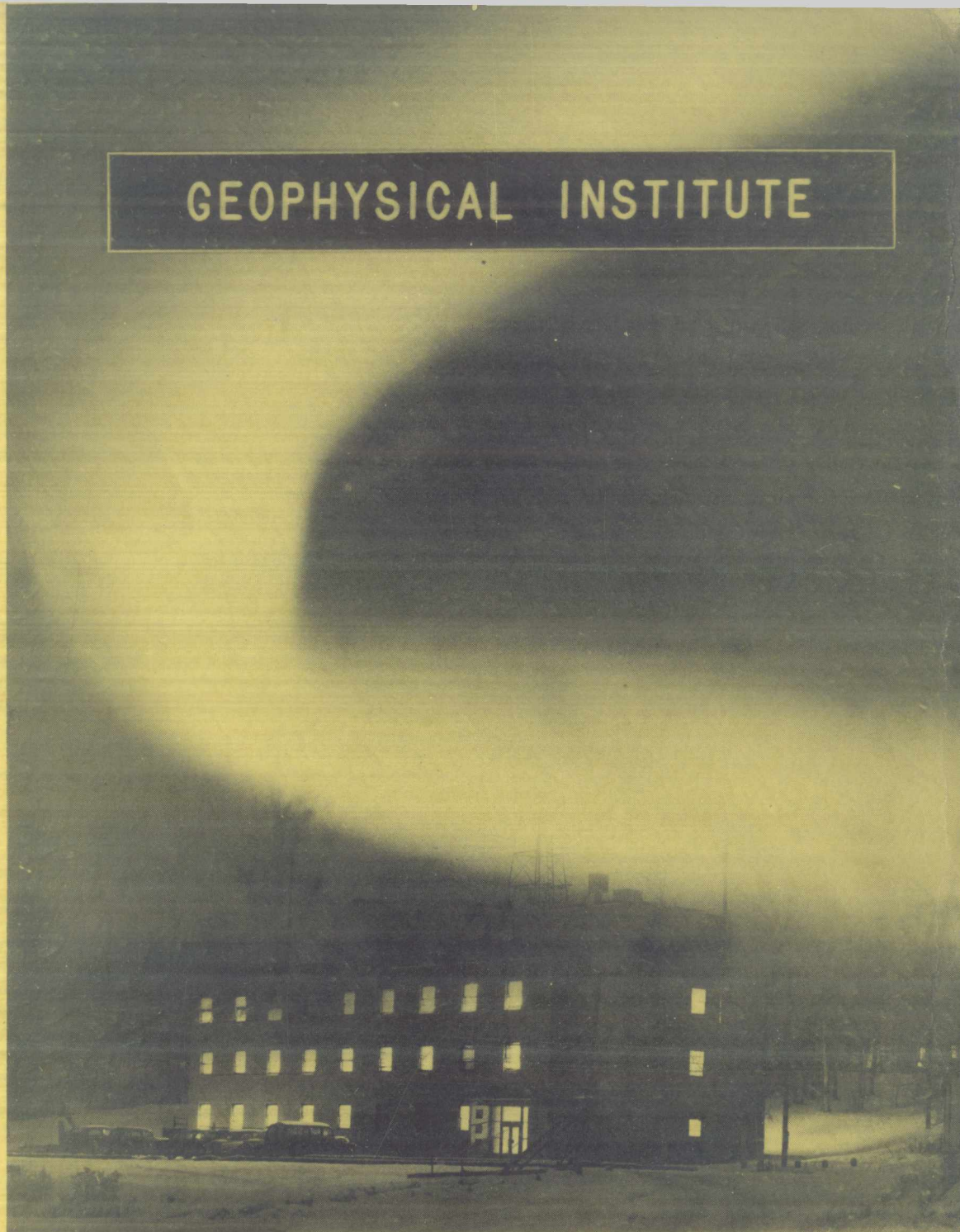


# GEOPHYSICAL INSTITUTE

UNIVERSITY  
OF ALASKA

COLLEGE  
ALASKA

UAG R53



## RADIO PROPAGATION IN THE ARCTIC

Final Report

under

Contract No. AF 19(604)-1089

Covering period

April 15, 1954 to April 15, 1956

AFCRC-TR-56-121

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## SECTION I

### PURPOSES OF CONTRACT

To conduct Arctic propagation studies of both tropospheric and ionospheric modes of propagation directed towards the improvement of communication systems. Specific items to be investigated include the following:

1. Ionospheric backscatter at frequencies in the range of 5-25 mc utilizing either the Communication Zone Indicator or a sweep frequency recorder to determine:
  - a. Usefulness of ionospheric backscatter in auroral regions in determining optimum frequencies for HF point-to-point and ground-to-air communications.
  - b. Incidence of sporadic E and auroral curtains.
2. Auroral and meteor echoes at 50 mc and higher frequencies, depending upon the availability of equipment.
3. Propagation on an existing microwave link.
4. Prediction of auroral and ionospheric storms.
5. Whistlers, i.e. very low frequencies in the audio range.
6. Diffraction and scatter of VHF radio waves by mountains.
7. Ionospheric absorption.
8. Assistance to the Alaska Air Command on problems of radio propagation.

## SECTION II

### ABSTRACT

The main body of this report is divided into eight sections, corresponding to the eight aspects of Arctic radio wave propagation listed in Section I, Purposes of the Contract. In cases where the work has already been fully described in Interim Scientific Report No. 1 (AFCRC-TN-55-579, hereinafter referred to as R(1)), brief summaries only are given.

The progress in these eight fields is summarized as follows:

#### Task No. 1 Sweep-Frequency Ionospheric Backscatter

Because of lack of equipment, no progress was made on this task.

#### Task No. 2 Auroral and Meteor Echoes

Three frequencies were used in this work:

##### (a) At 50 mc

A low-power, 50 mc radar equipment, specially designed and built for auroral radar research, was operated with a steerable antenna to monitor both auroral and meteor activity. The results showed that the diurnal distribution of meteor activity is similar at College to that observed elsewhere, and that the meteor echo rates observed on this equipment are not affected by the presence of aurora.

##### (b) At 106 mc

The 106 mc SCR 270 DA radar was used for two main experiments, as described in R(1). First, the aspect sensitivity of the auroral echoes was investigated. The results showed clearly that the auroral ionization giving rise to VHF auroral radar echoes is aligned along the earth's magnetic lines of force, in that the auroral radar

echoes are strongest when the radio waves are traveling perpendicularly to the magnetic lines of force through the aurora. Second, the relationship between visual and radar aurora was investigated; this work showed that the auroral radar echoes are often closely associated in range and azimuth with visual aurora, although the strength of the echoes is not proportional to the visual brightness of the auroral forms.

(c) At 210 mc

The 210 mc SA-2 radar was installed in a trailer and tested without modification. It was then modified by the building of a steerable 16-Yagi array, by increasing the pulse length, and by reducing the receiver bandwidth. Simultaneous operation of the 50 mc and the improved 210 mc equipment resulted in the detection of many auroral echoes at the lower frequency; no auroral (or meteor) echoes were obtained on the 210 mc equipment during the contract period although good mountain echoes were obtained at ranges up to 250 km.

Task No. 3 Investigation of Microwave Link

As explained in R(1), the experimental observations carried out on this link showed the absence of significant tropospheric refraction effects, and the work was terminated at the end of the first year of the contract.

Task No. 4 Prediction of Auroral and Ionospheric Storms

Several types of work were undertaken in order to improve our understanding of auroral and ionospheric storms; these storms are two aspects of the bombardment of the upper atmosphere by particles from the sun. In particular, a solar radio interferometer was set up to monitor the solar radio emissions at 65 mc. As described in R(1), an all-sky camera and a photoelectric photometer were developed for the monitoring of the visual



auroral activity.

An investigation of earth potentials has shown that they provide a simple method of monitoring magnetic activity; some tests were also made using a rapid-response electronic magnetometer. Some of the results obtained with these equipments are discussed in the report.

A study of the form of the front surface of a neutral corpuscular stream advancing into a magnetic field similar to the earth's magnetic field is presented. This study shows the presence of equatorial and polar forbidden zones and the fact that only the particles arriving near the border between these forbidden zones can reach the earth's upper atmosphere. An equatorial motion of the zone of bombardment could be produced by an increase either in particle density or in particle velocity.

#### Task No. 5 Whistlers

A new type of whistler has been discovered that has simultaneous rising and descending components.

Analysis of data obtained during the contract period indicates a diurnal variation in the rate of occurrence of whistlers that appears to be correlated with ionospheric heights. A correlation between the day-to-day occurrence of the dawn chorus and the daily K-index sums is also found.

#### Task No. 6 Diffraction and Scatter of Radio Waves by Mountains

##### (a) Diffraction

The diffraction of VHF radio waves by mountains has been investigated over three diffraction paths. The results show that the experimentally observed signal strengths are in fair agreement with the values calculated theoretically using knife-edge approximations. One



important observation, which has not been reported previously, is the variability of the diffracted signal strength from point to point across the ground. Also, although diffracted signals are normally described as being very constant in amplitude, slow fades lasting some hours and occurring over a relatively narrow frequency band were observed over one 200-mile path.

(b) Mountain scatter

Observations of mountain scatter were made using the SCR-270 DA radar and a mobile receiving equipment. The results imply that detectable scattered signals can be obtained over a very wide range of azimuths (greater than  $\pm 135^\circ$ ) relative to the line joining the transmitter and the mountain. It was found that the scattered signals were considerably broadened in pulse length.

Task No. 7 Ionospheric Absorption

The work done in connection with ionospheric absorption under this contract has been described previously in R(1). Undertaken at the request of the 58th Weather Reconnaissance Squadron, USAF, this study demonstrated convincingly that their communication failures were caused by ionospheric absorption phenomena, rather than by equipment or personnel failures.

Task No. 8 Assistance to the Alaska Air Command on Problems of Radio Propagation

As described in R(1), an investigation of a VHF radio link was made at the request of the Alaska Air Command. Continuous records of received signal strength at each end of the link revealed that the communication failures were caused by tropospheric refraction effects. A low-noise preamplifier, built and operated in parallel with a normal equipment, was

found to reduce the number of fade-outs.

A one-day symposium on Arctic radio wave propagation was held at the Geophysical Institute on January 26, 1956, for the benefit of communications personnel in the territory. Approximately fifty visitors attended these meetings. The Geophysical Institute has also assisted the Alaska Air Command by the loan of electronic equipment and pen recorders as well as by supplying specialists who have acted in an advisory capacity on problems of radio wave propagation.

### SECTION III

#### EXPERIMENTAL WORK

##### Task No. 1 Sweep Frequency Backscatter (L. Owren)

No experimental sweep-frequency observations of backscatter from auroral ionization could be carried out during the contract period because of lack of equipment. A National Bureau of Standards C-4 type ionospheric sounder is on order under purchase contract AF 19(604)-1652 with Barker and Williamson, Inc., for use by the Geophysical Institute under the continuation of the present contract, viz., contract AF 19(604)-1859.

In March 1956 a study of the occurrence and properties of the third magneto-ionic or z-wave component, which is observed sporadically at higher geomagnetic latitudes in vertical incidence soundings, was started. Data for the months of January and February 1955 were scaled from the records obtained with the C-3 ionospheric sounder operated by the Geophysical Institute under contract with the National Bureau of Standards. The outstanding fact revealed by perusal of the first data is that F2z traces occurred during the daytime on almost every day of January and February 1955. On some days the records permit determination of the value of the F2z critical frequency ( $f_z F2$ ) continuously for four hours or more. This study was in its initial phase at the close of the contract period and will be continued on contract AF 19(604)-1859.

Task No. 2 Studies of Auroral and Meteor Radar Echoes (K. Bowles,  
R. B. Dyce, C. G. Little, L. Owren, R. B. Roof)

A. Equipment

Three radars were used in the course of this work on frequencies close to 50 mc, 100 mc, and 200 mc. The chief operating parameters of the three equipments are list in Tables 1 and 2.

A convenient method for comparing the relative sensitivities of different auroral radar equipments is to use the parameter S, defined by

$$S = \frac{(\alpha_1 P G_T) (\alpha_2 G_R \lambda^2) T}{N B} \text{ for } TB > 1 \dots \dots (1)$$

where T is less than the time required for propagation through the aurora

and where  $\alpha_1$  = proportion of RF power fed by transmitter into transmission line which is radiated by the antenna;

P = RF power fed by transmitter into transmission line during pulse;

$G_T$  = numerical gain of transmitting antenna;

$\alpha_2$  = proportion of RF power received by antenna that reaches the receiver;

$G_R$  = numerical gain of receiving antenna;

$\lambda$  = wavelength;

T = pulse length;

N = effective noise factor of receiver; and

B = receiver bandwidth .

In this expression,  $\alpha_1 P G_T$  is the effective radiated power, and  $\alpha_2 G_R \lambda^2$  is proportional to the received echo power from a small target. Because the auroral target is assumed to be spread in range

Comparison of radar transmitter parameters on 50 mc, 100 mc,  
and 200 mc auroral radars at College, Alaska.

TABLE 1.

Transmitter	50 mc	100 mc SCR 270		200 mc SA-2	
	Built at Geophysical Inst.	As Received	After Modification	As Received	After Modification
Frequency (mc)	51.7	104 - 112	106	215 - 225	210
Peak Power (kw)	5	100	100	150	50
Pulse length ( $\mu$ s)	200	15 - 40	100	5	50
Pulse rep. Freq. (pps)	100	621	100	60	120
Antenna	3 x 2 dipoles	8 high 4 wide dipole	8 wide, 5 high dipole	3 x 2 dipoles	16 5-element yagis 4 x 4 array
Polarization	Vertical	Horizontal	Horizontal	Horizontal	Vertical
Estimated free- space gain (over isotropic radiator)	13db	20db	21db	13db	22db
Estimated beam- width between half power points (free space)	(a) Az. 40° (b) El. 50°	30° 15°	15° 20°	40° 50°	15° 15°
Beam elevation (neglecting ground)	+10°	0° - 10°	+5°	0°	0° - 10°
Antenna rotation (rpm)	0 - 1	0 - 1 or 5	0 - 1 or 5	0 - 1 1/4	0 - 2 1/2

Comparison of radar receiving parameters on 50 mc, 100 mc and  
200 mc auroral radars at College, Alaska.

TABLE 2

Receiver	50 mc	100 mc SCR-270		200 mc SA - 2	
	Built at Geophysical Inst.	As Received	After Modification	As Received	After Modification
Antenna	Two 3-element Yagis	Same as transmitting antenna		Same as transmitting antennas	
Receiver noise figure (absolute)	3*	10	4	50	10
Receiver bandwidth (kc)	6	100	10	350	10-20
Display	1. A - scope 2. Range - time 3. P.P.I.	1. A - scope 2. P.P.I.	1. A - scope 2. P.P.I.	1. P.P.I.	1. P.P.I. 2. A - scope
Minimum usable range (due to ground clutter)	About 200 km	About 100 km	About 200 km	About 200 km	About 200 km
Maximum range	1200 km	120 km	1250 km	400 km	1250 km
Minimum detectable signal power at receiver terminals	About $10^{-15}$ w	About $10^{-14}$ w	$10^{-14}$ w	About $10^{-14}$ w	$2 \times 10^{-16}$ w

\* Equivalent noise figure (including cosmic noise) taken as 20 (13 db)

over a distance greater than the velocity of light multiplied by the pulse length, (for pulse lengths up to the maximum length used on these equipments), the received echo from an aurora will be proportional to the pulse length,  $T$ . The noise power in the receiver will be proportional to  $NB$ , where  $B$  is the receiver bandwidth. It is usually desirable to keep the product of  $BT$  constant at about unity. Under these circumstances  $S$  can be written as

$$S = \frac{\alpha_1 P G_T \alpha_2 G_R \lambda^2 T^2}{N}$$

It will be seen that  $S$  is proportional to the signal-to-noise ratio in power.

Calculation of the sensitivities of the different equipments to auroral echoes shows that the 50 mc equipment was roughly 1,000 times more sensitive than the unmodified 200 mc radar, and about 5 times less sensitive than the unmodified 100 mc SCR-270. By increasing the pulse length and the antenna collecting area and by reducing the bandwidth, however, the auroral sensitivity of the 100 mc radar was increased by about 100 times and the auroral sensitivity of the 210 mc SA-2 radar was increased about 10,000 times. Thus the relative auroral sensitivities of the final equipments were of the order 1:500:10 for the 50-, 100-, and 200 mc equipments.

## B. Observations

### 1. Simultaneous Meteor and Auroral Studies at 50 Mc

In 1954, Bowles reported<sup>(1)</sup> that observations at 106 mc with the SCR-270 radar at College indicated that the rate and strength of meteor

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(1) K. L. Bowles, "V.H.F. Auroral and Meteor Echoes Including Simultaneous Observations," *TRANS. AM. GEOPHYS. UN.* 35, 375 (1954).



echoes were considerably enhanced during periods of aurora. The meteor echoes were identified as such, rather than as short-lived bursts of aurora, because they did not show the strong azimuthal aspect sensitivity shown by auroral echoes, and because they possessed fading rates roughly one order slower than the auroral echoes.

An experiment was conducted during the spring of 1955 to investigate whether a similar effect could be observed using the 51.7 mc radar at College. The radar was operated continuously for a period of one month, a range-time display being obtained by photographing an intensity modulated A-scope on moving film. The azimuth of the antenna was alternately directed toward magnetic north and magnetic south for periods of four minutes, an extra minute being taken each time to move the antenna between the two positions. In this way a total of six complete cycles were obtained each hour, each cycle comprising four minutes of observations with antenna stationary looking toward magnetic north, one minute with antenna moving southward, four minutes of observations with antenna looking magnetic south, and then one minute with antenna moving northward again. The operation was completely automatic. A continuous rough check of radar sensitivity was obtained from the intensity of the mountain echoes in each direction.

These records were used for three main purposes:

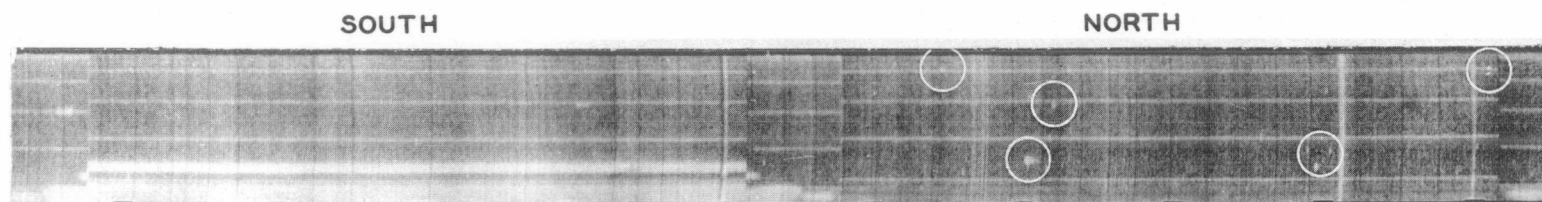
- (1) To determine the incidence of aurora during the summer months, when the bright night skies prevent visual observations;
- (2) To obtain information on the diurnal distribution of meteor echoes at this latitude; and
- (3) To determine the effect of auroral activity upon the meteor rate.

In addition, it was possible to measure the relative frequency of occurrence of meteor or auroral echoes from the northerly and southerly quadrants.

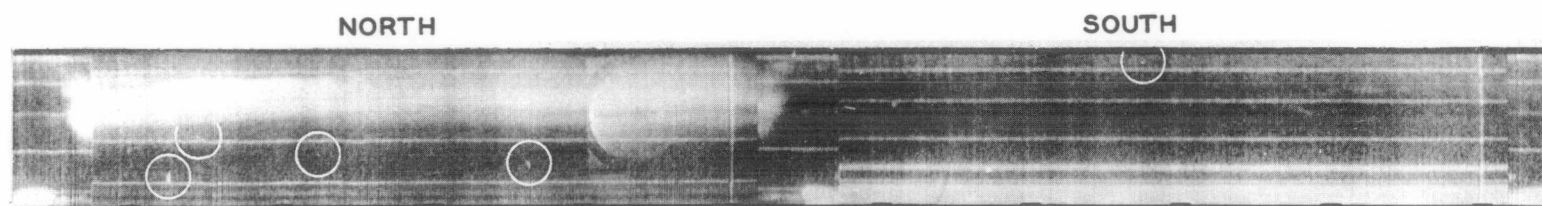
The records were analyzed as follows: Each four-minute section of film was inspected in turn in the film viewer, the presence or absence of auroral echoes and the number of meteor echoes during that period being noted. The data were then summed for each hour for each of the two azimuths. Because of the presence of strong mountain echoes from Mt. McKinley, at a range of 250 km on the south quadrant, it was necessary to neglect all echoes closer than 300 km on both azimuths, in order to preserve similarity between the data from the two azimuths. The meteor echoes were also classified according to whether or not auroral echoes were observed during the same frame.

Figure 1 is a reproduction of short sections of some of the records. The illustration shows a portion of the records of two days. The upper record shows several meteor echoes but no auroral echoes; both types of echoes may be seen on the lower record. Each record covers a period of about ten minutes; the displaced sections at each end and in the center of each strip were produced while the antenna was rotating from one azimuth to the other. The thin horizontal lines are range markers at 200 km intervals. The wide line at about 250 km on one long frame of each film is the echo from Mt. McKinley, showing that the antenna was directed south during these periods.

Figure 2 is a plot of the average daily variation of meteor echo rate and of the occurrence of auroral echoes for each azimuth for the duration of the experiment. The meteor activity was found to increase



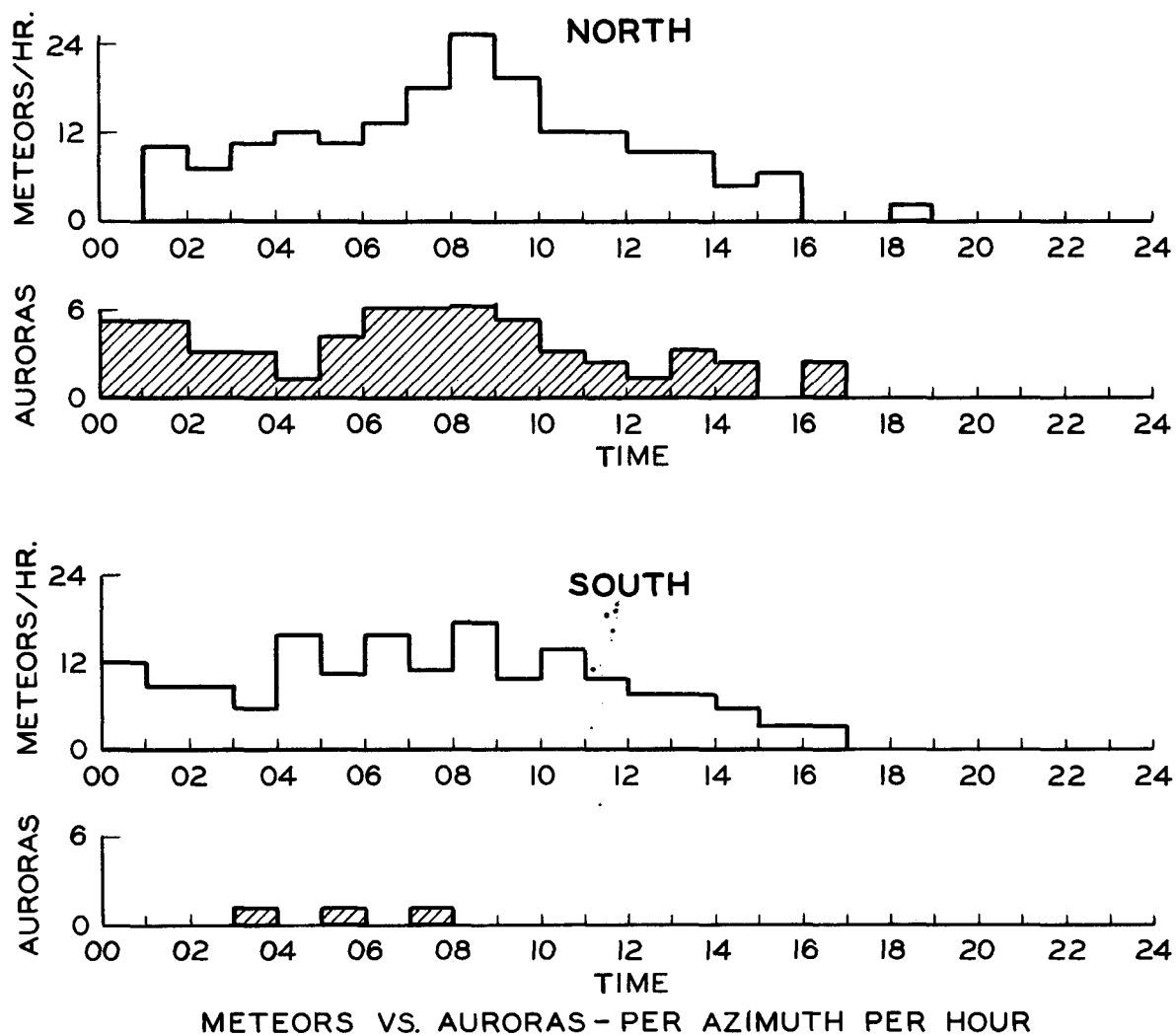
METEORS WITHOUT AURORA. 0700-0710. JULY 6 1955.



METEORS WITH AURORA. 0700-0710. JULY 12 1955

Reproduction of Short Section of Simultaneous Meteor and Auroral Records.

Figure 1.



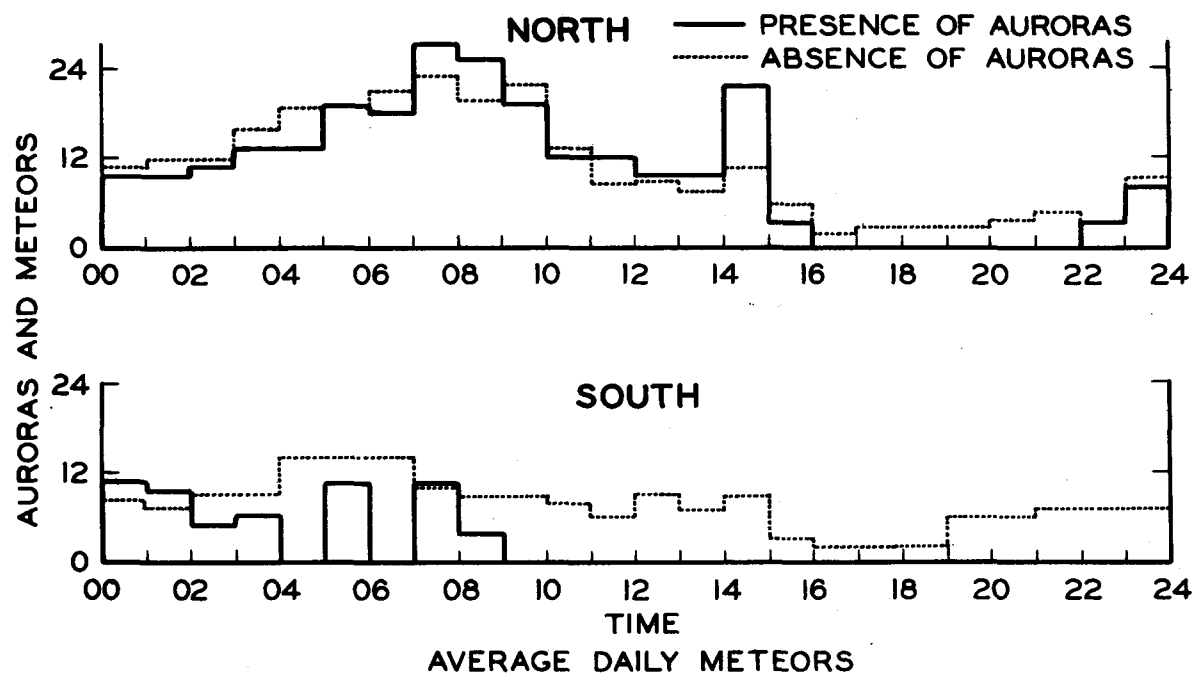
Plot of the Average Daily Variation of the Meteor Echo Rate and the Occurrence of Auroral Echoes for each Azimuth

Figure 2

to maximum at about 0700 AST, with a minimum at about 1900 AST, in fair agreement with observations at other latitudes. This daily variation was in striking contrast with the daily variation of auroral echo activity, which showed a strong peak at about midnight. This daily variation of auroral echo activity during the summer is in good agreement with similar data for equinoctial and winter months. More meteors were observed when the antenna was directed north than south.

The meteor echo rates were then divided into two categories, according to the presence or absence of auroral echoes on the same frame. The average daily variation of these two classes was then plotted (Figure 3). It will be seen that, for this equipment, the meteor echo rate is not significantly affected by the presence of auroras.

On a few occasions short-lived echoes were observed when the antenna was directed south. In most cases, these could plausibly be attributed to echoes that were being picked up on the back lobe of the antenna, since strong echoes were observed at the same range on the preceding and following frames taken in the north direction. In two cases, no such echoes were observed when the antenna was looking north, so this interpretation is therefore not likely to be correct. On both these occasions, however, the C3 vertical incidence sounder at College showed strong sporadic E ionization overhead ( $f_c > 20$  mc), and it is believed that the echoes observed at a range of 700 km to the south were in fact due to backscatter from the ground via these extended sporadic E clouds. No clear case of auroral-type echoes from the south was observed during the course of the experiment.



Average Daily Variation of Meteor Echoes with and without Auroral Echoes

Figure 3

## 2. Auroral radar observations at 106 mc

As described in R(1), the 106 mc SCR-270 was first modified for auroral radar studies and then used in two main experiments. Because the experimental methods and results have already been fully described in R(1), only a brief summary is given here.

### a. Aspect sensitivity

Operation of the radar was started early in August, 1954. Because of the almost continuous daylight in Alaska at that time of year, aurora could not be seen visually, but auroral echoes were received on the equipment on every night that operation was attempted. This is also true of about 95 per cent of the observations at 50 mc.

The patterns on the 106 mc PPI 'scope show a slight clockwise rotation with respect to geomagnetic east-west for about 6 hours after midnight. These results agree with the visual observations made by other investigators<sup>(2)</sup>.

Three different modes of propagation of auroral echoes have been proposed to explain this aspect sensitivity.

One model - proposed by Currie, Forsyth, and Vawter<sup>(3)</sup> - assumes that a highly absorbing layer occurs just under the aurora, preventing detection of aurora from below by radar but not affecting radio waves incident upon the aurora from other angles.

The second model - postulated by Harang and Landmark<sup>(4)</sup> - assumes the existence of horizontally stratified ionized clouds associated with

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(2) R. E. Jensen and B.W. Currie, "Orientations of Auroral Displays in West-Central Canada," J. GEOPHYS. RES. 58, 201-208 (1953).

(3) B.W. Currie, P.A. Forsyth, and F.E. Vawter, "Radio Reflections from Aurora," J. GEOPHYS. RES. 58, 53-66 (1953).

(4) L. Harang and B. Landmark, "Radio Echoes Observed during Auroras and Geomagnetic Storms Using 35 and 74 Mc Simultaneously," J. ATMOS. TERR. PHYS. 4, 322-338 (1954).



aurora. Radio waves are assumed to be reflected by these clouds forward toward the ground, and the observed radio echoes are interpreted as back-scatter from the ground received via the auroral E-region ionization.

The third model - due to Booker and his associates<sup>(5,6,8)</sup>-suggests that the ionization causing auroral echoes is aligned along the magnetic lines of force. It is known that visual auroral rays are so aligned. The strongest echoes would then be obtained when the radio path is approximately perpendicular to the magnetic lines of force as shown by Chapman<sup>(7)</sup> and Booker<sup>(8)</sup>. Since these lines of force are nearly vertical at high latitudes, radio echoes would not be expected from overhead aurora.

In spite of the fact that all these theories explain the absence of echoes from overhead aurora, they differ concerning the predicted sensitivity to aurora south of the transmitter. The absorption and ground-scatter theories predict no azimuthal variation in sensitivity (assuming uniform distribution of aurora across the sky), whereas the third theory predicts that aurora will most frequently be detected to the magnetic north and will not be observed to the south of the transmitter.

A tabulation of more than 300 photographs of PPI auroral displays on 106 mc was made, and the results were plotted. This method of analysis showed that the great majority of echoes were received from a direction approximately along geomagnetic north, with an average range of about

- (5) R.K. Moore, "Theory of Radio Scattering from the Aurora," TRANS. I.R.E. PGAP, no. 3, 217-230 (1952).
- (6) H.G. Booker, C.W. Gartlein, and B. Nichols, "An Interpretation of Radio Reflections from the Aurora," J. GEOPHYS. RES. 60, 1-22 (1955).
- (7) S. Chapman, "The Geometry of Radio Echoes from Aurorae," J. ATMOS. TERR. PHYS. 3, 1 (1953).
- (8) H.G. Booker, A Theory of Scattering by Non-Isotropic Irregularities with Applications to Radar Reflections from the Aurora. Research Report EE 269, School of Electrical Engineering, Cornell University, October 1955.

600 km, and that less than 1 per cent of the total echoes were received from any direction south of the east-west geomagnetic line.

To further test the third model of propagation mentioned above, consideration was given to the fact that the scattering coefficient should decrease as the angle between the wave normal of the incident radio wave and the ionization column changes from the perpendicular.

A careful computation of the contours of equal angle off the perpendicular was made for various ranges and azimuths at a height of 100 km. These contours show a striking similarity to the echo probability curves obtained experimentally, giving strong evidence in favor of the theory explaining VHF auroral echoes in terms of direct backscatter from ionization columns aligned with the magnetic lines of force. Because of the shape of the echo probability contours, it is believed that the reflecting surface is not smooth, but consists of irregularities possibly 50 meters in length and perhaps 10 meters wide aligned along the lines of magnetic force.

#### b. Relation between visual and radar observations of aurora

The relation between visual aurora and 106 mc radar echoes from aurora was also investigated. The existence of such a relationship has been a subject of dispute among various workers. In order to check it, a large number of simultaneous photographs were taken of the 106 mc PPI display and of the visual forms. The pairs of photographs were then placed one above the other with slant lines connecting identical azimuths. The range on the photographs of the visual forms was then calculated, assuming an average height of 100 km for the lower border of the display.

Many pairs of photographs showed good correlations. Others showed much more visual aurora with little if any radar echo. Sometimes the opposite was true, with little visual aurora corresponding to the radar echoes on the PPI display. It is felt that this may have been due to a faint but widespread auroral activity that was always present in the sky when radio echoes were seen and did not correlate with the visual auroral forms.

Since the frequent correlation of radio echoes with visual aurora cannot be regarded as accidental, there is reason to believe that the anomalous echoes must also be due to auroral activity. It is clear, however, that the visual brightness of the aurora is not a satisfactory index of the radar echo strength.

### 3. A Search for Auroral Radar Echoes at 210 mc

#### a. Initial tests

As described in R(1), a careful search for local VHF or UHF transmissions suitable for auroral studies was unsuccessful, and after a low-power (10 watt) CW link was set up, the decision was made to delay further operations at frequencies above 100 mc until the arrival of the 200 mc, 150 kw SA-2 radar.

This equipment reached the Institute toward the end of October 1955. The first step was to repair damage it had incurred in transit due partly to rough handling, and partly to nuts vibrating loose and allowing heavy components to come free. The numerous multiwire interconnecting cables required to couple the different units together were not supplied with the radar, and much time was spent in preparing a complete set. Once the repairs were completed, the equipment was tested chassis by chassis and

then installed in a specially prepared trailer, suitable for Arctic winter operation. The radar antenna (a six dipole array) was erected, with its rotator, on the roof of the trailer and connected to the transmitter. (This process necessitated the machining of two large constant-impedance tapered connectors to connect the 2" airspaced coaxial transmitter output to semi-flexible RG-17 cable and thence to the 1 5/8" airspaced coaxial antenna input.) The trailer was then towed to a specially prepared site, close to the 50 mc and 100 mc radars.

The radar was operated in its unmodified state for two or three nights, and good mountain echoes were obtained (e.g., three times noise from Mt. McKinley, 250 km away). No auroral echoes were obtained during this period, nor were any expected, owing to the very low sensitivity of the unmodified equipment as an auroral radar.

b. Modification of SA-2 radar

Equation (1) shows that the signal-to-noise ratio can be improved by increasing the pulse length. The original pulse length of the SA-2 radar was 5 microseconds, since the equipment was designed for accuracy at short distances; because of the greater range required for auroral research, a much longer pulse length can be used, resulting in increased sensitivity.

The transmitter used two RCA 8014 triodes in a push-pull Colpitts oscillator. It was normally self-blocking, each pulse being triggered by a signal supplied by the power frequency through a pulsing transformer. Many attempts were made to apply various keyer amplifiers to extend the pulse to the desired 50 microseconds. Because these were not successful, a self pulsing arrangement was adopted and worked well. The pulse repe-

tition rate was changed from 60 per second to about 125 per second in order to eliminate spurious echoes due to power line interference.

These changes produced a duty cycle of about 1/170, or about 20 times greater than before. The power supply built into the equipment could not handle the greatly increased load, so a spare power supply from an SCR-270 radar was placed next to the trailer in which the SA-2 radar had been installed, and used instead. Its control system was connected into the interlock system of the transmitter to insure the safety of operating personnel. The normal operating voltage and current of the modified transmitter are now 5.5 kv, and 0.060 amperes respectively.

As stated earlier, decreasing the bandwidth of the receiver increases the overall sensitivity, up to a point, by increasing the signal-to-noise ratio. To secure this increased sensitivity a second converter and 456 kc I.F. strip were built. The bandwidth obtained was 10 kc, which is, from the standpoint of sensitivity, a very desirable reduction of the former 310 kc. This narrow bandwidth made the tuning of the local oscillator of the radar receiver extremely critical; a 40:1 vernier dial was therefore installed.

A grounded grid preamplifier was constructed for the receiver input. The input and output impedances of this amplifier were measured with an impedance bridge and carefully adjusted to be as near as possible to 50 ohms.

To check the sensitivity of the receiver, its input of 50 ohms impedance was connected directly to the 50 ohm output of a standard signal generator adjusted to a frequency of 210 mc. After the warm-up period, a signal of 0.1 microvolt was readily seen above the noise. This result

corresponds to the  $2 \times 10^{-16}$  watt sensitivity stated in the table of operating parameters.

To check the transmitter, a half-wave dipole was placed on a flagpole 35 feet high at a distance of 725 feet from the transmitting antenna. It was found that the transmitted wave produced a potential difference of 15 volts across a 75 ohm resistor that terminated the end of a piece of RG-59 coaxial cable.

From the radar equation,

$$\text{Power} = \frac{\alpha_1 \alpha_2 P_T G_1 G_2 \lambda^2}{16 \pi^2 D^2} \quad (2)$$

where  $\alpha_1$  = Proportion of the RF power fed by the transmitter into transmission line which is radiated by the antenna;

$\alpha_2$  = Proportion of the RF power received by the receiving antenna which reaches the receiver;

$P$  = RF power fed by transmitter into transmission line;

$G_1$  = Numerical gain of the transmitting antenna;

$G_2$  = Numerical gain of the receiving antenna;

$\lambda$  = Wavelength; and

$D$  = Distance between transmitting antenna and receiving antenna;

and taking  $\alpha_1 \alpha_2 = \frac{1}{2}$  (which assumes that half of the power is lost in the coaxial cables and the T-R switch) and

$P_T = (5500 \times 0.06 \times 170) = 56 \text{ kw}$  (i.e. assuming complete efficiency in the transmitter);

$G_1 = 150;$

$$\begin{aligned} G_2 &= 1.64; \\ \lambda^2 &= 22 \text{ ft.}^2; \text{ and} \\ D &= 725 \text{ ft,} \end{aligned}$$

one obtains

$$P = 1.76 \text{ watts.}$$

If complete in-phase reflection is assumed, then the received power should be four times this free space value, or 7.1 watts.

The actual received power is  $= \frac{15^2}{75} = 3.0$  watts, giving an efficiency of  $= \frac{3.0}{7.1} = 42.5$  per cent.

The receiver was also checked under operating conditions as follows:

1. The signal generator was connected to the input of the receiver, and the A-scope was calibrated for a reasonable range of signal strengths. For this calibration, a separate pulse generator was used to pulse the signal generator.
2. The dipole used in the transmitter check was placed at the top of the flagpole and connected by coaxial cable to the 210 mc signal generator and pulse generator located on the ground. Then the receiver, in its normal position in the trailer, was connected to its normal antenna, the 16 five-element Yagi array. The received signal strength for a given transmitted signal was then read off the calibrated A-scope.

Equation (2) was used to calculate the received power. The result was then compared with the power from the signal generator connected directly to the receiver input required to give the same A-scope signal.

This test was made on two occasions, before and after installation of the grounded grid amplifier mentioned earlier. Although lacking precision, the test indicated a properly working system with T/R switch



insertion loss of less than three db.

c. Operation of 210 mc auroral radar

Twenty-two evenings were devoted to manual A-scope observation, totalling approximately 70 hours. This equipment was functioning with the above parameters, except that a receiver noise figure of about 50 absolute was in effect. No auroral echoes were detected on 210 mc, although some were detected on 51.7 mc at least once each evening (with at least 10 db less radar cross-section sensitivity). The 210 mc antenna was generally pointed toward magnetic north unless intense visible aurora suggested some other direction. Mt. McKinley at 250 km provided an echo visually estimated as at least 10 db above minimum detectable signal. While this was less strong than would be predicted from the approximately five square kilometers of optically exposed area, the discrepancy is explainable by poor low-angle antenna performance. Despite critical equipment tests described earlier, no meteor echoes were detected at any time. If this discrepancy cannot be resolved soon, the equipment will be abandoned in favor of much more powerful and stable equipment on a similar frequency to be set up for meteor research this fall.

(Later observations, made after the end of this contract on AF 19 (604)-1859, resulted in detecting three meteor echoes during eight hours of observations of the Perseid meteor stream. No auroral echoes have been observed. It is not anticipated that further observations will be made with this equipment, since a more sensitive equipment is likely to be available shortly.)

Lack of auroral echoes on 210 mc suggests (subject to the uncertainties expressed above) that the frequency dependence of auroral echo strength

(equivalent isotropic scattering radar cross-section) must be  $\lambda^3$  or greater between 50 and 200 mc. A  $\lambda^2$  dependence is expected because of the departure of refractive index from free space. Furthermore, at this latitude perpendicularity between radio path and magnetic field is not quite attainable at E-region heights. A radar on 200 mc should, therefore, show weaker echoes than a radar on 50 mc because the perpendicularity condition becomes more strict as the wavelength is decreased. Booker<sup>(9)</sup>, using a scattering approach, predicts an  $\exp \left( - \frac{8\pi L^2}{\lambda^2} \right)$  law, where L is the statistical dimension of the scattering blobs measured along the earth's field. It is probably safe to say that UHF auroral echoes are much less likely at this magnetic latitude than at a magnetic latitude south of about Anchorage.

(9) Ibid.

Task No. 3 Study of Propagation on an Existing Microwave Link (R. S. Leonard)

To investigate the effects of Arctic temperature and humidity variations on propagation, the strength of the signal arriving at each end of a 25-mile microwave link between a valley floor and one of the surrounding hilltops was recorded during the winter months. Meteorological data were obtained from a site approximately one mile from the lower terminus. From this data it became apparent that the wintertime ducts were too close to the ground to include the path. The terminal antenna was moved closer to the ground, but again the variations in signal strength were smaller than equipment variations. The conclusion is that meteorological phenomena have little effect on this particular link because of the relatively short and inclined path. A more detailed account of this study appears in R(1).

#### Task No. 4 Prediction of Auroral and Ionospheric Storms

##### a. Development of all-sky camera (C. T. Elvey)

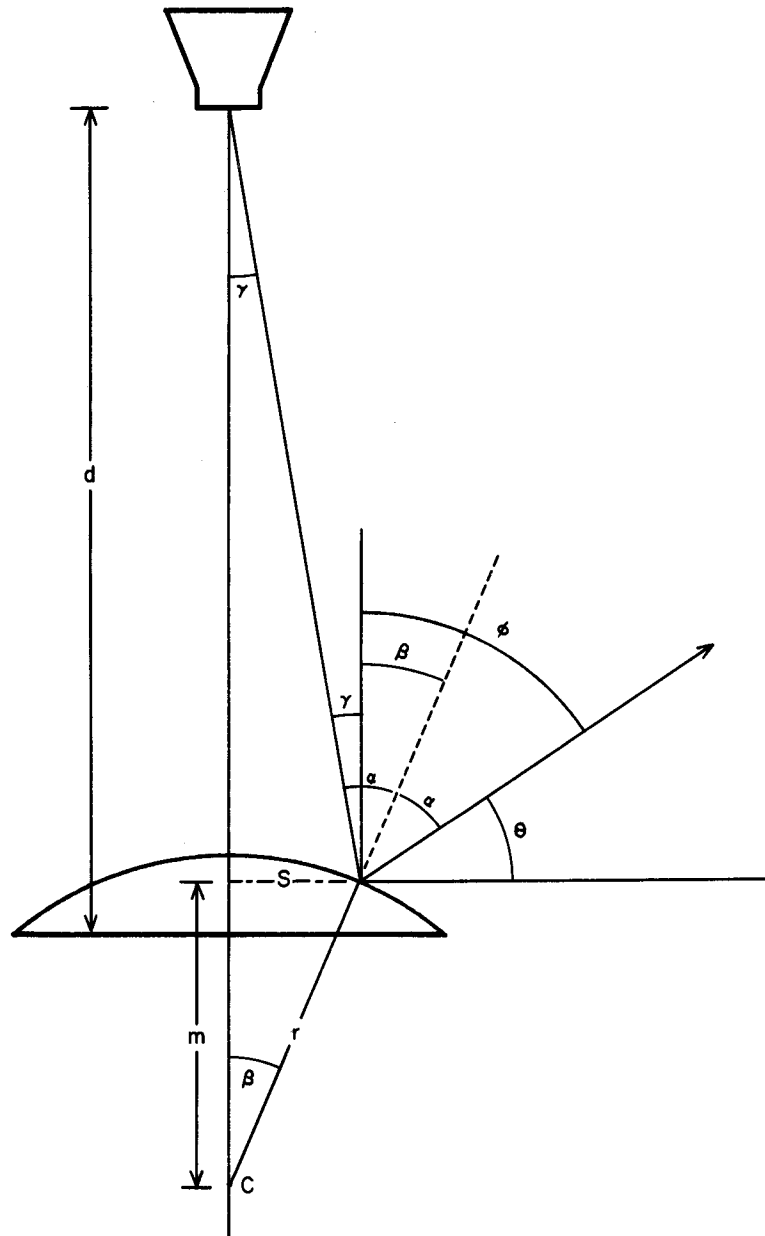
An "all-sky" camera has been developed at the Geophysical Institute in order to record the visual auroral forms for synoptic mapping of the aurora and for other studies. The camera permits routine monitoring of auroral activity over the whole sky by means of exposures, 55 seconds in duration, taken at the rate of one frame per minute.

The optical arrangement is shown in Figure 4. A 16 mm movie camera having a 50 mm f 1.5 lens is mounted above a convex mirror so as to photograph the entire night sky from reflection in the mirror. The azimuth and elevation angle in the sky corresponding to any point on the photographic image may be determined from the geometry of Figure 4. By assuming that the base of the auroral forms occurs at a height of 100 km above the earth's surface, the location of the aurora over a radius of about 1,200 km can be mapped.

An example of a photograph taken with this technique is given in Figure 5. The photograph was used to determine the distribution of auroras over Alaska at that time, and the results are shown in Figure 6.

During the past year at College and Pt. Barrow, Alaska, an exposure time of 55 seconds has been used with Linograph Panchromatic film and normal D-19 (Eastman Kodak) development. The use of new films and development techniques may reduce the necessary exposure time.

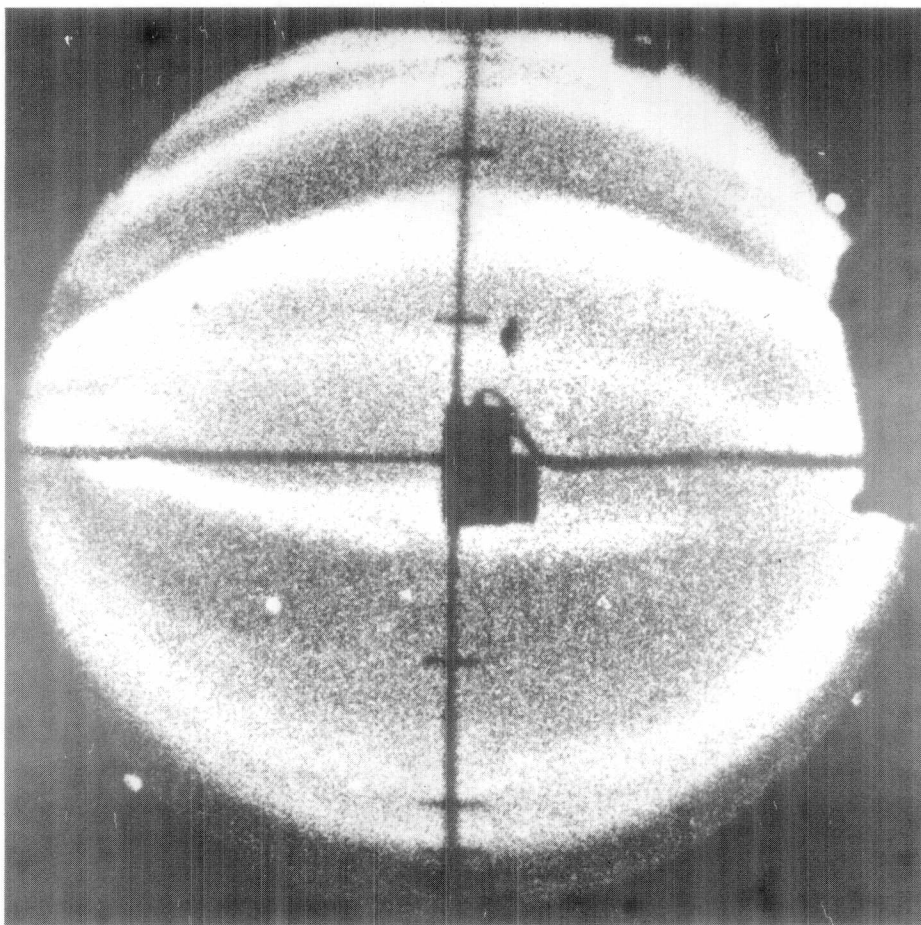
The reduction of data may be made in several ways: one, that of making synoptic maps of auroral forms, is useful for detailed studies of development and motion. For this purpose, the film is projected on a reader to enable the positions of lower borders to be located with respect



OPTICAL DIAGRAM OF THE ALL-SKY CAMERA

Optical Arrangement of All-Sky Camera

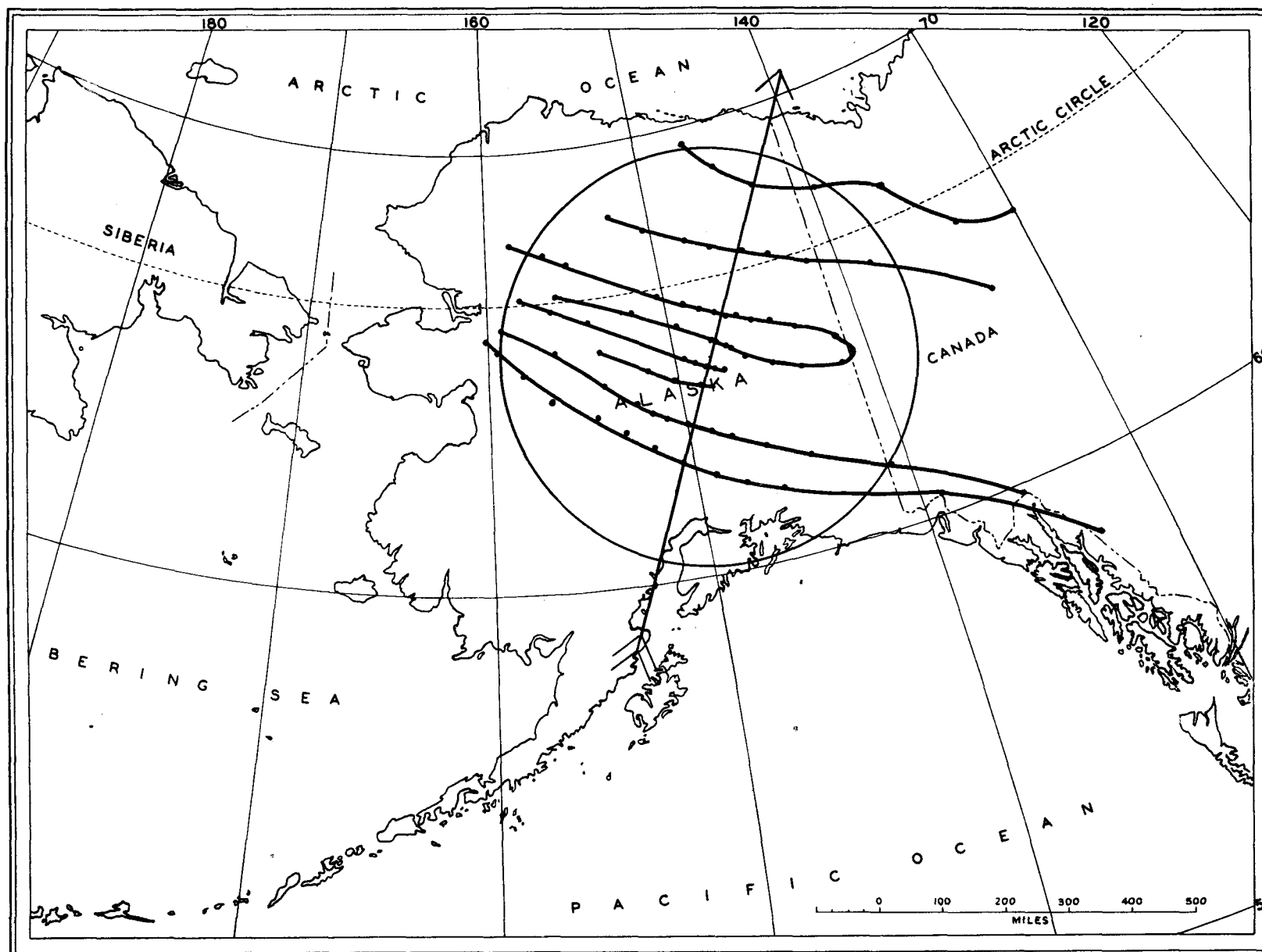
Figure 4



AURORAL ARCS. 2134 A.S.T. SEPT. 30, 1954

Photograph Taken with All-Sky Camera

Figure 5



**DISTRIBUTION OF AURORAS OVER ALASKA  
AT 21:34 A.S.T. SEPT. 30, 1954**

Distribution of Auroras Over Alaska Obtained by Scaling Figure 5.

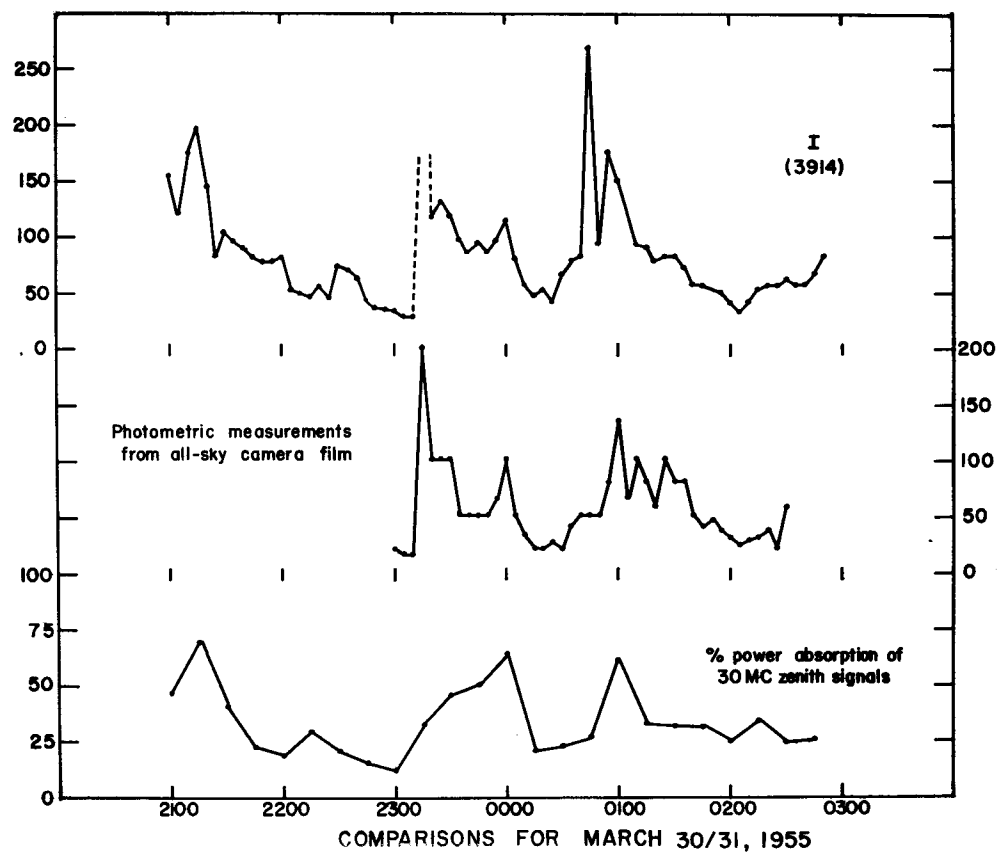
Figure 6

to some coordinate system.

An index of auroral activity may be obtained from densitometric measurements of the photographs of the entire sky or any portion of it. A comparison of the auroral intensity (relative) derived by this method with that measured with a photoelectric photometer integrating the light of 3914A over the entire sky is shown in Figure 7. Also shown in Figure 7 are measurements of the zenith absorption by the ionosphere of galactic radio noise, showing a strong correlation between absorption and auroral intensity. This photographic index of auroral activity has merit as has been shown by several investigators, and it is urged that all films made with the all-sky camera during the International Geophysical Year be calibrated with a sensitometer.

For statistical purposes a method is being tested whereby the information given by the film is punched into IBM cards. For this purpose that portion of the sky along the geomagnetic meridian is divided into sections representing one degree of latitude each for individual description. Each sector is allotted certain columns on the card where the aurora is described. A classification of four forms has been used as follows: arcs, being well defined forms paralleling geomagnetic latitude; broken forms, those well defined forms without particular shape; small areas of aurora lacking definition, being termed as diffuse surfaces; and veils, large areas lacking definition. Because of the long exposures, rayed forms are not well defined on the photographs. Future reduction of exposure times may allow more forms to be defined. In addition to this information, space is allowed for the recording of unusual configurations such as 180 degree turns in bands. A number of columns are reserved for





Comparison of Auroral Intensity with Zenith Absorption

Figure 7

observational information such as camera location, timing, and general sky condition. In the past, the information from each fifteenth frame has been recorded on the cards. The data recorded in this form are convenient for use in statistical studies of various sorts, which may be done entirely by machine methods. Devices are available to enable the sorting and counting of the cards according to any punch or series of punches, or the data may be printed by machine in tabular form. This work is now proceeding, but has not yet been completed.

b. Photometry of the aurora (W. Murcray)

In studying the luminous aurora and its relation to other phenomena attributed to corpuscular radiation from the sun, it is desirable to have some numerical index to express the relative "amount" of auroral activity at a particular time or during a specified period. Many important parameters are involved in any given display, for example, the auroral forms present, their positions in the sky, their colors and motions. Various other aspects are important to an understanding of the events that constitute the corpuscular storm. An index that took all these aspects into account would be difficult to establish because of the need to weight all the various factors. Furthermore, the application of such an index would limit the data to the times when visual records are obtainable. With weather conditions such as those at College, complete dependence upon visual records would be a severe handicap.

The measurements here reported, therefore, do not attempt to take into account all of these complex factors. They are related, nevertheless, to the total energy of the display in the portion of the sky visible from College. Consequently they express, in a rough way at least, the relative

magnitude of one of the most important parameters of an auroral display. In fact, these measurements may be considered to give the relative "amount" of luminous aurora in the sky at College.

As a result of a suggestion by Dr. Elvey, the technique used consists of the continuous measurement and recording of the brightness of a horizontal matte surface exposed to radiation from the entire sky. Measurements, of course, are possible only during the hours of darkness.

The matte surface used is an unglazed white porcelain plate situated on top of the astrodome at the Geophysical Institute. This location is sufficiently elevated so that the plate is exposed to radiation from almost the entire sky. In actual practice, the matte surface consisted of snow during the major portion of the observing period. During very cold weather such as is experienced at College, snow was found to make a satisfactory diffusing surface, whose properties are not greatly different from those of the porcelain. Observations with the moon as a source showed that a snow surface gave a brightness very nearly proportional to the cosine of the moon's zenith angle. (The cosine relation is the theoretical one for a perfectly diffusing surface.) Snow surfaces fulfilled this condition only when the weather stayed cold, however. When it became even as warm as 20°F., the snow surface was no longer suitable.

The photometer itself consisted of a telescope with an objective lens about 6 cm in diameter and a focal length of about 25 cm. The lens put an out-of-focus image on the sensitive surface of a 1P 21 photomultiplier tube. The unit was mounted about a meter above the matte surface so that the surface filled the field of view of the telescope. The telescope tube projected about 1 inch past the lens and filters, and a blackened funnel

about 3 inches long was used to prevent illumination of these elements by radiation from sources other than the plate. To provide a zero reading, a camera shutter mounted in the telescope tube could be closed by means of a solenoid. The 1P 21 was run at 1,000 volts. Its output went to a d-c amplifier and thence to an Esterline-Angus recorder. Power supplies were regulated, and the input voltage was stabilized by means of a Sorenson regulator.

Amplifiers, power supply, and photometers were part of a unit originally designed <sup>(10)</sup> for measurement of the night sky emission and consequently had much more sensitivity than was necessary for the relatively bright aurora. Sensitivity was controlled at the amplifier input by variation of the resistance across which the signal was taken. Adjustment was by steps, each step increasing the sensitivity by a factor of two. There were ten steps, and so the sensitivity could be varied by a factor of  $2^{10}$ , or about 1,000. When the unit was operating under supervision, the sensitivity was usually set so as to give a sizeable deflection under existing conditions, and the sensitivity reduced as activity increased. When the unit was operating unattended, the sensitivity was set at a low level to avoid loss of data if the recorder were to be driven off scale. However, the range of luminosities encountered was so great that it was not possible to avoid all such losses if the moderate activities were to be recorded at all. As a consequence of this procedure, the "zero" readings recorded do not all have the same meaning in terms of the luminosity which might have been present without detection. In all cases, however, a zero reading means that the auroral luminosity was at a very low level, though it does not always eliminate the possibility that there might have

<sup>(10)</sup> P. St. Amand, Ph.D. Thesis, California Institute of Technology, 1953.

been faint aurora visible low in the north. The presence of weak northern aurora is often the case at College, even on "quiet" nights, so that failure to detect it is not significant.

Measurement of the total luminosity was not attempted because there is a large amount of artificial light in the immediate vicinity of the Geophysical Institute, and it was felt that measurements through filters passing some of the characteristic auroral emission lines would be more significant. Two photometers were originally used, one equipped with a filter passing the green auroral line at  $5577 \text{ \AA}$ , the other passing the  $3914 \text{ \AA}$  radiation of  $\text{N}_2^+$ .

It soon became evident that the  $3914 \text{ \AA}$  measurements were less susceptible to disturbances from most manmade sources and from moonlight. This fact is to be expected since  $3914 \text{ \AA}$  is quite far out in the violet, and consequently most light sources contain little radiation in this region. Unfortunately, this is not so of mercury vapor lamps. The filters used were Baird interference filters with the appropriate Corning glass filters to eliminate the unwanted transmission peaks. Half intensity widths of the combinations were about  $150 \text{ \AA}$  with transmission coefficients of around 30 per cent.

The measurements reported are those made with the  $3914 \text{ \AA}$  filter. Because it was felt that these measurements were better suited for index purposes, effort was concentrated upon this photometer and, consequently, the records in this wave length are more complete.

Measurements made in this way obviously discriminate against aurora low in the sky. This is not necessarily a disadvantage, because the zenith auroras are closest to the observing station, and are therefore of greatest

importance for that station. Such effects as these, however, make it quite evident that the readings are not accurately proportional to the total energy emitted. Moreover, inspection of the records taken with different filters shows that the energy emitted in  $3914 \text{ \AA}$  is not a fixed percentage of the total energy. The  $5577 \text{ \AA}$  radiation, for instance, increases and decreases very nearly in phase with the  $3914 \text{ \AA}$  emission, but the changes are not of the same magnitude. Harang<sup>(11)</sup> gives values for the intensity ratio  $I_{3914}:I_{5577}$  which vary from 1 to 4 for different auroral forms. Because the relative amount of the various forms in the sky is constantly changing, the intensity ratios also change. In these measurements, the ratio  $I_{3914}:I_{5577}$  varies considerably, although it remains within the limits 1 to 3.

The major sources of difficulty were the moon and cloud cover; equipment and operator failure were also responsible for some lost records. Artificial lights interfered to some extent, but in general it was possible to correct for their effect, which was easily recognizable. The only time that artificial light became a serious problem was during snowstorms when light reflected from the falling snow caused large and variable disturbances for which allowance could not be made. Correction for moonlight was necessary since the moon had a significant effect on the readings in a sizable fraction of the nights during the winter of 1955-1956. The correction was made by assuming the luminosity due to the moon to follow a curve of the form  $L = A \cos Z$ , where  $Z$  is the zenith angle of the moon, and  $A$  is a constant determined for the particular night by fitting the curve during the minima of auroral activity. This correction can be made (11) L. Harang, The Aurorae. New York Wiley, 1951.

with considerable confidence since the data for nights of little or no aurora show the moon's luminosity curve to fit the cosine curve quite well. Correction could even be applied when the moon was masked by cloud cover, provided that the cover remained constant throughout the night. The combination of moonlight and variable cloud cover, however, resulted in some lost records.

Aurora was easily detectable through cloud cover. Since the auroral light is scattered, rather than absorbed by the clouds, most of it eventually reaches the earth's surface. The principal effect of the clouds is to cause the radiation to come in from a broad region of the sky rather than from a discrete source. The upper surface of the cloud layer has a high albedo, and it is evident that a considerable portion of the light must be reflected back to space and lost, so that there should be a decrease in the total light received from the sky because of the overcast. The exact magnitude of this correction is not yet established, and it probably depends somewhat upon the type of cloud cover and the number of distinct layers of clouds present. The correction is thought to be in the vicinity of 20-25 per cent.

It should be pointed out that high precision is not really necessary for index purposes; and that even though the uncertainty in these measurements is considerable, they still indicate the times of significant auroral activity and give an indication as to the relative magnitude of this activity.

The data are finally recorded in the form of a luminosity time curve on an Esterline-Angus strip chart. The record is made at a chart speed of 6 inches/hr. Since the record covers only the hours of darkness, the

whole equipment is turned on and off automatically by an electrical timer. Timing marks are put on once or twice a night by the operator, the chart drive clock being sufficiently accurate to make closer supervision unnecessary. The records are scaled in arbitrary units, actually chart divisions at a particular amplifier gain setting. To give some idea of what these units represent, with the 3914 Å filter, the full moon at about 40° above the horizon (50° zenith angle) would give a reading of about 200 of the units employed. Scaling is done by measuring the average value of the luminosity over five-minute periods; 12 of these are then added to give the hourly scalings. These sums represent the area under the luminosity-time curve for that hour. Three-hour indices are then obtained by addition of the readings for the three hours concerned. The results are averaged and rounded off to the nearest hundred. This rounded figure in hundreds is quoted as the three-hour index for that period. For instance, the period 06:00 - 09:00 Greenwich time for November 24, 1955, had hourly scalings of 233, 383, and 579 to give a sum of 1,095, an average of 365, and an index number of 4.

Averages are used rather than the sums because they yield more manageable figures. The scale is open ended, but values above ten are likely to be very rare. The character figure for the day is based upon the average hourly scalings for that day. The use of the average is necessitated by the variable number of hours of observations possible during different months of the year. This criterion so far is rather tentative and may prove unsatisfactory because of the effect of the quiet early evening period on the average during the months of December and January. However, for the present, the character figure for the day is being assigned



on the basis of the hourly scaling average for the whole period of observation on that day. Hourly averages of less than 200 units are assigned the figure zero; averages of from 200 to 800 units, the figure one; and over 800, the figure two. The propriety of assigning an index for the whole day on the basis of observations covering less, and often considerably less, than 12 hours may be questioned. Although it is not possible to give a definite answer to this objection, it might be pointed out that aurora is not often visible before operation of the photometer is possible. The nights when it is visible at this time are generally the nights when the activity is high, and hence will rate a character figure one or two, even though the activity during the day is not recorded. The mornings, however, are another matter; the aurora frequently carries over past the end of the observing period. Thus, it is possible that an aurora starting late in the morning might reach large magnitude before noon. Such an event would actually change the character figure if it were recorded.

Integrated auroral luminosities have been measured by various means. Harang<sup>(12)</sup>, for instance, describes a method whereby light from selected portions of the sky was allowed to fall upon a moving strip of film. Some work has been done along similar lines at the Geophysical Institute by making use of the films from the all-sky camera used by Elvey<sup>(13)</sup>. If the films were properly selected, the results obtained from these films matched the 3914 Å photometer records quite well. The film record, however, is not usable during cloudy weather and is considerably more subject

to disturbance from artificial light sources, moonlight, etc. Also, cor-

- (12) L. Harang, "The Mean Field of Disturbance of the Polar Earth-Magnetic Storm", GEOFYS. PUBL. 16 N 13 (1946); TERR. MAG. 51 353 (1946)  
 (13) C. T. Elvey, "Auroral Observations with an All-Sky Camera," Geophysical Institute, 1955.

rections are not easy to apply, so less usable data are obtained. The method, however, has possibilities and is a means of obtaining additional information from the all-sky camera films.

In addition to the index measurements, considerable information about the general character of the display can be obtained from the photometer records. A record typical of an active display is shown in Figure 8. It can be seen that the buildup of the display to its climax is extremely rapid, often taking place in less than a minute. The very high levels of luminosity are generally quite short, sometimes of less than a minute's duration, sometimes a little longer. However, when the recorder is not driven off scale by such bursts of luminosity, it does not pause at the peak. It starts back down immediately, and the inference is that the other bursts differ only in magnitude. Specifically, the luminosity does not level off. It increases very rapidly for a short time and then suddenly reverses the trend and decreases, not quite so rapidly and not back to its former level.

The bursts just described are part of a pattern that is observed very frequently. The bursts occur during periods of relatively high luminosity, after the display has broken up into active forms. The rapid rise appears to mark the culmination of the breakup, rather than the beginning. After the first of such bursts, the luminosity remains high for some time, generally of the order of fifteen minutes to half an hour. Occasionally the high level may persist even longer. During this time there are usually more bursts, but this is not invariably the case.

The highest luminosities measured during bright aurora have been of the order of 100 times the lowest measured during quiet periods. At these

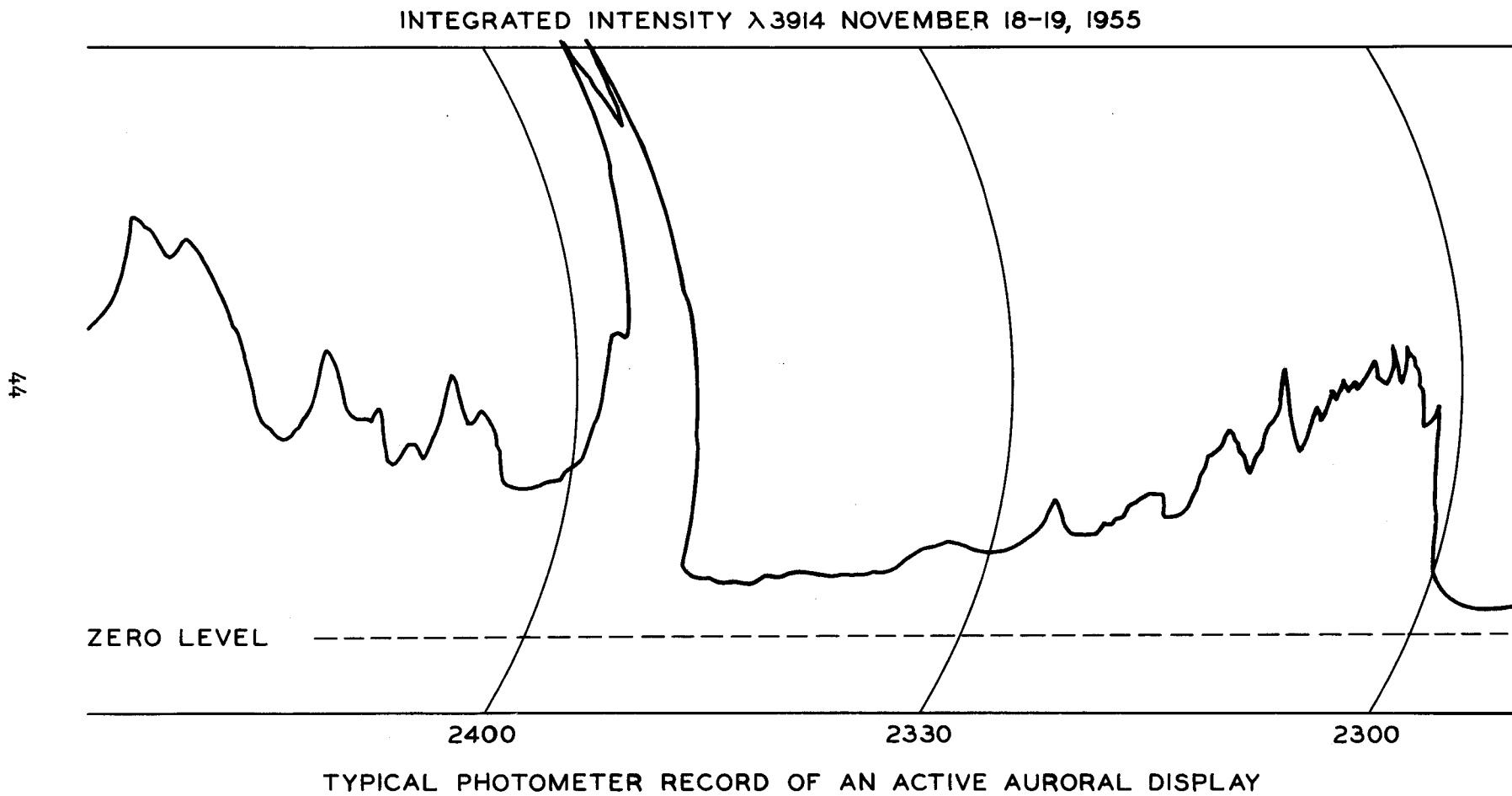


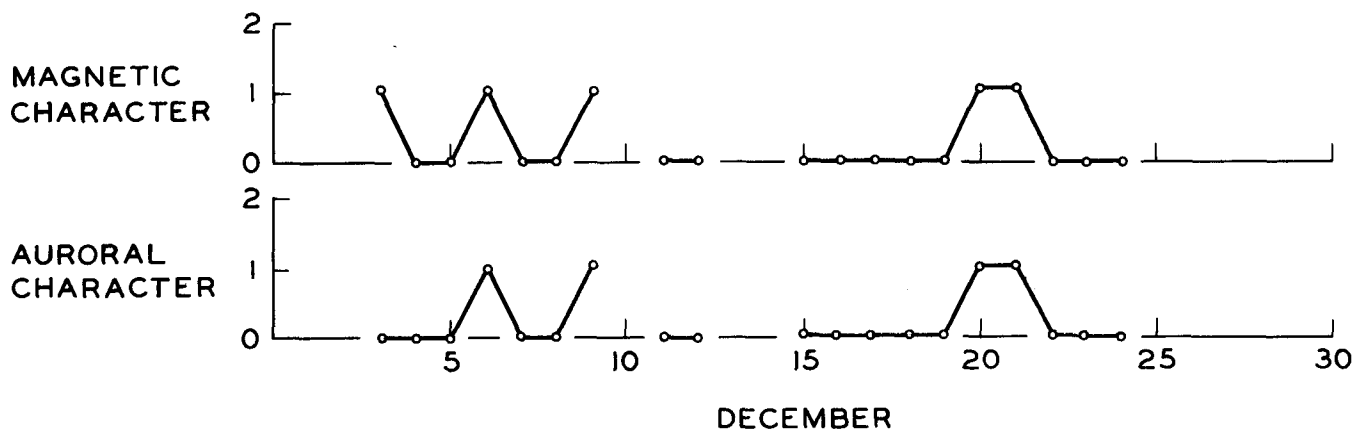
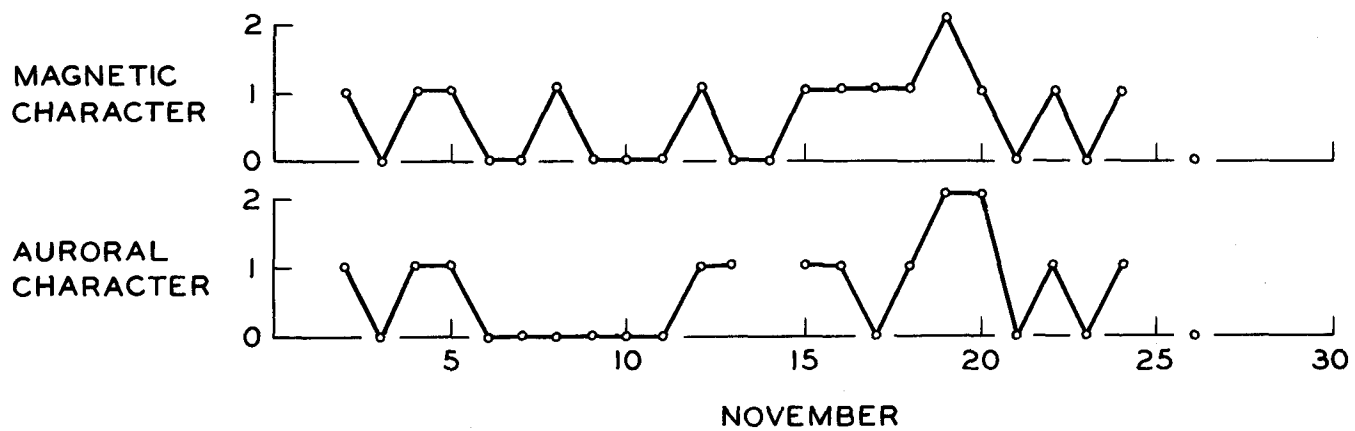
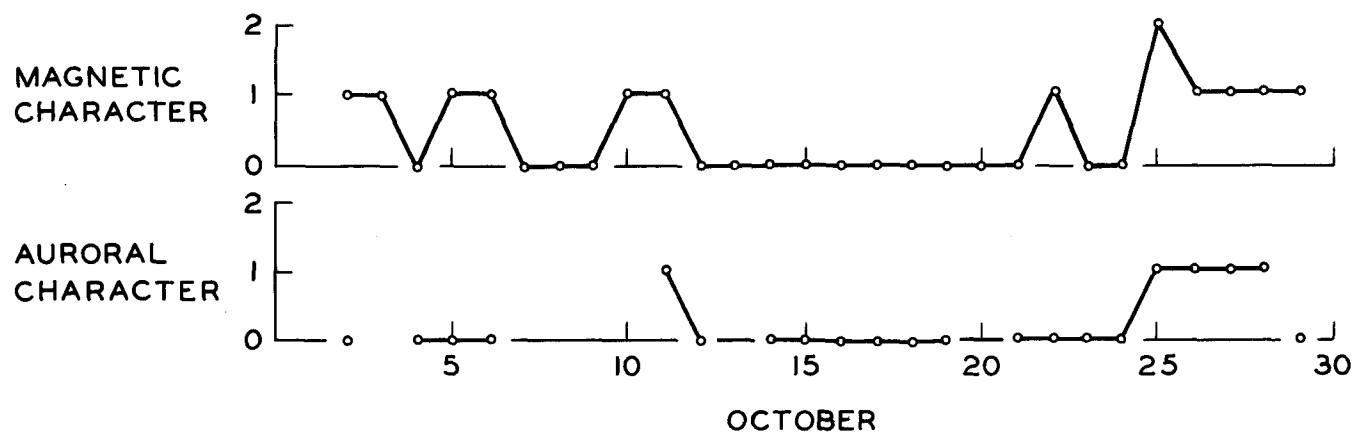
Figure 8

high readings, however, the recorder was off scale, so a lower limit is represented. The low readings are also subject to considerable uncertainty, with the result that the factor may be as much as 500, instead of 100.

Figures 9 and 10 illustrate some obvious applications of these measurements. They are based on data from 63 nights of observations during October, November, and December of 1955. More observations are available, but they have not yet been scaled. Figure 9 shows the relation of the magnetic and auroral whole day characters for the nights when the observations took place. The correlation is very high, though not perfect. Examination shows that both magnetic disturbances with aurora and auroral activity on magnetically quiet days do occur. A comparison of the magnetic K-indices and the three-hour auroral indices does not show such complete agreement as the day characters show, but the correlation is significant. As yet, however, the volume of data is not large enough to draw conclusions.

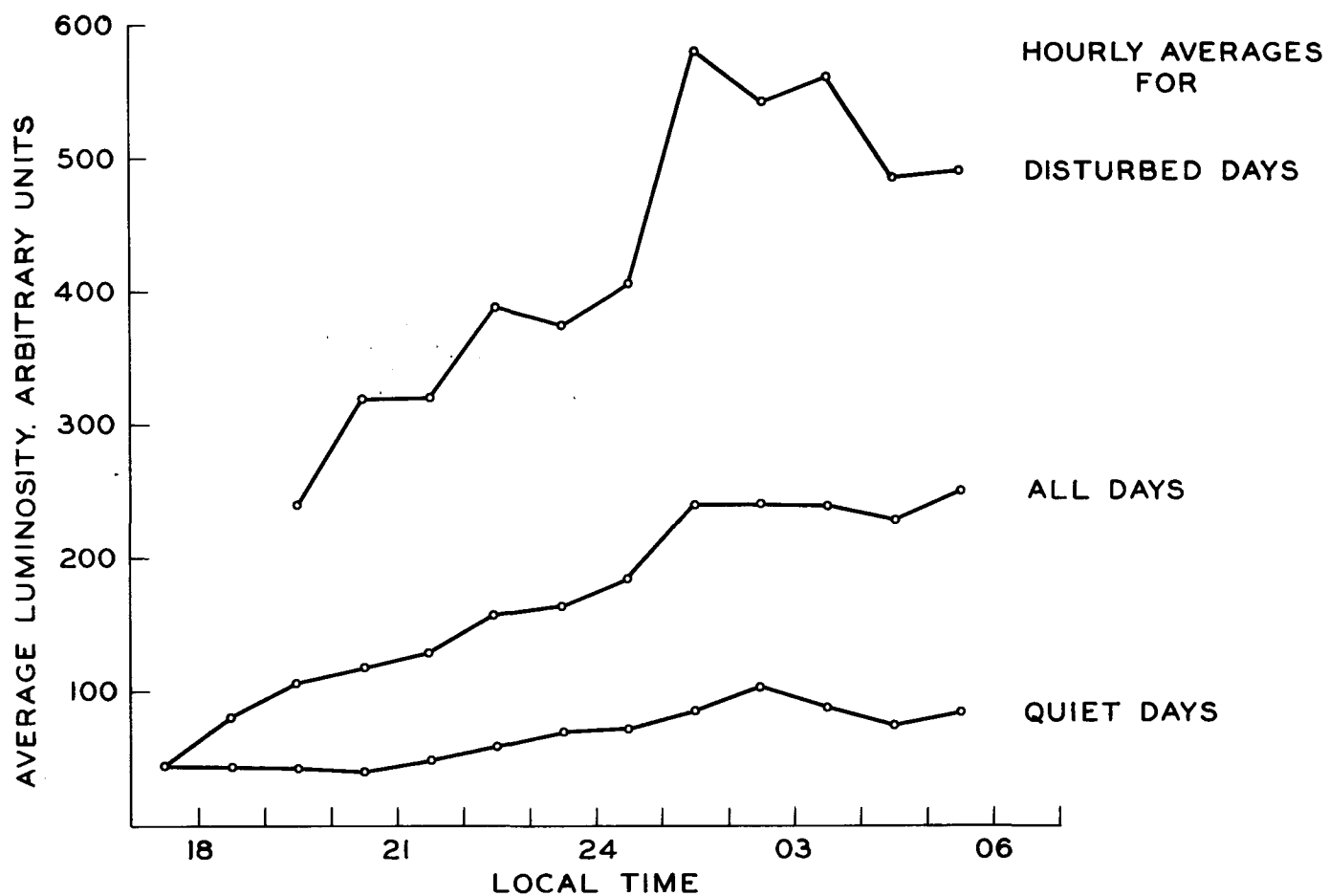
Figure 10 shows the diurnal variation of auroral luminosity as obtained by averaging hourly values. Because of the small number of observations and the short period covered, both of which could introduce seasonal factors, it is not expected that these curves will prove definitive as a study of diurnal variation. Nevertheless some interesting things show up in this figure.

The lowermost of the three plots was obtained by averaging data for quiet nights only. The second lowest used data from all the available observations, and the highest was obtained from the disturbed nights. In spite of the small amount of data, they are all similar in general form, with low values in the early evening, building up to a maximum some time after 01:00 local time and staying close to that level thereafter. The



Relation of Magnetic and Auroral Whole Day Character

Figure 9



DIURNAL VARIATION OF LUMINOSITY. OCTOBER 1 TO DECEMBER 25, 1955

Diurnal Variation of Luminosity Obtained by Averaging Hourly Mean Values

Figure 10

plots for quiet and disturbed nights differ only in magnitude. The plot for all observations agrees quite well with that given for the frequency of zenith aurora by Elvey, Leinbach, Hessler, and Noxon<sup>(14)</sup> for the years 1951-53. It can also be seen that the activity on disturbed nights is relatively high during the whole night, but it shows the same rise as the quiet-night data. The apparent decrease toward morning is probably a consequence of the limited number of observations and may be neglected.

c. Monitoring of solar radio emission (L. Owren)

A promising practical method for prediction of ionospheric storms from solar observations was first reported by Virginia Lincoln of the Central Radio Propagation Laboratory, National Bureau of Standards, at the URSI-IRE Meeting in Washington D.C. in May, 1954. This method was based on the finding that ionospheric disturbances followed with a 70 per cent reliability within 48 hours after the occurrence of solar flares accompanied by radio emission at 200 mc. This finding was based on material contained in a paper by Dodson, Hedeman and Owren<sup>(15)</sup>. Since then, CRPL has adopted as a criterion for selecting potential sources of particle streams capable of producing geomagnetic storms those solar flare regions which are accompanied by transient meter wave radiation, in particular radio emission at or near 200 mc. It is understood that this criterion has been applied with an increasing measure of success.

In the middle of February, 1956, a program for monitoring solar radio emission at 65 mc was started at the Geophysical Institute. The monitoring is done by means of a spaced-antenna interferometer connected to a sensitive

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(14) C. T. Elvey, H. Leinbach, J. Hessler, and J. Noxon, *TRANS. AM. GEOPHYS. UN.* 36, 390-94 (1955).

(15) H. W. Dodson, R. E. Hedeman, and L. Owren, "Solar Flares and Associated 200 Mc/s Radiation," *AP. J.* 118, 169, (1953).

total power receiver. At 65 mc, use of an interferometer system for solar observations is desirable because this method enables one to isolate the quiet sun radiation from the general galactic background. The quiet sun represents a convenient reference level for relative measurement of the enhanced radiation associated with solar activity.

The frequency of 65 mc was selected because of the availability of equipment as well as the desirability of studying solar radio emission at a frequency below 100 mc. While in their main features the characteristics of solar radio emission below 100 mc are similar to those in the range 100 - 300 mc, the former are not well known in detail, and concurrent study of the radiation at 65 and 200 mc could serve to close the gaps in the present prediction methods. There is more hope of attaining this by going to lower than to higher frequencies. Also, Hey<sup>(16,17)</sup> has reported that the solar flares associated with 73 mc emission appear to show an asymmetry in distribution with respect to the eastern and western half of the sun's disk. More flares associated with 73 mc radiation occur in the eastern than in the western half of the disk. Hey ascribes this asymmetry to absorption of the 73 mc flare-associated radiation in particle streams in passage between the sun and the earth. Since no such effect was observed in connection with the 200 mc flare-associated radiation (Dodson, Hedeman and Owren<sup>(15)</sup>), it would be of great value to make an independent observational test at a lower frequency such as 65 mc. If such an absorption effect were indeed found to exist, it would provide a powerful method for estimating the density of the ionized matter in the particle streams.

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(16) J. S. Hey, S. J. Parsons, and J. W. Phillips, "Some Characteristics of Solar Radio Emission". MONTHLY NOTICES 108, 354 (1948).

(17) J. S. Hey and V. A. Hughes, "Solar Radio Asymmetry at 4-Metres Wavelength," NATURE 173, 771 (1954).



d. Earth currents (V. P. Hessler)

1. Introduction

Earth currents have been recorded extensively by geophysical observatories and telephone systems since their discovery on the early telegraph lines. Much of the work, however, has been directed toward determining the diurnal variation of the electric field. During the 1932-33 polar year, earth currents were recorded at College and at Chesterfield, located at about N64° and N74° geomagnetic latitude respectively. However, no rapid run data were obtained, and the Chesterfield equipment was adjusted to a sensitivity that would give good diurnal variations. Since these are the only two high geomagnetic latitude observatories that have obtained extensive earth current records heretofore, very little earth current disturbance data for the polar regions have been available in the literature or in the archives of the geophysical observatories.

During the time of grounded telephone and telegraph line operation a considerable amount of data was obtained, particularly on long lines. As an example, during the great storm of July 16, 1892, the following voltages were recorded:

New York to Providence	200 miles	644 volts
New York to Boston	290 miles	492 volts
New York to Elizabeth	9 volts/km	210 volts
Chicago to Omaha		390 volts

With the advent of carrier communication systems and better protective devices, the problem of earth-current interference was minimized; and thus there was less immediately practical need for continuing earth-current studies. Furthermore, the results of the diurnal variations seemed not

to have contributed materially to a better understanding of solar-terrestrial electrical phenomena. However, the available records of earth currents constitute a major contribution to the natural history stage of investigation of the phenomena. Additional data and analysis will eventually result in an acceptable theory for the means of generation of the earth currents, or as some investigators would prefer to term the phenomena, earth potentials. For the present it must be recognized that an explanation on the basis of electromagnetic induction alone seems quite inadequate. Substantiation for this statement follows later.

## 2. Earth Potential Studies at the Institute.

The Institute started its study of earth potentials during the summer of 1953. A review of the literature was made, and some records were taken during the summer and fall with hastily assembled equipment and driven electrodes. A concerted attempt was made during the fall studies to correlate auroral forms and movements with fluctuations of the earth potentials.

The studies were discontinued late in the fall and resumed again for a 10-week period during the summer of 1954. During this second period the equipment was improved and studies of the directional effect of the disturbance made. In July, 1955, the studies were again taken up and have been carried on continuously to the present. In addition to the studies at College, the Institute has been conducting a similar, but less extensive, program at Barrow since September, 1955.

## 3. Equipment

Electrodes. Driven steel rods were used as electrodes in the early studies. It was recognized that such electrodes would result in small

changes in thermal potential but the major objection consisted of large changes in chemical potential whenever any lateral pressure was applied at the top of the rod. All short-duration field studies are now made with a spiral of lead cable buried to a depth of 30 inches in a one and one-half foot square hole. The permanent electrodes at College consist of about 30 feet of 1/2 inch diameter lead cable buried at a depth of 30 inches in a pair of crossed trenches each 5 feet long. The electrode pair resistances vary from about 125 ohms in the summer to about 400 ohms in winter. Electrode spacings range from 300 to 1,000 feet.

Recorders. All recording has been done with Esterline-Angus and Brown recorders. The Esterline-Angus recorders are equipped with 1 ma 1,500 ohm movements. The Brown Electronic recorders, have a range of 0 to 5 mv and a maximum pen speed of 1"/sec. A chart speed of 6"/hr is used on the Brown instruments and 3"/hr on the Esterline-Angus instruments.

Coupling Network. The Brown recorders are connected to the electrodes through an attenuating and centering network. A disturbance of 2,000 mv/km, which is not uncommon at College, results in a voltage of about 200 mv between electrodes spaced at 300 feet. Thus, a 40 to 1 voltage dividing network is required to record such a disturbance on the 0-5 mv Brown recorder. The attenuating network consists of a fixed 10,000 ohm resistor in series with a plug-in resistor which is varied from 250 to 1,000 ohms depending upon the sensitivity desired. The coupling network also includes a centering circuit for balancing out the chemical and thermal potential of the electrodes. The electrode and centering network potentials are so stable that no adjustment of the centering circuit is required for periods of several weeks.

Transistor Amplifiers. The 1.5 volts signal required for full-scale deflection of the Esterline-Angus recorders is obtained with the aid of transistor amplifiers. The amplifiers consist of two balanced stages, each containing two Raytheon type CK722 transistors. Gain, zero, and balance controls are incorporated in the chassis. Power supply consists of six number 6 ignition batteries which give nine months of service on continuous duty. For field work, where it is desired to minimize the weight to be transported, six type D flashlight cells are used for the power supply.

The balanced design eliminates all difficulty with zero drift, but the amplifier gain varies with temperature. The variation is small in a laboratory installation. For use in the field the Esterline-Angus recorder is equipped with a microswitch that inserts a calibrating voltage in the common lead at timed intervals.

X-Y Plotter. For low-frequency earth potential disturbances, that is, for fluctuations of a few minutes' duration, the hodogram of the electric field disturbance vector can be derived readily from the N-S and E-W records. However, for the higher frequency disturbances with fluctuations of several seconds duration and for continuous determination of the hodogram, an X-Y plotter is indispensable. To meet this need, an X-Y plotter table was constructed and coupled to the two Brown recorders. The recorders were mounted on a table with their pen drives oriented at right angles to each other, and the X-Y plotter table was placed in the angle between them. One recorder pen drive was coupled to a paper holder consisting of a plastic sheet free to move in guides attached to the plotter table. The other pen drive was coupled to an arm that carried the recording pen and was constrained to move in a direction perpendicular to the

motion of the paper. Thus the variations in the east-west and north-south components of the electric field are recorded as a hodogram of the electric field disturbance. The Brown recorders have powerful servomotors and are not retarded measurably by the additional load. The recording pen is a Scripto liquid lead pencil which is completely reliable, makes a dense black line, and lasts for months of continuous operation. A distinct advantage of this construction is that it provides simultaneous x-t, y-t, and x-y plots for an investment of not more than an x-y plotter alone.

Auroral Warning System. A microswitch is attached to the x-y plotter table adjacent to the pen arm. Raised sections attached to the pen arm close the microswitch when the earth-potential fluctuation exceeds a predetermined value of mv/km. Closing of the microswitch actuates signals at the residences of Institute staff members who wish to be informed of disturbed conditions. Experience has shown that the signal is an excellent indicator of active visual aurora.

#### 4. Long Line Equipment.

Early in 1956, lines from Tok Junction, Big Delta, and Healy to Fairbanks were made available to the Institute for recording earth potentials. Use was made of the physical circuit for the earth potential recording with no interference to the many carrier channels being operated on the same lines by the Alaska Communications System. The recording equipment consisted simply of an Esterline-Angus 1 ma recorder with sufficient series resistance to give full-scale deflection for a nominal disturbance. Unfortunately from the standpoint of the earth potential records, the Tok Junction and Big Delta lines are equipped with shunting varistors at several points for the protection of the communications equipment. These

nonlinear resistances make it quite difficult to determine an accurate value of mv/km over the long lines.

5. Earth Potential Records in College Archives.

a. Records for College are available for the period July 24, 1953, through August 12, 1953, but are useful for form of the disturbance only. Magnitude and time are not known precisely, and polarity is not known positively.

b. Records for College are available for the period July 15, 1954, through August 2, 1954. Quality corresponds with the 1953 records.

c. Records for College are available for the period July 22, 1955 to the present with the exception of a few days, during which the equipment was out of order or lines were broken. From October 26, 1955, to the present time continuous dependable records are available for a given site at College. From this time on, the most southerly and most westerly electrodes are connected to the positive terminal of the recorder. Thus an upscale deflection signifies a change in the electric field from south to north or west to east.

d. Almost continuous records for Barrow are available for the period February 1, 1956, to the present time. Some of these records were taken with electrodes in the tundra, some with electrodes in a salt lagoon. The great conductivity anomaly involved must be considered when comparing these records with each other and with College records. Support for the studies at Barrow was obtained under another contract.

6. Analysis.

Electric Activity. The earth potential records have been scaled for electric activity continuously from September 1, 1955, to the present

time by a procedure similar to that with which the magnetic K-index is determined. The records are scaled for maximum range in the north-south electric field vector for the same 3-hour periods used in determining the K-indices. However, the activity is recorded in mv/km instead of in terms of a K-type index because the mv/km method gives more precise information concerning the magnitude of the disturbances. The electric activity for the month of January, 1956, is presented in Table 3 as an example of a fairly disturbed month.

The electric activity for September-December, 1955, is presented in the 27-day recurrence chart of Figure 11. In this chart each day starts at 0800 of 150th meridian time. The tendency for disturbances to occur at about local midnight is quite evident, but the 27-day recurrence phenomenon is not nearly so pronounced.

Diurnal variation. No attempt has been made or is contemplated to scale the records for hourly mean values. The sensitivity has always been adjusted with the hope that most of a major disturbance will be recorded. Since a major disturbance at College is of the order of 2,000 mv/km, whereas the diurnal variation as determined during the 1932-33 polar year is of the order of 20 mv/km, it is evident that a choice of study must be made unless a duplicate set of instruments is available. The need for disturbance data in the polar regions seems more essential than additional data on diurnal variations.

Hodogram of Disturbance Electric-Field Vector. Hodograms of the disturbance electric-field vector have been obtained with the aid of the x-y plotter and with north-south and east-west earth potential records for six different locations. The x-y plotter was set up and operated for

**TABLE 3**  
**ELECTRIC ACTIVITY**

Observatory: Geophysical Institute  
College, Alaska

Month: January, 1956.

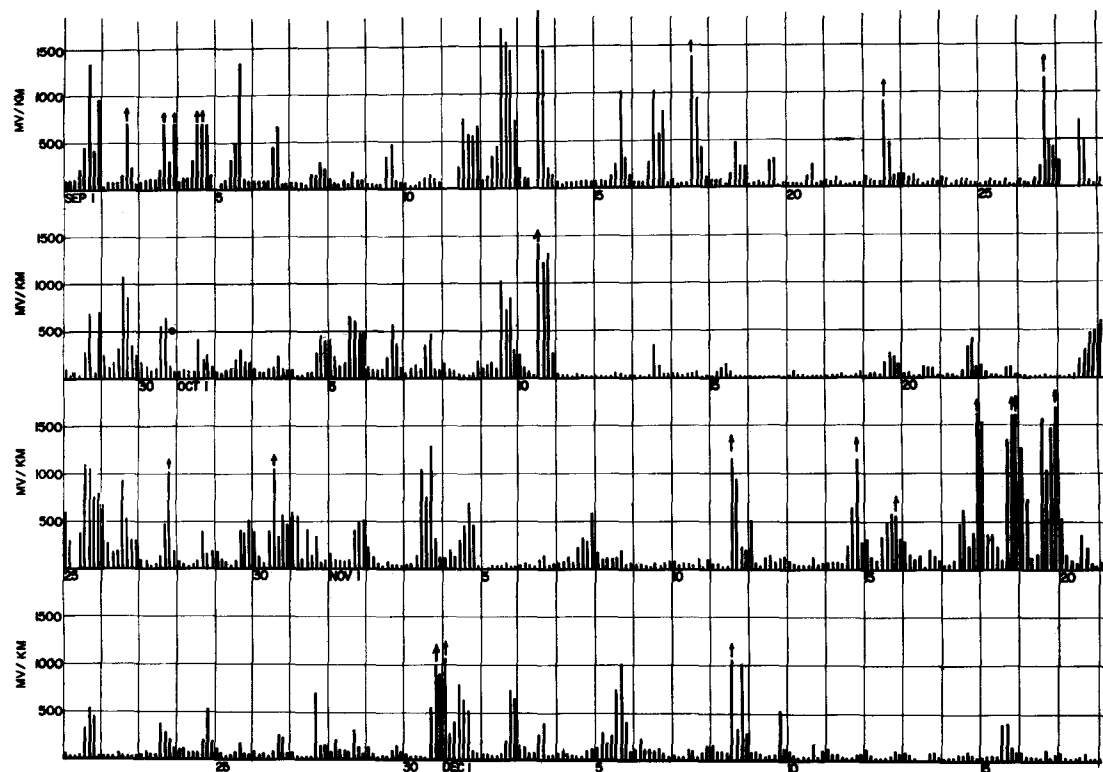
Range of North-South Electric Field Vector - Mv/Km

Electrode Spacing - 300 Ft.

Hour (Universal Time)

Date	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24
1	105	70	35	584	467	770	385	514
2	304	105	47	70	187	514	514	234
3	175	128	210	549	152	338	163	163
4	140	82	292	338	175	187	735	304
5	304	117	105	362	70	152	326	105
6	162	94	38	69	>600	>623	222	140
7	82	93	35	326	292	595	210	152
8	93	35	58	303	70	47	93	58
9	58	105	256	478	455	256	140	82
10	35	245	863	500	1085	>1168	525	210
11	292	256	525	>1120	816	>1085	863	222
12	163	268	70	>1168	525	525	>1050	280
13	93	82	35	23	70	47	70	47
14	23	292	163	245	152	105	93	35
15	23	23	58	163	233	35	35	35
16	35	35	23	420	23	58	93	58
17	47	58	58	292	292	47	47	93
18	187	326	443	>1168	560	443	478	396
19	210	82	>700	898	>1168	1006	374	257
20	82	35	385	350	82	58	47	35
21	35	23	12	12	117	490	152	187
22	315	560	292	152	163	70	630	117
23	70	198	140	12	47	467	210	385
24	117	280	502	>1168	>1168	>1168	>1168	550
25	409	164	479	550	327	70	281	117
26	35	47	23	70	70	58	23	47
27	47	35	292	550	714	620	936	340
28	199	>1170	808	632	503	386	398	222
29	117	211	281	187	866	703	398	258
30	175	129	58	398	340	538	175	270
31	140	94	164	527	234	234	187	234





Recurrence Chart 27-Day of Electric Activity September - December 1955

Figure 11

a considerable period at four locations in the vicinity of College. At the Ballaines Lake site, the 500-foot spaced electrodes were located in a level area with the nearest stream bed or major ridge of hills located a few miles away. At this site the disturbance vector followed a line about  $22^{\circ}$  west of geographic north. At the Steele Creek site the 300-foot spaced electrodes were located on a south slope with no apparent east-west anomalies. Here the disturbance vector followed a general geographic north-south line, but these x-y plots displayed more activity in a direction perpendicular to the preferred direction than the Ballaines Lake records. Next, a 300-foot spaced set of electrodes were installed across the Alaska Railroad tracks near College. The tracks at the electrode site are oriented about  $82^{\circ}$  west of geographic north. At this location the disturbance vector tended to follow the line of the tracks, but the records were not so consistent as at the other sites.

A major high-frequency disturbance of several hours duration was recorded at the railroad site during the morning of October 25, 1955. The x-y record shows a heavy east-west blur, but with major excursions of the plot extending to all parts of the record. The equipment was moved from the railroad site to the Institute site, where the x-y plotter was operated for a period of several weeks. At the Institute site the disturbance vector follows a line about  $35^{\circ}$  west of geographic north. It is of interest to note that the Institute electrodes are located only about 1,000 feet from the railroad tracks, and thus the effect of the railroad conductivity anomaly is quite localized. Studies made at Point Barrow under another contract show that the locus of the disturbance vector there, as determined in two different locations, tends to be in the north-south

geographic direction.

The generally north-south locus of the disturbance vectors other than at the railroad anomaly suggests that only a part of the directional effect can be attributed to local geology. Considerably more data and analysis will be required to establish the relative importance of local geology and of ionospheric charge motions and configurations in determining the locus of the electric field disturbance vector.

Correlation of Electric and Magnetic Activity. Day-to-day comparison of the electric and magnetic activity suggests a very close correlation between the two phenomena. Table 4 illustrates this close correlation for a 17-day period at College. The magnetic activity presented is based on the College magnetic K-index scale and the Coast and Geodetic scalings of the magnetic records. It is proposed to make a more extensive correlation based upon individual magnetic and electric disturbances of short duration, using the total magnetic disturbance vector instead of the maximum component of the K-index scalings.

Correlation of Electric Activity with Visual Aurora. A close correlation between the electric activity and visual auroral displays was observed during the 1932-33 polar year at College. Størmer utilizes reports of electric activity from the telegraph department as a warning service for auroral observations. The present signal system at College is quite effective except that it tends to lag rather than to anticipate the auroral display. The equipment is normally adjusted to give a warning for disturbances greater than 200 to 300 mv/km, thus avoiding signals from minor disturbances. However, with this setting the auroral display is often well advanced toward break-up before a warning is received.

TABLE 4.

Correlation of Magnetic and Electric Activity,  
January 14-31, 1956.

K - Index	No. of Occurrences	Magnetic Activity			$\gamma$ Ratio	Electric Activity			Mv/km Ratio
		Min	Max	Avg		Min	Max	Avg	
0	20	0	25	12.5		12	58	33.2	
1	22	25	50	37.5	3.00	23	93	54.6	1.64
2	20	50	100	75	2.00	58	270	145	2.66
3	21	100	200	150	2.00	70	550	251	1.73
4	24	200	350	275	1.83	187	808	365	1.45
5	15	350	600	475	1.73	292	>1170	690	>1.89
6	10	600	1000	800	1.68	443	>1168	787	>1.14
7	1	1000	1650	1325	1.66		>1168		
8	1	1650	2500	2075	1.56		>1168		
9	0	2500							

Simultaneous observation of the earth potential recorders and of the aurora shows a one-to-one correspondence between rapidly moving bright auroral forms and major electric field fluctuations. However, the electric field disturbance often continues in a very active form long after the auroral display has subsided. Attempts to find a correlation between the direction of motion of the auroral form and polarity of the earth potential fluctuation have not been fruitful as yet. Further studies of this type should be made with the aid of the x-y plotter.

Casual observance of the incidence of high frequency (cycles per minute) earth potential disturbances and similar pulsations in the 3914 all-sky photometer records indicates a close correspondence. Such records are available for a full auroral season at College, and a more careful analysis will be made.

Electric Activity on Long Lines. One significant result has been obtained from a casual study of the long-lines records. On a number of occasions the forms of the Tok-Fairbanks, Big Delta-Fairbanks, and the Institute earth potential disturbance records are practically identical. The electrode separations for these electrode pairs are 200 miles, 100 miles, and 300 feet respectively. These results suggest that the current system or charge configuration that is generating the electric field disturbance must be large in comparison with the Tok-Fairbanks electrode separation. The records of a number of disturbances should be compared carefully for both similarities and differences in the form. The Barrow records should also be included in this study. Large disturbances seem to appear simultaneously at College and Barrow, but the form of the disturbance is usually quite different.

Theory of Generation of Earth Potentials. It seems to be generally assumed that earth potentials are generated by the electromagnetic induction of changing ionospheric currents. However, there is also the possibility of electrostatic induction from ionospheric charge configurations, and at present the relative importance of electromagnetic versus electrostatic induction must be considered an open question. The forces that charges experience by virtue of their relative motion at ordinary velocities are exceedingly small in comparison with the forces experienced by virtue of their relative position. This suggests that any major separation of positive and negative charges in the ionosphere would be a prime factor in the generation of earth potentials.

If the earth potentials are the result of electromagnetic induction, the form of the earth potential variation should correspond with the derivative of a component of the magnetic variation. The form of both disturbances is generally so complex that it is difficult to make this comparison, but the earth potential disturbance frequently seems quite similar to either the D or H component of the magnetic disturbance.

If the earth potential is primarily the result of electromagnetic induction, it seems that there should be some correlation between the measured potential and the voltage induced in a corresponding loop. On October 10, 1955, a square-wave earth potential disturbance of magnitude 700 mv/km and of 15 minutes' duration was recorded at College with electrodes spaced at 500 feet. Let us assume that the voltage was induced in a 500-foot square loop and calculate the required change in magnetic field intensity.

$$\dagger \text{ maxwell} = e \text{ abvolt}^t \text{ sec.}$$

The measured voltage corresponding to 700 mv/km and 500-foot spacing of the electrodes is

$$e_{\text{volt}} = 700 \times 10^{-3} \times 500/3280 = 0.1067.$$

The change in flux necessary to generate a potential difference of 0.1067 volts in the assumed loop continuously for a period of 15 minutes

is  $\Delta \phi_{\text{maxwell}} = 0.1067 \times 10^8 \times 15 \times 60 = 9.61 \times 10^9.$

The corresponding change in flux density is

$$\Delta B_{\text{gauss}} = \Delta \phi_{\text{maxwell}} / A_{\text{sq cm}}$$

$$\Delta B_{\text{gauss}} = 9.61 \times 10^9 / (500 \times 30.48)^2 = 41.4 ,$$

from which the change in magnetic field intensity in gammas is

$$\Delta H_{\text{gamma}} = 41.4 \times 10^5 = 4,140,000 .$$

Thus on the basis of the above assumption electromagnetic induction fails by a few orders of magnitude to account for the observed voltages.\* The above cannot be regarded as proof, but it does suggest the need for devising more critical experiments and more careful analysis before concluding that earth potentials are primarily the result of electromagnetic induction.

e. Rapid-response, rapid-run magnetometer. (W. M. Rayton, V. P. Hessler)

Progress has been made on the development of a rapid-run, rapid-response magnetometer based on the National Union Magnetic pick-up tube type 6462. (This tube utilizes a split-anode technique to observe the deflection of an electron beam by the changing magnetic field.) A major difficulty was encountered in developing power supply and amplifier circuits of sufficient stability to maintain the trace on scale for more than a few hours. The output signal of the pick-up tube is particularly sensi-

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\* Disturbances greater than 2,500 gammas are assigned a K-index of 9 at College. This has occurred only once during the past several years.

tive to changes in its deflecting plate voltage and to a lesser extent upon the various grid and accelerating voltages. At one stage in the development a change of less than 1 percent in input voltage resulted in full scale deflection of the recording instrument. This difficulty has been overcome with the aid of regulated voltage to the amplifier power supply and battery operation of the pick-up tube. With this arrangement the quiet period trace shows no appreciable drift for a week or more with the sensitivity of the equipment adjusted to a full scale range of the order of 500 gammas. Early records have suggested that this unit will be of considerable value in presenting the magnetic data in a form suitable for comparison with geophysical data obtained by other techniques (e.g. earth potentials, ionospheric absorption, all-sky photometry studies).

f. A consideration of the behavior of a solar corpuscular stream in the vicinity of the earth (M. Sugiura)

1. A model problem.

A preliminary study is made on the form of the front surface of a neutral corpuscular stream advancing into a magnetic field which has formal resemblance to the earth's magnetic field.

With reference to a cylindrical polar coordinate system  $(\tilde{\omega}, \phi, z)$  in which the origin coincides with the earth's center and the  $z$ -axis with the geomagnetic axis (the positive  $z$ -axis being directed to the north), the vector potential of the earth's centered dipole may be chosen as  $\vec{A} = (0, A_\phi, 0)$ , where  $A_\phi = -M \tilde{\omega} / (z^2 + \tilde{\omega}^2)^{3/2}$ . Here,  $M$  is the moment of the dipole, which is given by  $M = H_0 a^3$ , where  $H_0$  is the magnetic field intensity at the equator (0.3 Gauss) and  $a$  is the radius of the earth.



The components of the magnetic field,  $(H_{\tilde{\omega}}, H_{\phi}, H_z)$  are given by

$$\begin{aligned} H_{\tilde{\omega}} &= -3M \tilde{\omega} z / (z^2 + \tilde{\omega}^2)^{5/2}, \\ H_{\phi} &= 0, \\ H_z &= M(\tilde{\omega}^2 - 2z^2) / (z^2 + \tilde{\omega}^2)^{5/2}. \end{aligned}$$

The magnetic field considered in this model problem is such that its components with reference to a system of cartesian axes  $O(x, y, z)$  whose origin and  $z$ -axis coincide with the origin and the  $z$ -axis of the cylindrical coordinate system are  $(H_x, H_y, H_z)$ , where

$$\begin{aligned} H_x &= -3 M x z / (x^2 + z^2)^{5/2}, \\ H_y &= 0, \\ H_z &= M (x^2 - 2z^2) / (x^2 + z^2)^{5/2}. \end{aligned} \tag{1}$$

Lines of magnetic force of this field thus lie in planes parallel to the  $(x - z)$  plane, and are, in any such plane, identical with those of the centered dipole in the meridian plane. Lines of force of the magnetic field given by Equation (1) are shown in Figure 12.

## 2. Existence of the auroral zones.

A neutral completely ionized corpuscular stream is assumed to be projected toward the  $(y-z)$  plane; the individual particles in the stream are supposed to advance parallel to the  $x$ -axis (in the direction of decreasing  $x$ ) with velocity  $v$  at an infinitely remote epoch. Let the mass of the positive ions and that of the electrons in the stream be denoted by  $m_+$  and  $m_-$ , respectively, and their number density per  $\text{cm}^3$  by  $N$  (which is common for the ions and electrons). Momentum carried by the particles in a unit volume at an infinitely remote epoch is then  $N(m_+ + m_-)v$ , which is in the direction of decreasing  $x$ . Since  $m_+ \gg m_-$ , the result is very nearly  $Nm_+v$ .

When the stream advances into the magnetic field, the main body of the stream will be shielded from the magnetic field by the front surface layer in which electric currents are induced. The thickness of the current carrying layer must be very small compared with the dimension of the stream. The surface will be retarded by the magnetic field, and consequently be continually reformed by oncoming particles. As the stream approaches the (y-z) plane, a hollow will be carved in the stream owing to the large retarding effect near the y-axis. The stream surface near the y-axis will eventually be brought to rest, thus forming the boundary surface of a "forbidden" region. As long as the surface layer is supplied with fresh oncoming particles, the main body of the stream will be well shielded from the magnetic field.

Thus most of the particles will carry their initial momentum up to the front surface and will then be turned back into the interior of the stream. If there is no electric field acting upon the particles, their energy will be conserved; their momentum will suffer changes. If the particles maintain the initial motion up to the front and are turned back at the front as if they collided with an elastic wall, the rate of momentum change is clearly  $2Nm_+v$ .

Owing to the electric current induced in the surface layer of the stream, the magnetic field in front of the stream will be greater than it would be in the absence of the stream. Assuming a unidirectional primary field  $H_p$  which varies as  $H_p = H_0 (a/x)^s$ , where  $s \geq 2$ , Ferraro<sup>(18)</sup> shows that the total field at the stream surface,  $H_s$ , is given by

$$H_s = H_p + H_p/(s - 1) = \frac{s}{s - 1} H_p$$

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(18) V. Ferraro J. GEOPHYS. RES. 45, 245-268 (1940).

Thus, for  $s = 3$ ,  $H_s = (3/2) H_p$ .

As was first pointed out by Martyn<sup>(19)</sup>, and as has been restated in more accurate terms by Ferraro<sup>(18)</sup>, the front surface comes to rest at the distance where the rate of momentum change equals the energy density of the magnetic field. In Ferraro's case one half of the momentum change is due to the normal pressure of the tubes of magnetic field, and the other half due to the electrostatic field built up in the front layer by the polarization of positive ions and electrons.

Let us suppose that this momentum balance is such that

$$2 f N m_+ v^2 = (\propto H_z)^2 / 8 \pi. \quad (2)$$

That is, at the boundary of the forbidden region, fraction  $f$  ( $0 \leq f \leq 1$ ) of the momentum is reversed by the normal pressure of the magnetic field, and the rest  $(1 - f)$  by the electric potential barrier due to the polarization. Obviously, the  $z$ -component of the magnetic field plays the most important part in the deflection of the particles. This component is supposed to be intensified by the magnetic field produced by the induced current in the front surface of the stream by a factor  $\propto$ . In Ferraro's case  $f = \frac{1}{2}$  and  $\propto = 3/2$ . Equation (2) can be rewritten as

$$H_z = (4 \pi \beta N m_+ v^2)^{\frac{1}{2}}, \quad (3)$$

where

$$\beta = 4 f / \propto^2. \quad (4)$$

The parameter  $\propto$  is not much greater than 1. If the deflection of the particles is solely magnetic,  $f = 1$ . Even when an electrostatic field is present in the front surface of the stream, as in Ferraro's case, the parameter  $f$  is unlikely to be very much smaller than 1. Hence the factor  $\beta$

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(19) D. F. Martyn, NATURE 167, 92-94 (1951).

always takes a value of the order 1;  $\beta$  will, therefore, be tentatively considered as being constant in the following discussions.

Introducing latitude  $\theta$  and radial distance from the y-axis  $r$  so that  $x = r \cos \theta$ ,  $z = r \sin \theta$ ,  $H_z$  given by (1) can be expressed as

$$\begin{aligned} H_z &= M (1 - 3 \sin^2 \theta) / r^3 \\ &= H_0 (1 - 3 \sin^2 \theta) / R^3 \end{aligned} \quad (5)$$

where  $R = r/a$ ;  $M$  was replaced by  $H_0 (a/r)^3$  with analogy to the actual geomagnetic field.  $H_z$  changes its sign at  $\theta = \theta_0$ , where  $\theta_0$  is determined by

$$1 - 3 \sin^2 \theta_0 = 0 ;$$

the value of  $\theta_0$  is about  $35.3^\circ$ . In the planes  $\theta = \pm \theta_0$ ,  $H_z$  is zero; thus the magnetic force is parallel to the initial direction of motion of the particles. Hence the magnetic deflecting effect in the vicinity must be very small.

Until the front surface of the stream is appreciably distorted by the magnetic field, electric currents in the front layer will be reversed in their direction at  $\pm \theta_0$ . If the field is that of a magnetic dipole, there will be two foci in the induced currents whose distance from the equator is  $\theta_0$  in angle, as was shown by Chapman and Ferraro<sup>(20)</sup>.

From Equations (3) and (5) the equation of the surface on which the condition (3) is satisfied is obtained as

$$R = (C/\beta)^{1/6} F(\theta), \quad (6)$$

where

$$C = \frac{H_0^2 / 8 \pi}{\frac{1}{2} N m_e v^2} \quad (7)$$

(20) S. Chapman and V. Ferraro, *TERR. MAG.* 36, 77-97, 171-186 (1931); bid. 37 147-156, 421-429 (1932); bid. 38 79-96 (1933); bid. 45 245-268 (1940).

and

$$F(\theta) = \left| 1 - 3 \sin^2 \theta \right|^{1/3}. \quad (8)$$

The constant  $C$  is the ratio of the energy density of the magnetic field at the equator (on the surface of the earth) to the kinetic energy density in the stream.

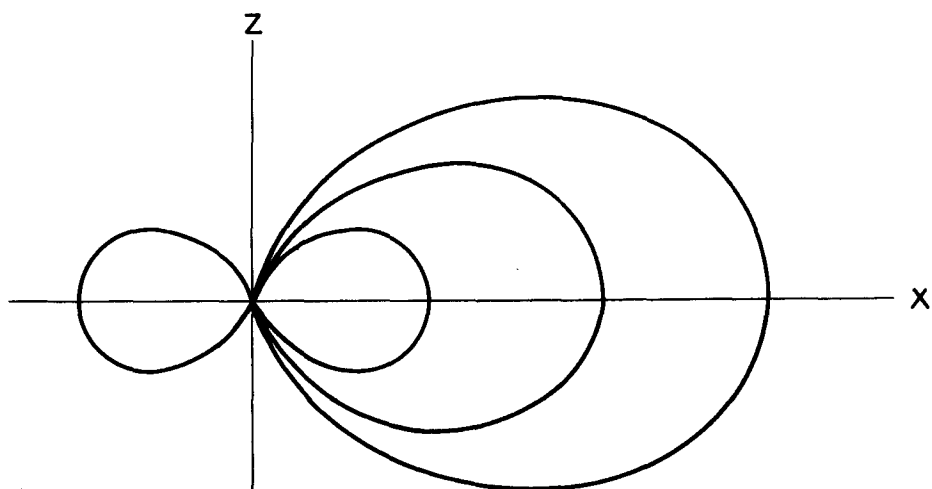
The contour of Equation (6) in the (x-y) plane (and in any plane parallel to it) is shown in Figure 13 as  $\Delta POP'B$ . Discussions will be confined to the region  $z \geq 0$  or  $\theta \geq 0$  because of symmetry with respect to the (x-y) plane.

If  $z/a$  is denoted by  $Z$ ,  $Z = R \sin \theta$  along the contour. Clearly  $R = (C/\beta)^{1/6}$  at  $\theta = 0$ . First,  $Z$  increases and  $R$  decreases as  $\theta$  increases,  $Z$  reaching maximum at the point  $P$  in Figure 13, at which  $\theta = \theta_m$  ( $\theta_m < \theta_o$ ). The angle  $\theta_m$  is determined by  $\partial Z / \partial \theta = 0$ ; this gives  $\sin \theta_m = 1/\sqrt{5}$ , or  $\theta_m = 26.6^\circ$ . Both  $Z$  and  $R$  decrease, as  $\theta$  exceeds  $\theta_m$ , and become zero at  $\theta = \theta_o = 35.3^\circ$ . As  $\theta$  further increases,  $R$  and  $Z$  increase along the curve  $OP'B$  in Figure 13, and are  $2^{1/3} (C/\beta)^{1/6}$  at  $\theta = \pi/2$ .

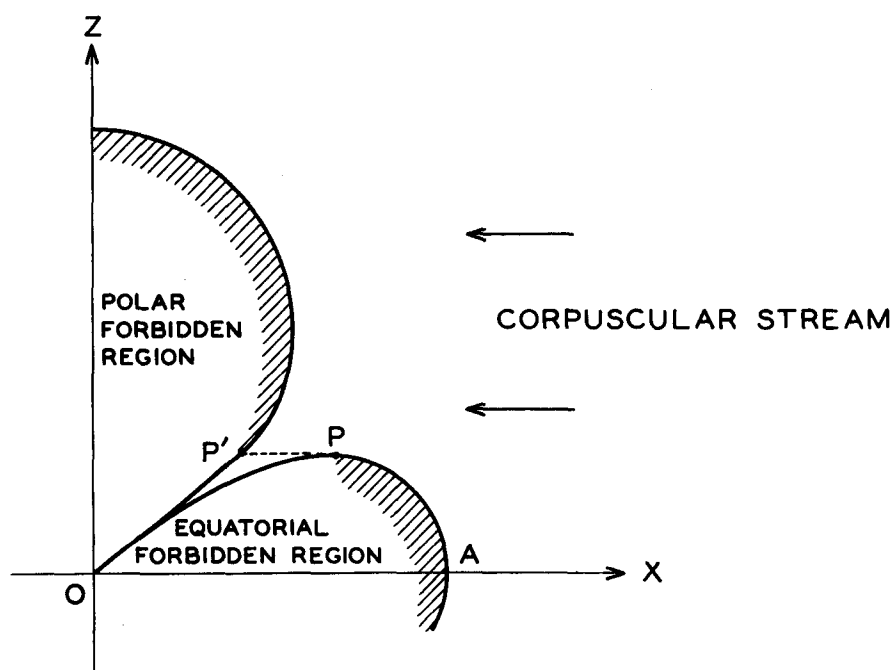
Because the particles move in the direction parallel to the x-axis, there will be a shadow of the equatorial boundary  $AP$ , and the particles will not enter the area  $POP'$ , where  $P'$  is the projection  $P$  upon the curve  $OB$  along the horizontal line parallel to the x-axis. If the latitude of  $P'$  is denoted by  $\theta'_m$ ,  $\theta'_m$  is determined by

$$(1 - 3 \sin^2 \theta_m)^{1/3} \sin \theta_m = (3 \sin^2 \theta'_m - 1)^{1/3} \sin \theta'_m.$$

Putting  $\theta_m = 26.6^\circ$ ,  $\theta'_m$  is found to be  $38.3^\circ$ . This angle is very close to  $\theta_o$  ( $= 35.3^\circ$ ); hence the lines of magnetic force of the primary field near there are only slightly inclined (downward) to the direction of motion of the particles. Angle  $\psi$ , by which the lines of force of the



Lines of Force of the Magnetic Field from Equation (1)  
Figure 12



Contours of the Forbidden Regions  
Figure 13

primary field are inclined to the horizontal (i.e., the direction parallel to the x-axis), is shown in Figure 15 as a function of  $\Theta$  along the boundary.

If  $H_z$  is enhanced by the induced current in the front surface of the stream, the angle  $\Theta_0$  (i.e., the latitude at which the magnetic field is parallel to the x-axis) will be increased. If  $\Theta_0$  is increased to  $\Theta'_m$ , particles which have passed just above the equatorial boundary (AP in Figure 14) will advance in the direction parallel to the lines of force near P'; these particles may be guided by the lines of magnetic force to the earth's atmosphere.

The line of force (of the primary field) passing through P' ( $R'$ ,  $\Theta'_m$ ) meets the surface of a cylinder of radius  $a$ , whose axis coincides with the y-axis, at  $\Theta_i$  determined by

$$\begin{aligned} \cos \Theta_i &= R'^{-1/2} \cos \Theta'_m \\ &= (C/\beta)^{-1/12} (3 \sin \Theta'_m - 1)^{-1/6} \cos \Theta'_m. \end{aligned} \quad (9)$$

It is shown below that the distortion of the lines of force due to the induced current in the front surface of the stream is irrelevant in the determination of  $\Theta_i$ . Putting  $\Theta'_m = 38.3^\circ$ , we have

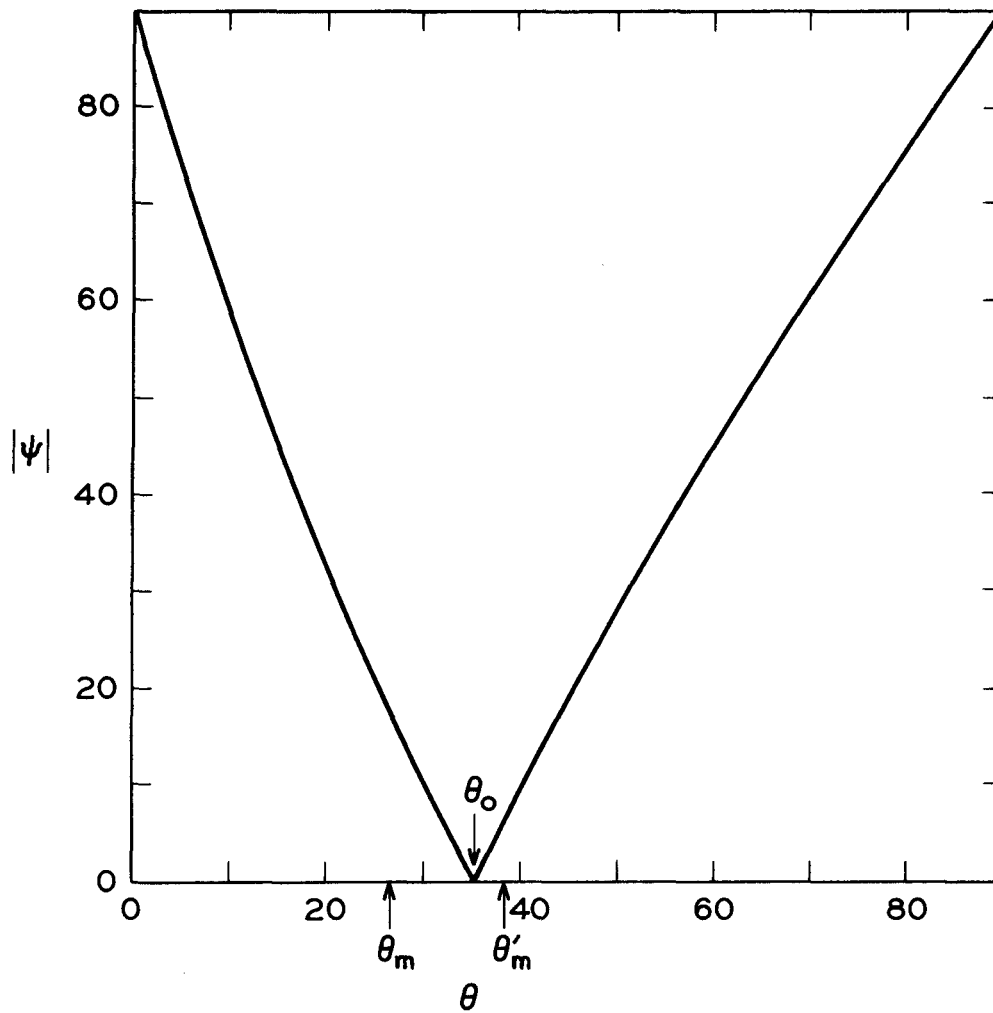
$$\cos \Theta_i = 1.07 (C/\beta)^{-1/12}. \quad (10)$$

Equation (10) shows that  $\cos \Theta_i$  varies as  $\beta^{1/12}$ . Hence the dependence of  $\Theta_i$  on  $\beta$  is very weak.

Equation (10) can be written in logarithms as

$$\log \cos \Theta_i = \log 1.07 + (1/12) \left[ \log \left( \frac{H_0^2}{4\pi} \right) + \log \beta + \log m_+ + 2 \log (\sqrt{N} v) \right]. \quad (11)$$

Hence  $\Theta_i$  is a function of  $N$  and  $v$  with parameter  $\beta$ . Given  $\beta$ , isolines of  $\Theta_i$  can be drawn in a diagram with abscissae  $\log N$  and ordinates  $\log v$ .



Inclination of Lines of Force Along the Boundary of the Forbidden Area  
to the Horizontal Direction

Figure 14



Furthermore, isolines of  $\theta_i$  for different values of  $\beta$  can be represented by the same set of curves with abscissae shifted by changes in  $(1/12) \log \beta$ .

In Figure 15 are shown the isolines of  $\theta_i$  for  $\theta_i = 40^\circ$  to  $80^\circ$  at  $5^\circ$  intervals. The positive ion is assumed to be that of hydrogen. Two scales are given for  $N$  corresponding to  $\beta = 8/9$  (Chapman-Ferraro like: electromagnetic deflection) and  $\beta = 4$  (magnetic deflection). The particle density for the normal auroral zone ( $\theta_i = 67^\circ$ ) is 3 to 0.03 for velocities  $10^8$  to  $10^9$  cm/sec. For a fixed velocity,  $\theta_i$  decreases as the density of the particles increases. The southward movement of the auroral sheets may thus be accounted for by an increase in the particle density.

From Equation (11) we get

$$\frac{\delta(\cos \theta_i)}{\cos \theta_i} = -\tan \theta_i \cdot \delta \theta_i = \frac{1}{12} \frac{\delta(Nv^2)}{Nv^2}.$$

Putting  $\theta_i = 67^\circ$ ,

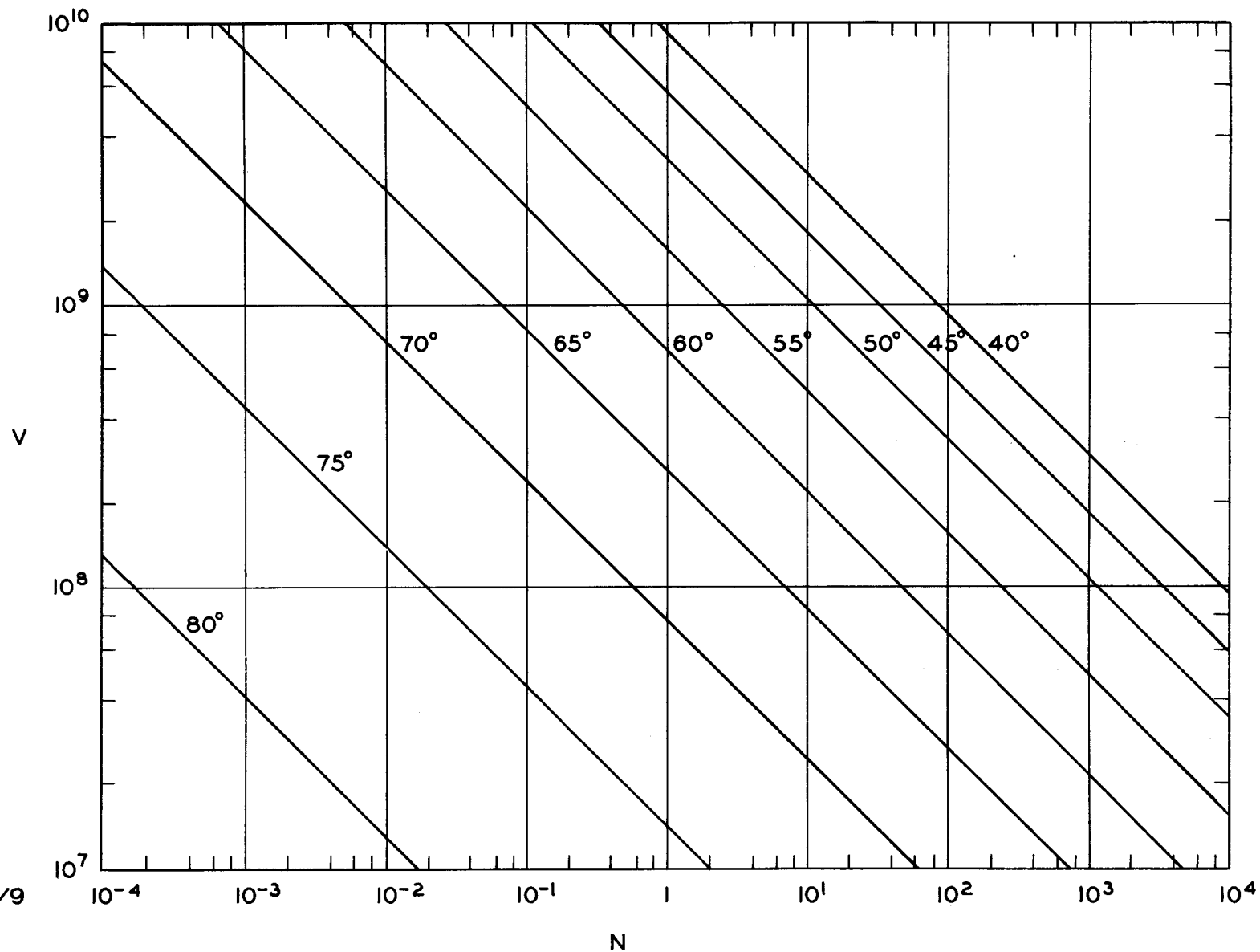
$$-\delta \theta_i = 2 \frac{\delta(Nv^2)}{Nv^2} \quad (\text{degrees}).$$

In terms of distance this is  $225 \frac{\delta(Nv^2)}{Nv^2}$  kilometers; for a change by 1 per cent in  $Nv^2$  the southward shift is about 2 km.

### 3. Conclusion.

The validity of the present theory must be examined by a detailed analysis of the behavior of the particles near the front surface of the stream. However, it is possible that an equatorial forbidden region and north and south polar forbidden regions may exist near the earth, and that a gap may be created between the equatorial and the polar forbidden regions. Particles could thus reach the earth's atmosphere along the lines of magnetic force through this gap.

CM/SEC



$\beta = 8/9$

$N$

$\beta = 4$

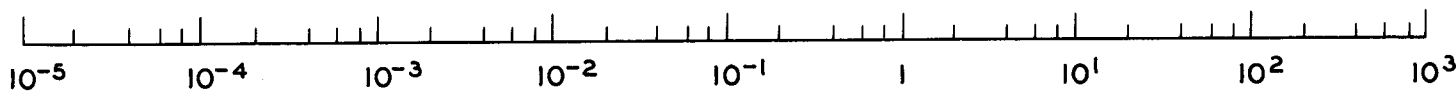


Figure 15 Isolines of  $\theta_i$

Task No. 5 Whistlers (J. H. Pope)

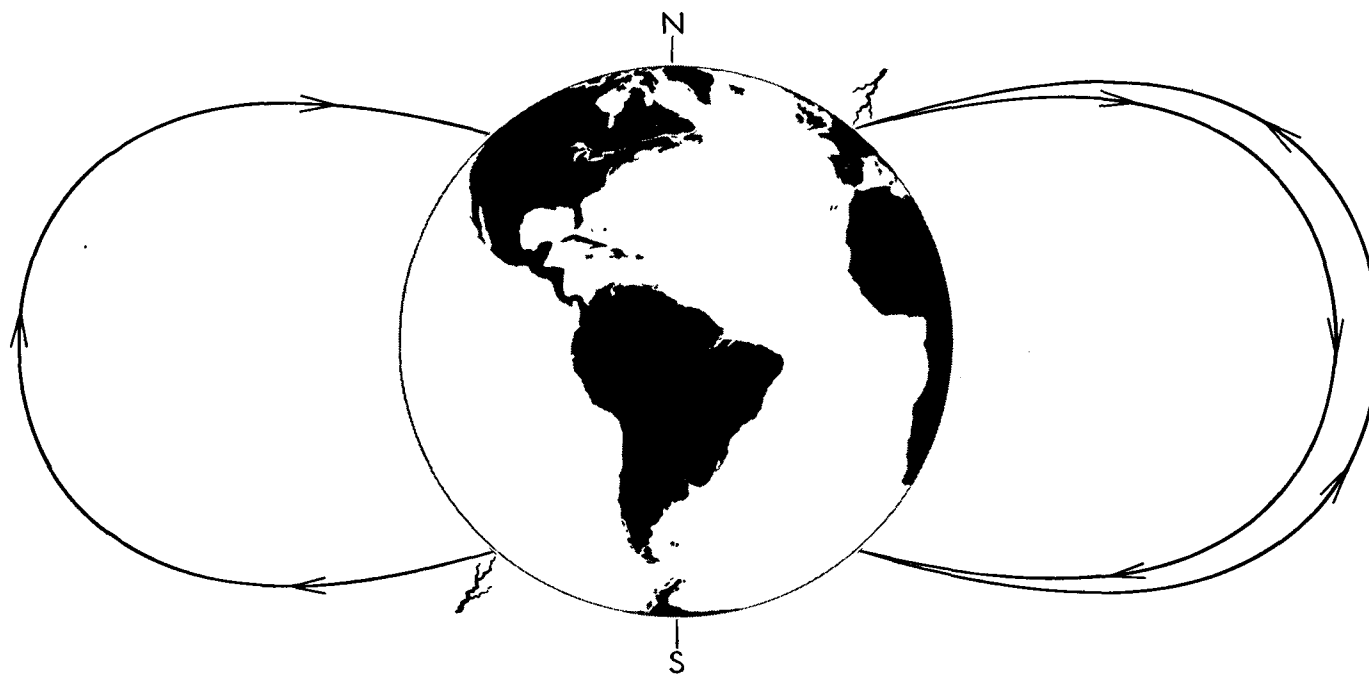
Introduction

The low frequency end of the electromagnetic spectrum contains a number of natural phenomena known as "audio atmospherics," observed by means of a high gain audio amplifier and an antenna. A descending tone starting perhaps above the audio limit and ending at about 1 kc one or two seconds later is an example of one such audio atmospheric. These descending tones, known as "whistlers," have been the subject of much investigation during recent years. Whistlers were first reported by Barkhausen<sup>(21)</sup> in 1919 and a plausible theory of their nature was presented by Storey<sup>(22)</sup> in 1952.

According to Storey's theory, whistlers are originated by lightning discharges. Part of the radiation of the discharge is constrained to follow the geomagnetic lines of force to the magnetic conjugate point of the opposite hemisphere (Figure 16). Some of the energy is reflected to travel back along the same path. Of course, this process may be repeated several times. In order that the pulse be constrained to follow the magnetic force lines, the theory requires that an ion density of several hundred ions per cubic centimeter be present along the path. Thus the pulse originating from the discharge must propagate a long distance through a dispersive medium. It is known that in traveling in a dispersive ionized medium, the velocity of propagation is, in general, greater for the high frequencies than for the low. The result, then, is the descending tone which is observed.

(21) Barkhausen, Heinrich. "Zwei mit Hilfe der neuen Verstärker Entdeckte Erscheinungen," PHYS. ZEIT. 20, 401-403 (1919).

(22) Storey, L. R. O. "An Investigation of Whistling Atmospherics," PHIL. TRANS. ROY. SOC. LONDON A246: 113-141 (1953-1954).



# PROPAGATION PATHS OF WHISTLERS

Figure 16

Since the length of the geomagnetic lines of force is a function of the observer's latitude, it might be supposed the characteristics of whistlers change with latitude. Therefore, it was proposed to attempt to observe whistlers at College, Alaska (latitude 64.5°). If whistlers did not occur at these high latitudes, this determination would in itself be interesting. Contrary to the conjectures it was found, however, that whistlers are observed at College. (23)

The characteristics to be studied are the dispersion, the diurnal and seasonal variations of the rate of occurrence, and the time between two successive whistlers in an "echo train." All of these characteristics might vary with latitude, and their study might lead to a determination of some of the characteristics of the outer ionosphere, such as the functional dependence of the ion density with height as far as 30,000 km.

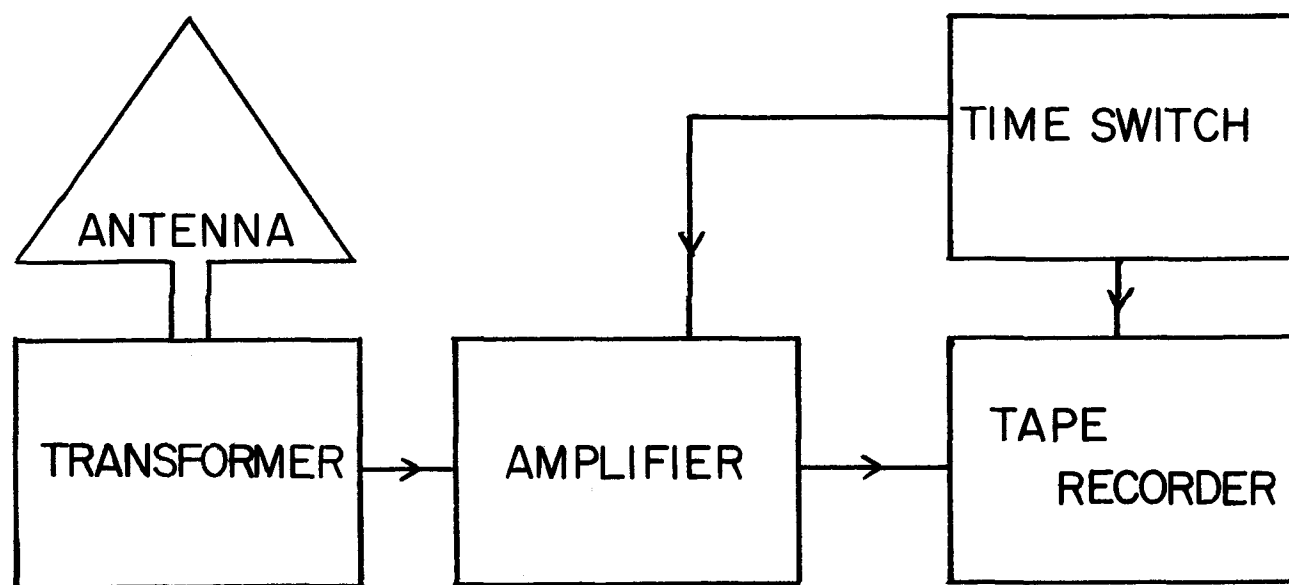
Other atmospherics, such as the "dawn chorus," which are received on the same equipment can also be studied. The dawn chorus is characterized by a multitude of random rising tones. These tones are short in duration (of the order 0.1 seconds) and cover the frequency range from 1 kc to 3 kc. The origin of the dawn chorus has not yet been successfully explained.

#### Instrumentation

The equipment used to receive audio atmospherics is essentially that which was described in a previous report. (23) Figure 17 is a block diagram showing the detector. The signal is received on a loop antenna in the form of a triangle having a height of 30 feet and a base of 60 feet.

Since the loop is of only one turn, it is necessary to use a specially

(23) Geophysical Institute, "Radio Wave Propagation in the Arctic,"  
AF 19(604)-1089 Interim Scientific Report #1 for the period April 15  
to July 15, 1955.



BLOCK SCHEMATIC OF WHISTLER RECORDING EQUIPMENT

Figure 17

built transformer to couple the very low impedance of the loop to the preamplifier. The preamplifier, which has a gain of 120 db, is coupled to a tape recorder. A programming unit is provided to turn the detector on at prearranged intervals. This unit is capable of turning the device on each hour for an integral number of minutes, and has generally been set for one minute to give an hourly sample. This sample permits an estimate of the diurnal variation and makes it possible to undertake correlation studies with other phenomena such as magnetic activity.

#### Observations

Table 5 shows the periods during which the detector was in operation since July 15, 1955. The long intervals between the periods of operation were necessary in order to permit playback of the tapes. The programming unit was placed in operation November 7, 1955. Before that date, operation was done on a one hour per night basis by means of a time switch.

TABLE 5

Periods since July 15, 1955, when the detector was in operation.

<u>Begin</u>	<u>End</u>
Aug. 8	Sept. 4
Nov. 7	Nov. 7
Nov. 25	Dec. 5
Dec. 23	Jan. 21
Feb. 1	Apr. 5

Some examples of whistlers which were recorded on July 10, 1955, were analyzed at Stanford University by means of an instrument known as an "audio spectrograph." These analyses revealed a new and unusual property

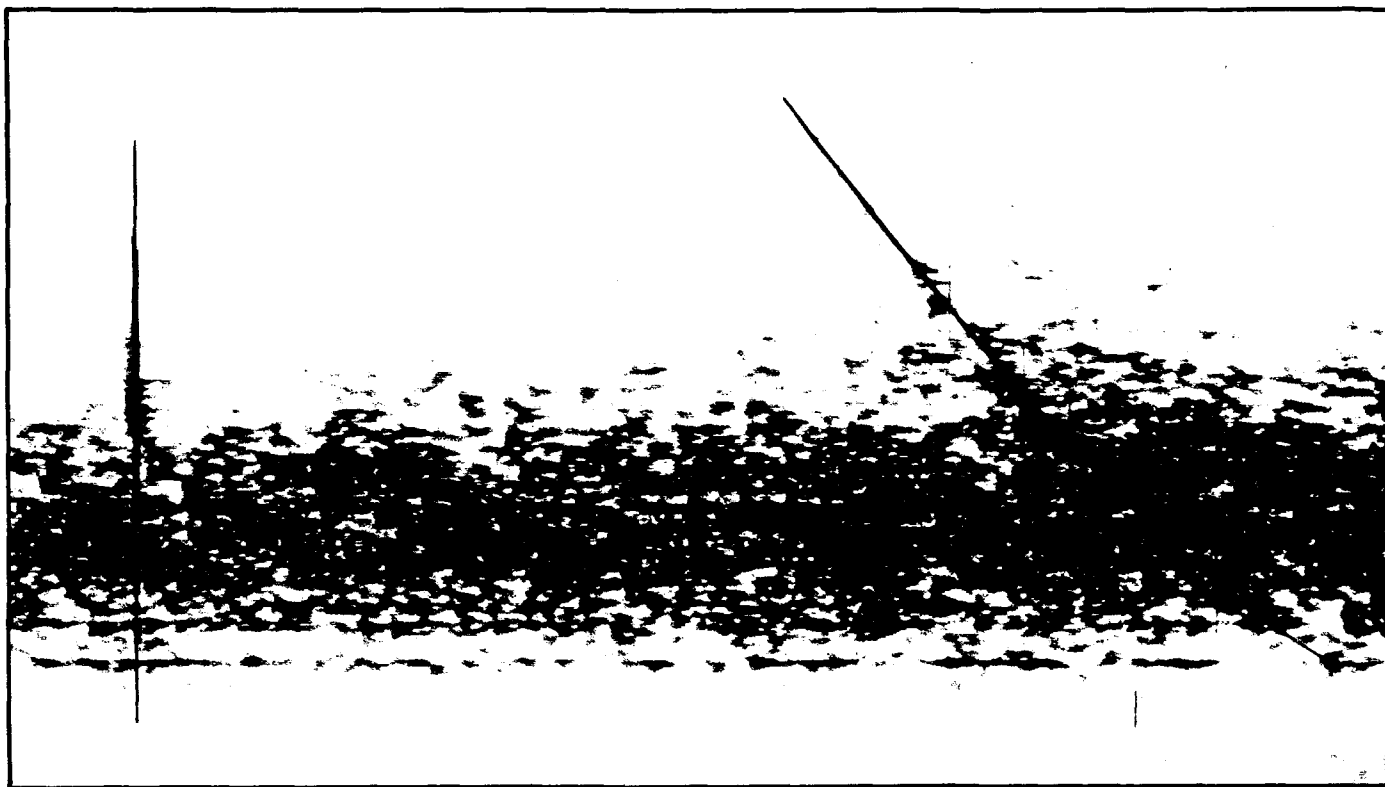
of the high latitude whistlers. As noted above, the usual whistler begins at some frequency and descends in tone. Figure 18 is a spectrogram of a typical whistler. The high latitude whistlers begin at some intermediate frequency (3-4 kc) and both rise and descend in tone. As plotted by an audio spectrograph, the shape is approximately a parabola with its axis aligned along the time coordinate; hence the name, "nose" whistler (Figure 19). On the basis of these results a theory was developed by a research group at Stanford University<sup>(24)</sup> which indicates that an approximation made by Eckersley in the development of his dispersion theory does not hold for high latitude whistlers.

From this correction to the dispersion theory the maximum frequency of propagation is inferred to be of the order of one quarter of the gyro-magnetic frequency. The magnetic field lines at the latitude of College, Alaska, caused the disturbance to propagate to a point about 30,000 km from the earth. At this large distance the magnetic field strength is such that the gyromagnetic frequency is of the order 12,000 cps. Thus the frequency of maximum velocity is 4,000 cps. This theory predicts that the frequency of maximum velocity will be at about 30 kc for some of the low latitude whistler stations. It is anticipated that an attempt will be made to observe the phenomenon at low latitudes by some of the low latitude stations. (A paper embodying the above results was presented to the December, 1955, meeting of URSI at Gainesville, Florida, and has recently been published.<sup>(24)</sup>)

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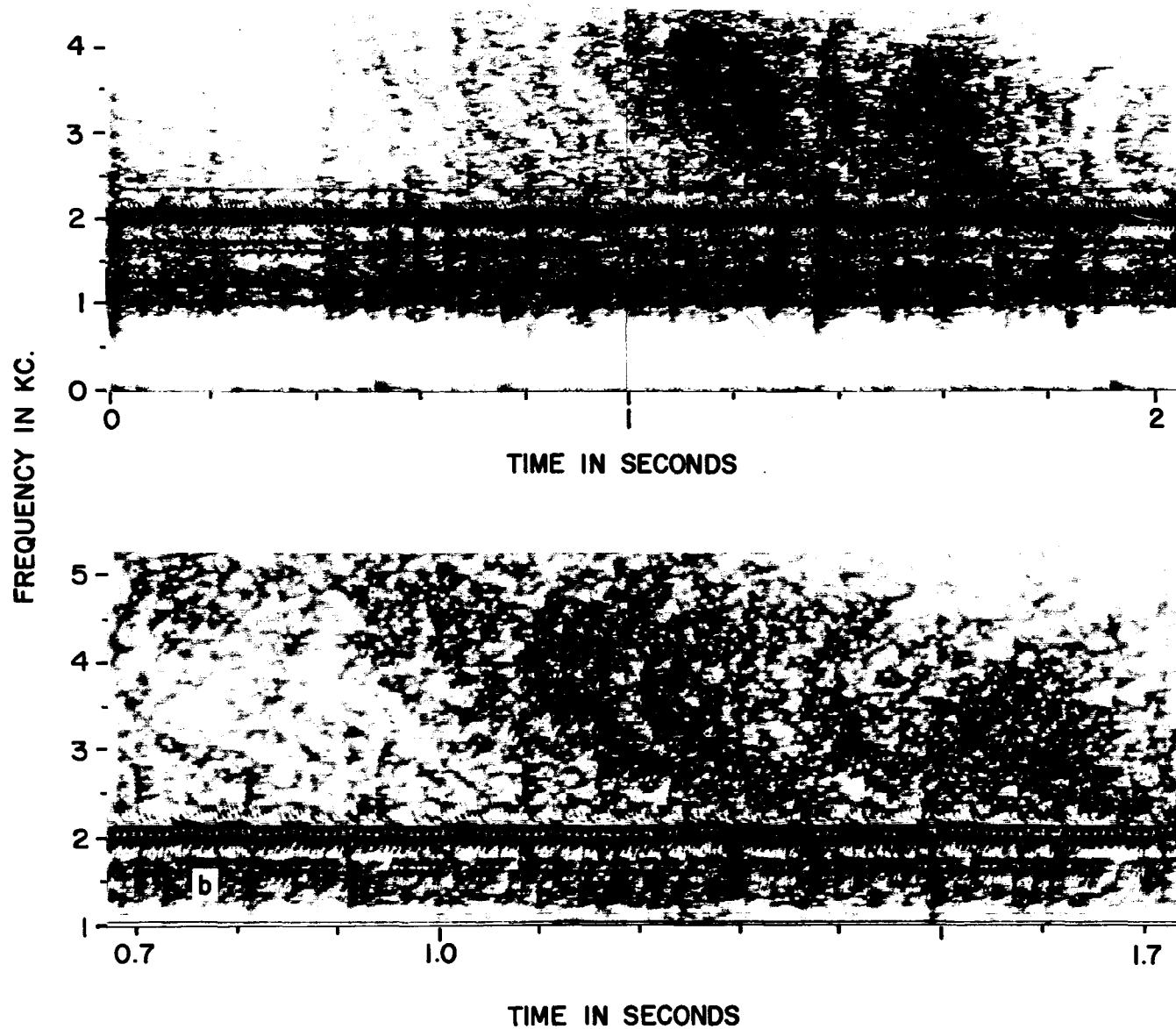
(24) Helliwell, R. A., J. H. Crary, J. H. Pope, and R. L. Smith.  
 "The 'Nose' Whistler - A New High Latitude Phenomenon," J.  
 GEOPHYS. RES. 61, 139-142 (1956).





TYPICAL SPECTROGRAM OF A WHISTLER AND ITS INITIATING TWEAK

Figure 18



SPECTROGRAM OF A TYPICAL NOSE WHISTLER RECORDED AT COLLEGE ALASKA

Figure 19

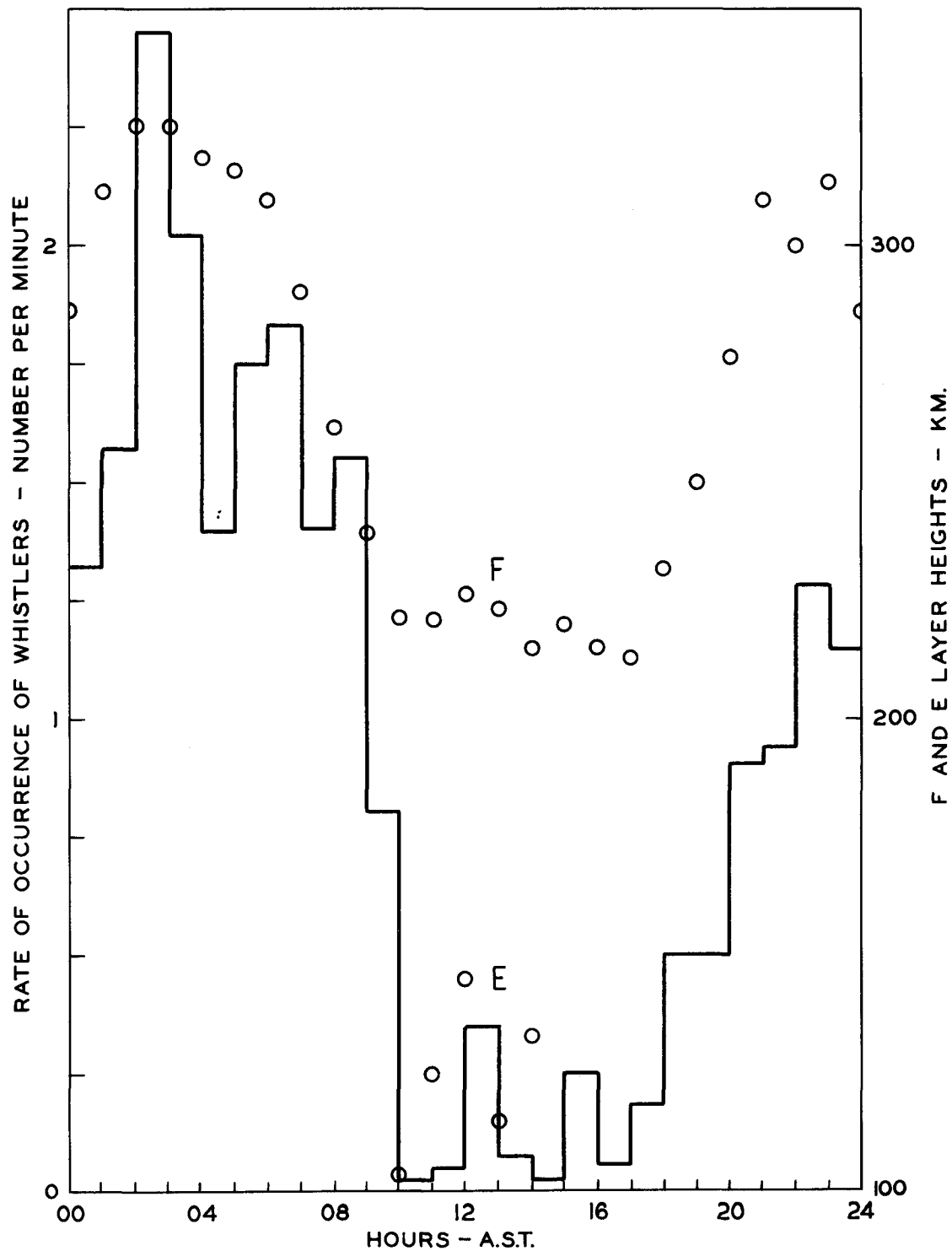
## Analysis

A preliminary statistical analysis of the data for the period of November 25 - December 5 reveals a pronounced diurnal variation in the rate of occurrence of whistlers. The average diurnal variation over this period is correlated quite well with the average diurnal variation of the heights of the F and E layers of the ionosphere as determined by a C-3 ionospheric sounder operated by the Geophysical Institute. The analysis has not yet progressed to a point to determine whether this correlation is merely a chance correlation between two phenomena having similar diurnal variations. Figure 20 is a histogram of the average rate of occurrence of whistlers for this period. Superposed on this drawing is a curve giving the average heights of the F and E layers.

A preliminary examination of the occurrence of dawn choruses for the period December 23, 1955, to January 21, 1956, reveals a correlation with magnetic activity. Figure 21 shows this correlation. The daily sums for the K index as recorded by the Coast and Geodetic Survey in College, Alaska, are plotted for the period between December 31 and January 20. The daily sum for the dawn chorus during this period is also plotted. The daily sum of the dawn chorus is defined as the number of periods during which the dawn chorus was heard for each day. The analysis, which has not yet been completed, indicates that if a phase difference of about 10 hours is introduced between the two phenomena the correlation is somewhat enhanced.

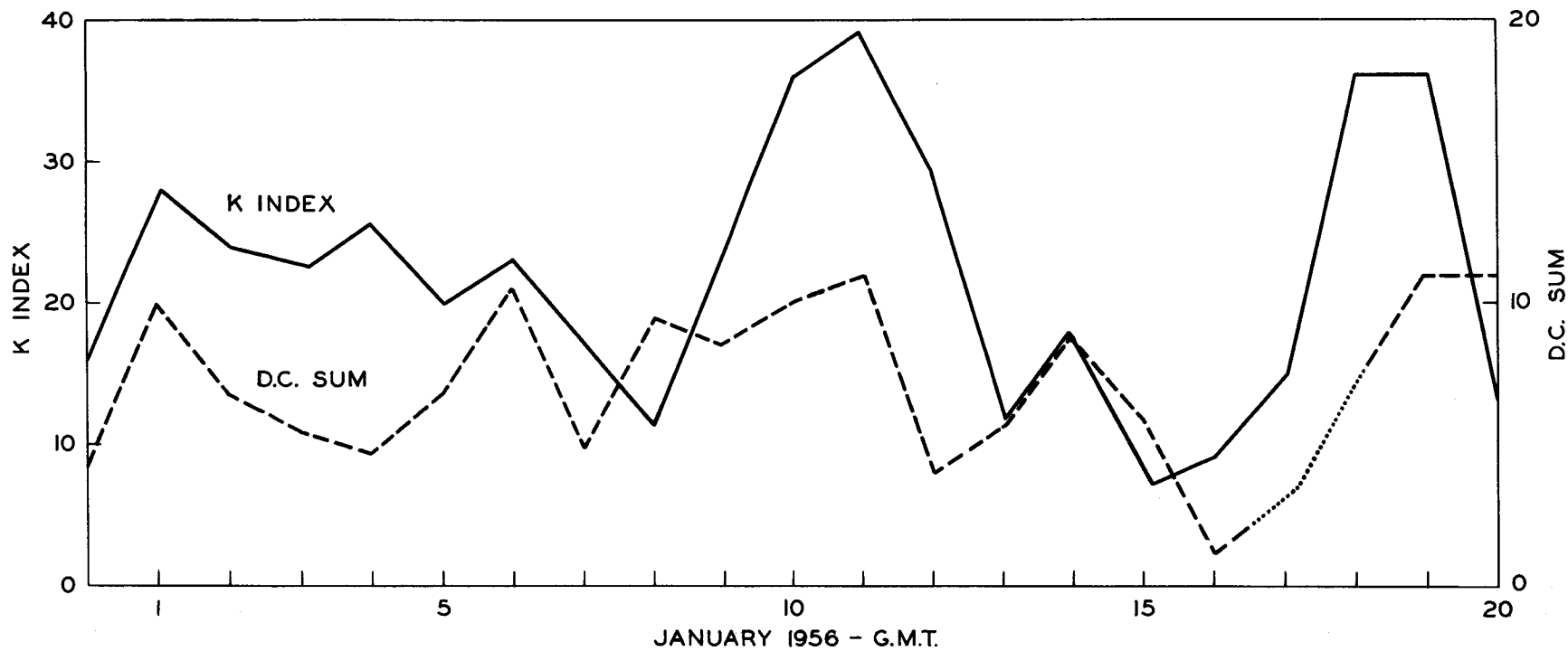
## Conclusions

Observations show that a difference exists in the dispersions between high and low latitude whistlers. An apparently successful theoretical analysis has been made that accounts for this difference. Preliminary



AVERAGE DIURNAL VARIATION OF RATE OF OCCURRENCE OF WHISTLERS AND HEIGHTS OF THE F AND E IONOSPHERE LAYERS FOR THE PERIOD OF NOV. 25 - DEC. 5, 1955.

Figure 20



DAILY K INDEX AND DAILY DAWN CHORUS SUMS

Correlation of Dawn Chorus with Daily K Index

Figure 21

analysis indicates that a pronounced diurnal variation of the rate of occurrence of whistlers exists at high and low latitudes. A connection between the occurrence of the dawn chorus and magnetic activity is also indicated. Further work is necessary in order to confirm and augment these results.

Task No. 6 Scattering and Diffraction of VHF Waves by Mountains

(R. B. Dyce, C. G. Little, G. W. Swenson Jr., E. Stiltner)

During the winter of 1953-54 it was learned that television signals of usable quality were being received at Lake Minchumina, Alaska, from two transmitters at Anchorage, 200 miles away. As Mt. McKinley, over 20,000 feet high, lies almost directly on the line of sight between the two locations, it is evident that the propagation mode involves diffraction. Signals were received on two frequencies, 57 mc and 200 mc, with roughly equal intensities, the peak transmitted power of the latter signal being 400 watts and the antenna gain about 7.

A preliminary field investigation in the summer of 1954 suggested that this television reception provided interesting opportunity for studying diffraction propagation over very long paths. On either side of the line between Anchorage and Minchumina are two very prominent peaks, Mt. McKinley (20,300 feet) and Mt. Foraker (17,395 feet) which are connected by a rugged ridge 15 miles long studded with peaks between 10,000 and 14,000 feet high. Mt. McKinley is the highest mountain in North America, and probably the highest in the world above its base plateau. There are no extensive foothill systems. The valleys on either side are extremely flat, over a hundred miles across, and nearly uninhabited.

In order to study temporal variations of signal strength, a receiving station was established at Lake Minchumina, in the home of Mr. and Mrs. R. H. Collins. The equipment comprised a receiver, a graphic recorder, and a direction finding antenna. To simplify antenna construction, the 200 mc (Channel 11) signal was selected. The signal strength was monitored continuously on an AN/APR-4 receiver with an Astatic cascode pre-

amplifier, connected to a single 7-element yagi antenna. The home television receiver was equipped with an a.g.c. voltmeter, and was connected to the direction-finding antenna, which consisted of eight 5-element yagis connected in two bays of four. These bays could be connected in phase for ordinary TV reception or 180 degrees out of phase for direction-finding. A motor driven antenna rotator and a selsyn repeater were provided for the operator's convenience.

Throughout the winter of 1954-55, occasional severe fades were noted, accompanied by swings in the direction of arrival of up to 12 degrees. On occasion the fading would be frequency selective, so that the video signal would fade out while the audio signal remained strong, and vice versa. At all other times the signal strength varied in a less extreme manner with periods of from one to several hours. In part, this fading has been correlated with the rise and fall of the tides in the estuary (Knick Arm) at Anchorage; however, it seems certain that the major influences are meteorological. This finding contrasts with previous experiences with diffracted signals over shorter paths, which show, in general, relatively small variations with time.

During the summer of 1955, efforts were made to establish a transmitter at Anchorage, in order to avoid the difficulties experienced by virtue of restricted transmitting hours of the Anchorage TV station and interference from another Channel 11 station in Fairbanks. A 100-watt transmitter was used, feeding a vertically polarized, 8-element yagi 30 feet above the ground in the center of Anchorage. No signals from this transmitter were ever heard at Minchumina, either on a ground receiver or on an airborne receiver at altitudes up to 10,000 feet above the ground.



It now seems clear that more power and a better antenna site were needed.

In order to investigate the diffraction pattern in the Tanana - Kantishna Valley in more detail, an Air Force C-47 airplane operated by the 5001st Operations Squadron was equipped with a 4-element yagi antenna and an AN/APR-4 receiver with a cascode preamplifier tuned to 200 mc. The receiver "diode-current" meter was calibrated in the laboratory to serve as an indication of input voltage from the antenna. During these tests the Anchorage Channel 11 station transmitted a "black" picture; that is, a signal unmodulated except for synch pulses. On August 21, 1955, a five-hour flight was made over Lake Minchumina and environs to measure signal strengths. Navigation was accomplished with the aid of the Minchumina radio range, which has a magnetic bearing of  $216^{\circ}$ - $36^{\circ}$ , almost exactly perpendicular to the direction of signal propagation. Radar fixes were obtained at the beginning and end of each run, and dead reckoning was used to interpolate to positions between these fixes. Measurements were made at altitudes of 5,000; 10,000; 15,000; and 20,000 feet along the radio range for 50 miles each side of Minchumina. The most noticeable feature of the results was the very rapid fluctuation of signal strength from point to point over distances of the order of 600 feet. Signals of as much as about 10 microvolts (antenna output) were obtained on local maxima; at minima the signal often faded into the noise (roughly 2 microvolts). At all points in the radio shadow of the mountains the signal displayed this violent variation. During the 20,000 feet altitude run, the plane was heading northeast along the range; and when it approached a point in line with the northeastern extremity of the McKinley mountain complex, the signal became steady and strong (up to 19 microvolts). At this point the descent was started, and the signal

declined steadily and smoothly until it disappeared into the noise at about 12,000 feet. It is evident, then, the mountains are, indeed, responsible for the presence of the signal in the vicinity of Minchumina, but that the existence of the pronounced fine structure of the diffraction pattern makes the selection of a site for a receiving antenna extremely important.

It was noted during analysis of the flight data that coarse-structure maxima were obtained when the plane was in line with the larger mountains. These maxima, however, are much less important than the fine-structure maxima.

In order to verify the fine structure, some additional data were taken on the ground at Minchumina Airport on September 8, 1955. As in the airborne tests, the Fairbanks Channel 11 station remained off the air, and the Anchorage Channel 11 (200 mc) station transmitted a steady signal of the video channel only. In the latter case, however, a test pattern was used. It was found that the fine structure did, indeed, exist. A run was made along the "lower runway" in the direction  $110^{\circ}$ - $290^{\circ}$  magnetic, roughly parallel with the direction of propagation, and here it was found that the signal varied between 2.5 and 10.5 microvolts (output across 50 ohms from a 10-element Yagi, gain 7.5 db) with periods of from 600 to 700 feet. The maxima were not all of the same intensity, but the pattern repeated itself, approximately, throughout the entire 4,000 foot run. A similar result was experienced on the  $20^{\circ}$ - $200^{\circ}$  runway, roughly perpendicular to the direction of propagation, except that the minima were spaced from 50 to 100 feet apart. On this run the highest signal strength was obtained of any measured at the airport, 13 microvolts.

The transmission loss of the diffracted signal for the Anchorage-Minchumna path was computed for the case in which the receiving antenna was situated at the theoretically optimum height above the runway, and was found to be 131 db. Using the theory of diffraction of a scalar wave by a perfectly absorbing, semi-infinite screen of infinitesimal thickness (the ideal "knife-edge"), the transmission loss for a single ray (no image antennas) was computed to be 150 db. Adding 12 db for the gain to be expected from two optimally situated image antennas gives a transmission loss of 138 db, or seven db higher than that actually measured.

On August 31 and September 1 and 2, 1955, a transmitter was set up 1 1/2 miles west of Donnelly Dome, a symmetrical mountain 3,910 feet high (above sea level) and about 2,000 feet above its base plateau. The Dome is isolated by at least five miles from any other mountains and presents a unique situation for life size tests of diffraction propagation. The frequency used was 227 mc, the transmitting antenna was a vertically polarized discone from an AN/GRC-27 radio equipment. Two receiving set-ups were used, one in an airplane and one in an automobile. In each case a vertically polarized "ground-plane" antenna was used, consisting of a folded quarter-wave monopole and four horizontal ground rods. It was found necessary to adjust the lengths of both ground rods and monopole to achieve satisfactory impedance match at 227 mc. The receiver was battery-operated and consisted of three conventional r. f. amplifier stages using 6AK5 tubes, a 6AK5 mixer, three i. f. stages (9.25 mc) using 6BA6's, a 12AX7 second detector, and two triode audio amplifier stages. An additional stage of audio amplification was provided for a full-wave bridge (copper oxide) rectifier which drove the Esterline-Angus recording micro-

ammeter. The local oscillator consisted of a crystal oscillator at 7,857 kc and multiplier stages to give an injection frequency of 236.25 mc. This receiver worked well but drew excessive plate current for battery operation, necessitating frequent battery replacement.

The airborne tests consisted of a qualitative survey of the diffraction pattern, quantitative data being unobtainable because of difficulty in accurately navigating the light airplane (Cessna 140) in the prevailing high winds. It was found that the region was relatively free from interference by reflected waves from nearby mountains, and that the diffraction pattern of the dome could be studied satisfactorily, given enough time and reliable equipment. In flying from the transmitter toward the dome a series of maxima and minima were found as the plane approached the summit of the dome. As the plane passed over the dome and beyond, the signal was weak until another series of fringes appeared, corresponding to those appearing in the Fresnel solution of an absorbing straight edge. As the plane passed into the shadow zone, the signal dropped abruptly into the noise. Flights made perpendicular to the line between the transmitter and the dome also yielded results of interest. As the plane flew on such a course, with the dome between transmitter and plane, a very strong, steady signal was received as long as the line-of-sight path obtained. As the plane approached the shadow zone, a series of interference fringes was observed; then the signal dropped abruptly into the noise as the plane entered the shadow, remaining so until the series of fringes on the other side was reached, after which the signal rose to its former high level. No enhancement of the signal directly behind the dome was observed at any altitude or with any disposition of transmitter and receiver.

With the transmitter situated at Bench Mark 2735 on the west side of the Dome (see U.S.G.S. map "Mt. Hayes (D-4)"), emitting 70 watts 100 per cent modulated with a 1,000 cycle tone, antenna height 8 1/2 feet, a series of measurements were made on the east side of the Dome, along the Richardson Highway. No line-of-sight propagation existed, but the results correlate quite well with those obtained in the airborne tests. The series of interference fringes exist on both sides of the Dome, with very low signals, relatively, directly behind the Dome. On the line through the top of the Dome and the transmitter an antenna output of 4 microvolts was obtained, with an antenna height of 8 feet. The terrain height at this point is 2,200 feet.

One additional result in the study of diffraction was obtained during studies of scatterings by mountains. With the SCR-270 radar at College transmitting on 107 mc with 100 kw peak power, 100  $\mu$  sec pulses, 100 pulses per second, a signal of peak amplitude 500 microvolts was obtained at the McLaren River bridge on the Paxson-Cantwell road, a distance of 135 miles from College. The receiving antenna was a 7-element Yagi with a balun, and the signal was measured across 50 ohms. The SCR-270 antenna was aimed toward Mts. Hayes and Hess. The line of sight passes about halfway between Mt. Hayes and Mt. Hess at a point about 95 miles from College. Moving the receiving antenna one-half mile east caused the signal to disappear into the noise, probably because of the intervention of low foothills. From the bridge site, the high mountain ridge between Hess and Hayes should be visible on a clear day, looking up the McLaren Glacier.

Using a  $4/3$  earth radius, the one-ray transmission loss was computed to be 132 db. Adding 12 db for maximum image gain, to be obtained by use

of the 4-ray assumption, would give 120 db transmission loss. These figures agree quite well with the measured transmission loss of 126 db. Taken together with the results of the Anchorage-Minchumina test, they appear to give substantial support to the validity of the knife-edge approximation in cases similar to those described here.

The study of scattering was carried out in qualitative fashion. It became known that TV signals on Channel 11 from Fairbanks (KTVF) were received at Lake Minchumina from about the direction of Anchorage. Upon further investigation, the signal turned out to be an azimuth of  $105^{\circ}$  magnetic ( $131^{\circ}$  true) or 25 degrees east of the direction of Anchorage. This signal seems to be quite consistent.

With the 106 mc radar operating at College, measurements were taken at various points on the Richardson Highway south as far as Paxson Lake. Scattered signals were observed at all points tested between North Pole and Rapids, all those stations north of Rapids giving strong PPI indications from the Mt. Hayes area. Measurements were also taken at Nenana, to the west of College, with strong echoes being received from the mountains to the south. No signals were observable from the direction of College at any of these test sites. In all cases the scattered pulses were very much broader than the transmitted pulses, in contrast with the very sharp pulses observed over "diffraction" paths. It is estimated that typical echoes would show broadening to from ten to fifty times the transmitted pulse lengths. This fact suggests that "scattering" propagation paths might have severe bandwidth limitations, whereas "diffraction" paths would not, except on occasions. It is certain that a transmitter of sufficient power located at College can illuminate the entire Tanana-Kantishna Valley system

by scattering from the Alaska Range, though whether the available bandwidths would be sufficient for communication purposes is a subject that requires further study. It is believed that such a study could be made from College, without the necessity of other field sites.

Task No. 7 Ionospheric Absorption (C. G. Little)

During the early part of 1955, the Geophysical Institute undertook a study of communication failures over the circuits in use by the 58th Weather Reconnaissance Squadron at Eielson Air Force Base. A statement of the results of this study may be found in the Interim Scientific Report #1, issued under the contract.

In summary, it was found that nearly all communication failures could be attributed to ionospheric absorption as measured by absorption of 30 mc cosmic noise at the College zenith. In some cases circuits were open, even though zenithal absorption was present. It was felt that in these cases the absorption may have been limited in extent, such that the circuit path lay outside the zone of absorption. Another possible explanation lies in the fact that the absorption equipment is sensitive enough to detect absorption too weak to affect communications.

The study showed that the absorption tended to be strongest in the daytime hours, and also tended to be most severe during the equinoctial months. On the basis of these results, it was recommended that flights be made during the night hours whenever possible, particularly during the equinoctial months.



## Task No. 8 Assist Alaska Air Command in Problems of Radiowave Communication

(C. G. Little)

### 1. V.H.F. Communication link

An investigation of a VHF communication link in the territory was made at the request of the Alaska Air Command. The purpose of the investigation was to determine the cause of the frequent fade-outs reported on this link, and if possible, to reduce their effect.

As described in R(1), pen recorders were installed at each end of the link to monitor the received signal strengths. A comparison of the records with the corresponding B curves, prepared from radiosonde data, showed that the fading was tropospheric in origin.

To improve the signal-to-noise ratios, a special cascade preamplifier was built and tested on the link. The results showed that a significant decrease in outage time could be achieved by the use of low-noise preamplifiers.

### 2. Radio Wave Propagation Symposium (Institute Staff)

The second Arctic radio wave propagation symposium was held at the Geophysical Institute on January 26, 1956. Eight papers were read (seven by members of the Institute) on various aspects of radio wave propagation and research in the Arctic. Over fifty visitors from several different agencies in the territory attended the meetings, which included visits to two of the Institute field sites.

The papers read at these meetings have been collected together and printed in the form of a special Institute Report. The program of the meetings is given in Appendix B.

3. Symposium on the Effects of Low Energy Particle Bombardment  
(Institute Staff)

A symposium on the effects of low energy particle bombardment was held at the Geophysical Institute on March 1-2, 1956. Fourteen papers were read during the two days, nine by Institute staff and five by visiting scientists. It is hoped that it will be possible to publish these papers in the form of a Special Report; the program for this symposium is given in Appendix C at the end of this report.

4. Loan of Scientific Equipment

On several occasions, the Geophysical Institute has been able to assist Air Force personnel working on propagation problems by the loan of test equipment, pen recorder, d-c amplifiers, etc.

5. Consultation

On many occasions, Institute personnel have been able to assist the U.S. Air Force in Alaska by acting in an advisory or consultant capacity on problems connected with radio wave propagation and the aurora.

## SECTION IV

### RECOMMENDATIONS

The following recommendations are made in regard to the continuation of the work described in this report.

#### 1. Sweep-frequency ionospheric backscatter

It is expected that the sweep-frequency ionospheric backscatter equipment will be received early in 1957. It is recommended that two rhombic antennas (one for transmitting, one for receiving) be constructed and that they be directed toward magnetic north, in order to explore propagation conditions in the Arctic basin.

#### 2. Auroral and meteor echoes

The Stanford Research Institute will be operating powerful VHF-UHF radars at College by late '56 or early '57. In view of this, the auroral and meteor research program at the Geophysical Institute should be designed to provide information of a type not available from the Stanford equipments. It is therefore suggested that the emphasis of the Institute program should be on the study of auroral echoes at frequencies below about 100 mc. Current plans include the study of the Doppler shifts of auroral echoes at various frequencies in the range 10-100 mc.

#### 3. Microwave propagation

No recommendations are made for further work at the Institute in this field.

#### 4. Prediction of auroral and ionospheric storms

Several new methods of studying the particle bombardment of the earth's upper atmosphere have been developed at the Institute with the

aim of improving our knowledge of the phenomenon, and obtaining, if possible, a means of predicting auroral and ionospheric storms. In order to obtain sufficient information for statistical studies, and to carry out the necessary studies of the correlations between the different phenomena, it is important that these new techniques be used for a period of some years. It is therefore recommended that this phase of the work, which should be regarded as a long term project, be continued.

#### 5. Whistlers

As described in the main body of the report, the monitoring of whistler activity at College is now proceeding on a routine basis. These observations have already led to the improvement of the theory of whistler propagation. Further observations will give information on electron densities at distances above the earth's surface greater than those which can be studied at lower latitudes. It is therefore recommended that these studies be continued.

#### 6. Mountain scatter and diffraction at VHF

No recommendations are made for further studies in this field.

#### 7. Ionospheric absorption

Depending upon the availability of personnel and equipment, studies should be made of the frequency dependence of the ionospheric absorption.

#### 8. Assistance to Alaska Air Command

On many occasions during the past two years, members of the Institute have been able to assist U.S. Air Force personnel in the territory on problems relating to Arctic radio wave propagation. Since the Geophysical Institute is probably the only radio wave propagation research group in the territory, it is recommended that this phase of the contract be continued.

## Additional Items

The above eight sections refer to the continuation or termination of the different types of work which have already been conducted at the Institute on AF 19(604)-1089. Recommendations are now made for the addition of two new types of work.

### 9. Radio star scintillations, 30-200 mc

An investigation of the VHF-UHF properties of the ionosphere is being made using radio stars at frequencies above 200 mc on Contract AF 19(635)-2887. It is desirable that similar studies be made in the frequency band 30-200 mc, where the effects will be more pronounced and therefore more readily detected. Such studies would permit the investigation of the frequency dependence of the phenomena, and would also make possible the study of polarization and absorption effects which are not observable at the higher frequencies since they are dependent upon the ratio of the observing frequency and the gyro-magnetic and electron collision frequencies. The recommendation is therefore made that, subject to the availability of personnel and equipment, studies of the signals from radio stars in the range 30-200 mc be commenced at the Geophysical Institute.

### 10. Transpolar HF communications

Owing to the increased interest in transpolar communications, and the almost complete lack of detailed information in this field, it is desirable that such research be undertaken at the Geophysical Institute. The Institute is admirably situated for transpolar communications to northern Europe, since the great circle paths from College to Norway pass within a few degrees of the geographic and the magnetic north poles. It is therefore recommended that a program of research in transpolar HF communications be set up in cooperation with the Norwegian authorities, who have already expressed interest in such work.

## SECTION V

### PERSONNEL

The following persons were employed on Contract AF 19(604)-1089 during the period April 15, 1954, to May 14, 1956.

Le Nelle Bergt	Technician
Kenneth L. Bowles	Assistant in Geophysical Research
T. Neil Davis	Assistant in Geophysical Research
Thomas S. Dickinson	Electronic Technician
Rolf B. Dyce	Assistant in Geophysical Research
C. T. Elvey	Director of the Geophysical Institute
Jack Garrison	Technician
James E. Kahle	Technician
Louis T. Kegler	Technician
Robert S. Leonard	Graduate Assistant
C. Gordon Little	Assistant Director of Geophysical Institute
Marion S. Mitchell	Technician
Wallace B. Murcray	Instructor in Geophysical Research
Leif Owren	Associate Prof. of Geophysical Research
Joseph H. Pope	Graduate Assistant
Raymond B. Roof	Research Assistant
Domenic A. Schiavulli	Technician
Richard N. Shoup	Electronic Technician
Delavan W. Sipes	Electronic Technician
Carole J. Smith	Assistant in Geophysical Research
Ernest Stiltner	Graduate Assistant in Geophysical Research
Masahisa Sugiura	Assistant Prof. of Geophysical Research
George W. Swenson, Jr.	Consultant
Eleanor M. Tikka	Technician

APPENDIX A  
AURORAL INDICES, 3 HOUR AND DAILY

College, Alaska

Greenwich Mean Time

October			November				December							
Date	6-9	9-12	Day	3-6	6-9	9-12	12-15	Day	3-6	6-9	9-12	12-15	15-18	Day
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	2	2	0		0	4	5	1	1**	1	0	-	-	0
3	-	-	-		0	0	0	0	0	0	1	4	2*	0
4	-	0	0		3	6	1	1	1	1	1	0	0*	0
5	0	1	0		-	3	2	1	0	0	0	0	0*	0
6	1	1	0		0	0	0	0	1	5	3	2	2*	1
7	-	-	-		0	1	1	0	0	0	0	0	0*	0
8	-	-	-		1	2	3	0	0	0	0	0	0*	0
9	-	-	-		1	2	1	0	1	2	2	4	3*	1
10	-	-	-		1	0	1	0	-	-	-	-	-1**	
11	2	3	1		0	1	1	0	0	0	1	0	1**	0
12	0	0	0		2	3	2	1	0	0	0	0	0**	0
13	-	-	-		2	2	3	1	-	-	-	-	-**	-
14	1	3	0		-	-	-	-	-	-	-	-	-**	-
15	0	0	0		2	5	8	1	-	-	1	1	0**	0
16	0	0	0		4	4	5	1	1	1	2	2	1**	0
17	0	0	0		1	1	1	0	1	1	1	1	1**	0
18	0	0	0		3	4	5	1	0	0	0	0	0**	0
19	0	0	0		2	9	11	2	0	1	2	3	3**	0
20	-	-	-	1	10	8	9	2	1	1	3	8	4**	1
21	1	2	0	-	1	1	1	0	-	1	2	5	5**	1
22	0	1	0	0	0	2	8	1	2	1	1	2	2**	0
23	0	1	0	0	0	0	0	0	0	1	1	2	1**	0
24	0	0	0	2	4	4	5	1	0	1	2	3	2**	0
25	6	8	2	-	-	-	-	-						
26	5	8	1		0	0	0	0						
27	4	4	1											
28	4	5	1											
29	1	0	0											
30														
31														

\* 1 hour  
\*\* 2 hours

# AURORAL HOURLY SCALINGS

October 1955

College, Alaska

Greenwich Mean Time

	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14
1						314	108	194	106
2		50	102	300	232	90	166	156	94
3									
4			0	0	0	0	0	0	0
5		0	0	12	54	56	100	210	208
6		40	86	102	140	102	66	60	58
7									
8									
9									
10									
11				482	300	462			
12		0	0	0	0	0	0	0	0
13									
14			162	240	251	228	272	226	144
15		45	48	40	26	34	46	32	24
16		0	0	0	0	0	0	0	0
17		0	0	0	0	0	0	0	0
18		0	0	0	0	0	0	0	0
19		0	0	0	0	0	0	0	0
20									
21		46	46	59	124	122	342	45	
22	17	24	24	39	85	139	210	248	374
23	24	24	24	32	36	43	117	279	124
24	0	0	0	0	0	0	0	0	0
25		796	562	584	924	588	912	652	1216
26		455	658	536	672	656	950	456	500
27	426	458	370	498	366	328	624	326	266
28	396	448	432	420	404	538	506	728	720
29	207	178	172	84	50	18	4	94	118



# AURORAL HOURLY SCALINGS

November 1955

Greenwich Mean Time

	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16
1												
2			0	0	22	151	460	588	474	422	480	
3	0	0	0	0	0	0	0	0	0	0	0	
4	359	547	412	237	46	208	606	932	298	104	0	
5		170		176	215	250	338	215	365	122	8	
6		0	0	0	0	0	0	0	0	0	0	
7		48	48	48	48	54	76	114	150	110	80	
8			88	115	156	230	224	168	254	148	354	
9		133	96	117	118	132	167	210	110	77	70	
10			52	54	47	36	38	56	105	99	54	
11	0	0	0	0	47	82	128	89	60	64	94	
12	36	36	36	72	456	518	320	186	378	242	128	96
13	230	212	212	198	224	228	200	202	224	352	256	184
14												
15	104	123	119	188	217	213	525	664	813	839	842	620
16	160	197	335	287	485	572	320	244	476	426	482	420
17			72	72	85	81	53	52	61	125	148	126
18		524	274	294	470	398	404	364	364	534	420	284
19				144	162	600	840	1234	1290	972	980	1155
20	178	176	646	1044	1396	482	596	1256	768	856	1228	1546
21	96	82	96	114	154	162	132	108	96	68	10	0
22	0	0	0	0	20	44	184	404	838	960	532	120
23	0	0	0	0	0	0	0	0	0	0	0	0
24	237	240	233	283	572	278	308	682	536	470	412	412
25												
26			0	0	0	0	0	0	0	0	0	0
27												
28												

# AURORAL HOURLY SCALINGS

December 1955

Greenwich Mean Time

Day	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	150	76	120	100	50	0	0	62	116	180			
3	-	24	0	0	0	0	0	106	290	436	506	214	154	
4	124	140	154	136	108	76	182	128	64	0	0	0	0	
5	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	55	125	157	519	592	282	172	310	400	292	208	192	192	
7	0	0	0	0	0	0	0	0	0	0	0	0	0	
8	0	0	0	0	0	0	0	0	0	0	0	0	0	
9	72	62	57	93	192	253	80	55	385	440	429	452	278	
10	-	-	-	-	-	-	-	-	-	-	-	-	-	
11	0	0	0	0	0	37	57	61	42	29	24	24	34	116
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13														
14														
15	-	-	-	-	-	65	58	84	93	94	73	49	43	36
16	77	87	85	118	149	165	211	211	186	183	144	125	125	112
17	86	79	65	95	87	89	85	119	108	88	75	79	84	112
18	60	60	20	0	0	0	35	20	0	0	0	0	0	0
19	11	24	24	38	48	78	307	184	177	402	267	146	445	483
20	81	121	144	147	110	155	184	268	548	830	924	786	512	210
21	-	-	-	85	123	161	187	225	312	364	672	592	600	328
22	164	144	144	140	146	132	102	72	72	118	166	245	250	180
23	0	0	4	24	48	96	96	150	192	320	232	164	144	144
24	0	0	0	60	56	96	96	160	296	338	268	160	148	336
25														
26														
27														
28														
29														
30														

## APPENDIX B

### SECOND ARCTIC RADIO WAVE PROPAGATION SYMPOSIUM

Geophysical Institute  
University of Alaska  
January 26, 1956

9:15	Introductions	C. T. Elvey
	Welcome	E. S. Patty, President University of Alaska
9:30	Radio Astronomy as a Tool for Studying the Ionosphere at VHF	C. G. Little
9:50	The Radio Telescopes at the University of Alaska	R. P. Merritt
10:10	Ionospheric Absorption	J. M. Lansinger
10:30	To Institute (coffee) Field Trip (Radio Telescopes & Low Frequency Radar)	
12:30	Lunch (University Food Service Building)	
13:45	Forecasting Radio Propagation Conditions	M. E. Nason
14:15	Whistlers	J. H. Pope
14:35	To Institute (coffee) Tour Through the Geophysical Institute (Including Ionospheric Recorder)	
15:45	HF Radio Backscatter	R. Stark
16:05	Radar Echoes from Meteors	R. N. Shoup
16:25	Radar Echoes from Aurora	R. S. Leonard
16:55	Concluding Remarks	C. G. Little

APPENDIX C  
SYMPOSIUM  
ON  
"EFFECTS FROM LOW ENERGY PARTICLE BOMBARDMENT"

Geophysical Institute  
University of Alaska

March 1, 1956

09:00	Statement of the Problems and Program of the Geophysical Institute	C. T. Elvey
09:30	Solar Radio Noise and Geomagnetic Phenomena	L. Owren
10:15	Coffee Break	
10:30	Photometry of Auroras	E. V. Ashburn
11:00	Index of Auroral Activity	W. B. Murcray
11:30	Photometric Detection of 5577A and 6300A Auroral Emissions With Large Continuous Background	E. Manring
14:00	Polar Ionospheric Storms	A. Shapley
15:00	Coffee Break	
15:30	Ionospheric Absorption in Auroral Zone	C. G. Little
16:15	X-ray Ionization Below the Auroral Layer	S. Chapman

SYMPOSIUM  
ON  
"EFFECTS FROM LOW ENERGY PARTICLE BOMBARDMENT"

Geophysical Institute  
University of Alaska

March 2, 1956

09:00	Long-Range Radar Auroral Echoes	A. M. Peterson
09:45	Radar Techniques of Investigating Aurora	R. S. Leonard
10:30	Coffee Break	
10:45	Faraday Effect on VHF Auroral Echoes	I. Dyce
11:30	Earth Potential Disturbances in the Auroral Zone	V. P. Hessler
14:00	Magnetic Disturbances in the Auroral Zone	M. Sugiura
14:45	K-Indices	C. T. Elvey
15:00	Coffee Break	
15:15	Final Review of Conference Papers and Discussion	S. Chapman