Ionospheric Effects of Solar Flares 1948

Preliminary Report No. 1

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Abstract

Regular recordings of ionspheric effects of solar flares with different kinds of apparatus were started at the *Geophysical Observatory, Chalmers University of Technology, Gothenburg* early in 1948. The results of the first half year are presented and analysed in this preliminary communication. The statistical distribution of radiation sources of stronger and weaker fade-outs across the solar disk is shown. The magnitude and probability of the absorption of the ultraviolet fade-out radiation in the solar corpuscular beam is discussed.

Introduction

Almost ninety years ago the well known solar observer R. C. CARRINGTON [1] happened to observe the simultaneous occurrence of a bright solar flare, in the regions of sun spots, and certain disturbances of terrestrial magnetism. The disturbances found by CARRINGTON (when surveying the Kew Observatory magnetic records a day or two after the detection of the chromospheric eruption) were followed about 18 hours later by one of the most outstanding magnetic storms within the last 100 years. This storm, and especially the remarkable coincidence of the solar flare and the crochet in the magnetograms, was not considered seriously by other workers in the field at that time. Lord KELVIN for example regarded the evidence as a mere coincidence. CARRINGTON himself, although considering the phenomenon as deserving of notice, said that "he would not have it supposed that he even leans towards hastily connecting them".

About thirty years later C. A. YOUNG called attention to simultaneous occurrence of brightening of $H\alpha$ light in sun spot regions and short bay-disturbances of terrestrial magnetism. He believed [2] that the active agent connecting the two phenomena was propagated from the Sun to the Earth with the velocity of light. This important suggestion was not considered favourably by contemporary investigators. This was probably due to the fact that one had found the great perturbations of terrestrial magnetism, the magnetic storms, to be related to solar activity in a statistical sense only. Further attempts to associate magnetic storms with central-meridian passages of sun spots indicated a time lag varying from one to several days.

A fresh impetus was given to the study of these phenomena when in 1937 R. JOUAUST [3] and J. H. DELLINGER [4] independently drew attention to simultaneous solar eruptions, short magnetic disturbances and short, intense radio fade-outs. The magnetic disturbances shared the characteristics of the radio effects, *viz.* absence of disturbance over the dark hemisphere, simultaneity throughout the portion of the earth affected, suddenness and finally maximum intensity in the regions where the Sun's radiation descends vertically.

J. A. FLEMING [5] and A. G. McNISH showed that the magnetic effect is an augmentation of the normal daily variation over the sunlit hemisphere, probably due to increased ionization of the atmosphere, by ultra-violet light from the solar eruption at the bottom of or below the *E*-layer.

Although some of the magnetic effects resemble magnetic bays it should be stressed, in this connexion, that ordinary bays are different phenomena, especially since they occur frequently during the night hours.

A considerable amount of fade-out data was collected and published in the years 1936—1938 and it later appeared that the fade-out frequency decayed in very much the same way as the solar activity after the sun spot maximum in 1938. Now we are passing a maximum of particularly high relative sun spot numbers, *R*, and it is not astonishing that fade-out phenomena occur rather frequently.

Although a great many fade-outs have been observed so far, we know only the general nature of the terrestrial effect of the solar flare. Meagreness of data, for example on the nature of light-emission from the chromospheric eruptions and on the physical state of the lower ionosphere, renders speculation regarding the ionic processes involved quite difficult. A more careful radio investigation seems to indicate that the radio effects of the solar flare in the lower ionosphere, i.e. the long wave effect, are not unambiguous. Similarly the magnetic effects vary. Often the disturbance has a characteristic V-shape, sometimes it is oscillatory and sometimes a combination of both types with a more or less irregular form. If the actual change with time of ultra violet radiation from the solar flare were known, the shape of the magnetic disturbance would be very important as a measure of the recombination rate in the lower ionosphere, where the ultra violet flare radiation is believed to be absorbed. M. WALDMEIER [6] has determined the general shape of the visual light intensity curve and finds roughly that the increase is quite steep and covers about one third of the flare time. The flare intensity curve may thus be V-shaped. Consequently the crochet in the magnetograms should have about the same shape if the effective recombination is rapid enough.

Another interesting feature concerns the emission of radio noise from sun spot regions. Sir EDWARD APPLETON and J. S. HEY [7] report as a definite result that when a solar flare occurs which is accompanied by a radio fade-out, there is also in many cases a marked enhancement of solar noise. On the other hand C. W. ALLEN [8] from Australia finds, that briefly put, the position is that while an outburst of radio-noise may on occasions accompany a flare, most flares are not accompanied by radio noise. It should also be pointed out that for different wave-lengths there is comparatively little detailed agreement between the bursts of radio noise. Several workers in this field, like ALLEN, seem to believe that the location of the source of the noise is not in or near the photosphere or chromosphere but is probably high in the corona. It is further suggested that the noise is stimulated by for example ultraviolet excitation proceeding from a flare. However, it does not seem unlikely to us that both the flare and the noise arise from a single source of discharge character producing, at the same time, a flare in the lower levels and an excitation in the higher levels where the ion and electron density is sufficiently low to let the ultra short wave radiation through.

It appears from what has just been mentioned that much more observational material is needed if we are going to be successful in understanding the nature of the solar flare and its terrestrial effects. International cooperation is especially important in this connexion, between the astronomers, the radiophysicists and the geophysicists so that enough material can be exchanged for statistical treatment.

The *Geophysical Observatory* of the *Research Laboratory of Electronics, Chalmers University of Technology*, Gothenburg, Sweden, therefore early this year (1948) started extended series of observations regarding the terrestrial effects of solar flares. These observations include continuous ionospheric recordings, recording of long and short wave signals and, quite recently, also recordings of peaks of solar noise. These observations, which will be further extended, are intended to run over a number of years. Our results will be published as a series of preliminary reports, generally covering a period of six months each. The following sections contain the main results and preliminary conclusions from the first half year of 1948.

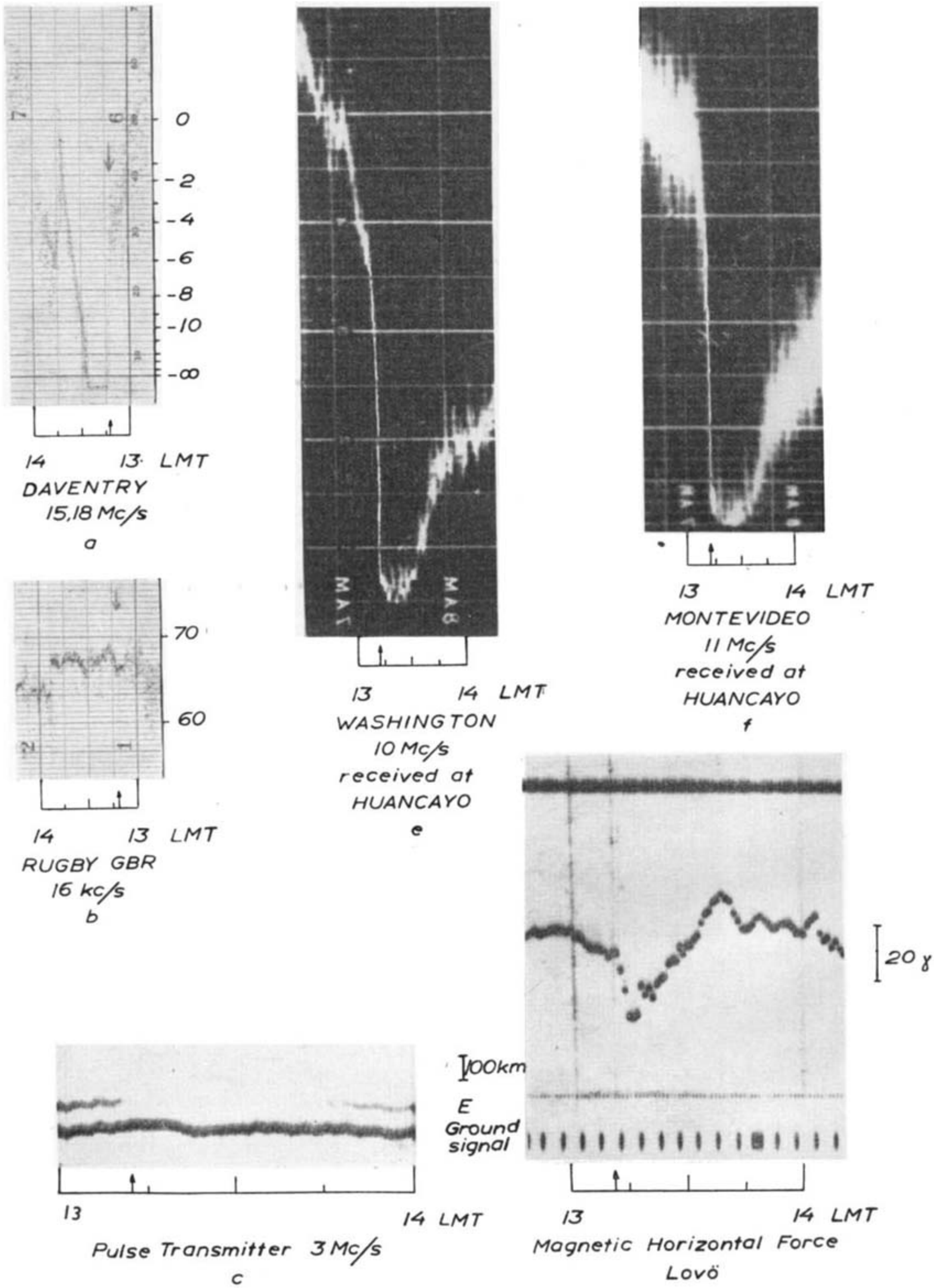

Fig. 1. The radio fade-out and magnetic disturbance on March 20, 1948.

Discussion of recorded results.

Continuous observations at the *Askim* field station (57°41′ N, 11°59′ E) [9] of the ionosphere have been undertaken for a number of years, unfortunately with several long interruptions during the war and immediately after. For the purpose of fade-out recording the field station was later equipped with recording signal strength meters, both for short and for very long waves. All of these recorders have been running continuously since February 1948.

Of the wealth of recorded data a few typical examples will be presented and discussed in this section. On March 20, 1948 at least two typical fade-outs were recorded, a weaker one between 10.44 and 10.55 Local Mean Time (LMT = GMT + 48 minutes) and a stronger one between 13.12 and 13.27 LMT. *Zürich* reported solar eruption ($H\alpha$) from about 10.44 to 10.58 on the western edge of the solar disk. Unfortunately no further observations were carried out at Zürich that day. *Huancayo Geophysical Observatory*, Peru, reported two fade-outs the same day, one beginning at 13.13, the other one at 18.33 (all time figures in the following are given in Gothenburg LMT). The late Huancayo fade-out of course could not be recorded on our hemisphere.

In fig. 1 a is shown the field strength record of the *Daventry* 15.18 Mc/s signal. As usual the fade-out begins with a very sharp decrease in signal strength followed by a slower recovery. It seems likely that at about 13.45 a new burst of ultra-violet radiation (although considerably weaker than the first one) causes a second and marked depression in the signal strength curve. The long wave record of the *Rugby* 16 kc/s signal, as shown in fig. 1 b, shows a marked perturbation which however, as is often the case, is difficult to analyse. To this question we will have occasion to return later. It is sufficient in this connexion to note that the fade-out radiation was sufficiently intense to penetrate to the low ionospheric level of 16 kc/s wave reflection. This fade-out is classified as belonging to the group labelled Intensity 3. This is also obvious after an inspection of the vertical incidence 3 Mc/s record from Askim reproduced in fig. 1 c. Shortly before complete absorption the wave experiences an increase in virtual height of not less than 15 km.

The horizontal component of the terrestrial magnetic field shows the typical V-shaped impetus as shown in fig. 1 d, which is an enlargement of a magnetogram kindly supplied us by Dr N. AMBOLT from the *Lovö Observatory* (59°24′ N, 17°48′ E). At about the time of the possible second influx of ionizing radiation there is a second small crochet in the diagram, but whether this is a mere coincidence or not can not be decided at this stage.

Finally we reproduce in figs. 1 e and 1 f copies of 10 Mc/s and 11 Mc/s signal strength records from Huancayo kindly sent to us by the Geophysical Observatory. Both show typical equatorial features. A very sharp decay followed by a slow and characteristic recovery.

In conclusion it should be remarked that for example the *Witteveen* magnetic observatory recorded the effect of a strong solar flare lasting from 13.12 until 13.32 LMT with a maximum deviation in H of -40 gammas.

A month later, April 20, another fade-out of similar intensity was recorded as depicted in fig. 2. The fade-out was recorded at Askim

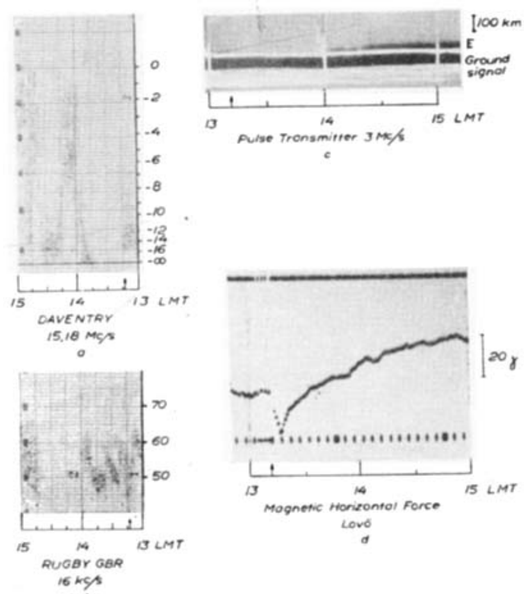

Fig. 2. The radio fade-out and magnetic disturbance on April 20, 1948.

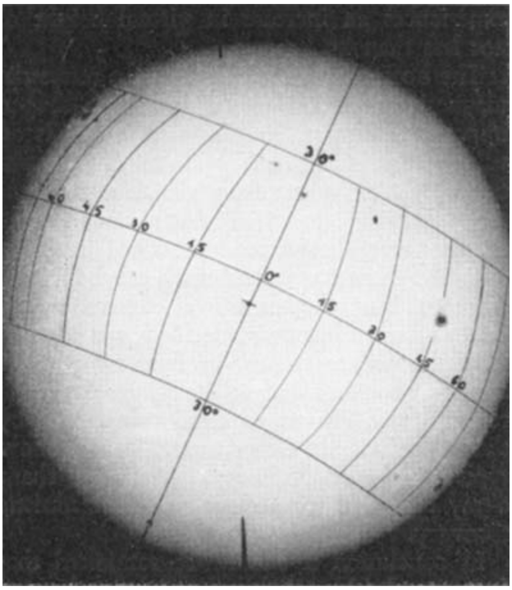

Fig. 3. Photograph of the sun taken on 1948 April 20 (Stockholm Observatory, Saltsjöbaden).

as lasting from 13.12 until 14.02. On the same day Huancayo reported a fade-out 13.03—13.48.

As far as the variation in *H* is concerned we notice in this particular case a clean example of fade-out magnetic impetus. The pulse rise was about 5 minutes long with a decay time roughly four times as long. That such a rapid rise is possible is in itself a certain indication of the fast recombination at the lower ionospheric levels where the variation currents, augmenting the daily variation in *H*, flow.

The 16 kc/s record shows a sign of perturbation but, as before, its nature is difficult to analyse.

A moderate magnetic storm began gradually at about 00.48 LMT on April 22 and continued until about 18.48 the same day. This has been confirmed by reports from several magnetic observatories, for example *College Magnetic Observatory* at longitude 147°49'.3. If the fade-out and the storm are traced to the same source this would mean that the charged particles causing the storm would have been on their way from Sun to Earth about 36 hours. This corresponds to an average velocity of about 1 150 km/sec., a reasonable value if the ejected atoms are supported by radiation pressure in the solar atmosphere.

In fig. 3 is shown a solar photograph taken by Dr Y. Öhman at the *Stockholm Observatory, Saltsjöbaden*. The solar flare can be attributed to any of the spot regions. To what group could the corpuscular effect, eventually causing the moderate magnetic storm, be attributed? There are only faint groups near the sun's optical center and even for these groups the distance from the center never is less than about 22°. In order therefore to explain the moderate storm we have to assume in this case either that one of the spot groups was capable of considerable corpuscular radiation in a non-radial direction or that polarized corpuscular beams in space might be able to induce gaseous discharges in the upper terrestrial atmosphere producing, perhaps, a kind of auroral current zone.

It seems obvious that a very extended statistical analysis of the solar flare and its terrestrial effects is necessary in the future discussions of these problems. All considerations must at present be of a very speculative character.

In fig. 4 we reproduce typical records of a fade-out of intensity 2 on May 8, 1948. As recorded on the sensitive vertical incidence ionospheric recorder the fade-out lasted from 19.17 until 19.22. The decrease in the short wave field strength was not as sharp as in the case of a fade-out of intensity 3 but the long

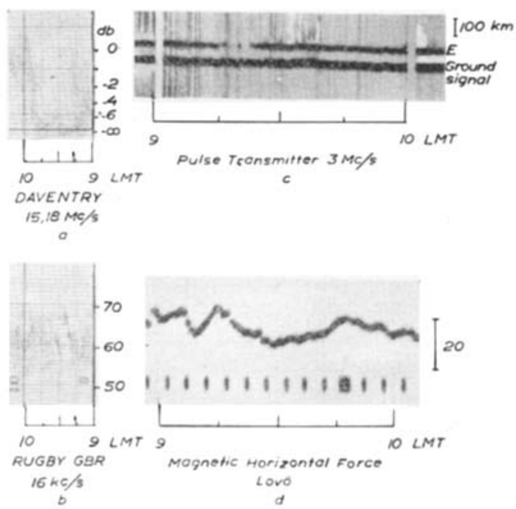

Fig. 4. The radio fade-out and magnetic disturbance on May 8, 1948.

wave record, on the other hand, showed a characteristic variation as depicted in fig. 4 b. A marked peak in signal strength was followed by a rapid but marked depression. This variation resembles the fade-out variation recorded on shorter long waves which are reflected at a higher level in the lower ionosphere, in day time, than are the 16 kc/s waves. A typical impetus was recorded in the magnetograms as reproduced in fig. 4 d. The maximum deviation was about — 10 gammas.

As a final typical example we have collected the fade-out records of June 3, 1948, shown in fig. 5. The phenomenon was classified as being of intensity 3 with a duration of about 28 minutes beginning at 10.11. The short wave signal strength record showed a typical second depression and the *H* magnetograms a characteristic impetus with an amplitude of about 11 gammas. The pulse increased to this value in about 6 minutes and then decayed in about 23 minutes. As so many times before, at our geographical location, the time of decay was about four times as long as the rise time for this clean sample. The atmospherics, received on 15 kc/s, increased irregularly during the fade-out, as shown in fig. 5 a. This is in ac-

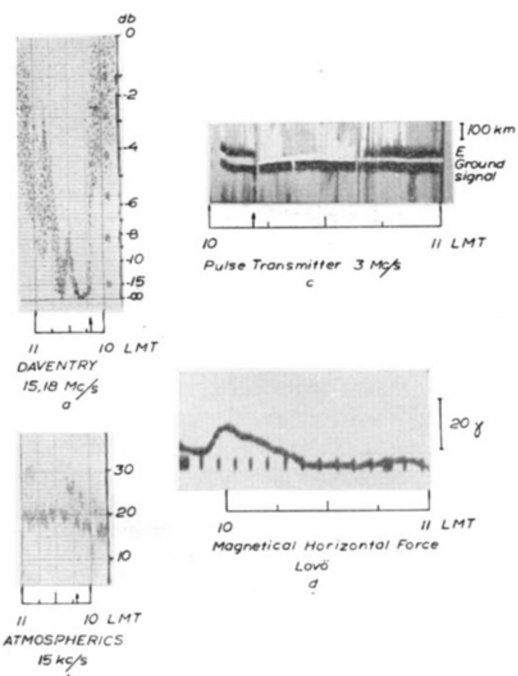

Fig. 5. The radio fade-out and magnetic disturbance on June 3, 1948.

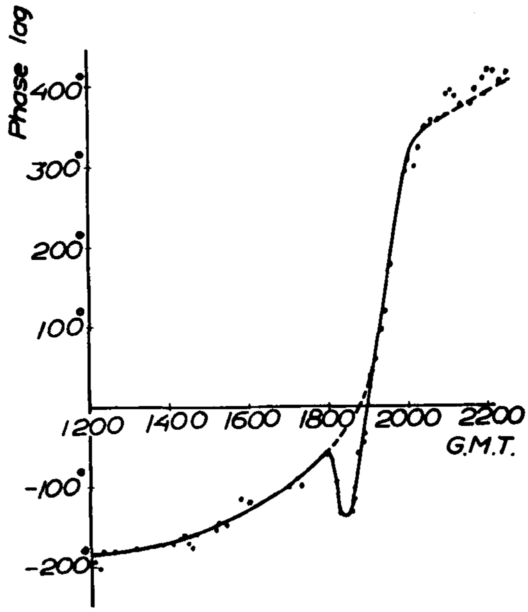

Fig. 6. Short-lived sudden disturbance as observed on long waves (16 kc/s) with phase apparatus (6 July 1938) by Budden, Ratcliffe and Wilkes.

cordance with the early results of R. BUREAU [10] who more than ten years ago demonstrated the increase of long wave atmospherics during solar flares.

Let us return to the question of long wave reflection in the ionosphere at the time of a fade-out. In fig. 6 we have reproduced a curve deduced by K. G. BUDDEN, J. A. RATCLIFFE and M. V. WILKES [11] from observations on a long wave (16 kc/s) phase apparatus during a short-lived disturbance of fade-out. For the reflexion heights in question (of the order of 70 km) and over the range of phase angles involved changes of phase are proportional to changes of reflexion height. The required change of scale is such that 100° represents 3.16 km. The dashed curve indicates the characteristic phase change on an undisturbed summer day.

First of all it is worth noting that the average reflexion height at noon is about 17 km lower than at night. A probable height range is say 73 to 90 km at the time in question. The first question one asks before considering the effect of the sudden disturbance concerns the regular reflector. The shape of the regular phase curve shows that the (in this case vertical incidence) long wave is reflected from the tail of a Chapman region. Of course it is of specific importance to investigate whether this can be the tail of the *E*-region.

The normal *E*-region formed with a maximum at a height of say 110 km, however, should not be sufficiently ionized at a level of 73 km to produce the required reflexion. It is on the other hand possible that shorter and less absorbable ultraviolet wave-lengths, beyond the absorption limit, will be of importance in augmenting the tail ionization of the layer. Further radio measurements regarding this question thus are of considerable importance.

Turning now to the fade-out augmentation of the ionization at the base of the *E*-layer we find, from fig. 6 for example, that the change in the reflecting region is remarkably rapid even if it occurs late in the summer afternoon. In the case of fig. 6 the reduction in height was of the order of 3 km. Still the noon level of reflexion was not reached on the particular occasion.

On account of the rapidity of the phenomenon one must assume that $\sqrt{q\alpha}$, where q is the intensity of the ionizing fade-out radiation and α the effective recombination coefficient for the reactions involved at the low ionospheric level, is quite large. In order to explain the augmentation of the magnetic field during the fade-out as due to currents produced at this low level one has to assume that the low layer gets an integral conductivity at least as great as that of the *E*- and F_1-layers combined. This is necessary, it seems, because theoretical work on atmospheric tides indicates that the tidal motions tend to increase with height. The electric forces causing the currents at the fade-out level therefore can hardly be greater than in the *E*- and F_1-layers.

BUDDEN, RATCLIFFE and WILKES find that even at the low level of 70 km the free electrons must be mainly responsible for the return of the very long waves. In order to produce the required integral conductivity by ions at this level, where the scale height only is of the order of 6 km[1], the ion density would have to be about $2 \cdot 10^9$ per c.c. So many ions are enough to reflect waves of about 200 meter wave-length if the influence of the high collisional friction at this level is neglected. The required electron density to produce the same integral conductivity as before is of the order of $2 \cdot 10^6$. Again, neglecting the collisional friction, this would correspond to a critical frequency of about 12.5 Mc/s. The high ion density is hardly consistent with the result of BUDDEN, RATCLIFFE and WILKES. The high electron density, on the other hand, could hardly be verified with vertical incidence radio reflection methods on account of the high collisional frequency. In the rare cases of even intenser ionization it might be possible that ultra short waves of very oblique incidence could be transmitted over considerable distances. — Here seems to be a possible field for further investigations.

The puzzling question at present remains unsolved, however. The time for the electron density to reach equilibrium roughly is of the order of $5/\sqrt{q\alpha}$ seconds. With α at least 10^{-8} and the electron density $2 \cdot 10^6$ this time would be less than about four minutes, a quite reasonable value.

Sweep frequency measurements of the ionosphere indicate, as is well known, that there is hardly any change in the *E*-layer immediately after the fade-out, at the most a very small increase in electron density. One therefore has to assume, that a low level ionization of the magnitude suggested actually is produced during fade-outs. This means not only that the level of reflection is decreased but probably also that the magnitude of the reflection coefficient must increase.

BUREAU [12] recording long wave noise in February—March 1941 found insignificant effects of solar flares on a wave-length of 25 km (12 kc/s) but very marked effects on a wave-length of 10 km (30 kc/s). This is in complete agreement with our own results which show that the 51 kc/s British long wave practically always is perturbed during fade-outs while the effect on the 16 kc/s wave sometimes is doubtful. Thus it appears that normally the fade-out radiation is not effective much below the level of reflection of 16 kc/s waves. This indicates that the "fade-out layer" is fairly sharp perhaps with a faint *D*-type ionization below its base.

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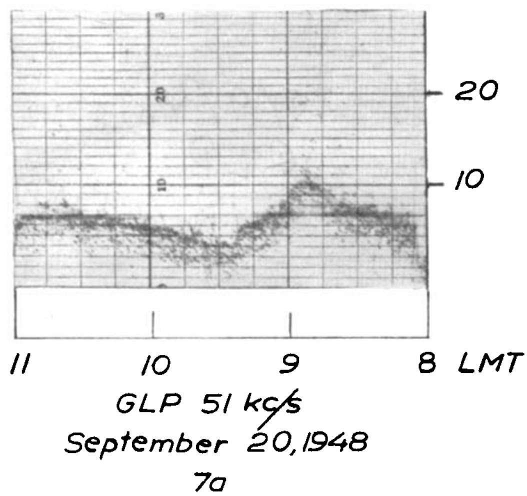
[1] The temperature minimum at the 70 km level (about 180° K) predicted by HUMPHREYS (from observations of noctilucent clouds) and measured by radio methods by BUDDEN, RATCLIFFE and WILKES has now been proved in USA with V-2 rockets. Naval Research Laboratory Report R-3294, 1948.

The fade-out effect on the long waves (say 30 kc/s or higher frequency) thus is two fold. The amplitude of the returned wave increases and the phase lag is reduced. At the receiving end the resultant sum of ground wave and reflected waves therefore is likely to exhibit a complex character. It is not impossible, if the distance from the sender is not too short and not too long, that a total signal maximum will be produced instead of a minimum if the phase change between the components is sufficient. At first sight one would expect an intensity curve, on the signal intensity recorders, bearing a symmetrical relation to the rise and decay time of the magnetic impetus. This should be possible only around noon when the height of the normal reflector above the "fade-out layer" is fairly constant.

Let us look at a few examples of typical fade-out effects on the British 51 kc/s wave. In fig. 7 a is reproduced a typical longwave effect of a morning fade-out, September 20, 1948. The initial increase in signal strength is followed by a characteristic depression. Fig. 7 b on the other hand depicts a noon effect of quite different nature.



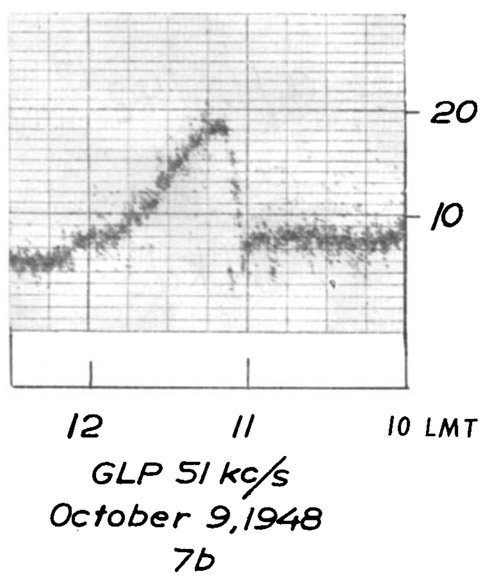
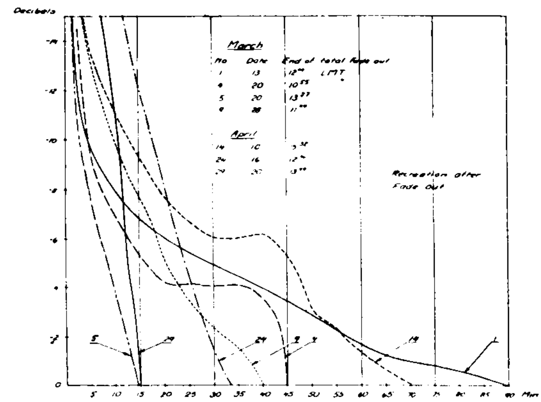


Fig. 7. Fade-out effects on the British 51 kc/s signal recorded at Askim September—October 1948.



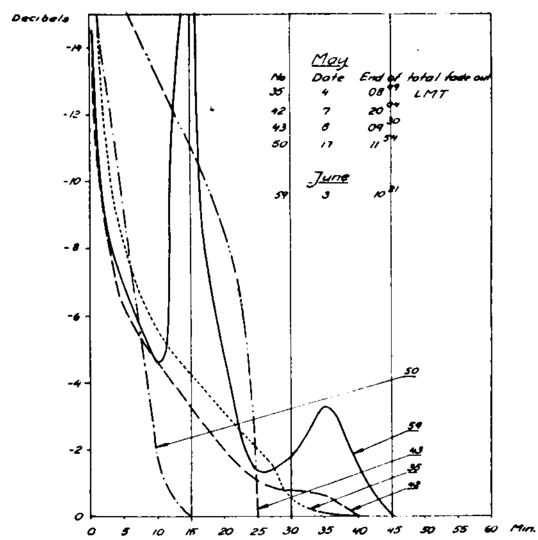


Fig. 8 and 9. Recovery of Daventry 15.18 Mc/s signal strength after fade-out.

Table 1

No	1948 Date	Pulse echo 3 Mc/s Duration of fade-out	Station GSO Daventry 15.18 Mc/s Duration of total fade-out	Station GBR Rugby 16 Kc/s	Magnetic Observatory Lovö—Stockholm: Start	Magnetic Observatory Lovö—Stockholm: ΔH ΔD ΔZ in γ	Magnetic Observatory Lovö—Stockholm: disturbance following	Rel. sunspot number R (Zürich)	Fade-out intensity 3	intensity 2	intensity 1	improbable cases	Remarks
1	13—3	—	11.05—12.00	11.00—12.15	11.03	—22— 2— 4	● (?)	125	●				Very intense, Zürich reports eruption before 11.17 Huancayo reports two fade-outs 11—12h and 20.03
2	17—3	Interruption	08.53—09.01 09.17—09.32		08.53	+ 3	● (?)	83		●			
3	19—3	10.29—10.31	10.28—10.35	—				77			●		weak
4	20—3	?	10.45—10.55	—			● (?) (nos. 4–5)	61		●			Zürich reports solar eruption (Hα): 10.44—10.46 and 10.58 (Western edge). Bureau reports noise augmentation on 10 000 m, [18]
5	20—3	13.10—13.45	13.12—13.27	13.07—13.13	13.13	—23—14— 5		61	●				Huancayo reports 13.13 and 18.33
6	23—3	09.45	09.49—(?)	09.46				41			●		weak
7	24—3	—		08.53—09.10(?)				54				●	
8	27—3	09.42—10.02(?)	—					76				●	time signals uncertain
9	28—3	10.45—10.55	11.00 min.	—				98			●		weak, not total
10	28—3	15.11—15.14(?)	15.15 min. (?)	—				98			●		» » »
11	29—3	10.24—10.36	—	—				136				●	probably $f_E < 3$ Mc/s
12	2—4	13.10—13.15	13.13 min. (?)	—				190			●		Bureau reports noise augmentation on 10 000 m
13	9—4	—	14.35 a. 14.45 min.	—			●	167			●		weak, not total
14	10—4	—	15.30—15.32	15.30 (?)				173			●		
15	13—4	11.50—11.56	11.56—11.59		11.48	+ + 3+ 5	● (?) (nos. 15–18)	219		●			Bureau reports noise augmentation on 10 000 m
16	13—4	13.23—13.25	13.23 min.	13.27		Only traces		219			●		
17	13—4	14.57—14.58	very feeble					219				●	very weak
18	13—4	—	17.25 min.					219				●	» »
19	14—4	08.37—08.43	08.45—08.47	uncertain				243			●		
20	14—4	13.15—13.17	13.09 min.		?	uncertain	● (?)	243				●	
21	15—4	13.48—(?) (?)—14.15	14.17 min.		14.13	—14+14— 4		215		●			weak, Zürich reports no eruption
22	16—4	09.33		09.35				200			●		
23	16—4	09.42						200			●		
24	16—4	12.27—12.43	12.36		12.28	uncertain	● (nos. 24–26)	200		●			Bureau reports noise augmentation on 10 000 m
25	16—4		13.22 min.	?	13.03	+22—21+ 7		200			●		time difference? not total
26	16—4	14.38		—	14.38	+ 5— 4— 3		200			●		
27	17—4	11.10—11.15						190			●		
28	19—4	08.17—08.43	08.17—08.42	—	—	— — —	●	228		●			Zürich reports eruption beginning before 08.10
29	20—4	13.11—14.02	13.15—13.44	?	13.13	—27—10— 2	● a	206	●				Huancayo reports fade-out 13.03—13.48 Bureau reports noise augmentation on 10 000 m
30	21—4	08.00—11.37	08.04—(?)		08.10	— 9— 5— 3	● a	179	●				Probably a series of several fade-outs. Zürich reports no eruption
31	22—4	—	14.23 min.	—	14.33	—17+10— 9		184				●	time difference?
32	23—4	—	13.05 min.					212			●		weak
33	27—4	06.46—07.12		—	06.43	— 4—9! + 3		188			●		»
34	1—5	16.47—17.00						131			●		»
35	4—5	08.37—08.56	08.45—08.49					180		●			

36	4—5	14.42—14.51	14.44—14.58		14.43	+ 7 — 2	●	180		●			
37	5—5	12.21—13.00	12.30—12.42		12.43	— 3+ 2	● α	203		●			Bureau reports noise augmentation on 10 000 m
38	7—5	06.40		—				254				●	Magnetic storm already in progress
39	7—5		08.30 min.	?				254				●	» » » » » : not total
40	7—5		12.35—13.20	12.35—12.55(?)	12.33	+17—10— 6	● ?	254				●	» » » » »
41	7—5	15.50—16.00	15.50—16.02	·	15.53	—10+ 5	●	254			●		weak, not total
42	7—5		20.04 min.	—				254				●	
43	8—5	09.17—09.22	09.17—09.30	09.24	09.08	—10+15— 6	●	288	●				
44	9—5	12.45—13.26	12.46—13.35	—	12.48	—12— 8— 7		299			●		Magnetic storm in progress
45	9—5		15.15—16.00	—				299				●	
46	10—5	08.57—09.35	09.09 min.		09.09	—10— 4— 2		312		●			Zürich reports eruption beginning before 09.01
47	10—5		09.52—10.08					312				●	weak
48	14—5	13.13—13.18	13.13 min.	—				230			●		earlier magnetic disturbance still in progress
49	14—5	13.27—13.31	13.29 min.	—				230			●		
50	17—5	11.41—11.49	11.45—11.54				α	144	●				Bureau reports noise augmentation on 10 000 m
51	24—5	—	16.37 min.	— *				115				●	very weak
52	24—5	—	17.00—17.40	—	17.08	Baydisturbance		115				●	obviously no fade-out: not total
53	28—5	15.16—15.40(?)						132				●	
54	29—5	16.14—16.16	16.16 min.	?	16.13	+58—20+15	● α	165		●			weak
55	1—9	08.42—08.44		08.46				131				●	
56	6—6	10.30						131				●	weak
57	1—6	13.35—13.58						131				●	with interruptions
58	2—6	09.44 (?)			09.43	+ 7+ 5	● ?	127			●		unreliable pulse record
59	3—6	10.11—10.39	10.15—10.21	10.17?	09.55	+11—11+ 6		126	●				time difference in magnetic record? Bureau
60	9—6	—	06.36—06.40	06.37	06.32	+ 5+ 8		178		●			reports noise augmentation on 10 000 m
61	14—6		07.16—07.20	—				151			●		
62	18—6	—	08.23—08.35	—				193	●				Bureau reports noise augmentation on 10 000 m
63	18—6	—	13.07—13.15		13.15			193				●	ransmitter closing down?
64	19—6	—	14.43—14.45	14.43 **				163		●			
65	19—6	—	14.53—14.54					163		●			
66	19—6	—	15.15 min.	15.10				163			●		not total
67	20—6	—	—	11.08	?	very weak		133			●		
68	21—6	—	08.28—08.30	—	08.33	— 4+15— 3		151		●			
69	21—6	—	16.44 min.	—	16.45	+22+ 2		151			●		
70	22—6	—	17.16 min.	—				155			●		
71	23—6	—	10.45—10.48	—	10.46	+13—14+ 5	● ?	160		●			
72	24—6	—	06.35—06.45	—	06.33	+ 2+ 1	} ● ?	184			●		weak
73	24—6	—	09.32—09.42	—	09.33	very weak		184		●			
74	27—6	—	10.45—10.54	—	10.46	— 5		205		●			very weak
75	29—6	—	06.23 min.	—				216			●		

Appendix: The following fade-out reports reached us from Huancayo Observatory. They are perceptible in our records, but could not be identified as fade-out without comparison with the Huancayo records.

13a	9—4		17.22 min.						very weak
47a	10—5		13.59 »						» »
59a	5—6		17.30 »						» »
b	6—6		17.27 »						» »
c	7—6		18.43 »						» »
d	8—6		17.45 »						» »
60a	10—6		18.00 »						» »
68a	21—6		12.03 »						» »

* No 51—63: Atmospherics on 15 kc/s. ** No 64—67: GLP on 51 kc/s.

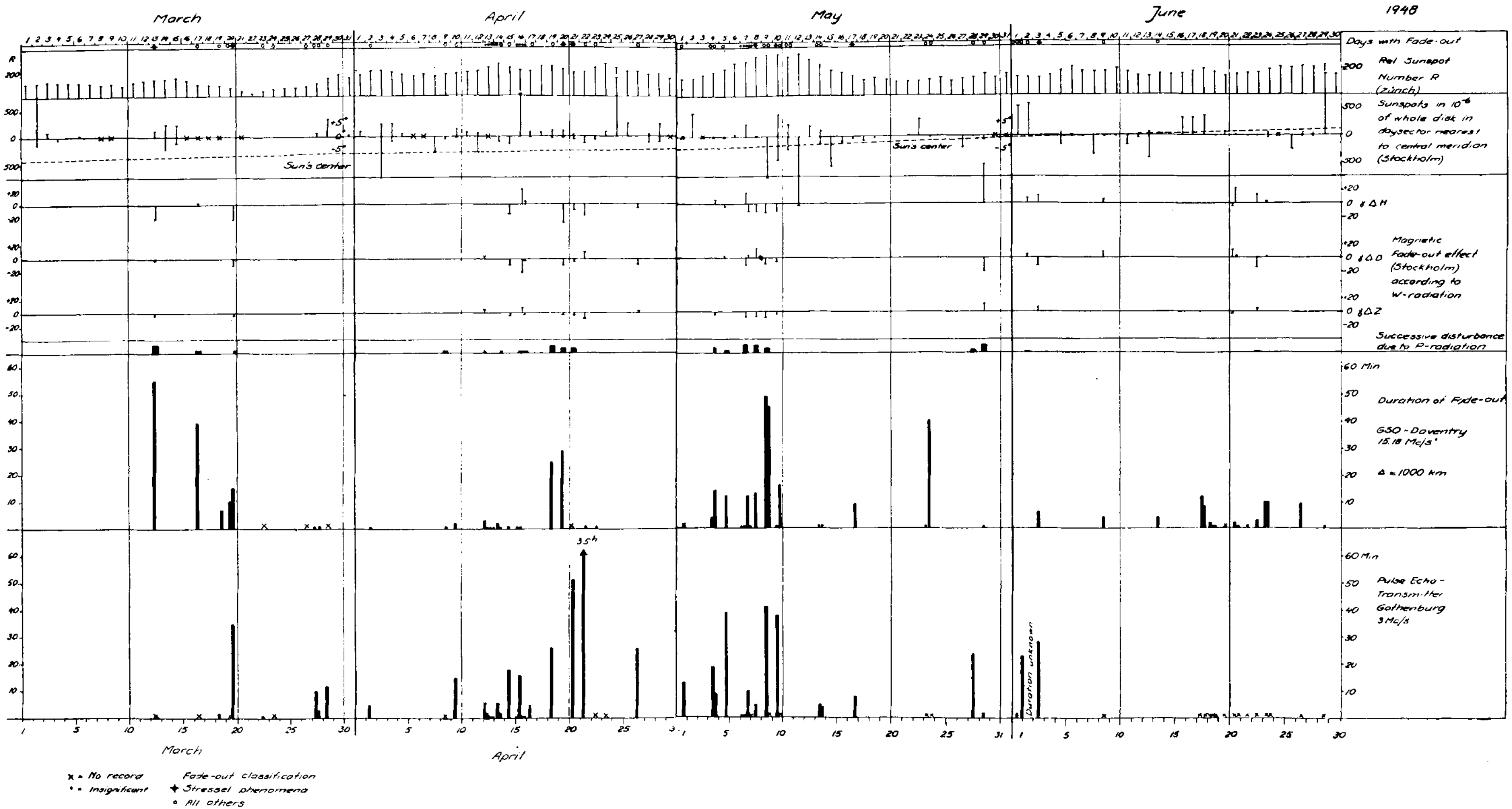


Fig. 10. Graphical representation of fade-out effects, Gothenburg, March—June 1948.

It is obvious from what has already been mentioned in this section that an analysis of the long wave records is very difficult at the present stage of our knowledge. That further long wave measurements, with an improved technique, are highly desirable is certain. It is also possible that future statistical treatments of the long wave disturbances may give an indication of the actual nature of the phenomenon. For our immediate object, however, the statistical treatment of the solar flares, it is sufficient to examine first of all the magnitude of the long wave perturbation, not its shape or form which must be left to a later investigation.

Finally we have in figs 8 and 9 depicted several characteristic examples of the recovery of the Daventry 15.18 Mc/s signal strength after fade-out. If it is assumed that the receiver is reached by only one ray the increase in decibels roughly is proportional to the decrease in integral conductivity of the "fade-out" layer. It appears from these figures that seldom the recovery time is shorter than about 15 minutes. A recovery time of 45 minutes is about normal.

All cases of ionospheric disturbance which gave reason to be ascribed to fade-out ionization, thus including cases of intensity 3, 2 and 1 and even improbable cases, have been compiled in table 1. In the table all time figures are given in LMT as before. Dash means that no record is available. The time figures are: Pulse $\pm$ 0.5 min., short wave and long wave $\pm$ 1 min., magnetic observations $\pm$ 2.5 min.

In this table we find the times of begin and end of fade-out as observed on the 3 Mc/s ionospheric pulse record, and on the short and long wave stations. Further the start of magnetic impetus in the three elements H (horizontal force), D (declination), and Z (vertical force). All amplitudes are given in $\gamma = 10^{-5}\ \Gamma$. If a magnetic disturbance followed the phenomenon this is also indicated. Nothing can, of course, be said about the coherence of the eruption effect and magnetic disturbance yet. Perhaps this feature can be illuminated somewhat statistically when a longer period of observations will be available. The table, finally, shows relative sun spot numbers R kindly supplied by the *Eidgenössische Sternwarte* in Zürich.

The main features of this table have been represented graphically in fig. 10. Sun spots, in 10^{-6} of the whole disk, in day-sector nearest to central meridian have also been shown after reports from the Stockholm Observatory.

Preliminary statistical considerations

Out of 75 cases which have been examined, 26 or 34 % are fade-outs of intensity 3 to 2. Of these 8, or 31 %, are marked or of intensity 3. In other words, while there happened 19 fade-outs per month, only 2 cases a month, in average, were of striking intensity. Further, out of 75 cases 29, or 39 %, were of intensity 1 and 20, or 27 %, were improbable ones.

Considering the 26 fade-outs of reasonable intensity we find that 8 of them or 31 % were followed by a magnetic disturbance after intervals lying between about 20 and 36 hours. In 6 further cases the observations are uncertain but in 11 cases or 42% *no* magnetic disturbance could be detected following a fade-out phenomenon. This means that at least half of the solar disk or even two-thirds would not contribute to combined fade-out and magnetic disturbance displays. The remaining fraction roughly corresponds to a part of the solar disk covering an area between two meridians of about 60° distance from each other, thus giving a very rough image of the cone of corpuscles and its aperture[1], since eruptions causing fade-out must be expected in equal distributions across the whole solar disk.

Further as to terrestrial influence we find the following percentage of fade-outs with respect to solar altitude.

Table 2

Marked fade-outs at $h_\odot$	0—10°	10—20°	20—30°	30—40°	40—50°	50—60°
Weighted number (as to duration of observations)	0	0	3	10	8	6

Thus for the season studied no fade-outs were observed at solar zenith distances of more than 70°.

[1] M. N. Gnevishev and A. I. Ol [13] from comparison of the 11-year curves of solar and geomagnetic activities conclude that the average solid angle of the corpuscular stream is of the order of 8°.

It is quite interesting to make a preliminary statistical investigation as follows. One must expect an equal distribution of areas producing fade-out phenomena across the solar disk as already mentioned. If we now assume spots situated anywhere to be combined with bright sudden eruptions we can divide the sun in day-sectors and count the sectors containing spots or spot-groups on any day with fade-out observations. The figures necessary for these investigations are kindly placed at our disposal by the Stockholm Observatory, Saltsjöbaden, through the courtesy of Professor B. Lindblad and Dr Y. Öhman. This observatory delivered for every day the figures for each of the six sectors between eastern edge and central meridian of the sun representing the area in 10^{-6} of the total disk covered by spots or spot-groups. Assuming these figures to have a certain tendency of persistence and in lack of the corresponding figures for the western half of the sun's disk[1], the figures in the sector 1 at days 0, ± 1, ± 2, etc. were attributed to figures of sectors 1, 2, 3, etc. east and west of central meridian on the day when a fade-out effect was observed. Because of insufficient material no division of spot figures as to size has been possible. This attribution of weights to the figures ought to be reserved for a later investigation.

[1] These figures are now supplied for the entire disk.

In the present investigation the phenomena were divided into the three groups, strong and medium fade-outs (intensities 3 and 2), weak fade-outs (intensity 1), and uncertain or improbable cases. The results are shown in fig. 11 demonstrating that, as would be expected, strong and medium fade-outs are distributed rather equally across the whole disk with least standard deviation (fig. 11 a), while weaker phenomena yield a slightly increased standard deviation, but particularly a distinct minimum of active area at the third sector west of the central meridian, fig. 11 b.

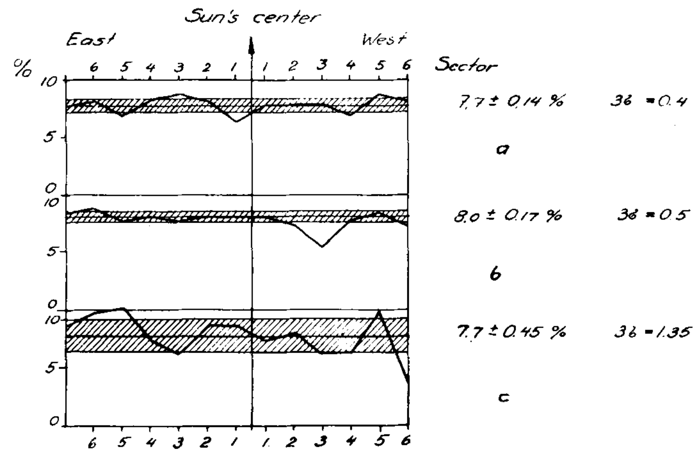


Fig. 11. Statistical distribution radiation sources of *a*) stronger fade-outs, *b*) weaker fade-outs, and *c*) improbable cases across the sun's disk.

This minimum, which naturally is not definitely verified by this preliminary statistical treatment, could be interpreted perhaps along the following line. When spots or spot groups have advanced on the solar disk as far as 30—60° beyond the central meridian their stream of corpuscles, according to their migration time, will reach the earth's orbit. Looking from the earth towards the sun the ray directed to the eastern parts of the sun will have to pass through a shorter distance of corpuscular jet than that directed to the western half of the sun as demonstrated by fig. 12. The absorption of active ultra-violet light should therefore be less on path a) than on path b). If this absorption is small its terrestrial effects will be noted on weaker eruptions only.

According to E. A. Milne [14] the process of corpuscular emission from the sun should eject atoms of all the kinds which show evidence of being supported by radiation pressure in the chromosphere. Likely to be ejected are ionized atoms such as Ca^+, Ti^+, Sr^+, and neutral excited atoms such as H, He, Na,

Quite recently C. W. GAERTLEIN [16] has been able to show spectrographically that it is very likely that hydrogen in violent random motion is present during many auroras. He suggests that protons enter the upper atmosphere

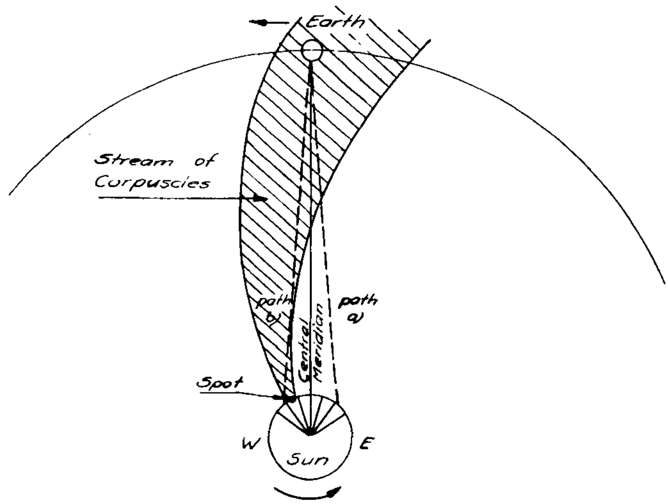


Fig. 12. Ray paths through solar corpuscular beam.

Fe, Mg. MILNE further showed that the corpuscular velocities, at a great distance from the sun, do not much depend on the mass of the atom or on its particular absorption line. These velocities are of the order of 1 600 km/sec.

The selective radiation pressure on the upward-moving atoms is more powerful than the general radiation pressure on the electrons in the solar atmosphere. Therefore the emission of neutral atoms and atomic ions are favoured so that streams or bursts from the disturbed solar areas initially will be positively charged. The charged mass, ejected from the solar atmosphere, naturally will exert a strong electrostatic attraction on the abundant electrons below. Hence electrons must be drawn into the stream of neutral and positively charged atoms. This stream thus continuously becomes electrically neutral. The electrons lag behind until the separation of positive and negative charges sets up a compensating electrostatic field sufficient to equalize the acceleration of negative and positive particles. S. CHAPMAN [15], who early studied the properties of solar corpuscular streams, showed that a very small separation is enough for this purpose.

during auroras at velocities exceeding 200—500 km/sec.[1]. On fourteen out of fourty-four nights the hydrogen appeared before and during sudden outbursts of the aurora. This suggests, GAERTLEIN remarks, that the influx of hydrogen may initiate the larger outbursts. The quieter auroras do not show the hydrogen.

It next remains to study whether acceptable values of particle density of the corpuscular beam could produce the distinct minimum of fig. 11 b. Obviously the absorption must be moderate or small. Otherwise its effect should be noticed also in the case of the stronger fade-outs.

A line of sight which traverses the corpuscular stream from the sun to the earth will pass over approximately $3 \cdot 10^{15} \cdot N_0$ atoms per cm^2 of the beam if N_0 is the number density at the earth's distance. For hydrogen atoms the effective absorption coefficient for the fade-out radiation could be estimated at $4 \cdot 10^{-18}$ with an error at least of about one magnitude. The total absorption through the beam thus would

[1] C. W. ALLEN actually has observed a corpuscular emission from the sun travelling towards the earth with a velocity of 750 km/sec. [17].

amount to about $1.2 \cdot 10^{-2} \cdot N_0$. Therefore an atomic (or ionic) density of about $10/cm^3$ at the earth's distance might produce the minimum tendency. For calcium ions the absorption coefficient should be at least ten times greater thus producing noticeable effects when present at the earth's distance even in quantities as small as $1/cm^3$.

If this should be an indication of the average value it might be possible that during very strong magnetic storms the density should approach a figure as high as $10^2/cm^3$. It is therefore tempting to investigate briefly how much ultra-short wave radiation from the sun would be absorbed by the beam electrons through collisions with atoms and ions.

If the gas emitted is likely to have the solar temperature the electronic collisional frequency should be of the order $4 \cdot N \cdot 10^{-8}$/sec. where N is the atom density of the beam. For an ultra-short wave with a frequency of $k \cdot 100$ Mc/s the effective absorption coefficient per electron would be approximately

$$N^2 \cdot 10^{-26}/2\,k^2 \sqrt{1 - N \cdot 10^{-8}/1.24\,k^2},$$

as long as $N < 1.24 \cdot k^2 \cdot 10^8$. As N should be approximately $46\,000 \cdot N_0$ close to the sun this means that the above expression could be used over the entire path as long as $N_0 < < 2.7 \cdot k^2 \cdot 10^3$.

Neglecting N in the root expression we find after integration through the beam, from earth to sun, that the total absorption becomes $\geq 2.3 \cdot N_0^2 \cdot 10^{-7}/k^2$. The ultra-short wave absorption thus is quite small. An electron density, at the distance of the earth, of as much as $300/cm^3$ only would produce an absorption of about 0.08 at 6 meter wavelength. At a wave-length of 12 meters $N_0 = = 100$ electrons/cm^3 would produce an absorption of about 0.04. The ultra-short wave effect, therefore, generally should be very small. Nevertheless we feel that a future statistical investigation of solar ultra-short wave noise bursts along the lines used here for the fade-out radiation should be of considerable interest.

Returning to our statistical investigation we refer in conclusion to fig. 11 c. This demonstrates that there is a rather large standard deviation in the batch of improbable cases. Several cases will perhaps be due to other effects, and any equal distribution across the solar disk must not be expected.

Acknowledgements

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