DECAMETER STORM RADIATION, I

TOMAS E. GERGELY and WILLIAM C. ERICKSON
Astronomy Program, University of Maryland, College Park, 20742, U.S.A.

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Abstract. A log-periodic array, 3 km long in the E-W direction is in operation at the Clark Lake Radio Observatory. The solar brightness distribution is swept once per second in the 65–20 MHz frequency range. The analysis of the interferometer records allows the determination of one dimensional solar burst positions, to an accuracy of 0.1 $R_{\odot}$ at 60 MHz and 0.3 $R_{\odot}$ at 30 MHz, approximately.

Six long duration noise storms have been observed over an eight month period, extending from January to September, 1971. The storms are described and their relation to chromospheric active regions and flares is discussed. Decametric storms are found to be related to complexes of interacting active regions. The interaction is studied in terms of the number of 'simultaneous' flares observed to occur in the various active regions. On the average, twice as many 'simultaneous' flares are observed than would be expected if flares occurred at random. An analysis of coronal magnetic field maps computed from longitudinal photospheric fields shows magnetic arcades and some divergent field lines at the site of storm regions. Decimeter and meter wavelength sources are found to be associated with all decameter storms. At decimeter wavelengths double or multiple sources are often seen above individual active regions forming part of the chromospheric complex.

1. Introduction

Noise storms, type II and type III bursts have been observed from heights of about 0.2 $R_{\odot}$ above the photosphere all the way to 1 AU. These bursts present radio evidence of disturbed conditions in the solar corona. Noise storms are particularly interesting, since they are long lasting (of the order of days), and thus enable us to study relatively persistent features which might be present in the corona.

Meter wavelength noise storms consist of a more or less steady continuum and of superimposed type I bursts. Comprehensive reviews of noise storms at meter wavelengths have been given by Wild *et al.* (1973), Kundu (1965) and by the Solar Radio Group at Utrecht (1974). Fine structure in metric storms has been discussed recently by Rosenberg (1971, 1972) and Rosenberg and Tarnstrom (1972). At the kilometer and hectometer wavelengths the storms have been studied with the aid of satellite-borne equipment (Fainberg and Stone, 1974). Storms at decameter wavelengths have been first described by Warwick (1965). At these wavelengths the storms are seen to consist of type III bursts and other fine structure (de la Noë *et al.*, 1973) superimposed on a more or less steady continuum. The radiation originates at heights from approximately 0.5 $R_{\odot}$ to 2.5 $R_{\odot}$ above the photosphere. Thus the study of decametric storms is of interest not only because it provides a link between metric and kilometric observations of the storms, but also because it provides some insights into the properties of coronal regions where the solar wind originates.

In this paper we describe the evolution of six decametric storms which took place during the period January to August, 1971. We discuss the relationships of decametric

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storms with chromospheric active regions, coronal magnetic fields, and meter and decimeter wave activity.

The storms described here were observed with the swept frequency interferometer of the Clark Lake Radio Observatory operated by the University of Maryland. This array (hereinafter referred to as the LPA) consists of sixteen log-periodic antennas, equally spaced on a two mile east-west baseline. The array is swept in frequency over the range 20–65 MHz once per second. This system gives the one dimensional position and angular size of emissive regions on the Sun nearly simultaneously at all frequencies. The array beam spacing and width are such that only one beam is on the Sun at one time. The angular resolution is about 5′ at 60 MHz decreasing to 15′ at 20 MHz. A more detailed description of this instrument was given by Erickson and Kuiper (1973).

2. Observations

When observed with a time and frequency resolution of about 1 s and 10 kHz respectively, decametric storms are seen to consist of a background continuum of varying intensity, often with considerable structure in frequency. Superimposed on this background we often observe a large number of type III bursts. These bursts can be distinguished from the underlying continuum because of their much higher intensity and characteristic frequency drift. Type I bursts are seen much less frequently at decameter wavelengths than on meter wavelengths. Although type I bursts are known to occur less frequently at longer wavelengths, the low number seen on the Clark Lake records may be partly attributed to instrumental effects. Since the duration of these bursts is usually less than a second, at a one per second sweep rate the bursts are often integrated into the background continuum. There are extended periods during some of the storms when no type III or I bursts can be seen.

At the maximum of solar activity noise storms can be observed about 80% of the time on meter wavelength dynamic spectra. Good correspondence has been shown to exist in time between the meter and decameter storms by Boischot *et al.* (1971). Thus, it can be expected that decametric and metric storms will occur with approximately the same frequency. In their studies of metric and decimetric storms, Malinge (1963) and Clavelier (1967) defined storms on a day-to-day basis. In view of the evident continuity of the phenomenon when following a storm day by day, we prefer to define a storm as the whole of the activity related to a center during its disk passage. We shall show that a decametric storm can be related to several active regions on the disk. Therefore, the above statement should not be interpreted as implying a one-to-one correspondence between storms and active regions. The storms at long wavelengths often show much detail and occasionally consist of double sources. For this study we selected a relatively quiet period during which there was only one storm region on the Sun at a time. According to our definition a total of six storms were observed during the period considered, which extends from January to August, 1971. Typical examples of storms, corresponding to the dates of 1971, January 9 (decametric region 1) and of 1971, April 14 (decametric region 3) are shown in Figures 1a and 1b. A list of the

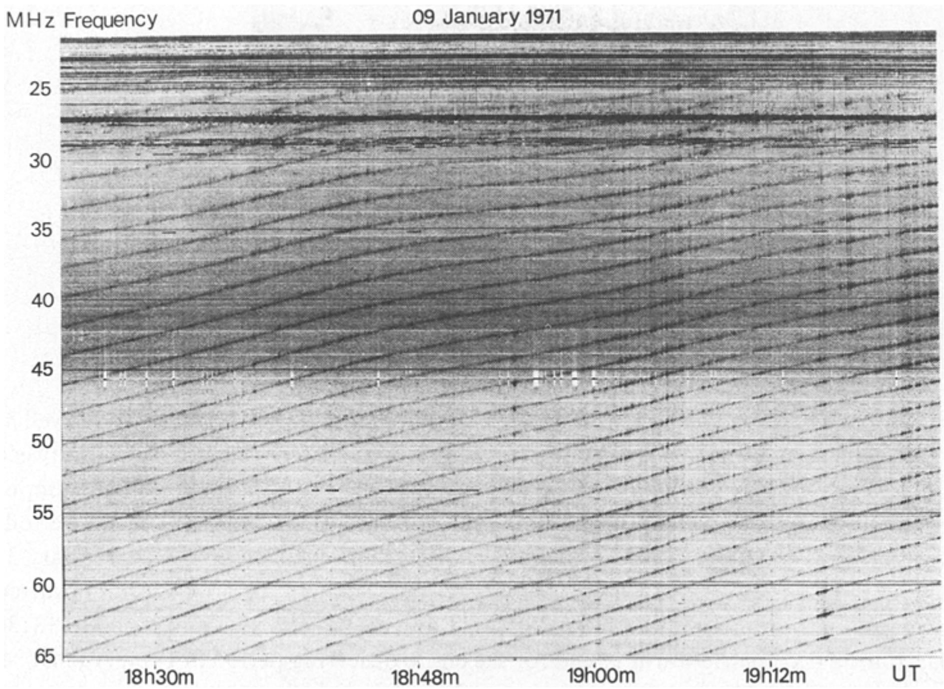

Fig. 1a. Typical examples of a decametric storm recorded at Clark Lake, in 1971, January 9 (storm region 1).

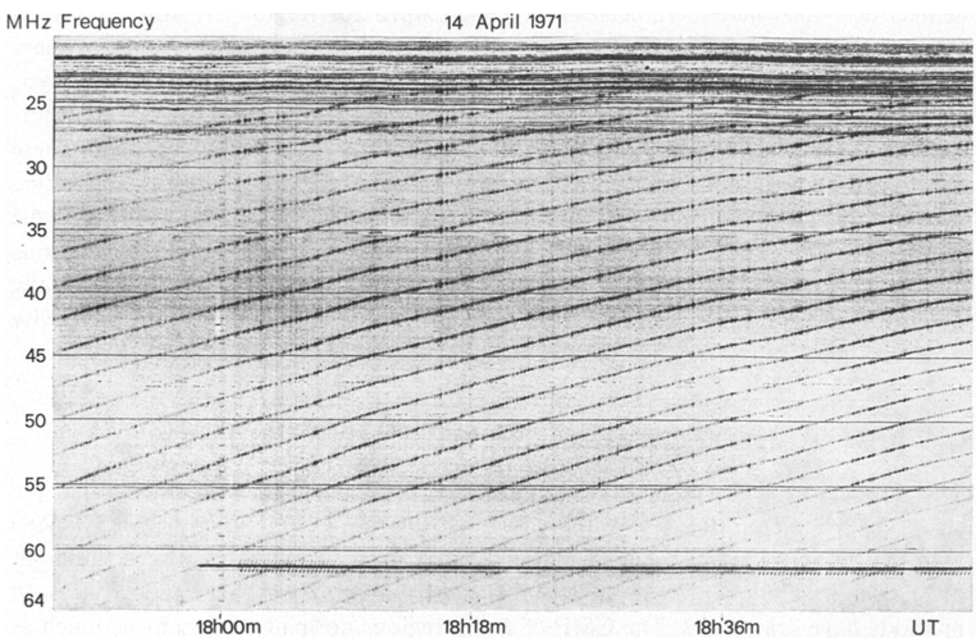

Fig. 1b. Same as Figure 1a for 1971, April 14 (storm region 3).

TABLE I

Periods of type III and continuum activity related to decametric storms

Decametric region	Type III activity		Continuum activity		Peak of activity
	Start	End	Start	End	
1	Jan. 4	Jan. 17	Jan. 5	Jan. 12	Jan. 7–9
2	Jan. 19?	Jan. 24	Jan. 19?	Jan. 24	Jan. 19–21
3	Apr. 6	Apr. 19	Apr. 11	Apr. 17	Apr. 14–16
4	May 4	May 12	May 7	May 12	May 7–9
5	July 13	July 22	July 14	July 19	July 15–17
6	Aug. 15	Aug. 29	Aug. 19	Aug. 25	Aug. 20–24

storms observed, the first and last day of continuum and of type III activity, as well as the days when the storms peaked are given in Table I. There was no overlap between the several storms observed. Occasionally the type III or the continuum emission, or both, stopped for a couple of hours or even for an entire observing period. Periods with no emission at all occurred in course of decametric storm 2, in 1971, January 22 and decametric storm 3 in 1971, April 10. Periods lacking type III emission occurred on January 9, from about 19:40 to 21:00 UT and on January 11, from 18:00 to 18:30 UT during decametric storm 1; and for the entire observing period in 1971, August 24, in course of decametric storm 6. It is worth mentioning that on these occasions the continuum emission was extremely intense and was always modulated by strong ionospheric refraction. Moving type IV or type II-type IV events, related to the storm centers described here have been observed on April 20 (Region 3); May 13 and 14 (Region 4), and September 1 (Region 6). These bursts have been discussed elsewhere in detail (Gergely and Kundu, 1974; Gergely, 1974). The intensity of both the type III and the continuum emission fluctuated widely during all storms. The rate of occurrence and the starting frequency of type III bursts was also highly variable. These topics will be discussed in a forthcoming paper. Some shortlived storms, exhibiting sporadic activity, also occurred during the period discussed here. Such sporadic storms last for a couple of hours and occasionally reappear the next day. These storms are not discussed here. In February and March, 1971, the Sun was exceptionally quiet in the decametric range. Isolated type III bursts were the only form of activity observed during these months and were studied in detail by Kuiper (1973).

3. Association with Optical Activity and Photospheric Fields

The association of storms with active regions can be studied in two ways. First, the storms have long duration and we can associate their central meridian passage (CMP) with that of active regions. Second, we may look for a correlation between the onset or the intensification of a given storm and related chromospheric activity. Both methods have drawbacks. The CMP of storm regions normally differs by as much as 0.5 days when observed at different frequencies in the 20–65 MHz range. Parts of several active regions are sometimes observed at the central meridian during this period. More importantly, the decametric storms may originate in non-radially oriented coronal structures (Malinge, 1963; Stewart and Labrum, 1972). The second method can also give rise to erroneous identifications because several flares may occur in a given period of time preceding or following the onset of a storm. To minimize errors due to these possibilities we studied the association using both methods.

Table II presents the CMP date for each storm observed at different frequencies. The CMP times are accurate to approximately 0.4 days. The table also shows the CMP date for the active regions that might be associated with the storm regions (for the cases where CMP active region = CMP storm $\pm$ 3 days).

The CMP of region 1 occurred on January 10; the active regions with the nearest

TABLE II

CMP date of decametric and metric storms and of associated active regions

Decametric region	Freq. (MHz)	CMP date	McMath number	CMP date	Age and magnetic field of region
1	60	Jan. 10.0	11114	Jan. 11.5	young region; strong fields
	50	Jan. 9.9	11111	Jan. 10.6	old region; weak fields
	40	Jan. 9.7	11112	Jan. 10.2	
	30	Jan. 9.6	11120	Jan. 9.6	
			11110	Jan. 9.1	
	169	Jan. 10.1	11124	Jan. 9.0	
			11108	Jan. 8.3	decaying region; weak field
2	50	Jan. 20.8	11128	Jan. 20.5	strong fields, young regions,
			11129	Jan. 23.5	satellite spots in McMath
			11130	Jan. 23.0	11128
	169	Jan. 21.2	11133	Jan. 25.0	
3	50	Apr. 15.1	11253	Apr. 14.1	emerging region; strong fields
	40	Apr. 15.0	11249	Apr. 16.2	young region; intense fields
			11250	Apr. 16.8	weak fields
	169	Apr. 15.7	11256	Apr. 17.7	young region; intense fields
			11257	Apr. 17.7	young region; intense fields
4	60	May 7.7	11294	May 6.9	developed region; strong field
	50	May 7.6	11296	May 8.4	emerging region; weaker field
	40	May 7.7			
	30	May 7.9			
	169	May 6.9			
5	50	July 19.0	11423	July 16.2	
	30	July 18.8	11424	July 18	old region; weak field
			11425	July 18.8	young region; strong field
			11429	July 20.0	young region; strong field
6	50	Aug. 20.6	11480	Aug. 22.4	strong field
	40	Aug. 20.8	11482	Aug. 23.4	complex region; extremely
	169	Aug. 22			strong field
	169	Aug. 23.9			

CMP date being McMath 11120, 11111, 11112. However the region McMath 11120 developed on January 11, at a time when the noise storm has already reached its maximum. At decameter wavelengths the region 2 crossed the central meridian between January 20 and 21, shortly after the large active region McMath 11128.

At 50 MHz the CMP of region 3 occurred on April 15.1. The three regions with closest CMP date were McMath 11253, 11249 and 11250. The CMP of the next two regions (Nos. 4 and 5) falls between that of two active regions. For region 4 the CMP at 60 MHz occurred on May 7.7 between the plages McMath 11294 and 11296. The CMP of region 5 occurred on July 19.0, between plages McMath 11425 and 11429. Finally, the CMP of region 6 occurred on August 20.6. No active region passed the central meridian on this day. It can be seen that no clearcut association of storms with chromospheric active regions can be established purely on the basis of the CMP date.

A total of 48 storm intensifications and onsets occurred during our observing period at Clark Lake. To establish the beginning of a storm from the interferometer records presents no difficulty. Since no quantitative flux measurements were available, personal judgment had to be exercised to establish the times of intensifications. It must be emphasized that since the sensitivity of the system varies with direction, galactic background temperature, and receiver settings, all intensifications noted are relative to the emission level that existed in the preceding few minutes. The build-up of a storm was very gradual in all but a few cases and intensification or onset should be taken as approximate to ± 10 min.

A complete list of the flares and subflares which occurred during the three hour period preceding each decametric storm onset or intensification has been given elsewhere (Gergely, 1974). The occurrence of some flares prior to a storm onset must be considered accidental on the basis of the relative position of the flaring region and the decametric source. Eliminating these flares from the sample two interesting facts emerge. First, the flares which preceded the onsets or intensification which occurred in course of a given storm did not always originate in the same chromospheric active region. For example, from the flares preceding the eight observed intensifications or onsets related to decametric storm region 5, four occurred in McMath region 11425, three in McMath region 11429, and one in McMath region 11423. We recall that the decametric source appeared to cross the central meridian between the McMath regions 11425 and 11429.

Six onsets or intensifications were observed at Clark Lake, related to storm region 3. Four of them occurred following subflares in McMath region 11253. Out of the other two, one occurred in between two subflares which were reported to occur in McMath region 11250, the other one followed a subflare in McMath region 11257. The decametric source crossed the central meridian shortly before the complex of active regions McMath 11249-50-56-57; and approximately a day after the McMath region 11253.

Secondly, flares and subflares occurred very closely in time in several neighboring active regions before and after some of the storm intensifications. For example prior to a storm onset on July 15 at 17:45 UT subflares occurred in McMath regions 11423 and 11425 at 17:20 and 17:18 UT respectively. Another storm intensification on April 11 at 19:35 UT was preceded by subflares which started at 18:04 and 18:02 in McMath regions 11257 and 11249 respectively. A storm intensification on April 13 at 22:36 UT was preceded by a subflare at 22:33 UT in McMath region 11253 and was in turn followed by a subflare at 22:40 UT in McMath region 11250. In the above we have only given some examples of quasi-simultaneous flare activity in several active regions during decametric storms. Other examples have been given by Gergely (1974). Quasi-simultaneous flare activity in several active regions is often observed not only at the onset time but also while the decametric storm is in progress. Figure 2 illustrates this kind of behavior. The flare activity in neighboring active

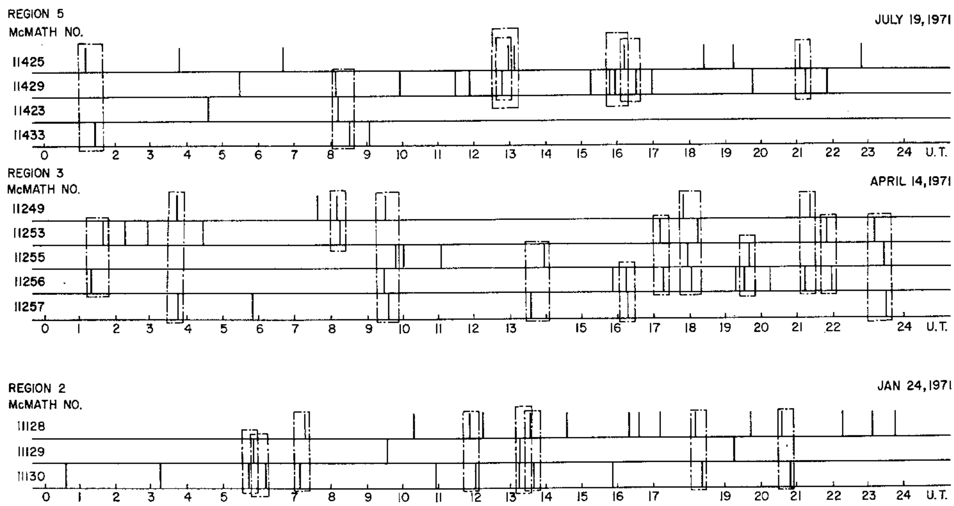

Fig. 2. Quasi-simultaneous flare activity in active regions related to decametric storms 5, 2 and 3. The subflares which are enclosed in boxes occurred with a separation in time of less than 20 min.

regions, which underlie the decametric storms 2, 3, and 5 is shown for one day in each case. The starting times of flares and subflares is indicated by the vertical lines. The flares which occurred in different active regions and were separated in time by 20 min or less are shown in enclosed in boxes. The clustering of flares at certain times is obvious. These observations suggest that a given decametric storm may be related to several, interacting active regions, rather than to a single active region. 'Sympathetic' flares have been discussed previously by Waldmeier (1938), Becker (1958), Fritzová (1959), and Smith (1962) among others. These authors studied either some well documented, albeit isolated cases of simultaneous flare activity in distant active regions, or the global flare statistics over extended periods of time. In the latter case no physical relation was known to exist between the regions considered and the results have not been conclusive. In what follows we analyze statistically the flare occurrences in the active regions which, due to their position, appeared to be related to each decametric storm. This approach provides us with a reasonable time interval over which to consider possibly correlated activity, as well as with a criterion which permits us to consider only those regions which might indeed be physically related.

Let us assume that a given active region produced N_1 flares and subflares in a given period of time T. Subdividing this period of time into I intervals of duration Δt each, the probability for a flare to occur in any interval Δt is given by

$$P_1 = \frac{N_1}{I}. \tag{1}$$

If a second region is flare-active over the same period T, we can predict the number of 'simultaneous' flares where 'simultaneous' is defined as flares occurring in both active regions within the same interval Δt. We chose the time interval Δt to be 20 min in order to consider two flares as 'simultaneous', and in the rest of this paper the word 'simultaneous' will be used in this context.

Assuming that the activity in the two regions is uncorrelated, the number of intervals, N_{12}, containing simultaneous flares is given by

$$\frac{N_{12}}{I} = p_1 p_2 = \frac{N_1 N_2}{I^2}, \tag{2}$$

where N_2 and p_2 are the total number of flares and the flare probability in region 2. If the actual number of simultaneous flares, N'_{12}, exceeds the estimate N_{12} to a statistically significant degree, then the flare activity in the two regions must be correlated. The standard deviation of the estimate, N_{12} will be

$$\Delta N_{12} = \frac{1}{I}(N_1 \sqrt{N_2} + N_2 \sqrt{N_1}) \tag{3}$$

assuming that the flare occurrences in both active regions follow a Poisson distribution. It will be shown below that in several cases, N'_{12} is approximately two times N_{12} and this excess is statistically significant. Therefore, we conclude that when active regions show evidence of physical interaction through their association with a single decametric source, then the flare activity in the regions is often significantly correlated. The interacting regions will now be discussed in more detail.

Figures 3a to f show the Fraunhofer Institute maps close to the CMP of each storm region. The active regions underlying each decametric source are indicated by their McMath numbers. The mean position of the radio source is indicated by the heavy line and its size by the two broken lines at the highest frequency of measurement. Since the times of observation of the plages and the radio sources do not coincide exactly, we interpolated the radio positions between two consecutive days. We analyze below the flare activity related to each radio region along with its magnetic field and filament configuration.

The projected position of the centroid of radio source 1 appears at the location of McMath regions 11111 and 11112 (Figure 3a). Other active regions also apparently

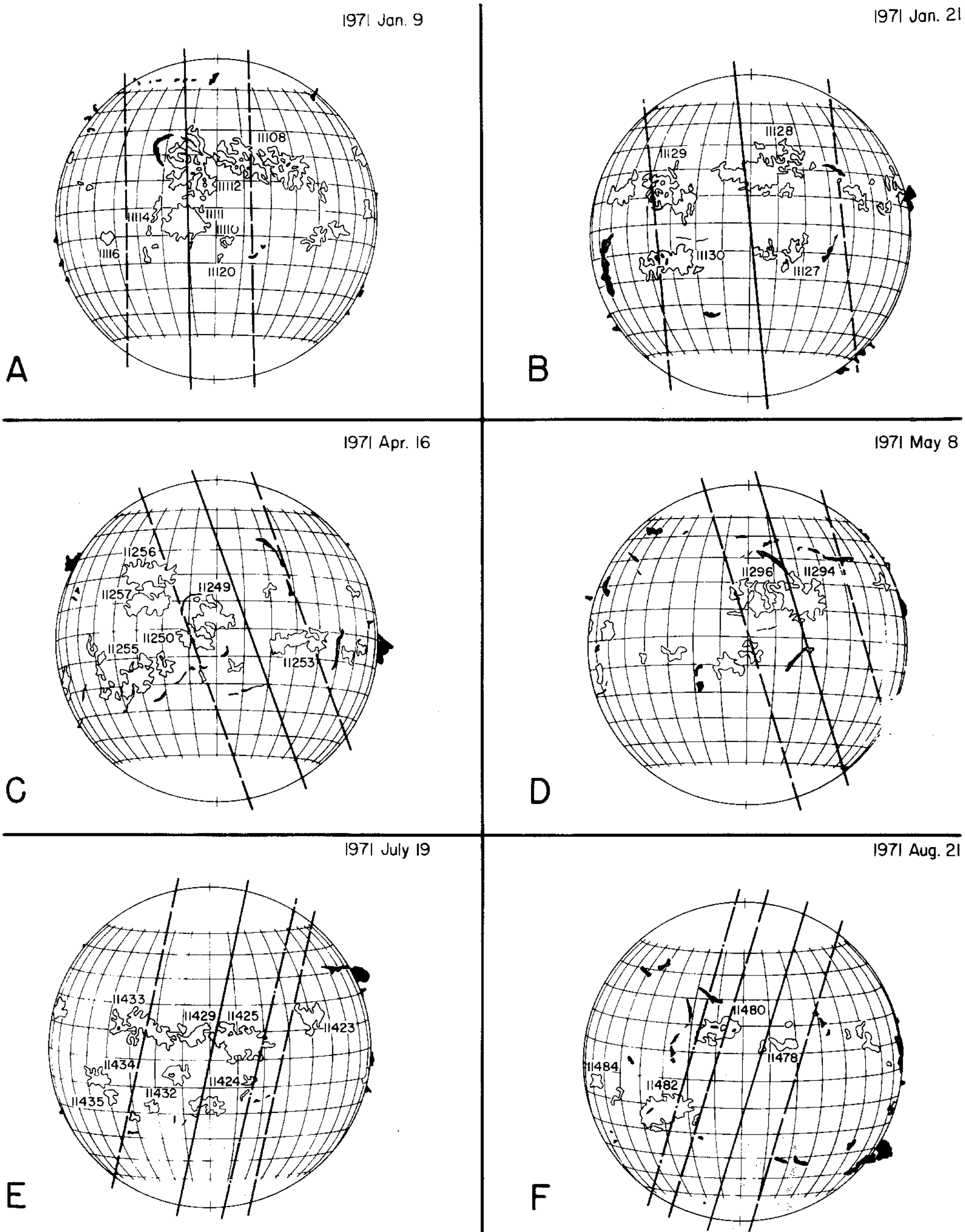

Fig. 3. (a) Projected position of the decametric storm 1, 1971, January 9, is indicated on the Fraunhofer Institut Map. Associated active regions are identified by their McMath numbers. The solid line indicates the centroid of the source at 60 MHz, and the two dashed lines indicate its size. (b) Same for decametric storm 2, 1971, January 21. (c) Same for decametric storm 3, 1971, April 16. (d) Same for decametric storm 4, 1971, May 8. (e) Same for decametric storm 5, 1971, July 19. The line indicates the centroid of the type III group mentioned in the text. (f) Same for decametric storm 6, 1971, August 21. The line indicates the centroid of the type III's, displaced eastward from the continuum source which occurred this day.

associated with the decametric source are McMath 11108-10-14-20. A large stable filament separated McMath regions 11112 and 11108; smaller filaments were observed delineating the neutral line in McMath regions 11111 and in some of the other regions. Most of the flare activity was produced by McMath region 11111. It produced 63 flares and subflares between January 6 and 12. Only four simultaneous flare pairs were observed to occur during the period January 6 to 12; all four involved the region McMath 11111 and one or the other of the regions mentioned. This small number of simultaneous flare pairs was judged to be insufficient to perform a meaningful statistical analysis. However, it should be pointed out that Caroubalos *et al.* (1973) analyzed a pulsating radio event that occurred in 1971, January 14 at meter wavelengths and was related to the continuum source we have studied. They reported that during most of the disk passage of the meter wavelength storm two stable sources were observed at 80 MHz; one was located above the complex of regions McMath 111-10-20, the other one above McMath 11108. The occasional interaction of these two sources at 80 MHz was reported (Caroubalos *et al.*, 1973).

The decametric region 2 was located above the large active region McMath 11128 (Figure 3b) which gave origin to the proton flare of 1971, January 24. Active regions McMath 11127, 11129 and 11130 were also located under the decametric source. The McMath region 11127 contained weak magnetic fields and produced only two subflares during disk passage. The other three active regions contained intense magnetic fields. The magnetic configuration of McMath 11128 was especially complex. This was the most active of the three regions associated with the decametric storm. It produced 132 flares and subflares between January 17 and 26. A large number of simultaneous flares occurred between January 17 and 26. The number of expected and observed simultaneous flares which occurred in these regions, as well as the standard deviation of the expected number of simultaneous flares is shown in Table IIIa. In those cases where the formal standard deviation is less than 0.5 it is shown as zero in the table.

The number of observed simultaneous flares indicates strong interaction between McMath regions 11128–11129 and 11128–11130, and a smaller degree of interaction between the regions McMath 11129–11130. This result is not unexpected in view of the magnetic configuration and the dominant flare activity in McMath region 11128. Further evidence for interaction between McMath region 11128 and the other two regions comes from 80 MHz observations of the radio event, related to the proton flare of 1971, January 24 (Riddle and Sheridan, 1973). Numerous sources were observed during the early phase of this event, most of them close to, or above, the west limb of the Sun. However two of the sources (designated E and F by the authors) appeared approximately above the active regions McMath 11129 and 11130.

Several active regions were found to be associated with decametric storm region 3 (Figure 3c). Slightly to the east of the projected position of the centroid of the decametric source we find the complex of regions McMath 11249-50-55-56-57. To the west is located McMath region 11253. We noted already that some of the intensifications of the decametric source took place following subflares that occurred in McMath

TABLE III

Simultaneous flare activity in active regions related to decametric storms

(a) Active regions related to storm 2

McMath region	11128	11129	11130
11128	–	(13) 5±2	(24) 10±2
11129	–	–	(4) 2±1
11130	–	–	–

(b) Active regions related to storm 3

McMath region	11249	11250	11253	11255	11256	11257
11249	–	(0) 1±1	(4) 1±1	(2) 0±0	(3) 2±1	(2) 1±0
11250		–	(2) 2±1	(1) 1±0	(7) 3±1	(2) 1±1
11253			–	(3) 1±0	(4) 6±1	(4) 2±1
11255				–	(5) 2±1	(2) 1±0
11256					–	(10) 3±1
11257						–

(c) Active regions related to storm 5

McMath region	11423	11425	11429	11430	11433
11423	–	(7) 3±1	(1) 1±0	(2) 0±0	(1) 2±1
11425		–	(8) 3±1	(7) 1±0	(12) 6±1
11429			–	(3) 0±0	(3) 2±0
11430				–	(0) 1±0
11433					–

The upper figure at the intersection of a given column and row indicates the number of observed flare coincidences for the pair of regions involved. The lower figure indicates the number of expected flare coincidences and the error; assuming random flare occurrence in both regions.

region 11253, while others occurred after subflares in McMath regions 11250 and 11256. Several long filaments appear near the active regions McMath 11256-57-50-49-55. These filaments separate regions of predominantly positive fields from predominantly negative fields, as observed on the corresponding Mt. Wilson magnetograms. The simultaneous flares for the active regions involved is shown in Table IIIb. The regions which appear to interact most strongly are McMath 11249-57; 11249-53; 11250-56; 11253-55; and 11256-57. These regions are the same as the ones that produced flares before the intensifications of storms.

Two active regions were associated with decametric storm region 4. One of them, McMath 11294 was very flare active, producing 52 flares and subflares between May 6 and May 13. It was the site of several major flares during this time; moving type IV bursts related to two of these were observed at Clark Lake. The other region, McMath 11296 produced only two subflares, both simultaneous with flares in McMath 11294. A stable filament existed between the two active regions (Figure 3d).

Numerous active regions were associated with decametric source 5 (Figure 3e). The disk passage of these regions was characterized by a high level of flare activity; 190 flares and subflares were observed from the complex between 1971, July 12 and 24. We already noted that storm intensifications followed subflares that occurred in McMath regions 11425 and 11429. The numbers of simultaneous flares for these regions are given in Table IIIc. A high degree of correlation between some of the active regions involved is obvious.

The active regions McMath 11478 and 11480 were associated with decametric

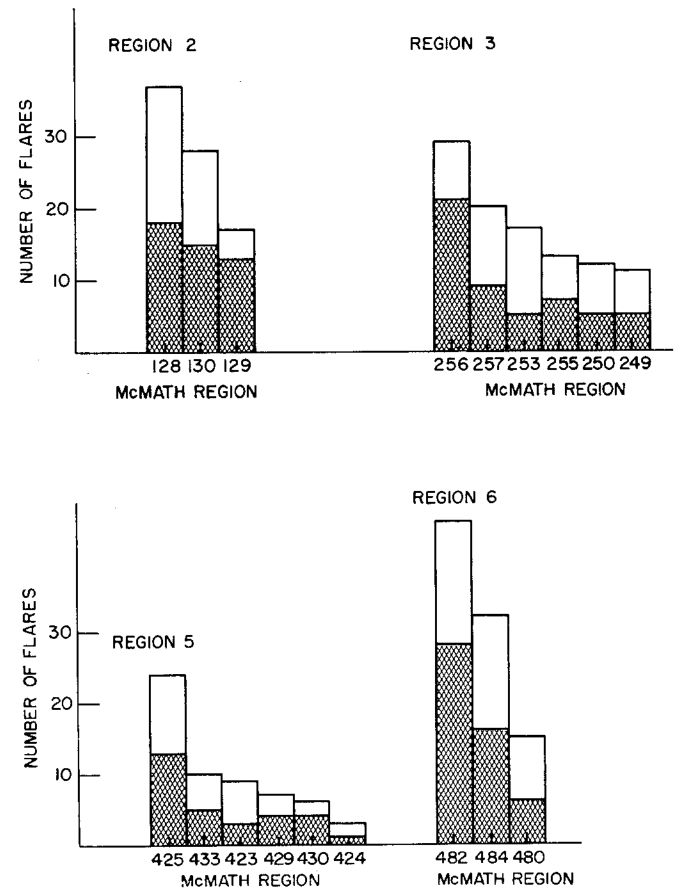

Fig. 4. Histograms of simultaneous flares in storm related active regions. 'Cross-hatching' indicates the flare pairs which started in the region.

source 6 (Figure 3f). The McMath region 11478 was marginally active during the storm and will not be considered here. To the east of the decametric source we observe the McMath region 11482. There is no doubt that this region was related to the decametric storm. It was extremely flare active, some of the flares giving rise to very intense type III groups. These type III groups occurred slightly to the east of the continuum source. Both active regions McMath 11480 and 11482 contained intense magnetic fields. A long filament, stretching in the north-south direction again separated magnetic regions of opposite polarity. During the period August 16 to 26, 28 flares occurred in McMath region 11480, 12 of these simultaneous with flares that occurred in McMath region 11482. The McMath region 11484 also interacted strongly with the McMath region 11482 and produced 32 simultaneous flares from a total of 54.

Figure 4 shows a histogram of the simultaneous flares involving the active regions associated with each storm. The coincidences corresponding to the occurrence of the first flare of the pair occurring the region are shown in dark. Even for the most flare-active regions, such as McMath 11482 or 11128 about 50% of the initial flares of a pair occurred in some other, less active region. In every case that we studied, a decametric storm appeared to be associated with multiple active regions and there is at least some evidence of interaction between these regions.

In order to determine whether or not a direct association between flares and decametric storms could be established, we considered the distribution of the time differences between the start of a flare and the associated radio storm. The distribution peaked at a time interval of about 20 min between the start of a flare or subflare and the associated radio storm. However, the average time between flares and subflares was also about 20 min during these periods so it was impossible to make an unambiguous relationship between the radio events and the chromospheric flares and to determine an average time difference between the chromospheric flares and to determine an average time difference between the chromospheric flare and the radio storm onset or intensification. With the exception of one Imp 1 flare, all the storm onsets or intensifications were preceded by subflares.

4. Relation of Decametric Storms to Coronal Magnetic Fields

Altschuler and Newkirk (1969) computed coronal magnetic fields from observations of the longitudinal component of photospheric fields. They used a current-free approximation and assumed that the field lines reaching up as high as 2.5 $R_{\odot}$ were drawn out by the solar wind into interplanetary space. Since only the longitudinal component of the photospheric field is available for the computations, data collected over half a solar rotation must be used to construct the map for any given day. Rapid changes in the magnetic fields are not reflected in the maps for this reason. Newkirk and Altschuler (1970) compared the coronal structures observed in white light with the calculated magnetic fields and found good agreement between the density structure of the corona and the calculated field configurations. Several characteristic shapes of these configurations were described by them. Diverging fields (DF) reach out from a

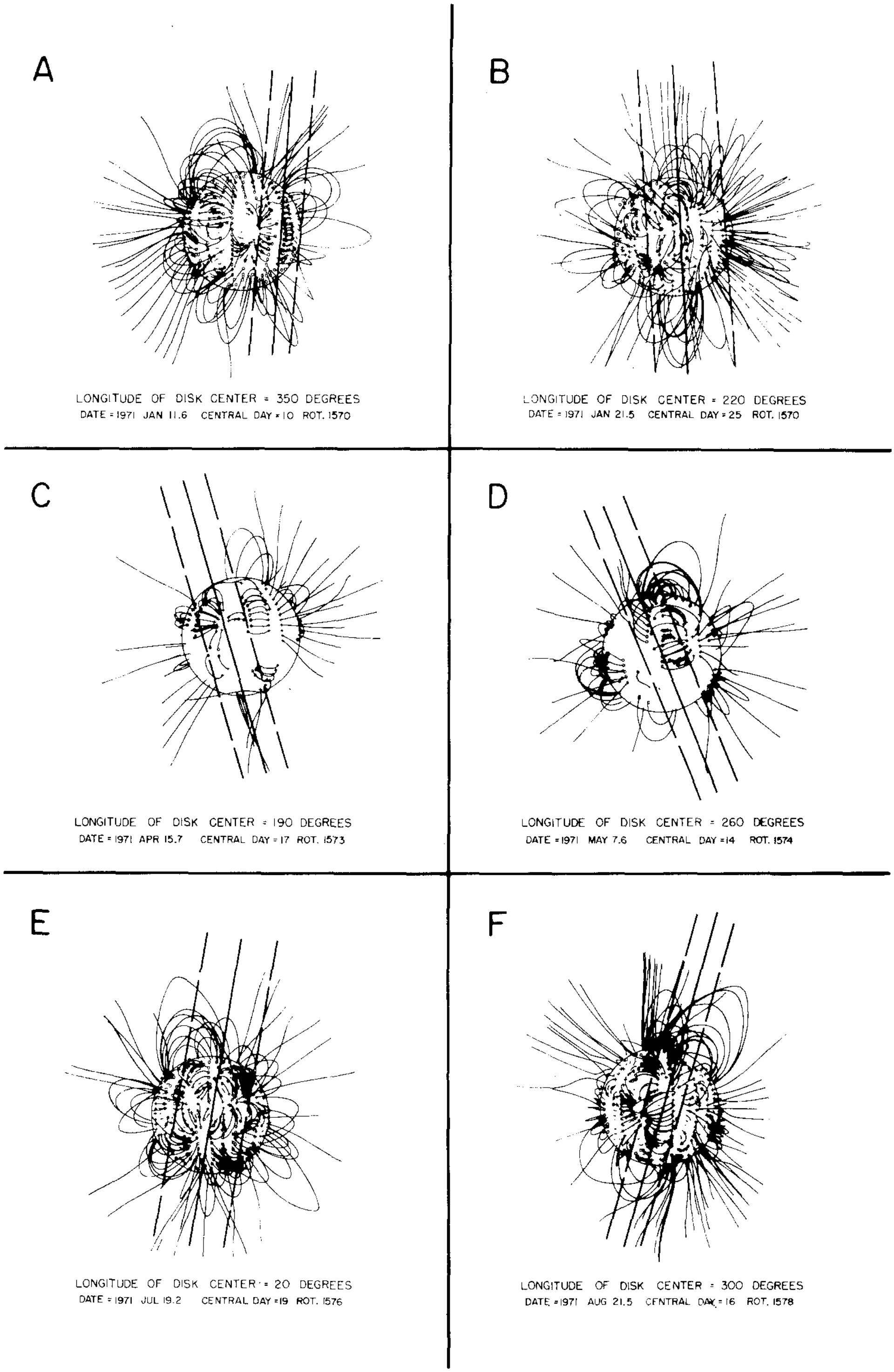

Fig. 5. (a) Magnetic fields related to decametric source 1. The centroid of the source is indicated by the solid line, its size by the two dashed lines. (Magnetic maps courtesy of Ms. D. Trotter, High Altitude Observatory.) (b) Same as Figure 4a for decametric storm region 2. (c) Same as Figure 4a for decametric storm region 3. (d) Same as Figure 4a for decametric storm region 4. (e) Same as Figure 4a for decametric storm region 5. (f) Same as Figure 4a for decametric storm region 6.

central focal point to neighboring, low field regions. Low magnetic arcades (LMA) consist of loops, forming long corridors; the top of these loops do not exceed 0.5 $R_{\odot}$ above the photosphere. High magnetic arcades (HMA) are similar, except that they do extend to greater heights and may appear distorted because they were computed using an artificial boundary condition simulating the solar wind surface. Finally, magnetic rays (MR) show the presence of open field lines which extend so high above the surface that their point of reconnection is outside the domain of calculations.

We examined the calculated potential fields (provided kindly by Miss D. Trotter, High Altitude Observatory, Boulder, Colorado) for each storm around the CMP date. Figure 5 shows the magnetic fields, as well as the continuum source for the day shown. All the regions appear to be characterized by magnetic arcades, low in some cases and high in others.

Region No. 1 was characterized by an arcade, running in the north-south direction (Figure 5a). A tightly wound LMA stretches over McMath regions 11108, 11110 and 11120. The field lines are closed in the corona above McMath region 11111. A more open structure (DF) is found to the north, above McMath 11112, which is an old, decaying region. That DF's and LMA's are not mutually exclusive structures have been noted by Newkirk and Altschuler (1970), since LMA's sometimes form an annulus, partially surrounding a DF. An LMA extends under an HMA at the location of active regions 11128 and 11129, associated with decametric source No. 2 (Figure 5b). Open field lines appear under the south-western end of the arcade. A DF appears at the site of McMath region 11130; no obvious connection with the northern arcade is seen. Region 3 appears to have the most open configuration of all regions considered here. An LMA is seen running in the north-south direction over McMath regions 11256-57-55. The field lines appear to diverge around McMath regions 11249-50; another arcade is seen to the west, above McMath regions 11252-53. All the regions appear to be magnetically connected (Figure 5c).

An LMA stretching under an HMA towards the north pole appears at the site of region 4. Note that the LMA once again embraces the eastern portion of a DF. A substantial number of type III bursts displaced towards the west from the continuum source and generally starting at the high frequencies were observed during this storm (Figure 5d).

Region 5 coincided with an HMA running in the east-west direction, approximately over the solar equator. We note that only a small number of type III bursts were recorded during this storm and that the continuum source was large (Figure 3e, 5e) as can be expected from the orientation of the magnetic arcade.

Finally, the magnetic structure related to region 6 is a complex one, just as the storm itself was complex (Figure 5f). Two LMA's, slightly twisted, embrace a region, from which field lines are diverging. The decametric source was situated above the western arcade. Two sources were observed at 169 MHz for the entire duration of the storm, one above each of the magnetic arcades. These magnetic arcades were situated on each side of McMath 11482, an extremely flare-active region. A series of very intense type III bursts, all of them flare associated were observed from this region.

These type III bursts were clearly of a different nature than those occurring during the storm. They were much more intense, to the point of saturating the records, almost always occurred in groups and their starting frequency was always higher than 65 MHz.

The magnetic configurations were examined one solar rotation after the dates considered here. Most of the structures described were still recognizable, but all of them appeared to be more open than at the time of the storm. Such open field lines often extend to interplanetary space.

The general appearance of the magnetic fields supports the evidence presented in the previous section for interaction between several active regions. As Newkirk and Altschuler pointed out, although the coincidence of a given field line with a particular region is meaningless, a comparison between the shapes of the field configurations and the coronal structures is still valid. In the case of the decametric storms, the magnetic structures appear to connect the underlying chromospheric regions and possibly provide a channel along which energetic particles can travel.

5. Association with Decimeter and Mater Wavelength Activity

No burst activity at centimeter wavelengths is known to be associated with noise storms. It has been observed (Malinge, 1963) that the occurrence of a large centimeter wave burst during a metric noise storm seems to inhibit the production of type I bursts. We examined the rate of occurrence of centimeter bursts during the three hours preceding and following storm onsets and intensifications, and found no correlation between these two phenomena. The rate of occurrence of centimeter wavelength bursts was found to be the same during these periods as when storms were in progress, or even at times when no storm was present at all.

If decametric storms are associated with interacting active regions as discussed earlier, we may expect to find multiple sources at the lower heights in the corona during storms. Indeed, the Nançay interferometric observations at 408 MHz (published in *Solar Geophysical Data*) confirm this (Figure 6). In this figure the crosses indicate the position of the sources at 408 MHz, the heavy lines indicate the trajectory which would be followed by a source located above the active regions whose McMath numbers are indicated.

Two sources were observed on January 19, the day decametric source 2 appeared. One of them was located above McMath region 11128, the other above McMath regions 11129-11130. Three sources were present on January 20 and 21, when the decametric emission was strongest. Decametric emission was much weaker or was entirely absent during the next three days, when only one source appeared at 408 MHz. Multiple sources were seen from April 12 to April 17 at 408 MHz, simultaneously with decametric source 3. The east-west position of these sources corresponds rather well with the position located radially above McMath regions 11253 and 11257 at a height of 1.3 $R_{\odot}$, and above McMath region 11250 at a height of 1.05 $R_{\odot}$. We note that no multiple source at 408 MHz was observed after April 17, and that after this day the

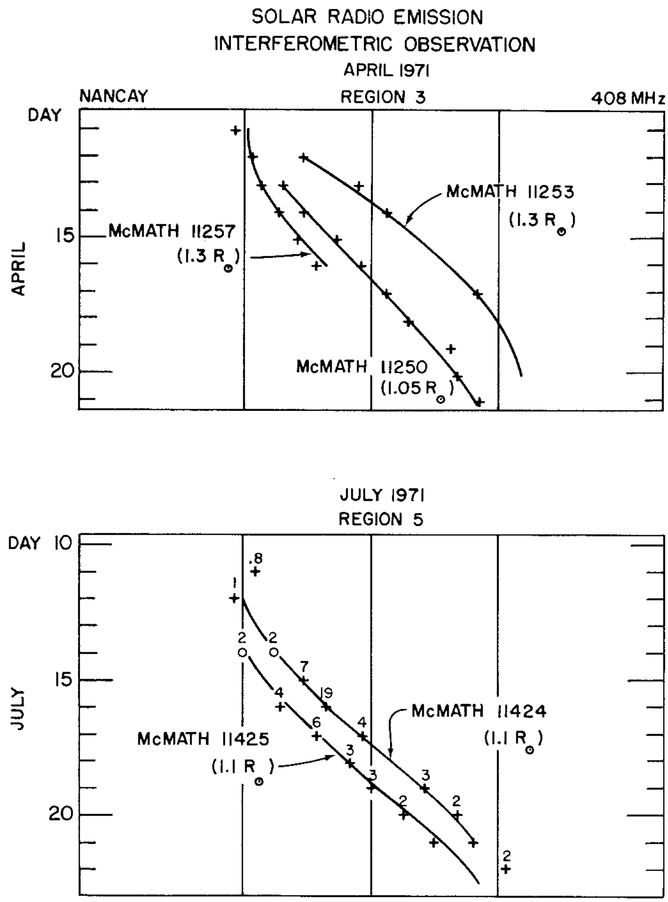

Fig. 6. Positions of 408 MHz regions associated with decametric storm regions 3 and 5. The crosses indicate the positions of 408 MHz sources; the heavy lines indicate the trajectory that would be followed by a source located at the indicated heights above the active regions.

decametric emission also ceased completely. Multiple sources were observed for the whole duration of decametric source No. 5. The east-west position of the 408 MHz sources corresponds to that of sources located at 1.1 $R_{\odot}$ above McMath regions 11424 and 11425. Once again the decametric source lasted only as long as multiple sources were observed at the lower heights.

Similar situations are found for decametric sources No. 4 and 6. Double sources were observed for the whole duration of decametric storm 6 and for most of the duration of decametric source 4. A double source was observed one day only while storm 1 was in progress. It is likely, however, that a double source was present, since such a source-oriented in the north-south direction was indeed observed at 80 MHz (Caroubalos *et al.*, 1973).

Boischot *et al.* (1970) suggested that metric storms, consisting generally of type I bursts, and decametric storms, consisting mainly of type III bursts, constitute different manifestations of the storm phenomenon. Using the data obtained in 1967 they found that in 86% of the cases when a metric storm was present a decametric storm was also observed. Conversely, 87% of the decametric storms could be associated with a metric storm. No positional observations were involved, the association was made only on the basis of coincidence in time. We investigated this association, examining the Nançay 169 MHz interferometric observations (*Solar Geophysical Data*) along with our positional data. Thus we were able to compare not only the coincidence in time but also the position of metric and decametric storms. We found that a metric storm was indeed associated with each of the decametric sources. Good agreement was found between the metric and decametric storms; the CMP of the decametric storm coincided usually within 1.5 days with that of the metric storm. The CMP dates for the metric storms are given in Table II. A systematic correction was included, to account for the fact that the 169 MHz positional observations were made at the local meridian (approximately 12:00 UT). During the period considered by us, a decametric storm was present on the disk on 75% of the days when a metric storm was reported. On the other hand, a metric storm was reported to occur on 92% of the days when a decametric storm occurred. From a total of 37 days of decametric storm emission a metric storm was not reported for only three days. Three storms not examined

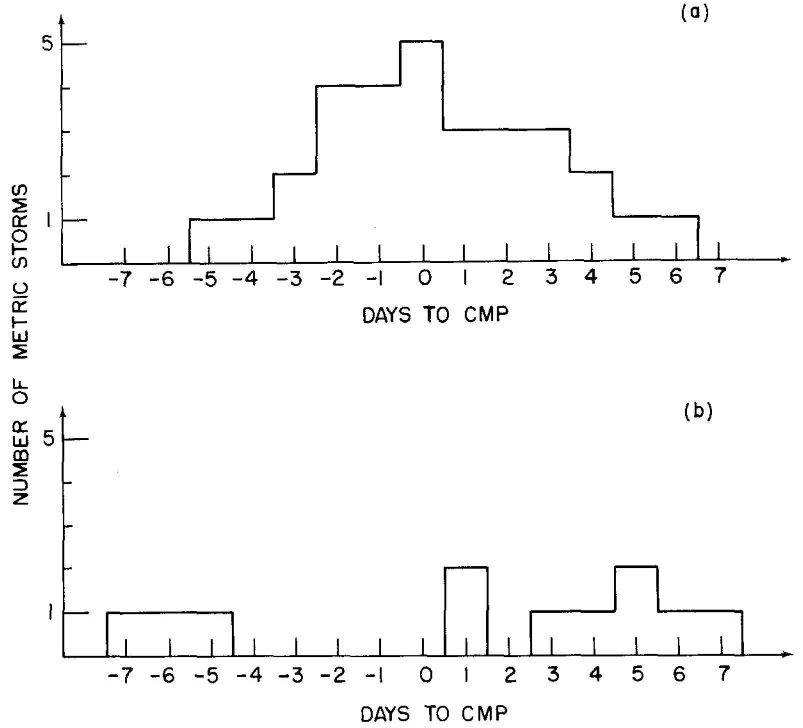

Fig. 7. (a) Longitude distribution of metric storms associated with decametric storms. (b) Same for metric storms without associated decametric storm.

here can be observed on the Nançay charts during the period 1971, January-August. Decametric storms of shorter duration were observed on the date of the metric storm or on the following day in each case. The coincidence of meter and decameter storms can be considered even more significant, since there is no overlap between the observing periods at Nançay and Clark Lake. Figure 7 shows the longitude distribution of metric storms (a) with no decametric counterpart and (b) with decameter storm. The figure suggests that the absence of decametric storms for some of the days when metric storms have been observed can be explained by a higher directivity of the decametric storms.

6. Conclusion

Until recently, solar activity was discussed in terms of independent active regions. Wild (1968) pointed out the existence of several interacting centers in the case of a noise storm observed with the Culgoora radioheliograph. In the case he reported, activity correlated in time and arising from several sources was observed for half an hour before the start of a major flare (imp. 2). This flare was followed by a noise storm. Some of the participating regions were separated by large distances and the triggering of activity in one center by another would have required faster-than-light particles. For this reason, Wild assumed an initiating disturbance located at a central point high in the corona. Kai (1969) also presented several events, showing the interaction of various centers, sometimes separated by as much as 1.0 $R_{\odot}$. Both Kai and Wild observed that the sources involved had opposite senses of polarization in most cases, suggesting that they were connected by magnetic fields looping through the corona. In agreement with Kai, we find that a given source may sometimes be the initiating and at other times the triggered disturbance.

Further, Wild (1969) suggested that interaction between active regions may occur in two ways; through MHD shock waves, travelling at speeds of 10^3 km s^{-1} triggering eruptions at distant centers, and by fast particles travelling along magnetic field lines. These two classes of interactions have rather different manifestations in the radio regime. The former is seen in the form of type II or type II–IV bursts, while the latter may be represented by type III bursts, '*U*'-bursts and reverse drift bursts, all commonly observed during metric noise storms.

In this paper we have studied the relationship of decametric storm sources with other aspects of solar activity. Specifically, we related the storm sources to interacting active region complexes in the chromosphere. In every case that we studied, a decametric storm implied evidence of interaction between pairs of active regions. In most cases the flare occurrence in neighboring regions turned out to be non-random with the number of simultaneous flares approximately twice as large as that expected on the basis of random occurrences. We have not addressed the opposite question of whether or not interacting regions always produce decametric storms. Intensifications or onsets of decametric storms do not seem to relate *directly* to flares.

We showed that decametric storms are always associated with storms at the meter and decimeter wavelengths, and that multiple sources are often observed at these wavelengths. The magnetic structures associated with the storm sources were found to be high or low magnetic arcades, the latter sometimes partially surrounding regions of open or diverging field lines. The centroid of the continuum source frequently coincides with filaments or chains of filaments, known to indicate the presence of neutral sheets higher in the corona.

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