Localization of Aurorae with 10 m High Power Radar Technique, using a Rotating Antenna

By GÖSTA HELLGREN and JOHAN MEOS
Research Laboratory of Electronics, Chalmers University of Technology, Gothenburg

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Abstract

The paper describes the 10 m high power recorder with a rotating antenna that is used since May 1951 for the localization of aurorae at the Radio Wave Propagation Laboratory of the Kiruna Geophysical Observatory (67.8° N, 20.5° E). Continuous observations during the time May 1951—March 1952 have disclosed periods of auroral activity. The preliminary results from these observations indicate that there is a good correlation between the auroral activity, the magnetic activity, and the appearance of the N1-layer, a special type of sporadic E ionization often appearing in connection with magnetic bays and supposed to be caused by the same ionizing agent as the aurora. The distribution in range and bearing of the recorded aurorae agrees with the simple theory that most of the radio wave scattering comes from those points where the radar beam is perpendicular to the surface of the auroral discharges. The calculated height distributions of the reflection centres have maxima around 120 km.

1. Introduction

In order to extend the study of the general features of the polar ionosphere and other associated phenomena it was early planned by the Chalmers Research Laboratory of Electronics to study long distance scattering of radio waves from the Aurora Borealis (RYDBECK, 1949). Since May 1951 the Radio Wave Propagation Laboratory of the Kiruna Geophysical Observatory (see fig. 1) has therefore been equipped with an aurora recorder of radar type operating on 10 m wavelength (frequency 30.3 Mc/s) using a rotating antenna. A great number of very interesting echoes have been received. Their distribution in range and bearing and the correlation with visually observed aurorae strongly support the theory that echoes are caused not by an ordinary type of ionosphere (ordinary or sporadic E) but by reflections from auroral discharges.

Scattering of radio waves from the Aurora Borealis has earlier been reported by HARANG (1940) on a frequency of 40 Mc/s and by LOVELL, CLEGG, and ELLYETT (1947) on 46 Mc/s. During 1949 ASPINALL and HAWKINS (1950) identified a number of aurora formations in the range 400—900 km by the characteristic echoes which were produced on 72 Mc/s.

This paper describes our 10 m aurora recorder and presents the observations and the preliminary results obtained during the period May 1951—March 1952.

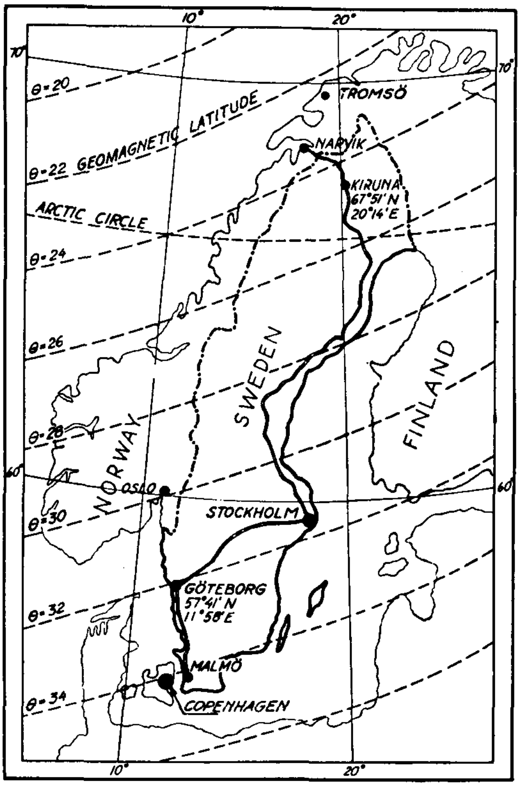


Fig. 1. Location of Kiruna Geophysical Observatory.

2. Recording equipment

The equipment is principally the same as that used at our Råö Observatory in the vicinity of Gothenburg for the recording of meteor trails. Power is transmitted and received by the same antenna. The received echoes are shown on an intensity modulated cathode ray tube display of PPI-type, which is photographed. The transmitter is a quite conventional self-pulsed tuned-grid-tuned-plate oscillator with 100 kW peak pulse power, 40 μs pulse width, and a pulse repetition rate of 50 c/s. The rotating antenna, a three-element Yagi, is mounted on the roof of one of the observatory buildings (see fig. 2). It is elevated 30° above the horizontal and has an estimated gain of 9 db compared with that of an isotropic radiator. The receiving unit of the recorder (fig. 3) consists of a modified Hallicrafter receiver, type R44/ARR-5, and a 10 cm radar SO-13 indicator. The smallest signal detectable on the cathode ray tube is equivalent to 3×10^{-14} W at the receiver input. The antenna and the synchronized beam on the scope make two rotations per minute. The camera is open for exposure for 30 seconds, i. e. the time of one complete revolution of the antenna. It can be run automatically either continuously, taking one picture of each rotation, or intermittently, taking only 12 pictures every full hour.

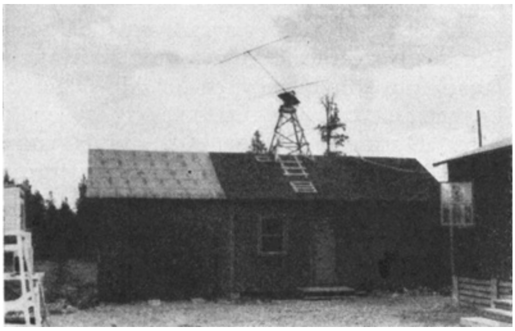


Fig. 2. Rotating antenna of 10 m aurora recorder.

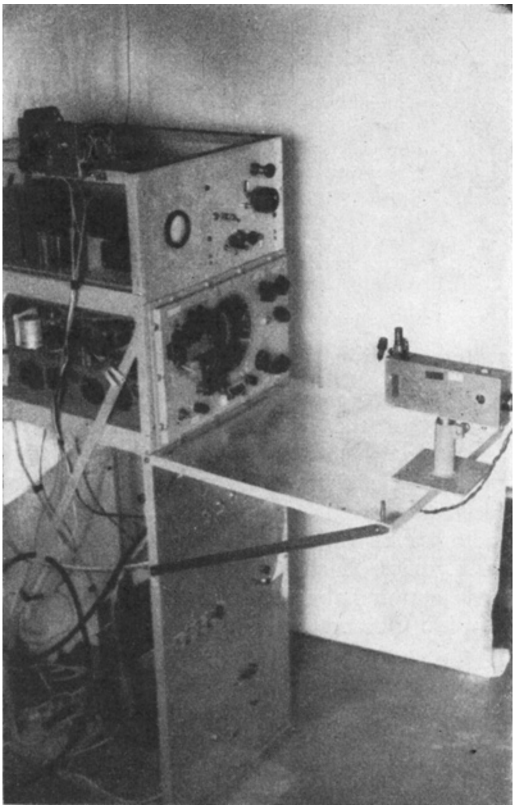


Fig. 3. Receiving unit of 10 m aurora recorder.

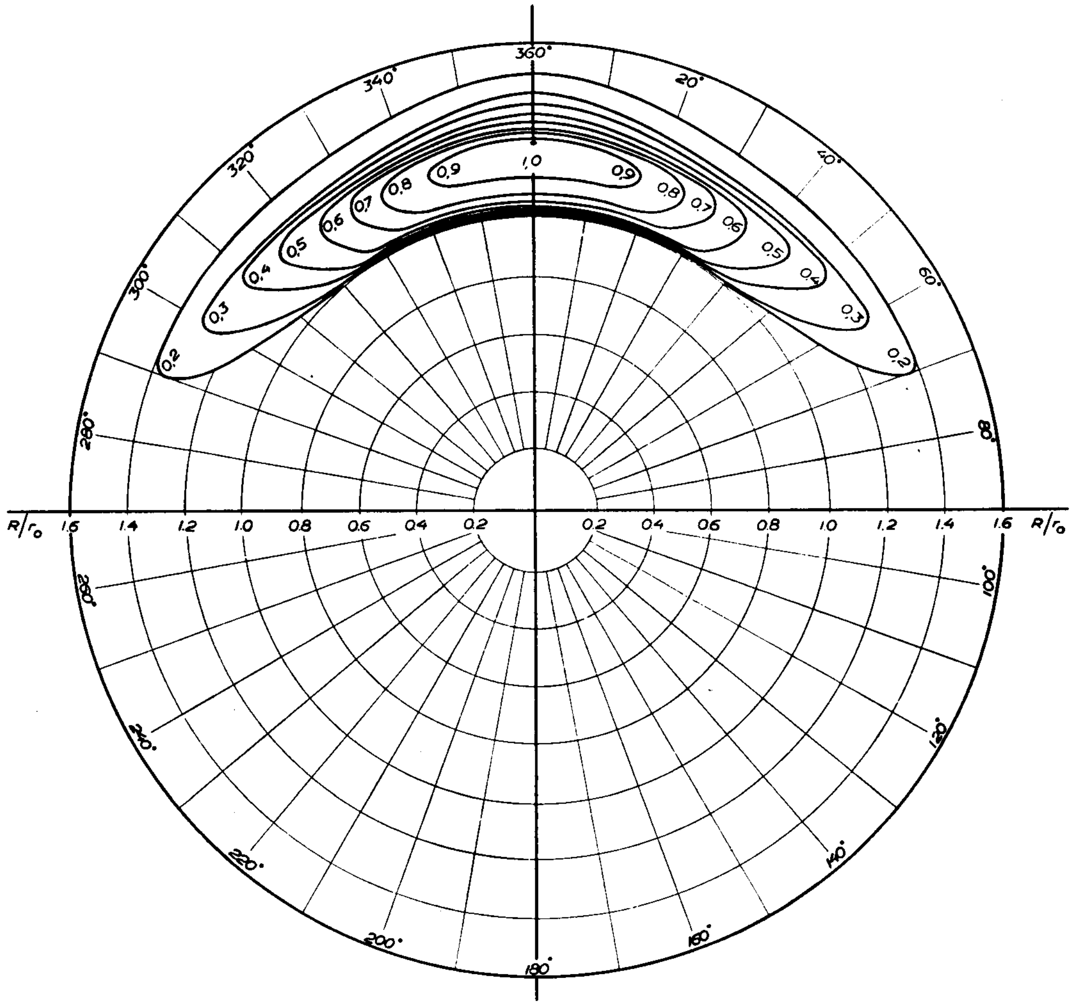


Fig. 4. Theoretical radio echo from an auroral curtain.

3. Types of echoes

Roughly speaking, the great variety of auroral echoes can be classified into one or the other of two different types, diffuse or discrete. The diffuse echo must be due to reflections from an extended irregular surface or a large heterogeneous region with a random distribution of electron density. The discrete echo, on the other hand, must originate from a regular surface containing a relatively homogeneous electron distribution. Therefore, as already done by Aspinall and Hawkins (1950) it is reasonable to associate a diffuse echo with an auroral glow or a curtain, and a discrete one with a streamer. In the following we will use the terminology, curtain, for a diffuse echo, and streamer, for a discrete one. Most of the reflected energy must come from those points of the curtains and streamers where the radar beam is perpendicular to the corresponding surfaces. For a certain locality the most favourable direction of reflection is the direction of the magnetic north, if one assumes the auroral discharges to take place on surfaces generated by the magnetic field lines which pass through curves on the earth's surface of constant horizontal force.

Applying the theory of radio wave scattering from a turbulent medium (Booker, Gordon, 1950) to the case of reflection from an auroral curtain we get a diffuse echo on the indicator screen like that illustrated on fig. 4, when the

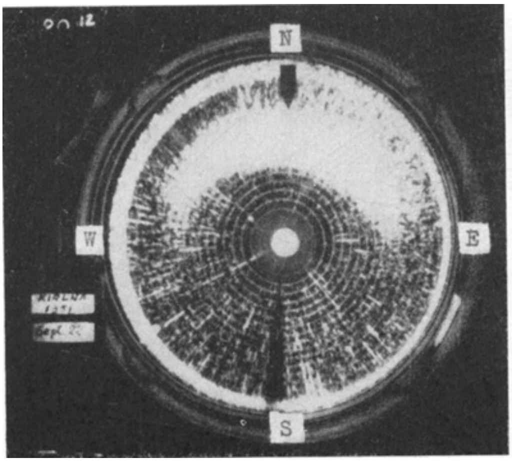


Fig. 5. Typical radio echo from an auroral curtain.

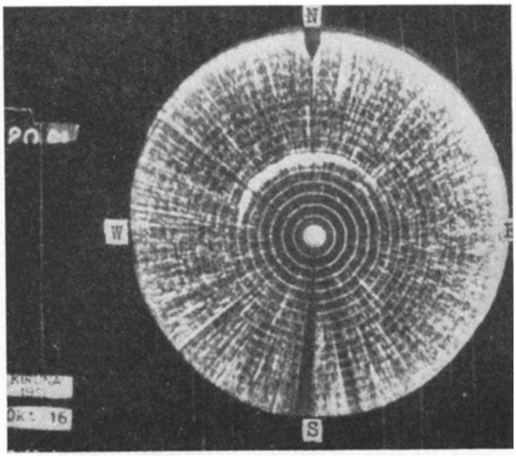


Fig. 6. Typical radio echo from an auroral streamer.

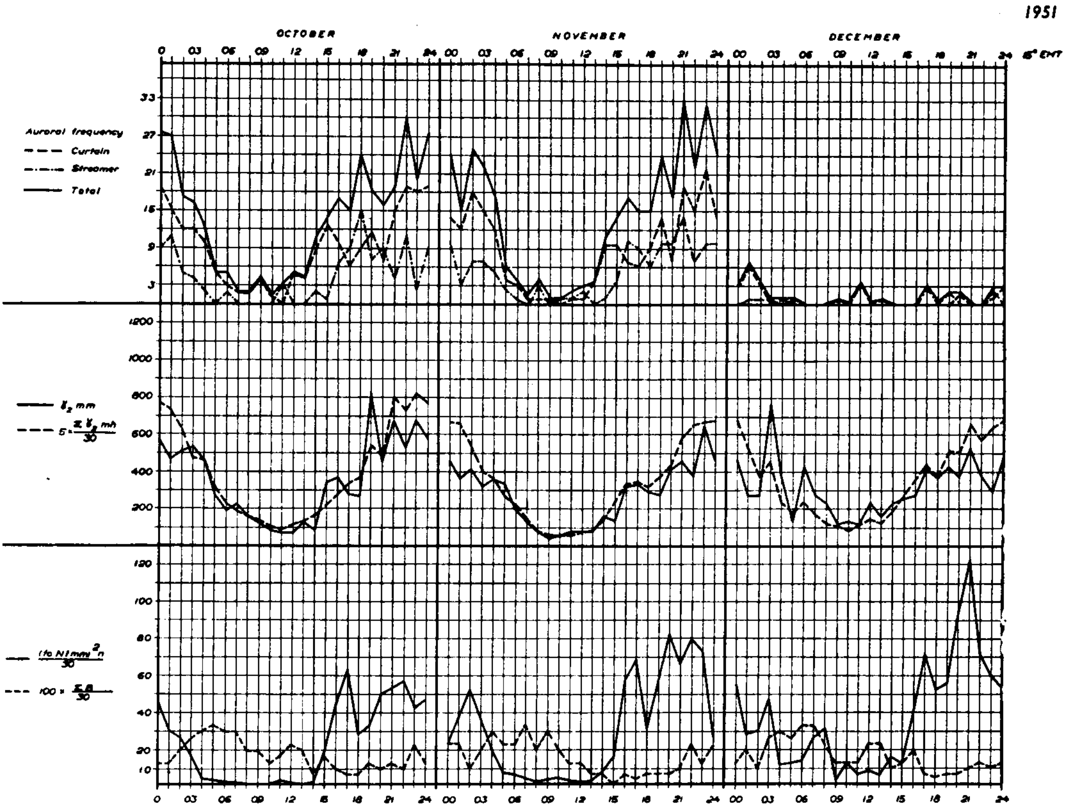


Fig. 7. Hourly variation of the auroral and the magnetic activities, the intensity of the N I-reflections, and the appearance of polar blackouts during October—December 1951.

antenna rotates. We have here assumed the curtain to be an infinitely extended plane sheet with a thickness of 0.25 R_0, where R_0 is the minimum range to the sheet, and the antenna to have constant gain throughout an angle of 90°. Further, we have assumed that the scale of turbulence is large compared with the wavelength, and that the mean square deviation of the dielectric constant of the layer is small. If, instead, the reflections had come from an auroral streamer, supposed to be a circular cylinder (with a diameter of the order of 2 km) containing a uniform electron density the echo picture would have been a uniformly bright, very narrow 90° arc of a circle. Figs. 5 and 6 show the two different echo types, as obtained by our Kiruna recorder on September 22nd, 2012 15°EMT and on October 16th, 2001 15°EMT respectively. The arrow on the top indicates the north, east is to the right and west to the left. The difference in range between two concentric circles is 50 km and the maximum range 1,000 km (this could be increased if required up to 2,000 km but is ordinarily quite sufficient).

Kiruna, 2202 15° EMT, Febr. 13, 1951.

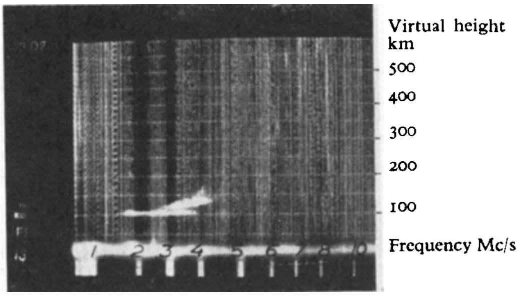


Fig. 8. Record showing simultaneous reflections from sporadic E-layer (100 km height) and N1-layer (115 km height).

4. Preliminary recorded results

During the time May 1951—March 1952 the aurora recorder ran day and night with the

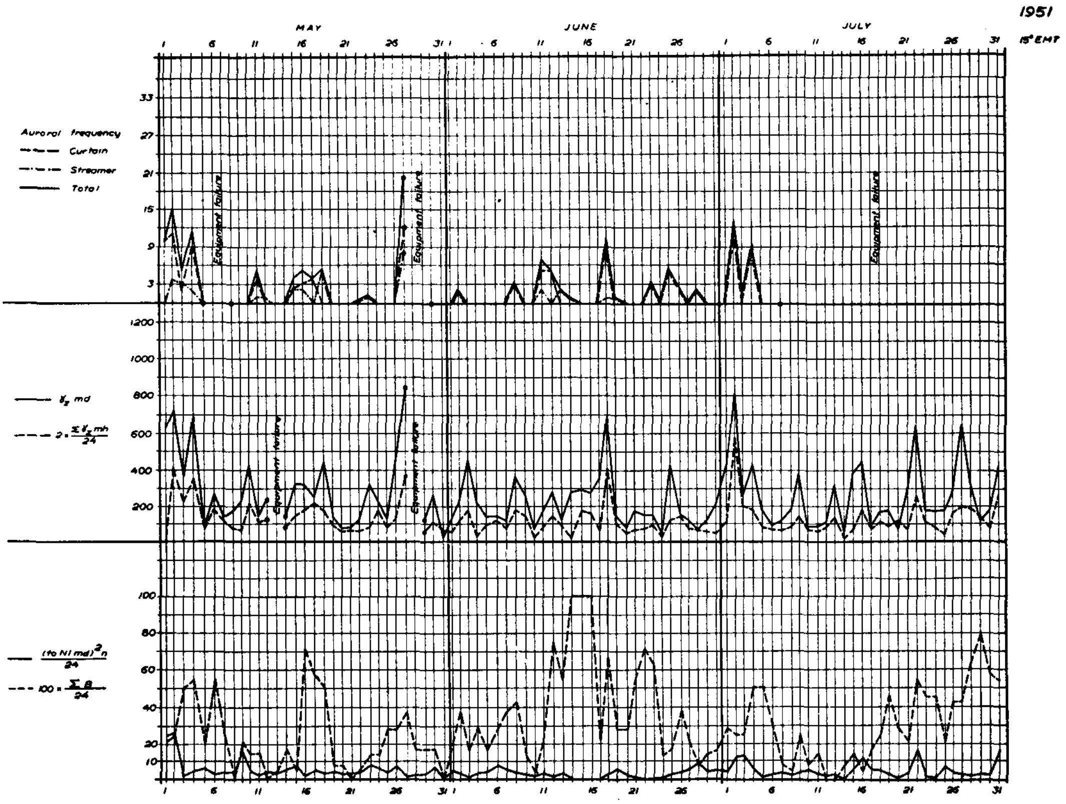


Fig. 9. Day to day variation of the auroral and the magnetic activities, the intensity of the N1-reflections, and the appearance of polar blackouts during May, June, and July 1951.

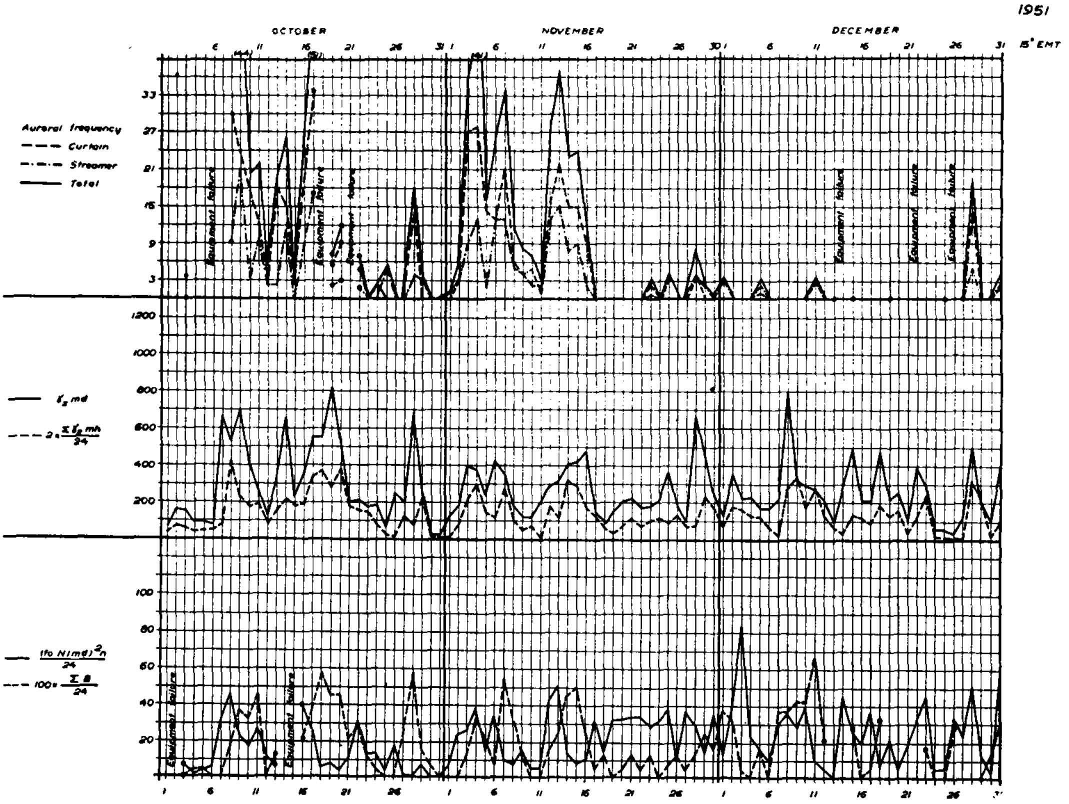


Fig. 10. Day to day variation of the auroral and the magnetic activities, the intensity of the N1-reflections, and the appearance of polar blackouts during October, November, and December 1951.

exception of a period of relatively small auroral activity in August and September 1951 when part of the installation had to be made more permanent. Normally, in order to save film, only 12 consecutive pictures were taken during every hour, but in the case of special auroral activity, and at least once a week, each sweep was photographed for a period of 24 hours, when, also, the ordinary panoramic ionospheric recorder was in continuous operation. The hourly recordings are quite sufficient to permit statistical investigations of the aurora, but the continuous films, of course, give a better and a dynamic picture of the whole phenomenon, and are of special value for a detailed comparison with the ionospheric soundings and the magnetic records.

To interpret the hourly records one characteristic echo picture out of the 12 obtained has been analyzed with regard to the appearance of diffuse echoes (curtains) and discrete echoes (streamers). According to its strength each echo has been given a weighted number in the following way:

1 = aurora of small intensity
2 = aurora of moderate intensity
3 = aurora of strong intensity

(The maximum auroral activity, or frequency, of either kind is consequently during 24 hours $24 \times 3 = 72$). Of course, many objections could be raised to such a procedure; the personal errors are important in the reading of the records, no consideration has been given to the influence of distance on the echo intensity and so on. The method is justified only by the fact that it forms a basis for a preliminary statistical investigation of the observations.

The variation throughout the day of the auroral activity, as shown by the hourly records, indicates a maximum activity around midnight and a minimum around noon. Fig. 7

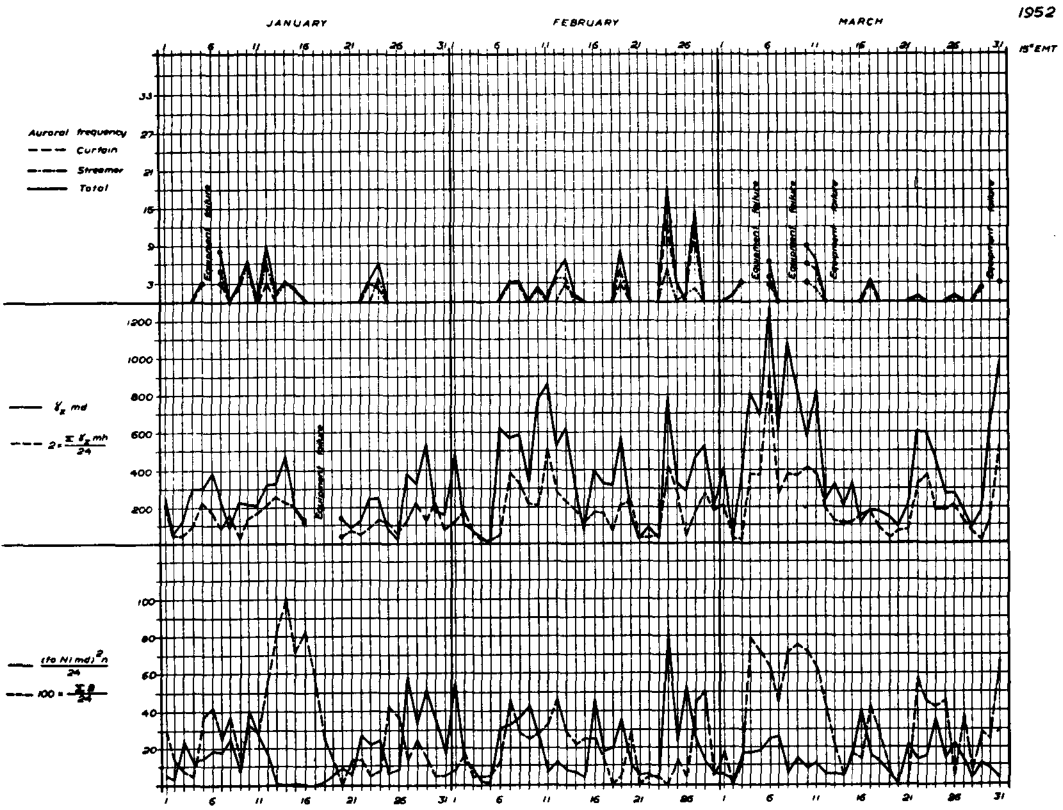


Fig. 11. Day to day variation of the auroral and the magnetic activities, the intensity of the N1-reflections, and the appearance of polar blackouts during January, February, and March 1952.

shows the curves obtained for October and November 1951, the months of highest auroral activity, and for December 1951, a month with relatively low activity. The curves are typical. On the same graphs the hourly variation of the magnetic activity as well as the intensity of the so called N1-reflections and the number of polar blackouts has been plotted, as given by our Kiruna magnetograms and ionospheric soundings. $\gamma_z mh$ is here defined as the maximum departure in γ of the magnetic z-component from undisturbed value during a certain hour, and $\gamma_z mm$ is the maximum value of $\gamma_z mh$ for the whole month. $foN1mm$ is the highest frequency for a certain hour during the whole month on which echoes from the N1-layer have been observed, and n is the number of times that N1-echoes have been obtained during the month ($n \leq 30$). ΣB is the total number of

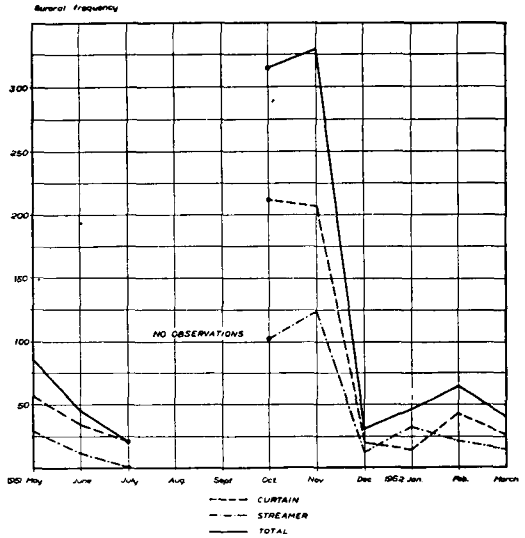


Fig. 12. The monthly variation of the auroral activities during the time May 1951—March 1952.

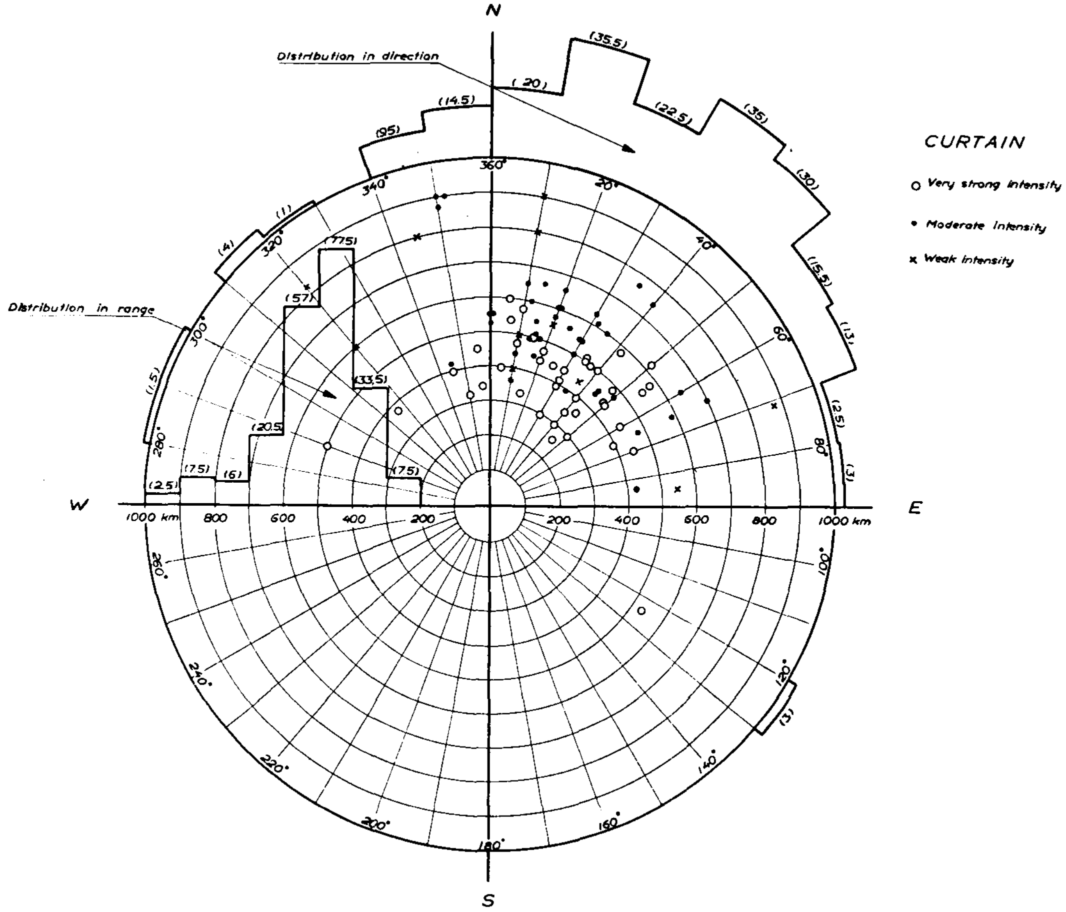


Fig. 13. The reflection centres of auroral curtains during October 1951.

blackouts observed during a certain hour for the whole month ($\Sigma B \leq 30$).

The N1-layer is a special type of sporadic E-ionization often appearing in polar regions and always in connection with magnetic bays and supposed to be caused by the same ionizing agent as the aurora. The hf-trace of N1 looks quite similar to that of the ordinary E-layer except for the fact that the N1-layer seems to be thicker and often shows complicated splitting near the penetration frequency (see fig. 8). For more detailed information about the N1-reflections the reader may be referred to Lindquist (1950).

The polar blackout is a certain type of "no echo" condition, which occurs in polar regions and shows no apparent connection with solar flares. The disappearance of reflections from all ionospheric layers during a blackout is believed to be due to an abnormally high absorption in a region below the 100 km level. This increased absorption may be caused by the impact of some ionizing agent in the ionosphere. The N1-reflection appears before and after almost every blackout (Lindquist, 1951).

As can be seen from the graphs there exists a good correlation between the auroral frequency, the magnetic activity, and the intensity of the N1-reflections. It is very interesting to note that the curve of the blackouts has the same form as the curves of the other phenomena but is delayed about 6 hours.

The day to day variation of the recorded auroral activity is given on figs 9, 10, and 11 for the whole period of observation, May

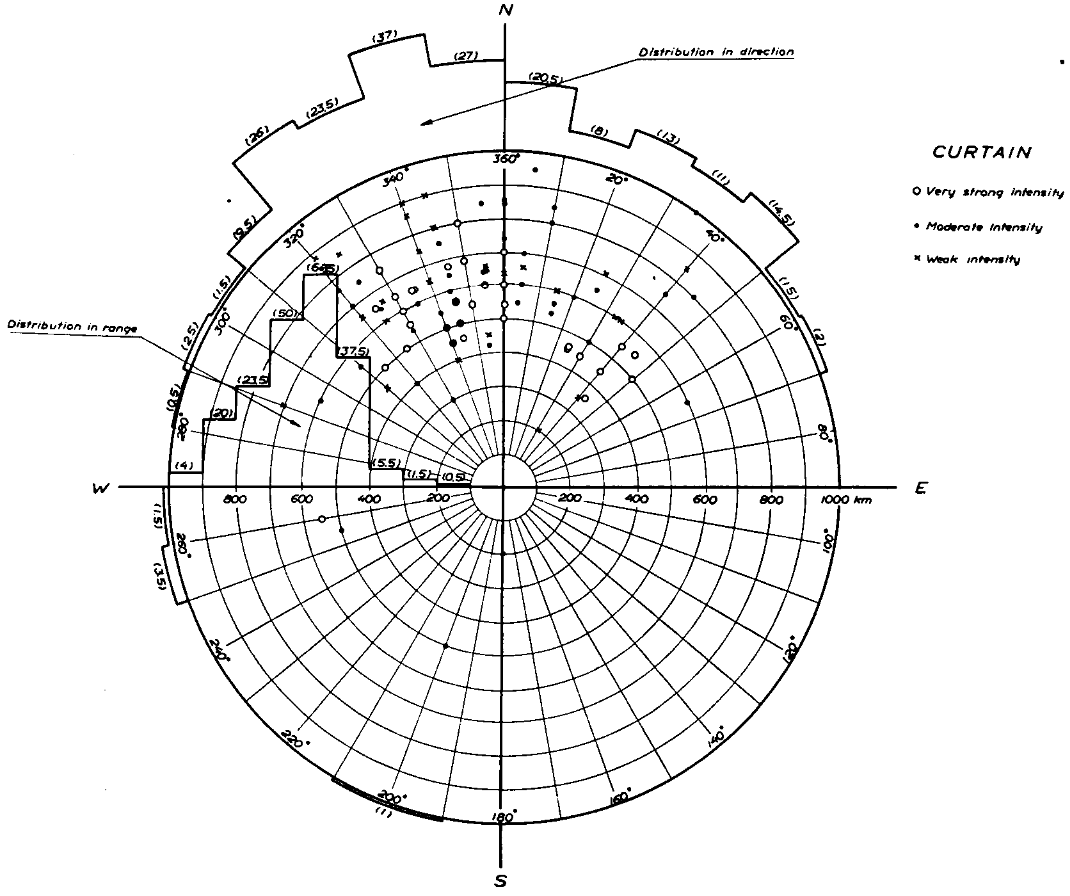


Fig. 14. The reflection centres of auroral curtains during November 1951.

1951—March 1952. On the same graphs we find the corresponding curves for the magnetic activity, the intensity of N1-reflections, and the appearance of polar blackouts. $\gamma_z md$ is here the maximum departure from undisturbed value of the magnetic z-component during the day, and $foN1md$ is the highest frequency during the day on which echoes from the N1-layer are observed. n is the number of times during the day that $foN1$ has been obtained ($n \leq 24$). ΣB is the total number of hours during the day on which polar blackouts occurred ($\Sigma B \leq 24$). There is a good correlation between all the curves and especially between those of the auroral activity and the appearance of polar blackouts. No significant difference exists between the two kinds of radar echoes, curtains and streamers.

The monthly distribution of the recorded auroral frequencies has a very marked maximum in October and November 1951 and a second but smaller maximum in Februari 1952 (see fig. 12). This is in good agreement with what is known about aurorae from visual observations during many years.

During the time of observation the highest auroral frequency always appeared in the bearings northeast to northwest and very seldom in the south. This well agrees with the simple theory that the most probable direction of reflection is the direction of the magnetic north. To show typical cases we have plotted in polar coordinates on figs 13, 14, 15, and 16 all the centres of reflections obtained during October and November 1951 for auroral curtains and streamers respectively.

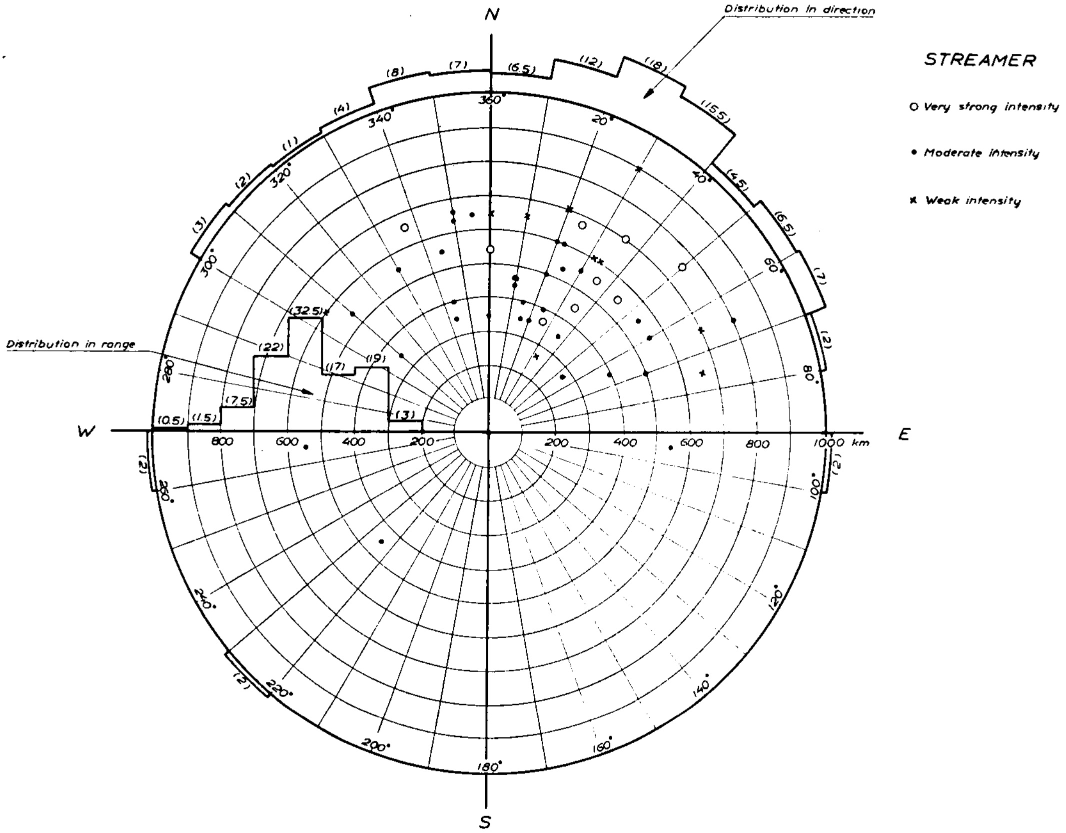


Fig. 15. The reflection centres of auroral streamers during October 1951.

It is interesting to note that the optimal direction of reflection was constantly north to northeast during all the months except November when it changed to north-northwest. As for the distribution in range, the reflection centres of curtains have a maximum in the interval 500—600 km, and those of streamers, in the interval 550—650 km, as can also be seen on the same figures.

From the direction and range measurements it is possible to calculate the height distribution of the reflection centres if one assumes the maximum reflected energy to come from those points where the radar beam is perpendicular to the reflecting surface. These surfaces are supposed to be circular cylindrical surfaces parallel with the lines of magnetic force (streamers), or surfaces generated by the lines of force passing through the curves on the earth's surface of constant magnetic horizontal intensity (curtains). Such calculations have been made for all the reflection centres obtained within an angle of ± 45° from the direction of the magnetic north (at Kiruna: magnetic declination 2°E, inclination 77°). The results for October and November 1951 are given in fig. 17. The height distributions have maxima of about 120 km and thus they fall in the region of maximum luminosity of visible aurorae. (CHAPMAN, BARTELS, 1940).

The continuous radar recordings of the aurora give an indication of the comparatively rapid appearance and disappearance of the discharges, as well as the swift movements of the aurora, or rather the swift displacement of the ionizing agent causing the aurora. This rapid variation is illustrated by the collection of pictures reproduced on fig. 18. The pictures show an aurora of a complex type with both curtains and streamers, lasting from 2228 to 2245 15°EMT, October 26th 1951. A

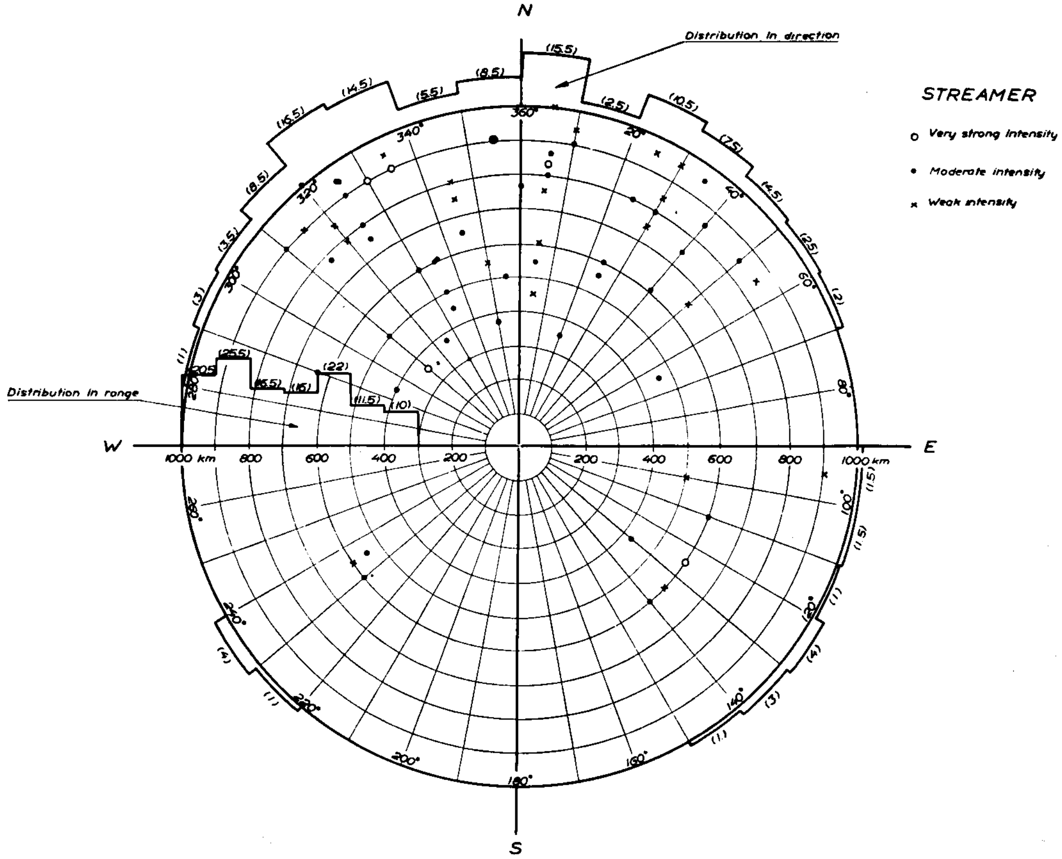


Fig. 16. The reflection centres of auroral streamers during November 1951.

study of the continuous recordings gives times of duration of about 240 and 100 seconds for diffuse and discrete echoes respectively. The longest time observed during a representative period in October 1951 was 420 seconds for curtains and 240 seconds for streamers. Echo times shorter than 30 seconds occurred very seldom.

From the amount of the reflected energy Aspinall and Hawkins (1950) have calculated the typical electron density of a streamer to be approximately 6×10^5 electrons per cc, supposing the streamer to be a circular cylinder (radius 1,000 m) enclosing a region of uniform electron density. An estimate on the same basis that we have made in some cases where the amount of the reflected energy could be determined with enough accuracy, gives densities of the order of 2×10^6 electrons per cc as typical for streamers. This density value is

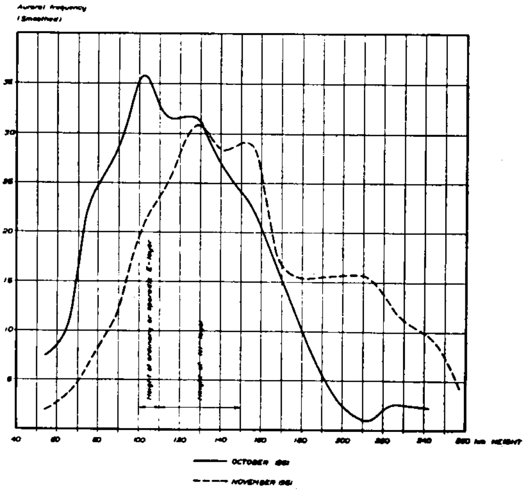
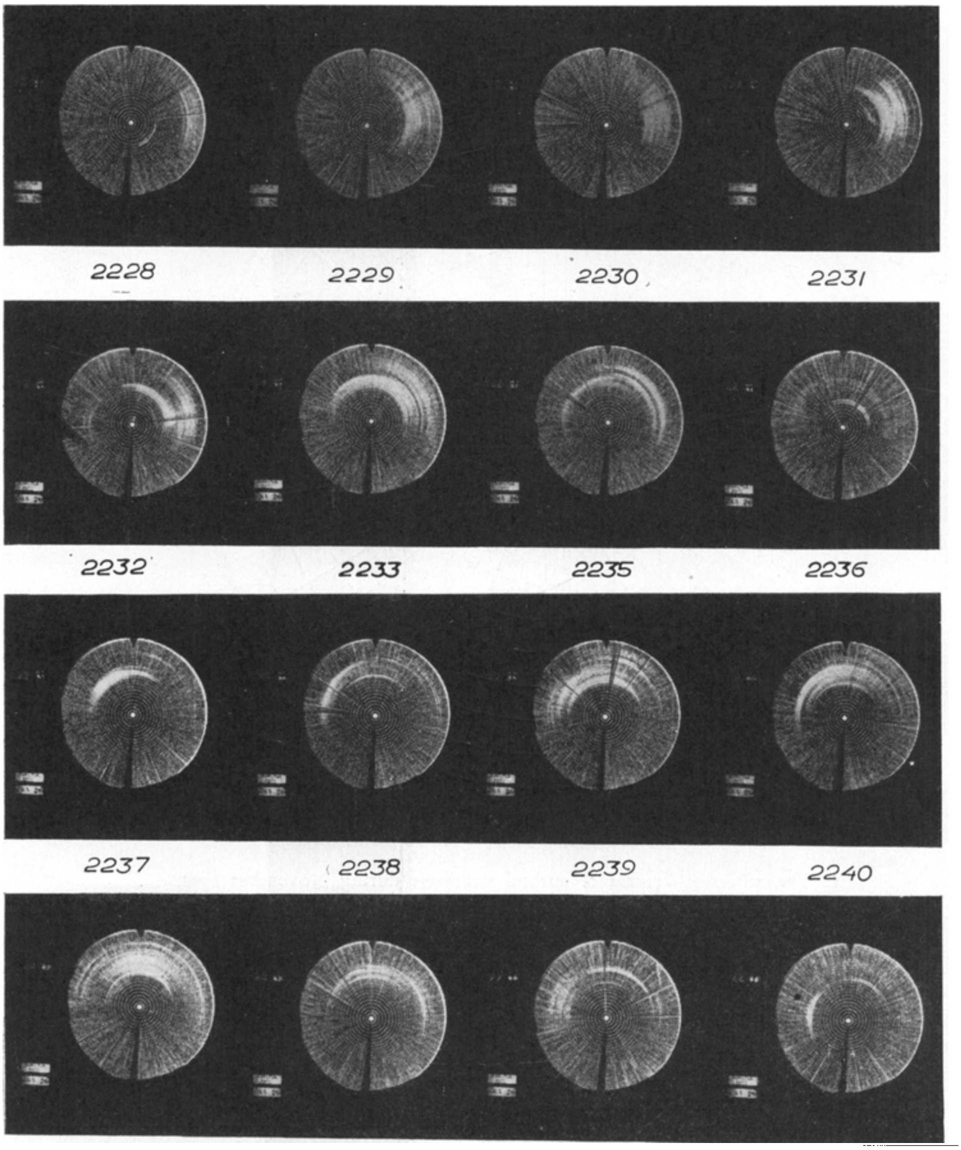


Fig. 17. Height distribution of reflection centres within an angle of ± 45° from the direction of the magnetic north of Kiruna during October and November 1951.



2228 2229 2230 2231

2232 2233 2235 2236

2237 2238 2239 2240

2242 2243 2244 2245 15° EMT

Fig. 18. A series of records from an aurora appearing between 2228 and 2245 15° EMT, October 26, 1951.

sufficient to explain the rapid fluctuation of the echo pattern mentioned above. Solving the inhomogeneous Riccati equation, describing the simplest type of production and recombination of electrons

$$\frac{dN}{dt} = q(t) - \alpha N^2,$$

where

N = electrons per cc
q = production of ions per cc and second
α = effective recombination coefficient
t = time,

for the case of a sudden disappearance of the ionization agent ($q(t) = q_0$, $t \leq t_0$; $q(t) = 0$, $t > t_0$) gives as a solution

$$N = \frac{N_0}{1 + \alpha N_0 (t - t_0)}; \quad t \geq t_0.$$

Taking N_0, the initial value of the density, equal to 2×10^6 and choosing the value of the recombination coefficient found by RYDBECK (1946) for the ionosphere at the height of 100 km, $\alpha = 1.1 \times 10^{-8}$, we get an idea of the relaxation time τ by putting $\alpha N_0 \tau = 1$. This gives us $\tau \approx 45$ seconds, which is in good agreement with the observations.

5. Concluding remarks

Concurrently with the radar observations of the aurora visual observations were made. Because of unsuitable weather conditions the material is incomplete and a comparison between the results of the two observations is therefore very difficult. However, it turns out that during the months of highest auroral activity radar echoes were practically always seen on the scope when visual observations of the aurora were made, but often a simultaneous radar and visual aurora did not agree completely with respect to direction and character. There is little doubt, however, that the observed radio scatterings are due to reflections from auroral discharges. The distribution in direction and range of the echoes is the strongest evidence for the fact that the echoes could not come from the ionosphere or be any form of backscatter from ground via the ordinary or sporadic E-layer, the N1-layer, or the F_2-layer.

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