TYPE III SOLAR RADIO BURST STORMS OBSERVED AT LOW FREQUENCIES

I. *Storm Morphology*

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Abstract. Storms of type III solar radio bursts observed from 5.4 to 0.2 MHz, indicate the quasi-continuous production of type III events observable for a half solar rotation but persisting in some cases for well over a complete rotation. The characteristics of these storms, including the dependance of occurrence and apparent drift rates on the disc position of the associated active region are discussed. The drift rate dependance is shown to be a consequence of the propagation time of emission from the source to the observer. The occurrence rate of a burst every 10 sec observed near CMP implies that if this level of activity persists, then about a quarter of a million exciter packets are released into the interplanetary plasma during a complete rotation. Storm bursts are less intense than most isolated type III's and occur over a more limited frequency range. There appears to be a very close relation between these storms and decametric continuum.

1. Introduction

More than 12 months of solar radio data have now been obtained in the frequency range from 0.2 to 5 MHz from observations by the first Radio Astronomy Explorer Satellite, RAE-1. During this time, an extremely large number, tens of thousands, of sporadic bursts have been observed, but in general they may all be classified as type III or fast drift emissions. Considering the typical heights in the solar corona that one expects for the location of these bursts, i.e. between 10–100 solar radii for the RAE-1 frequency range, it is perhaps not too surprising that the diversity of radio emissions observed close to the sun is absent here. Yet even within this classification as type III emission, one finds a considerable variability of characteristics such as the drift rate, drift bandwidth, intensity, profile shape, structure, and occurrence rate. Through the study of such characteristics one can investigate the exciting mechanism as well as the properties of the interplanetary plasma. Furthermore these observations provide a connection between phenomena close to the sun and the energetic particles presumably of solar origin which are measured by counters on space probes beyond the magnetosphere.

We assume the validity of the plasma hypothesis (Wild, 1950) for the generation of type III bursts. The frequency drift is produced by the outward movement of a disturbance which excites plasma waves of decreasing frequency as it moves through regions of decreasing electron density. This disturbance, the 'exciter', is believed to be a packet of superthermal electrons. Comprehensive reviews of solar radio emission mechanisms have been given by Wild *et al.* (1963) and Takakura (1967). We also assume that the emission is observed preferentially when the exciters move along

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regions of enhanced density, i.e. streamers from which the radiation can escape over a wide range of angles. Newkirk (1967) has reviewed the structure of the solar corona, including streamers.

Individual, compound, and groups of type III bursts have been observed at low frequencies by the RAE-1 as well as other space experiments. In all cases antennas of low resolving power, such as the electrically short dipole, have been used, so that the position of the radio emission and its motion must be inferred by using a model with the analysis of observed dynamic spectra (Alexander *et al.*, 1969; Hartz, 1969; Slysh, 1967; Haddock and Graedel, 1970).

However, in the present series of papers, we direct attention to the phenomenon which will be referred to as a 'storm' of type III bursts. These events are distinct from individual or groups of type III bursts because of their long duration. Storms have been observed over a half solar rotation, from the time that the active region appears on the east limb to its disappearance at the west limb. In several instances, the storm activity was observed again a half solar rotation later suggesting that the event can last a full rotation or more.

The nature of the mechanism responsible for such continual production of type III exciters is a problem which will be better understood by investigating the storm characteristics and their relation to other solar observations. Therefore in this paper we present in some detail the morphology of a typical storm.

In later papers we utilize these data to derive characteristics of the exciter packet, the interplanetary plasma, and the generating source itself. In Part II of this series we deduce, by a new method, the exciter speed as a function of distance between 10 and 40 solar radii. Part III, again based on the storm data, presents a differential plasma distance scale for the streamer as well as a measure of the solar wind velocity in the 10 to 40 solar radii range. Still later papers will deal with the correlation between these data and the emissions close to the sun and with the energetic electrons measured by spacecraft beyond the magnetosphere.

2. The Observing System

The first Radio Astronomy Explorer, RAE-1, launched on July 4, 1968, is in a 5860 km circular orbit inclined at 59° to the equator. The satellite is equipped with two oppositely directed Vee antennas, each 230 m long, forming an 'X' configuration suitable for the gravity gradient stabilization. Therefore one V and its associated radiometer system scans the celestial sphere, while the down directed V and its radiometer system scans the lower magnetosphere. However, observations of the dynamic spectra of the solar events discussed in these papers were obtained mostly with a 37 m dipole, the third spacecraft antenna system. The dipole radiometer system is composed of a swept frequency receiver which covers the frequency range from 0.2 to 5.4 MHz in eight seconds and a group of six fixed frequency radiometers operating at 0.54, 0.70, 0.995, 1.31, 1.65 and 2.80 MHz. These channels are each sampled twice per second to provide greater time resolution. All radiometers are calibrated periodically against

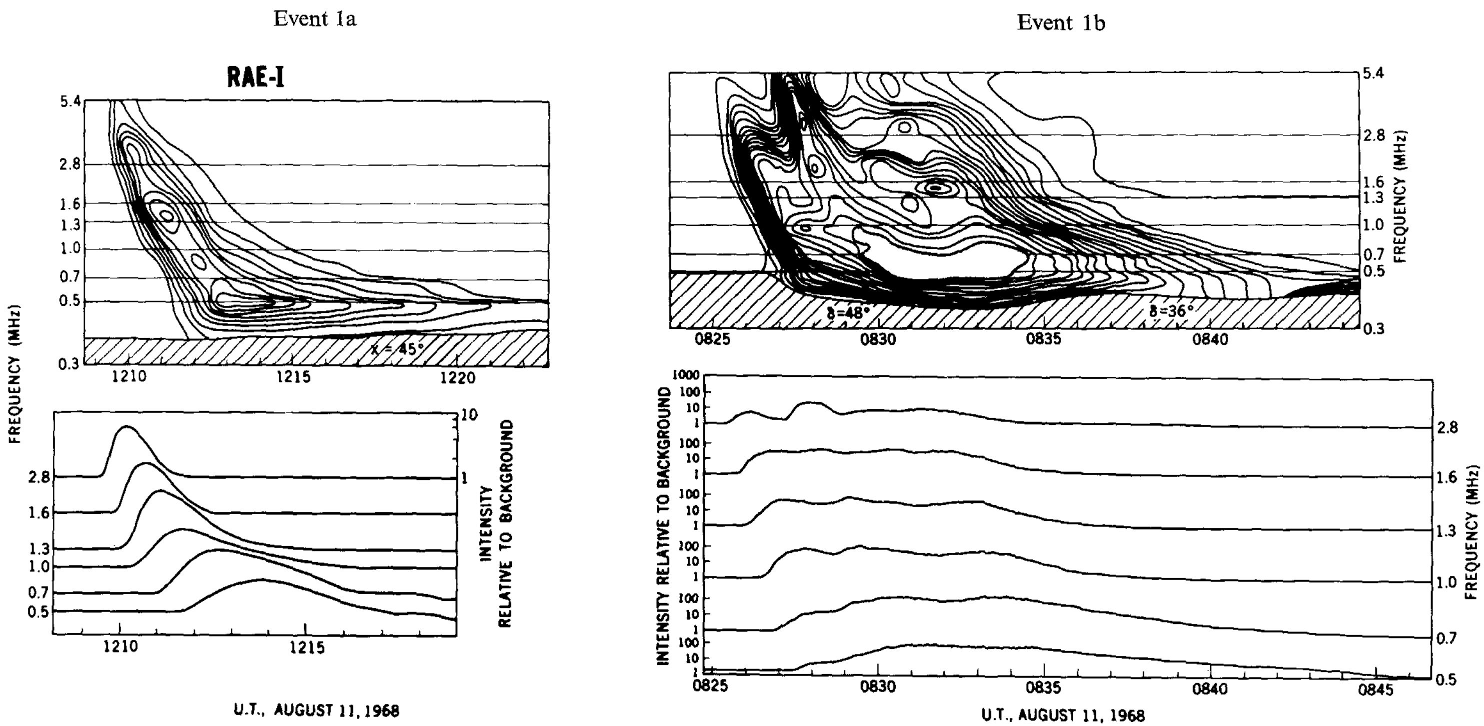

Fig. 1. Examples of type III bursts observed by RAE-1. The outputs of both the fixed and swept radiometers are shown. Event 1a illustrates the typical rise, decay and drift times observed in this frequency range for a simple burst. Event 1b illustrates some of the complex structure arising from burst 'pile up'.

a standard noise source and, at the same time, antenna impedances and ambient plasma parameters are also measured. The radiometers have a useful dynamic range of 50 db and the pre and post detection bandwidths establish the minimum detectable signal at 10% of the cosmic background level. A detailed discussion of the RAE-I experiment may be found elsewhere (Weber *et al.*, 1970). Examples of dynamic spectra obtained with these systems are shown in Figure 1 and will be discussed below.

The spacecraft orbit of 5860 km is within the ionosphere for a considerable period of time. For data obtained near the equator, where the ambient plasma density is greatest, observations below 700 kHz are not used because of the transmission characteristics of the magnetoionic medium as well as its influence on antenna impedance. However at higher latitudes, observations down to 200 kHz are obtained. The plasma effects as well as refraction in the ionosphere need not concern us here because, for the reasons discussed below, the greater part of the analysis is confined to frequencies above 700 kHz.

The storm data analyzed in this paper were obtained during the period of August 1968. The sun was in view of the satellite continuously during this period.

3. Type III Bursts at Low Frequencies

Intense individual as well as groups of type III events have been observed quite frequently by the RAE-1 and also in other space experiments. In most, but by no means all cases, these drifting bursts are the low frequency continuation of type III's observed at higher frequencies. In general these bursts occur over a wide possible range of intensities from, in the case of RAE-1 observations, just detectable to 60 db above the cosmic noise continuum background. At a frequency of 1 MHz, this corresponds approximately to an antenna temperature range of 10^6 K to 10^{12} K.

In this paper, we are interested only in the relative intensity of storm events compared to isolated type III bursts. Intensities will be referenced to the average cosmic noise background. Average antenna temperatures for this background at the fixed radiometer frequencies are listed in Table I. A more detailed discussion of the background and its interpretation may be found elsewhere. (Alexander *et al.*, 1970) Examples of a simple as well as a compound type III event are shown in Figure 1. The outputs of the fixed frequency receivers and the computer developed contour plot of the sweep receiver output are shown. Horizontal lines drawn through the contour

TABLE I

Background f (MHz)	Antenna temperatures T_B (K)
0.540	3.3×10^7
0.700	2.8×10^7
0.995	2.0×10^7
1.31	1.4×10^7
1.65	1.0×10^7
2.80	0.47×10^7

plot (contours in these figures are 1 db apart) correspond to the fixed frequency channels. The use of such dynamic spectra to estimate streamer properties may be found elsewhere (e.g. Kundu, 1965) and will not be discussed further here. However, in reference to the storm discussed below, it is important to note not only the typical drift rate but also the dependance of rise and decay time on frequency. Note from Figure 1, that if several events occur over an interval that is short compared to the time scale of the intensity profile, it may be difficult or impossible to separate several bursts. This problem becomes more serious at lower frequencies where the individual burst duration increases.

4. Type III Storms

We have defined a type III storm as a quasi-continuous production of fast drift bursts which persist over an observing period of a half solar rotation. Storms in some cases last for more than a full rotation as is evident from the storm recurrence when the associated active region again crosses the east limb. This long duration appears to be one characteristic which makes the phenomenon distinct from groups of type III's occurring over periods of hours or longer.

In contrast to isolated or groups of type III's the storm bursts rarely exceed 10 db above the cosmic noise background. Generally there exists a preponderance of still less intense bursts, many just at the level of detection. In some respects, a single frequency record resembles the behavior of a noise storm (Kundu, 1965; Malville, 1962) although at this time we do not imply any connection. For example, there is a hierarchy of burst sizes, a randomness of occurrence in short term distribution, and at the lower frequencies, an apparent 'continuum' background with occasional bursts above that level.

The occurrence rate of individual drifting bursts, although variable, shows a strong dependance on the heliographic longitude of the associated active region. This occurrence rate, for the storm of August 1968, reached a peak value of a burst every ten seconds on 20 August 1968. A section of data is shown in Figure 2 to illustrate not only the high occurrence rate, but also the problem concerning burst 'pile up' which becomes more evident at the lower frequencies where the occurrence interval is small compared to the individual burst durations. The lower frequencies appear as a slowly varying continuum, with occasional burst peaks recognizeable as such. It is for this reason that the main analysis of the storm data was restricted to frequencies above 700 kHz. Had the sampling rate been too slow, then even the higher frequency data might have been interpreted as continuum instead of as a sequence of individual bursts. The analysis of the data would indeed be difficult if the occurrence rate remained this large throughout the storm. However this rate shows a systematic decrease with time from the period of peak activity. Figure 3 illustrates the lower level of activity several days prior to the storm peak. The general behavior of occurrence rate is the same after the storm peak. Consequently the occurrence rate distribution is apparently symmetrical about the period of peak activity. Away from the storm

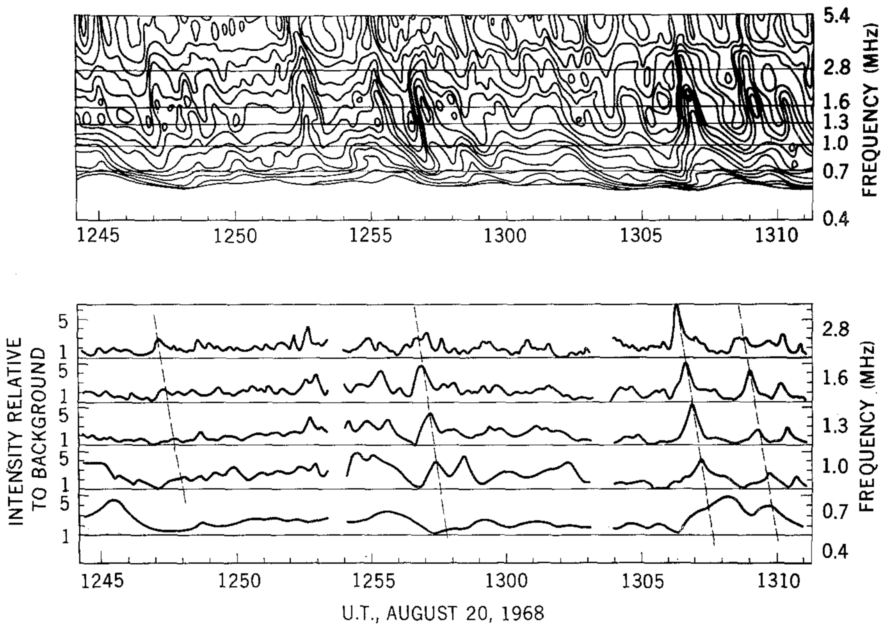

Fig. 2. A 30-min segment of data obtained near the time of peak storm activity. The high occurrence rate, limited burst bandwidth, and range of burst sizes can be seen.

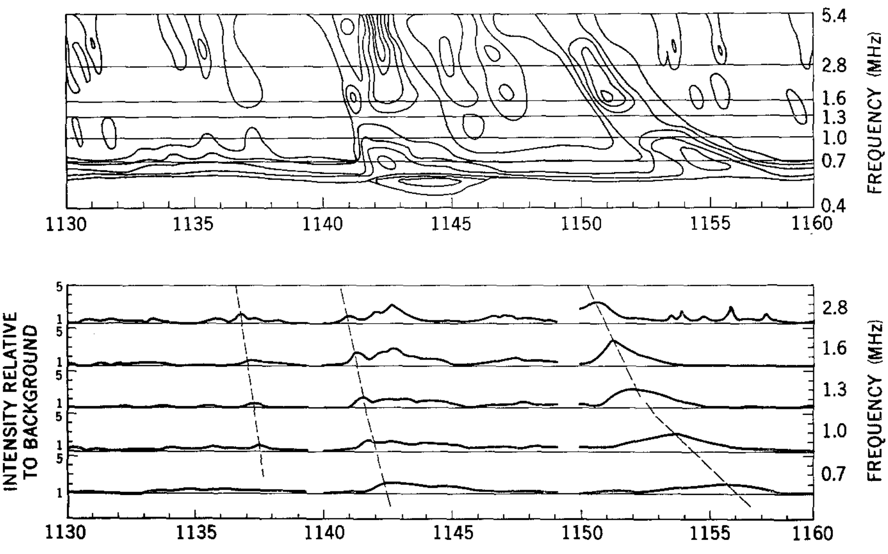

Fig. 3. A 30-min segment of data obtained 4 days prior to that shown in Figure 2. Because the occurrence rate is smaller the confusion problem at the lower frequencies is less severe. Note also the slower drift rates.

peak, the occurrence rate is lower and the confusion problem resulting from burst 'pile up' is not as serious at the lower frequencies.

A systematic dependance of occurrence rate on the heliographic longitude of an active region on the solar disc can be found by plotting the number of bursts per unit time interval over the period (approximately 14 days) that the storm was observed. In fact this technique was utilized to locate the approximate position of the associated active region. A detailed count of the number of bursts as a function of time is not as yet completed, since this involves counting well over 10000 bursts. To illustrate this dependance, however, data from a few selected dates are shown in Figure 4. The

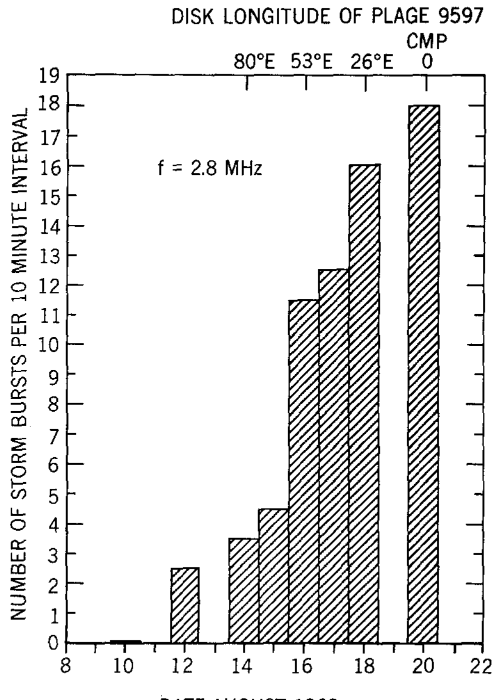

Fig. 4. A preliminary distribution of burst occurrence rate at 2.8 MHz as a function of the heliographic longitude of the associated active region. Note that bursts can be seen at least to the limb position of the active region.

more complete data will provide information about the 'directivity' of the radio source, i.e. source directivity and/or escape conditions of the radio emission (Kundu, 1965; Takakura, 1965). However for the present, we note that Figure 4 shows that observed storm activity is maximum near CMP and minimum at the limb position of the active region.

Figures 2 and 3 also show a change in the observed burst drift rate. Near CMP the apparent drift rate is maximum and as the active region approaches the limb, the average drift rate decreases. This does not imply that the actual drift rate changes as a function of heliographic longitude but that the observed rate is modified by the observing situation. An analysis of 2500 drift rates for this storm event is shown for one pair of frequencies in Figure 5, where the number of bursts per 2 second drift interval is plotted as a function of drift time for each storm day. The histograms in the figure represent not the total number of bursts observed but only the number analysed on the basis of a clear drift rate determination. Suffice it to say here, that the apparent drift rate dependance is caused by the modification introduced by the 'light time' correction which must be applied for propagation between source and observer.

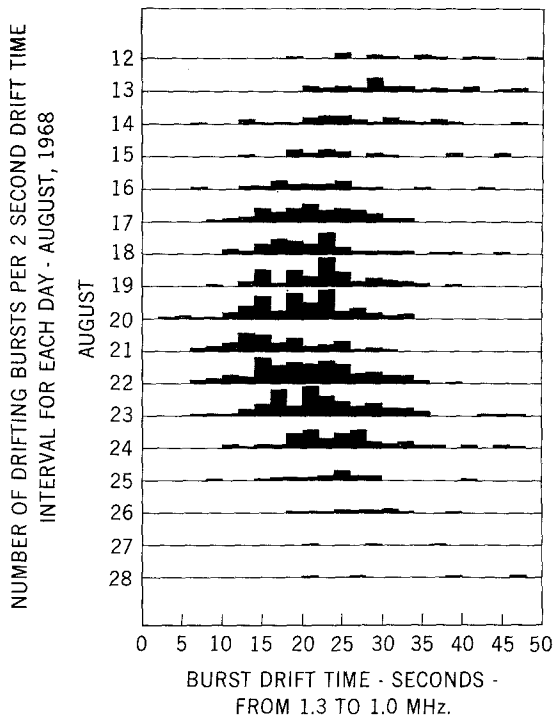

Fig. 5. The apparent burst drift rate distribution between 1.3 and 1.0 MHz as a function of burst drift time. Each histogram shows the distribution of burst drift times for a 24-h period.

The histograms in Figure 5 show the distribution of the drift rates over 24 h. A spread of drift rate is also evident over much shorter time intervals of less than an hour. Although such a spread could be caused by a variation of exciter speed, the most probable cause is the inhomogeneous density structure along the path traversed by the exciter. For example, there is evidence that a streamer has a non-uniform lateral density as well as inhomogeneities superimposed on the average density gradient along the streamer. Newkirk (1967) has presented a general review of streamer properties. If the exciter cross section, for example, is small compared to that of the streamer, then individual packets might pass through regions of differing electron density gradient. Similarly an individual exciter in traveling along a streamer would encounter inhomogeneities. One of the values of establishing the storm statistics is evident for this type of problem. If we can assume that the average exciter properties remain reasonably constant, then the statistical distribution of characteristics such as drift rate may provide a method of investigating the microstructure of the streamer.

From Figures 2, 3, 4 it should also be evident that individual storm bursts do not occur over the entire observing band. This is in contrast to individual intense drifting events such as shown in Figure 1 which most frequently are observed across the entire band. For the storms, the intensity versus frequency behavior appears to be at first sight random in the sense that as many bursts are stronger at the lower frequency end of the sweep as at the high end. This limited 'bandwidth' which is illustrated in Figure 6 may also have its origin in the inhomogeneous structure of the

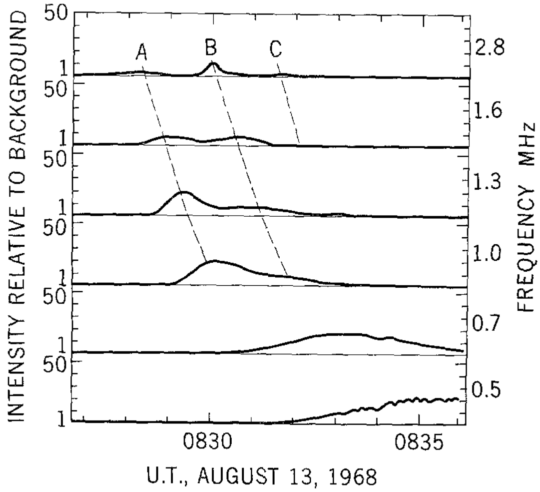

Fig. 6. Examples of the limited 'bandwidth' of storm bursts. Event 'A' is more intense at the lower end and event 'B' more intense over the higher end of the spectrum. The bursts at the lowest frequencies, 0.7 and 0.5 MHz are part of event 'A' as confirmed from the swept frequency contour plots. This illustrates the necessity of both high time and frequency resolution.

plasma. The escape of radiation depends to some extent on the density enhancement above the mean density. Thus as exciters pass through regions of density enhancement, for example within a streamer, the radiation is observed for the time that the exciter remains in the enhanced region.

The drift 'bandwidth' does on occasion show a systematic behavior in the sense that the frequency range over which the bursts were most intense 'drifted' with time from the high to the low end of the observed spectrum. This slow drift is illustrated in Figure 7 for selected time intervals. In the context of the discussion above, this phenomenon can be accounted for in terms of a cloud of enhanced (above the ambient streamer) density traveling outward along the streamer with a velocity of the order of 100 km/sec.

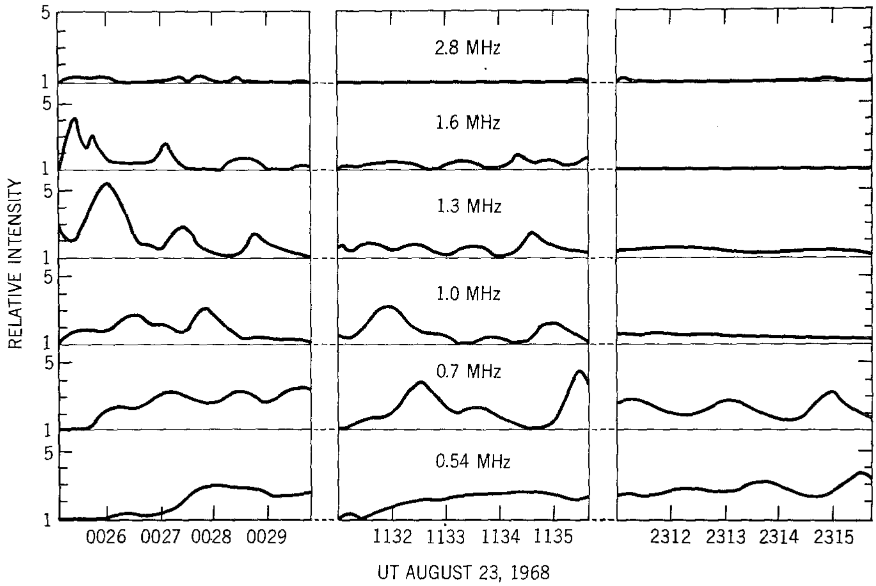

Fig. 7. A systematic change of the burst starting frequency has been observed on several occasions. This 'drift' from high to low frequency can be interpreted as a cloud of enhanced density moving outward with a radial velocity of the order of 100 km/sec.

5. Related Observations

Both the distribution of occurrence rate and drift times with heliographic longitude lead to the conclusion that the related active region is associated with McMath Plage number 9597. Sakurai and Stone (1970) have presented the related data on high frequency radio emission, flare activity, and magnetic configuration which may be of particular significance for the observed type III storm.

In this connection, the observations at decametric frequencies seem particularly significant. Data from the Clark Lake grating spectroheliograph are available in the 20 to 60 MHz frequency range. These observations show the presence of continuum above the same active region that is presumably responsible for the type III storms. There seems in general to be a very clear relation between the type III storm and the decametric continuum in each instance. Warwick (1965) distinguishes between decametric type IV emission and what he classifies as decametric continuum. This is characterized by a continuum background upon which are superimposed 'massive' number of type III events. Since the present observations are closely related to the occurrence of continuum in the decametric range it seems reasonable that the two phenomena are indeed closely related and that at still lower frequencies, decametric continuum may degenerate into just the massive numbers of type III events, i.e. our type III storm. However, we have not ruled out the possibility of a continuum component to our type III storm.

Warwick (1965) has also suggested that the presence of decametric continuum indicates the existence of conditions suitable for the production and escape of superthermal electrons into the outer corona. This indeed appears to be confirmed from the present study which shows a connection between the continuum and the storm of type III events occurring far out in the interplanetary plasma.

6. Conclusion

The major emphasis of this paper has been on the morphology of type III storms observed at low frequencies. This paper has been more descriptive than analytic in nature and therefore serves as a basis for the later papers of the series. The storm phenomenon is of interest not only because it poses basic problems about the quasi-continuous production of exciter particles but also because the large statistical sample of type III bursts provides an opportunity to investigate the properties of the exciting mechanism and the interplanetary plasma. These investigations based upon the storm observations form the basis for the remainder of this series of papers. The storm is not a rare phenomenon at least during the current period of high solar activity. At least three major events and a number of much less pronounced possible storms have been observed over the period from July 1968 to July 1969.

In summary, the storms are characterized by a quasi-continuous production of type III bursts, observable over a half solar rotation. If the rate of occurrence observed at CMP exists for a full rotation, the order of a quarter of a million exciters must be released into the interplanetary plasma each rotation. Both the occurrence rate and apparent drift rates show a dependance on the heliographic position of the associated active region. These rates are maximum near CMP and minimum near the limb positions. Individual bursts mostly occur over a limited frequency range and are generally less than 10 db above the cosmic noise background and show a concentration towards smaller intensities.

A close correlation exists between the occurrence of these storms and decametric continuum. Quite possibly the hectometric storms are the lower frequency continuation of decametric continuum.

At the same time, Boischot *et al.* (1970) have suggested a connection between meter and decameter storms. It may not be premature to suggest that meter, decameter, and hectometer storms are all produced by the same outward streaming electrons, and that under suitable conditions such energetic (40 keV) electron streams are measured by space probes beyond the magnetosphere. As noted in this paper there are many similarities between the meter and hectometer burst characteristics. However the detection of a hectometric continuum component to the storms would make the connection more definite. A search for such a continuum is now underway.

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