely that the A,–C and the R,–C values for storms in tables 3 and 4 are too high rather than too low. Bell's paper has pointed out that for cycles 17 and 18 a higher percentage of great-storm sources was found in the C-period hemisphere when flare data were used to identify the probable storm source.

In conclusion, the data discussed in this paper clearly indicate that short-term inequalities contributes nothing beyond what is obvious from the previously known tendency of great storms to arise from great spot groups. Only the long-term or C-period inequality in the spottedness of the hemispheres appears more fundamentally related to the relative efficiency of a solar hemisphere in producing corpuscular emission sufficient to cause a great geomagnetic storm.

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Abstract

Data for the years 1840 through 1954 were studied in an attempt to evaluate the relative importance of long-term (one and several spot-cycles) and short-term (27-day and 1 year) inequalities in the spottedness of the two solar hemispheres as factors in the location of sources of great geomagnetic storms. There is a significant tendency for the more-spotted hemisphere to produce a majority of the great storms, but no significant linear relation for any of these intervals of time was found between the magnitude of the inequality in spottedness and the magnitude of the inequality in number of storms arising from the two hemispheres. The short-term inequalities were shown to be unimportant. Only the long-term inequality in the spottedness of the hemispheres appears to be related in any fundamental way to the relative efficiency of the two solar hemispheres in generating corpuscular emission sufficient to cause a great geomagnetic storm.

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