This fact has already been pointed out by Dr. K. Sinno too.

Hultqvist, B.K.G.: You showed a relation between the heliographic longitude and the travel-time for the fast solar particles producing PCA. Are also the fairly high-energy events of the last years similar to the one of 23 Feb. 1956 when the PAC was accompanied by an increase of the cosmic-ray flare also at the earth's surface? In other words, have you not made any allowance for the differences in energy spectrum between the different cases?

Maeda: No, we have not, because we have no information about the detailed energy spectrum of solar cosmic rays for each event.

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I-1-8. Details of the Relation between Type IV-Outbursts and sc-Geomagnetic Storms

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Introduction

Since recent years it has been shown that solar radio-noise outbursts of spectral type IV (great burst of long duration covering a major part of the spectrum) are very often followed by a sc-geomagnetic storm (cf. de Feiter *et al.*, Planet. Space Sci. 2, p. 223, 1960). This paper deals with some details of this relation. It is based on material covering the period 1956 January 1—1961 July 31. Unfortunately the spectral patrol coverage is not very complete. Therefore the spectral classification of the solar radio noise material has been left out of consideration. On the contrary, single-frequency data are available for the three frequency ranges about 200, 500 and 3,000 MHz to a high degree of completeness. Since the beginning of the IGY complete coverage on 200 and 545 MHz is available by the coorperation of the three stations NERA, Paramaribo and Hollandia, the records of which were at our disposal. The 3,000 MHz-range is nearly completely covered by the records made at NERA and the published data from the observatories Ottawa, Tokyo and Toyokawa and Berlin. Up to 1957 July 1, 200 and 545 MHz-records of the observatory NERA were completed by data from various other observatories, as published in the Quarterly Bulletin on Solar Activity. The advantage of the single-frequency over the spectral data is the possibility of a better calibration of the former records. The significance of this will appear from this paper: the energy-content of the outburst is an important quantity in the relation between outbursts and ssc's.

Previous studies have shown that type IV-outbursts can be seen as important marks of the occurrence of eruptive sources of corpuscular radiation. However, it is well known that by no means every source is accompanied by a type IV-outburst. This is illustrated by the fact that only 40% of all ssc's are preceded by such a burst within reasonable intervals of time. But it appears that the important sources are more often marked by type IV-bursts: 73% of the sc-storms reaching at least $Kp=8$ are preceded by such bursts.

Since this paper is concerned with solar radio noise events, the optical flare-data have only been used to give information about the approximate position of the outburst on the solar disc. In particular the optical importance has been left out of consideration.

§ 1. Magnitudes of outbursts, responsible for ssc's

In order to investigate the relationship between outbursts and ssc's, we measure the outbursts according to their total energy-content Φ, *i.e.* duration × mean flux density, in units 10^{-22} w. min/m². Hz, as compared with the energy produced by the quiet sun during one minute. A logarithmic scale is used. In previous work we defined a great outburst on 200 MHz as exceeding at least 100 times the quiet sun, on 500 MHz 20 times the quiet sun, on 2,000 MHz 12 times the quiet sun (1,000, 1,000 and $2,500 \cdot 10^{-22}$ w.min/m². Hz respectively). On a logarithmic scale these limits are $\log \Phi = 2.0$ on 200 MHz, 1.3 on 500 MHz, 1.1 on 3,000 MHz. A universal great outburst exceeds the limits on all three frequencies simultaneously.

The dependence of the storm-association on the intensity of the outburst is shown by Fig. 1. It contains all universal great outbursts that were associated or definitely not associated with a ssc, the latter ones being denoted by a circle. Moreover, 28 less intense outbursts are entered in the figure, down to $\log \Phi = 1.6$ *on 200 MHz,* $\log \Phi = 0.5$ *on 500 MHz,* $\log \Phi = 0$ *on 3,000 MHz, for which the decision about ssc-association could be made. As far as the material allowed, no less intense outbursts were omitted, that could reliably be held responsible for a ssc.*

It appears from Fig. 1, that in drawing the heavy lines as indicated, we generally separate the ssc-associated outbursts from the not ssc-associated ones. In this way reliable lower limits of the energy-content on both 200 and 500 MHz are determined. This enables us to revise the above definition of great outburst on 200 and 500 MHz in such a way, that a great outburst is generally followed by a ssc. The lower limits then are $\log \Phi = 2.2$ on 200 MHz and 1.0 on 500 MHz (1,500 and $500 \cdot 10^{-22}$ w. min/m². Hz respectively). We must make an exception for the outbursts, situated in the rectangle between heavy and dashed lines in Fig. 1 (200 MHz: $\log \Phi < 2.6$, 500 MHz: $\log \Phi < 1.8$), which appear to be not very prolific in storms. (Among the remaining 80 outbursts, only 15 failed to be followed by a ssc.)

On 3,000 MHz the critical value for storm-association is also easily found: among the 7 bursts with $\log \Phi < 0.7$ entered in Fig. 1, 3

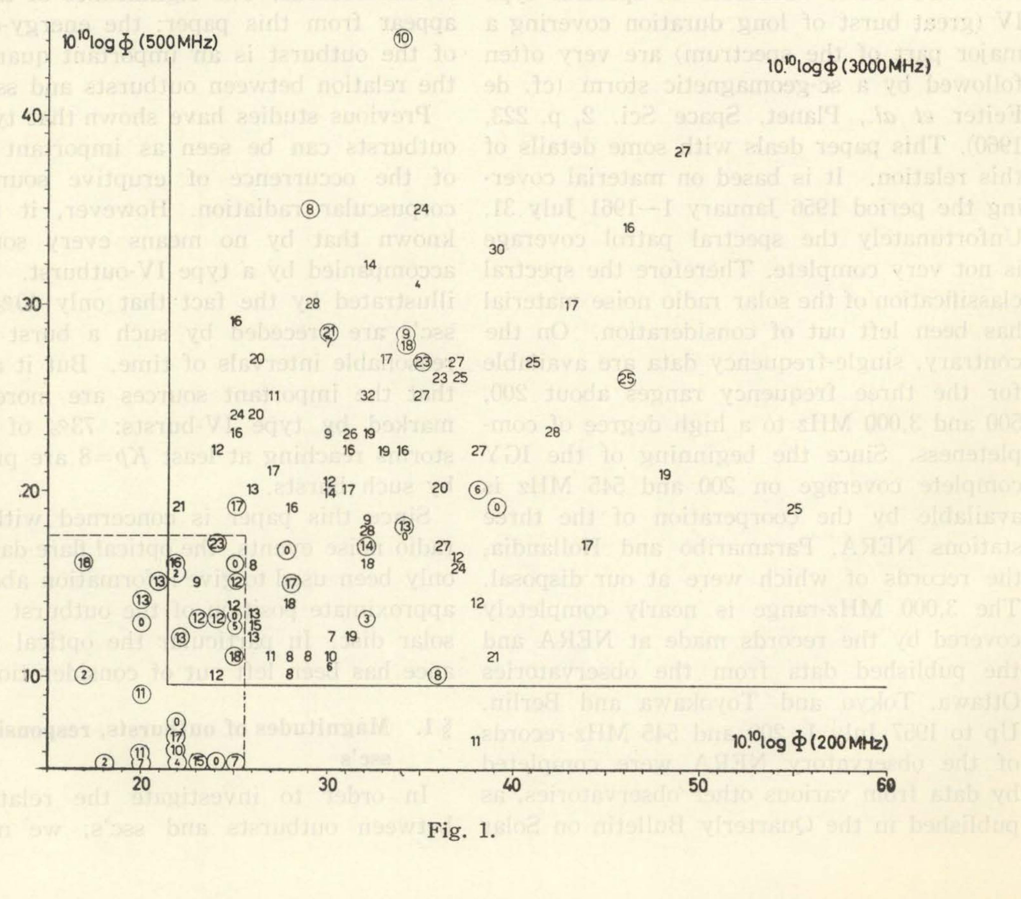

Fig. 1.

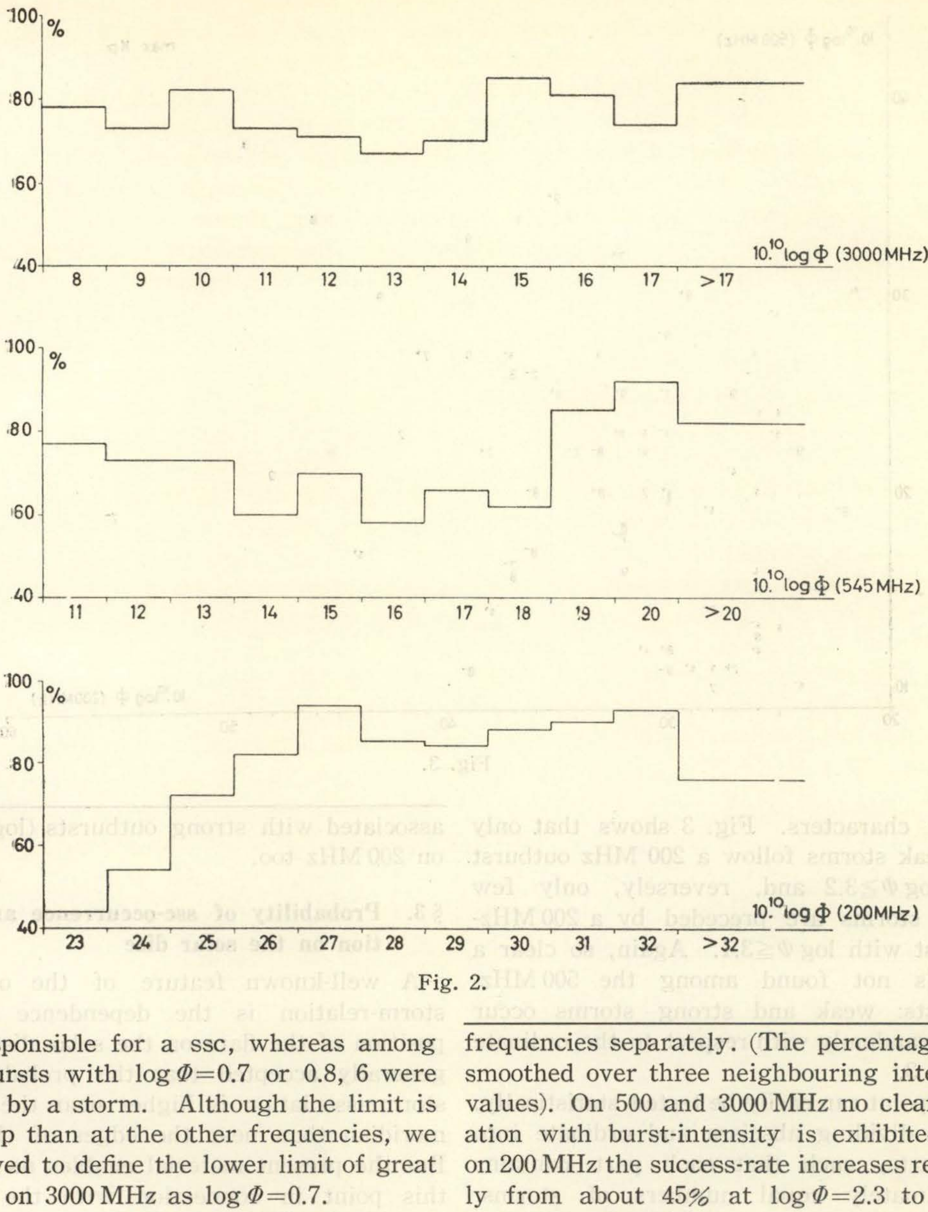

Fig. 2.

were responsible for a ssc, whereas among the 8 bursts with $\log \Phi = 0.7$ or 0.8, 6 were followed by a storm. Although the limit is less sharp than at the other frequencies, we are allowed to define the lower limit of great outburst on 3000 MHz as $\log \Phi = 0.7$.

Thus, there are 73 universal great outbursts outside the dashed rectangle in Fig. 1; 62 or 85% of them were associated with a ssc. The 11 "failures" are distributed rather randomly over the outburst-intensities on all frequencies, so that the correspondence between outburst and ssc cannot be further improved by choosing other intensity-criteria.

Fig. 1 suggests that the ssc-responsibility depends on the outburst on 200 MHz in a more distinctive manner than on the other frequencies. This point is shown clearly by Fig. 2, which gives the "success-rate" as a function of burst-intensity for the three frequencies separately. (The percentages are smoothed over three neighbouring intensity-values). On 500 and 3000 MHz no clear variation with burst-intensity is exhibited, but on 200 MHz the success-rate increases regularly from about 45% at $\log \Phi = 2.3$ to about 85% at $\log \Phi = 2.6$.

§ 2. Magnitude of outburst and amplitude of geomagnetic storm

Next, we shall look for a relationship between outburst- and storm-intensity. As a measure of the storm-intensity we chose, among many possible criteria, the maximum Kp reached. It is plotted against the total energy-content of the outburst on 200 and 500 MHz in Fig. 3. For the sake of clearness storms are divided into "weak" and "strong" storms, with max. $Kp \leqq 6^+$ and $\geqq 6^-$ respectively; weak storms being denoted by

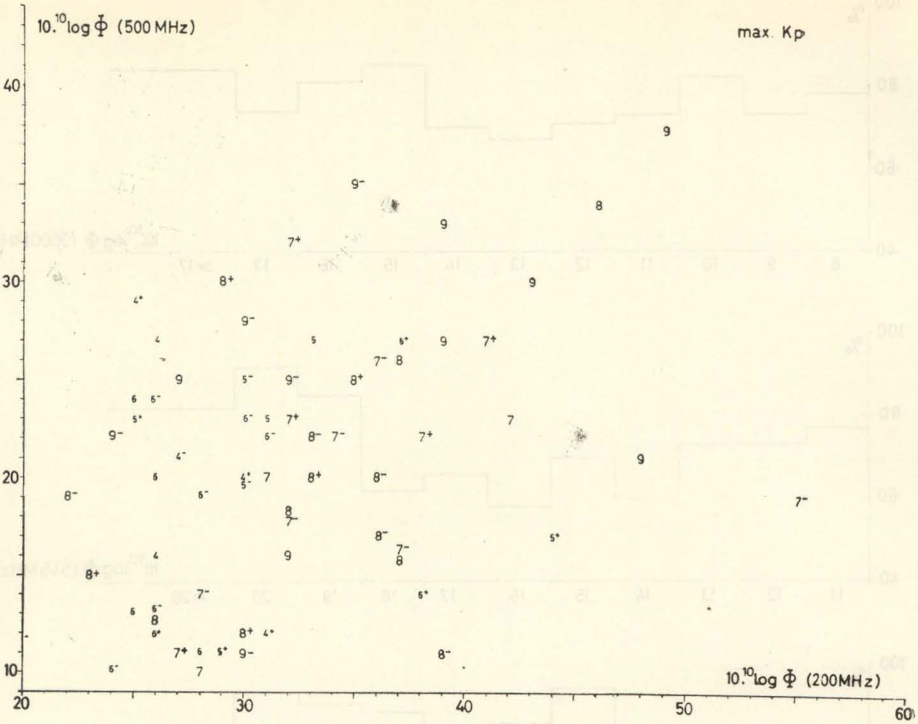

Fig. 3.

smaller characters. Fig. 3 shows that only few weak storms follow a 200 MHz outburst with $\log \Phi \geqq 3.2$ and, reversely, only few strong storms are preceded by a 200 MHz-outburst with $\log \Phi \leqq 3.1$. Again, so clear a limit is not found among the 500 MHz-outbursts: weak and strong storms occur rather randomly with respect to the ordinate in Fig. 3.

This point can easily be tested statistically, *e.g.* by dividing abscissa and ordinate into two parts, such that each part contains approximately equal numbers of storms. Then, on 200 MHz the stronger outbursts cause 28 strong and 4 weak storms, but the weaker outbursts 13 strong and 22 weak storms. This distribution has a probability much less than 1% of occurring by chance. On 500 MHz the difference is absent: the strong and 14 weak storms, nearly exactly what is to be expected by chance. Fig. 4 shows how the mean geomagnetic storm-intensity (max. *Kp*) is related to the outburst-energy on the three frequencies. It must be noted that the curves are not quite independent, because the very greatest outbursts on 500 and 3000 MHz are generally associated with strong outbursts ($\log \Phi \geqq 3.2$) on 200 MHz too.

§ 3. Probability of ssc-occurrence and position on the solar disc

A well-known feature of the outburst-storm-relation is the dependence on the position of the flare on the solar disc. It is generally accepted that the probability of storm-association is higher near the central meridian than near the edges of the disc. But the present material enables us to treat this point in connection with the results already obtained. Fig. 5 gives the position of the flare together with the energy-content of the 200 MHz-outburst. Bursts that were not followed by a ssc are again denoted by a circle.

We may firstly note the very low concentration of "failures" near the central meridian. Over 90% of the bursts occurring here are followed by a ssc. Obviously no positional dependence prevents the storm-production in this part of the solar disc, so that this again may be regarded as a confirmation of our criterion for ssc-association.

We already showed that the outbursts in

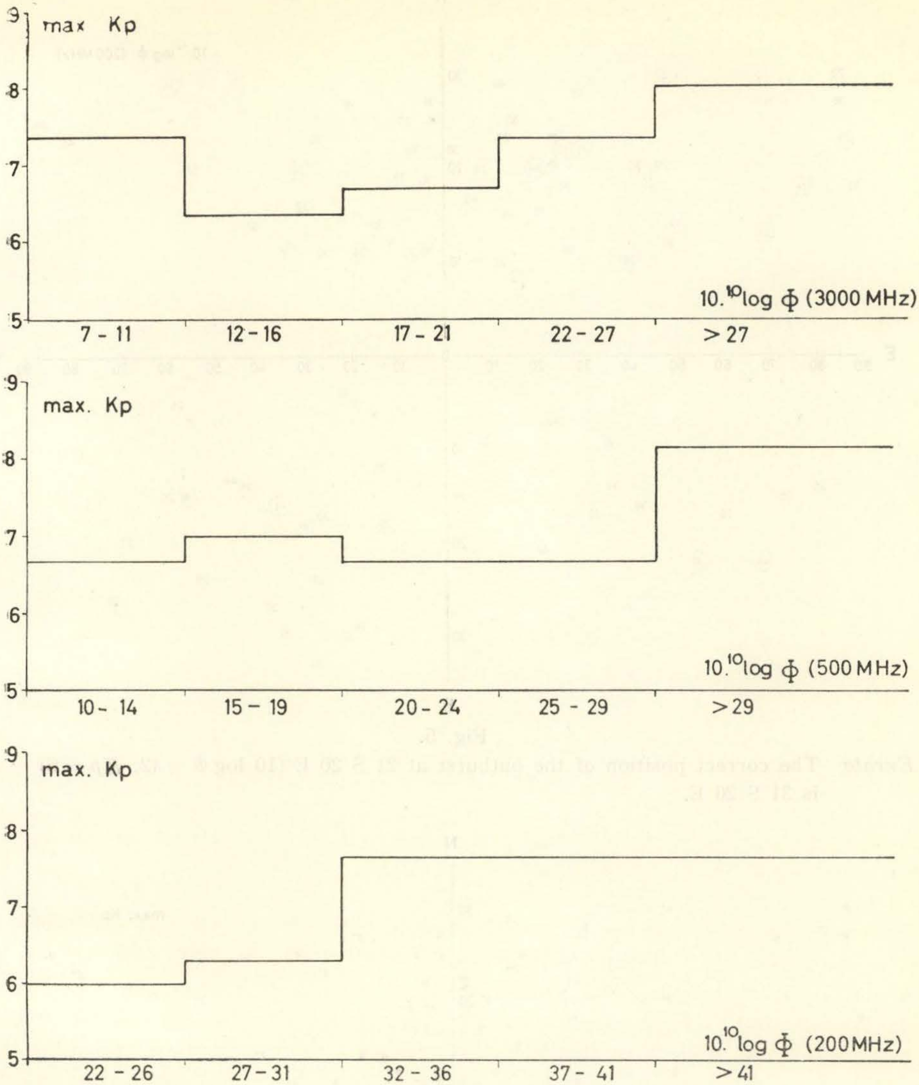

Fig. 4.

the lower-left rectangle of Fig. 1 are much less often responsible for a ssc. The positions of these bursts are denoted by the smaller characters in Fig. 5. They appear to occur mainly at greater distances from the central meridian. The significance of this effect can easily be shown statistically by dividing the sun into centre and limb zones, separated by the 30° E and W meridians. Counting all bursts and the small bursts under consideration, we find the numbers given in Table 1.

The resulting $\chi^2=6.7$ ($\nu=1$), probability= 1%. Being cautious because of the few cases concerned, we may say that there is a tendency of suppressing the outburst-energy in the limb zones. A slight, but not significant E-W asymmetry is present.

The same test may be applied to the distribution of the outbursts, that were not followed by a ssc. The numbers are given in Table II. The close correspondence between energy of the outburst and storm-association is thus also found (although less significant) in the distribution over the solar disc. But we can separate these longitude-effects by omitting the smaller outbursts, that are less prolific in ssc's, and occur mainly in the limb zones. We then find the numbers as shown in Table III.

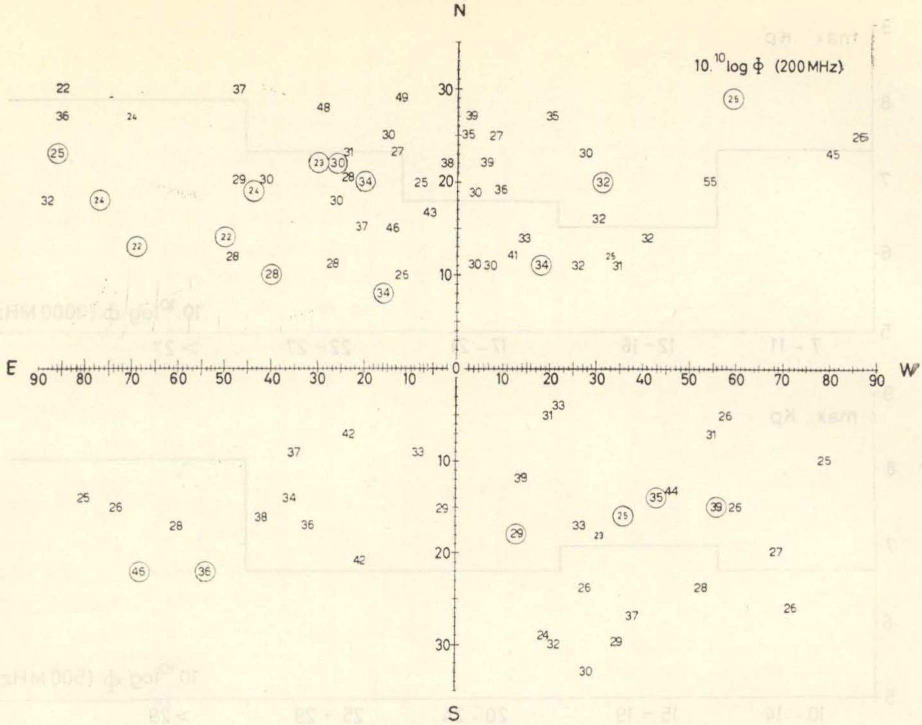

Fig. 5.

Errata The correct position of the outburst at 21 S 20 E (10 log $\Phi = 42$, $Kp = 6$) is 31 S 20 E.

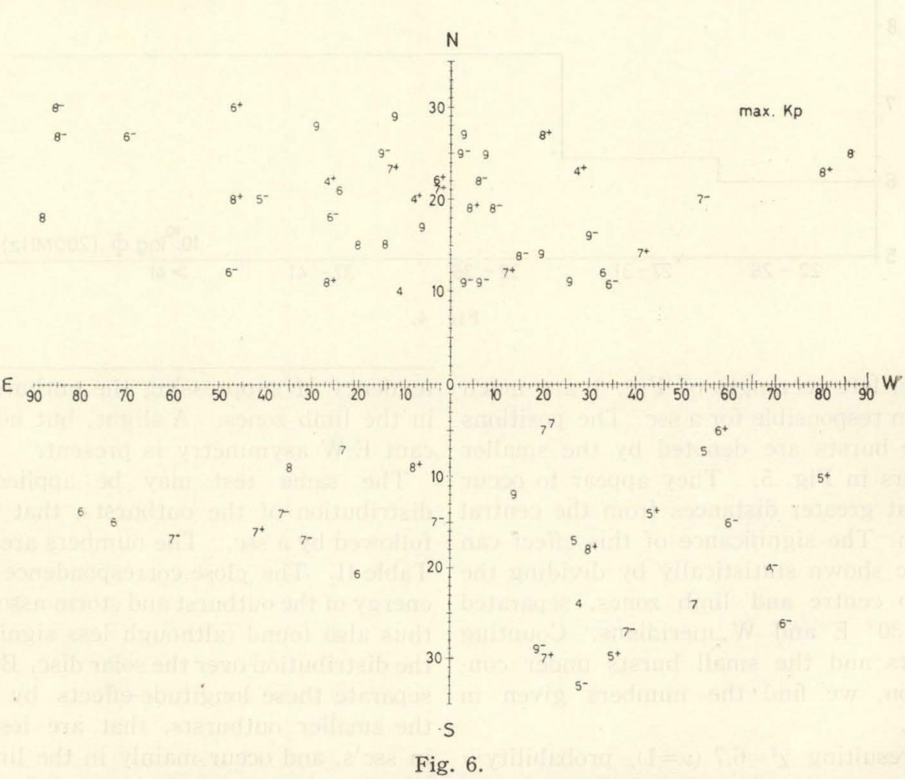

Fig. 6.

Errata The correct position of the outburst at 16 S 20 E (10 log $\Phi = 38$, $Kp = 7^+$) is 14 S 49 W.

Table I.

Zone	All bursts	Small bursts	
		Observed	Expected
Central	46	1	5.1
Limbs	45	9	4.9

Table II.

Zone	All bursts	Not followed by ssc	
		Observed	Expected
Central	46	5	9.6
Limbs	45	14	9.4

$\chi^2=4.4$ $(\nu=1)$
$P=3\%$

Table III.

Zone	Bursts	Not followed by ssc	
		Observed	Expected
Central	45	5	6.7
Limbs	36	7	5.3

$\chi^2=0.98$ $(\nu=1)$
$P=30\%$

A slight, but not significant variation in ssc-occurrence is left. Within 15° E and W from the central meridian the probability of ssc-association is 95%, within 40° from the limbs about 75%.

Thus our material leads to the conclusion that the lower ratio of storm-occurrence in the limb zones corresponds narrowly to the lower energy-content of the outbursts in this part of the solar disc.

Independently from this, the storm-production of flares, associated with great universal outbursts, shows no significant variation with heliographic longitude.

§ 4. Positional dependence of geomagnetic storm-intensity

In this connection another question arises, viz. the variation of the intensity of the geomagnetic storm with the position of the flare preceding it. Our Fig. 6 gives max. *Kp* in connection with the position of the flare. The concentration of high values to the central part of the disc is striking, as can be seen from Table IV, which gives the numbers of strong storms in the centre and limb zones.

The storms 9 and 9^- are mentioned separately for the sake of completeness, notwithstanding their small number.

Table IV.

Zone	Total number of storms	Number $\geqq 7^-$ obs.	Number $\geqq 7^-$ exp.	Number $\geqq 8^-$ obs.	Number $\geqq 8^-$ exp.	Number $\geqq 9^-$ obs.	Number $\geqq 9^-$ exp.
Central	43	32	27.3	24	18.0	14	8.1
Limbs	31	15	19.7	7	13.0	0	5.9
χ^2		5.3		8.2		12.6	
P		2%		0.5%		<0.1%	

We already noted the increase of storm-intensity with the energy-content of the 200 MHz-outburst preceding the storm. But it appears that no concentration of stronger bursts towards the central meridian is present. Thus the increase of max. *Kp* towards the central meridian is independent from the energy of the 200 MHz-burst. It may be regarded as an indication for the directional intensity-diagram of the source of the corpuscles, which obviously differs from the corresponding diagrams of the 200 MHz-outbursts.

This fact may also throw some light on the following point. 13 strong storms are preceded by relatively less important outbursts, as can be seen from Fig. 3 ($10^{10} \log \Phi$ (200 MHz) $\leqq 31$). Among these storms, 8 appear to be due to flares in the central zone of the solar disc, and in this way are possibly favoured to reach a high value of max. *Kp*.

A further conspicuous feature of Figs. 5 and 6 is the N-S asymmetry. In the northern hemisphere we count 55 outbursts (Fig. 5) and 44 ssc's (Fig. 6), in the southern hemisphere 36 outbursts and 30 ssc's. These numbers show that the probabilities of ssc-occurrence in both hemisphere are equal. The asymmetry is, however, very remarkable for the intense geomagnetic storms ($Kp \geqq 8^-$). Especially in the vicinity of the central meridian N is favoured over S very strongly. As a counting of flare 2-and 3-production in active regions during the previous sunspot-cycle showed similar preference for the N-hemisphere, the effect may be a particular feature of the present and the previous cycles.

§ 5. Discussion

Though the observed numbers of outbursts with $\log \Phi \geqq 2.6$ show up a strong concentration towards the centre of the disc, the average Φ (for these high values) does not depend on the position of the flare. This seems to indicate that the lack of great outbursts near the limb is due to a certain effect of hiding the source in directions tangential to the solar surface. When the outburst is not hidden, the observed energy does not depend on the direction of observation.

Essentially, the probability of ssc-occurrence is determined by Φ: a value $\log \Phi \geqq 2.6$ is necessary for the escape of the corpuscular radiation. Because of the "hiding effect", relatively seldom escape will take place in tangential direction.

Moreover, we showed that higher *Kp*-values are reached in directions perpendicular to the solar surface than in tangential direction. Apart from its variation with Φ, the intensity of the storm has its own directional diagram, whereas Φ does not depend on the direction, as far as high values of Φ are concerned.

Summary of conclusions

A statistical examination of type IV-outbursts and ssc's occurring in the years 1956-1961 leads to the following conclusions.

1) 85% of the outbursts exceeding to following limits are associated with a ssc: at 200 MHz 4000, at 500 MHz 500, at 3000 MHz $1000 \cdot 10^{-22}$ w. min/m^2. Hz.

2) Among the outbursts between 1500 and 4000. 10^{-22} w. min/m^2. Hz at 200 MHz the percentage of ssc-occurrence increases with energy.

3) Since the lower energy-values at 200 MHz occur more often at great distances from the centre of the solar disc, relatively fewer ssc's are caused here. No important centre limb variation of ssc-occurrence is exhibited by the stronger 200 MHz-outbursts.

4) 85% of the outbursts exceeding $15000 \cdot 10^{-22}$ w. min/m^2. Hz at 200 MHz are followed by a sc-storm reaching at least $Kp = 7^-$.

5) The outbursts near the centre of the solar disc are followed by stronger sc-storms than are the outbursts far from the central meridian.

6) Near the central meridian more universal great outbursts occurred in the northern than did in the southern hemisphere. Moreover, the geomagnetic storms caused in the N-hemisphere were stronger than those caused in the S-hemisphere.

Addendum

The last part of the introduction (p. 49) is to be read as follows: For a detailed statistical investigation we cannot but use reliable correspondence between outbursts and ssc's. Thus doubtful relations (*e.g.* 2 outbursts followed by 1 ssc) have been omitted. In our opinion, based on previous work, the outburst-ssc connection is reliable if there is a one-to-one correspondence within a time-interval between 17 and 60 hours. Moreover, during the years 1956-1960, 13 one-to-one correspondences showed greater delays, the values of which were 64, 66, 66, 67, 68, 68, 73, 74, 74, 76, 80, 80, 115 hours. We may regard the value of 115 hours as due to chance. Thus, being cautious because of the few cases considered, we find a values of about 80 hours as upper limit for the delay. For security an upper limit of 76 hours is adopted in selecting the material for this study. A fairly reliable relation is also stated when the trace of a sequence of outbursts can be found in a sequence of ssc's (*e.g.* the November 1960—sequence).

Discussion

Cook, F.E.: Your slide shows no relation between the amplitudes of 200 Mc/sec event, and solar meridian distance. Is this result expected?

de Feiter, L.D.: No, we did not expect it.