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SOLAR RADIO BURSTS OF SPECTRAL TYPES II AND IV: THEIR RELATIONS TO OPTICAL PHENOMENA AND TO GEOMAGNETIC ACTIVITY

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Solar Radio Bursts of Spectral Types II and IV: Their Relations to Optical Phenomena and to Geomagnetic Activity

By Barbara Bell [1]

This paper will discuss solar radio bursts of spectral types II and IV, with primary attention to the magnetic type of the associated sunspot, and to the north-south asymmetry in their numbers and durations. Their relation to geomagnetic storms and to solar proton events (PCA) is also explored. Before considering the radio bursts themselves, however, it may be useful to summarize information on other manifestations of solar activity with respect to magnetic type and the north-south asymmetry.

In a study of the geomagnetic effects of major solar flares from 1937 through 1959, Bell (1961) showed that a flare from a magnetically complex ($\beta\gamma$ and γ) sunspot group is much more likely to be followed by a geomagnetic storm than is a flare from a simple bipolar (β) or unipolar (α) spot group. Table 1 presents a convenient summary of previous information on the distribution of various active-sun phenomena among the four Mount Wilson magnetic types of sunspots. The top four lines are derived from Bell and Glazer (1959), the remainder from Bell (1961).

The top line of table 1 shows that the complex $\beta\gamma$ and γ types account together for only about 3.4 percent of all classified sunspots. The second line includes only large spot groups, of area greater than 500 millionths of the solar disk (Greenwich, 1955). Here the complex $\beta\gamma$ and γ types make up about 27 percent, while they together comprise about half of the spots over 1000 millionths of the disk. The fourth line shows the distribution of all flares reported over the same years, 1937–1953. The percentages do not differ greatly from those for spots larger than 500 millionths, as one might expect, since most flares arise from the larger sunspot groups.

The lower half of the table gives the distribution of major flares, of importance $\geq 2^+$, from 1937 through 1959. Major flares are more concentrated to large spots than are flares in general. But also, on the average, complex spots produce more major flares (and more flares in general) than do β and α spots of comparable size. This may be seen from a comparison of the line for major flares with the last line for spot groups producing one or more major flares.

The major flares are also divided according to their geomagnetic consequences, that is, according to whether they were followed within three days by no storm, a small ($Ap \geq 25$), moderate ($Ap \geq 50$), or great ($Ap \geq 100$ and/or $Kp \geq 9^-$) storm (see Bell, 1961). Failures and small-storm flares are relatively more numerous among β and α major flares, while moderate and great storms are relatively more numerous among the complex $\beta\gamma$ and γ types.

Bell (1961) further found that about 62 percent of major flares arose from the northern solar hemisphere, and that the northern hemisphere produced a disproportionate 86 percent of the flares followed by a great geomagnetic storm. Subsequently Bell (1962) showed that

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TABLE 1.—*Percentage of solar activity in each magnetic class, and in the northern solar hemisphere*

Activity	Years	Number	Magnetic class				Percent North
			α	β	$\beta\gamma$	γ	
All spot groups	1937–53	4668	37.8%	58.8%	2.7%	0.7%	50.4%
Area ≥ 500 x 10^{-6}	"	248	11.3	61.3	19.8	7.6	54.4
Area ≥ 1000 x 10^{-6}	"	59	5.1	44.1	35.6	15.2	54
All flares	"	8403	14.3	60.4	16.7	7.5	53.4
Major flares	1937–59	560	12.8	46.6	24.5	16.1	62
followed by:							
no storm	"	270	15.6	53.3	21.0	10.0	60
small storm	"	146	9.6	51.3	22.0	17.1	52
moderate storm	"	71	9.9	42.1	24.0	24.0	70
great storm	"	72	11.1	16.6	43.1	29.2	86
Major-flare spots	"	344	16.0	54.6	18.9	10.5	58

this tendency for great storms to arise preferentially from the northern solar hemisphere extended back for two additional sunspot cycles to about 1913. For cycles 10 to 14 (1856–1912) the southern solar hemisphere appeared to be the preferred source of great storms, while in cycle 9 (1844–1856) the north was again the more geoactive.

The final column of table 1 provides reason to postulate that the north-south asymmetry increases with the vigor of the solar event. Since 1937 major flares are more concentrated to the north than are flares in general. The concentration to the north is greater for sources of great geomagnetic storms than for sources of lesser storms, and greater for ground-level cosmic-ray events than for PCA events. We shall investigate below whether it is greater for major than for lesser radio bursts of spectral types II and IV.

Slow-drift radio bursts were first studied with a dynamic spectrum analyzer by Wild and McCready (1950) in Australia. They introduced the designation "spectral type II" for these phenomena. Type II bursts commonly have a lifetime of a few minutes. They begin at high frequencies and spread to lower ones in a manner suggestive of a source of excitation moving outward through the solar atmosphere with a velocity of around 1000–1500 km/sec. Various properties of type II bursts have been described by Wild (1950), Roberts (1959), Maxwell, Thompson, and Garmire (1959), Maxwell and Thompson (1962), and Wood (1961).

Continuum radiation of type IV was first identified by Boischot (1957, 1958), and has been further described by McLean (1959), Thompson and Maxwell (1960a, 1960b), and Pick (1961). Type IV emission has a duration of a few minutes to a few hours, covers a broad range of frequencies, varies more or less smoothly in intensity, and, in accordance with the suggestion of Boischot and Denisse (1957), is generally believed to be synchrotron radiation from relativistic electrons spiralling in magnetic fields.

Data

The observational data were obtained from lists of bursts recorded with the dynamic spectrum analyzer at the Harvard Radio Astronomy Station, Fort Davis, Texas, from 1956 October through 1960 December 31, and at the Radiophysics Laboratory of C.S.I.R.O., Sydney, Australia, from 1956 November through 1960 August 11. Maxwell, Thompson, and Garmire (1959) estimate that these two stations cover an average of 14 hours per day. Other data on type IV events (e.g. Pick, 1961) might have been used, but in the interest of a homogeneous sample I have restricted the analysis to spectral observations. Records at the two stations yielded 96 type IV events and 197 type II.

The flare lists in the *I.A.U. Quarterly Bulletin of Solar Activity* were used to select the flare most probably associated with each burst. In general, the highest "importance" rating was used for each flare, rather than a mean of the often discordant estimates.

Each burst was classified according to its geomagnetic success, that is, according to whether it was followed within the interval of 10 hours to 3 days by no storm, a small ($Ap \geq 25$), moderate ($Ap \geq 50$), or great ($Ap \geq 100$ and/or $Kp \geq 9^-$) storm.

Bursts of each type were also subdivided according to their duration, the best available criterion of their importance. Type II bursts were divided into those lasting less than 10 minutes and those lasting 10 or more minutes. In 1956–1958 the frequency range of the Harvard equipment was 100–580 Mc/s; in January 1959 it was extended to 25–580 Mc/s (see Thompson, 1961). Accordingly, because of the greater range of the equipment, type II bursts in 1959–1960 have on the average a longer duration, and the bursts from 1957–1958 and from 1959–1960 have where pertinent been discussed separately.

Type IV events were divided initially into six duration groups: $\leq 15^m, 16–29^m, 30–59^m, 60–119^m, 2^h–3^h59^m$, and $\geq 4^h$. For most purposes I found that no significant information was lost by combining the four middle intervals and discussing only three categories of type IV events.

Association with flares

Table 2 shows the relation between flare importance and bursts of type II and IV. About half of the type IV events are found to be associated with a major flare of importance 2^+ or greater, about 20 percent with class 2 flares, and 20 percent with class 1 flares. Of the remainder, 3 occurred when there were no flare observations, 4 apparently had no observed flare, and 3 had two or more equally likely flares. In six of the assigned cases there is also some ambiguity, but the type IV burst was assigned to the more important flare.

There is a clear relation between the duration of the burst and the importance of the associated flare. Over half of the short-lived bursts are associated with class 1 flares, while 88 percent of the longest-lived bursts are associated with major flares.

Type II bursts are less strongly associated with major flares than are type IV bursts. Only 28 percent of the 197 type II bursts are associated with a major flare; 24 percent have a class 2 flare; 12 percent a 1^+ flare; 17 percent a class 1 flare; and 8 percent a 1^- flare. Thirteen bursts occurred when there were no flare observations, and 7 apparently occurred without any flare. In 9 cases the assignment was ambiguous but given to the more important flare. The distribution found for type II bursts is in satisfactory agreement with those found by Roberts (1959), and by Maxwell and

TABLE 2.—*Relation between radio bursts of spectral types II and IV and the importance of the associated flare*

Activity	No. flares of importance			No. uncertain	Total bursts
	$\leq 1^+$	2	$\geq 2^+$		
Type II	73	48	55	21	197
Type IV	20	18	48	10	96
of duration:					
$\leq 15^m$	8	1	4	3	16
$16^m–59^m$	8	6	15	5	34
$1^h–3^h39^m$	3	10	15	2	30
$\geq 4^h$	1	1	14	0	16

Thompson (1962). The percentage of type IV events associated with major flares is somewhat lower than the 67 percent found by McLean (1959) from a much smaller sample.

North-south asymmetry

Data on the north-south asymmetry for the years 1957–1960 for various active sun phenomena are given in the last column of table 3. The percentage of type IV events generated in the north is only slightly greater than the percent of major flares over the same period. The percentage of type II bursts coming from the north is somewhat larger, but probably arises from the greater completeness of Harvard type II data in 1959–1960, years of more extreme concentration of solar activity to the north than were 1957–1958. Type II bursts occurred 60 percent north in 1957–1958 and 80 percent north in 1959–1960.

The years 1957–1960 exhibit a striking tendency for the north-south asymmetry to increase with increasing intensity of the solar activity. In agreement with table 1 for a longer time span, table 3 shows that major solar flares are more concentrated to the north than are flares in general. The percentage of flares in the north significantly ($P < 10^{-10}$) exceeds that of spots. Major flares followed within three days by a great geomagnetic storm are more concentrated to the north than are flares followed by lesser or no geomagnetic disturbance. The sources of ground-level cosmic-ray increases are more concentrated to the north than are the sources of the less energetic PCA events.

Similar trends are clear also among both type II and type IV events. Bursts associated with major flares are more concentrated to the north than are bursts associated with lesser flares.

TABLE 3.—*Distribution of active-sun phenomena among the sunspot magnetic types, and between the two solar hemispheres*

Activity	Years	Number	Magnetic type				Percent North
			α	β	$\beta\gamma$	γ	
Major flares	1957–60	309	13%	43%	27%	17%	64%
followed by:							
no storm	''	128	18	50	19	13	60
small storm	''	83	10	52	24	14	57
moderate storm	''	44	9	43	23	25	68
great storm	''	54	7	15	54	24	83
Type IV events	1957–60	86	9	29	37	25	67
associated with:							
flare $\geq 2^+$	''	48	6	23	44	27	75
flare ≤ 2	''	38	13	37	29	21	58
of duration:							
$\leq 15^m$:	''	13	23	46	23	8	38
16^m to 59^m	''	29	3	24	35	38	69
1^h to 3^h59^m	''	28	14	32	29	25	64
$\geq 4^h$	''	16	0	19	69	12	88
Type II bursts	1957–60	166	16	48	23	12	68
associated with:							
flare $\geq 2^+$	''	52	9	38	30	23	80
flare ≤ 2	''	113	20	53	20	7	63
Sunspot groups	1957–60	2998					56. 5
All flares	''	12979					59. 8
Polar cap events	1956–60	46	8	22	37	33	70
Ground level events	1942–60	12	0	8	34	58	92

Thus a northern major flare is more likely to have an associated radio burst than is a southern flare of similar importance. We find 0.18 type IV events per northern and 0.11 per southern major flare, with a probability of 0.06 of finding by chance two such large deviations from the mean of 0.155 type IV bursts per major flare. Similarly, we obtain 0.23 type II bursts per northern and 0.10 per southern major flare, with a probability of 0.003 of finding by chance two such large deviations from the mean. Because the observations do not cover 24 hours, these numbers are only relative and the actual probability that a major flare will be accompanied by a type II or type IV event is estimated to be at least 50 percent greater.

If we consider the importance of the radio bursts themselves, as measured by duration, we find that the percent generated in the north is greater for the long-lived than for short-lived events. In table 3 the type IV bursts exceeding 4 hours duration show an especially strong preference for the northern solar hemisphere. Among type II bursts the percentage from the north is greater for events lasting 10 or more minutes than for shorter ones, in both 1957–1958 and 1959–1960. The percentages north are 75 and 52 for long and short bursts in the earlier years, and 88 and 71 in the later years.

We have already noted that the sources of ground-level cosmic-ray increases appear more concentrated to the north than do the sources of PCA events. It is of interest to explore the north-south asymmetry in relation to the intensity of the PCA events themselves. Unfortunately, the answer depends on whether one employs Bailey's (1962) VHF forward scatter signal, or Reid and Leinbach's (1959) riometer intensity measures. I used the list of PCA's and their most probable associated flares compiled by Warwick and Haurwitz (1962) which gives intensity measures from both sources. Using Bailey's scale we find 9 "large to very large" PCA's, of which 8 appear to have come from the north; his 33 "moderate to very small" events come 64 percent from the north. Using Reid and Leinbach's intensity measures, however, I find no relation between the north-south asymmetry and the intensity of the PCA.

From the delay times between flare and PCA determined by Warwick and Haurwitz, I find average values of 3.7 hours for northern and 5.2 for southern PCA's. Due to the large dispersion in delay times this difference has no statistical significance, but it seems nevertheless suggestive when viewed with the other evidence on north-south asymmetry.

In summary, the data on type II and type IV radio events, and with less certainty on PCA events, lend further support to the hypothesis that the north-south asymmetry is a phenomenon whose magnitude increases with the energy of the solar event. It should not be expected, of course, that the northern hemisphere will remain the more energetic indefinitely (see Bell, 1962). However, there is at present no theoretical basis for a prediction of when it may cease to be so.

Magnetic type

Data on the distribution of active-sun phenomena among the four basic types of sunspot magnetic field pattern also appear in table 3 for the years 1957–1960. The distribution for major flares does not differ significantly from that presented for a longer interval in table 1. In agreement with previous results (Bell, 1961), sunspot groups with complex $\beta\gamma$ and γ field patterns contribute a proportion of geomagnetic storms that increases with the intensity of the storm.

Table 3 shows a marked contrast between type II and type IV radio events. Complex spot groups produced only 36 percent of the type II bursts as compared with 61 percent of the type IV events.

Complex spots produced 54 percent of the type II bursts associated with a major flare. We find 0.20 bursts per major $\beta\gamma$ or γ flare, and 0.14 bursts per major α or β flare, with a probability of 0.07 of obtaining by chance two such large deviations from the mean. The difference is therefore of marginal statistical significance. Complex spots produced 28 percent of the lesser-flare bursts, as compared with 23 percent of all flares over the same time interval.

In striking contrast, complex spots produced a disproportionate 71 percent of the type IV events associated with a major flare, and 44 percent of those associated with a lesser flare. We find 0.25 bursts per major $\beta\gamma$ or γ flare, and only 0.08 bursts per major α or β flare, with a probability of only about 10^{-5} of obtaining by chance two equally large deviations from the mean. The contribution of complex spots is at a minimum for the shortest-lived bursts and maximal for those lasting over 4 hours.

Finally, table 3 shows that complex spot groups contributed 70 percent of all PCA events and, over a longer time span, 92 percent of the ground-level increases in cosmic-ray intensity. (See also Noyes, 1962, and Ellison et al., 1961)

Because of the parallelisms between percent in the north and percent complex, one may wonder about the percentage of complex spots and flares in the solar north. Table 4 provides information on this question. Comparison with tables 1 and 3 indicates that a relatively higher percentage of complex spots and of their associated active phenomena occur in the north. Simple spots are more evenly divided between the two hemispheres. Table 4 also shows that northern complex spots are more active than their southern counterparts in producing major flares and radio bursts. The activity of α and β spots is more nearly equal in the two hemispheres, that is, more closely in proportion to the numbers of spot groups.

TABLE 4.—*Percentage of complex ($\beta\gamma$ and γ) magnetic types occurring in the northern solar hemisphere*

Activity	No.	Percent North
1937–53:		
Sunspots	155	57. 5%
Great spots	75	57. 5
Flares	1996	59. 5
Major flares	115	77. 5
1937–59:		
Sunspots	228	58. 3
Flares	4714	60. 0
Major flares	226	73. 4
1957–60:		
Sunspots	82	67. 0
Flares	2974	66. 7
Major flares	136	73. 5
Type IV bursts	53	83
Type II bursts	57	81

The data presented in this section provide further support for the earlier conclusion (Bell and Glazer, 1958; Bell, 1961) that the magnetic type of the sunspot is a criterion that should receive more attention in efforts to forecast major flares, geomagnetic storms, and increases in cosmic-ray intensity.

Geomagnetic effects of type II and type IV bursts

Since the first suggestion by Sinno and Hakura (1958) that type IV events have a significant probability of being followed by geomagnetic disturbance, additional evidence favoring this hypothesis has been presented by McLean (1959), de Feiter et al. (1960), Simon (1960), and Mustel and Yegorova (1961). The geomagnetic consequences of type II bursts are more controversial. Because of their spectral characteristics, Wild (1950) suggested that they might be caused by the ejection of a corpuscular stream of the sort believed responsible for geomagnetic storms. Some evidence for a relation between type II bursts and geomagnetic storms was found by Roberts (1959) and by Maxwell, Thompson, and Garmire (1959). Other authors, however, find type II bursts to be of negligible geomagnetic significance, and Maxwell et al. also pointed out that type II with type IV had a greater probability of geomagnetic success than did type II alone.

The bursts discussed in this paper have been analyzed for geomagnetic success. They form a larger sample than previously studied. Table 5 gives the percentages of type II (left) and of type IV (right) events followed within three days (with a minimum allowed time delay of ten hours) by various levels of geomagnetic activity. The bursts are subdivided by several associated properties in an attempt to evaluate the relative importance of these features.

The last line of table 5 shows the percentages for a random sample of days. The random sample was determined from the total number of days and the total number of storms at each intensity level within the four years. For example, 26 great storms occurred within the four years. The probability that any day chosen at random will be followed within three days by a great storm is $1460/26 \times 3 = 0.054$. The similar probability that a given day will

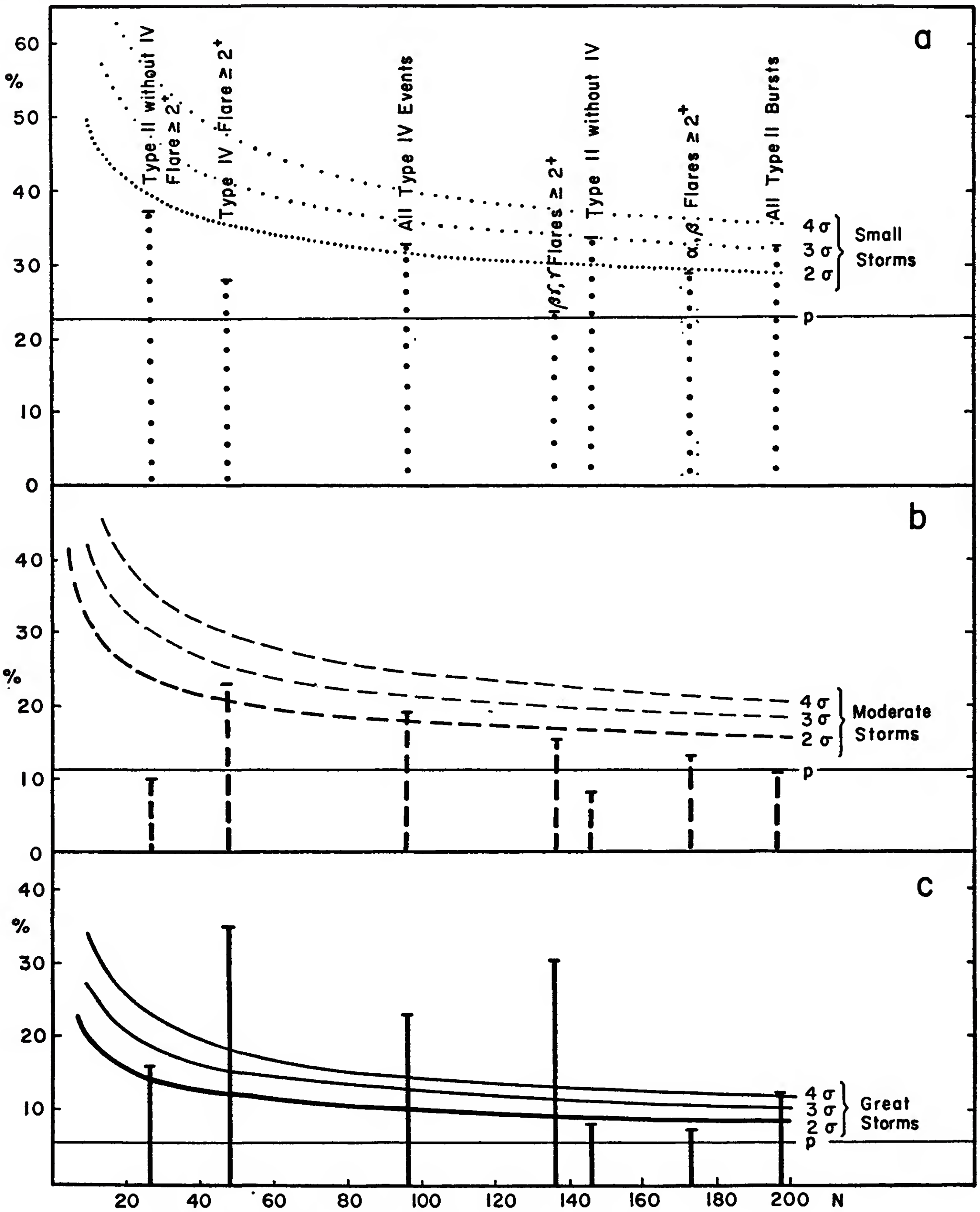

FIGURE 1.—The heavy vertical lines indicate the percentage of various active sun phenomena followed within three days by a great (solid lines), moderate (broken lines), and small (dotted lines) geomagnetic storm. The curved horizontal lines represent standard errors (σ) above the percentage (p) expected from a random sample.

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TABLE 5.—*Percentage of type II and type IV bursts followed within three days by various levels of geomagnetic activity, subdivided by properties of the solar event. Values deviating less than 2σ and more than 4σ from the random sample are designated by parentheses and bold face type, respectively.*

Properties of events	Type II bursts				Type IV bursts			
	No.	Percent followed by			No.	Percent followed by		
		Great storm	Moderate storm	Small storm		Great storm	Moderate storm	Small storm
a) All events	197	**12**	(11)	33	96	**23**	19	34
b) $\leq 9^m$ 1957–58	73	(8)	(13)	34				
$\geq 10^m$ 1957–58	33	15	(21)	(28)				
$\leq 9^m$ 1959–60	47	(11)	(6)	(32)				
$\geq 10^m$ 1959–60	44	16	(9)	36				
$\leq 15^m$					16	(6)	(0)	(44)
16^m–29^m					14	28	(15)	(36)
30^m–59^m					20	(10)	30	(35)
1^h–1^h59^m					17	17	(17)	(42)
2^h–3^h59^m					13	23	(23)	(31)
$\geq 4^h$					16	**56**	(25)	(19)
c) Flare $\geq 2^+$	55	**24**	(16)	35	48	**35**	23	(28)
Flare $< 2^+$	121	(7)	(9)	34	38	(8)	(13)	47
d) $\beta\gamma$, γ sunspots	58	**21**	(13)	37	53	**27**	22	(32)
α, β sunspots	104	(9)	(11)	33	33	18	(12)	43
e) North hemisphere	118	**15**	(12)	32	58	**31**	22	(32)
South hemisphere	52	(6)	(13)	35	28	(7)	(11)	46
f) East	75	13	(12)	35	40	**25**	(15)	42
West	97	12	(12)	32	46	**22**	22	(30)
g) $< 30°$ from CM	59	15	(10)	38	44	**30**	(20)	(34)
30°–59°	64	(9)	(25)	(32)	29	21	(20)	(28)
$\geq 60°$	49	12	(12)	(31)	13	(8)	(7)	62
h) Flare $\geq 2^+$ $\beta\gamma$, γ	28	**32**	(11)	39	34	**38**	(24)	(24)
Flare $\geq 2^+$ α, β	24	17	25	(25)	14	29	(21)	(36)
Flare $< 2^+$ $\beta\gamma$, γ	30	(10)	(17)	(33)	19	(14)	(12)	48
Flare $< 2^+$ α, β	80	(6)	(8)	35	19	(10)	(6)	47
i) Flare $\geq 2^+$ north	45	**24**	(14)	38	36	**44**	23	(25)
Flare $\geq 2^+$ south	11	(18)	(27)	(28)	12	(8)	(25)	(34)
Flare $< 2^+$ north	73	(10)	(10)	(29)	22	(9)	23	(41)
Flare $< 2^+$ south	42	(2)	(10)	37	16	(6)	(0)	57
j) $\leq 15^m$ $\beta\gamma$, γ	33*	18	(12)	(37)	4	(25)	(0)	(25)
$\leq 15^m$ α, β	63*	(6)	(10)	(32)	9	—	—	56
16^m–3^h59^m $\beta\gamma$, γ	25**	24	(16)	(36)	36	14	25	39
16^m–3^h59^m α, β	41**	(12)	(15)	(34)	21	24	(14)	(38)
$\geq 4^h$ $\beta\gamma$, γ					13	**62**	(22)	(16)
$\geq 4^h$ α, β					3	(33)	(33)	(34)

TABLE 5 (*continued*).—*Percentage of type II and type IV bursts followed within three days by various levels of geomagnetic activity, subdivided by properties of the solar event. Values deviating less than 2σ and more than 4σ from the random sample are designated by parentheses and bold face type, respectively.*

Properties of events	Type II bursts				Type IV bursts			
	No.	Percent followed by			No.	Percent followed by		
		Great storm	Moderate storm	Small storm		Great storm	Moderate storm	Small storm
k) $\leq 15^m$ flare $\geq 2^+$	24*	21	(17)	(37)	4	(25)	—	(25)
$\leq 15^m$ flare $<2^+$	76*	(7)	(9)	(30)	9	—	—	56
16^m–3^h59^m flare $\geq 2^+$	31**	26	(16)	(32)	30	**30**	23	(30)
16^m–3^h59^m flare $<2^+$	39**	(8)	(13)	(35)	27	(4)	(18)	49
$\geq 4^h$ flare $\geq 2^+$					14	**50**	28	(22)
$\geq 4^h$ flare $<2^+$					2	(100)	—	—
l) $\leq 15^m$ north					5	(20)	—	(20)
$\leq 15^m$ south					8	—	—	(50)
16^m–3^h59^m north					39	**21**	23	41
16^m–3^h59^m south					18	(11)	(17)	(39)
$\geq 4^h$ north					14	**64**	(22)	(14)
$\geq 4^h$ south					2	—	(50)	(50)
Random sample	1460	5. 4	11. 3	23. 2	1460	5. 4	11. 3	23. 2

* $\leq 9^m$ for type II
** $\geq 10^m$ for type II

be followed within three days by a moderate storm is 0.113, and by a small storm is 0.232.

Figure 1 shows the percentage of type II and type IV events that are followed within three days by the three levels of geomagnetic activity, and provides also a guide for evaluating the significance of the difference from the random sample. The curved horizontal lines indicate deviations of two, three, and four standard errors above the random values, where $\sigma = (Npq)^{\frac{1}{2}}$ and N is the number of cases, p is the random probability (0.054, 0.113, and 0.232) for obtaining a given level of geomagnetic activity, and $q = 1 - p$. Figure 1 also shows the probability of a geomagnetic storm after all major $\beta\gamma$ and γ flares, and all major β and α flares without regard for radio bursts; and after type II bursts without type IV. Further data comparing type II with and without type IV appear in table 6 and figure 2. The σ-lines in figure 1 were used to estimate the statistical significance of all values in tables 5 and 6; the three different type faces distinguish values less than 2σ, 2 to 4σ, and more than 4σ above the random values.

Figure 1*c* shows a highly significant probability of obtaining a great geomagnetic storm in the three days following a type IV event, and also following a major flare from a $\beta\gamma$ or γ sunspot. The probability of a great storm after type II events is also significantly above the random; however, it is not significant for type II's that are unaccompanied by type IV, nor for α and β major flares. The more detailed data in table 6 support this conclusion. In the absence of type IV, type II bursts appear to have only slightly more than the random probability of being followed by a great geomagnetic storm. The most successful of type II alone are those accompanied by a major flare and arising from a complex sunspot (table 6, line *h*).

The other category, type IV without type II, is shown in table 7. Thompson (private communication) cautions that to be certain that a type IV burst is not accompanied by a type II it is necessary that the start of the event be recorded completely over a frequency range extending down to 50 Mc/s or lower. This condition was fulfilled at Fort Davis only

Table 6.—*Percentage of type II with and without type IV followed within three days by various levels of geomagnetic activity, subdivided by properties of the solar event. Values deviating less than 2σ and more than 4σ from the random sample are designated by parentheses and by bold face type, respectively.*

Properties of events	Type II without type IV				Type II with type IV			
	No.	Percent followed by			No.	Percent followed by		
		Great storm	Moderate storm	Small storm		Great storm	Moderate storm	Small storm
a) All bursts	146	(8)	(8)	34	51	**24**	(17)	(32)
b) ≥10^m	40	(2)	(10)	41	30	**33**	(20)	(27)
≤9^m	84	(10)	(9)	(30)	16	(12)	(19)	(44)
c) Flare ≥2+	27	16	(10)	(37)	29	**31**	(21)	(34)
Flare <2+	98	(5)	(9)	32	17	18	(17)	(30)
d) βγ, γ sunspots	32	19	(9)	41	26	**23**	(19)	(31)
α, β sunspots	84	(4)	(9)	(32)	20	**30**	(20)	(35)
e) North	85	(8)	(10)	33	33	**33**	(19)	(30)
South	40	(5)	(10)	(33)	10	(8)	(23)	(38)
f) East	51	(6)	(12)	35	24	**29**	(13)	(33)
West	75	11	(6)	(32)	22	18	27	(32)
g) <30° from CM	42	(10)	(7)	(35)	17	**29**	(18)	(41)
30–59°	46	(2)	(9)	39	18	**28**	28	(11)
≥60°	38	13	(13)	(24)	11	(9)	(9)	55
h) Flare ≥2+ {βγ, γ	9	33	—	(45)	19	**32**	(15)	(37)
h) Flare ≥2+ {α, β	14	(7)	(22)	(21)	10	30	(30)	(30)
Random sample	1460	5.4	11.3	23.2	1460	5.4	11.3	23.2

after January 1959. Therefore the bursts for 1959–60 are shown separately in table 7. Their geomagnetic success does not differ from that of the larger but less reliably defined four-year sample. Table 7 suggests that type IV and type II bursts should both be present for the maximum probability of a great geomagnetic storm, although, of the two, type IV is the more essential.

Figure 1*b* and line *a* of tables 5 and 6 (i.e., lines 5*a* and 6*a*) show that type IV bursts have a greater probability than type II of being followed by a moderate geomagnetic storm. In the probability of a small storm, on the other hand, we find no significant difference between type II and type IV bursts. The highest probability of a small storm is given by type IV without type II; however, the small sample in table 7 limits the significance of the difference.

Because of the larger number of type II bursts observed, about an equal *number* of type II and type IV are followed by great and moderate storms. About twice as many type II's as type IV's are followed by a small storm. Thus the finding that type II alone has significant geomagnetic success only at the small-storm level does not necessarily disprove Wild's (1950) attractive hypothesis that type II bursts arise from the ejection of a corpuscular stream which is related to geomagnetic storms. Indeed the data tend to support Wild's (1960) later suggestion that the presence of type IV radiation may be an indication of the amount of matter transported from the flare by the type II phase of the disturbance.

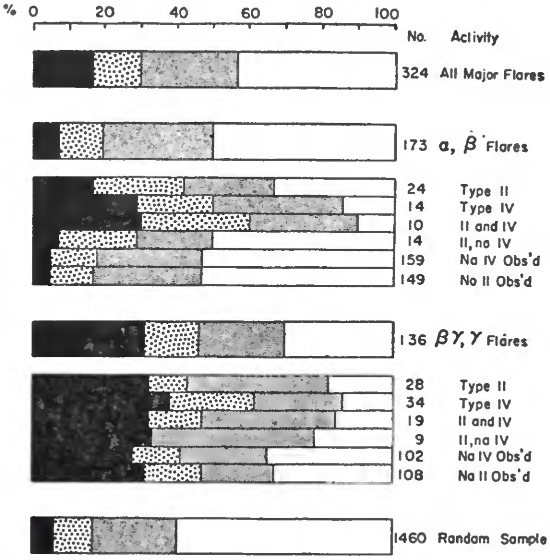

FIGURE 2.—Percentage of major flares followed within three days by a great (black), moderate (dots), or small (gray) geomagnetic storm, subdivided by magnetic type of the flaring sunspot and by the types of accompanying spectral radio bursts.

TABLE 7.—*Percentage of type IV events without type II followed within three days by various levels of geomagnetic activity*

No. events	Years	Percent followed by		
		Great storm	Moderate storm	Small storm
14	1959–60	(14)	(15)	50
35	1957–60	14	(20)	40

From an examination of the details of tables 5 and 6 we can draw some additional conclusions. Line 5*b* shows that type IV bursts of long duration tend to be more geoactive than short-lived ones, especially in the production of great and moderate storms. With respect to geomagnetic success the bursts appear to divide into three duration categories: $\leq 15^m$, effective only for small storms; 16^m to $3^h\ 59^m$; and $\geq 4^h$, with the latter especially effective in the production of great storms.

Similarly, among type II bursts the long-lived surpass the short-lived in geomagnetic success. The numbers of cases in line 6*b* show that a much higher percentage of long- than of short-lived type II bursts are accompanied by type IV. Line 6*b* also shows that, even among type II's with type IV, the longer-lived type II's are more successful, especially in producing great storms. If matter is transported at all during the type II phase of the disturbance, one would expect that the amount of matter transported would be related to the duration of the burst. Thus the data of line 6*b* provide further support for Wild's (1960) suggestion that the presence of type IV radiation may be an indication of the amount of matter transported.

Table 5 shows that association with a major flare (line *c*), origin from a magnetically complex spot group (line *d*), and location in the northern solar hemisphere (line *e*) are all factors that increase the probability of success of a type IV burst. The significance of these factors is substantial for great and moderate storms, but becomes minimal, and indeed even reversed, for small storms. Line 5*e* is in accord with Bell's (1961) earlier finding that the north-south asymmetry was significant only for sources of great storms, not for lesser storms. The association with a major flare and a complex sunspot also increases the probability that a type II burst will be accompanied by one of type IV (lines 6*c*–6*e*).

Line 5*f* shows that a few more bursts of each type occurred west than occurred east of the solar central meridian. In agreement with Bell's result from major flares, there is no evidence of any east-west asymmetry in the geomagnetic success of either type IV or type II bursts. From line 5*g* we can see that the number of type IV bursts falls off to the solar limb much more than does that of type II. For comparison, Bell's 1937–1959 data give a decrease by a factor of two in the number of major flares from the central to the limb zone—with 260, 190, and 130 major flares in the three zones—a decrease intermediate between that for type IV and that for type II radio bursts. For type II the level of geomagnetic success appears independent of meridian distance. The type IV behavior parallels that for major flares, with a striking decrease in the probability of a great storm and a compensating increase in the probability of a small storm toward the limb.

Lines 5*h* to 5*l* indicate that the various factors contributing to the geomagnetic success of a solar-activity event cannot be readily separated. Duration being equal, some advantage remains to major flares (line 5*k*) and to northern bursts (line 5*l*), but the magnetic class of the spot (line 5*j*) appears unimportant. Figure 2 also shows that the probability of geomagnetic success following a major flare with a type IV burst does not depend significantly on the magnetic type of the sunspot. However, lines 5*h* to 5*l* reemphasize the point made earlier, that complex spot groups—and the northern hemisphere—generate a disproportionate share of the longest-lived type IV events.

The principal conclusions of this section may be summarized as follows. The data clearly indicate a very strong association between radio bursts of spectral type IV and great geomagnetic storms. The success of a type II burst appears to depend on the presence of a type IV. Type II bursts that are unaccompanied by type IV are significantly related only to small storms. However, type IV and type II bursts occurring together give the highest probability of a great storm.

Among the attributes considered in this paper, a major associated flare, location in the north, and long duration of the burst appear to be the most important in raising the probability of a great or moderate storm. Type IV events lasting less than 15 minutes are unlikely to be followed by more than a small storm.

When radio spectrum observations are available, the magnetic class of the sunspot is of minor value in forecasting the probable geomagnetic consequence of a given flare. A major flare with type IV emission lasting more than 15 minutes has a large probability of success whatever its spot class. However, a major $\beta\gamma$ or γ flare is about three times more likely to be accompanied by type IV emission than is a similar β or α flare. Also, among the spot groups producing at least one major flare (table 1), the $\beta\gamma$ and γ spots produced an average of 1.7 times as many major flares as the β and α spots. These two factors together indicate that in a given time interval a complex spot has at least five times the probability of generating a type IV burst than does a similar α or β spot group. Thus, when we are interested in forecasting over a longer term in advance of the observation of an actual flare with or without radio bursts, the magnetic type of the sunspots appears to be the most useful criterion known to date.

PCA and type IV events

The present data confirm previous findings (Boischot, 1958; Kamiya and Wada, 1959; Hakura and Goh, 1959; Thompson and Maxwell, 1960a, 1960b; Obayashi and Hakura, 1960a, 1960b; Pick, 1961) of a significant association between type IV radio events and PCA proton events. Of the 96 type IV events observed at Sydney or at Fort Davis, 23 were followed within a few hours by a PCA. Of these 23 events, 13 had a type II burst also; and only three (in 1959–1960) can be said with confidence to lack a type II burst. All but one of the 23 were associated with a major flare. Thus about half (46 percent) of the type IV events with a major flare were followed by a PCA. Eighteen other PCA's were most probably associated with flares which occurred at times when neither the Fort Davis nor the Sydney spectrum analyzer was operating.

Table 8 shows the relation between the duration of the type IV emission and the intensity of the PCA as measured by Bailey (1962). The final column indicates that the percentage of type IV bursts that are followed by a PCA increases with increasing duration of the radio emission. Reference to table 2 reveals, however, that the percentage of type IV events associated with a major flare similarly

TABLE 8.—*Relation between radio bursts of spectral type IV (by duration) and PCA events (by intensity)*

Duration of type IV burst	No. followed by PCA of intensity: L–VL	M	S–VS	Total No.	Percent followed by PCA
$\leq 15^m$	—	1	—	1	6%
16^m–29^m	—	—	2	2	14
30^m–59^m	—	—	5	5	25
1^h–1^h59^m	—	1	3	4	24
2^h–3^h59^m	2	2	—	4	31
$\geq 4^h$	4	2	1	7	44
Total	6	6	11	23	24
No spectrum observations	2	5	11	18	—

increases with the duration of the burst. If we consider only type IV bursts with a major flare, the percentage followed by a PCA appears to be independent of the duration of the burst, at least for bursts lasting more than 15 minutes. On the other hand, the intensity of the PCA shows a rather striking relation to the duration of the burst. Among PCA's of moderate (M) or greater intensity (L, VL) in table 8, 83 percent were preceded by a burst lasting at least two hours, while 91 percent of the small (S) and very small (VS) PCA's were preceded by a burst lasting less than two hours. A 2×2 chi-square test gives a probability of less than 0.001 that the observed distribution might occur by chance. Thus in spite of the rather small sample size, it seems probable that there is a significant relation between the intensity of the PCA and the duration of the preceding type IV emission. It would, indeed, be rather disturbing if no such relation existed.

We have already noted that table 3 shows that a substantial majority of PCA events originate from magnetically complex sunspot groups.

Table 9 shows the relation between the intensity of the PCA and the intensity of the associated geomagnetic disturbance. Only 5 (11 percent) small or very small PCA's were not followed within three days by at least a small storm. (If we characterize the intensity of the storm by its maximum 3-hr Kp, then we find that 28 percent of the PCA events were followed by $Kp \geq 9^-$, 50 percent by $Kp \geq 8^-$, and 72 percent by $Kp \geq 7^-$. Only 13 percent failed to be followed by a $Kp \geq 6^-$.) The correlation, if any, between the intensity of the PCA and the intensity of the subsequent geomagnetic storm is too weak to be statistically meaningful. On the other hand, as we shall see in the last section, the probability that a given geomagnetic storm was preceded by a PCA is strongly dependent on the intensity of the storm.

Solar activity preceding geomagnetic storms

In a previous section we considered the geomagnetic activity following solar radio bursts. Here we investigate the inverse problem. We begin with a list of great, moderate, and small geomagnetic storms, defined as before, and determine the percentage preceded within three days by a major flare, a type IV burst, a type II burst, and various combinations of these events. The results appear in tables 10 and 11. The statistical significance of each deviation from the random probability, or percentage to be expected by chance, was estimated as before. (In determining the random probabilities a given day was counted only once even when it had several bursts; a burst observed on the day following another burst-day added only one to the number of days following within three days of a burst, etc.)

The first line of table 10 shows that with one exception (1960 Oct. 6) each great storm was preceded within three days by at least one major flare. Just over three-fifths were preceded by type IV and by type II bursts. Since 31 percent were preceded by a major flare that occurred at a time when neither the Fort Davis nor the Sydney spectrum analyzer was oper-

TABLE 9.—*Relation between PCA events and geomagnetic activity following within three days*

Intensity of PCA	No. followed by				Total No.
	Great storm	Moderate storm	Small storm	No storm	
L–VL	5	2	2	—	9
M	5	4	3	—	12
S–VS	8	5	7	5	25
All PCA's	18	11	12	5	46
Percent	39%	24%	26%	11%	100%

TABLE 10.—*Percentage of geomagnetic storms preceded within three days by various manifestations of solar activity. Values (in cols. 3–6) deviating less than 2σ and more than 4σ from the random sample are designated by parentheses and bold face type, respectively.*

Storm intensity		No.	Percent preceded by: Type IV burst	Type II burst	Major flare	PCA	No activity: All	No activity: Recurrent	Total percent recurrent
Great	G	26	**62**	62	**96**	**65**	4	4	23
Moderate	M	55	(24)	(35)	60	(16)	33	29	44
Small	S	113	(21)	(27)	(40)	(11)	44	24	35
Max *Kp*									
≥9⁻	G	15	**73**	73	**93**	**87**	7	7	7
8⁻ to 8⁺	G–M	24	(29)	(33)	**83**	29	17	17	46
7⁻ to 7⁺	M–S	41	29	(44)	68	24	24	20	29
6° to 6⁺	M–S	43	33	(42)	(44)	(9)	37	23	40
6⁻	S	32	(22)	(47)	(34)	(9)	41	28	47
5⁻ to 5⁺	S	40	(5)	(20)	(28)	(7)	60	30	35
Σa_p 4									
≥900	G	12	**75**	75	92	**83**	8	8	8
500–899	M–G	22	41	(36)	**91**	**50**	9	9	41
300–499	M–S	42	31	(45)	71	21	19	14	26
200–299	M–S	55	29	(40)	(42)	(7)	40	35	51
160–199	S	36	(11)	(31)	(31)	(6)	58	25	36
110–159	S	27	(7)	(30)	(30)	(11)	56	26	30
Random sample		1460	16.0	32.5	41.2	9	—	—	—

ating, it seems probable that most of the great storms in table 10 were actually preceded by type IV emission.

The equality of the percentages for type IV and type II bursts is somewhat misleading, for, as table 11 shows, only 35 percent of the great storms were preceded by type IV and type II in association with the same (major) flare. (Two additional cases had type IV bursts in progress at sunrise at Fort Davis, so there was no possibility to observe type II if it occurred.) Most of the great-storm type IV bursts were associated with a major flare, but a substantial portion of the type II bursts occurred independently, in association with some lesser flare.

The percentage of moderate storms preceded by these solar activities is sharply below that for great storms. A significant number are still preceded by a major flare, but the association with radio bursts hardly exceeds the number expected by chance. Even major flares are not associated with small storms more often than one would expect to occur by chance.

The last columns of table 10 show that a substantial proportion of moderate and small storms are recurrent. As used here, "recurrent" means a member of a sequence with at least three recurrences at an interval of 26–28 days; most of the sequences contain more than the minimal three recurrences. The high percentage of recurrent storms in these intensity-groups, and the low association with solar activity is in accord with the hypothesis proposed first by Allen (1944) that there are two fundamentally different types of magnetic storms—the sporadic sc-type which includes most of the great storms, and the recurrent or M-region type of lesser intensity. Allen found that although the sporadic storms showed a positive association with the central meridian passage of large sunspot groups, the recurrent

TABLE 11.—*Percentage of the geomagnetic storms preceded within three days by a major flare with and without associated radio bursts of types II and IV. Values (in cols. 3–5) deviating less than 2σ and than 4σ from the random sample are designated by parentheses and bold face type, respectively.*

Storm intensity		No. with major flare	Percent with associated				
			IV, II	IV	II	No spect. obs'ns	No burst observed
Great	G	25	**36**	**60**	40	32	4
Moderate	M	33	(18)	30	(24)	58	6
Small	S	45	20	(24)	29	38	29
Max Kp							
$\geq 9^-$	G	14	36	**72**	43	14	7
8^- to 8^+	G–M	20	(20)	(30)	(20)	65	5
7^- to 7^+	M–S	28	25	32	32	50	11
6° to 6^+	M–S	19	32	42	37	37	16
6^-	S	11	(18)	(27)	(36)	27	27
5^- to 5^+	S	11	(0)	(0)	(9)	45	45
$\sum_4 a_p$							
≥ 900	G	11	45	**73**	54	9	9
500–899	G–M	20	25	45	(25)	55	0
300–499	M–S	30	(20)	(27)	(27)	57	10
200–299	M–S	23	26	39	35	39	13
160–199	S	11	(18)	(18)	(36)	27	36
110–159	S	8	(0)	(0)	(0)	38	62
All major flares		309	9.4	15.5	17.8	~43*	~33*

*Estimate derived from 103 storm-flares only; sum of the last two columns is 76% of the 309 flares.

storms showed a negative association. In addition, Bell and Glazer (1957) found a negative relation between recurrent storms and the intensity of the green (λ5303) emission line corona.

Table 12 compares the solar activity preceding the recurrent and the nonrecurrent storms in my four-year sample. Nonrecurrent storms at each intensity level show a stronger association with major flares and with radio bursts than do recurrent storms. Small recurrent storms show a significantly ($\geq 2\sigma$) *lower* association with major flares and with type II bursts than would be expected to occur by chance. The tendency of small and moderate recurrent storms to avoid major flares and radio bursts is in accord with Allen's finding of a negative relation between recurrent storms and large sunspots from an independent sample of data, and strikingly supports his hypothesis of two fundamentally different types of geomagnetic storm.

It seemed unlikely that my rather arbitrary choice of $Ap \geq 100$ and/or $Kp \geq 9^-$ as the criteria for a great storm should define as well as possible the boundary between storms that seem well accounted for in terms of preceding major flares and radio bursts and those that are not accounted for. The first three lines of tables 10 to 12 invited a refinement of the storm classification, particularly a subdivision of the class of moderate storms. Two additional measures of the intensity of the storm were therefore considered—the maximum value of Kp attained during the storm; and $\sum_4 a_p$, the sum of the four largest consecutive 3-hr a_p values. In tabulating the data I kept separate each value of Kp; for $\sum_4 a_p$, I used steps of 100 above 700, of 50 from 200 to 700, and of 20 below 200. The groupings in table 10 were suggested by inspection of these initial tabulations; to the best of my judgment they represent

TABLE 12.—*Comparison of solar activity preceding recurrent and nonrecurrent geomagnetic storms. Values in cols. 3–5, 7, 9–11 deviating less than 2σ and more than 4σ from the random sample are designated by parentheses and bold face type, respectively.*

Storm intensity	Nonrecurrent storms						Recurrent storms				
	No.	Percent preceded by					No.	Percent preceded by			
		Type IV burst	Type II burst	Major flare	No activity	PCA		Type IV burst	Type II burst	Major flare	No activity
Great	20	**65**	65	**100**	0	**75**	6	(50)	(50)	83	17
Moderate	31	32	(48)	**84**	6	26	24	(12)	(17)	(29)	67
Small	73	26	48	(49)	32	(14)	40	(12)	17	22	68
Max Kp											
$\geq 9^-$	14	**79**	72	100	0	**93**					
8^- to 8^+	13	(31)	(31)	100	0	39	12	(25)	(33)	(58)	42
7^- to 7^+	29	35	55	**86**	7	31					
6° to 6^+	26	46	54	(54)	23	25	29	(14)	(21)	(28)	62
6^-	17	(18)	71	(41)	24	(12)					
5^- to 5^+	26	(8)	(27)	(35)	46	(12)	29	(14)	14	21	72
$\sum_4 a_p$											
≥ 900	11	**82**	82	100	0	**91**					
500–899	13	46	(31)	100	0	77	10	(30)	(40)	(70)	30
300–499	31	36	55	**84**	6	26					
200–299	27	37	67	67	11	(11)	39	(20)	15	23	64
160–199	23	(17)	(35)	(30)	52	(22)					
110–159	19	(11)	(37)	(37)	42	(16)	21	(0)	19	(24)	76
Random sample		16.0	32.5	41.2	—	9		16.0	32.5	41.2	—

groups homogeneous in degree of association with solar activity. By these new criteria there is a considerable range of overlap between great and moderate, and between moderate and small storms. The bottom categories are not necessarily complete; they include only those events also satisfying the requirements for a "small storm" ($Ap \geq 25$).

Great storms, with $Kp \geq 9^-$ or $\sum_4 a_p \geq 900$, show the expected very strong association with all three types of solar activity. Table 11 shows that the association with type IV remains stronger than that with type II bursts. With the new criteria the percentage of storms preceded by radio bursts falls off rather abruptly below this intensity limit, while the percentage preceded by a major flare declines more gradually. Serious doubt is cast on the reality of the sharp decline in percentage of storms preceded by radio bursts by the next-to-last column of table 11, which shows that a particularly high percentage of the major flares preceding storms in the ranges $7^- \leq Kp \leq 8^+$ and $300 \leq \sum_4 a_p < 900$ occurred at times without radio spectrum observations. At least down to $Kp = 8^-$ and $\sum_4 a_p = 500$ it remains possible, indeed even probable, that most nonrecurrent storms were preceded by type IV emission as well as a major flare. Even down to $Kp = 6^\circ$ or $\sum_4 a_p = 200$ the percentage preceded by a major flare without an observed burst of either type is small.

The inverse analysis tends to confirm the previous finding that type IV emission is more essential than type II for a great storm. Study of the percentages in tables 10 and 11 indicates that a large proportion of type II bursts, especially for the weaker storms, were associated with minor flares. Not infrequently a type II burst with a minor flare appeared to be the only "explanation" for a small or moderate storm. Table 12 shows that more nonrecurrent storms of medium intensity were preceded by type II than by type IV bursts, although in terms of deviation from the random probability the type IV association remains the more significant.

In table 10 the percentage of storms accounted for by a major flare falls off smoothly with decreasing storm intensity, whichever storm criterion is used. The percentage of storms preceded by no activity (of the three kinds considered here) rises. The percentage belonging to recurrent sequences also rises, but less smoothly, and is actually greater for moderate than for small storms. Most of the moderate storms without preceding solar activity can be accounted for as members of M-region sequences. Recurrent storms with maximal $Kp < 8^-$ or $\sum_4 a_p < 500$ show (table 12) a striking avoidance of major flares and radio bursts. A similar, although statistically less significant, avoidance is shown by the weaker nonrecurrent storms. A substantial proportion of even nonrecurrent storms with maximal $Kp < 7^-$ or $\sum_4 a_p < 200$ are not accounted for by solar activity. It seems reasonable to postulate that some of these are M-region storms whose sources were disrupted before they had produced the minimal three recurrences required for identification.

The PCA's, as we would expect, are almost entirely associated with storms of the nonrecurrent type. Their association with recurrent storms is no greater than might be expected to occur by chance. Most of the greatest storms were preceded by a PCA (see tables 10 and 12). The percentage drops rapidly with diminishing storm intensity, which might suggest that the percentage of storms preceded by type IV emission also actually drops about as shown in the tables. Since less than half of the type IV bursts with a major flare were followed by a PCA, such an argument does not seem to be compelling. The anomaly in the completeness of the radio spectrum observations makes it impossible to set more precisely the limits of storm intensity above which almost all of the storms are preceded by a major flare and type IV emission, at least until nonspectrum data on type IV bursts are added to the analysis. This work is in progress.

Note in tables 10 and 12 that $\sum_4 a_p$ appears to be a better guide than the maximal Kp to the possibility that a given storm was preceded by a PCA. $\sum_4 a_p$ also provides a sharper boundary below which a substantial proportion of nonrecurrent storms are unaccounted for. For these reasons $\sum_4 a_p$ is probably the more useful measure of the intensity of a storm.

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Abstract

Solar radio bursts of spectral types II and IV, observed in the years 1957–1960, are discussed in relation to flares, the magnetic class of the associated sunspot, the north-south asymmetry, and to geomagnetic and solar proton (PCA) effects. A total of 96 type IV and 197 type II bursts were studied.

About 50 percent of the type IV and 28 percent of the type II bursts were associated with a major ($\geq 2^+$) flare.

Sunspot groups of complex ($\beta\gamma$ and γ) magnetic class produced 61 percent of the type IV but only 36 percent of the type II bursts. Comparative data are given for sunspots, flares, and geomagnetic storm and PCA sources.

The north-south asymmetry appears to increase with increasing intensity in various types of solar activity. Long-lived bursts of each type are more concentrated to the north than are short-lived bursts. But there is no significant difference between type II and type IV bursts in north-south distribution.

The data indicate a very strong association between type IV bursts and great geomagnetic storms. The increase in probability of a great storm within three days after a type II burst is also significant but less striking. However those type II bursts that were not accompanied by type IV appear to be significantly associated only with small storms.

The bursts were subdivided by various properties. A major flare or a long duration of the burst each increases the probability of geomagnetic success. Type IV bursts lasting less than 15 minutes have little geomagnetic importance. Given a major flare with type IV emission, the magnetic class of the sunspot is of minor significance. However, a $\beta\gamma$ or γ sunspot is about five times more likely to produce a major flare with type IV emission than is a β or α spot group of comparable size.

The inverse problem, of solar activity preceding geomagnetic storms, was analyzed as a function of storm intensity. A significant difference between recurrent and nonrecurrent storms was found, in that recurrent storms tend to avoid centers of major flare and radio burst activity.

A strong association is found between type IV radio events and PCA events, with 23 of the type IV bursts followed within a few hours by a PCA. The duration of the burst is positively related to the intensity of the PCA. A high percentage of proton events arise from complex sunspot groups.

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