to determine the exact current distribution since it is difficult with the ground-based observations to distinguish between line and sheet currents in the ionosphere. If the electrojet current is contained entirely within the visual auroral forms, it is found that currents of 10,000 to 100,000 amperes per auroral arc are required to produce the magnetic disturbance observed at the ground.

References

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Discussion

Dungey, J. W.:

1) What is the separation between arcs?

2) Are you suggesting that the current is actually confined to the arcs?

Davis, T. N.:

1) Auroral arcs can be only a few kilometers apart. During the evening the average spacing between auroral arcs over College is near 30 km; the spacing increases to the north.

2) With the observations that we have it is impossible to tell whether the current is in the form of narrow horizontal sheets of 100 or so kilometers width or is in the form of line currents. However, the answer to your question is: yes, I do suspect that the main part of the ionospheric current at the auroral zone is confined within the arcs.

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I-4-5. Radio Studies of the Aurora*

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§ 1. Introduction

Previous studies of the aurora by radio and radar techniques have yielded considerable data concerning the occurrence of the aurora and its relationships with the earth storms and magnetic disturbances. The radar technique of auroral observations has been the principal means of studying the existence and nature of daytime aurora and has been a relatively good method of determining the motions and the position in space of the aurora. In addition, the ability to examine the spectra of the aurorally reflected signals has allowed some studies of the ionospheric current system to be made.

Although the one-to-one correlation between radar auroral echoes and visual auroral forms has not been established, the fact that magnetic disturbances, percent of visual aurora and earth-potential disturbances are well correlated with radar auroral echoes tends to make the radar technique of considerable value. Such a study of the aurora by radar will be presented.

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§ 2. Description of rader and data collection procedure

The radar used for these investigations, designed and built by Stanford Research Institute (SRI), was located at Fraserburgh, Scotland.

Geographic longitude	2° 5′ 42″W
Geographic latitude	57° 39′ 26″N
Geomagnetic latitude	61°
Magnetic dip angle	71°.

The antenna consisted of a completely steerable (in elevation and azimuth) 142-foot diameter parabolic antenna.

The radar equipment had the characteristics listed below:

Frequency	400 Mc	800 Mc
Peak Power	150 kw	50 kw
Antenna Beamwidth	1.2°	1.2°
Pulse Length	50–2000 μs	50–2000 μs
PRF	75 cps	75 cps

Both radars were operated simultaneously providing an ideal means for frequency comparisons.

The auroral reflecting region was scanned systematically by the antenna. The antenna rotated continuously in azimuth (360° every 3 min) and the elevation angle was changed in steps of 0, 2.0, 4.5, 8.5 and 16 degrees each time the antenna was pointing magnetically south. Thus, each 15 minutes the entire auroral reflecting region was examined.

§ 3. Discussion of results

Auroral echoes are seen most frequently and with the greatest strength when the radar ray intersects the earth's magnetic field lines at right angles. In addition, the strength and percent of occurrence are greatest when the orthogonality condition occurs within the zone of maximum auroral occurrence and within the E region[1].

Previous 400 Mc auroral echo investigations in Alaska indicated that two distinct types of auroral echoing regions exist[2]. These were named discrete and diffuse, due to the shape of the echoes as seen on an A-scope display. The discrete echo was in general, a good replica of the transmitted pulse while the diffuse echo was much spread in range as seen on an A-scope display. The physical differences in the reflecting region were quite pronounced. The discrete echoes appear to arise from a thin sheet of auroral ionization that is aligned with the earth's magnetic field lines, such a simple homogeneous auroral arc. The diffuse echo arises from a layer of magnetic field-aligned auroral ionization which is many hundred kilometers in extent in both the north-south and east-west directions. The discrete echoes appear primarily during the nighttime hours and the diffuse echoes during the period of time when the sun illuminates the reflection region.

During the Scotland investigations only diffuse auroral echoes were seen. In addition, the Scotland echoes indicated a preference for the late afternoon and early evening hours but in no way particularly resembled the period of time when the region was sunlit.

An interesting relationship between the strength of the auroral echoes (seen when looking at precisely right angles to the earth's magnetic field lines) and the percent of time occurrence was found to exist during the Scotland studies. This relationship is shown in Fig. 1 where percent of occurrence is plotted vs. auroral echo strength.

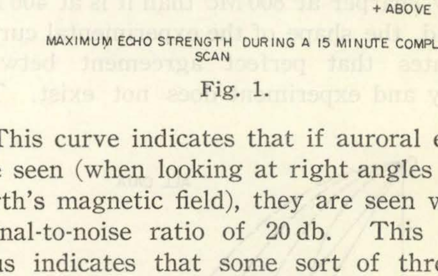

Fig. 1.

This curve indicates that if auroral echoes are seen (when looking at right angles to the earth's magnetic field), they are seen with a signal-to-noise ratio of 20 db. This curve thus indicates that some sort of threshold effect is influencing the occurrence of auroral echoes. It is possible that this threshold is related to the energy level of the incoming primary auroral particles.

At the present time the best description of the auroral scattering mechanism is that which was developed by Booker. He treats the auroral ionization as though it were made up of elongated blobs aligned with the earth's magnetic field lines and imbedded in the ionospheric layers. The equation derived by Booker for the scattering from these elongated blobs is given below[3];

$$\sigma_B = \frac{2^{3/2}\pi^3}{\lambda_N 4}\left(\frac{\Delta N}{N}\right)^2 \cdot T^2 L \exp\left[\frac{-8\pi^2 T^2}{\lambda^2}\right] \exp\left[\frac{-8\pi L^2 \Psi^2}{\lambda^2}\right]$$

where

σ_B = the backscatter coefficient per unit solid angle per incident power density

λ_N = plasma wavelength

$\left(\frac{\Delta N}{N}\right)^2$ = mean square fractional deviation of electron density

L = correlation distance along the field line

T = correlation distance transverse to the field line

λ = radio wavelength

Ψ = off-perpendicular angle with respect to the earth's magnetic field lines.

The scattering polar diagram of the elongated blobs determines the longitudinal correlation distance, L, and is therefore, a measure of the aspect sensitivity of the auroral reflecting mechanism.

The scattering polar diagram for 400 and 800 Mc is shown in Fig. 2. Also plotted on the same coordinates are theoretical polar diagrams from Booker's equation for various values of L/λ. First, the experimental curves indicate that the polar diagram is not appreciably sharper at 800 Mc than it is at 400 Mc. Second, the shape of the experimental curves indicates that perfect agreement between theory and experiment does not exist. The

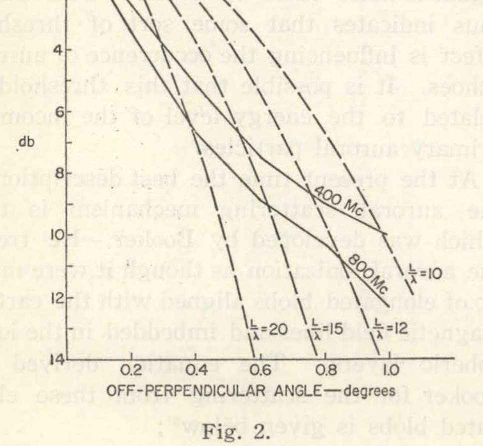

Fig. 2.

very small change in the aspect sensitivity with frequency indicates that L/λ is nearly a constant. That is to say that a selective mechanism is at work which chooses to be almost proportional to the wavelength of the probing radar signal.

By comparing the strength of the auroral reflections at 400 Mc to the strength obtained at 800 Mc (normalizing all equipment parameter differences and assuming that the auroral ionization fills the beam at both frequencies), it is possible to obtain a measure of the transverse correlation distance T (or the diameter of the scattering blob).

A comparison of the 400 and 800 Mc normalized echo strengths for several hours of data is shown in Fig. 3. A distribution of values with a mean amplitude difference of 23.2 db was found to exist. Thus, the auroral ionization appears to be a poorer reflector at 800 Mc than at 400 Mc by 23.2 db on the average. This results in a wavelength dependence of $\lambda^{7.7}$ or a transverse correlation distance of 0.122 meters. Thus, the diameter of the elongated scatterers based on these data would be $0.122 \times 2\pi$ or approximately 0.75 meters.

It was fortunate that magnetograms from a point underneath the auroral reflecting region were available for comparison with the radar data. The magnetic data were recorded at Lerwick, Scotland, a point which corresponded quite well with the data obtained during the azimuth scan at 16.0 degrees elevation angle. Comparisons of the magnetic data and the strength of the 400 Mc auroral echoes were made for a number of occasions, and a typical example is shown in Fig. 4. It is easy to see that the strength of the 400 Mc auroral echoes seen overhead at Lerwick corresponds most closely to the deviation from the quiet day magnetic curve. It was also found that the greater the deviation from the quiet day magnetic activity, the further south auroral echoes were detected. It was also found that it did not matter whether or not the deviation in the magnetic activity was positive or negative in so far as the strength of the echoes was concerned. That is, the strength of the auroral echoes was found to be proportional to the deviation of the magnetic activity from the quiet day curve. Similar correlation between magnetic activity and the strength of

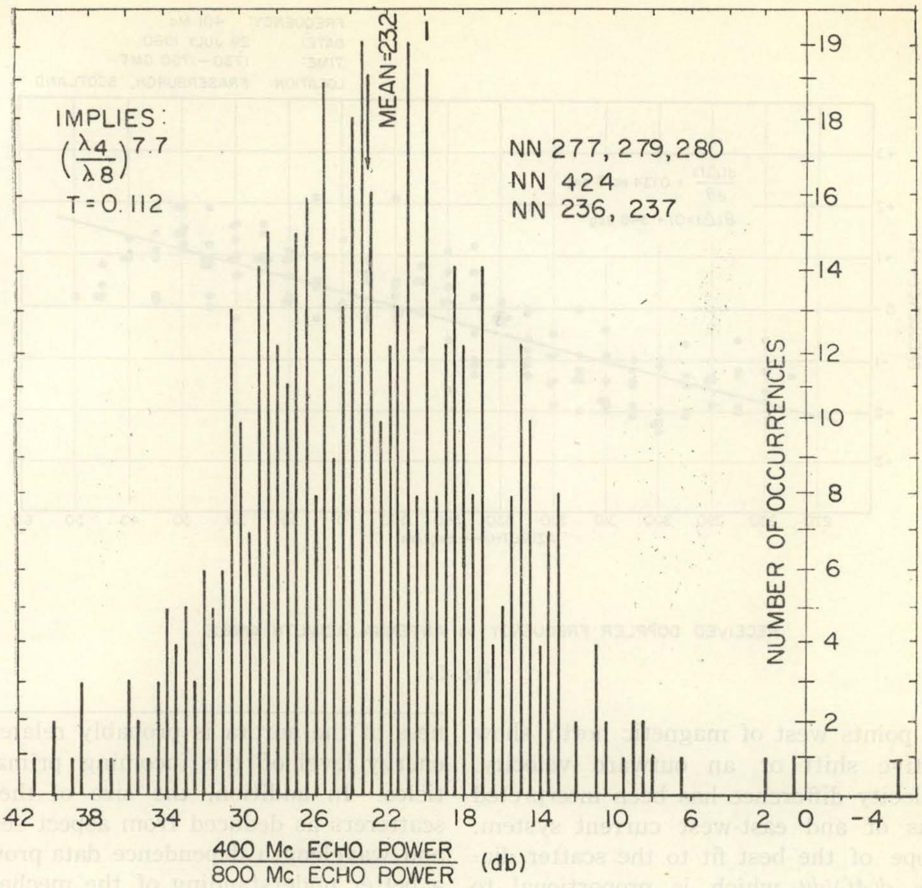

Fig. 3.

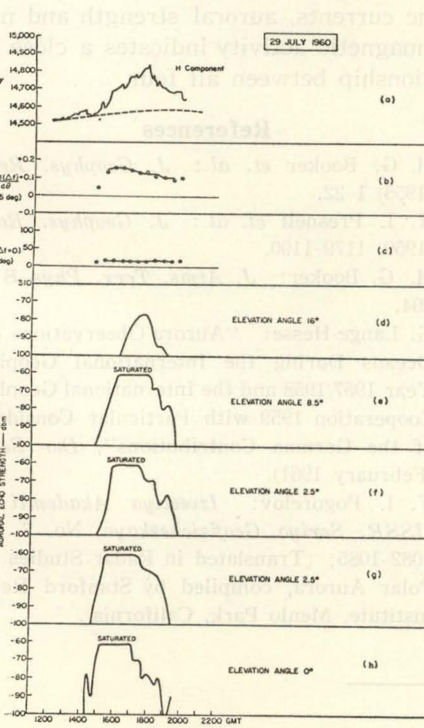

Fig. 4.

auroral echoes has been found by others[4),5)].

When a radar signal is reflected from auroral ionization, its spectral characteristics are altered significantly. First, the signal reflected from the aurora is spread in frequency by the combined effect of the multiplicity of the auroral scatterers so that it is several kilocycles wide at 400 Mc. Second, the center of the aurorally reflected signal is shifted in frequency above and below the transmitted frequency by or 2 kc at 400 Mc. The spectral shift is related to the velocity of the auroral scatterers approximately by $K \cdot \Delta f/\theta$ where Δf is the Doppler shift and θ is the azimuth angle.

Fig. 5. shows an example of a scatter plot of 400 Mc spectral shift during a 20 minutes period plotted on a Doppler shift vs. azimuth coordinate system. It can be seen that the majority of the points east of magnetic north show a positive shift or an inward velocity

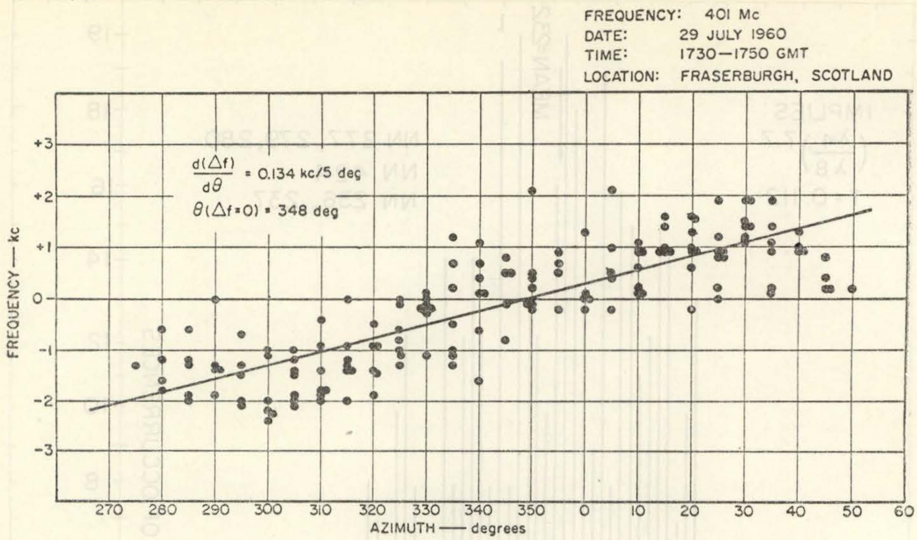

Fig. 5.

and the points west of magnetic north show a negative shift or an outward velocity. This velocity difference has been interpreted in terms of and east-west current system. The slope of the best fit to the scatter diagram is $d(\Delta f)/d\theta$ which is proportional to velocity of motion. The azimuth angle at which the Doppler shift is zero, $\theta(\Delta f=0)$, is related to the orientation of motion of the aurora.

These relations are also plotted in Fig. 4 for an eight hour operating period. It can be seen that in general, a positive magnetic bay (corresponding to an east-west flow of the ionospheric currents) results in a positive velocity component indicating an east-west direction of the aurora. In addition, the orientation of motion is constant and aligned approximately along the geomagnetic latitude flowing either east-west or west-east.

§ 4. Conclusion

This paper has attempted to demonstrate the usefulness of the radar technique in auroral studies and its ability to obtain data of geophysical significance. The existence of a threshold effect in the scattering effectiveness of the aurora is probably related to the energy level of the incoming primary particles. In addition, the size of the auroral scatterers as deduced from aspect sensitivity and wavelength dependence data provides for a better understanding of the mechanism of auroral reflections. A comparison of ionospheric currents, auroral strength and motion and magnetic activity indicates a close interrelationship between all four.

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