

ON THE ASSOCIATION OF SOLAR RADIO EMISSION AND SOLAR PROMINENCES*

By J. P. WILD† and H. ZIRIN‡

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Summary

Prominence cinematograms made at Sacramento Peak and Climax in the years 1949–55 have been examined and compared with the solar radio records at 167 Mc/s. No close connexion was found between limb events and radio events, but some eruptions were found to be associated with simultaneous radio bursts. Three such cases are discussed in detail.

The limb passages of large sunspots in 1949–55 were studied on both cinematograms and single exposure surveys with the view of finding a criterion for radio-noisy spots. It was found that spot groups showing looped prominences and downward streaming from the corona showed a marked tendency to produce radio noise storms. This result is ascribed to the fact that the seat of such storms must lie in the corona and in the presence of strong ordered magnetic fields.

I. INTRODUCTION

Our knowledge of the association of disturbed radiation from the Sun with activity observed in the optical spectrum is at present very limited. Considerable attention has been given to the relation between radio disturbances and transitory optical events observed on the Sun's disk; but such events are seen mainly at the time of flares, whereas radio bursts frequently occur at other times. Coronagraph observations of the solar atmosphere reveal frequent activity in the form of sunspot prominences, eruptive prominences, surges, etc. at times other than flares. Most of this activity is seen in the corona at heights between about $0.05R_0$ and $0.5R_0$. This is just the region in which the radio emission is believed to originate.

In the present paper we summarize the results of a search for prominence activity associated with the generation of radio emission. Such an investigation is complicated by the fact that the limb is less favourable to the escape of radio waves compared with the central region of the disk. We have therefore approached the problem in two ways. Firstly, we looked for discrete transitory events on coronagraph records which coincided in time with bursts of radio emission. Secondly, we studied the general appearance on the limb of centres of activity which produced intense radio storms during their passage across the

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† Visiting High Altitude Observatory from Division of Radiophysics, C.S.I.R.O., Sydney.

‡ High Altitude Observatory of University of Colorado, Boulder, Colorado.

middle of the disk, and looked for persistent features which distinguished them from active centres which produced no storm. These two parts are discussed in Sections II and III respectively.

II. ERUPTIONS ON THE LIMB ASSOCIATED WITH BURSTS OF RADIO EMISSION

During an examination of prominence motion pictures recorded at Climax and Sacramento Peak in the years 1949-55, we noted three outstanding eruptions which coincided in time with isolated radio events and for which circumstances

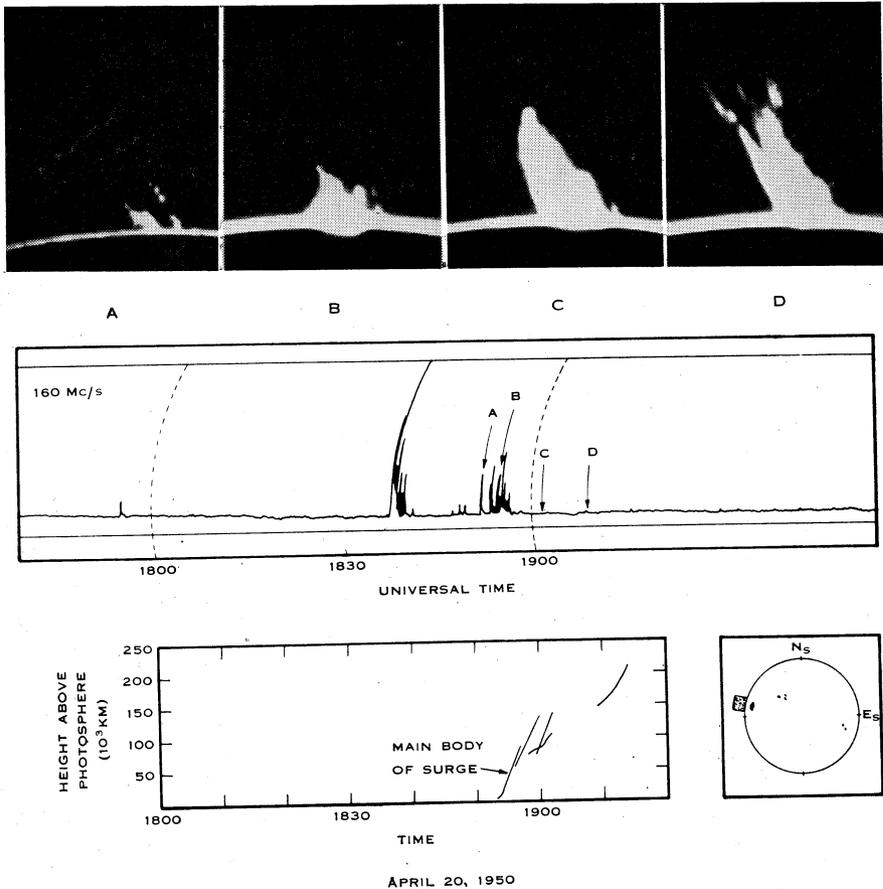


Fig. 1.—Great surge of April 20, 1950.

indicated that the optical-radio association was very likely to be real. These three events are described below.

Great surge, April 20, 1950.—This was the largest surge noticed in our search. Details of this event are shown in Figure 1 which gives (i) a sequence of four coronagraph pictures, (ii) the radio flux record at 160 Mc/s, (iii) a plot of the projected height above the limb of certain clearly recognizable features

of the surge, and (iv) a sunspot sketch. The $H\alpha$ disk pictures taken at Boulder and the coronagraph pictures show the following sequence of events before and during the surge :

- 1805–1850 hr Flare near the centre of the disk (maximum at 1820 hr)
- 1825–1835 hr Sub-flare at active region near the west limb (see sunspot picture)
- 1852 hr on Large surge originating in the vicinity of the large sunspot near the west limb, about 45,000 km (projected) inside the edge of the disk.

The main body of the surge rises with a projected velocity of about 300 km/sec, and fragments can be followed up to about 2×10^5 km before becoming invisible. The coronagraph observations were interrupted by clouds at about 1912 hr, and the return course of the surge, if any, is not known.

The radio event consists of a cluster of intense short-lived bursts at 1839 hr and a series of short-lived bursts starting at 1852 hr. From their appearance on the record, the first group is almost certainly of spectral type III, for which existing evidence points to an origin in very fast disturbances travelling upwards through the corona. The classification of the later series of bursts is doubtful, although their appearance suggests spectral type I ("storm" bursts). The level of the radio record remains practically undisturbed for at least $3\frac{1}{2}$ hr before and after this disturbance. Although it is difficult to fix the precise connexion of the bursts at 1838 hr with the optical events, the exact time coincidence of the series of bursts starting at 1852 hr with the first appearance of the great surge strongly suggests a causal relationship between the latter two.

Comparison of the radio record and height plot reveals an interesting conclusion : that the second part of the radio event takes place only during the early part of the surge, apparently while its leading edge is penetrating the lower levels of the corona. This is consistent with the notion that the visible matter follows immediately in the trail of the disturbance responsible for radio emission.

Surge-like eruption, May 2, 1950.—Details are shown in Figure 2. The limb event occurred near a large active area and appeared to constitute the eruption of a low-lying prominence located close to the sunspot prominence shown in Figure 4. The eruption initially resembled a somewhat nebulous surge (picture *B*) rising with a projected velocity of about 150 km/sec ; from this matter, fragments subsequently rose to heights up to 200,000 km with velocities up to 250 km/sec. Such fragments are indicated by arrows in pictures *C* and *D*. An $H\alpha$ disk picture showed no evidence of a flare at that time.

The radio level shows a gradual increase in activity immediately before the main eruption, increasing in intensity throughout the optical phenomenon and dying down to almost quiet level immediately after. In this respect the event differed from the preceding case ; but it is noteworthy that fragments were being ejected throughout the main period of radio emission, so that again

it is reasonable to associate the radio-producing disturbance with the leading edge of the visible matter. As before the coincident radio event appeared to consist of type I bursts.

Ascending prominence, January 18, 1955.—Details are shown in Figure 3. A quiescent prominence situated on the west limb at latitude 40°N . was observed in the early stages of eruption when coronagraph observations began at 2030 hr (picture A). The top of the expanding arch rose with a mean velocity of more

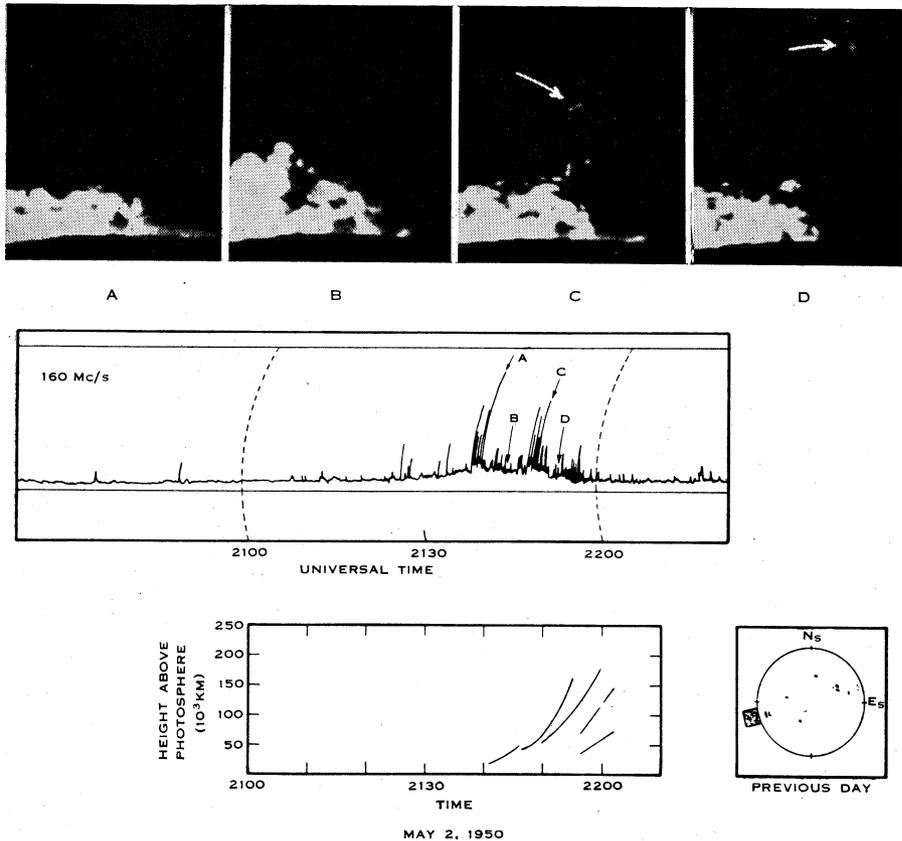


Fig. 2.—Eruption of May 2, 1950.

than 200 km/sec, and at 2050 hr (picture C) had reached a height of nearly 300,000 km. Observations ended at 2105 hr when downstreaming had begun (picture D). The eruption took place near the most active centre on the disk at that time, but no flare was reported from either Climax or Sacramento Peak.

The radio record shows an extended storm, undoubtedly of spectral type I, beginning at 2000 hr and ending at about 2030 hr. Unfortunately the most intense radio emission occurs near 2130 hr after the coronagraph observations had ended. It is interesting that previous reports of ascending prominences by Dodson and Donselman (1951), Das and Sethumadhavan (1953), and Davies

(1953) also indicate that the most intense radio emission occurred in the late stages of the eruption.*

In addition to the three events described above, we noted numerous other eruptions at times for which 160 or 167 Mc/s records were available. The following is a summary of all cases noted :

	Surges	Ascending Prominences
Discrete radio events coincident in time ..	8	2
Radio emission in progress, but association indefinite	23	1
No coincident radio event	27	1

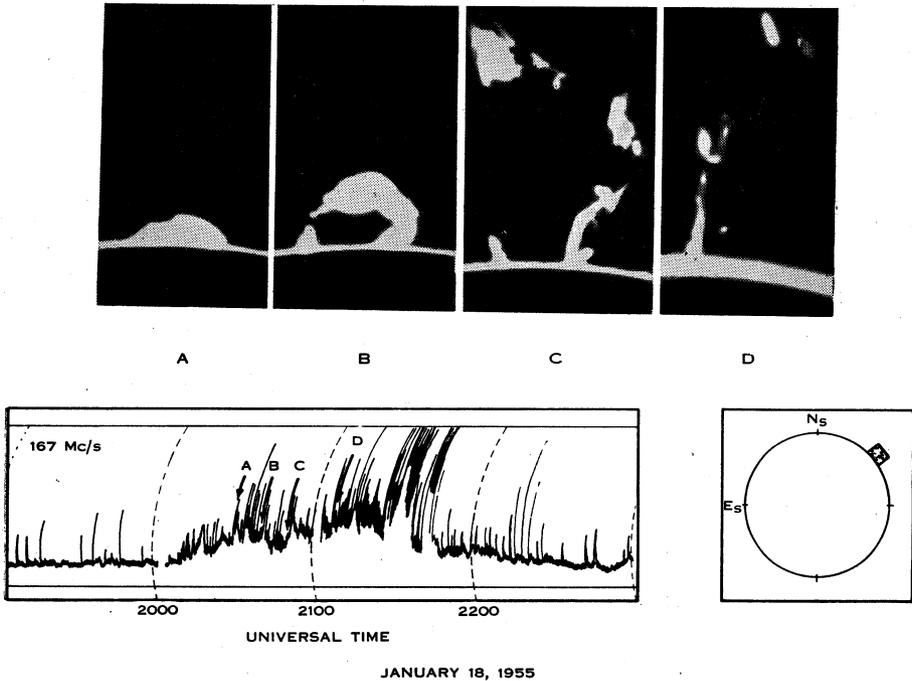


Fig. 3.—Ascending prominence of January 18, 1955.

It is seen that the proportion of surges which could reasonably be associated with discrete radio events is not high. This contrasts with the results of a survey by Warwick (1954) who found that 80 per cent. of surges observed coincided with unusual activity at 200 Mc/s.

In most of the cases for which the optical-radio coincidence was positive, the appearance of the radio event followed the general pattern of the three cases detailed above—i.e. suggesting a sequence of type I bursts.

* Dr. A. E. Covington has kindly informed us that a gradual rise and fall, starting at 2045 hr and lasting 45 min, was observed on 2800 Mc/s at Ottawa. The maximum flux was $10^{-21} \text{ W M}^{-2} (\text{c/s})^{-1}$.

III. PROMINENCE ACTIVITY CONNECTED WITH SOLAR RADIO NOISE STORMS

Radio noise storms are a phenomenon long associated with large sunspots. Payne-Scott and Little (1951), for instance, concluded that the presence of a sufficiently large sunspot in a spot group is necessary for the production of a storm. Furthermore, the observations of circular polarization in the storms and of the reversal of the sense of this polarization with change of hemisphere and of sunspot cycle is clear evidence of the importance of the spot magnetic

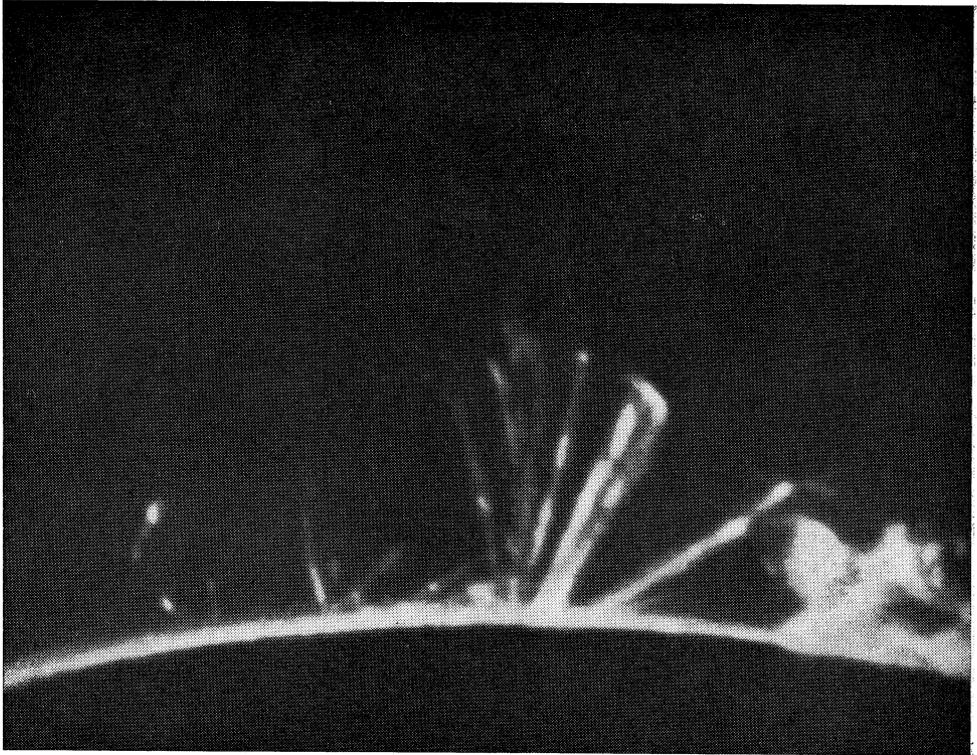


Fig. 4.—Typical complex loop prominence.

field. The sunspot, however, is in the photosphere, and, as already noted, the radio emission originates from higher levels. We are therefore interested in the solar atmosphere directly above the sunspots.

Payne-Scott and Little located by means of an interferometer the source of several large storms in 1949 and 1950 at certain spot groups. Examination of the limb appearance of these spots showed them to be accompanied predominantly by complex looped prominences and downward streaming from the corona. Interestingly enough, this sort of motion had not produced any radio coincidences at the limb, whereas the surges of the type discussed in Section II did not seem to be particularly characteristic of the radio-noisy spots.

We studied the prominence activity connected with each spot group in the following way. First, the CMP's of spot groups classified *E*, *F*, or *G* on

the Zurich system were obtained from the daily medians of radio noise flux received from the Sun as reported in the *Quarterly Bulletin of Solar Activity*. Only those cases were retained where a clear decision was possible as to whether or not the spot group produced a radio storm. Then we obtained whatever $H\alpha$ prominence films from Climax and Sacramento Peak were available, and also examined the daily $H\alpha$ prominence surveys. In each case the appearance of the limb was classified with respect to the presence or absence of loop prominences and streaming from the corona. These correspond roughly to the classes

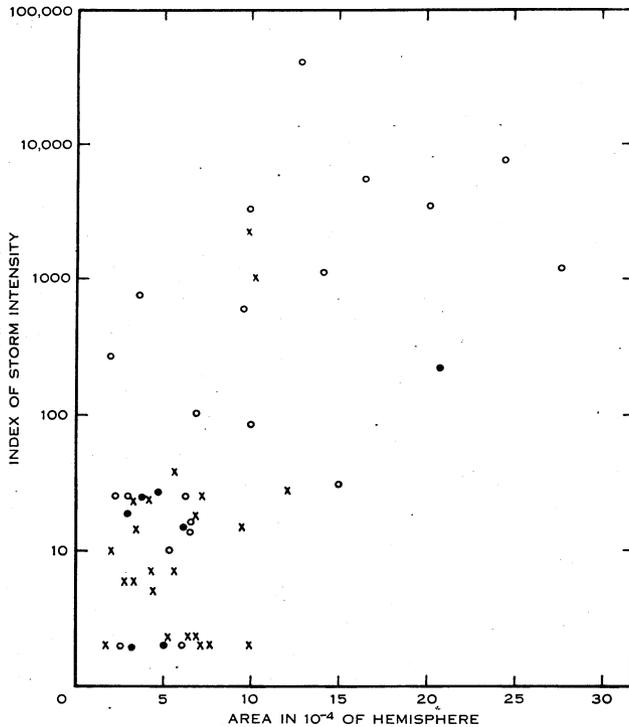


Fig. 5.—Radio storm intensity, sunspot group area, and limb characteristics.

- Loops and/or streamers.
- E. and W. limbs contradictory.
- × Quiescent, streaming from quiescent, or no prominences.

AN_s and AS described by Menzel and Evans (1953). When those were present we measured the maximum height and estimated the importance. Streaming from quiescent prominences and ordinary quiescent prominences were considered negative cases on the basis of our original survey. Since the prominence motion pictures did not give very good coverage of all the dates (particularly for negative cases, since the observers customarily did not take prominence motion pictures when there was no interesting activity on the limb), the principal classification was done on the prominence surveys, which, between Sacramento Peak and Climax, gave quite good coverage. Although a motion picture is

the best way to assay prominence activity, it is usually quite easy to interpret on the basis of experience a single survey photograph. Figure 4 is a good example of the kind of loops considered a positive case.

In view of the sharp contrast in magnitude in the radio record, a somewhat arbitrary index was used. The daily values in excess of $10^{-21} \text{ Wm}^{-2} (\text{c/s})^{-1}$ flux at 62, 80, 98, 175, and 200 Mc/s respectively, were added for each day of the storm, being limited in all cases to within 5 days of CMP. Then the values on all five frequencies were added together to give an index of the intensity of the storm.

The scatter diagram of Figure 5 presents most of the data in graphical form. Storm intensity is plotted against spot group area, and each entry indicates whether the limb appearance was positive, negative, or contradictory (opposite classes from E. and W. limbs). The predominance of loops in the large storms is clearly marked. That this is not due to a correlation between

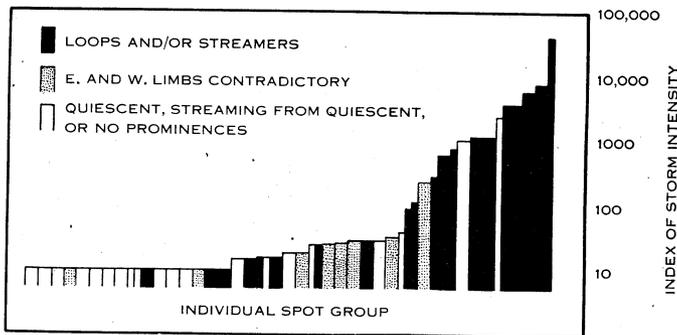


Fig. 6.—Spot groups arranged in order of increasing radio intensity, shaded according to limb characteristics.

spot area and loops is shown by the storms produced by small spots with loops. Since the prominences were observed 7 days from CMP, where the noise storm normally culminates, the correlation is surprisingly good. There is never any guarantee that a spot showing loops at one or both limbs would necessarily have them at CMP.

The results of the investigation are presented in a somewhat different way in Figure 6. Figure 6 presents the various spot groups in order of increasing intensity and shaded according to limb appearance. Double width is given when observations were made at both limbs, and single when only one limb was observed. All spots with index of storm intensity less than 10 are grouped together, since distinction between low values is meaningless.

The general import of the data reported here seems to be that there is a close connexion between the ordering of the coronal material by the magnetic field, producing loops and streamers, and the production of radio noise storms. This agrees with the obvious implication of the observational facts at the beginning of this section, namely, that, in order to produce circular polarization, the magnetic field must extend up to the level of emission of radio noise. When we observe loops and streamers we know this to be the case.

IV. CONCLUSIONS

The results of this paper may be summarized as follows :

(1) While the connexion between visible activity on the Sun's limb and radio emission received at the Earth is not very close, certain eruptions cause almost simultaneous radio bursts at wave lengths of about 2 m. Such eruptions are characterized by the *outward* ejection of material, e.g. surges and ascending prominences.

(2) Analysis of two surges that generated radio emission suggested that the radiation originated from the *leading edge* of visible material—either the main body of the surge or ejected fragments—in its passage through the lower corona.

(3) An ascending prominence generated radio emission probably throughout the eruption ; consistent with previous cases reported, the maximum radio intensity occurred late in the life of the eruption.

(4) While the active sunspot-prominences (characterized by downstreaming material from the corona and within high loops) produce no obvious increased radio emission when the active centre is on the limb, there is some evidence that they are responsible for radio storms during their passage across the central regions of the disk. The latter conclusion cannot be demonstrated conclusively owing to the limited and intermittent life of such coronal activity ; but it has been found that the presence on the east limb of these active prominences provides a fair criterion for the occurrence of a radio storm around 7 days later ; this criterion is at least as good as that based on the area of the spot group at the time of the storm. The hypothesis that the loop prominences are associated with the production of radio storms is attractive on the physical grounds that the seat of the storm must lie in the corona and in the presence of strong, ordered magnetic fields.

The prolonged radio storms, and possibly the transitory radio disturbances accompanying eruptions, consist of bursts. We therefore suggest that it is this type of radio emission which may be the most closely associated with visible disturbances in the corona.

V. ACKNOWLEDGMENTS

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