ANALYSIS OF POLAR CAP EVENTS IV -

ALMOST NECESSARY AND/OR SUFFICIENT CONDITION

FOR SOLAR PROTON WARNING

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INTRODUCTION

This report summarizes the data analysis that was used in the search for an observational technique that will, with a high degree of confidence, distinguish flares that were followed by a polar cap absorption event from those that were not.

The study was carried out in several phases:

(a) A list of PCA events was compiled from the published data and all available associated solar and solar induced terrestrial phenomena were investigated for the four or five days preceding the event and a few days after the event in the search for conditions that might indicate those phenomena that are common to PCA events either individually or in combinations.

(b) All major flares with corrected importance ≥ 3 were studied to find if possible why some were followed by PCA events and others were not. Phenomena including sunspot and plage characteristics before and at the time of the flare, the time relations of the flare with importance of shortwave radio fadeouts, spectral radio emissions of the slow drift type (Type II) and broadband continuum emissions of Type IV, and emissions at single frequencies at centimeter wavelengths (frequencies from 1420 to 3750 Mc/s).

(c) Minor flares with corrected importance < 3 that were followed within a reasonable time by a PCA event were studied in terms of the associated solar region, and those phenomena that were evaluated during the study of the major flares. In addition, the flare and radio activity of the region from the time of east limb passage to the start of the flare were studied for possible indication of an energy buildup and storage.

(d) All solar radio emissions at centimeter wavelengths with peak emissions $\geq$ 500 flux units*, were evaluated for flare association and flare importance; the time relation of flare RF emission start time; the time relation of the flare maximum intensity with the time of RF peak flux.

* One flux unit equal $10^{-22} W (m^2 c/s)^{-1}$

(e) The shape of the RF time history and the possibility that flares associated with multi-peak RF emissions, have sequences of brightening and dimming was investigated for a number of events.

1.0 SUMMARY

Several solar or solar induced conditions or phenomena were found that could be considered as "almost necessary" conditions for a PCA event to occur:

Plage region must be in at least its second rotation.

Sunspot group area must be greater than 500 millionths of the solar hemisphere on flare day.

The flare must cause a short wave radio fadeout.

The flare must be accompanied by a solar radio burst of spectral Type IV.

The flare must be associated with RF emission at cm wavelength with a peak flux $\geq 500 \times 10^{-22} W(m^2 c/s)^{-1}$.

At this point in the study we find three solar or solar induced conditions or phenomena that appear to be "almost sufficient" conditions for "predicting" that a flare will be followed by a PCA event.

The time of the RF emission peak flux follows the time of the associated flare maximum intensity.

The major flare covers some minimum part of the sunspot umbra.

A flare on the visible disk is followed by a loop prominence system.

The degree of confidence in each of these so-called necessary or sufficient conditions and their limitations are listed below. Possible modification, combinations, and problems associated with some of these conditions will be discussed in the subsequent sections of this report.

1.1 GENERAL STATISTICAL SUMMARY

1.1.1 "Almost Necessary" Conditions

Plage Regions:

96% of the PCA plage regions were in at least the second transit of the visible solar disk

74% of the PCA plage regions had an average maximum area $\geq$ 5000 millionths during disk passage.

Sunspot Size:

90% of the basic PCA flares occurred in sunspot groups with a maximum area greater than 500 millionths

88% of the PCA flares between E80 and W80 for the years through 1959 had an area greater than 500 millionths on flare day.

Less than 7% of the large sunspot groups were the source of PCA-flares

Sunspot Magnetic Field:

65% of the PCA flares occurred in sunspot groups with a complex (γ or $\beta\gamma$) magnetic classification on flare day

Flare Importance:

76% of the PCA flares had an importance $\geq$ 2+

Only 1% of the flares with importance $\geq$ 2+ were followed by a basic PCA event

Short Wave Radio Fadeout:

100% of the PCA flare caused short wave radio fadeouts

83% of the PCA flares caused an SWF with importance $\geq$ 2+

Solar Radio Bursts of Spectral Type II and Type IV*

41 of the basic PCA events occurred during the normal observing times at the Harvard Radio Astronomy Observatory at Fort Davis, Texas, or the CSIRO Observatory at Dapto near Sydney, Australia.

80% of the PCA flares were accompanied by spectral Type IV

60% of the PCA flares were accompanied by spectral Type II

50% of the PCA flares were accompanied by both Type II and Type IV emissions

In the case of events not followed by a basic PCA, the percentage with Type II and/or Type IV emissions were:

Only 2% non PCA events accompanied by spectral Type IV

Only 3% non PCA events accompanied by spectral Type II

Only 2% non PCA events accompanied by both Type II and Type IV

RF Emission at cm Wavelength

85% of the PCA flares were associated with RF emissions at cm wavelengths with a peak RF flux $\geq 500 \times 10^{-22}$ $W(m^2c/s)^{-1}$

Only 2% of the RF bursts $\geq 500 \times 10^{-22} W(m^2c/s)^{-1}$ were associated with a PCA flare

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* It should be noted that the numbers and percentages in our data differ from Harvey (ref. 25). We have used all major events (i.e., associated with flares of importance $\geq$ 3 and with RF peak $\geq$ 500 flux units for flares < 3) at frequencies 1420 through 3750 Mc/s, during the normal observing time of both CSIRO and Harvard while Harvey limited her study to RF bursts at 10.7 cm and the spectral observation at Fort Davis during the Ottawa observing time.

1.1.2 <u>"Almost Sufficient" Conditions</u>

<u>Events with Flares Importance $\geq$3 Associated with cm RF Emissions with Peak Intensity $\geq$ 500 Flux Units</u>

83% of the basic PCA events, the time of the RF Peak intensity followed the time of the flare maximum.

100% of the non-PCA events, the time of the RF peak intensity preceded the time of flare maximum

<u>Events with Flares Importance $<$ 3 with cm RF Emissions with Peak Intensity $\geq$500 Flux Units</u>

78% of the non-PCA events the time of the RF peak intensity preceded the time of flare maximum

2.0 GENERAL DISCUSSION

2.1 POLAR CAP ABSORPTION EVENTS

During the progress of the contract a list of 106 polar cap absorption events (PCA) or possible PCA events were chosen from a large number of sources (Table 2, reference 9). These PCA events were classified into three groups: basic, small, and very small.

The 59 PCA events in the basic group are those detected by two or more techniques that could be associated with a solar flare with reasonable certainty.

The small PCA events are those reported by two or more independent investigators based on ionosonde f_{min} data. There are 23 events in this group and the flare association is questionable for about half of them.

The very small events are those events during 1960 that were reported by Gregory only. They were discovered through the use of high sensitivity vertical incidence back scatter sounding of the lower ionosphere at a frequency of 2.3 Mc/s at 79° south geomagnetic latitude. Several of the 24 events in this group can be associated with a solar flare with reasonable confidence.

It is probable that none of the PCA events classified as small or very small can be considered as dangerous for manned space flight in near-earth orbit, in cislunar space or on the surface of the moon. However, they were included in the analysis to increase the statistical significance of the investigation.

The association of the 106 events with flare importance is shown in Table 2.1.

Flare Importance	PCA Group			Total
	Basic	Small	Very Small	
No reasonable flare assoc.	0	5	7	12
2	14	13	8	35
2+	7	2	2	11
3	38	3	7	48
Total	59	23	24	106

TABLE 2.1

ASSOCIATION OF THE PCA EVENTS WITH FLARE IMPORTANCE

2.1.2 Basic PCA Events and Associated Solar Phenomena

Most of the period of the basic contract was devoted to a detailed analysis of the 59 basic PCA events.

The possible effect of sunspot and plage morphology on the flare and radio emission productivity during disk passage, was investigated in an attempt to find necessary and/or sufficient conditions for the cause or possible source of PCA flares.

While it was found that a large (area $\geq$ 500 millionths) sunspot group is an "almost necessary" condition for a PCA flare, the probability that a major flare from a large sunspot group will be followed by a PCA event is very small. We found that 53 of the basic PCA flares occurred in 34 different sunspot groups with areas greater than 500 millionths of the solar hemisphere on flare day. In fact, 34 of the PCA flares occurred in 20 different sunspot groups that during disk passage had a maximum area greater than 1000 millionths.

However, the probability that a large sunspot group would be the source of a flare followed by a PCA event becomes almost insignificant if we consider the total number of days when there was at least one large sunspot group on the visible hemisphere of the sun. For example, there were 304 days during 1959 when there was at least one sunspot group with an area greater than 500 millionths on the visible solar hemisphere (reference 18). The number of days with one or more large sunspot groups on the visible hemisphere of the sun is given in Table 2.2.

No. of Days	NUMBER OF LARGE SUNSPOT GROUPS						
	None	One	Two	Three	Four	Five	Six
	61	127	104	47	18	6	2
Total Large Spots	0	127	208	141	72	30	12

TABLE 2.2

NUMBER OF DAYS DURING 1959 WITH ONE OR MORE LARGE SUNSPOT GROUPS ON THE VISIBLE FACE OF THE SUN

This gives a total of 586 large sunspot groups on the visible hemisphere of the sun during 1959.

During this period 32 flares were reported with importance ≥ 3 and 6 were followed by basic PCA events. Ths six PCA flares occurred in sunspot groups with areas greater than 1000 millionths on flare day.

Similarly, we find that there were 148 days during 1959 with large sunspot groups (areas ≥ 500 millionths) that were also magnetically complex (magnetic class γ or $\beta\gamma$). Only five of these large magnetically complex sunspot groups produced flares that were followed by a basic PCA event.

The area and brightness of the plage region did not show any significant relation to the production of PCA flares; however, flare productivity and age in rotations of the plage region did show some promise.

2.2 SOLAR INDUCED PHENOMENA

Changes in the Earth's Magnetic Field

Solar induced changes in the earth's magnetic fields as indicated by the three-hour planetary index K_p and the derived daily index, A_p, during the four or five days preceding the PCA flare did not show any correlation with the PCA intensity or time delay.

Short Wave Radio Fadeout

Severe short wave radio fades (importance >2) accompanied all but two of the basic PCA events and all but one of the 38 PCA flares of importance ≥ 3. On the other hand, Dodson and Hedeman (reference 4) found that 84% of all flares with importance ≥ 3 reported from July 1957 through 1961 were accompanied by severe SWF, while we have found that only 37% of these flares were followed by a basic PCA event.

Again, we can say that a severe SWF at the time of the flare is an "almost necessary" condition for the flare to be followed by PCA, while the probability that a flare with a severe SWF will be followed by a PCA event is very small.

2.3 SOLAR RADIO BURSTS OF SPECTRAL TYPE II AND TYPE IV

Many investigators have established correlations between the occurrences of solar radio bursts of spectral types with major flares, and with flares followed by polar cap absorption events. In reference 10 we found that the flares responsible for 52 of the 59 basic PCA events were accompanied by solar radio burst of spectral Type IV, based on spectral observations by CSIRO, and the Harvard Radio Astronomy Station, and probable Type IV emissions based on selected single frequency outbursts.

We have here summarized the data showing the distribution of the spectral bursts among the events studied.

Observations of solar radio bursts of Spectral Type II and Type IV have been reported by CSIRO, Sydney, Australia, over the frequency range of 240 to 40 Mc/s with a normal observing period from approximately 2300 UT to 0600 UT October through March and 2300 UT to 0800 UT April through September for the entire 19th solar cycle, and by the Harverd Radio

Astronomy Station, Fort Davis, Texas, since January 1957 over the frequency range 580 to 25 Mc/s and 3900 to 2100 Mc/s since February 1960 with a normal observing period approximately 1230 to 2545 UT during the summer and 1345 to 2400 UT during the winter.

As indicated in our summary, 80% of the PCA flares were accompanied by a solar radio burst of spectral Type IV, thus classifying the Type IV as an "almost necessary" condition. However, as with the other "almost necessary" conditions, only about 2% of the Type IV bursts that were reported during the approximately 18 hours of observing time were associated with flares that were followed by basic PCA events. The distribution of spectral Type II and Type IV among the events studied under the contract is shown in Table 2.3.

	No. Events During Obs. Time	Type II Only	Type IV Only	Type II & IV	Total Type II	Total Type IV
With Basic PCA	41	4	14	20	24	34
Flares Imp. $\geq$ 3 Flux < 500	38	8	2	7	15	9
Flux $\geq$ 500 All Flares	109	24	7	24	48	31
Total Rep.		219	62	86	305	148

TABLE 2.3

DISTRIBUTION OF SOLAR RADIO BURSTS
OF SPECTRAL TYPE II AND TYPE IV AMONG THE EVENTS STUDIED

2.4 PCA FLARES, NON PCA FLARES, AND RF EMISSIONS

In the search for necessary and/or sufficient conditions that might distinguish PCA flares from non PCA flares we have investigated the characteristics of the active regions associated with major flares and/or major RF bursts at centimeter wavelengths at the time of the flare. We have also studied known characteristics and time relations of the different phenomena. These have included:

(a) The flare central meridian distance.

(b) Flare - PCA delay time as a function of central meridian distance, and PCA intensity.

(c) Heliographic longitude distribution of the PCA flare sunspot groups.

(d) PCA intensity and flare importance.

(e) Association of spectral emissions of Type II and Type IV with PCA and non PCA flares.

(f) RF emissions at single frequencies in the range from 1420 Mc/s to 3750 Mc/s.

(g) The occurrences of loop prominence systems on the disk associated with the PCA flares.

2.4.1 Flares with Importance ≥ 3

The 142 flares with importance ≥ 3, listed in the Solar Activity Catalogue, and the McMath-Hulbert working lists of solar flares were studied (refs. 42, 43). Sufficiently reliable data were found to evaluate 94 of these flares and the associated RF flux at centimeter wavelengths. Thirty-four of the flares were followed within a reasonable time by a basic PCA event and eight by a small or questionable PCA.

The time of the RF peak flux followed the time of the H α flare maximum for 84% of the flares with importance $\geq$ 3 with a peak flux $\geq$ 500 flux units that were followed by a basic PCA event.

In the case of flares with importance $\geq$ 3 not followed by a known PCA event the time of the RF peak flux preceded the time of the Hα flare maximum for all of the flares with RF peak flux $\geq$ 500 flux units, and 92% with RF peak flux < 500 flux units.

The results of the investigation of the difference between the time of the RF peak intensity and the time of the Hα flare maximum for all flares of importance $\geq$ 3 are shown on Figure 1. Since the energy released at the time of a flare is directly proportional to the time integral of the RF flux, we have shown the time duration of the RF emissions together with the range of peak flux and the time delay between the time of the RF peak intensity and the time of flare maximum on Figure 2.

Figure 2a shows that most of the RF emissions that were not associated with PCA flares (80%) had a peak intensity < 500 flux units.

On the other hand Figure 2b shows 90% of the RF emissions associated with importance $\geq$ 3 flares that were followed by PCA events had peak intensities $\geq$ 500 flux units.

The central meridian distance of the 142 importance $\geq$ 3 flares on the solar disk is shown on Figure 3. There does not appear to be a preferred central meridian distance.

The number of successes, failures, and questionable events for each frequency is shown in Table 2.4.

	Basic Events			Small Events		Very Small Events		
	s	Q	f	s	f	S	Q	F
1500	2	0	1	0	1	0	0	0
2000	0	0	0	0	0	0	0	0
2800	12	0	2	0	2	0	1	2
2980	1	0	0	0	0	0	0	1
3000	0	1	1	0	0	1	0	0
3750	6	2	6	0	0	0	0	0
Total	21	3	10	0	3	1	1	3

s = Success (PCA event) $\Delta t > 0$
f = Failure (PCA event) $\Delta t < 0$
S - Success (no PCA) $\Delta t < 0$
F = False Alarm (no PCA) $\Delta t > 0$
Q = $-0.5 \lesssim t \lesssim +0.5$, the choice for success, failure or false alarm is questionable since the time of flare maximum is given to the nearest minute while in most cases the time of RF peak intensity is given to 0.1 minute.

where Δt = time of RF peak intensity - time Hα flare maximum

TABLE 2.4

SUMMARY OF PCA EVENTS FLARES IMPORTANCE

$\gtrsim$ 3 FREQUENCY DISTRIBUTION

2.4.2 Events with RF Peak Intensity $\gtrsim$500 Flux Units Associated with Flares of Importance $\gtrsim$3

A total of 180 events were found in the published literature with peak flux $\gtrsim$ 500 flux units at centimeter wavelengths associated with flares with importance < 3.

The time of the Hα flare maximum (if a flare was reported) and the time of the RF peak intensity was reported for 113 of these events. It was found that if the event was not followed by a known PCA, the time of the RF peak flux preceded the time of the Hα flare maximum for 78% of the events. (This includes 15 events when no flare was reported although a flare patrol was indicated.)

Flares with importance < 3 followed by a PCA event failed to show the strong time relation found for the importance ≥ 3 flares. Only three of the nine minor flares with RF peak flux ≥ 500 flux units and four of the eight minor flares with flux < 500 flux units satisfied the condition that the time of RF peak should follow the time of the Hα flare maximum.

	WITH POLAR CAP ABSORPTION							WITHOUT PCA		
	Basic Events		Small Events			Very Small				
	s	f	s	Q	f	s	f	S	Q	F
1420	1	0	1	1	0	0	0	1	0	0
1500	0	0	0	0	0	0	0	3	0	2
2000	0	0	0	0	0	0	0	1	0	2
2800	1	3	0	0	0	0	0	21	2	8
2980	0	0	0	0	0	0	0	5	1	0
3000	0	1	1	0	1	0	0	17	3	7
3750	1	2	0	1	0	2	0	17	5	2
Total	3	6	2	2	1	2	0	65	11	21

TABLE 2.5

SUMMARY OF EVENTS, FLUX $\geq$ 500 FLARE IMPORTANCE $\leq$ 2+, FREQUENCY DISTRIBUTION

2.5 SUCCESSES, FAILURES, AND FALSE ALARMS

A summary of the successes, failures, and false alarms for the 224 events is given in Table 4.

FLARE IMP	RF PEAK FLUX UNITS	WITH POLARCAP ABSORPTION						WITHOUT PCA			TOTAL
		IMPORTANT			SMALL OR QUESTIONABLE			SUCCESS		FALSE ALARMS	
		SUCCESS		FAILURE	SUCCESS		FAILURE				
		NUMBER	%	NUMBER	NUMBER	%	NUMBER	NUMBER	%		
≥ 3	≥ 500	22	76	7	1	50	1	16	100	0	47
	<500	2	40	3	1	20	5	33	92	3	47
$\leq 2+$	≥ 500	3	33	6	6	86	1	76	78	21	113
	<500	4	50	4	3	33	6				17
TOTAL		31	61	20	11	48	13	125	83	24	224

TABLE 4. SUMMARY OF 224 EVENTS STUDIED SHOWING SUCCESSES, FAILURES AND FALSE ALARMS

The time delay between the time of the RF peak flux and the time of the Hα flare maximum for the 149 events that were not associated with a known PCA event is shown on Figure 4.

2.6 OTHER PHENOMENA OR CONDITIONS

2.6.1 Loop Prominence Systems

During the study reported in reference 9, only 7 of the 32 basic events during the years 1954 through 1958 had an associated loop prominence system reported in the literature. However, a loop prominence system was reported for 20 of the 27 basic PCA events during 1959 through 1963.

This phenomena is essentially "unobservable" on spectroheliograms recorded in the center of the Hα (Dodson, reference 5) but are observable on spectroheliograms with systematic shifts from 3Å or more on the violet, to 3Å or more on the red side of the center of the Hα and calcium K lines. Bruzek (reference 2) discusses some of the problems, and methods required to identify loop prominence systems on the disk.

Since special observational techniques and experienced interpreters are required to record and identify loop prominence systems on the disk, its use as an input for a proton warning system may be questionable. However, further study is desirable.

2.6.2 <u>Flare Morphology and RF Time Histories</u>

It is a well known fact that the times reported for start, end, and maximum intensity of flares may be in error by from one to several minutes. In particular the time of flare maximum may be in error due to a number of factors such as:

(a) The flare may have been in progress for some time when the observation was started and the time of true maximum may have been missed.

(b) A temporary obscuration of the sun by clouds of more than a minute or so may result in a questionable Hα maximum report or no report at all.

(c) The time based on photographic records and visual observations depends on the judgment of the observer.

(d) Many flares exhibit alternating diminution and brightening. The time of flare maximum is reported by some observatories as the time of maximum brightness while others use maximum area.

(e) An examination of a number of flares with different reported times for the flare maximum by different observatories, particularly flares of importance $\geq$ 2+, indicate that some Hα flares have multiple-maxima similar to the multi-peak intensities reported for RF emissions and shown as RF-intensity time histories.

Based on the difficulties, and in many cases the uncertainty of the association of a multi-peak RF emission with the reported time of H flare maximum, a thorough investigation of all flares associated with known multi-peak RF emissions must be carried out to improve the reliability of a solar proton warning based on the time from the Hα flare maximum to the time of RF-peak intensity.

2.6.3 Hα Flare Position in the Sunspot Group

Dodson and Hedeman have found at least fifteen events where flares covered the sunspot umbra, one event where the coverage was possible, and one, partly covered. All of these flares were followed by PCA events.

Malville and Smith (reference 14) have listed 31 flares of importance > 2 that covered some part of the umbra of the associated sunspot. While the Dodson and Hedeman analysis shows a good correlation between flares covering the sunspot umbra and PCA events, the Malville and Smith list of flares is less convincing since only eight of them were followed by a known PCA event. However, we have found that of the 23 flares that were not followed by a PCA event,no centimeter RF emission was reported for three; the RF peak was less than 250 flux units for 17, and the time of the RF peak flux preceded the time of the Hα flare maximum for the three flares with RF peak $\geq$ 500 flux units. Malville and Smith also list 13 flares with no umbral coverage, none of these were followed by a known PCA.

While the statistical sample is small and the position of the flare with respect to the sunspot umbra may not differentiate PCA from non-PCA flares, it does show considerable promise when combined with the RF-Hα flare time relation.

3.0 ANALYSIS OF FAILURES, FALSE ALARMS AND DOUBTFUL CASES

Several problems were encountered during our search for a solar proton warning criteria. These could have a serious effect on the statistical results that were derived during the initial analysis of the time relation between the time of the RF peak flux and the time of the flare maximum intensity.

For example, an examination of Figure 4 where we have shown a histogram of the 149 events that were not followed by a known PCA events. According to our criteria we classified three of the events associated with flares of importance ≥ 3, and 21 associated with flares of importance < 3 with a peak RF emission $\geq$ 500 flux units as false alarms.

It is a well known fact that the reported times of the flare maximum intensity are in general based on the observer's personal judgment or impression and the frequency of the observations, or in the case of flare patrol films, the time between frames may vary from a few seconds to, in some cases, several minutes.

This could mean that in the case of events not followed by a known PCA event our criteria that the event was a success and the time of the RF peak flux preceded the time of the flare maximum, or the two times did not differ by more than 0.5 minutes, the "true" time of flare maximum could in some cases shift the statistical "success" to a "false alarm." Referring to Figure 4 we have 65 events with $-2 \leq \Delta t \leq 2$. If these are considered to be questionable for the analysis and reduce our sample from the 149 to 84, the probability of successfully "predicting" that an event will not be followed by a PCA event is reduced from 83% to 80%.

We were also faced with the problem of choosing the time of flare maximum in the cases where more than one observatory observed the flare and reported different times for the maximum intensity. If the range of reported times did not differ by more than a few minutes, we used the average value as reported in the solar activity catalogue and the McMath working lists of flares. This problem will be discussed in considerable detail in the subsequent sections of this report.

The situation is quite similar when we examine the published data for the RF emissions. In general, if the RF event was observed at more than one frequency, the reported times of peak flux agreed to within a few tenths of a minute. However, it was frequently indicated that there were several peaks, or the emission was reported as complex, but values and times of the other peaks were not reported; or if reported, the rate of change of the flux was not given. Consequently, the association of the times of RF peak and the flare maximum was considered to be questionable and the event was not used in our statistical study. Several of these questionable events are listed in Table 1, together with a few cases where more than one flare at widely separated positions on the visible hemisphere occurred within a few minutes of each other.

In order to evaluate as completely as possible the observational accuracies or techniques that will be required to make real time decisions with a high probability of success, we have analyzed the correlation of the RF time histories with reported flare and associated data for a number of the failures, false alarms, and questionable events.

3.1 EVENTS WHERE THE RF EMISSION-FLARE ASSOCIATION IS QUESTIONABLE

This phase of the work was devoted to an analysis of:

Several events where the flare-RF association or the times of flare maximum or RF peak were questionable, or where several different times of flare maximum were reported and the RF time histories showed multiple peaks.

Selected cases where two or more outstanding events occurred in the same active solar region during disk passage.

These events were chosen (Table 1) for detailed study since they are representative of problems that were encountered many times during the statistical analysis.

A detailed analysis of these events, and in some cases related events, is given in notes N-1 through N-15 on pages 23 through 58.

N-1 MAJOR RF EVENT ON 27 JUNE 1957

The flare associated with the large 10 cm burst at 2408 UT and the long delay time from the reported start of the flare to the reported start of the RF burst (greater than 38 minutes) when combined with the reported time of the RF peak approximately 83 minutes after the end of the flare makes a flare-RF emission association questionable.

Two flares occurred within a few minutes of each other in two different regions on the sun at W62 and E32, respectively. Both flares occurred near sunrise at Tokyo (3000 Mc/s) and Nagoya (3750 Mc/s) and it is possible that the start and an earlier peak intensity may have been missed.

The flare at 2322 UT occurred in the large magnetically complex sunspot group which crossed the central meridian on June 22.5. The spot had an area of 524 millionths, a βf magnetic classification, and a Zurich classification of G on flare day. The sunspot group was the source of 30 minor flares during disk passage. Two of the flares prior to the flare on June 27 were followed by PCA events.

The weak PCA on June 19 was associated with a flare of importance 2 and a very great radio burst at 2800 Mc/s which was superposed on a very long enduring rise and fall in flux which started about 84 minutes before the start of the flare.

The second PCA, with a maximum absorption of 5 db, occurred on June 22, 2 hours 24 minutes after a flare with importance 2 at 0236 UT. This flare was accompanied by a major burst at 3000 Mc/s.

TABLE N1

POSSIBLE FLARES ASSOCIATED WITH THE MAJOR RF BURST
AT 3000 Mc/s ON 27 JUNE 1957 WITH THE RF ACTIVITY FROM THE TWO REGIONS

	FLARE					MAJOR BURSTS on WAVELENGTH								SOLAR REGION DATA			FLARE DAY			
Date	Start	Dur.	Max.	Position	Imp.	f	Start	Peak	Dur. Min.	Max. Flux	At	PCA	Fig.	Plage	Mt. Wilson	Green.	Area	Zur. cl.	Mag. cl.	N
19	1609	40	1613	N20 E45	2	2800	1609	1610	10.0	2325	-2.6	Weak					1177	F	β	32
22	0236	21	0241	N23 E12	2	3000	0231	0238.4	21.3	570	-2.6	5.0 db.		4024	12417	18073	1035	F	βγ	35
27*	2322	56	2335	N20 W62	1+	3000	2408	2541.5	25.0	504	N_1	No					524	G	(βf)	--
27*	2330	57	2335	N14 E32	1+	3000	2408	2541.5	25.0	504	N_1	No					606	G	(βp)	--
7/3	0712	274	0740	N14 W40	3+	3750	0727	0742	45.0	337	+2	9.2 db.	C-1	4039	12434	18084	500	H	γ	18
	0830	195	0840	N10 W42	3+	3750	0832	0843.1	25.0	763	+3.1									

* Flares probably responsible for the RF burst at 3000 Mc/s.

The events on June 19 and June 22, have been classified as failures (Table 3a), since the time of the RF peak intensity preceded the time of the Hα flare maximum.

The other flare at 2330 UT, also occurred in the large sunspot group which was the source of three flares with importance 2+ on June 28 at 0658, June 30 at 0124, and July 2 at 0705. None of these flares was accompanied by major RF bursts or other outstanding events. The one on July 3 with importance 3+ had two distinct phases, and was followed by a large PCA event. This flare will be discussed in considerable detail below, since the RF time history (Figure C-1) is typical of a number of events.

N-1a THE MAJOR SOLAR EVENT ON 3 JULY 1957

The solar flare at N14 W40 on 3 July 1957 was reported by 17 observatories with maximum intensity times ranging from 0731 to 0750 and between 0838 and 0847, N10 W42. This flare, like many others, has two distinct phases. Seven of the observatories reported two great flares, the first with start times ranging from 0712 to 0728 and the second starting between 0827 and 0836; four observatories reported only one flare starting between 0714 and 0722 lasting until after 1109; six others only observed part of the second phase of the flare.

The double phase showed up in the SWF with onsets at 0729 lasting 61 minutes with importance 2+, and at 0830 lasting 44 minutes with importance 3.

In the case of the RF emissions at centimeter wavelength, the two phases were reported by Nagoya as seen on Figure C-1 where the RF time history at 3750 Mc/s is plotted. This flare was followed by an important PCA event with a maximum absorption of 9.2 db. The PCA was reported by at least 15 observers based on f_{min}, Riometer, and the forward scatter techniques.

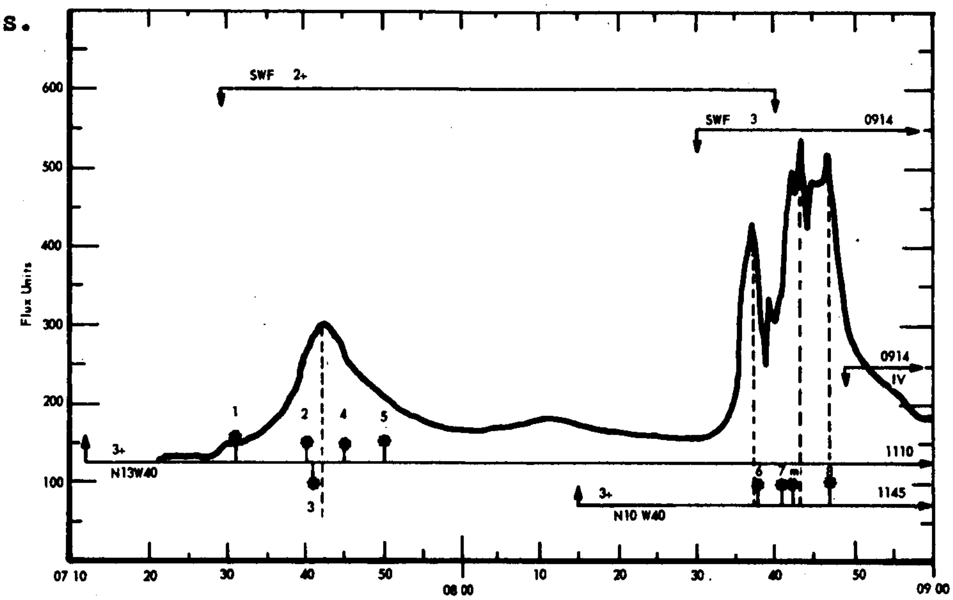

FIGURE C-1 RF TIME HISTORY 3750 Mc/s 3 JULY 1957 FROM 0710 TO 0900 UT WITH ASSOCIATED PHENOMENA FLARE IMP. 3 +, WITH DOUBLE ASPECT FOLLOWED BY PCA STARTING BETWEEN 0815 AND 1100 UT

Reported times of Flare Maxima: 1 – Crimee ; 2 – Zurich; 3 – Ondregov; 4 – Capri F; 5 – Meudon, Flare Imp. 3+ N13W40; 6 – Zurich, 7 – Crimee, 8 – Tachkent, Flare, Imp. 3+, N10W40. m, Mean value

The f_{min} increase, starting by 0800 UT in the northern hemisphere, and by 0900 in the southern hemisphere, was probably caused by low energy particles from the first phase of the flare with a delay time of approximately one hour.

The main phase observed by Riometer and the forward scatter technique started by 1000 UT must be related to the second phase of the flare which started at about 0815 with maximum intensities reported at 0838, 0841, and 0847 (Figure C-1). The major phase of the RF burst started at 0832 with intensity peaks at 0837.5, 0843.1 and 0847, giving an RF peak-flare maximum delay time of 1.1 minutes if we use 0842 UT as the time of the flare maximum, the mean value of the maxima reported by Tachkent, Crimee, and Zurich.

It is important to note that there is a one-to-one correspondence between the time of the three RF peaks and the three different reported flare maximum times.

N-2 MAJOR RF EVENT ON 21 DECEMBER 1957

It is probable that this event does not meet the requirements for this study. The peak RF flux of 556 flux units was reported by Tokyo at 3000 Mc/s, while Nagoya reported only 41 and 180 flux units at 2000 and 3750 Mc/s respectively. The starting and peak flux times were within a minute of each other at all three frequencies and the durations were only 3.0, 5.0, and 2.0 minutes, respectively.

The only flares reported within a reasonable time of the RF emissions were from three different regions on the sun at S15 E60, N25 E27, and N17 W27. All three of these flares occurred in sunspot groups that during disk passage attained a maximum area >500 millionths. Two had areas greater than 500 millionths on flare day.

As with our previous note (N-1) prior and subsequent activity of the regions associated with the flares leaves a choice unanswered. The region associated with the flare at 2344 was followed on the 24th and 28th by flares with large RF bursts, and a small PCA event on the 28th.

Similarly, the flare at 2349 was preceded and followed by flares with large RF bursts and a small PCA on the 17th.

Data for the three flares and region activity is given in Table N-2. An examination of these data strongly indicates that the major RF burst at 3000 Mc/s on the 21st at 2345 UT should be associated with the flare from sunspot group 12855, especially since this region was the source of two major bursts at centimeter wavelength prior to the 21st.

TABLE N2

POSSIBLE FLARES ASSOCIATED WITH THE MAJOR RF BURST
AT 3000 Mc/s ON 21 DECEMBER WITH RF ACTIVITY FROM THE THREE REGIONS

	FLARE					MAJOR BURSTS on WAVELENGTHS								SOLAR REGION DATA			FLARE DAY			
Date	Start	Dur.	Max.	Position	Imp.	f	Start	Peak	Dur. Min.	Max. Flux	At	PCA	Fig.	Plage	Mt. Wilson	Green.	Area	Zur. cl.	Mag. cl.	N
21	2334	26	2345	S15 E60	1-	3000	2345	2346.3	5.0	556	N2	No		4323	12882	18413	484	C	αp	15
21*	2344	18	2347	N25 E27	1-	3000	2345	2346.3	5.0	556	N2	No					1223	E	βp	23
24	0221	13	0227	N21 E03	1	3000	0222	0222.5	1.0	570	-4.5			4321	12874	18407	1385	F	βγ	19
28	2229	62	2230	N25 W50	2	1420	2230	2230	7.0	916	0	Weak					1389	E	βp	15
13	<0227	>79	0234	N15 E90	1	3000	0143	0232	70.0	1130	-2	No					East Limb			
17	0734	150	0737	N20 E41	2+	1420	0736	0741	15.0	626	+4	Weak					736	E	γ	18
21*	2349	36	2418	N17 W27	1-	3000	2345	2346.3	5.0	556	N2	No		4314	12855	18398	1034	E	βγ	18
22	0437	28	0442	N18 W27	1-	3000	0437	0439	7.0	505	N3									
22	1022	39	1034	N19 W28	1+	2980	1028	1031	6.5	583	-3	No					990	E	βγ	16
22	2240	52	2244	N20 W34	1	1420	2236	2240	6.0	952	-4									

* Flares probably responsible for the RF burst at 3000 Mc/s on the 21st.

While the three flares in this case and the four flares in Note 3, as well as the two flares in Note 1, were all small and no PCA event would be anticipated, we have considered them in considerable detail since there will be real time occasions when more than one major flare will occur within a few minutes of each other in different solar regions with a major RF burst. In addition to checking the other solar phenomena associated with the regions, the previous activity in the regions may, under some conditions, permit an early evaluation of the importance of the region as part of the warning criteria.

N-3 THE MAJOR RF EVENT ON 22 DECEMBER 1957

This event is quite similar to the event on the 21st discussed in Note 2. In this case we have four subflares occurring simultaneously at 0438 UT in four different regions on the sun at N17.5, S25.5, S15.3, and S17. Three of these flares occurred in sunspot group with an area > 500 millionths on flare day while one occurred in a very small sunspot group. However, the flare at N18 W26 occurred in a region that produced four flares prior to 0437 UT on the 22nd, and four flares after that time all with radio emissions greater than 500 flux units. The region was also the source of a flare of importance 2+ on the 17th that was followed by a weak PCA event (Table N3).

TABLE N3

POSSIBLE FLARES ASSOCIATED WITH THE RF BURST
AT 3000 Mc/s ON 22 DECEMBER WITH RF ACTIVITY FROM THE FOUR REGIONS

	FLARE					MAJOR BURST on WAVELENGTH							SOLAR REGION			FLARE DAY DATA			
Date	Start	Dur.	Max.	Position	Imp.	f	Start	Peak	Dur. Min.	Max. Flux	Δt	PCA	Plage	Mt. Wilson	Green.	Area	Zur. cl.	Mag. cl.	H
12/13	<0227	>79	0234	N15 E90	1	3000	0153	0232	70.0	1130	-2.0	No				East Limb			
17	0734	150	0737	N20 E41	2+	1420	0736	0741	15.0	626	+4.0	Weak				736	E	γ	18
20	0543	23	0545	N16 E00	1	3000	0544.3	0545.5	4.0	636	+0.5					1219	E	βγ	21
21	2349	36	2418	N17 W27	1-	3000	2345	2346.3	5.0	556	+6.0					1034	E	βγ	18
*	0437	28	0442	N18 W26	1-	3000	0437	0439	7.0	505	-3.0		4314	12855	18398				
22	1022	39	1034	N19 W28	1+	2980	1028	1031	6.5	582	-3.0					990	E	βδ	16
	2240	52	2244	N20 W34	1	1420	2236	2240	>6.0	>952	-4.0								
23	0025	215	0029	N18 W38	1	3000	0024.5	0025.5	4.0	582	-3.5	[illegible]							
	1436	81	1440	N18 W45	1-	2980	1441	--	10.0	602						959	E	βγ	18
22	0237	24	0239	S27 E30	1	3000	0232.7	0235.3	15.0	542	-4.7								
*	0438	5	0439	S21 E16	1-	3000	0437	0439	7.0	505	0		4319	12869	18407	933	J	β	21
22*	0438	7	0440	S20 W35	1-	3000	0437	0439	7.0	505	-1		4313	12851	18395	781	G	βρ	27
22*	0439	25	0443	S26 E41	1-	3000	0437	0439	77.0	505	-4		4322	12879	18412	95	C	βρ	12

As in the previous event, we have tabulated the important activity associated with the four regions, together with characteristics of the regions for the days of the associated activity. In this case, unlike the previous one, we can associate the flare at N18 W26 with the RF burst with reasonable confidence.

N-4 THE RF EVENT ON 23 DECEMBER 1957

The flare with importance 1 which started before 0025 UT at N18 W38 is probably associated with the RF burst which started at 0024.5 while the RF burst at 0038 may be associated with the importance 2 flare starting at 0038. With this possibility, this event may be broken down as follows:

FLARE										
Start	Dur.	Max.	Position	Imp.	f	Start	Max.	Dur.	Peak Flux	Δ t
0025	15	0029	N18 W38	1	3000	0024.5	0025.5	4	582	-3.5
					3750	0024.5	0025.5	2	123	-3.5
0038	14	0039	N25 E40	2	2000	0038	0038.5	1	14	-0.5
					3000	0038	0038.5	2	564	-0.5
					3750	0038	0038.4	2	90	-0.6

The flare at 0025 occurred in plage region 4314, the very active region which has been analyzed as part of N-2 and N-3, was the source of a weak PCA event on the 17th, while the flare at 0038 occurred in plage 4321 which was the source of a weak PCA event on the 28th (Table N-2).

We have discussed the four events in some detail since they illustrate the problem that will arise when more than one minor flare is observed at approximately the same time from different regions on the sun.

We have two examples of large magnetically complex sunspot groups, in large, bright, and flare production plage regions that did not produce a single major flare during disk passage, although the spots could be classified as radio noisy (at centimeter wavelengths) during disk passage. None of the events were outstanding and the reported durations of the RF bursts were less than ten minutes in all but two of the thirteen events.

In the case of plage regions 4314 we have not included two events, one with a flare of importance 2+ starting at 1245 UT on the 14th where neither the times of flare maximum or RF peak intensity were reported. This event occurred at sunrise at 2800 Mc/s and a peak of 1000 flux units was reported. The other event was reported by Nederhorst at 2980 Mc/s starting at 0917 UT on the 19th lasting for 21 minutes with a peak of 632 flux units. Meudon reported an importance 1+ flare starting at 0915 lasting one hour, again neither the time of flare maximum or RF peak intensity was reported.

N-5 MAJOR RF EVENT ON 5 JUNE 1958

During the period from 1615 through 1728 five observatories reported a flare in the SE quadrant as shown below:

Sac Peak	1615	1815	1635	S18	E70	2
USNRL	1619	1658	1628	S18	E70	2+
Schaunsland	1631	1820	--	S17	E66	1+
USNL	1656	1837	1711	S21	E70	2+
Ondrejov	1728	1745	--	S20	E63	2+
Capri F	1626	1700	1700	N18	W71	2

Capri F reported another flare of importance 2 in the NW quadrant. When these data are compared with the RF flux data reported by HHI and Ott, it is evident that the flare had two distinct phases, one starting at 1615 with a maximum between 1628 and 1635. The other starting at 1656 with maximum at 1711. A plot of the RF emission at 2800 is shown below, where it is seen that bursts starting at 1614, 1655, and 1718 with max event 1623, 1710, and 1723.5 were superposed on a long duration gradual rise and fall. Thus, the data given for this event should be considered as follows:

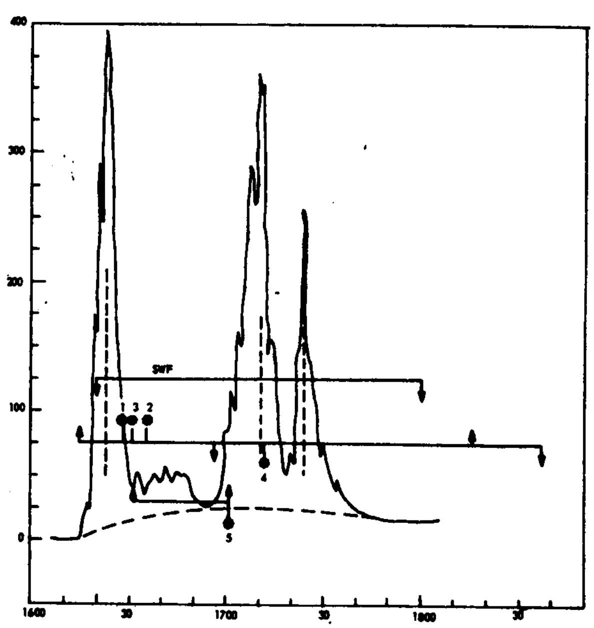

FIGURE A-1 RF TIME HISTORY 5 JUNE 1958, 2800 Mc/s, FROM 1600 TO 1830 UT SHOWING RELATED PHENOMENA AND TIMES OF FLARE MAXIMA

Reported times of Flare Maxima; 1 – USN Obs.; 2 – Sac Peak; 3 – Mean Value, Flare, Imp. 2+ S18 E70; 4 – USN Obs., Flare, Imp. 2+ S21 E70; 5 – Capri -F, Flare, Imp. 2 N18 W71

Flare Start	Flare Max.	Freq.	Start	Dur. Min.	Max.	Peak Flux	Δt
1615	1628	1500	1618		1623.5	62	-4.5
		2000	1615		1623.0	172	-5.0
		2800	1614	41	1623	395	-5.0
		3000	1617		1622.3	586	-6.7
1656	1711	1500			1710	150	
		2000			1710	300	-1.0
		2800	1655	23	1710	360	
		3000	Not recorded				
1728	Not reported	1500			1723.4	550	
		2000			1723	222	
		2800	1718	22	1723.5	255	

The times and peak values of maximum RF flux given here (for 1500, 2000, and 3000 Mc/s) were taken from the Heinrich Hertz Institute catalog of notable solar events during the IGY. The data for 2800 Mc/s was obtained from the original records.

This event, as well as several of those that we will discuss later, emphasizes the necessity for a reliable flare time history that will record the fluctuations in the brightening of the Hα flare with a reliability comparable to the RF time histories.

N-6 RF EVENT ON 26 June 1958

In this case, we have questioned the flare-RF association, or the values for Δt. The RF emission indicates two distinct phases--the first of short duration with a peak flux very early in the development of the flare. The second phase which starts at 0255 has peaks at 0300, 0307.8, and 0316 for the 3750 Mc/s emission, and 0302.5, 0310 and 0316.2 at 2000 Mc/s.

This is also one of the many cases we found where the peak flux reported at 3000 Mc/s by Tokyo is very much greater than that reported at the other centimeter wavelengths. Thus, if we had restricted our choices to the Nagoya or Ottawa data, this event would not have been included. The event was not included in our statistical study since the time of the RF peak and flare maximum is ambiguous.

N-7 THE MAJOR RF EVENT 20 AUGUST 1958

This major RF burst at centimeter wavelength and the importance 2+ flare occurred near the central meridian starting at 0042 UT, has generally been considered to be the source of the PCA event on the 21st with an absorption of 3.0 db. The PCA started sometime between 1400 and 1730 UT and if this association is correct, we have a time delay of more than 37 hours which makes this event almost unique. The only other PCA with a possible long delay was a very small event with an absorption of only 0.5 db. on 12 September 1957 starting sometime between 0200 and 2315 UT, more than 23 hours after an importance 3 flare at 0236 UT on the 11th at the central meridian.

The flare at 0042 on 20 August occurred in a large, bright plage in its third rotation and a sunspot group, which on flare day had an area of 1381 millionths, a Zurich classification E, and a $\beta\gamma$ magnetic classification. Although the plage was the source of 60 flares during disk passage, there had been no outstanding solar events prior to this flare. However, the region was the source of flares of importance 3 on the 22nd and the 26th with great bursts at centimeter wavelengths. The flare on the 22nd was followed, within approximately ninety minutes by a PCA event with an absorption of 10.6 db, while the flare on the 26th with a very great burst at centimeter wavelengths was followed within one hour by a very large PCA with an absorption of 16.6 db.

It is possible that one of the seven minor flares that occurred in this region between 0042 and 1617 UT on the 20th may have influenced the PCA event; however, none of these minor flares was associated with other phenomena that might indicate that protons were ejected from the sun. There was no RF activity at centimeter wavelengths and only moderate burst at meter wavelengths.

Similarly, the flare occurred during a magnetically quiet period with no three hour k_p greater than 3+ the day before the flare, or greater than 2 on flare day or the day following.

The PCA was observed by Riometers and in the ionosonde data with no indication of an onset before 1400 UT on the 21st. Consequently, this is an event that must be considered as a failure with no reliable explanation at this time.

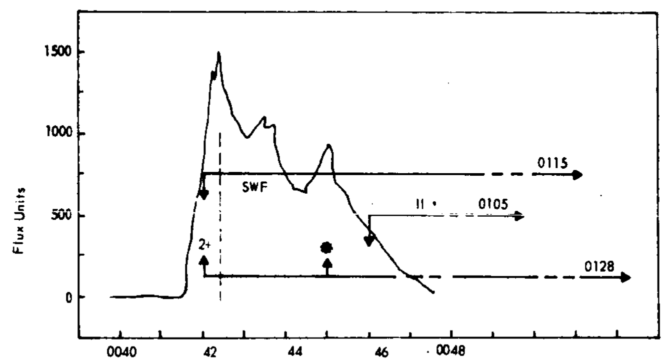

FIGURE A-2 RF TIME HISTORY, AUGUST 20, 1958, 3750 Mc/s, FROM 0040 TO 0052 UT SHOWING RELATED PHENOMENON

The RF time history at 3750 Mc/s (Figure A-2) shows a very rapid rise to a peak of 1450 flux units in less than a minute and had dropped to nearly background flux within five minutes. The time of the RF peak intensity at 0042.4, 0043.3, and 0044 at 3750, 3000, and 2000 Mc/s preceded the reported times of flare maximum by 3.6, 0.6, and 0.0 minutes, respectively, or 1.6 minutes if we use a mean value. Lopez, et.al., calculated an integrated RF energy of 15 x 10^{-18} $J(m^2c/s)^{-1}$ which according to interpretation would predict a particle flux $>10^5$ with energies greater than 30 Mev.

N-8 THE MAJOR RF BURST ON 28 AUGUST 1958

The association of the centimeter RF bursts with the flare at 1025 based on data gives in the IAU bulletin gives a value of Δt of +9 as shown in Table 1. However, three flares in three different regions of the sun (McMath plages 4710, 4712, and 4722) occur within a few minutes of each other. The plages 4710 and 4712 are considered by McMath to be a return of the region 4659 which was the source of an importance 3 flare on July 29, followed by a PCA with an absorption of 3 db. An examination of the graphical representation of the RF emissions at 1500, 2000, and 3000 Mc/s (Figure A-3) from the original HHI records (reference 24) makes the flare - RF emission reasonably certain.

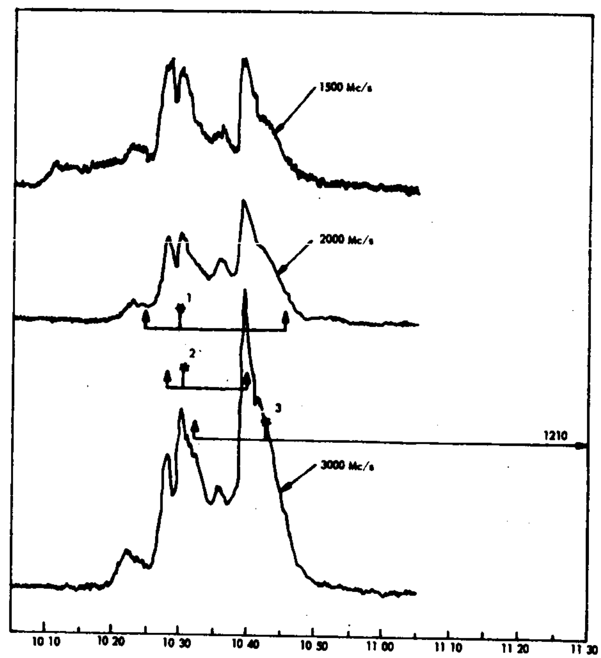

FIGURE A-3 RF TIME HISTORY, AUGUST 28, 1958 AT 1500, 2000, AND 3000 Mc/s NORMALIZED FLUX WITH THREE POSSIBLE FLARES.

1. Flare Imp. 2+, S18 W67, Capetown, and Uccle
2. Flare Imp. 1, S09 E38, Uccle and Wendelstein
3. Flare Imp. 1+, S14 W90, Capetown

Start	Dur.	Max.	Position	Imp.	Plage	f	Start	Max.	Dur.	Peak Flux	Δt
1025	20	1030	S18 W64	2+	4712	1500	1008.5	1028	20.5	207	-2
							1029	1030	9.0	182	
1028	19	1030	S10 E38	1	4722						
						2000	1019.5	1028.3	9.5	--	
								1030.1	9.0	--	
						3000	1019	1028.3	10.0	250	-1.7
							1029	1030	8.0	350	0
1032	98	1043	S14 W90	1+	4710	1500	1038	1039.3	23.0	215	
						2000	1038	1039.3	17.0		
						3000	1037	1039.2	18.0	573	-3.8

The first two peaks (or maybe only the first peak) can be associated with either or both of the flares that start at 1028 or earlier, while the third peak is clearly associated with the importance 1+ flare starting at 1032.

The flares at 1025 or 1028 do not meet our requirement of a peak flux $\geq$500 flux units and should not be included. The flare at 1032 would change the value of Δt from +9.0 (a failure) to -3.8 (a success).

N-9 GREAT RF BURSTS ON 14 SEPTEMBER 1958

The flare starting at 0822 with maximum at 0835 may have had a second maximum at 0900. However, it is not possible to evaluate the reliability of the flare-RF maxima peak time difference since we do not have the HHI original records at 1500, 2000, and 3000 Mc/s. The HHI tabulated data in reference 24 show peaks as follows:

f	Start	Peaks			End
1500	0833	0835.3	0858.2	0904	0959
2000	0832	0834.4	0857.5	0904	1036
3000	0830	0834.7	0858	0904	0939

This event could be classified as a questionable Δt and again emphasizes the requirements for reliable original data.

N-10 MAJOR SOLAR EVENTS DURING MARCH AND APRIL 1960

The flare on March 28 at 2042 occurred in a large complex sunspot group, (maximum area 1650 millionths of the solar hemisphere) which formed on the visible disk (Mt. Wilson No. 14778) on March 26 at approximately E65. This was the fourth flare from the sunspot group. The first three flares also occurred on the 28th at 0555, E45; 1453, E40; and 1634, E41; all of importance 1. The flares events 147, 148, 149, and 150 (Table 1, reference 11) importances 2+, 2, 2, and 2, all occurred in this sunspot group as well as the importance 3 flare on April 1. Four of these flares have been associated with PCA events as shown below.

TABLE N10

THE MAJOR RF EVENTS MARCH 28 THROUGH APRIL 5, 1960

	Flare				Spectral		Single Frequency					PCA			Total*
No.	Date	Start	Position	Imp.	II	IV	f	Start	Max.	Flux	Δ t	Onset	db	Δ T	RF Energy
146	3/28	2042	E37	2	2057	2050	2800	2047.7	2055	750	-1				127
								2102.5	2117	885	+21				
147	3/29	0640	E30	2+		(0656)	2000	0655	0733.4	49000	+23.4	29/0800	2.6	1^h20^m	915
							3750	0655	0733.5	82.50	+23.5				
148	3/30	1455	E13	2	1529	1526	2800	1518	1577	640	-13	30/2000	5.0	5^h05^m	160
								1556	1556	1750	+16				
	4/01	0843	W11	3		(0818)	1500	0816	0928	950	+29	01/1000	3.6	1^h17^m	
							3000	0848	--	1000					
149	4/03	0317	W33	2	No observ.		2000	0306	0310.5	400	-6.5	None reported			15**
							3750	0306	0310.6	1300	-6.4				
150	4/05 <	0215	W62	2	0152	0207	2000	0140	0206.1	1230					
							3000	0152	0202.7	2400	?	04/0400	3.1	1^h45^m	
							3750	0140	0202.3	6000					510

* $J \times 10^{-18} W(m^2 c/s)^{-1}$ ** Estimated   *** Number in Table 1, reference

The event on 28 March shows all of the characteristics generally associated with a solar flare, which after a few hours would be followed by a solar proton event in the vicinity of the earth. The Type IV emission covered the entire frequency range from 3000 to 60 Mc/s, lasting for more than four hours, and was still in progress at sunset at Fort Davis. No PCA event was observed or reported. However, the flare was followed approximately nine hours later by another large solar flare at 0640 on the 29th (Event 147) with very great bursts at centimeter wavelengths, a major SWF and probably Type IV continuum and 1^h20^m later by a PCA which Bailey describes as a "rather curious" event.

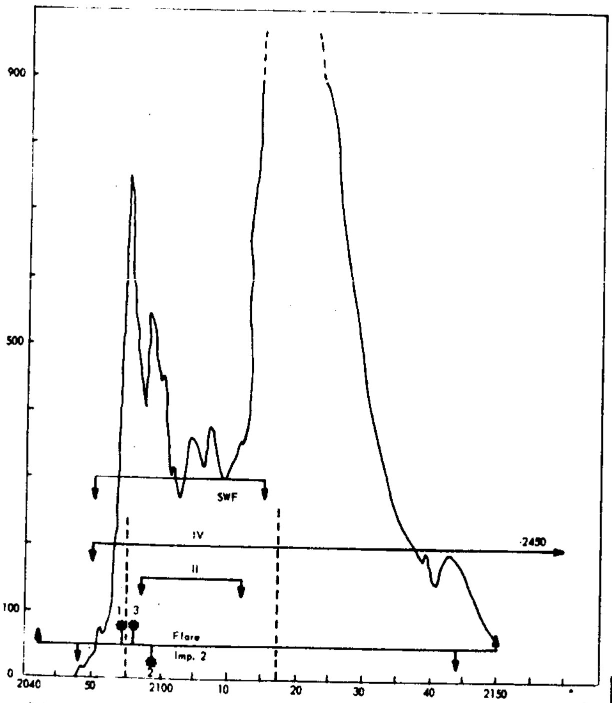

FIGURE A-4 RF TIME HISTORY 28 MARCH 1960, AT 2800 Mc/s, SHOWING RELATED PHENOMENA AND FLARE MAXIMA

Report times of Flare Maxima and Position: 1 – Sac Peak, N11 E39; 2 – Honolulu, N18 E34 3 – Mean Value

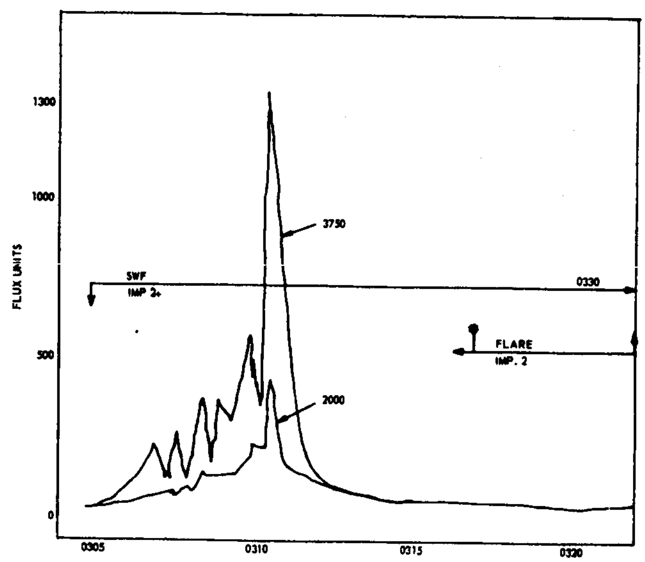

FIGURE D-3 RF TIME HISTORY 2000 AND 3750 Mc/s 3 APRIL 1960 1305 – 1320 UT; SWF AT 0305," FLARE, AT N12 W33.

The RF time histories for the two events are shown on Figures A-4 (2800 Mc/s on the 28th) and Figure C2 (3750 Mc/s on the 29th). Both events show a rapid increase in flux within a few minutes after the start of

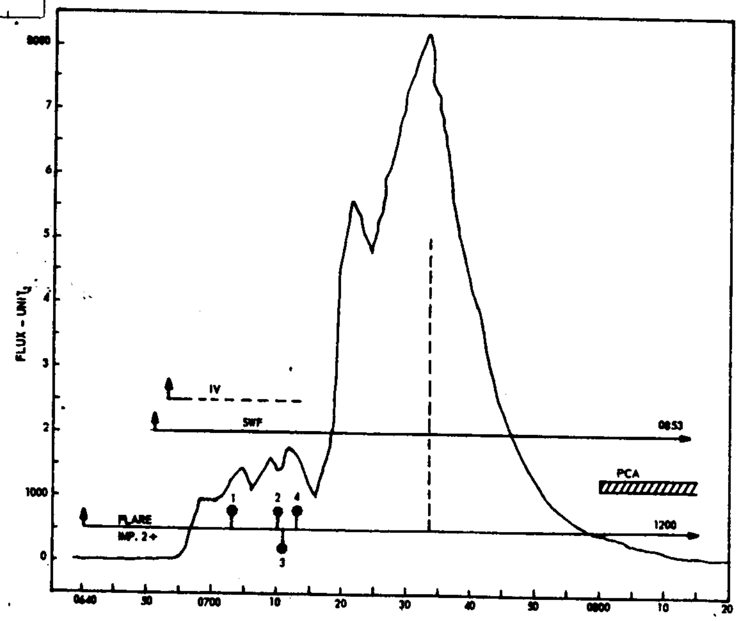

FIGURE C-2 RF TIME HISTORY 3750 Mc/s 29 MARCH 1960, 0640 TO 0820 UT WITH RELATED PHENOMENA AND FLARE MAXIMA

Reported times of flare maxima; 1—Alma - Ata; 2—Ondrejov and Mean Value 3—Abastumani; 4 - Baku the flare, with multiple RF peaks occurring at the times of the reported flare maxima, while the major RF peaks occur approximately 21 and 24 minutes, respectively, after the flare maxima (mean value of reported times). The time history, at 2800 Mc/s, of the large PCA event on 30 March is shown on Figure C3a. Again, we find the same general characteristics with the rapid rise to an early peak preceding the reported flare maxima, a decrease in flux, then another rapid rise to the peak flux followed by a post burst increase, with the reported flare maxima preceding the time of RF peak intensity.

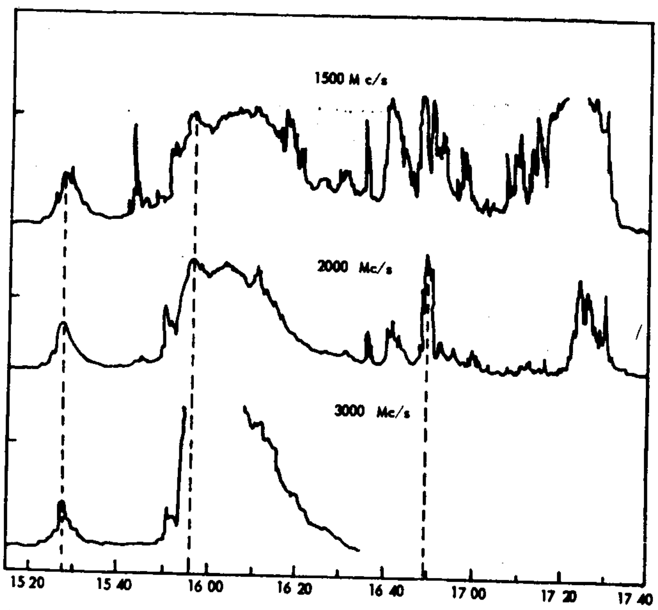

FIGURE C-3b RF TIME HISTORY, 1500,2000, AND 3000 Mc/s, 30 MARCH, 1960 1520 TO 1740 UT

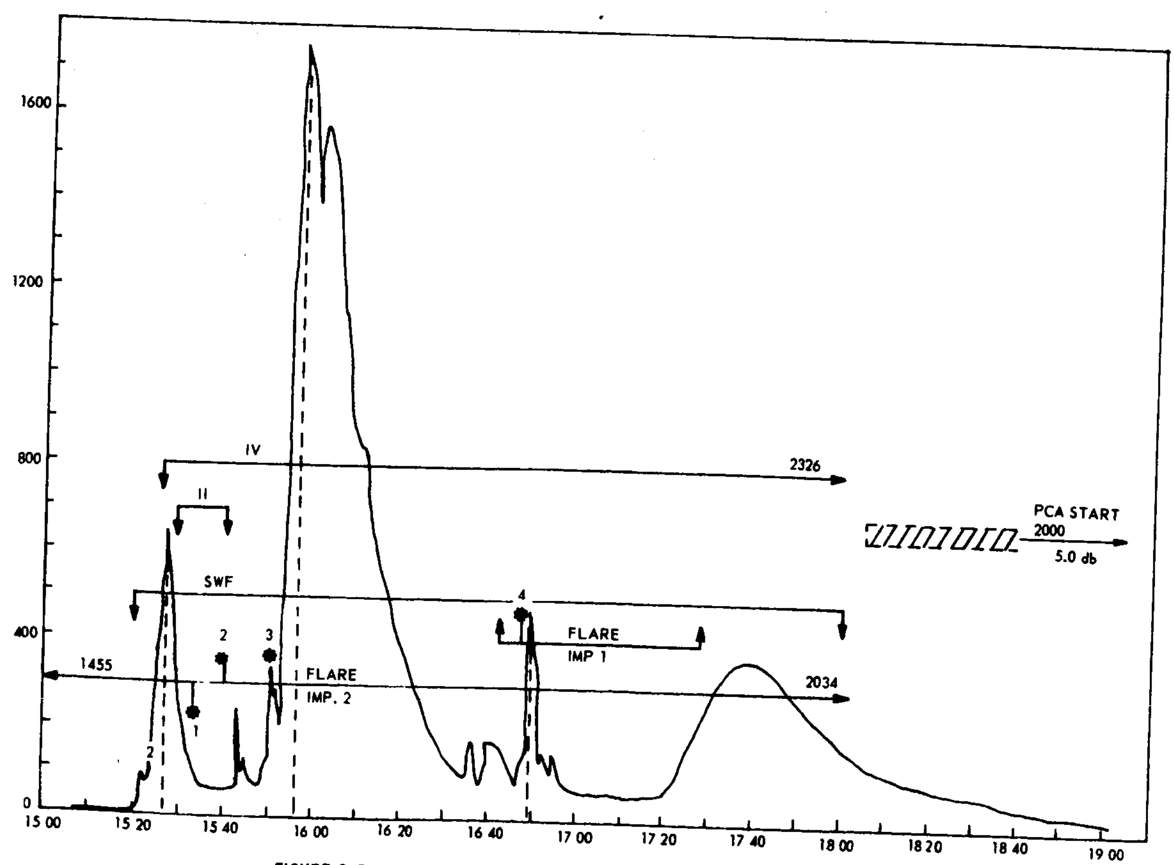

FIGURE C-3a RF TIME HISTORY, 2800 Mc/s, 30 MARCH 1960 1500 TO 1900 UT SHOWING RELATED PHENOMENA AND FLARE MAXIMA.

1 -- Sac. Peak; 2 – Capri F, and Mean Value 3 – Herstmonceux Imp. 2, N12 E13. Also 4 – Sac. Peak, Imp. 1, N24 W11.

The time histories at 1500, 2000, and 3000 Mc/s show the complete time agreement at the three frequencies 2000, 2800, and 3000 Mc/s, although there is considerable differences in the intensity of the peak fluxes which in the case of the three frequencies 1500, 2000, and 3000 Mc/s are expressed in term of the quiet sun level.

The RF time history for 2000 and 3750 Mc/s on 3 April is shown on Figure D-3. In this case the start of the flare was not observed and the flare maximum may have occurred earlier than the reported time. However, except for the very short duration of the burst (5 minutes), the general shape of the curve is similar to the time history in Figure C-2.

In order to complete the series of events we have included the RF time history at 3750 Mc/s on 5 April 1960 (Figure D-5). Because of the long time delay from the start of the RF emission until the flare was observed by Kodaikanal with a reported time of flare maximum at 0245, this event has not been included in the statistical study. Based on the relation of the RF time history to the SWF and the spectral emissions of Type II and Type IV, the flare probably started sometime prior to 0140 UT. This time history shows another example of an anticipated PCA event with a pre-maximum increase, followed by a rapid rise to peak flux and a post maximum increase.

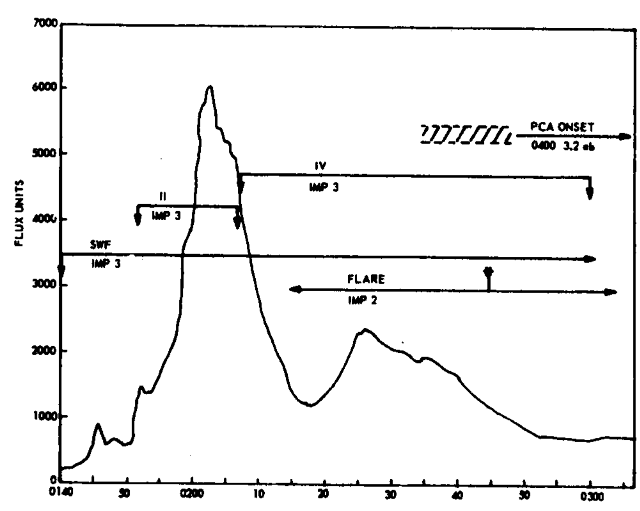

FIGURE D-5 RF TIME HISTORY 3750 Mc/s 5 APRIL, 1960, 0140 TO 0300 UT. WITH RELATED PHENOMENA

Lopez, Bragg, and Modisette (reference 13) have calculated the RF energy for four of the events as shown in Table N-10. The value for the 3 April event was not given in reference 13. We have estimated the value to be approximately $15 \times 10^{-18} J(m^2 c/s)^{-1}$.

N-11 THE VERY GREAT RF BURST ON 3 SEPTEMBER 1960

This event including a PCA which started approximately four and one-half hours after the start of an importance 2+ flare at the east limb was unique since it was followed by the only recorded case of an increase in radiation at ground level from the east limb of the visible disk. The RF emissions were outstanding at all frequencies. The peak flux at 3750 Mc/s was one of the highest ever recorded at centimeter wavelengths (exceeded by the peak at 2000 Mc/s on March 29, 1960, but was greater than the peak at 3750 Mc/s on the 29th). The RF flux at 3750 (Figure A-5) started to increase slowly almost simultaneously with the start of the flare. Approximately 27 minutes later the flux increased from slightly above normal background to a peak of 12000 flux units in less than one minute, decreasing to about 25% of the peak intensity in approximately five minutes, and to nearly background by 0120 UT followed by a post burst increase some ten minutes later.

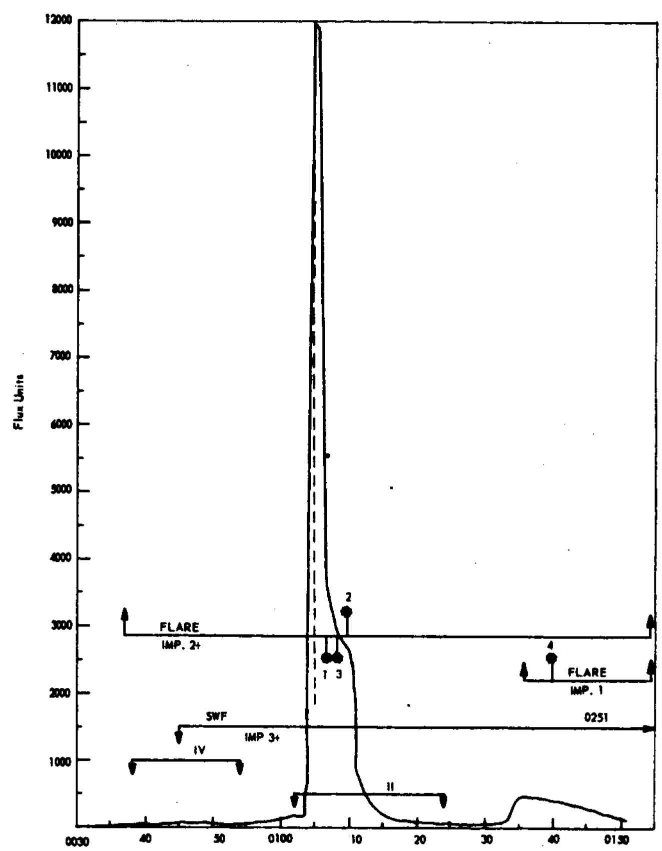

FIGURE A-5 RF TIME HISTORY 3750 Mc/s, SEPTEMBER 3, 1960 FROM 0030 TO 0150 UT SHOWING RELATED PHENOMENA, AND FLARE MAXIMA

Reported times of Flare Maxima: 1 – Lockheed; 2 – Honolulu; 3 – Mean Value N10E88; 4 – Honolulu, N20 E34.

The time of RF peak intensity preceded the time of flare maximum by 3.4 minutes thus becoming one of our failures. In other respects, this event failed to follow any standard pattern: the slow increase to flare maximum of approximately 30 minutes, with a similar slow initial increase in the RF flux of about 26 minutes and the relatively short duration of the main phase of about 10 minutes. The SWF and Type IV emission started during the premaximum increase while the Type II emission occurred nearly simultaneously with the great burst phase of the 3750 Mc/s increase.

In addition to the PCA there was a small ground level effect, and high energy solar protons were detected during rocket flights and by Explorer VII. Explorer VII observed an increase in high energy particles for more than five days.

N-12 THE GREAT RF EVENT ON 16 SEPTEMBER 1960

This great RF burst at 2800 Mc/s with a peak of 2000 flux units started at 1702, approximately eight minutes before a flare of importance 1 was reported by Huancayo near the east limb of the sun. McMath also observed the flare from 1723 to 1855 UT.

A major SWF with importance 3 starting at 1709 and lasting for 101 minutes was followed by a Type II burst at 1714 with importance 3 and a Type IV burst at 1717. The Type IV burst with importance 3 lasted for 104 minutes and covered the entire spectrum range from 3500 to 25 Mc/s at Fort Davis.

This event occurred in a large, bright plage with a large magnetically complex sunspot group which had a maximum area of 925 millionths on the 19th (Greenwich daily data not available). This region crossed the east limb on the 14th with bright loop prominence system (Bruzek, reference 2) between 1720 and 2256 UT with a sub-flare starting sometime before 1720 at S17 E90, a major SWF starting at 1620, and a very minor RF burst at 2800 Mc/s at 0703 lasting for six minutes. Bruzek also reports faint loop prominences at the same position on the 15th.

The event on the 16th with the major burst at 2800 Mc/s has all of the characteristics for a proton event (except possibly for the importance of the flare). These include the pre-burst increase, the Type II preceding the outstanding Type IV, and the major SWF. Also, the time of the RF peak intensity follows the reported time of flare maximum by 32 minutes and the RF burst energy of 185×10^{-18} $J(m^2c/s)^{-1}$ was calculated by Lopez, et.al.

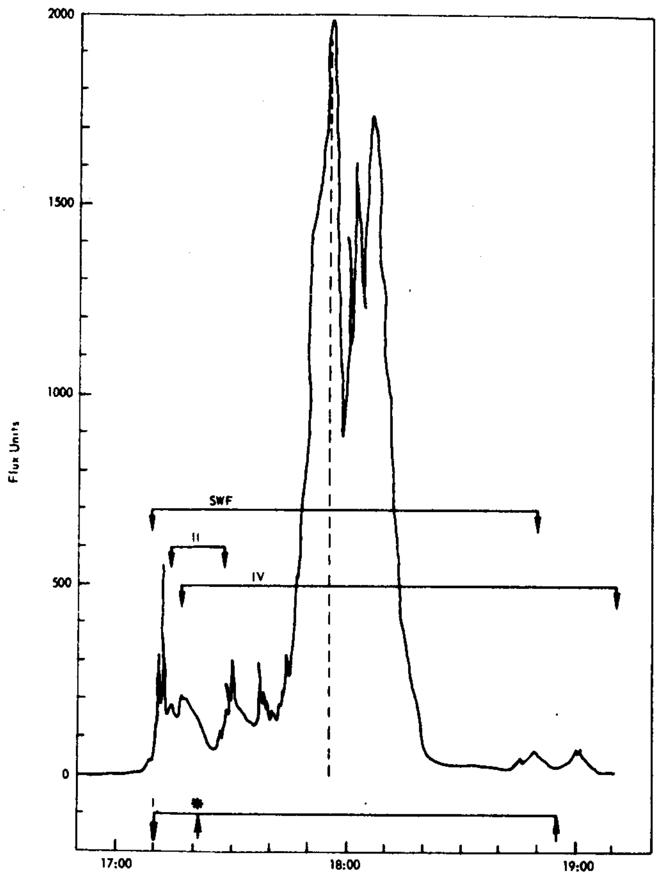

FIGURE A-6 RF TIME HISTORY 2800 Mc/s, SEPT. 16, 1960 SHOWING RELATED PHENUMENON

(reference 13), which by their criteria would indicate an event of approximately 10^8 protons with energy >30 Mev. These facts indicate the event on 16 September as a <u>major false alarm</u> since there is no report in the literature of even a small or weak PCA following this event.

In addition, data from Explorer VII* does not indicate any injection of solar protons or increase in counting rate above galactic background during the periods from 10 September through early October when the satellite was beyond approximately south geographic latitude 47 or northern geographic latitude 50.

N-12a EVENT 26 SEPTEMBER 1960

The only other important solar event associated with this region during disk passage was a flare of importance 1+ ten days later near the west limb.

The start of the flare was observed at 0525 on the 26th at S22 W64. The data for this event are summarized below:

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* Lin, W. C., "Observation of Galactic and Solar Cosmic Rays from October 13, 1959 to February 17, 1961 with Explorer VII (Satellite 1959 Iota)," Thesis partial fulfillment for MS degree, Dept. Physics & Astronomy, State Univ. Iowa (Aug. 1961).

	Start	Dur.	Max.	Imp.	Position
Flare	0525	51	0539	1+	S22 W64
SWF	0520	121	--	3+	
Type II	0543	21	--	2	
Type IV	<0554	>17	--	1	
1420 Mc/s	0529	38.0		>139 Flux Units	
3000 Mc/s	0532	28.0	0545	1120 Flux Units	
3750 Mc/s	0525	40.0	0539	1680 Flux units	
PCA	0900	120^h	--	2 db.	

The PCA on the 26th was observed:

Jenkins and Paghis	at 0900 UT	f_{min}
Jelly and Collins	at 1200 UT	f_{min}
Kahle	at 2300 UT	Riometer

Kahle states that this is a doubtful event since the Ionosonde starting 0800 the f_{min} rise lasts for only a few hours.

This event was verified when a sounding rocket carrying nuclear emulsions and counter instruments was fired on the 27th at 1444 UT from Fort Churchill, Fichtel, et. al.* report a proton flux at least 25 times normal, in the energy interval from 13 to 50 Mev.

The RF time history at 3750 Mc/s for the event on the 26th is shown on Figure D-6. The RF

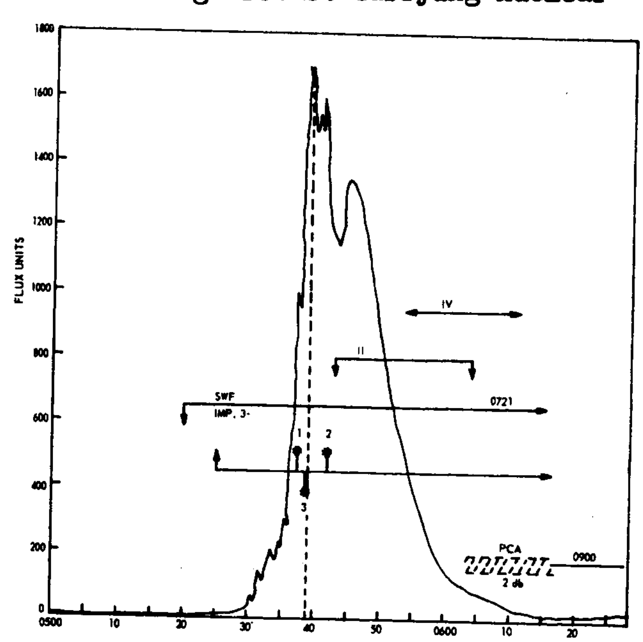

FIGURE D-6 RF TIME HISTORY 3750 Mc/s, 26 SEPT 1960 WITH RELATED PHENOMENA.

Reported Flare Maxima, 1 – Tachkent, and Mitaka;
2 – Crimea; 3 – Mean Value

* Fichtel, C. E., et.al., September 26, 1960, Solar Cosmic Ray Event, J. Geophys. Res., 67(10) (1962), 3669-3672.

emission has a relatively slow rise for about ten minutes, then an extremely rapid increase to the peak at 0539 UT. The second distinct peak at 0545 agrees with the time of peak intensity reported at 3000 Mc/s.

N-13 THE PCA EVENT ON 10 SEPTEMBER 1961

The PCA starting between 2000 and 2300 UT on 10 September 1961 was observed by Explorer XII at 2030 UT with a flux of 86 protons/cm^2 with energy greater than 23 Mev. Basler and Owren reported an onset at 2000 UT based on ionosonde data from the south pole and Resolute Bay, also by Riometer observation at Fort Yukon and College.

The large RF burst at 2800 Mc/s starting at 1930 with a very rapid rise in flux starting at 1945 is shown on Figure A-7. The major SWF and Type II and Type IV events are associated with a bright west limb flare of importance 1, which started sometime before 1950 UT and was followed by the development of a loop prominence of importance 3 at 2012 UT lasting for more than two hours.

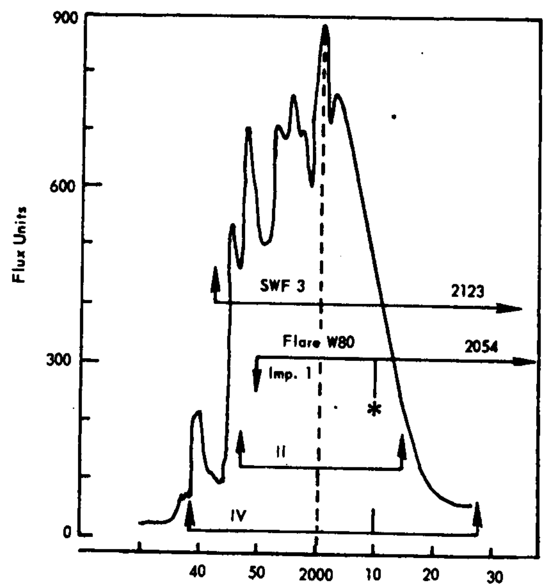

FIGURE A-7 RF TIME HISTORY 2800 Mc/s SEPT. 10, 1961, FROM 1930 TO 2030 UT SHOWING RELATED PHENUMENON.

This flare occurred in a large, very bright plage region in its second rotation and one of the largest sunspot groups to cross the visible disk during 1961 (maximum area 1350 millionths). Although this region did not produce a single major flare it was the source of 69 minor flares.

The SWF at 1942, 10 cm burst at 1930, and spectral emission of Type II at 1947 and Type IV at 1937, indicate that the flare started much earlier than the reported time of 1950 UT, probably behind the west limb, spreading to the visible part of the disk by 1950. Consequently, the reported time for flare maximum is very questionable.

The Type IV emission at 1937 covered the frequency range from 3900 to 2100 Mc/s while Warwick reported a Type IV in the range from 41 to 21 Mc/s starting at 2013 UT and lasting for one hour and 41 minutes. Warwick also reported a Type II starting at 1935 UT over his entire frequency range of 41 to 7.6 Mc/s.

N-14 THE MAJOR RF EVENT ON 30 JANUARY 1963

HHI reports a complex variation of intensity starting at 1322.5 UT with 13 peaks and a peak of 877 flux units at 1439.5; however, the major burst lasted less than 10 minutes although the reported duration was given as 100 minutes. Ottawa reported a long duration gradual rise and fall in flux starting at 1330 lasting for 450 minutes and a peak of only 11 flux units at 1355 UT.

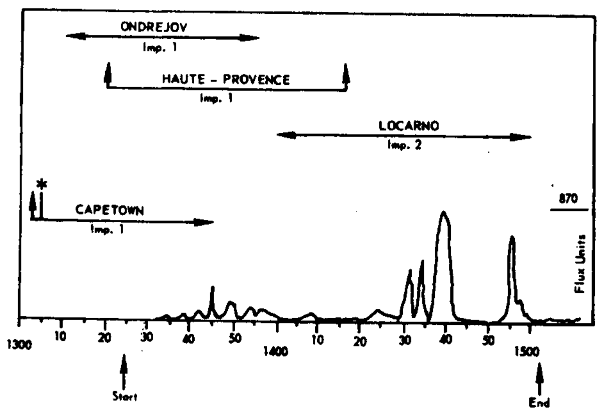

FIGURE A-8 RF TIME HISTORY 1500 Mc/s, JANUARY 30, 1963 FROM 1300 TO 1500 UT SHOWING DIFFERENT FLARE TIMES REPORTED

Indicates Beginning of the Flare Not Observed
Indicates end of the Flare Not Observed

An examination of the RF time history at 1500 Mc/s (Figure A-8) indicates that the inclusion of this event in our study is questionable and does not meet the requirement for a PCA event. This event was not included in our statistical study.

The only flare that can be associated with the RF event was reported by four observatories as indicated on the figure by four separate lines. Only Capetown reported a flare maximum, which is probably questionable.

N-15 THE ACTIVE SOLAR REGION 13 THROUGH 26 SEPTEMBER 1963

The largest and most active sunspot group crossed the visible solar disk between 13 September and 26 September 1963. The group was the source of 87 flares of importance ≥ 1. Seven of the flares were accompanied by RF bursts with peak intensity ≥ 500 flux units at centimeter wavelengths. There were two flares of importance 3 and two PCA's associated with this outstanding solar region. The outstanding events during this period are shown in Table N-15.

TABLE N15

FLARES, RF EMISSION AND PCA EVENTS
DURING THE PERIOD 14 SEPTEMBER THROUGH 26 SEPTEMBER 1963

	FLARE					MAJOR BURST AT cm WAVELENGTH							
Date	Start	Dur.	Max.	Position	Imp.	f	Start	Peak	Dur.	Max Flux	Δ t	Fig.	PCA
9/14	2112	53	2123	N12 E72	1	2800	2134	2144.5	7	550	+21.6		No
	2202	19	2206	N11 E71	1	2000	2230	2235.5	12	1880	+29.5		
15	0015	124	0042	N15 E75	2	3750	0015	0028		650			
								0036.5	90	4400		A-9	
								0049.4		8080			
16	0325	172	0422	N11 E57	3	3750	0419.5	0419.6	1.0	35	-2.4		
	1430	62	1503	N12 E48	2	2800	1436.5	1452		318			
								1543	133.5	710		D-4	
18	2236	144		N12 E20	1	2000	2231	2327	130	1100			
20	2314												
	2351	167	2403	N10 W09	2	3750	2350	2400.3	23	1400	Note		
							2429	2432.7	6	330	16	A-10	4.6 db
							2500	2515.2	45	5350			
26	0638	186	0717	N13 W78	3	3750	0705	0716.2	35	1850	-0.8	B-4	4.6 db
							0748	0749.3	15	200			

The Major Burst on 14 September at 2115

The first major event occurred on 14 September at 2115 UT near the east limb (N12 E72). The flare of importance 1 was accompanied by an RF burst at 2800 Mc/s starting at 2134 UT with a peak of 550 flux units 12.5 minutes after the flare maximum. This event was followed within an hour by a great burst at 2000 Mc/s starting at 2230, approximately 28 minutes after an importance 1 flare and at about the reported time of the end of the flare. There was a rapid rise in less than two minutes to a peak of about 480 flux units with a second sharp rise starting at 2233.3 to the peak of 1880 flux units at 2235.5 followed by a post burst increase. No SWF or spectral emissions were reported at the time of the flare or during the RF emission. Nagoya reports that there was no outstanding burst at 3750 or 9400 Mc/s. Ottawa reported unusual activity between 2106 and 2240 UT superposed on a gradual rise and fall in flux. The flux increase started at 2143 with a peak of 550 flux units by 2144.5.

The Great Burst on September 15 at 0015 UT

An importance 2 flare and a great burst at 3750 Mc/s started at 0015 UT. The RF burst reached a peak of 8080 flux units by 0049.4 UT, as shown on Figure A-9.

This great burst at 3750 Mc/s on the 15th shows all of the characteristics of an event associated with a PCA. The flare was reported by four observatories as indicated on the figure. Lockheed reported the start of the flare at 0015 UT and ending sometime after 0130. The times of the flare maximum ranged from 0027 to 0042 UT.

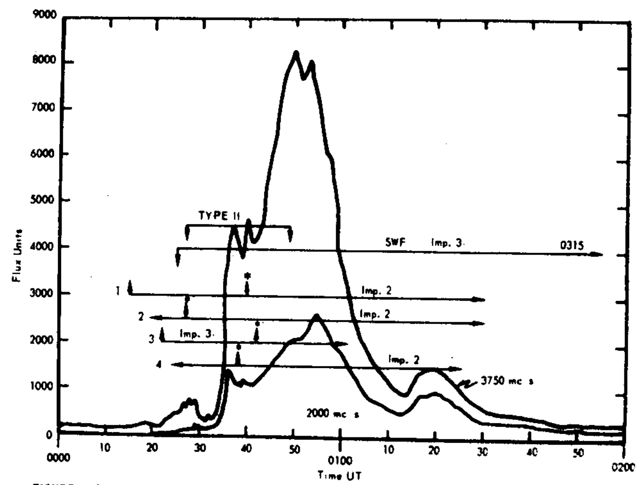

FIGURE A-9 RF TIME HISTORY 3750 AND 2000 Mc s, SEPTEMBER 15, 1963, 0000 TO 0200 UT., SHOWING DIFFERENT TIMES OF THE FLARE AND FLARE MAXIMA

1 – Lockheed, 2 – Ikomasan, 3 – Honolulu and, 4 – Manila

Since the time of the RF peak intensity follows the reported time of flare maximum, we have a false alarm since no PCA event was reported.

A comparison of the time of the different RF peaks and reported flare maxima shows a good correlation between the first three RF peaks and the flare maxima reported by Ikomasan, Manila, and Lockheed, while the maximum reported by Honolulu is followed by a rapid rise of the RF flux to the peak at 0049.4 UT.

The Importance 3 Flare on 16 September at 0325 UT

A flare of importance 3 was reported by four observatories starting at 0325 UT lasting for 172 minutes. No dynamic spectrum activity was reported although Sydney was observing, and no emissions were reported at single frequencies except of very minor bursts reported by Nagoya at 2000, 3750, and 9400 Mc/s (55, 35, and 110 flux units respectively).

The Large RF Burst at 1436 on September 16

The RF burst at 2800 Mc/s started at 1436 approximately six minutes after an importance 2 flare which was observed by four observatories with several reported times of flare maximum as shown on Figure D-4. This flare was preceded by an importance 2 flare starting sometime before 1330 and was still in progress when the flare at 1430 started. No dynamic spectrum activity was reported.

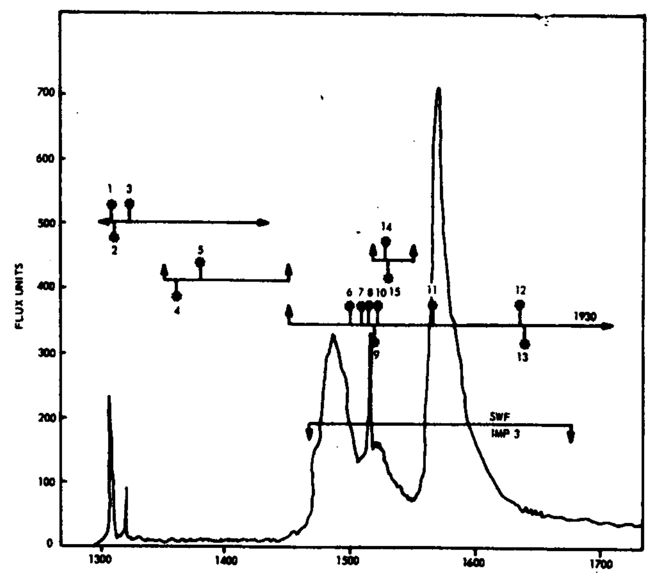

FIGURE D-4, RF TIME HISTORY 2800 Mc/s 16 SEPTEMBER 1963, 1300 TO 1700 UT., SHOWING POSSIBLE FLARES AND RELATED PHENOMENA

Flares and Reported Maxima
N12 E50, Imp. 2; 1. Ottawa, Capetown, Bucharest, and Kiev Ka;
2. Sac. Peak; 3 Herstmonceux
N12 E50, Imp. 1; 4 McMath; 5 Sac. Peak, and Wendelstein:
N13 E49, Imp. 2; 6 Ottawa; 7 Locarno; 8 Sac Peak; 9 Herstmonceux;
10, 11 & 12 Ottawa; 13 Sac Peak;
S09 W08, Imp. 1; 14 Sac Peak; 15 McMath, and Ottawa.

The Very Complex Event at 2000 Mc/s on 18 September

No outstanding events were reported between the event on the 16th and late on the 18th when a very complex burst at 2000 Mc/s started at 2231 UT approximately five minutes before an importance 1 flare was reported. The 2000 Mc/s burst reached a peak of 1100 flux units nearly an hour after the start of the burst. This complex burst was superposed on a long duration gradual rise and fall in flux. No SWF or activity in the dynamic spectrum was reported, and at 3750 Mc/s the emission consisted of a very small long enduring rise and fall in flux.

The Polar Cap Absorption on 21 September

Activity in the region was limited to minor flares until sometime before 2314 on the 20th when a flare of importance 2 occurred at the central meridian. Sacramento Peak reported a flare starting at 2314 ending after 2453 with maxima at 2407 and 2424 UT.

Lockheed reported a number of unusual features associated with the flare including bright spraylike ejections and giant dark surges preceding the flare with high speed disturbances during the flare.

Bailey (reference 50) reports the PCA onset at 2400 while Basler and Owren place the onset at 2420 based on McMurdo riometer data.

The major RF burst at 3750 Mc/s (Figure A-10) started at 2350 UT with peak intensity at 2400.3 and is probably associated with the PCA with the onset between 2400 and 2420 UT. The very great burst at 3750 Mc/s (peak intensity 5350 flux units at 2515.2) occurred more than an hour after the PCA onset and nearly an hour after the flare maximum at 2424 UT reported by

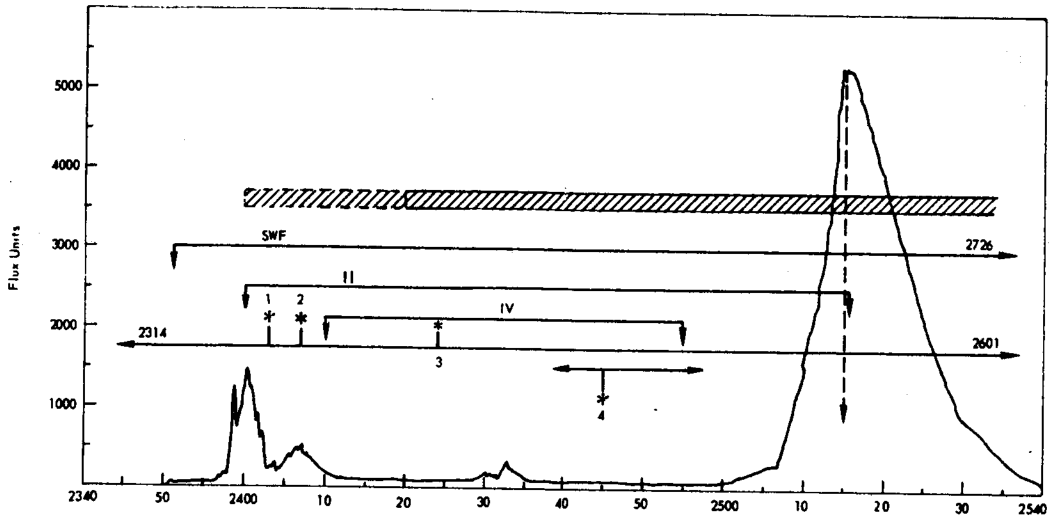

FIGURE A-10 THE RF TIME HISTORY AT 3750 Mc/s ON SEPTEMBER 20, 21, 1963 STARTING AT 2350 UT. SHOWING RELATED PHENOMENON AND DIFFERENT REPORTED TIMES OF FLARE MAXIMUM

Flare Maximum; 1 - Lockheed; 2 - Sac Peak and Honolulu; 3 - Sac Peak; 4 - Flare at N19W04

Sacramento Peak. This burst may be associated with an importance 2 flare reported by Irkutsk starting sometime before 0039 UT on the 21st with a maximum at 0045 UT. The shapes of the RF burst at 2350 and 2500 are both representative of events with spectral emissions of Type II and Type IV, but no spectral emissions are reported at the time of the second burst.

The Great RF Burst and PCA Event on 26 September

The final event associated with this very active solar region occurred on the 26th when the region was near the west limb of the sun. A flare of importance 3 started at about 0638 UT with a very slow rise in intensity until about 0712. During the next 16 minutes ten different times of maximum were reported as shown on Figure B-4.

A great SWF started at about the same time as the RF burst. No spectral observations were being made at the time of this event, but a Type IV burst probably occurred. It is seen from Figure B-4 that several of the reported times of flare maximum coincided with peaks of the RF burst. This flare was followed within about an hour by a PCA event with a maximum absorption of 4.5 db.

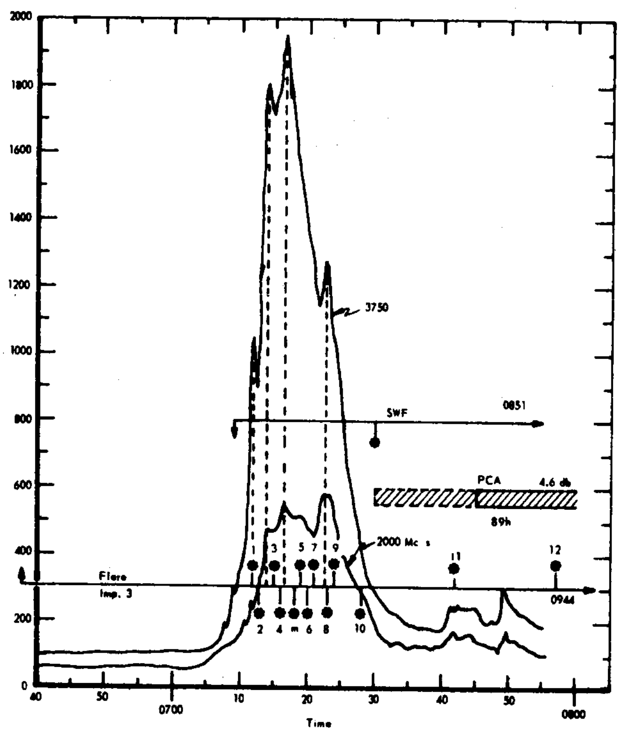

FIGURE B-4 RF TIME HISTORY AT 2000 AND 3750 Mc's 26 SEPTEMBER 1963, SHOWING RELATED PHENOMENA AND FLARE MAXIMA

Reported Flare Maxima 1 – Ondrejov; 2 – Athens; 3 – Tachkent; 4 – Capetown; 5 – Abastuman; 6 – Bakau; 7 – Crimea; 8 – Bucharest; 9 – Haute – Providence; m – Mean ALSO, 10 – Kieve; 11 – Capri – F; and 12 – Nizmir.

It is important to note that four of the five events that were not followed by a PCA are probable false alarms while the two events that were followed by PCA's are considered to be questionable successes. In all of these cases the classification of the flares as PCA or non-PCA events are critically dependent on the choice of the different times of flare maximum or more probably the determination of the true time of flare maximum. It is also possible that the time of rapid increase in flare brightness may be an important factor.

4.0 FLARES OF IMPORTANCE ≥ 3 AND THE SUCCESS OR FAILURE OF THE FLARE-RF TIME ASSOCIATION

The analysis of events in the previous section was devoted to cases where the flare-RF burst time relation was considered to be questionable or the association of a major RF burst with a flare was not possible with reasonable confidence. Most of the events were limited to flares of importance < 3.

In our summary and general discussion we stated that the correlation of most major flares (importance ≥ 3) with major RF bursts was possible with a high degree of confidence. However, in a number of cases the choice of the time of flare maximum and/or the associated RF peak intensity was not always possible. The decision that the time of the RF peak flux followed or preceded the time of the flare maximum is of major importance in our statistical probability of success, failure, or false alarm as a part of a warning system, and for establishing the flare-RF observational requirements.

With this problem in mind we have selected a number of events for detailed analysis for which RF time histories were available.

We have chosen a very active region which contributed six events during disk passage including a very large PCA, two large and one small PCA that were statistical failures,and a major flare that was a statistical false alarm

4.1 THE ACTIVE SOLAR REGION FROM 8 MAY THROUGH 21 MAY 1959

This region was chosen for detailed analysis as another example of a large and very active region which during disk passage was the source of a number of major events including three flares of importance $\geqslant 3$, three flares with very great, and two with large bursts at centimeter wavelength. The region was also the source of one of the largest PCA events observed during the 19th solar cycle. The plage was very large, bright, and unusually flare productive, and contained three magnetically complex sunspot groups, one of which formed on the visible hemisphere on the 16th. All of the major events except the importance 3 flare on the 11th were associated with the large, $\beta\gamma$, spot which crossed the central meridian on May 14 at 1900 UT.

TABLE 4.1

MAJOR SOLAR EVENTS FROM THE LARGE ACTIVE SOLAR REGION WHICH CROSSED THE SOLAR DISK BETWEEN 8 AND 21 MAY 1959

	FLARE			SWF		TYPE		cm EMISSIONS				SUNSPOT		
Date	Start	Imp.	Position	Start	Imp.	II	IV	f	Start	Flux	Δt	Area	Mag. Class	Type
08	2252	2+	N23 E86	2258	2	2259 20/3	Probable	2800 3750	2254 2254	2200 2750	0 -0.5	782	$\beta\gamma$	--
09	0123	3	N20 E78	None rep.								1853	$\beta\gamma$	E
10	2055 2315	3+ 3+	N19 E47 N19 E51	2110	3+	2123 8/3+	2116 164/3	2800	2100	2500	+9 PCA	1988	$\beta\gamma$	
11	2006	3	N10 E41	2015	3-	2020 19/3+	2028 18/3	2800	2010	900	-6	466	γ	
13	0457	2+	N22 E26	0511	2	0516 9/--	0525 65/--	3750	0510	570	-0.9	1952	$\beta\gamma$	E
17	0523 0700	2+ 1	N21 W30 N21 W30	0525 0705	2+ 2+		Probable	3750 3750	0523 0705	3300 1280	-2.0 -0.3	355	$\beta\gamma$	C

Major Activity on 8 May 1959

The first outstanding activity in this region occurred on the 8th when a flare of importance 2+ was observed at the east limb of the sun accompanied by a very great burst of short duration at 2000, 2800, and 3750 Mc/s of the impulsive type (Figure D-7) without a post burst increase. The event also included a moderate SWF, an importance 3 slow drift burst (Type II) and a probable dynamic burst of Type IV.

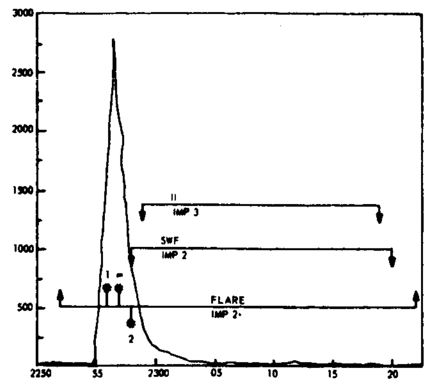

FIGURE D-7 RF TIME HISTORY 3750 Mc/s, MAY 8, 1959 SHOWING RELATED PHENOMENA

Reported Flare Maxima 1 – Voroshilov, 2 – Sec. Peak, m – Mean Value

The Major Flare on 9 May 1959

This flare of importance 3 also occurred at the east limb of the sun, was reported by Sydney only, lasted for more than 49 minutes. This was an unusual major flare since it was not accompanied by a SWF, dynamic spectra or emissions at centimeter wavelengths. However, there was almost continuous flare activity at the limb between the time of the importance 2+ flare on the 8th and 0123 when this flare started with major bursts at meter wavelengths.

The Great PCA on 10 May 1959

During the 43 hours this region was the source of 18 flares with importance < 2. Then at 2055 UT on the 10th a very great flare of importance 3+ lasting for more than five hours occurred at N19 E47. This flare was accompanied by a great SWF lasting more than nine hours, a major RF burst at 2800 Mc/s and both Type II and Type IV bursts in the dynamic spectrum.

One of the largest PCA events recorded, started two hours after the start of the flare and lasted for 15 days. We have chosen 2300 UT on 10 May as the PCA start time which is based on Riometer data at Thule. Others have reported times ranging to 0300 UT on the 11th. Leinbach reports an onset by 0130 on the 11th with an initial rate of increase of absorption of 3 db/hr. This event has been discussed in great detail in the literature by many investigators. Lopez, et.al., have calculated and integrated RF energy of 811×10^{-18} J $(m^2 c/s)^{-1}$ and Webber calculated a total flux of 9.6×10^8 protons with energy > 30 Mev. It is quite probable that the very long and unusual duration of this PCA is in part due to the major events that followed nearly 24 hours later on the 11th. However, Leinbach reports that there is no convincing evidence that the later events contributed any protons during the life of this PCA.

<u>The Major Flare on 11 May at 2006 UT</u>

The flare on 11 May occurred at N10 latitude in the γ sunspot group which moved across the sun south of the group responsible for the other events of this group. This group started out as a pair of spots, developed into an extended cluster by 11 May, then the whole group died out before reaching the west limb.

This flare and the related phenomena showed all of the characteristics generally associated with a PCA flare as shown below, and probably along with the events on the 13th and 17th was partly responsible for the long duration and strength of the PCA that started on the 10th and lasted for more than 15 days. The times of flare maxima at 2022 UT and 2034 UT were reported by Lockheed and Sac Peak respectively, while the two large

* Leinbach, H., "Interpretation of the Time Variations of Polar Cap Absorption Associated with Solar Cosmic Ray Bombardment," Geophys. Inst. Univ. Alaska, Sci. Rep. No. <u>3</u>, UAG-<u>R127</u> (May 1962), 230 pp.

RF bursts at 2800 Mc/s occurred at 2022 and 2033 UT with peaks of 900 and 750 flux units respectively. Lopez, et.al., calculated an RF energy of 75 x 10^{-18} $J(m^2c/s)^{-1}$, indicating a proton flux of approximately 10^7 particles.

	Start	Duration	Max.	Imp.	Position
Flare	2006	104	2022 2034	3	N10 E41
SWF	2015	67	--	3+	
Type II	2020	19	--	3+	
Type IV	2028	18	--	3	
2800 Mc/s	2010	40	2022 2033	900 750	Flux units

The RF time history shown on Figure D-2 is similar to many of the events that were followed by PCA's.

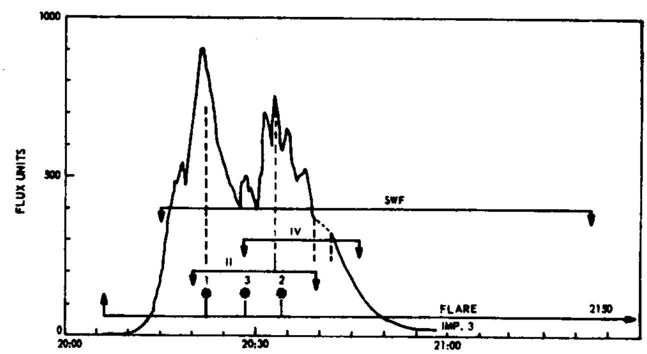

FIGURE D-2 RF TIME HISTORY, 2800 Mc/s, 11 MAY, 1959, 2005 TO 2130 UT SHOWING RELATED PHENOMENA AND AND REPORTED TIMES OF FLARE MAXIMA

Reported times of flare maxima: 1 – Lockheed; 2 – Sec. Peak; 3 – Mean Value

The Major RF Events on 13 May at 0510 UT, 17 May at 0523 UT and 0700 UT

We have grouped these three events together since they are similar in many respects. Two of the RF events at 3750 and 2000 Mc/s were of the impulsive type (13 May at 0510 UT, and 17 May at 0705 UT) similar to the event on the 8th (Figure D-7). The other event on the 17th with a peak of 3300 flux units at 0523 was also impulsive with a second peak of approximately 720 flux units at 0529 followed by a post burst increase. The event on the 13th included spectral bursts of Type II and IV starting two and eleven minutes respectively after the time of flare maximum.

Another impulsive event occurred on the 18th at 0403 lasting three minutes with a peak of 1750 flux units. This event may have originated in this very active region. However, there was no flare patrol between 0150 and 0430 UT and an association would be unrealistic. As stated earlier, the RF events on the 11th, 13th, 17th, and 18th may have contributed to the very long duration of the PCA on the 10th, although as we stated earlier Leinbach (loc.cit.) reports that he cannot find any indications of changes in the absorption that could be attributed to these later events.

4.2 COMPARISON OF THREE PCA FAILURES AND ONE FALSE ALARM

During the statistical study of the flare-RF time relation for events associated with flares of importance ≥ 3 followed by a basic PCA event we found eight events where the flare and RF data were considered to be reliable and the time of the RF peak flux preceded the time of the flare maximum (Table 2a).

RF time histories were obtained for three of these events: 10 July 1959; 6 May 1960; and 28 September 1961. These events are discussed in considerable detail below.

There were four cases (Table 2c) where flares of importance ≥ 3 that were not followed by a known PCA event, and the time of the RF peak intensity followed the reported times of flare maximum thus classifying the events as false alarms. The RF peak intensity was less than 500 flux units at centimeter wavelengths in all four cases. The RF time history was obtained for the event on 7 August 1958.

The Large PCA Event on 10 July 1959

The event on July 10 was the first of a series of three large PCA events from importance 3+ flares. The other two events occurred on the 14th at 0325, and the 16th at 2114.

These flares occurred in a large magnetically complex γ spot that crossed the solar disk between 8 and 21 July. The sunspot areas on flare days were 1053, 1314, and 1775 millionths of the solar hemisphere respectively. The spot was also the source of two importance 3 flares, one on the 13th with strong SWF and minor RF bursts and a reported time of flare maximum 75 minutes after the start of the flare, the other on the 16th approximately six hours before the importance 3+ flare which has been associated with the third PCA in this group.

Two importance 3+ flares occurred on the 10th, the first and probable source of the PCA protons, occurred at 0206 at N20 E63, approximately two hours before the reported start of the PCA. The other occurred at 0539 UT nearly two hours after the PCA start (Leinbach uses 0200 UT as the PCA onset time based on Riometer records at Thule. Hakura and Goh report solar protons over Russia by 0500 UT based on Ionosonde data while balloon observations at College, Alaska, show no increase in flux between 0210 and 0330 on the 10th.)

The flare at 0206 UT was accompanied by an intense SWF starting at 0200, a spectral Type II at 0222 and a probable Type IV at 0223. The very great RF emissions at 2000, 3000, and 3750 Mc/s started with a complex rise during the first ten minutes followed by a fast rise to a peak of 6300 flux units at 0224 and a second peak of nearly 5000 flux units at 0236 (Figure B-1). Two of the observatories reported flare maximum at 0222 and 0236, the third (Alma alta) gave the maximum at 0308 but did not observe the flare until 0257. If we use the average of the two earlier maxima, we have the time of RF peak preceding the time of flare maximum by six minutes. On the other hand, we see that the reported maximum at 0222 UT precedes the the time of RF peak intensity by two minutes, while the time of the second flare maximum

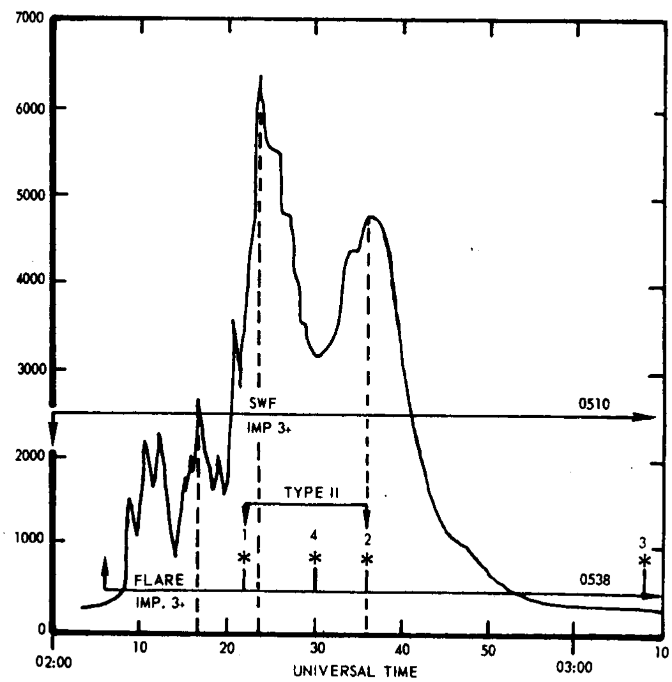

FIGURE B-1 RF TIME HISTORY 3750 Mc 's JULY 10, 1959, 0200 TO 0310 UT. SHOWING RELATED PHENOMENON AND DIFFERENT TIMES OF FLARE MAXIMUM

1 – Tachkent, 2 – Sydney, and 3 – Alma Alta
4 – Average Time.
PCA Starts at 0400 UT

precedes the second RF peak by a few tenths of a minutes. We have again encountered the problem of real time of the flare maximum which in this case can change our assumed (statistical) failure into a success.

In many respects the general shape of the RF curves, at 3750 Mc/s on Figure B-1 and at 2800 Mc/s on Figure B-2 are quite similar.

The Large PCA Event on 6 May 1960

The PCA on 6 May 1960 at 1600 UT followed an importance 3+ flare that started at 1404 UT at the central meridian. The PCA increased at an extremely slow rate during the first 34 hours of the event, reached a maximum absorption of 16 db at 0422 UT on 8 May.

The flare at S09 E01 was reported by a large number of observatories and time of flare maximum ranged from 1435 to 1515 UT. Honolulu observed the flare from 1744 to 2008 UT and reported it with importance 1 at 1846

The RF time history at 2800 Mc/s is shown on Figure B-2 where we have also shown the flare, reported times of maxima and related phenomena. As in several other cases we have studied at least three and possibly four of the times of flare maxima occur within less than a minute of the RF peaks.

Since the time of the RF peak flux preceded the time of the flare maximum by 5.5 minutes if we use the

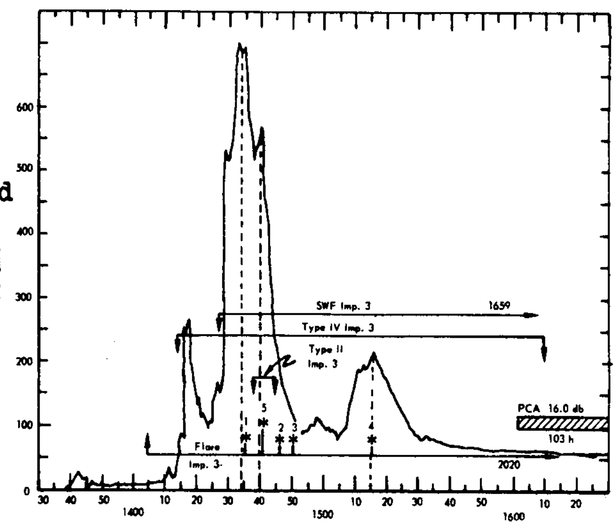

FIGURE B-2 RF TIME HISTORY 2800 Mc/s, MAY 6, 1960, 1330 TO 1630 UT, WITH FLARE AND OTHER DATA
Reported flare maximum 1 – Uccle, 2 – Sac Peak, 3 – Herstmonceux, 4 – Lockheed, 5 – Mean Maximum used for the Study

mean time of 1440 UT or by 0.5 minutes if we use the time reported by Uccle, the event is classified as a failure in our statistical analysis. On the other hand, the shape of the RF curve is typical of events associated with spectral Type II and Type IV and PCA events. We have another case where a two or three minute error in the reported time of flare maximum can change the event from a failure to a success.

The PCA-flare on May 6 occurred in an αp spot which was the source of only 14 flares during disk passage, twelve minor flares before and one minor flare after the PCA-flare.

It is interesting to note that this PCA started about an hour before the start of a moderately severe magnetic storm sudden commencement which reached a maximum planetary three hours k_p of 7+ between 2100 and 2400 UT on the 6th.

This storm had followed an importance 3 flare at the west limb at 1000 UT on the 4th and a PCA that started by 1030 UT which reached a maximum absorption of 3.4 db (Leinbach reports a maximum absorption of 5 db) between 1145 and 1230 UT on the 4th. The May 4 PCA was observed by 1030 at sea level with an increase of 300% at Deep River.

The Small PCA Event on 28 September 1961

The importance 3 flare responsible for the small PCA on 28 September at 2245 occurred at N13 E29 in a small, moderately bright plage region and β type sunspot group that during disk passage produced 17 minor flares, 13 before and 4 after the flare at 2202 UT on the 28th. The flare was accompanied by an intense SWF starting 16 minutes after the start of the flare, major solar spectral emissions of Type II and Type IV and major-RF bursts at 2000, 2800, and 3750 Mc/s. The RF burst of the impulsive type at 3750 Mc/s is shown on Figure B-3.

The two reported times of flare maximum follow the time of the RF peak by 4.7 and 6.7 minutes respectively. Hence, this event is a failure. The maximum intensity of the flare occurred at 2223 UT, 21 minutes after the flare was first observed and 10 minutes after the start of the RF burst and 8 minutes after the x-ray burst.

Maxwell (reference 49) has investigated the flare-RF association for this event. He found that although there was no explosive or flash phase for this flare, there was a rapid rise in the Hα emission between 2211 and 2213, at approximately the time of the x-ray burst (2214-2216), RF emission at centimeter wavelengths (2211), spectral emissions Type II (2217), Type IV (2212), and the SWF (2218).

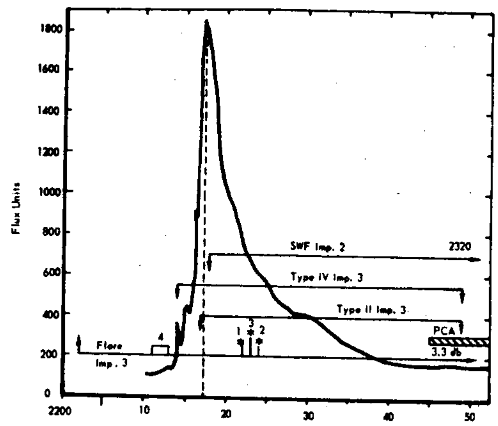

FIGURE 8-3 RF TIME HISTORY 3750 Mc's, SEPTEMBER 28, 1961, 2200 TO 2250 UT. SHOWING RELATED PHENOMENON AND DIFFERENT TIMES OF FLARE MAXIMUMS

1 – Honolulu, 2 – Lockheed, 3 – Average Time.Flare ends at 2530 UT., 4 – Rapid Rise in Hα

Maxwell concludes that the time of the flare maximum intensity may not be the important parameter but that the period of rapid increase in Hα emission, in this case, during the period 2211-2213 was the period of the major energy release and particle acceleration. This phenomena should be thoroughly investigated. On the other hand, none of the 44 flares during 1961-1963 investigated by Davies and Donnelly*, with an explosive phase, were associated with major RF bursts at centimeter wavelengths or were flares with an importance $\geq$ 3, or were followed by a polar cap absorption.

* Davies, K., and R. F. Donnelly, "An Ionospheric Phenomenon Associated with Explosive Solar Flares, " J. Geophys. Res. 71(11) (1966), 2843-2845.

This PCA which started sometime between 2245 and 2335 UT (by 2300 UT at Thule) was observed by Injun I and Explorer XII satellites and in balloon data from Flin Flon, Canada.

The plage region associated with this event is in its third rotation across the visible disk and is the return of a large, bright, and flare productive plage that crossed the visible disk between 28 August and 10 September, a region that was the source of an importance 1 flare at the west limb on 10 September, which was accompanied by an intense SWF, solar spectral bursts of Type II and Type IV, and a major burst at 2800 Mc/s. The flare was followed by a PCA sometime between 2000 and 2300 UT with a maximum absorption of 2.9 db. This event was also considered a statistical failure since the time of the RF peak preceded the time of the flare maximum by nine minutes.

Again, we have a situation which casts doubt on the reported times for the flare. The SWF started eight minutes earlier than the reported start of the flare, the Type IV, 13 minutes earlier and the RF emission at 2800 Mc/s started 20 minutes before the flare. This suggests that the true start and probably the maximum of the flare at the west limb was not observed.

The Major Solar Flare on 7 August 1958 - A Statistical False Alarm

Eight observatories report the start of the flare between 1457 (Sac Peak) and 1503 (Capri S) with the time of H α flare maximum ranging from 1505 (USN Obs.) and 1511 (Climax), while two observatories did not report a time of maximum. Flare importances of 2 (1 case) 2+ (3 cases) and 3(4 cases) were reported. The McMath-Hulbert working list assigns the importance 3 to the flare. Three observatories did not observe the flare until after 1555 UT. The U. S. Naval Observatory reported the flare ending at 1536 and a new flare of importance 1 starting in the same location at 1544 UT with a maximum at 1549 UT.

Figure D-1 shows the RF time history (reference 24) at 1500, 2000, and 3000 Mc/s reported by HHI with peaks at 1503 and 1522 with a third minor peak at 1548 UT. The largest peak of 216 flux units occurred at 1522 UT.

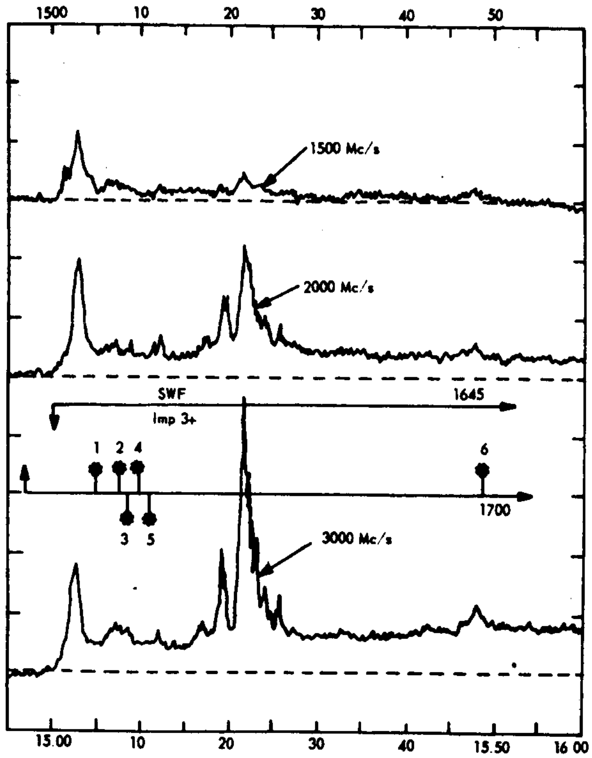

FIGURE D-1 RF TIME HISTORY, 1500, 2000, AND 3000 Mc/s 7 AUGUST 1958, 1500 TO 1600 UT SHOWING RELATED PHENOMENA, AND REPORTED TIMES OF FLARE MAXIMA

Reported times of Flare Maxima: 1 – USN Obs.; 2 – Edinburgh; 3 – Ottawa and McMath; 4 – Sac Peak; 5 – Climax; 6 – USN Obs.

We have also shown the severe short wave radio fadeout and the flare. The earliest time of $H\alpha$ maximum was reported by the U. S. Naval Observatory at 1505 UT while Climax reported a maximum at 1511 UT. Four others reported maxima at 1508 (2 cases), 1509 and 1510. The U. S. Naval Observatory reported a second maximum at 1549 UT. All but the last of these times of flare maximum precede the time of the RF major peak thus giving us a statistical false alarm.

RF emission was also observed by Ottawa at 2800 Mc/s with several bursts superposed on a long enduring rise and fall in flux; the peaks at 1503 and 1522 UT are the same as the times reported by HHI at 2000 and 3000 Mc/s.

No Type II or Type IV spectral emissions were reported, although Fort Davis was observing and reported Types I and III bursts.

The shape of the RF emissioncurve is in many respects similar to others that have been discussed in Section 3.0. In particular the events: 5 June 1958, Figure A-1; 28 August 1959, Figure A-3; 30 January 1963, Figure A-5; and 16 September 1963, Figure D-4.

The flare occurred in a large, complex sunspot group (Mt. Wilson 13434, Greenwich 18835) which on flare day had an area of 686 millionths and a $\beta\gamma$ magnetic classification with a field strength of 2300 gauss.

The sunspot group attained an area of 1150 millionths on the 14th, and was the source of an importance 3+ flare on the 16th at W50, which was followed within one hour by a large PCA event with an absorption of 15 db.

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TABLE 1

EVENTS WHERE THE RF EMISSION FLARE ASSOCIATION IS QUESTIONABLE

FLARES WITH IMPORTANCE < 3, RF PEAK FLUX ≥ 500 FLUX UNITS

		FLARE					SHORTWAVE FADE				SPECTRAL		RF EMISSIONS SINGLE FREQUENCY							
Serial No.*	Date	Start	Dur. Min.	Time Max.	Position	Imp.	Onset	Dur. Min.	Type	Imp.	II	IV	f	Obs.	Type	Onset	Max.	Dur. Min.	Peak Int.	Note
	1957																			
III-30	6/27	2322	56	2335	N20 W62	1	2325	55	SL	1		(2408)	1420	Syd	CD	2357		8.2	> 239	N_1
		2330	57	2335	N14 E32	1+							3000	Tok	CD	2408	2541.5	50.0	504	
													3750	Nag	CD	2411	2540	16.0	42	
III-63	12/21	2334	26	2345	S15 E60	1-	None reported						2000	Nag	SD	2346	2347	3.0	41	
		2344	18	2347	N25 E27	1-							3000	Tok	CD	2345	2346.3	5.0	556	
		2349	36	2418	N17 W27	1-							3750	Nag	SD	2346	2347	2.0	180	N_2
III-64	12/22	0437	26	0442	N18 W26	1-							1420	Syd	CD	0439	0439	1.0	479	N_3
		0438	5	0439	S21 E16	1-	None reported						2000	Nag	CD	0437	0439	5.0	93	
		0438	7	0440	S20 W35	1-							3000	Tok	CD	0437	0439	7.0	505	
		0438	25	0443	S26 E11	1-														
III-67	12/23	<0025	215	0029	N18 W38	1	0022	43	SL	1+			2000	Nag	SD	0038	0038.5	1.0	14	
		0038	14	0039	N26 E40	2							3000	Tok	ESD	0024.5	0025.5	4.0	582	
															ESD	0038	0038.5	2.0	564	N_4
													3750	Nag	SD	0024.5	0025.5	2.0	123	
															SD	0038	0038.4	2.0	90	
	1958																			
III-91	6/05	1615	142	1631	S18 E69	2+	1620	100	S	3			1500	HHI	CD	1616	1623.5 1713.5 1715.5 1720.3 1723.4	84.0	625	
													2800	Ott	SD	1614	--	180.0	25	N_5
																1614	1623	18.0	387	
																1655	1710	23.0	360	Fig. A-1
																1718	1723.5	22.0	255	
													3000	HHI	SD	1617	1622.7		586	
III-92	6/26	0245	152	0306	N10 E49	2+	0247	85	SL	2+	0304	(0255)	2000	Nag	CD	0244	0245.9	4.0	34	
											16/-	0319	3000	Tok	CD	0243	0245	7.0	410	
												116/1	3750	Nag	CD	0244	0244.9	3.0	51	
													1420	Syd	CD	0255	0316	30.0	189	N_6
													2000	Nag	CD	0255	0316.2	30.0	100	
													3000	Tok	CD	0255	0307.8	22.0	507	
													3750	Nag	CD	0255	0307.8	30.0	155	
	1959																			
III-100	8/20	0042	46	0044	N16 E18	2+	0042	33	S	2+	0046	(0042)	1420	Syd	CD	0040	0044	13.0	255	Fig. A-2
											5/3		2000	Nag	ECD	0040	0044	7.0	(620)	N_7
											0046		3000	Tok	CD	0041	0043.3	7.0	1260	
											19/-		3750	Nag	ECD	0041.5	0042.4	5.0	1450	-1.6
III-101	8/28	1025	20	1030	S18 W64	2+	1023	62	S	3		(1028)	1500	HHI	CD	1009	1039	53.5	215	
													2800	Ott		1028	1039.5	20.0	350	N_8
													3000	HHI	CD	1019	1039	36.0	573	+9.0
													HHI also max. at 1028 and 1030 Ott in sunrise oscillation							Fig. A-3
III-102	9/14	0822	128	0835	S10 W80	2+	0851	58	S	3		(0832)	1500	HHI	CD	0834	0904	85.0	460	
													2980	Ned	SD	0833.5	--	5.0	371	N_9
															CD	0847.5	--	43.0	870	
													3000	HHI	N	0830	0904	69.0	1259	+20
	1960																			
III-146	3/28	2042	68	2056	N15 E37	2	2050	50	S	2+	2057	2050	2800	Ott	C+	2047.7	2055	14.8	750	-1 N_{10}
											15/3	>240/3				2102.2	2117	55.2	885	Fig. A-4
IV-162	9/03	0037	77	0108	N18 E88	2+	0045	126	SL	3+	0102	0038	2000	Nag	C	0035	0105.2	90.0	7100	
											22/1	16/2	3000	Tok	C+	0059	0105	50.0	5800	N_{11}
													3750	Nag	C	0039	0104.6	85.0	12000	-3.4 Fig. A-5
III-163	9/16	1710	105	1724	S22 E68	1	1709	101	S	3	1714	17[illegible]	2800	Ott	C+	1702	1712	23.0	550	
											14/3	114/3			C+	1725	1756	74.0	2000	N_{12}
													2980	Ned						Fig. A-6
	1961																			
III-169	9/10	1950	64	2010	N08 W80	1	1942	101	SL	3	1947	1937	2800	Ott	C	1930	2001	61.0	880	-9.0, N_{13}
											27/3	50/3								Fig. A-7
	1963																			
IV-172	1/30	1305	70	1306	N10 W54	1	None reported						1500	HHI	c	1322.5	1439.5	100.0	877	
													2000	HHI						N_{14}
													2800	Ott	s	1330	1355	450.0	11	Fig. A-8
													2980	Ned						
IV-176	9/15	0015	124	0042	N15 E75	2	0015	180	S	3+	0027		2000	Nag	C+	0017	0028	110.0	210	
											22/2						0036.5		1600	Fig. A-9
																	0054.4		2500	
													3750	Nag	C+	0015	0028	90.0	650	N_{15}
																	0036.5		4400	
																	0049.4		8080	
IV-179	9/20	2314	167	2403	N10 W09	2	2351	214	S	3	2400		2000	Nag	C	2350	2358.4	15.0	1200	
											76/2									
											2403	2410			F	2405	2430.4	55.0	800	Fig. A-10
											12/3	45/3								
															C+	2500	2517.4	55.0	2100	
													3750	Nag	C+	2350	2400.3	23.0	1400	
															C	2429	2432.7	6.0	330	
															C+	2500	2515.2	45.0	5350	

* Serial refers to Table 1, Ref.11

TABLE 2a

FAILURES
FLARES WITH IMPORTANCE $\geq$ 3 FOLLOWED BY A BASIC PCA EVENT,
TIME OF RF PEAK FLUX PRECEDED THE TIME OF THE Hα FLARE MAXIMUM

Serial No.*		FLARE				SHORTWAVE FADE			SPECTRAL TYPE		SINGLE FREQUENCY							POLAR CAP ABSORPTIONS			
	Date	Start	Dur. Min.	Time Max.	Position	Start	Dur.	Imp.	II	IV	f	Type	Start	Max.	Dur.	Peak Flux	Δ t	No.**	Onset Range Start Times	Int. db.	Δ T
	1957																				
II-2-52	9/26	1907	278	1952	N22 E16	1925	100	2+		1927 48/3	2800	CD	1915	1945	60	110	-13.5	20	2100 2100 to 2315	2.0	1h 53m
	1958																				
II-2-62	3/23	0947	280	1005	S14 E18	0953	196	3		1003(A)	1500 2980 3000	 CA BCD	 0953 0958	 -- 1002	 110 10	 > 1340 > 1190	- 3.0	23	1500 1500 to 1830	3.2	5h 13m
	1959																				
II-2-84	2/12	2301	134	2325	N13 E48	2308	40	2		2303 66/3	2000 3750	CD CD	2250 2250	2314 2313	55 70	335 440	-12.0	33	13/0800 13/0530 to 13/1730	2.6	6h 23m
II-2-99	7/10	0206	212	0230 (0236 0222 0308)	N20 E63 See Fig.B-1	0800	190	3+	0222	(0223B)	2000 3000 3750	CD SD CD	0211 0206 0209	0224 0224 0224	90 35 38	3000 1300 6300	- 6.0	35	0400 9/2000 to 10/1000	20.0	1h 54m
	1960																				
II-2-113	4/28	0130	15	0137	S05 E34	0120	100	3+	0120 20/2	0145 45/-	2000 3000 3750	C BCD C	0115 0124.5 0116	0129.7 0130 0129.5	30 15 40	285 512 260	- 7.5	43	0230 0200 to 1000	3.5	1h 0m
II-2-115	5/06	1404	376	1440	S09 E01 See Fig. B-2	1427	151	3	1438 7/3	1414 116/3	1500 2800 2980 3000	C+ C C	1408 1406.3 1420	1435.4 1434.9 --	213 90 28	520 695 > 620	- 5.5	46	1600 1400 to 1800	16.0	1h 56m
	1961																				
II-2-135	7/18	0920	210	1005	S07 W59	1000	113	3			1500 2980	C+ C+	0936.5 0939	0951.2 0959	232 65	>590 ~1300 2400	- 7.0		1130 1130 to 1200	10.0	2h 10m
II-2-138	9/28	2202	208	2223	N13 E29 See Fig.B-3	2218	69	2	2217 32/3+	2212 37/3	2000 2800 3750	C+ C+ C+	2211 2211 3212	2220.2 2218 2217.3	40 >30 40	1000 800 1690	- 5.7		2245 2245 to 2335	3.3	0h 43m

* Serial refers to Table 2, Ref.10
** Number refers to Table A-1, Ref.10

TABLE 2b

FAILURES
FLARES IMPORTANCE $\geq$ 3 FOLLOWED BY A SMALL OR VERY SMALL PCA EVENT,
TIME OF RF PEAK INTENSITY PRECEDES THE TIME OF Hα FLARE MAXIMUM

Serial No.*		FLARE				SHORTWAVE FADE			SPECTRAL		SINGLE FREQUENCY								PCA		
	Date	Start	Dur. Min.	Time Max.	Position	Onset	Dur. Min.	Imp.	II	IV	f	Obs.	Type	Onset	Max.	Dur. Min.	Peak Int.	Δ t	Type & No.	Start	Int.
	1957																				
II-3-33	2/21	1607	360	1930	N20 W30				1605 2008 3/2		2800	Ott	SD	1750	1915	240.0	(19)	-15.0	S3	[illegible]xx	S
	1959																				
II-3-79	1/26	0842	108	0900	N16 W61	0855	20	2			1500 2980 3000	NHI Ned NHI	CD CD M	0855 0855 0852	0856.5 -- 1036	5.0 12.5 180.0	344 39[illegible] 964	- 1.5	S1[illegible]	15xx	S
	1960																				
II-3-110	1/11	2040	195	2126	N22 E03	2100	24	2-	2103.3 14.7/3	2105 170/3	2800	Ott	S	2056	2109	> 35.0	220	-18.0	S1[illegible]	22xx	S
II-3-118	6/01	0824	456	0900	N29 E46	0837	75	3		(0837)	1500 2980 3000	NHI Ned	C+ C+	0822.4 0831	0840.5 0842	~300.0 60.0	700 3100	-12.0	S20	14xx	VS
II-3-119	6/25	1131	239	1215	N21 E06	1203	67	2		1215 165/3	1500 2800 2980 3000	NHI Ott Ned NHI	C+ C+	1148.5 1143	1207.0 1200	241.0 89.0	610 425	- 6.0	S22	17xx	VS
II-3-122	6/27	2140	125	2156	N21 W27	2141	138	2+	2157 15/3	2150 44/3	2800 3750	Ott	S	2140	2155	36.0	140	- 2.0	S23	23xx	VS
II-3-128	12/05	1825	325	1838	N26 E74	1830	100	3	1834 16/3	1833.5 16.5/3	2800	Ott	C	1828 1855	1837.5 --	27.0 >120.0	330 45	- 0.5	S38	05xx	VS

* Serial number refers to Table 3, Ref. 10

TABLE 2c

FALSE ALARMS
FLARES IMPORTANCE $\geq$ 3 NOT FOLLOWED BY A KNOWN PCA EVENT
TIME OF RF PEAK INTENSITY FOLLOWS THE TIME OF THE Hα FLARE MAXIMUM

Serial No.*		FLARE				SHORTWAVE FADE			SPECTRAL		SINGLE FREQUENCY						
	Date	Start	Dur. Min.	Time Max.	Position	Onset	Dur. Min.	Imp.	II	IV	f	Type	Onset	Max.	Dur. Min.	Peak Int.	Δ t
	1957																
II-4-34	2/28	0005	255	0014	N18 W32	0010	110	1+	0009/ 17/3+	0029/ 57/-	3000	CD	0000	0045	>50.0	224	+31
II-4-48	9/18	1026 1303	347	1045 1325	N23 E11	1030	104	3			1500 2000 2800 2980 3000	CD Sunrise SD SD	1100 1102 1100	1103 -- 1102	7.0 2.5 6.0	(157) 308 --	+18
	1958																
II-4-58	1/25	0915	112	1005	S24 W69	0938	74	3			1500 2980 3000	CD CD SD	0948 0932 0949	1015 1015	51.0 40.0 83.0	122 278 398	+10
II-4-70	8/07	1457	123	1508	S16 E71 See Fig. B-1	1500	105	3+			1500 2800 2980 3000	SD CA CA	1500 1500 1516	1503 1503 1522	57.3 15.5 12.5	136 (95) (180)	+14

* Serial refers to Table 4, Ref. 10

TABLE 3a

FAILURES

FLARES WITH IMPORTANCE <3, FLUX ≥500 FOLLOWED BY A PCA EVENT
TIME OF THE RF PEAK INTENSITY PRECEDES THE TIME OF THE Hα FLARE MAXIMUM

Serial No.*	Date	FLARE Start	Dur. Min.	Time Max.	Position	Imp.	SHORTWAVE FADE Onset	Dur. Min.	Type	Imp.	SPECTRAL II	IV	SINGLE FREQUENCY Freq.	Obs.	Type	Onset	Max.	Dur. Min.	Peak Int.	Δ t	POLAR CAP ABSORPTION No.	Onset	Absorption	Δ T
	1957																							
III-1-28	6/19	1609	40	1613	N20 E45	2	1608	44	S	3	1615 5/3	(1609)	2800 2980	Ott Ned	SA	1609	1610	10.0	2325	-3.0	7	2215 2215 to 2300	Weak	6h 06m
III-1-29	6/22	0236	21	0241	N23 E12	2	0229	74	S	2		(0231)	2000 3000	Nag Tok	CD CD	0233 0231	-- 0238.4	8.0 21.3	32 570	-2.6	8	0500 0500 to 1000	5.0	2h 24m
III-1-35	8/28	2010	235	2024	S29 E30	2+	2020	18	S	2+	2021.9 4.1/3		2800	Ott	SD	2017.7	2019.5	5.0	760	-4.5	13	2400 2400 to 2900	3.2	3h 50m
	1958																							
III-1-85	3/31	0005	--	0014	S17 W22	2	0006	44	G	2+			2000 3000 3750	Nag Tok Nag	CD CD CD	0007 0006 0006	0010.3 0010.3 0010.3	7.9 9.0 7.0	86 561 188	-3.7	S14	1600	S	
III-1-100	8/20	0042	46	0044	N16 E18	2+	0042	33	S	2+	0046 5/3 191-	0042	1420 2000 3000 3750	Syd Nag Tok Nag	CD ECD CD ECD	0040 0040 0041 0041.5	0044 0044 0043.3 0042.4	13.0 7.0 7.0 5.0	255 620 1260 1450	-1.6	29	21/1400 1400 to 1730	3.0	37h 10m Fig.A-2
	1960																							
III-1-162	9/03	0037	77	0108	N18 E88	2+	0045	126	SL	3+	0102 22/1	0038 >16/2	2000 3000 3750	Nag Tok Nag	C C+ C	0035 0059 0039	0105.2 0105 0104.6	90.0 50.0 85.0	7100 5800 12000	-3.4	48	0500 0500 to 2300	2.7	4h 23m Fig.A-5
	1961																							
III-1-169	[illegible]/19	1950	54	2010	N08 W80	1	1942	101	SL	3	1947 27/3	1937 50/3	2800	Ott	C	1930	2001	61.0	880	-9.0	56	2000 2000 to 2300	2.9	Fig.A-7

* Refers to Table 1, Ref. 11

TABLE 3b

FALSE ALARMS

FLARES WITH IMPORTANCE <3, RF PEAK INTENSITY FLUX ≥ 500 FLUX UNITS,
FLARE NOT FOLLOWED BY A KNOWN PCA EVENT
TIME OF RF PEAK INTENSITY FOLLOWS THE TIME OF H FLARE MAXIMUM

Serial No.*	Date	FLARE Start	Dur. Min.	Time Max.	Position	Imp.	SHORTWAVE FADE Onset	Dur. Min.	Type	Imp.	SPECTRAL II	IV	SINGLE FREQUENCY Freq.	Obs.	Type	Onset	Max.	Dur. Min.	Peak Int.	Δ t
	1956																			
III-1-12	7/22	1624	56	1641	N29 W54	2	1635	110	S	2+		(1638)	2800	Ott	SD SD	1638 1646.5	1641.8 1648	8.5 11.5	660 339	+0.3
III-1-13	11/8	0231	17	0242	N14 E62	1	0243	17	S	1			3000 3750	Tok Nag	CD CD CD	0223 0238 0241	0224 0245	8.0 10.0 4.8	369 538 74	+3.0
III-1-16	12/26	1401	67	1412	S17 W11	2	1403	97	SL	3-		(1403)	2800	Ott	CD	1403	1454	165.0	800	+42.0
III-1-17	12/29	0040	100	0045	N16 E59	1+	0044	106	S	3+		(0043)	3000 3750	Tok	CD	0043	0056	90.0	1150	+11.0
	1957																			
III-1-45	9/20	0529	23	0533	N23 W13	1	0532	10	S	1			2000 3000 3750	Nag Tok Nag	CD CD SD	0537 0537 0536	0539 0539 0539	8.0 11.0 6.0	23 509 200	+6.0
III-1-56	11/15	0517	79	0537	N18 W45	1+	0527	51	G	1-			1420 2000 3000 3750	Syd Nag Tok Nag	SD CD CA CD	0542 0526 0522 0522	0543 0542 0542 0542	6.5 25.0 >38.0 30.0	165 138 537 93	+5.0
	1958																			
III-1-75	1/15	1640	77	1642	S13 W58	2+	1640	120	S	3		(1640)	2800	Ott	SD SA	1640 1640	1720 1642.7	240.0 28.0	40 1350	+0.7
III-1-95	7/04	0513	21	0517	N29 E26	1+	0517	11	S	1			1420 2000 2980 3000 3750	Syd Nag Ned Tok Nag	 CD ESD	 0516 0515	 0517 0517.1	 4.0 2.5	 > 789 800	+0.1
III-1-97	7/24	2327	121	2443	N10 E85	2+	2444	56	G	2			2000 3000 3750	Nag Tok Nag	SD ESD SD	2440 2441.3 2441	2443.2 2443 2443.1	6.0 7.0 4.0	(75) 828 535	+0.1
III-1-98	7/29	0458	28	0458	S14 W38	1							2000 3000 3750	Nag Tok Nag	CD CD SD	0403 0505.2 0503	0510 0512 0510	40.0 8.0 30.0	(31) 506 (10)	+14.0
III-1-99	8/02	1840	11	1841	S14 W90	1-	1840	153	S	3+	1843 8/3	(1840)	2800 2980	Ott Ned	SD SA	1840 1840	-- 1842.1	> 300.0 25.0	30 2050	+1.1
III-1-106	12/11	1116	37	1127	S01 E03	2	1122	22	S	2			1500 2980 3000	HHI Ned HHI	CD CD	1111 1115	1129 --	24.0 20.0	683 358	+2.0
	1959																			
III-1-132	8/28	0027	61	0039	N11 E71	1	0028	140	SL	2+	0038 10/2	0055 155/-	2000 3750	Nag Nag	CD CD	0029 0024	0043 0041	25.0 30.0	250 540	+2.0
III-1-133	8/28	0111	12	0113	N13 E69	1							1420 2000 3000 3750	Syd Nag Tok Nag	 CD ESD	 0111 0115	 0123 0120 0118	 30.0 20.0	 2250 1520 890	+10.0
III-1-139	11/30	0247	69	0250	N08 E16	2+	0249	31	S	3-	0251 67/-	0312 38/-	2000 3000 3750	Nag Tok Nag	CD CD CD	0247 0248 0247	0250.3 0252.5 0252.3	18.0 9.0 12.0	2750 1229 1750	+2.3
III-1-140	12/02	1219	113	1229	N07 W16	2+	1246	76	S	2+		(1250)	2800 2980	Ott Ned	SD CD	1245 1246	1248 --	182.0 9.0	875 543	+19.0
	1960																			
III-1-161	8/14	1242	92	1310	N20 E36	2	1307	53	S	3-			2800	Ott	S	1307	1310.7	16.0	680	+0.7
	1962																			
III-1-171	3/13	1444	116	1446	N10 E66	2+	1448	94	S	3			1500 2000 2800 2980	HHI Ott	C C	1448.7 1447.5	1451.6 1450.3	70.0 19.5	>880 470	+5.6
	1963																			
III-1-174	9/14	2112	53	2123	N12 E72	1							2800	Ott	Pre C S	2134 2143	 2144.5	9.0 7.0	24 550	+21.6
III-1-175	9/14	2202	19	2206	N12 E73	1							2000 2800	Nag Ott	C C	2230 2229.5	2235.5 2235	12.0 10.0	1880 180	+29.5
III-1-177	9/16	1430	62	1505	N12 E48	2	1440	125	G	3			1500 2800 2980	HHI Ott Ned	C+ C+	-- 1436.5	1456 1452 1543	240.0 133.5	930 318 710	+38

* Refers to Table 1, Ref. 11

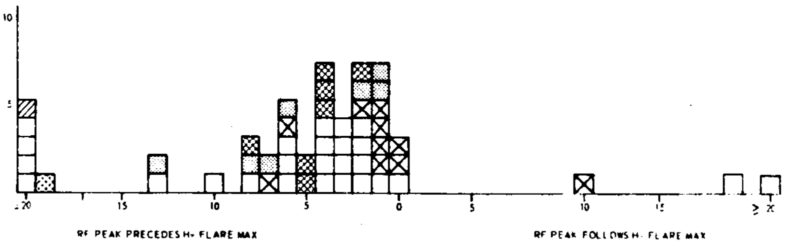

FIGURE 1a NOT FOLLOWED BY A KNOWN PCA

No RF Reported Probably Observing	19
No RF Patrol	5
Time of H$_\alpha$ Max. or RF Peak Unknown	14
Time of RF Peak Questionable	2

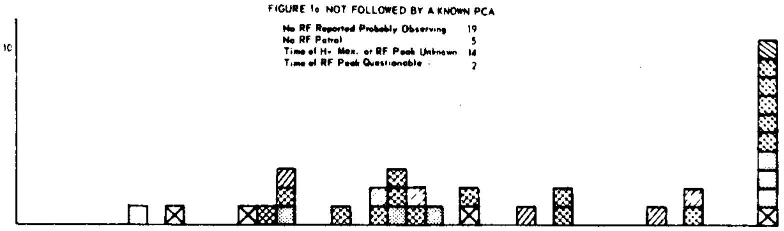

FIGURE 1b FOLLOWED BY IMPORTANT PCA

Value of Δt Unknown	4

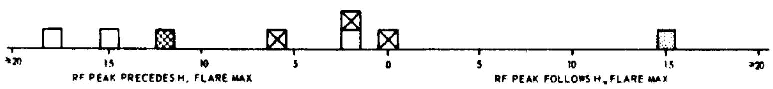

FIGURE 1c FOLLOWED BY VERY SMALL OR QUESTIONABLE PCA

Time of RF Peak Emission Unknown	1
Time of RF Peak Emission Questionable	1

FIGURE 1 DELAY TIME Δt BETWEEN Hα FLARE MAXIMUM AND RF PEAK INTENSITY. ALL FLARES IMPORTANCE ≥3, 1954 THROUGH 1963. RF FREQUENCIES 1420 THROUGH 3750 Mc/s.

Flux < 250, ☐ ; 250 ≤ Flux < 500 ☒

500 ≤ Flux < 1000, ▩ ; 1000 ≤ Flux ≤ 5000, ▩ ;

Flux > 5000, ▨

Units 10^{-22} W $(m^2$ c/s$)^{-1}$

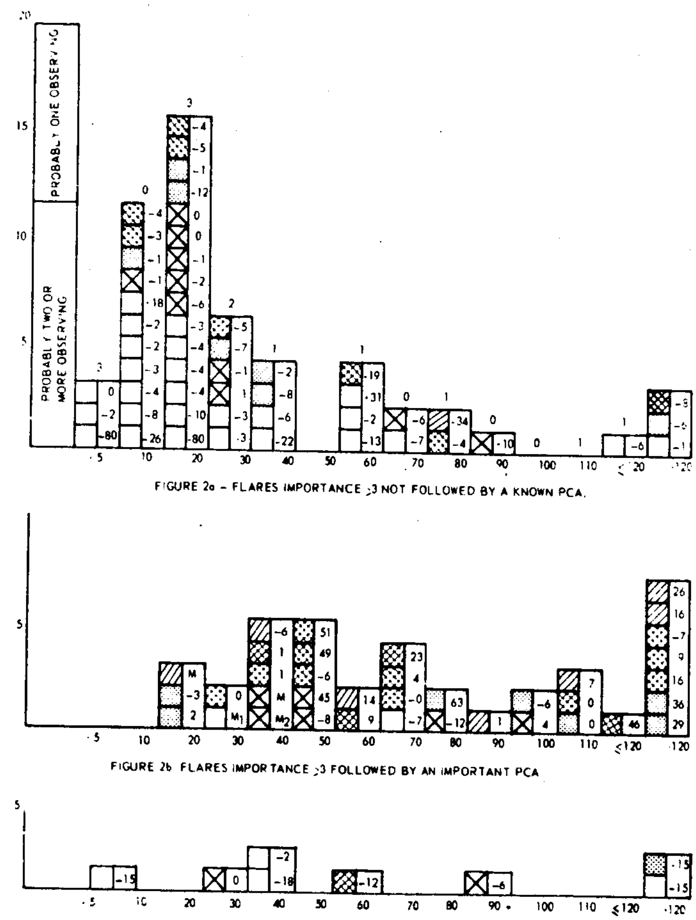

FIGURE 2a – FLARES IMPORTANCE ≥3 NOT FOLLOWED BY A KNOWN PCA.

FIGURE 2b FLARES IMPORTANCE ≥3 FOLLOWED BY AN IMPORTANT PCA

FIGURE 2c FLARES IMPORTANCE ≥3 FOLLOWED BY A SMALL OR QUESTIONABLE PCA

FIGURE 2 DURATION OF RF EMISSIONS 1420 TO 3750 Mc/s ASSOCIATED WITH FLARES IMPORTANCE ≥ 3 DURING 1954 THROUGH 1963

Duration of RF Emission – Minutes

Numbers to the right of Each Column give the Delay Time in Minutes; Numbers at the Top of Columns Show the Number of Flares Where Either the time of Flare Maximum or the RF Peak is Unknown

No RF Patrol	5
Time of RF Emission Questionable	2

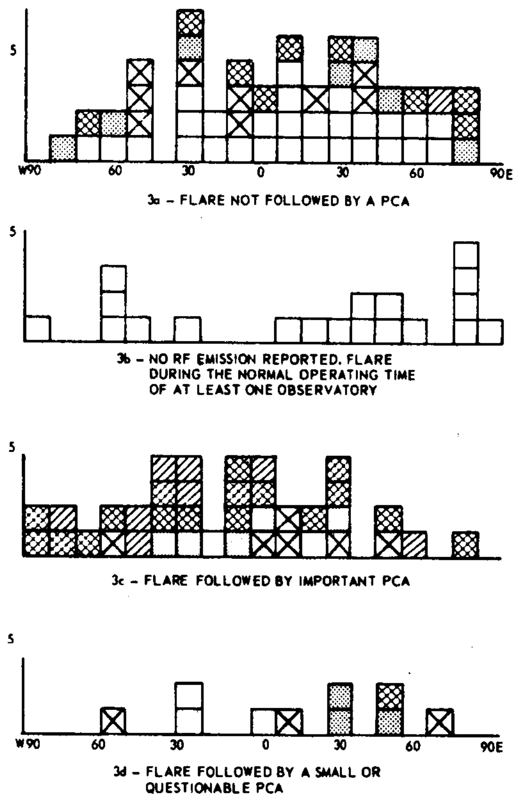

FIGURE 3 - SOLAR DISK DISTRIBUTION OF IMPORTANCE ≥ 3 FLARES

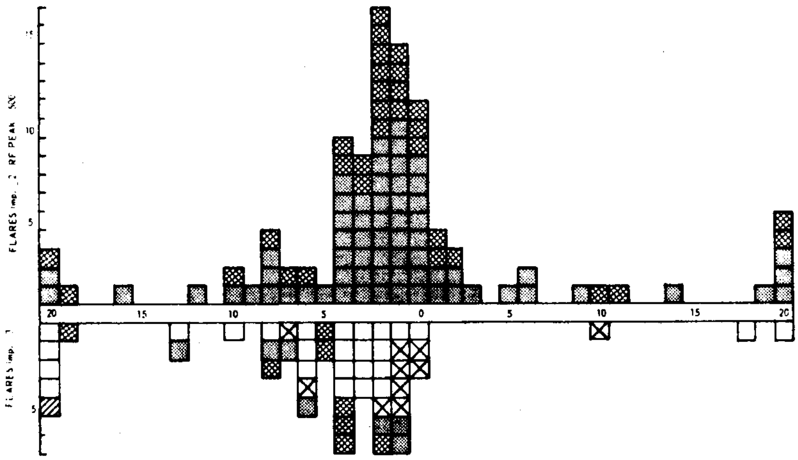

FIGURE 4 DELAY TIME IN MINUTES BETWEEN H FLARE MAXIMUM AND RF PEAK INTENSITY FLARES NOT FOLLOWED BY A KNOWN PCA EVENT. PERIOD 1954 THROUGH 1963. FREQUENCIES 1420 THROUGH 3750 Mc/s

Flux 250. 250 _ Flux 500

500 _ Flux 1000. 1000 _ Flux _ 5000

Flux 5000. Units 10^{-22} w/m^2 c/s^{-1}