UNIVERSITY
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GEOPHYSICAL INSTITUTE

Papers read at the

Conference on Arctic Radio Wave Propagation

held at the

Geophysical Institute

January 26, 1956.

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FOREWORD

On February 18, 1954, we held a conference attended by representatives of military organizations in Alaska to discuss general problems of radio communications in the Arctic. Since that conference was so successful, we have decided to hold a second conference broadening its scope in attendance and subject matter with the idea of making the conference an annual event. At this conference, and we hope future ones, we had the active participation of the North Pacific Radio Warning Service of the National Bureau of Standards.

Included in the discussions at this conference were some of the new equipments and techniques being used at the Geophysical Institute in its research work. In particular, I refer to the employment of radio astronomy as a tool for ionospheric research.

C. T. Elvey
Director

17 May 1956

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RADIO ASTRONOMY AS A TOOL FOR STUDYING THE IONOSPHERE AT V.H.F.

by

C. G. Little

The normal method for studying the ionosphere is to use the so-called echo-sounding technique. This, the first use of what later became known as radar, involves the radiation, vertically upwards, of short pulses of radio energy at a frequency in the region of a few megacycles per second. These pulses are reflected by the ionized layers and are received by a receiver, usually close to the transmitter. During the last twenty years this technique has proved a very valuable one. Using it, it is possible to measure the apparent height of the layers, and also to determine their electron densities.

The discovery of radio waves of natural origin coming into the earth from outer space has opened up the possibility of studying the ionosphere by transmission. These radio waves are coming in from all directions of space and are available over a wide frequency range.

It should be noticed that these two techniques are, to a degree, complementary. The echo-sounding technique works satisfactorily only up to a certain maximum frequency - the critical frequency - above which the radio waves penetrate the ionosphere and pass on into outer space. The radio astronomy case only works at frequencies above the critical frequency. (For frequencies below the critical frequency, the radio waves would be reflected out into space again.) Also, the echo-sounding technique essentially studies the reflection properties of the ionosphere, whereas the radio astronomical technique studies the transmission properties of the ionosphere.

Let us consider the different effects which the ionosphere may have upon V.H.F. radio waves passing through it. (By V.H.F. I mean frequencies in the range 30 - 300 mc.) This is clearly a problem of considerable interest in view of the need to communicate with and to observe the I.G.Y. satellites to be used during 1957-1958.

The following are the principal ionospheric effects that may be expected at V.H.F.:

(a) Scatter by Irregularities.

First, some of the incident radiation may be expected to be scattered by irregularities in the density of the ionization in the ionosphere. These irregularities may be due to aurora (resulting in auroral echoes), meteors (meteor echoes), or simply due to ionospheric turbulence. The "forward-scatter" system of communication via the ionosphere is believed to be due to these ionospheric irregularities. Two of the following papers describe observations at the Geophysical Institute of scatter by auroral and meteor ionization.

(b) Ionospheric Absorption.

It is well known that on certain occasions the ionosphere can absorb an appreciable fraction of the radio energy passing through it. A paper describing recent observations of this phenomena at the Geophysical Institute is included in this series.

(c) Amplitude Scintillations.

Observations of radio stars have shown the presence of a phenomenon very similar to the twinkling of the optical stars; the radio stars have been found to scintillate, with period of the order of 30 seconds, due to the diffraction of the incoming radiation by ionospheric irregularities.

This effect may be expected to be quite a serious problem for any radar-type observation of the I. G. Y. satellite at the lower V. H. F. frequencies, since 20 db fades (10 db for each direction of travel) lasting up to 15 seconds could occur at frequencies up to about 100 mc.

(d) Ionospheric Refraction.

V. H. F. radio waves passing through the ionosphere may be expected to be deviated due to the changing refractive index with height. This effect will take two forms; and irregular dancing in apparent position of a fixed object in space, superimposed upon a slowly varying deviation of the apparent position relative to the true position.

(e) Polarization Phenomena.

The characteristic polarization of a V. H. F. radio wave passing through the ionosphere may be changed due to multiple-scatter phenomena and to the Faraday rotation of the plane of polarization in an ionized medium traversed by a magnetic field, and also to the possible differential absorption of the ordinary and extraordinary waves.

Following this introduction, the purpose of this paper is to describe how the radio waves of extra-terrestrial origin can be used to obtain information on ionospheric absorption, scintillation, and refraction effects.

1. Radio Astronomy and Ionospheric Absorption.

The study of ionospheric absorption using radio waves of astronomical origin is a very simple technique and involves the use of a simple antenna connected to a stable, sensitive V.H.F. receiver whose output is continuously recorded on a pen recorder. In the absence of any ionospheric effects, the strength of the extra-terrestrial radio waves for a given equipment is a function only of sidereal time. To determine the ionospheric absorption at a particular time, it is therefore only necessary to compare the power actually received with that received at the same sidereal time under conditions of negligible ionospheric absorption. This technique has now been in use at the Geophysical Institute for almost two years; some of the results are briefly summarized in one of the succeeding papers.

2. <u>Studies of the Scintillation of Radio Stars.</u>

In its simplest form, this technique again involves the use of a directional antenna connected to a stable, sensitive receiver whose output is recorded continuously. In the absence of any interference, the output of the receiver consists of three components, one due to the noise generated in the receiver, the second due to the diffuse background of radio waves coming in from the sky, and the third due to the radio waves, from the particular radio star under investigation. By using antennas of sufficient directivity, this last component can be made sufficiently large for careful study. In this way, it is possible to investigate the occurrence of the irregularities which cause the radio stars to scintillate, and to study their size, shape, stability, and movements.

3. <u>The Study of Ionospheric Refraction.</u>

The radio astronomical method for studying ionospheric refraction is basically a very simple one. An accurate measurement is made of the instantaneous apparent position of a radio star; any discrepancy between this measurement and the known, true position of the radio star is attributed to atmospheric refraction. This refraction will be the sum of two components, one due to tropospheric refraction in the lower atmosphere, and one due to the ionosphere. The former will decrease rapidly with increasing source elevation, and will be almost constant with observing frequency. The ionospheric component will decrease less rapidly with increasing source elevation, but will decrease rapidly with increasing observing frequency.

The actual method used to determine accurately the apparent position of the radio star is to compare the relative phases of the radio waves from the star as received on two widely spaced antennas. This is done using the so-called phase-switch interferometer technique, in which the receiver is used as a null detector to indicate the presence of phase quadrature between the radio star signals from the two antennas. The phase relationships determined in this way are then compared with those calculated from the known position of the radio star and the equipment parameters. The discrepancy in phase may be transformed into the equivalent discrepancy in angle of incidence of the wave space length, i.e. to the equivalent refraction of the radio waves. It is hoped that the equipment currently being installed at Ballaines Lake field site will be capable of measuring the instantaneous (apparent) position of a radio star to an accuracy of about one minute of arc, at a series of different frequencies.

THE PHASE-SWITCH INTERFEROMETERS at the GEOPHYSICAL INSTITUTE

R. Merritt

For the past several months members of the Geophysical Institute have been engaged in the design and construction of phase-switch interferometers of a type similar to equipment developed by M. Ryle and associates at Cambridge, England. The receiving site, where equipments covering the frequency range from 50 to 1000 mc are to be installed, is located one mile north of College near Ballaines Lake. The site, running east and west 150 yds. and 50 yds. wide was cleared of small trees and brush with a bulldozer, and existing roads were extended 500 yds. into the new area. A special power cable was laid underground alongside the new roadbed to bring power into the site without overhead distribution lines, thereby reducing power line noise.

Test holes were drilled to a depth of 50 ft. to determine the type of foundations required to support the two parabolic antennas. Four steel piles were driven into the ground to a depth of 40 ft. with adjustable couplings on each leg to permit exact positioning of the parabolic surface. Heavy steel tubing, 4 in. in diameter, was used in the construction of supporting towers for these antenna which, with their polar mounts, each weighs five tons. The parabolic dishes are 28 ft. in diameter with a focal length of 12 ft. (See Fig. 1). The frame of the antenna is

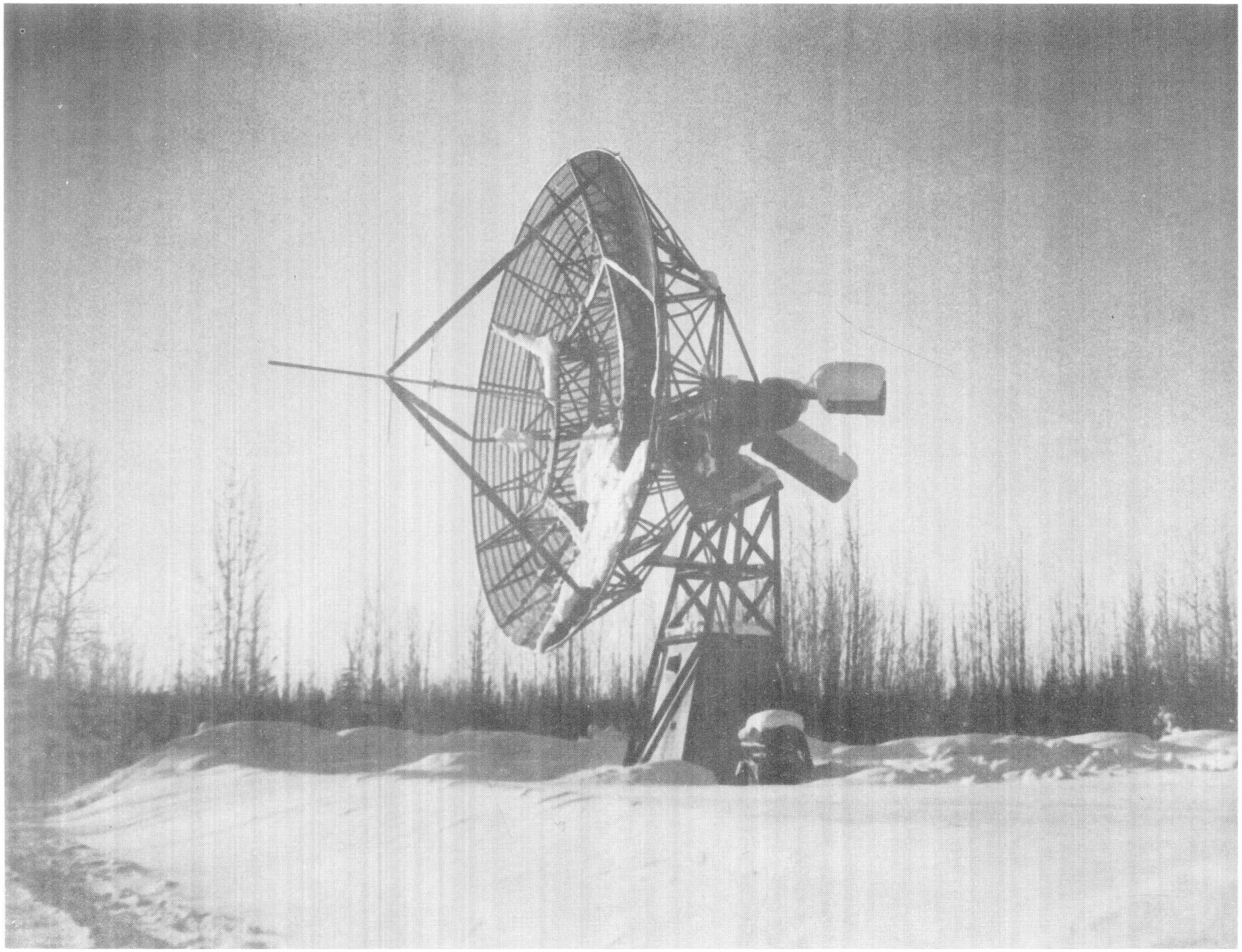
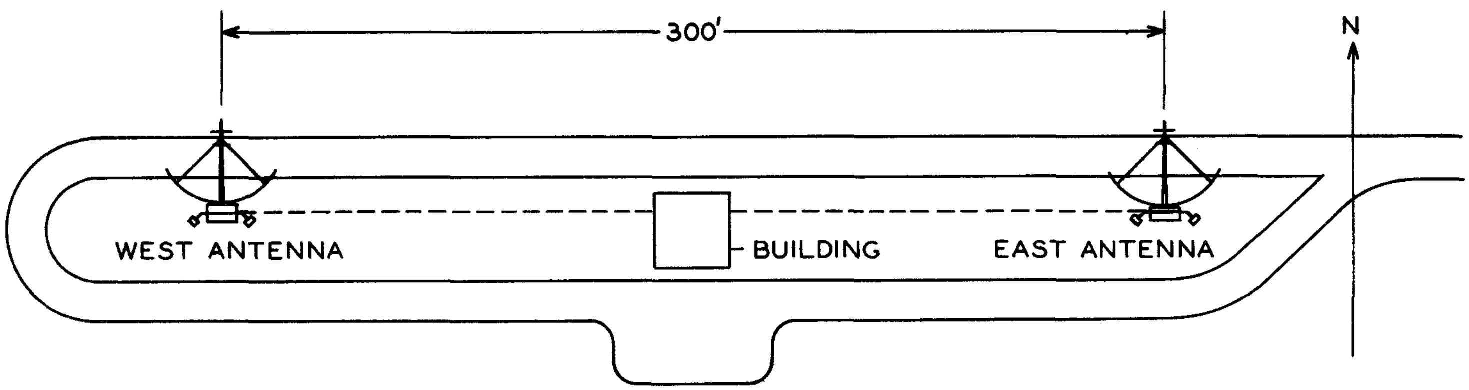


Fig. 1   Twenty-eight foot diameter Radar Telescope at the Ballaines Lake Receiver Site. Geophysical Institute, College, Alaska.

constructed of aluminum tubing with expanded aluminum sheet covering the parabolic surface. The surface is held to an accuracy of ± 1/8 of an in., for use up to at least 1000 mc. These antenna are located on a horizontal 100 yd. east-west base line surveyed to an accuracy of a fraction of an inch. Inside the base of each supporting tower is a small hut which contains preamplifiers and first detector units of the super heterodyne receiving equipment. A building, 24 ft. by 24 ft., located in the center of the antenna system holds the remainder of the equipment. Three 2 in. underground conduits connect the central building with each end hut. In these conduits are four coaxial cables for radio frequency circuits, two power cables, and over forty control wires. Fig. 2 shows the general layout of equipment in the receiving site. A block diagram of the 65 mc phase-switch interometer is shown in Fig. 3. The 65 mc radio signal is collected on the parabolic surface, focused to a folded dipole and reflector assembly and then carried to the preamplifier units by coaxial cable. The local oscillator signal for the super heterodyne receiver is generated in the central building and transmitted by coaxial cable in such a way that the signals arrive with equal amplitude and phase at the end huts. As an extra precaution, passive loss networks have been installed in this cable system to prevent stray radiation passing through the local oscillator system to the other antenna hut. This provision of our equipment design makes it necessary to provide 15 w. of power at 42 mc for the local oscillator. The first



LAYOUT OF RECEIVING EQUIPMENT NEAR BALLAINES LAKE

Fig. 2

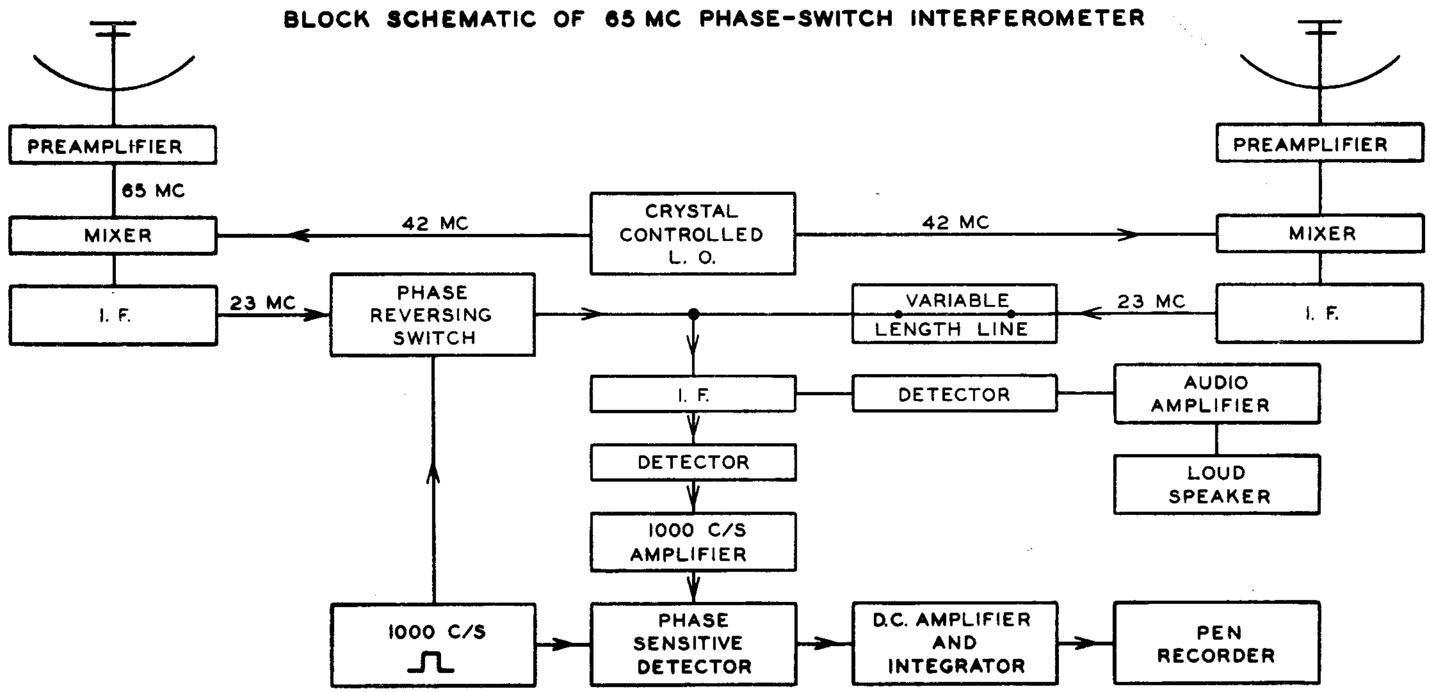

BLOCK SCHEMATIC OF 65 MC PHASE-SWITCH INTERFEROMETER
PREAMPLIFIER
65 MC
MIXER
42 MC
CRYSTAL CONTROLLED L. O.
42 MC
PREAMPLIFIER
MIXER
I. F.
23 MC
PHASE REVERSING SWITCH
VARIABLE LENGTH LINE
23 MC
I. F.
I. F.
DETECTOR
AUDIO AMPLIFIER
DETECTOR
LOUD SPEAKER
1000 C/S AMPLIFIER
1000 C/S
PHASE SENSITIVE DETECTOR
D.C. AMPLIFIER AND INTEGRATOR
PEN RECORDER

Fig. 3

detector or "mixer" is located on the preamplifier chassis along with the first intermediate frequency amplifier stage. These preamplifier units have been designed to give a maximum signal to noise ratio, and have noise figures of less than five db. Preamplifiers are being constructed for 223 mc in the Institute electronics laboratory while 455 mc preamplifiers are being built by the Airborne Instrument Laboratories, using special electronic tubes not yet in general production. The 23 mc intermediate frequency signals from each end hut are carried to the central building where they are mixed together after one of the signals is passed through the phase-switch equipment, in which a 180 electrical degree phase-shift is inserted and removed at the rate of 1000 times per second. The combined signals are then amplified by the main intermediate frequency amplifier which has a gain of 10^5 and band width of 0.5 mc. A crystal diode is used as the second detector of the receiver followed by a tuned audio frequency amplifier of the twin "T" feed-back type. The audio amplifier has a band width of 10 cycles per second with a center frequency of 1000 cycles per second. The 1000 cycle signal is developed from the "mixing" of the two intermediate frequency signals, one of which was phase switched at the 1000 cycle rate. The phase and amplitude of the 1000 cycle signal is a measure of the phase and amplitude of the received radio signal at the antennas. This 1000 cycle signal is introduced into the phase sensitive detector and compared with a reference signal from the master 1000 cycle per second generator that also controls the intermediate frequency phase-switch.

A direct current voltage is derived from the phase sensitive detector, amplified and applied to an Esterline-Angus pen recorder. A maximum direct current positive voltage indicates that the received signals at the two antenna are in phase and a maximum direct current negative voltage indicates that the received signals at the antenna are 180 electrical degrees out of phase. Zero direct current voltage indicates the two received signals at the antenna are in quadrature. These cross-overs, (zero direct-current voltage points) are of considerable importance in the analysis of the data obtained from the pen recorder. This places tremendous stability requirements on the phase sensitive detector and direct current amplifier circuits. It is desirable to have less than one percent drift in the zero point in 24 hours. The requirement of precision extends also to measurements of the base line, the orientation of the polar axis of rotation and the declination and hour angle settings, and of sidereal time. The overall phase stability will be checked using crystal-controlled target transmitters radiating less than one microwatt at a fixed location one mile south of the interferometer.

With these equipments, it is hoped to obtain measurements of the instantaneous positions of the more intense radio stars with an accuracy of about one minute of arc. It will also be possible to detect scintillations in amplitude when these exceed about 0.1 db.

IONOSPHERIC ABSORPTION

J. M. Lansinger

During the course of six months ending recently, we were privileged to have Dr. Willis Rayton from Dartmouth College here as a visiting professor engaged in research on ionospheric absorption at 30 mc. A brief outline of the essential features and results of his investigation in the field of absorption will be presented. A superficial general summary of the mechanism involved in absorption and information concerning the location and classification of the phenomena will be necessary in order that the reader gain proper perspective in the interpretation of the results obtained here at College.

Consider first the situation of an electromagnetic wave traveling through a medium containing only charged particles. Each individual particle will experience a force equal to the product of the charge and the instantaneous field intensity at its location in any one instant of time. Since the field intensity vector varies in a sinusoidal manner, the charged particles will oscillate at the wave frequency. Inherent to the fundamental fact that accelerated charged particles radiate electromagnetic energy, these charges will re-radiate energy at the frequency of the incident wave. It is by this mechanism that there is a transfer of energy from the wave to the medium and back to the wave again with no net loss of wave energy.

Because of the presence of atoms and molecules in the ionosphere, another important factor has to be considered. The electrons will collide with the molecules and will lose some energy by this collision process. In this manner there will be a transfer of kinetic energy from the electrons to the air molecules, the loss of wave energy being exactly equal to the gain in heat experienced by the medium. Thus, in the situation where the medium contains air molecules, the wave emerging from the medium will have less intensity than the incident wave, the ratio of the two intensities being a measure of the absorption present. (The effect of the positive ions is ignored, since, due to their comparatively heavy mass, they will remain practically inert in the passing wave field.)

Qualitatively, it can be seen that the rate at which the free electrons collide with the molecules is an influencing factor in causing absorption. The following table taken from data obtained in rocket measurements shows how the collision rate varies with altitude in the lowest ionospheric region.

Height (km)	10^7ollisional frequency (ν)
65	10^6 10^7 per second
80	10^6 per second
95	10^5 per second

From this logarithmic dependence of collisional frequency with height, it is seen that there is a relatively high increase in the collisional frequency as one approches lower elevations.

Experimental evidence indiates that a correlation exists between low ionization layer height (as indicated by short return echoes with a vertical incident sounder) and the occurrence of high absorption. This, coupled with the occurrence of high collisional frequencies at the lower heights, indicated that the D-region is the most likely location for the source of absorption.

The received wave is related to the absorption coefficient by the following relation:

$$E = E_o e^{- \quad kds}$$

where: E_o is the amplitude of the incident wave.

k is the absorption coefficient per unit path length.

It is necessary to integrate the absorption coefficient over the path of the wave because the absorption is not constant with a change in height, but varies in a complicated manner, depending upon the collisional frequency and the number of free electrons (N) per unit volume.

The basic proportionality relating the absorption coefficient to the known parameters of conditions existing in the D region is:

$$k \quad \frac{N}{f^2}$$

where: f is the wave frequency
is the collisional frequency
N is the number of free electrons per cubic meter

This expression for the absorption is an adequate approximation at 30 mc and assumes that the gyromagnetic frequency and the collision frequency are both very small compared with 30 mc. From rocket measurements over a range 165 to 95 km, it is found that the density of free electrons remains relatively constant with the height, the average value of N being 10^9 per m^3. From this we can conclude that for a given frequency at D region heights, the principal term affecting the absorption coefficient will be the collision rate.

At high latitudes absorption appears to be one manifestation of the corpuscular bombardment which also causes:

a) magnetic disturbances
b) polar sporadic E-layer
c) auroral effects
d) earth-currents

These associative high latitude effects are of sufficient magnitude to mask out the simple relationships between ionospheric absorption and solar zenith angle shown at lower latitudes.

Two methods of measurements are currently in use for the quantitative measurement of absorption. One method makes use of a vertical incident sounder and records the intensities of multiple F-region echoes. Making correction for the ground coefficient of reflectivity, the absorption present is found by taking the logarithm of the ratio of the intensities of the successive echoes. The other method utilizes extra-terrestrial radio noise coming into the earth from all directions of space. The unabsorbed value of the incident wave can be approximated by taking measurements over a period of time and using the highest value of intensity. Comparing this value with the measured value under attenuating circumstances will then give a measure of the amount of absorption present. Three such records are shown in Fig. 4, the dotted line in each case represents the signal level normally received under undisturbed conditions. This is essentially the method Dr. Rayton used at our Ballaines Lake experimental site. This latter technique has the advantage that the ambiguity of the ground reflectivity is not present, and no transmitting equipment is required.

Two equipments have been operating at the Ballaines Lake simultaneously, the zenith and the rotating antenna system, both at 30 mc. The rotating antenna system consists of a three element yagi, with a 55 degree beam width between the half power points. In the vertical plane, the direction of maximum gain is at an elevation of about 15 degrees above the horizontal. The antenna rotates continuously at a rate of one revolution every four minutes.

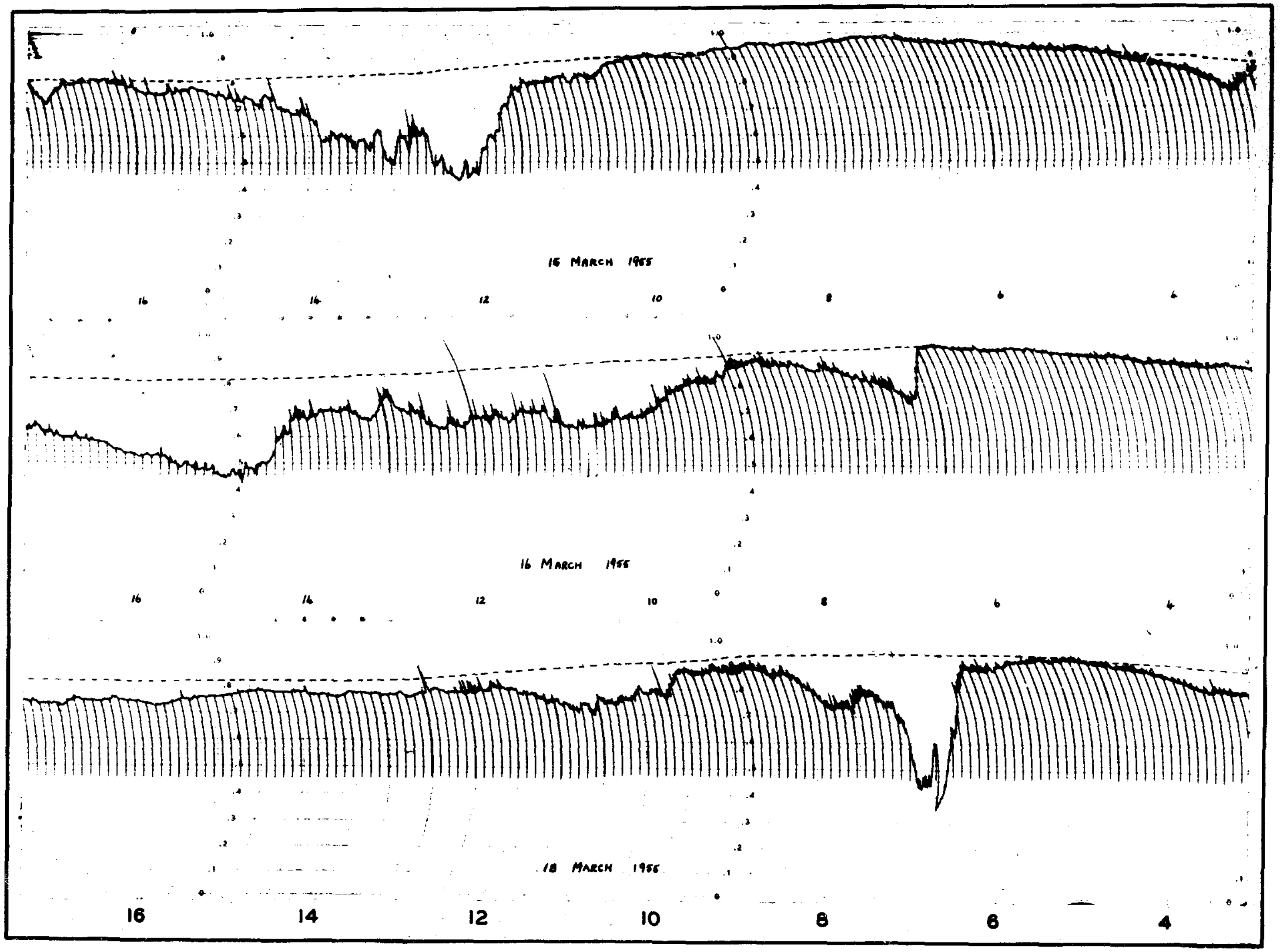
The received galactic signal from either of the equipments shows a variation of intensity which is caused by two factors:

1. Direction of Incoming Signal.

The signal reaching the earth will be a maximum from the direction of the center of our galaxy. This maximum intensity received will therefore vary in azimuthal direction according to the rotation of the earth, having a period of one sidereal day.

2. Amount of Ionospheric Absorption Present.

Lack of ionization and complete absorption are two possible con-

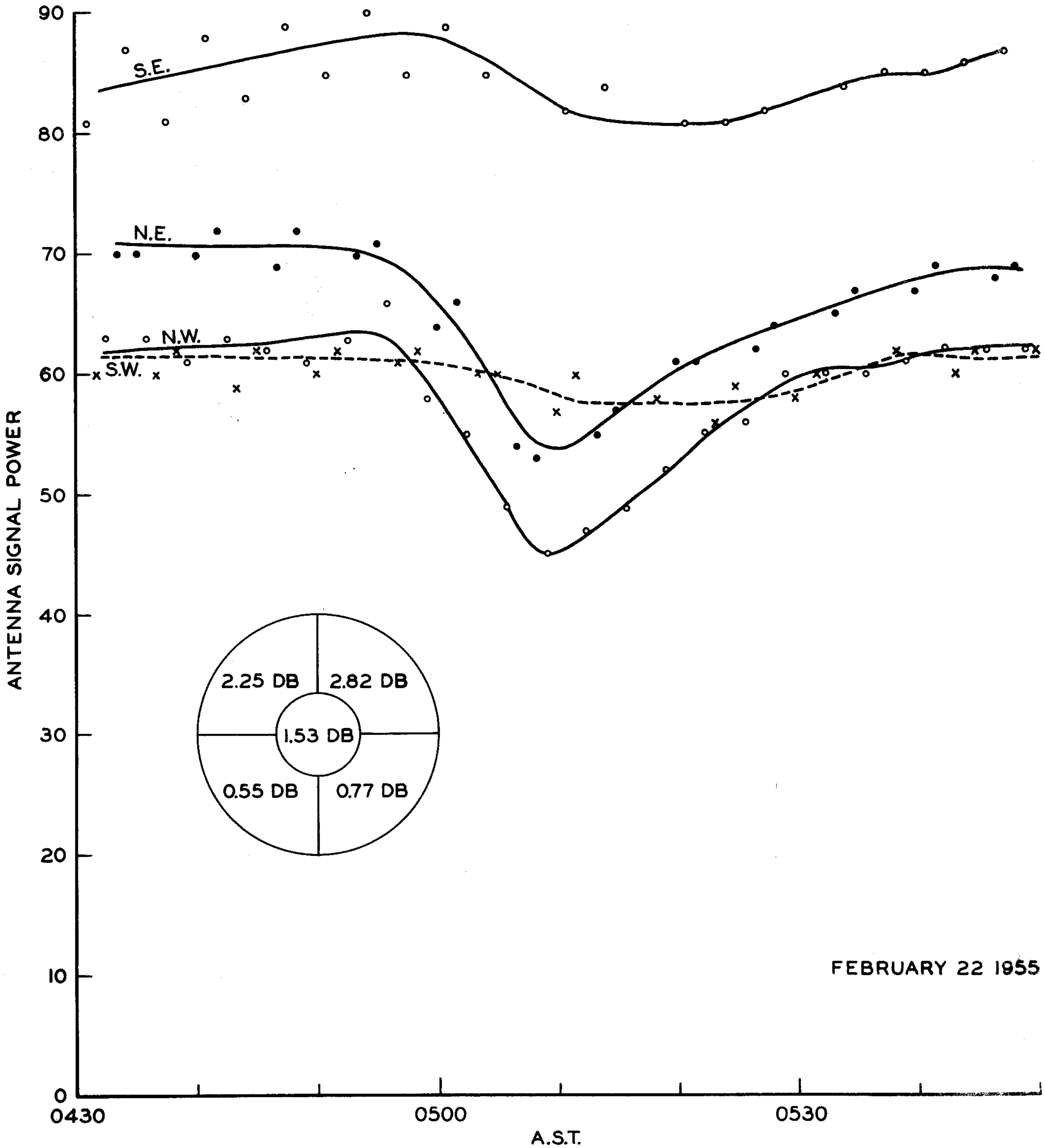


RECORDS SHOWING ZENITH ABSORPTION OF 30 MC EXTRA-TERRESTRIAL RADIO WAVES

Fig. 4

ditions that may explain the phenomena that occur when no echoes are received on the C-3 ionospheric recorder. This condition is commonly called "blackout" and is associated with times when normally ionospheric propagated signals cannot be heard. Data taken from the zenith equipment show that a linear relationship exists between the minimum frequency at which an ionospheric echo is detectable by a sweep-frequency recorder and the amount of 30 mc extraterrestrial absorption present. Thus, it is seen that it is absorption rather than lack of ionization that is responsible for blackout conditions. A small amount of absorption recorded at 30 mc will be greatly enhanced at the lower frequencies used in vertical ionospheric reflection work, due to the inverse square relation between the frequency and the absorption coefficient and also because of the double passage through the absorbing layer in the echo-sounding case. Zenith absorption of only one db is required to produce no-echo conditions on the C-3 ionospheric recorder.

The results indicate that, in general, absorption is non-uniform in direction (for example, see Fig. 5). Several records taken with the zenith equipment indicate that the galactic signal coming in from overhead has up to 75 percent absorption, while F-region propagated signals originating in the United States arriving at the same frequency are unaffected by the zenithal absorption. Data taken from the rotating antenna system have shown that the northerly directions give the most frequent and pronounced absorption. As high as 95 percent absorption



DIRECTIONAL ABSORPTION AT 30 MC.

Fig. 5

has been recorded at 30 mc.

While it is generally agreed that absorption at high latitudes is caused by charged particles emitted from the sun, the details concerning the exact process involved are not certain. For this reason, a greater emphasis is being placed upon comparing absorption with other high latitude phenomena that appear to be caused by these charged particles rather than the consideration of absorption as an entity in itself with no correspondence to other factors.

FORECASTING RADIO PROPAGATION CONDITIONS at the NORTH PACIFIC RADIO WARNING SERVICE

Martin E. Nason

Remarkably successful predictions of the gross characteristics of the various layers of the ionosphere have been made for about 15 years. The short-time variations, such as the ionospheric storms and SID's, are much more difficult to predict, however.

In the early days of World War II, a group was set up in the Washington, D. C., area to provide the military with forecasts of radio propagation conditions over the North Atlantic paths. The object was to predict periods of poor communications so that urgent messages could be transmitted with a minimum delay and, in general, so that important war-time circuits could be used more efficiently. This group is still in operation and is called the North Atlantic Radio Warning Service.

About five years ago, with the emphasis shifting to the North Pacific and Alaska, it was decided to set up a group to provide similar services of those areas. Anchorage was chosen as the site for the North Pacific Radio Warning Service because of its nearness to the great circle path from the west coast of the United States to the Orient and because it had the required facilities for distributing the forecasts.

The North Pacific Radio Warning Service regularly issues three types of forecasts of radio propagation conditions. Each of the forecasts is applicable to long distance sky-wave propagation in the North Pacific area. By giving them special interpretation, the forecasts may be used with less reliability for other paths such as the shorter Intra-Alaska circuits. The three types of forecasts are the advance forecast, the short-term forecast, and the 24 hour forecast. Each of the forecasts is made on CRPL's 1 to 9 scale of radio quality where 1 - useless, 2 - very poor, 3 - poor, 4 - poor-to-fair, 5 - fair, 6 - fair-to-good, 7 - good, 8 - very good, and 9 - excellent. In preparing the forecasts, it is the forecasters' basic assumption that the users have available the proper working frequencies and that they are in use.

Perhaps in order to discuss the forecasts, it would be easier to begin with the advance forecast, since it forms the basis for the shorter term forecasts. The advance forecast is issued twice a week. It gives the most likely periods for disturbed radio propagation conditions during the next 25 days and a more detailed forecast for each of the seven days following the date of issue.

These forecasts are based on the 27 day recurrence tendency of geomagnetic and ionospheric phenomena, sun-earth relationships, and the current quality of radio propagation conditions. Now that we are on the increase side of the solar activity cycle, more often than not the sun-earth relationships will be the deciding factor in arriving at the advance forecasts. We have a wealth of these types of data available at NPRWS. We receive by wire, once each day, reports from four magnetic observatories and from six ionosphere stations. Solar data from the world's observatories are relayed to us through the North Atlantic Radio Warning Service. Three times a day we receive reports of propagation conditions actually observed by Army and Air Force communication agencies and by Western Electric. All of these incoming data must be logged in usable form. We have found it most convenient to represent the data on a 27 day recurrence chart. Using the chart, it is possible to see the history of any particular cycle-day and thereby detect trends in conditions.

On forecast days, Tuesdays and Fridays, each of the forecasters at NPRWS studies the available data and independently arrives at his forecast for the coming week. This forecast he keeps to himself until the forecast conference. When the forecast conference is called, the duty forecaster brings the others up-to-date by giving them the details of his evaluation of conditions over the past 24 hour period. A moment is then allowed for any last minute revisions in the individual forecasts and then they are disclosed. As a rule, the independent forecasts will not be identical for each of the next seven days. This makes for the discussion period which follows. During the discussion, the relative merits of argument for a particular quality for a given day are taken into consideration. It may be that one or more of the forecasters have given undue importance to, or not enough importance to, a particular solar region, or that abnormal absorption reported by an ionosphere station was not fully considered. Usually a consensus is reached within an hour and the final forecast, and the basic facts considered in arriving at the forecast, are published as the CRPL-Jp Series. We currently mail over 300 copies of the Jp, and primary distribution by teletype is to 37 communication centers.

The second type of forecast is the short-term forecast. These short-term forecasts are issued three times a day; at 0200, 0900 and 1800 GCT. Each of the forecasts applies to the 9 hour period following the time of issue. In order to make these short time predictions successfully, it is very necessary for the forecaster to keep up-to-date in evaluating conditions so he will be able to detect trends. The data and reports we receive from our outside sources are certainly and aid in keeping up-to-date. Most of these data are less than 12 hours old at the time we receive them. However, data 12 hours old are in the "ancient history" class when speaking of radio propagation conditions - particularly in the Arctic regions. In order to keep abreast of conditions, NPRWS has its own observing program. Perhaps the backbone of the program is the hourly DF monitoring of 8 to 12 typical North Pacific circuits. For each circuit the bearing, bearing swing, and the amount and type of fade are observed and a quality figure is assigned to the signal, taking into account variations from normal in any of these parameters. After each of the circuits has been monitored, an average of the individual qualities is taken, and this average is interpreted as the overall quality for that particular hour. In addition to the DF, we also record field intensities of several circuits, and we have a visual recording magnetograph.

The short term forecast statement consists of a letter and a number. I must now emphasize that the letter portion of the statement is not the forecast. It is the forecaster's evaluation of conditions at the time the forecast is issued. There are three possibilities - N for normal conditions (6 to 9 on the quality scale), U for unstable conditions (quality 5) and W indicating that conditions are disturbed (1 to 4). The number portion of the forecast statement is the forecast itself. You may wonder why an estimate of current conditions is made part of the forecast statement. This can be rather simply explained. Let us say the forecast statement at a particular time is N5. This immediately tells the user that conditions are normal and the forecaster expects a drop in quality of at least one grade. Now suppose the user had already at the time of forecast been experiencing what he would call fair (quality 5) conditions and he had been given the number portion of the forecast only. It is easy to see that he would not be prepared for the expected drop in conditions. In other words, the letter portion of the forecast statement is a reference point for the number portion. The short term forecasts are phoned to about 15 communication agencies in Anchorage and distributed by teletype to 17 communications centers. The 0200 and 1800 forecasts are also broadcast WWVH, the NBS radio station on Maui, T. H.

The third type of forecast issued by NPRWS is the 24 hour forecast. This forecast is issued at 0900 GCT each day and consists of two numbers. The first number is the expected quality of conditions during the 1800-0600 GCT period following the time of issue, and the second number is the expected quality of conditions during the 0600-1800 GCT period of the following day. The 1800-0600 GCT period is roughly that of the daylight hours on the North Pacific paths, and the 0600-1800 GCT period approximates that of the night hours. The 24 hour forecast is currently distributed only to the CAA in Anchorage for use on their morning radio program during which they describe local flying conditions. The forecast is available to other users however.

In order to score the forecasts, we statistically reduce all our observations and the outside reports to the 1 to 9 scale of radio quality. All observations for a given day are correlated and, using the resulting correlation coefficients as weights, the weighted mean of the day's observations is taken as the quality figure for that day. In addition to the whole day quality figures, we also compute the quality for each of the three 9 hour periods covered by the short-term forecasts. These quality figures are published in Part B of the CRPL-F Series each month. A few copies of the Qp's, as they are called, for any particular month are available from NPRWS usually about the 10th of the following month. Preliminary quality figures for each of the three 9 hour periods are available within a few hours after the end of a period.

In closing, I should like to extend a cordial invitation to each of you to visit the North Pacific Radio Warning Service when you are in the Anchorage area. It will be our pleasure to show you around the station and perhaps go into more details concerning the preparation and use of the forecasts made available by the North Pacific Radio Warning Service.

WHISTLERS

J. H. Pope

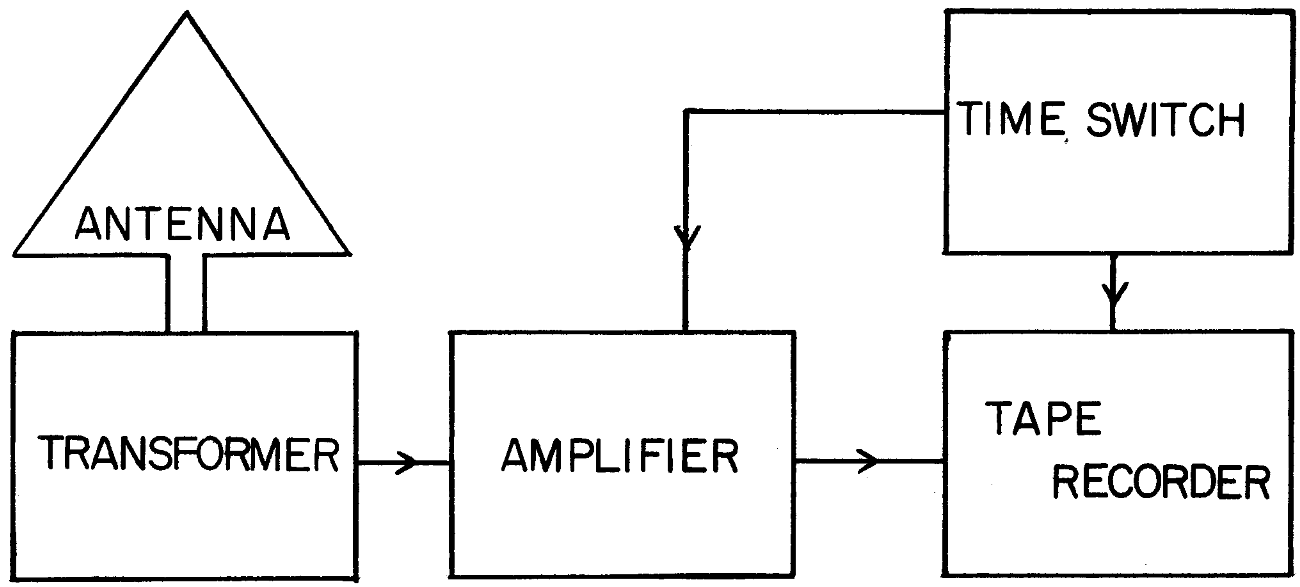
During the course of scientific investigation, various portions of the electromagnetic spectrum have been studied. Naturally, light was the first, followed by radio on the low frequency end, and x-rays on the high frequency end. Recently, the very low frequency portion of the spectrum, from 10,000 cycles per second down, has been studied. Various interesting phenomena known as atmospherics have been discovered on this band. One type of these atmospherics is known as the "whistler."

The whistler is characterised by a rapidly descending tone starting at 6 or 8 kc and terminating at about 1 kc. Whistlers last of the order of 1 or 2 seconds. They are sometimes preceded by twe ks or static crashes similar to static noises on a radio receiver.

These whistlers are received by an antenna and a high gain amplifier. Since the frequencies in which we are interested are in the audio range, it is convenient to use a tape recorder on the output of the amplifier. The receiving set-up is shown in Fig. 6.

Various other types of atmospherics are sometimes heard; rising tones, various combinations of whistlers with rising tones, and that known as "dawn chorus" - a multitude of short rising tones.

It has been shown that whistlers originate by lightning discharges.



BLOCK SCHEMATIC OF WHISTLER RECORDING EQUIPMENT

Fig. 6

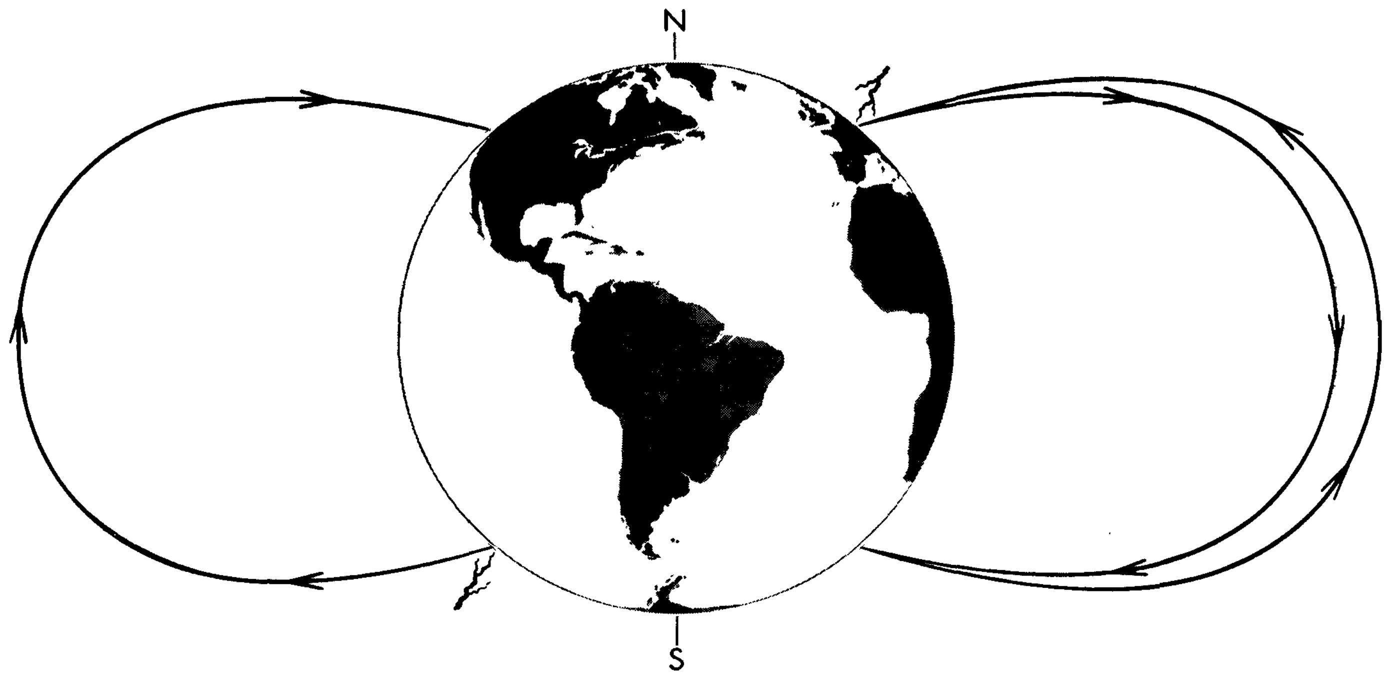
An electromagnetic pulse is radiated during such a discharge. It is well known that a pulse can be analyzed into a large number of frequency components. If this pulse is made to travel through a dispersive medium (one in which the velocity of propagation is a function of frequency), it is apparent that a frequency spread or dispersion will occur. Since the high frequencies travel faster in such a medium, they arrive first, followed by the lower frequencies. The ionosphere is an example of such a medium.

Since the index of refraction of the extraordinary ray is a minimum in the direction of the magnetic field for these very low frequencies, it can be shown that some of the energy in a pulse may be constrained to follow the geomagnetic lines of force.

Fig. 7 shows the propagation path of whistlers. Consider a pulse occurring in the northern hemisphere; some of the energy is radiated directly to the observer, and some follows the lines of force to the Southern Hemisphere and returns. The result is a tweek followed by a whistler. If the discharge occurs in the Southern Hemisphere, a whistler, but no tweek, is heard. Also, it is possible that the pulse makes several trips, in which case a multiple type known as "echoes" is heard.

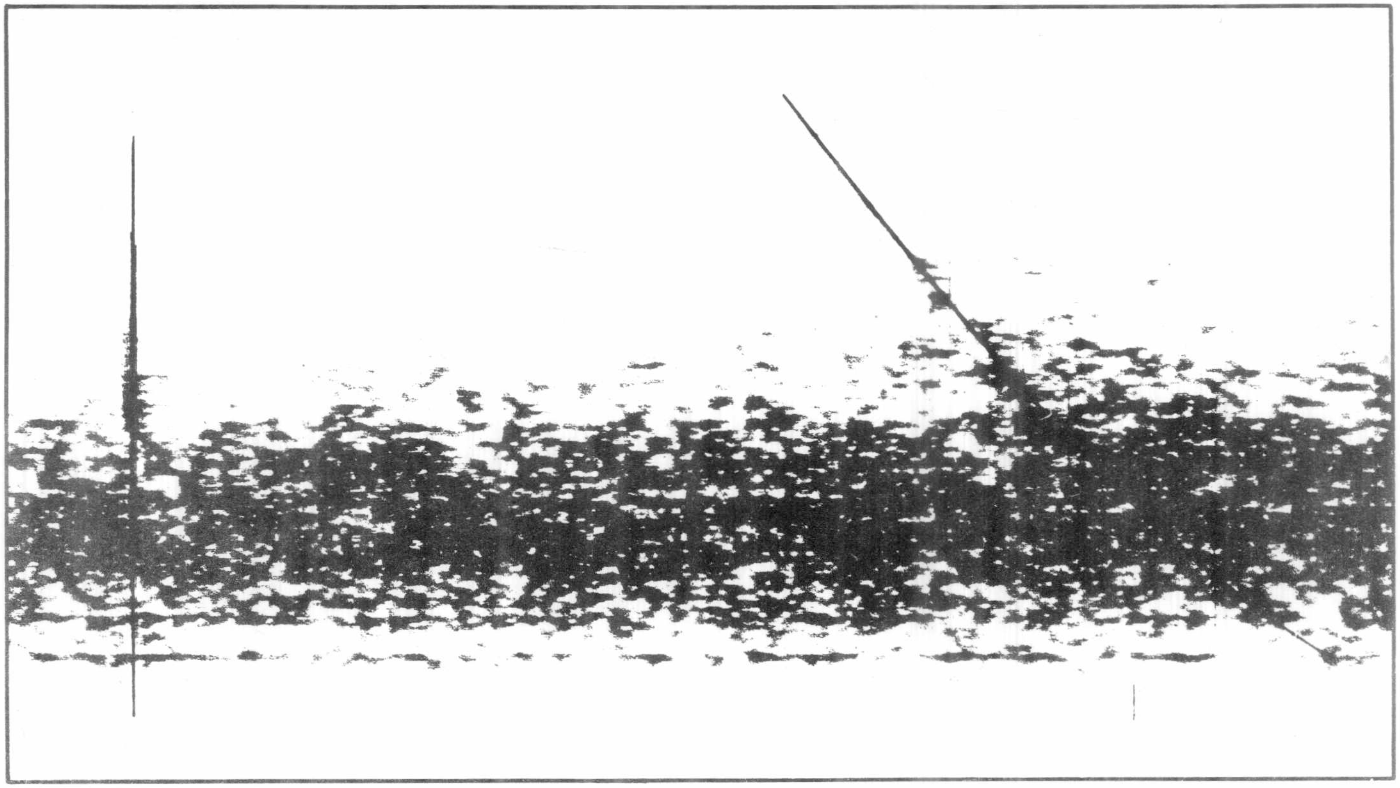
Whistlers are analyzed by means of a sound spectrograph, a machine which plots frequency as a function of time.

Fig. 8 is a frequency versus time display of a typical whistler. The initiation tweek is indicated by the vertical line, and the whistler is



PROPAGATION PATHS OF WHISTLERS

Fig. 7



TYPICAL SPECTROGRAM OF A WHISTLER AND ITS INITIATING TWEEK

Fig. 8

indicated by the sloping line. The short vertical line indicates a time of one second after the occurrence of the twe k. The frequency is on the vertical axis increasing from bottom to top from 200 cps to 4,000 cps.

These whistler curves have been shown to satisfy

$$t = D/f^{1/2}$$

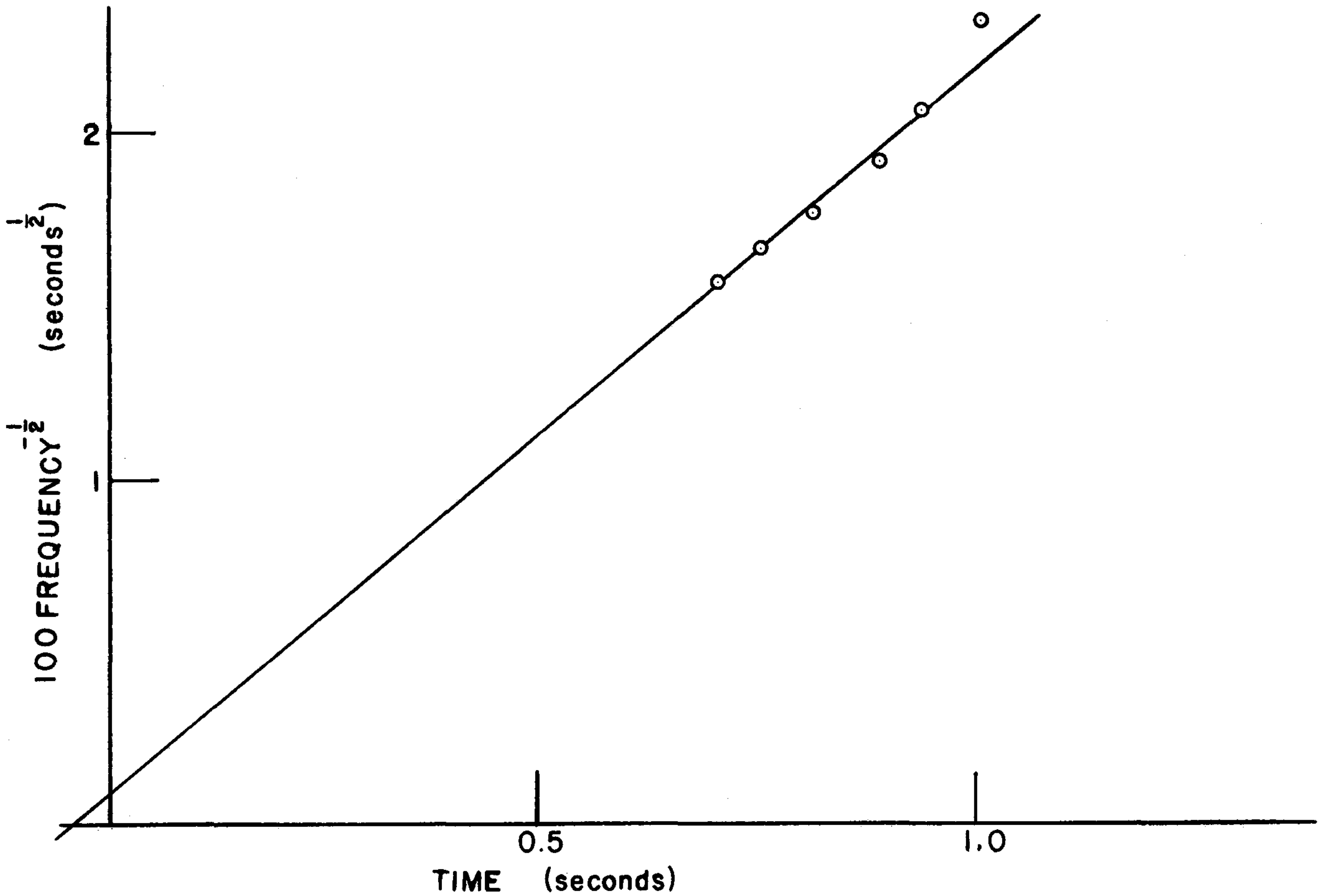
where f = frequency
t = time of occurrence of f
D = a constant for a particular whistler known as the dispersion

Thus, if we plot $f^{-1/2}$ as a function of time, we should get a straight line. Fig. 9 illustrates this fact. The circles are points obtained from the spectrogram of Fig. 8. The origin is taken as the time of occurrence of the tweek.

It has been found that the dispersion for whistlers originating in the Southern Hemisphere is in general one-half that for those originating in the Northern Hemisphere. This fact is in agreement with the theory.

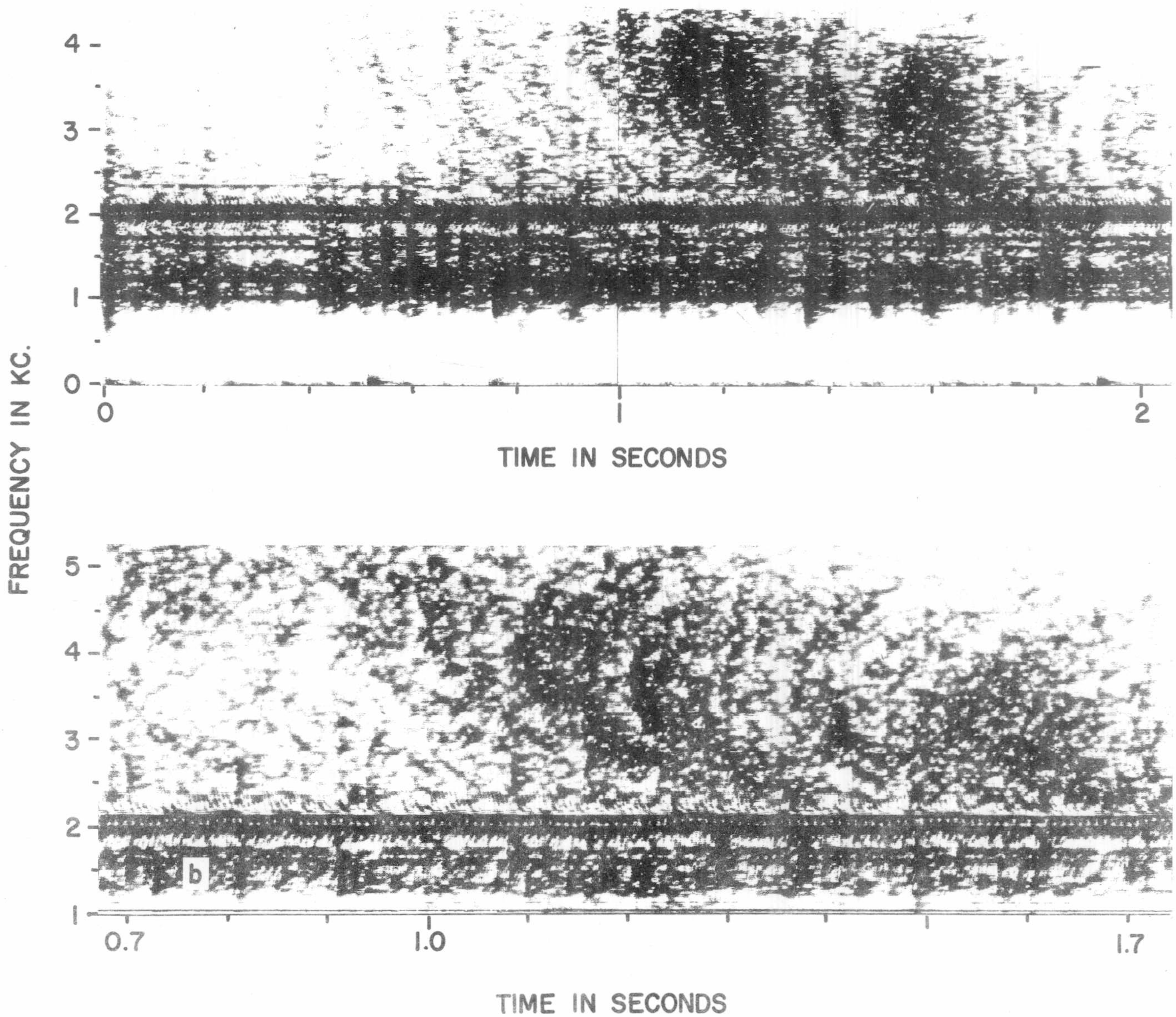
Analysis of the whistlers recorded here at College shows that these whistlers are quite different from those obtained at lower latitudes. Their distinguishing feature is that instead of starting at a high frequency and descending, they start at some frequency in-between and both descend and ascend in frequency. Their dispersion curves are much like parabolas. For this reason they are known as "nose whistlers." Fig. 10 is an example of a spectrogram of a "nose whistler."

It is supposed that their character is due to the fact that at these high latitudes the geomagnetic field line takes the pulse out to around



DISPERSION CURVE OF A WHISTLER

Fig. 9



SPECTROGRAM OF A TYPICAL NOSE WHISTLER RECORDED AT COLLEGE ALASKA

Fig. 10

30,000 km from the earth where the field is quite weak. The approximations to the propagation equations no longer hold and must be modified. The modified equations suggest that the velocity of propagation is a maximum for frequencies of the order of 4,000 cps.

The study of whistlers should give information as to the nature of the upper ionosphere. For instance, if the theory is correct, then it is necessary that the ion density at roughly 10,000 miles from the earth's surface must be around 400 ions per cc, a value which is very much higher than has previously been supposed. This region is so high that as yet no other techniques are available to study it.

H.F. RADIO BACKSCATTER

R. Stark

The maximum reflecting frequency of an ionospheric layer for a radio wave incident upon it at an angle i may be calculated from $f = f_o \sec i$, where f is the maximum reflecting frequency and f_o is the critical frequency of the layer at vertical incidence. The technique for H.F. radar is to operate at a frequency such that ionospheric propagation is possible most of the time. However, since the maximum reflecting frequency is a function of equipment parameters as well as ionospheric conditions, the highest frequency from which echoes can be expected will vary with ionospheric conditions and also with the equipment used.

The H.F. radar at College is operated on a frequency of 12.3 mc using a three element, horizontally polarized yagi rotating in a horizontal plane. The antenna pattern is such that an echo can be expected any time the critical frequency of the F-layer is greater than about 2 mc.

The equipment consists of a pulsed transmitter, a rotating antenna, and a receiver. The transmitter can be operated at preselected P.R.F.'s of 25, 50, 100, or 200 per second. The pulse length can be varied from 200 microseconds to 1.5 milliseconds. The final stage is a pair of 4-250 A tetrodes in push-pull. Average power is about 200 w. Typical operating conditions may be a P.R.F. of 50 and a pulse width of 400 microseconds with a peak pulse power in the neighborhood of 10 kw.

The power is fed into an inductively coupled three element yagi rotating at a speed of approximately 1 rpm. The receiver is connected to the same antenna. The receiver is of standard communication type but has been modified for pulse work. The output of the receiver is fed to a range-amplitude display or A-scan, which is used primarily for visual observations and identification of echoes. The output is also fed to a range-azimuth or P.P.I. display. This oscilloscope is continuously photographed with a single-shot ciné camera at one frame per revolution so that a complete antenna rotation is presented on each frame.

At least five echo sources have been identified. These are due to F-layer ground-scatter, auroral ionization, meteor trails, sporadic E-scatter (direct), and ground-scatter via sporadic-E. Work done previously here at College has shown that it is possible to differentiate between the different echoes by observing their respective amplitude fading and range characteristics. The simultaneous use of the A-scan and the P.P.I. is therefore essential since the intensity modulated P.P.I. display tends to average out the amplitude fading.

The P.P.I. equipment at the Institute has been in operation a relatively short time, and very little statistical work has been done. Data are being collected, and scaling procedures are being developed.

This discussion of the work will therefore be confined to such phenomena as have been recorded or observed visually to date. F-region

1800 km and an auroral type echo at 2200 km were observed simultaneously in the same direction. If we assume a height of 250 km for the F-layer and 100 km for the aurora, then some of the ground-scatter energy may have been scattered back to the receiver via the F-layer to produce the F-layer echo, at a range of 1800 km. In addition some of the radiation scattered from the ground in the forward direction may have been reflected from a distant aurora back over the same path to result in an auroral echo at a range greater than the F-layer echo. In cases when the F-region echoes are not present, we could only assume that the forward-scatter is much stronger than the back-scatter and that the auroral echo appears via the same mechanism, but that the back-scatter which previously gave an F-layer echo was in this case not strong enough to be received.

Short-range auroral echoes have been observed in virtually all azimuths and tend to occur at uniform ranges around the observing point (for example, see Fig. 12). This is in apparent contradiction to the work done by Bowles and Dyce at College in 1954-1955 which suggested that the auroral ionization exists in columns parallel to the earth's magnetic field, and therefore that the probability of receiving an auroal echo is greatest when the radar waves are incident perpendicular to the direction of the magnetic field in the aurora. However, these observations were made at 50 mc and 100 mc, and it was shown that this aspect sensitivity was less marked on the lower frequencies. By extrapolation,

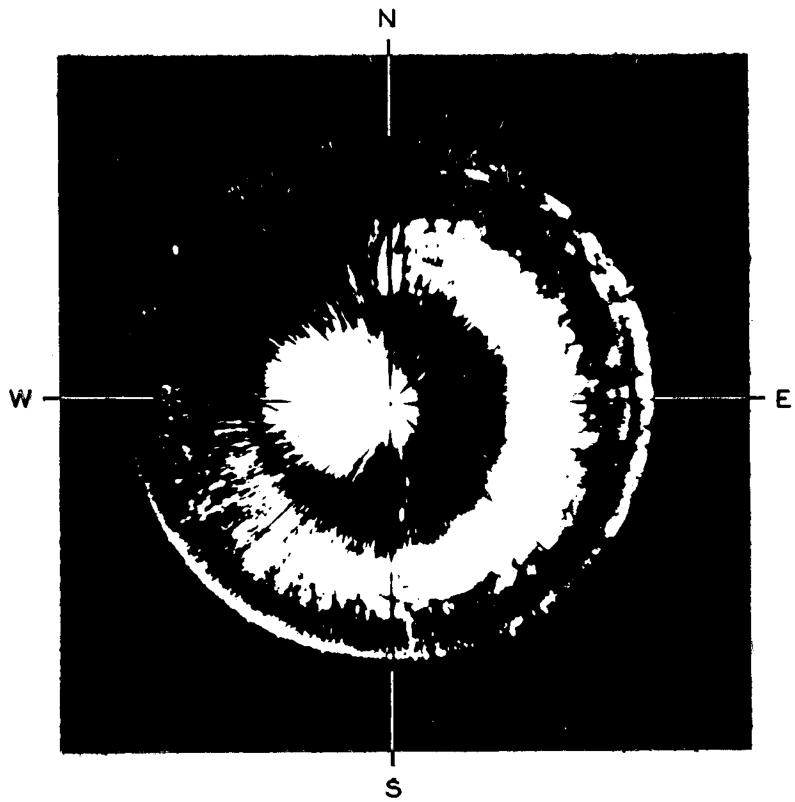


Fig. 11 F-Region Echo Blanketed by Sporadic E in Northwest Quadrant. Double-Hop F - Region just Appears on Edge of Scope in East and Southwest.

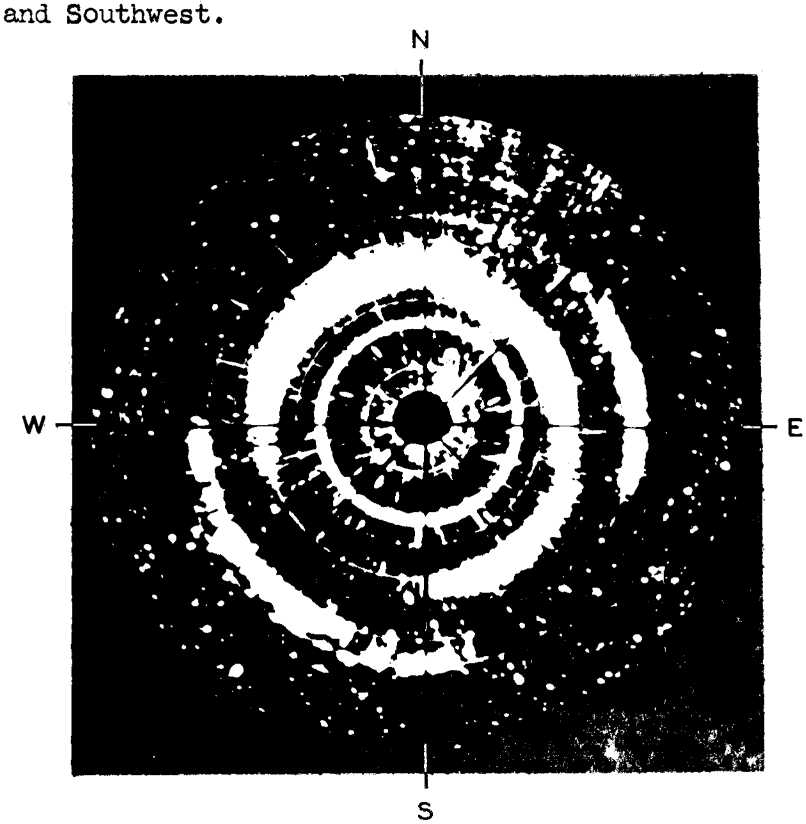


Fig. 12 Auroral Echo at about 400 km. Second Auroral Echo at about 800 km in East. Sporadic E Groundscatter in Southwest, Possibly Blanketing Aurora in that Quadrant.

echoes have so far corresponded to approximately what would be expected from known information. All F-region echoes appear to be ground-scatter; thus, the range of the echo is actually twice the range of the reflecting area in the ionosphere. The range appears to show diurnal variation in agreement with variations in critical frequency and virtual height of the layer. Double-hop echoes have been observed, and it is interesting that the second echo is not always an exact multiple of the first in range. This can be accounted for by the variation in virtual height and critical frequency with distance, since the separation of the reflecting areas may be separated by 1500 km or more. Calculations of critical frequency and M.U.F.'s for remote areas might be possible using this information.

Sporadic E-echoes have been observed at ranges between 150 km and 800 km. The lower range echoes are thought to be due to direct-scatter from sporadic E ionization near the zenith. The larger range echoes are probably due to ground-scattered signals, though this has not yet been confirmed. The observations to date have shown that the sporadic E ionization is usually a localized occurrence (see Fig. 11).

Auroral echoes have been observed over a range of 150 to 1100 km. Echoes exhibiting auroral characteristics have also been observed at ranges of over 2000 km. These echoes could be F-region propagated auroral echoes and may occur with or without an F-layer echo at some interim range. For example, on one occasion an F-region echo at it would appear likely that at 12 mc, the angle of departure from perpendicular could be as great as 20° - 30°. In this case, echoes would be expected at almost all azimuths, particularly when the antenna beam width is taken into account.

It might be pointed out that although aurora has been observed in the south, it has never appeared in that aspect only. It exists only in the south as a continuation of echoes which appear to be strongest in the northern quadrants. Quite often an echo appears over only 60° - 90° in azimuth. Since the antenna beam width is of the order of 50°, these echoes must arise from a highly localized source; this type of echo has never been observed in the south. Another point of interest is that auroral regions lasting only a few minutes have been detected, as well as some that last for several hours.

As yet not too much attention has been given meteors on the P.P.I. display; however, data of a statistical type is automatically being accumulated with the rotating antenna.

In conclusion, H.F. radar has obvious advantages over certain other techniques as a radio propagation tool. As compared to vertical incidence sounding, it should produce much additional information since it actually looks at the propagation path involved, and if a disturbance is in progress, will report on the activity of the disturbance. A second advantage arises from the rotating antenna, since the equipment looks at all azimuths.

It is also obvious from the discussion at the beginning of this article, that the technique could be improved by operating simultaneously on two or more frequencies, or by using a sweep frequency device at slant ray incidence. It is hoped that both these techniques will be used at the Geophysical Institute during the next year or eighteen months.

RADAR METEOR ECHO OBSERVATIONS
at
College, Alaska

R. N. Shoup

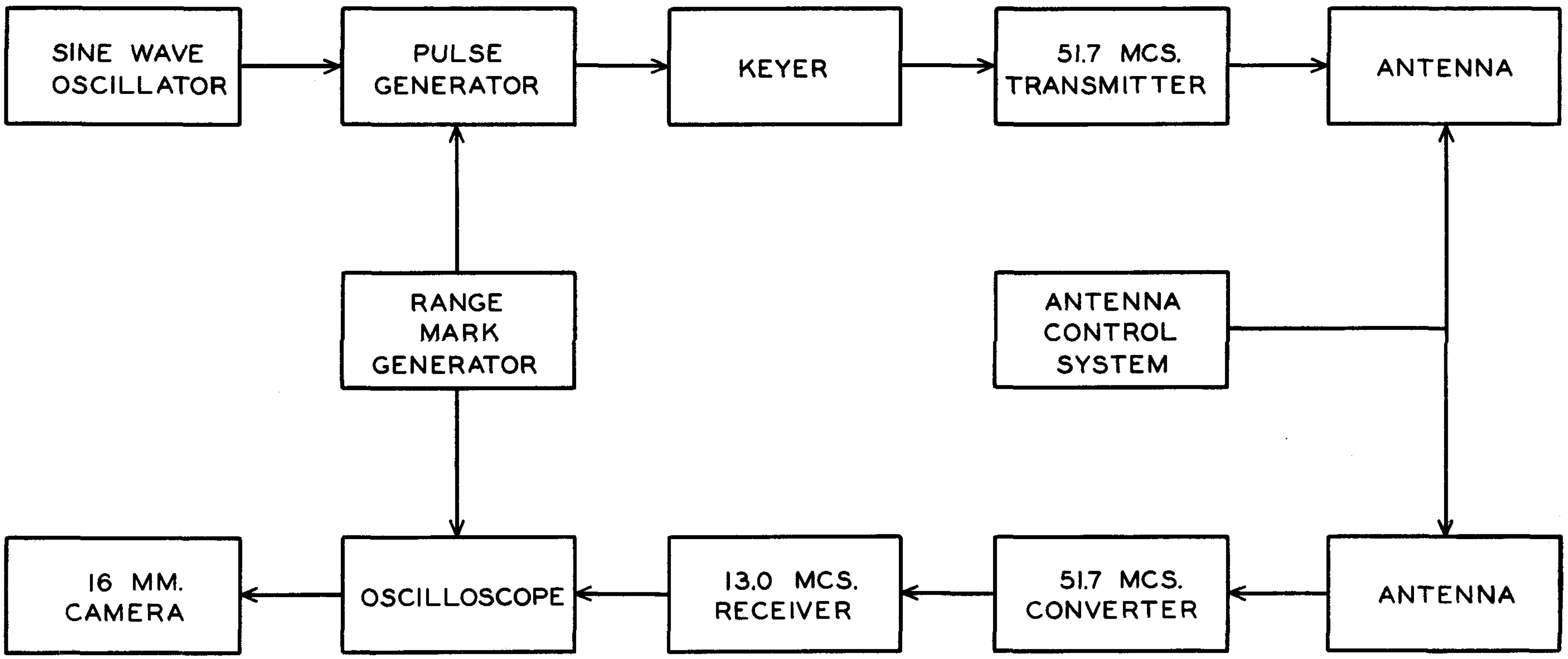
The first meteor observations were made visually by ancient man many ages ago, and this technique is still in use today. The latest technique dates back to slightly over twenty years ago when Eckersley showed that short lived bursts of signal within the normal skip zone, usually attributed to radio signals, were due to meteor trail ionization. Subsequent investigations by others in the field confirmed this. Due to the intervention of the last war, no major investigations of this phenomenon were made until 1946.

During the intervening years, 1929 - 1946, the observation of moving objects by means of pulsed radio transmitters and sensitive receivers was developed and perfected and became what is known familiarly today as radar. One needs but little reflection to see readily that radar has several advantages over the visual methods of observing meteors. For example, the meteor trails can be detected during daylight hours or under adverse weather conditions. Techniques for automatically recording the range, height, velocity, and direction of travel of the meteors have been developed, with the result that the understanding of meteor astronomy and of meteor physics has probably advanced more in the last ten years than in all previous centuries.

This radar method is now being used at College. Basically, the equipment (see Fig. 13) consists of a sine wave oscillator, a pulse shaper, keyer, and a transmitter operating on 51.7 mc with a peak power output of 5 kw which is fed to the transmitting antenna. The receiving equipment consists of the receiving antenna fed to a converter operating on the transmitter frequency, which in turn is fed to a National H.R.O. Converter for pulse work. The video output of the H.R.O. pulse receiver is piped into an intensity modulated oscilloscope. Data are recorded on continuously moving 16 mm film with a modified Kodak movie camera driven by a 1 rpm motor. The equipment is now situated on the hill immediately behind the Geophysical Institute.

The work which has been done so far here at College is of limited scope. Much of the work was done by Ken Bowles during his 1954 auroral research here at the Institute. Bowles suggested that the number of meteors per minute, and their echo strength as observed by radar, went up during the presence of aurora, decreasing again afterward. The meteor observations were discontinued upon Bowles' departure for the States, and the work was not taken up again until May, 1955.

At this time Dr. Little suggested that the matter be looked into again. This time the 50 mc equipment was chosen because it could readily be adapted for continuous automatic operation.



BLOCK DIAGRAM OF 51.7 MCS. AURORAL AND METEOR RADAR

Fig. 13

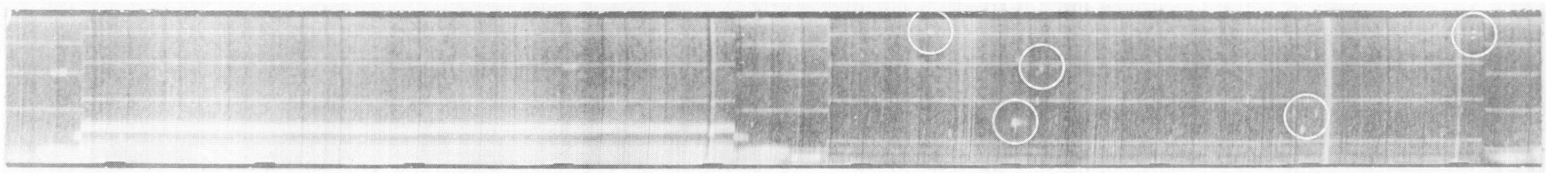
The central idea of this work was to prove or disprove Bowles' suggestion. This program called for 24 hour operation with the antenna looking north for four minutes, a one minute rotation period toward the south, a four minute period looking to the south, and a one minute return to the north. The experiment ran from June 24, to July 21, 1955.

The analysis of the 50 mc data was done as follows: The number of meteors per azimuth and auroras per azimuth was totaled for each hour and plotted. This gave a total of 24 minutes of information per azimuth per hour. The averages were computed by dividing the grand total for each hour of the day by the number of actual hours of operation.

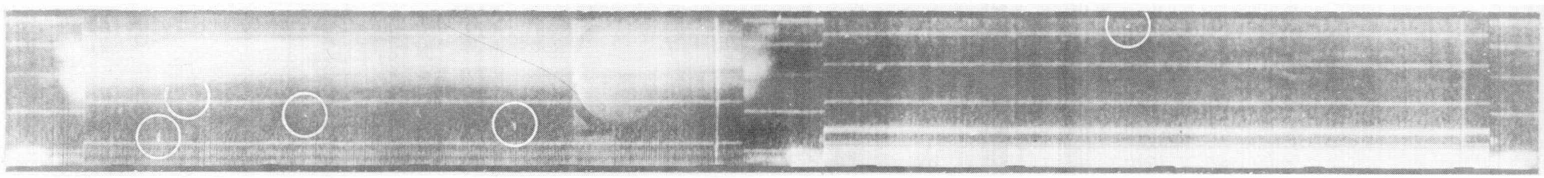
Fig. 14 displays a sample strip of film from an active day, during the absence of aurora, as compared to the same period from another day during aurora. These reproductions are unfortunately not as clear as the originals owing to the density of the film.

The upper strip shows meteors without aurora present. The time interval for each "long" frame is four minutes. Each vertical division represents an increment of 200 km in range. The displaced divisions represent the time required for the antenna to rotate 180 degrees. In the upper left hand corner and lower right hand corner, the heavy lines are echoes from Mounts Hess, Hayes, and Deborah; the line at about 210 km is the echo from Mt. McKinley.

The small bright dots within the white circles are short duration meteor echoes. In the lower sample we have meteors with aurora pre-



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



METEORS WITH AURORA. 0700-0710. JULY 12 1955

Fig. 14

sent. The wide heavy band is aurora at about 550 km. The "frames" displaying mountain echoes indicate the antenna was looking south.

Fig. 15 is the histogram for an average active day.

Beginning at midnight, local time, the meteor rate gradually increases. This is normally to be expected due to the direction of the earth's rotation, and this peak period of activity is present in all the records.

Plotted on the same time-scale as the meteor histogram, we find aurora present at midnight, decreasing gradually towards 0500 and increasing again until a peak is reached at the same time we arrive at the meteor peak. This is true for this day only, as previous auroral research has shown that echoes are most frequently observed at College at about 0030 hours.

Those who are familar with auroral research will note that auroral echoes were apparently detected to the south. We wish to point out that the majority of these southern echoes occurred when aurora was present simultaneously in the north. The author believes these echoes were received from the back lobe of the antenna, although two instances were noted where echoes at about 700 km from ionized regions in the south registered on the film. The preceding and following north azimuth "frames" did not display auroras. Records for this time from the Geophysical Institute ionospheric sounder display sporadic E echoes out to 20 mc. Calculations indicate that a "critical frequency" of 15 mc would produce sporadic E back-scatter

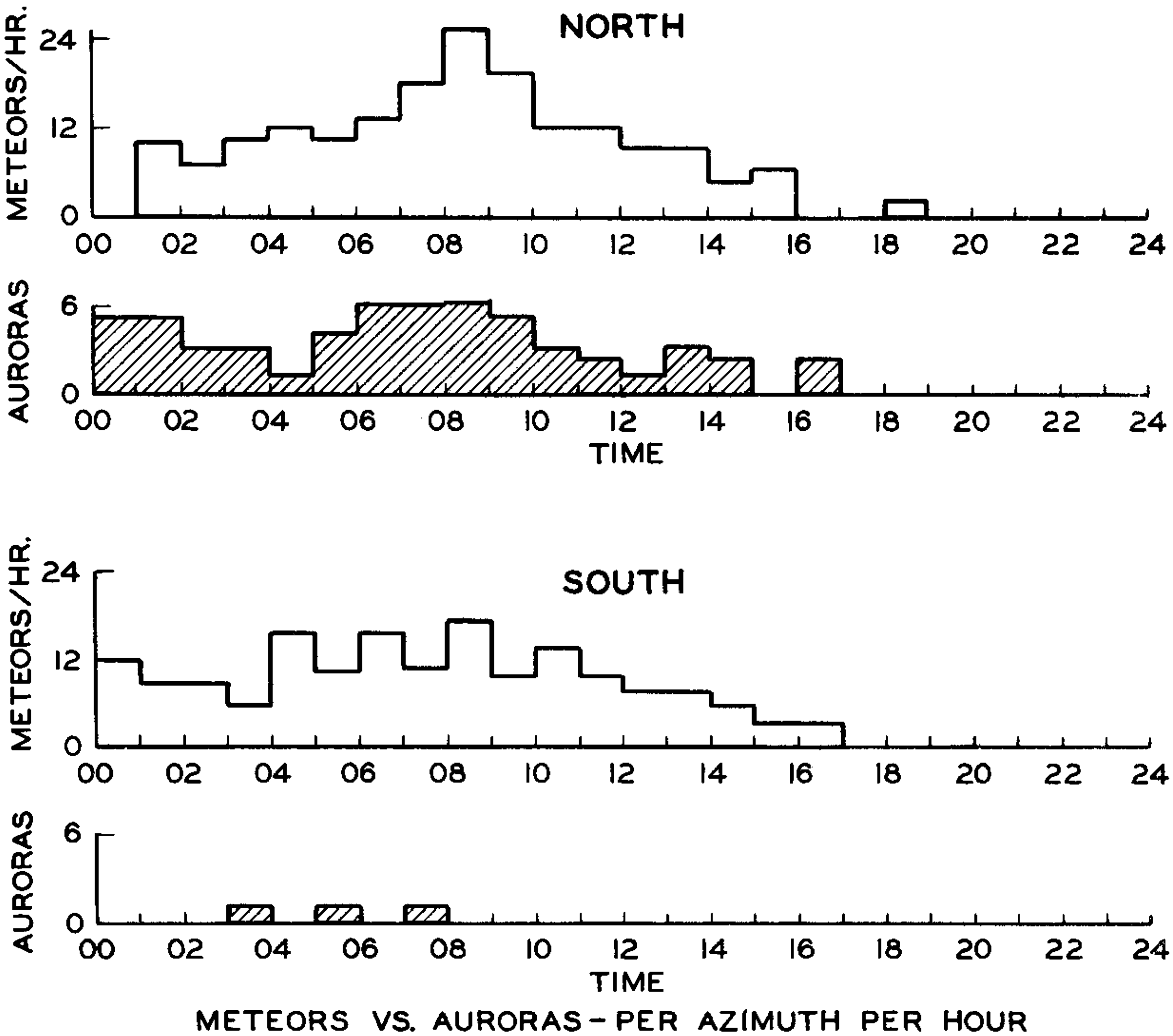

NORTH
METEORS/HR.
24
12
0
00 02 04 06 08 10 12 14 16 18 20 22 24
AURORAS
6
0
00 02 04 06 08 10 12 14 16 18 20 22 24
TIME
SOUTH
METEORS/HR.
24
12
0
00 02 04 06 08 10 12 14 16 18 20 22 24
AURORAS
6
0
00 02 04 06 08 10 12 14 16 18 20 22 24
TIME
METEORS VS. AURORAS - PER AZIMUTH PER HOUR

Fig. 15

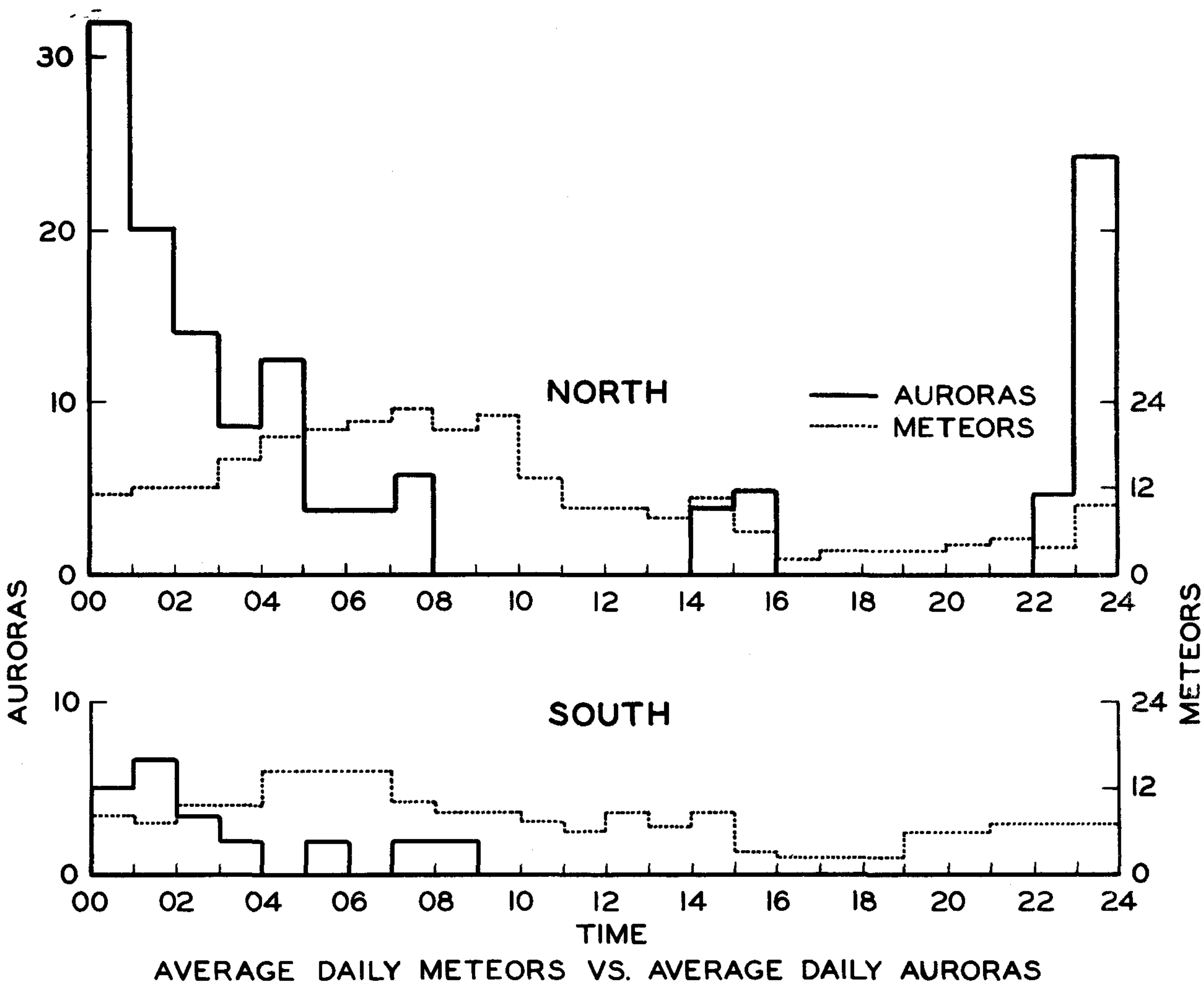
at a range of 750 km for a transmitter operating on 51.7 mc. As echoes from the south are very rare and are mentioned only once in the literature, we do not wish to comment further on this at this time, except to suggest that the echoes were due to ground-scatter propagated via sporadic E ionization.

Fig. 16 is a plot of average daily meteors and average daily auroras for both azimuths. The early morning meteor maximum, with the majority occurring in the north, occurs again about 0700. This is in striking contrast with the average incidence of aurora, which shows a strong peak about midnight.

In Fig. 17 the "average daily meteors during the presence of aurora" is compared with the "average daily meteors during the absence of aurora." This shows that, for this equipment, the meteor echo rate was not significantly affected by the presence of aurora.

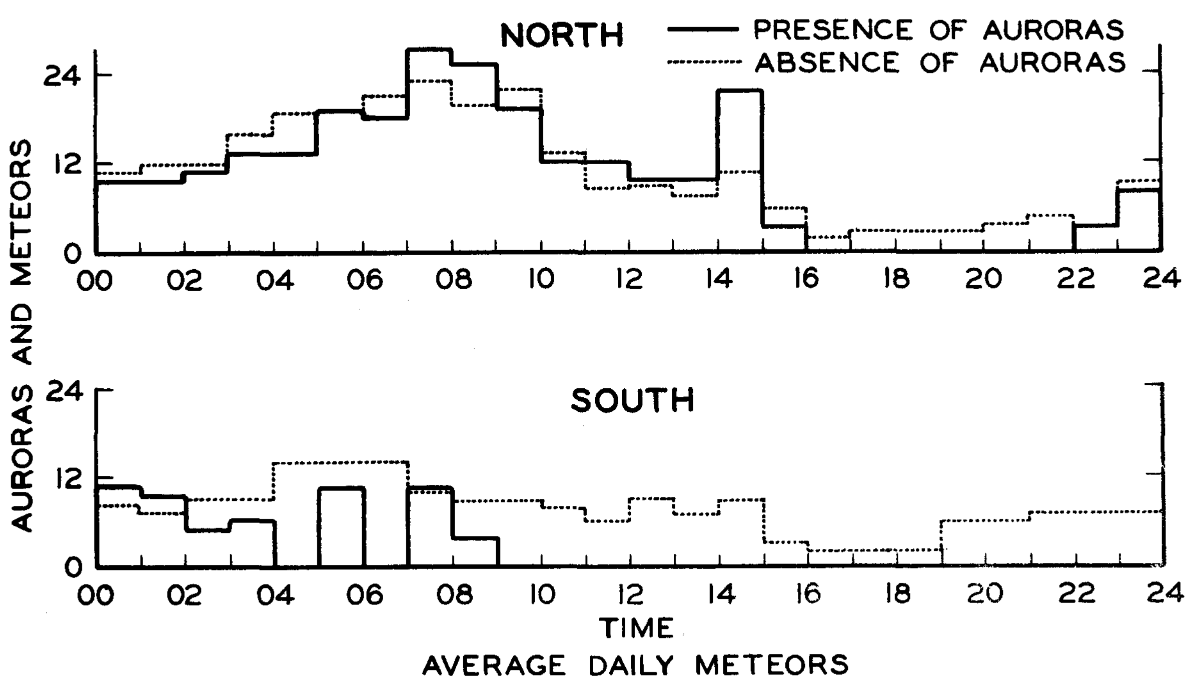
We therefore feel that this experiment indicates no correlation between the meteor activity and the presence of aurora. This result is apparently in conflict with Mr. Bowles' unpublished observations. It is, however, possible that some of this discrepancy is due to the very different equipment parameters involved in the two experiments.

We do wish to point out the larger number of meteors counted in the north. Analysis shows that, on the average, the meteor echo rate to the north was larger than to the south by a factor of 1.52. We advance the suggestion at this time that the larger meteor count in the north is



NORTH
AURORAS
METEORS
SOUTH
TIME
AVERAGE DAILY METEORS VS. AVERAGE DAILY AURORAS

Fig. 16



NORTH
PRESENCE OF AURORAS
ABSENCE OF AURORAS
AURORAS AND METEORS
SOUTH
TIME
AVERAGE DAILY METEORS

Fig. 17

due to non-cylindrical expansion of the meteor trail, in addition to the effect of the non-isotropic distribution of meteor radiants.

Referring to Fig. 18, at the time T_0 the trail is created, it is circular in cross-section. As time progresses through T_1, T_2, T_3, etc., and the trail expands, it gradually becomes elliptical in shape with the long axis of the ellipse aligned with the earth's magnetic lines of force. As such, it would present a larger target area to a radar pulse, whose slant range angle was perpendicular to the long axis of the ellipse.

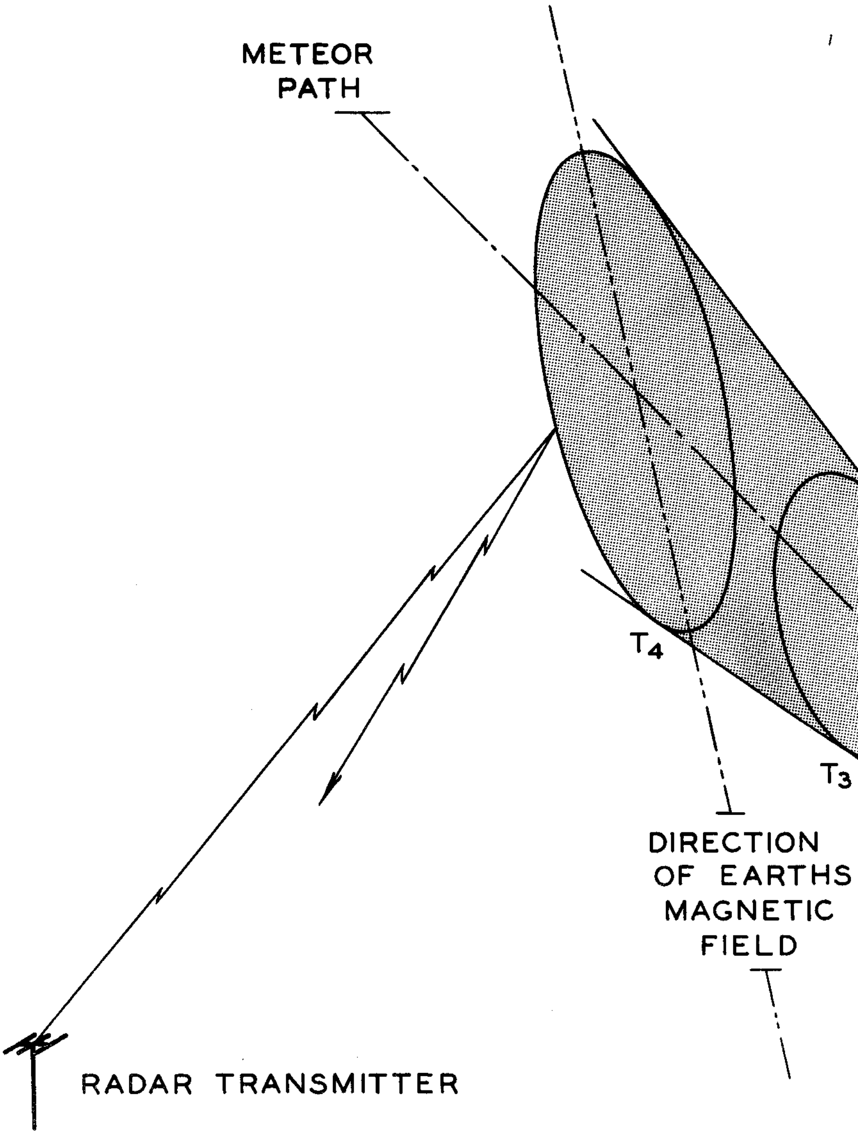
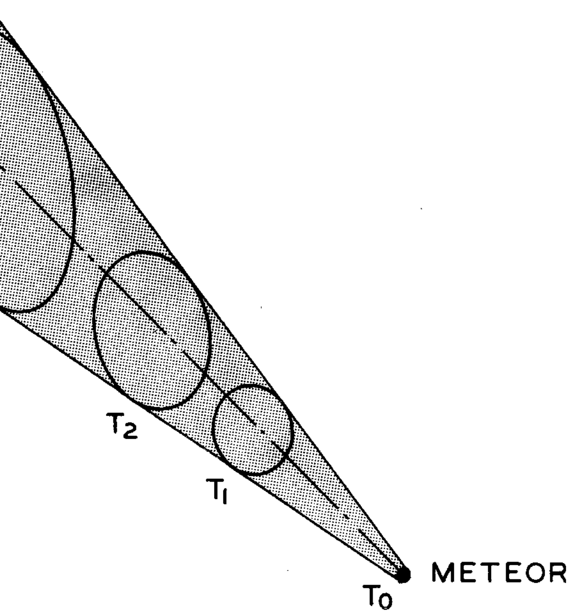

METEOR
PATH
T4
T3
DIRECTION
OF EARTHS
MAGNETIC
FIELD
RADAR TRANSMITTER

Fig. 18



METEOR
T0
T1
T2

RADAR ECHOES FROM THE AURORA

R. S. Leonard

This paper describes some of the auroral radar work done at the Geophysical Institute during the past two years. When we speak of auroral radars, we are talking about equipments similar to conventional radars, in that they send out a short pulse of radio energy to be reflected from some object, and then detected by a sensitive receiver tuned to the same frequency. The major differences are that we use pulse lengths on the order of 100 microseconds to one millisecond with the resulting narrow optimum band width. Also, our range is extended to about 1500 km or about 900 miles. In general our operating frequencies are much lower than the conventional radars; the frequencies used in the experiments described here are 50 and 100 mc.

One of the early discoveries in auroral radar experiments was that there are no echoes obtained from aurora overhead despite visual aurora in this part of the sky. Three theories were advanced to explain the auroral echoes observed to the north but not overhead:

a) Harang and Landmark postulated reflection from a thin layer to the ground where the signal was scattered back over the same path. Overhead echoes were not observed because the critical frequency was lower than the operating frequency.

b) Currie, Forsyth, and Vawter postulated direct reflection from the aurora. Overhead echoes were not observed due to an absorption layer located directly below the aurora.

c) Booker, Gartlein, and Nichols postulated direct reflection from aurora only when the radio waves are incident normally, or almost normally, to the direction of the earth's magnetic field.

These three theories are shown diagramatically in Fig. 19.

At the time these theories were advanced no one had been able to detect aurora to the south of the station, but this was dismissed as being due to the fact that the stations were located so far south that strong aurora seldom, if ever, occurred in that region of the sky. Note here that the first two theories would predict echoes to the south while the third does not.

In order to test this, Mr. Rolf Dyce took a small lightweight equipment operating at 51.9 mc to Pt. Barrow, which is located well within the auroral zone. Fig. 20 shows the results of his work. Note that over 90 percent of the echoes obtained were north of the east-west line. In order to see how important it was to have the radio ray perpendicular to the aurora, he plotted contours of off-perpendicular angles as a function of range and azimuth as shown in Fig. 21. This bit of data gives strong favor to the third theory.

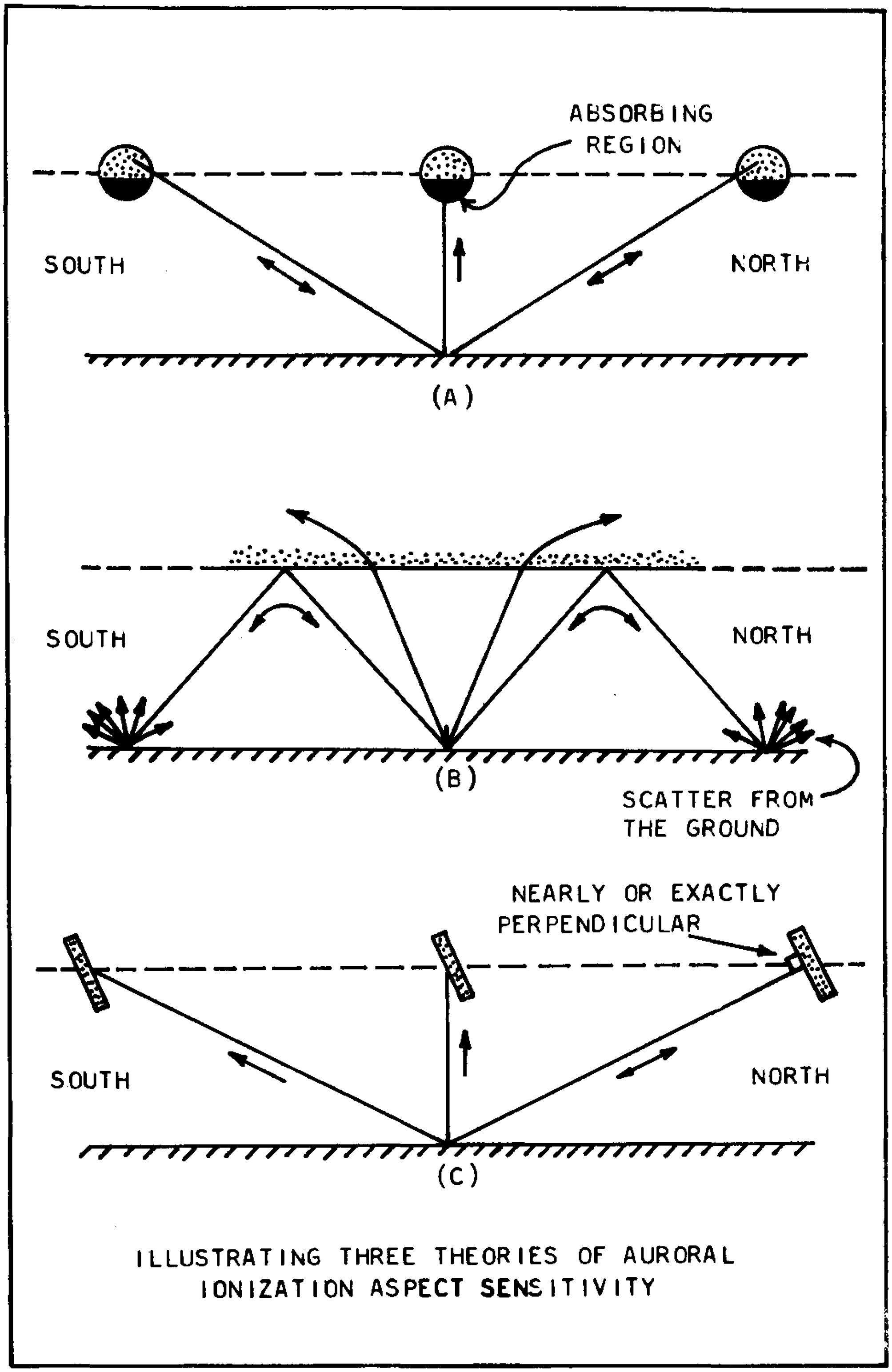
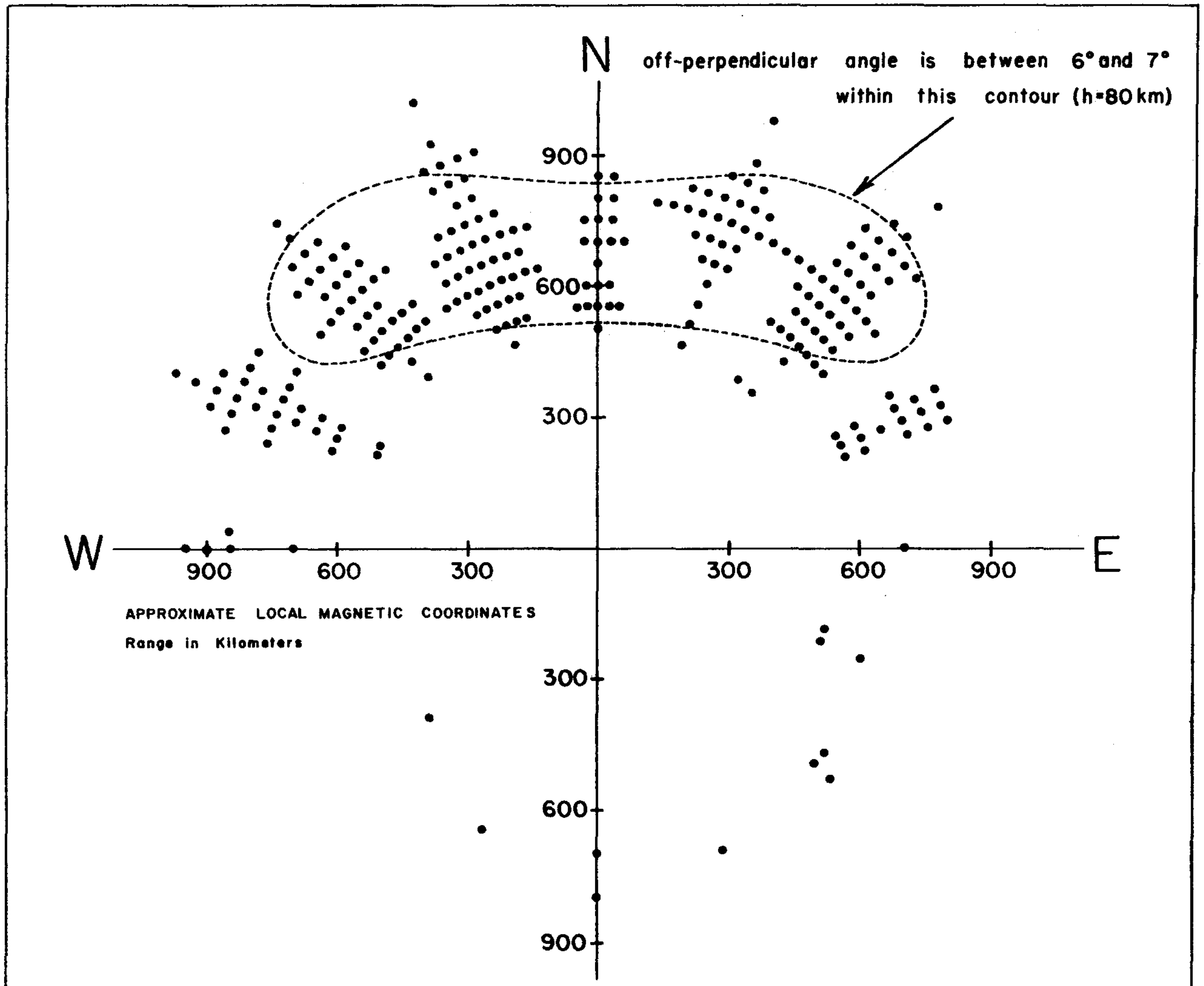
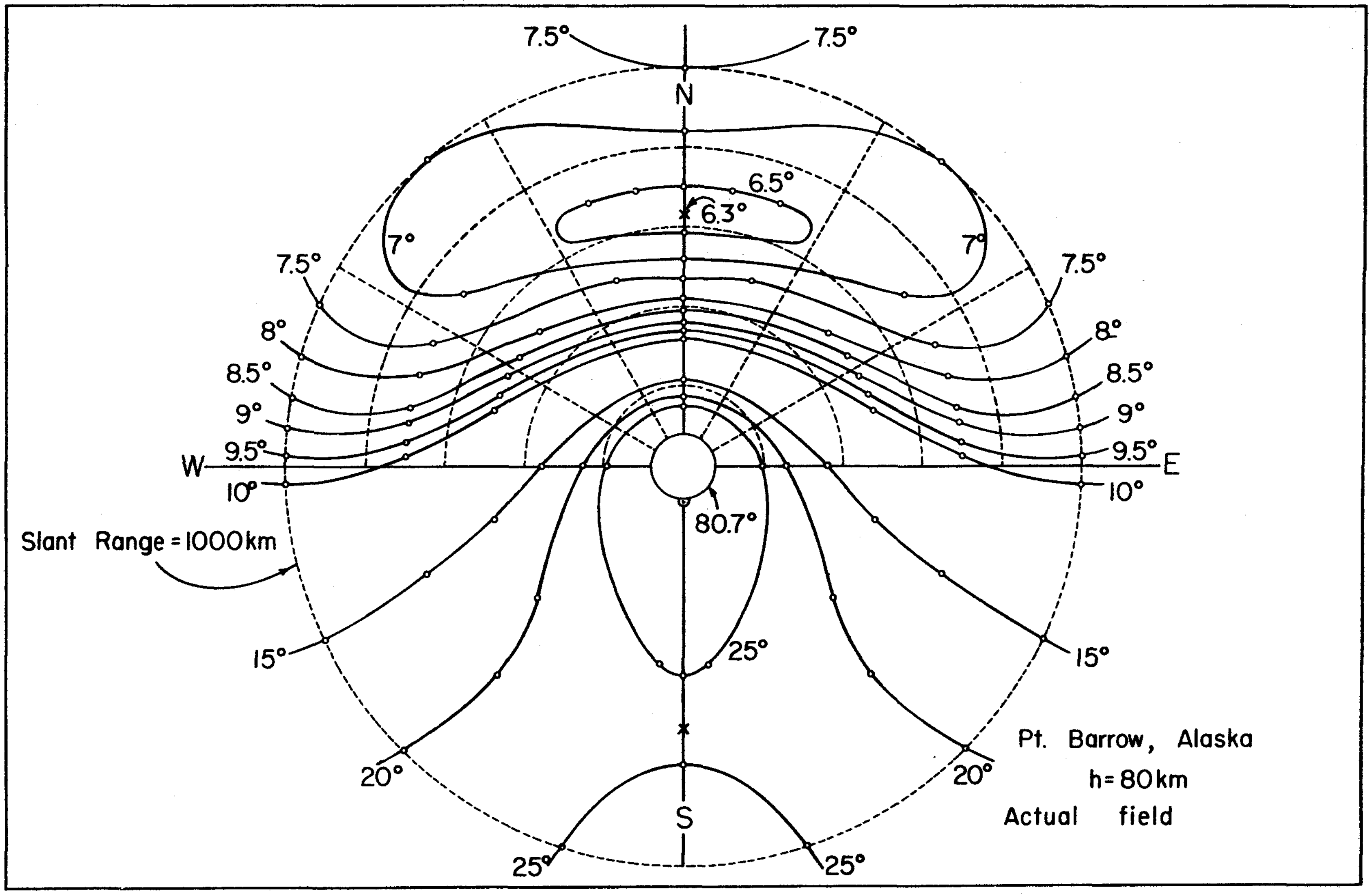

ABSORBING
REGION
SOUTH
NORTH
(A)
SOUTH
NORTH
(B)
SCATTER FROM
THE GROUND
NEARLY OR EXACTLY
PERPENDICULAR
SOUTH
NORTH
(C)
ILLUSTRATING THREE THEORIES OF AURORAL
IONIZATION ASPECT SENSITIVITY

Fig. 19



CENTERS OF AURORAL ECHOES OBSERVED FROM PT. BARROW, ALASKA NOVEMBER 1954.

Fig. 20



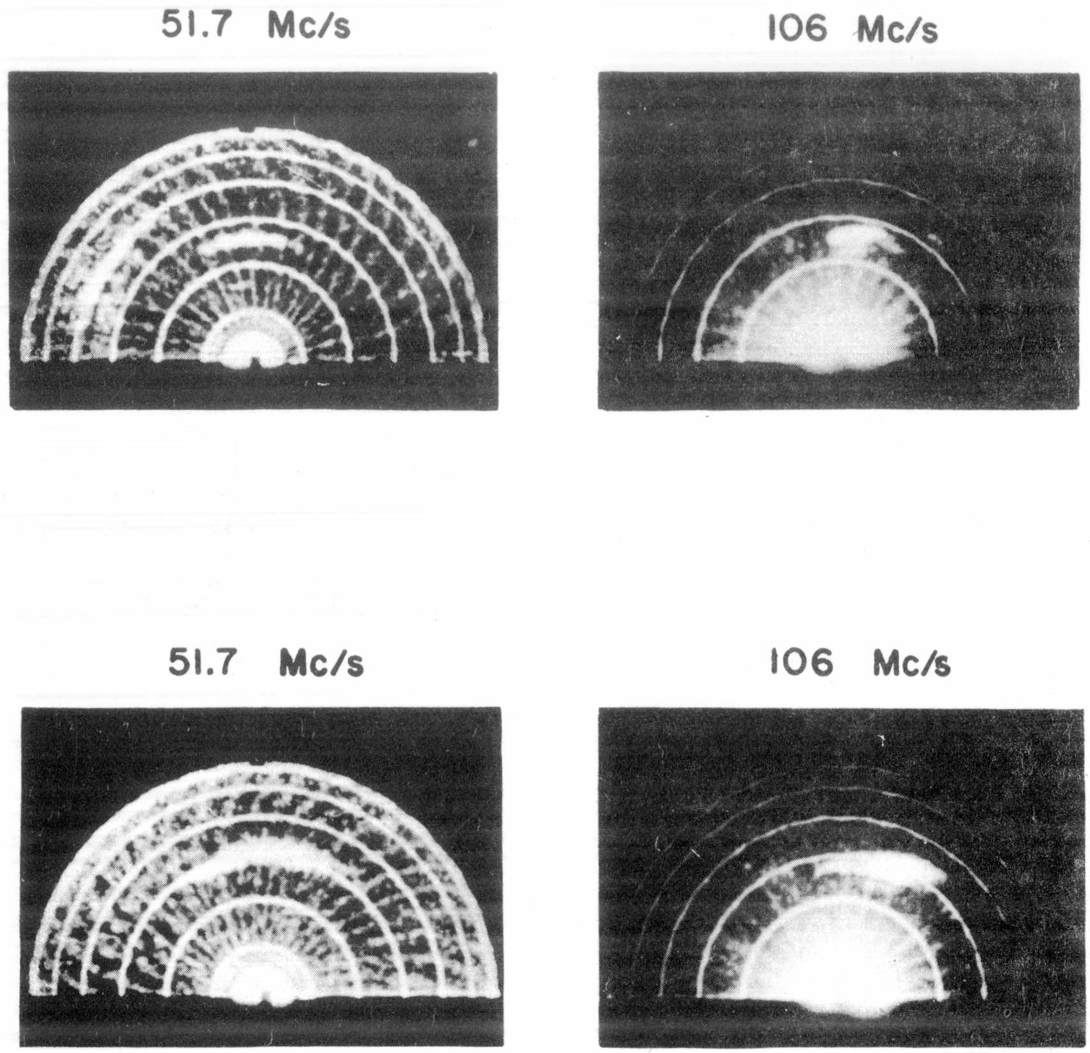
Contours of equal off-perpendicular angle as a function of range and azimuth from Pt. Barrow, Alaska. h = 80 km.

Fig. 21

In order to test this theory further, signals from the College radar operating on 51.7 mc were looked for at Barrow. These were noted as propagated by meteors, but there were no strong auroral signals as would be expected by the first theory. Some absorption measurements made at College by Dr. Little, when there was aurora in the zenith, indicated that there was insufficient absorption to prevent detecting the aurora because of the absorption. Thus, the second theory appears to be incorrect. The only conclusion is that the theory as postulated by Booker, Gartlein, and Nichols is the correct one, and echoes are only possible when the radio ray is nearly perpendicular to the aurora. However, to test this theory further, more detailed work was done here at College on both 51.7 and 106 mc which again supported this theory as the echo probability contours closely agreed with the off-perpendicular angle contours. Therefore, we have concluded that this theory is correct and explains the behavior of the auroral echoes.

As we had both the 106 mc and the 51.7 mc equipments running, an attempt was made to see how well they coincided as to the aurora they detected at any time. To do this, the antenna rotators were ganged electrically, the P.R.F.'s connected together and the P.P.I. scopes photographed simultaneously.

Fig. 22 shows some of the P.P.I. plots taken at the same time showing rather good correlation, considering the wide difference in the operating parameters of the two equipments.



Simultaneous dual-frequency PPI photographs
showing auroral echoes at the same range.
Time 0034 (above) and 0036 (below) AST, Jan. 9, 1955.

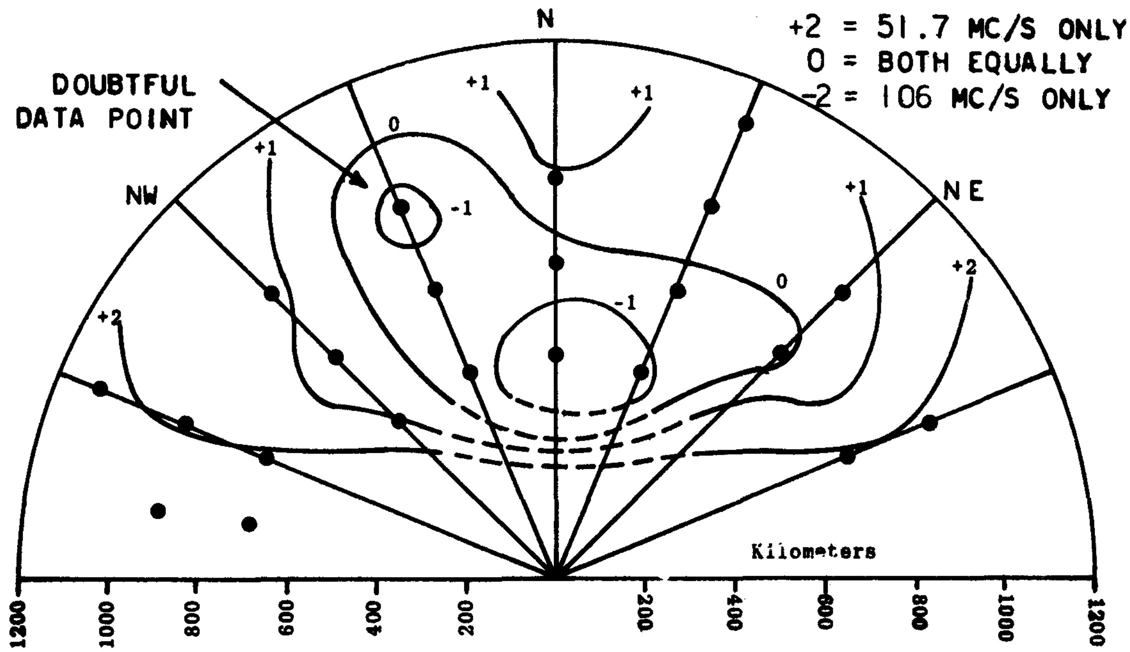
Fig. 22

Fig. 23 A shows the results of one night expressed as a ratio and as a function of position of the echo. Plus 2 indicates that only the 50 mc radar detected the aurora, plus 1 that the 50 mc echo was stronger than the 106 mc echo 0 that they were about the same, minus 1 that the 106 mc echoes are stronger, and that the 50 mc echoes are stronger at larger off angles.

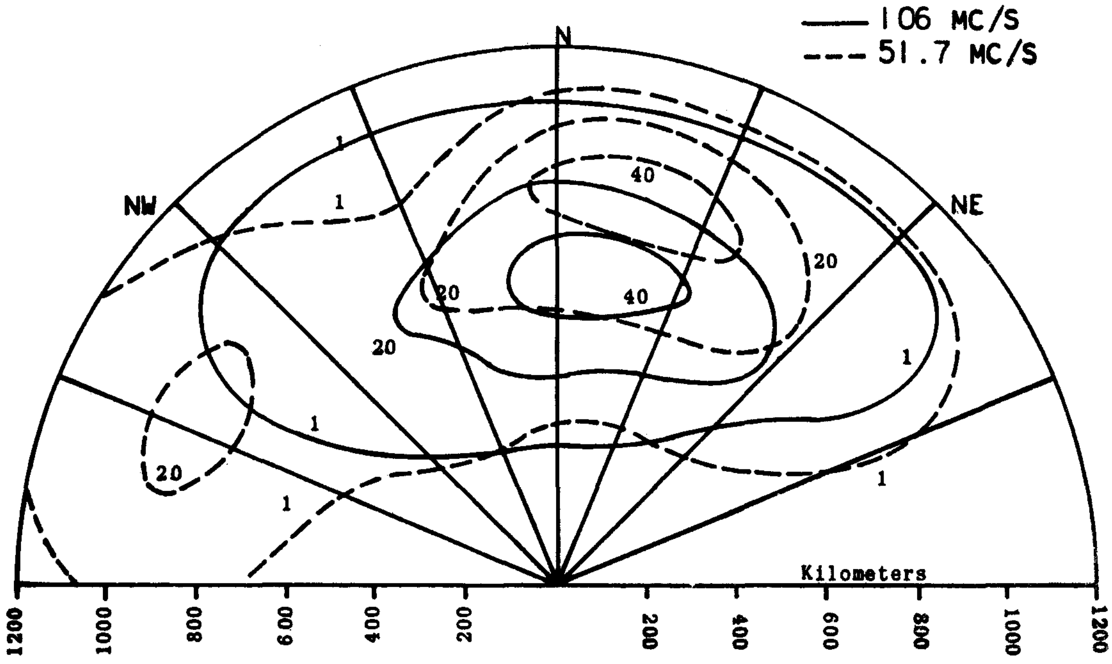
Another important experiment is the correlation of the auroral echoes with visual aurora. To do this Mr. Kenneth Bowles set up two cameras to photograph the sky to the north of College and a third camera to photograph the P.P.I. screen of the 106 mc radar. These photographs were made with a one minute exposure which included one full sweep of the P.P.I. The visual photographs were then scaled by measuring the angle of elevation and computing the location of the aurora by assuming a height to the lower border of 100 km. Inasmuch as the aurora does not always occur at this height, he calculated a range spread which is shown on one side of the pictures in Fig. 24 here the P.P.I. plots are reversed to give correspondence to the pictures.

In order to determine the diurnal variation in the echoes, the 51 mc equipment was operated continously for about two months with the data recorded on a range-time display.

The data, when summed, show a broad peak about midnight. However, by picking the five most active days and the five least active days during the two months, the curves in Fig. 25 may be obtained. Note

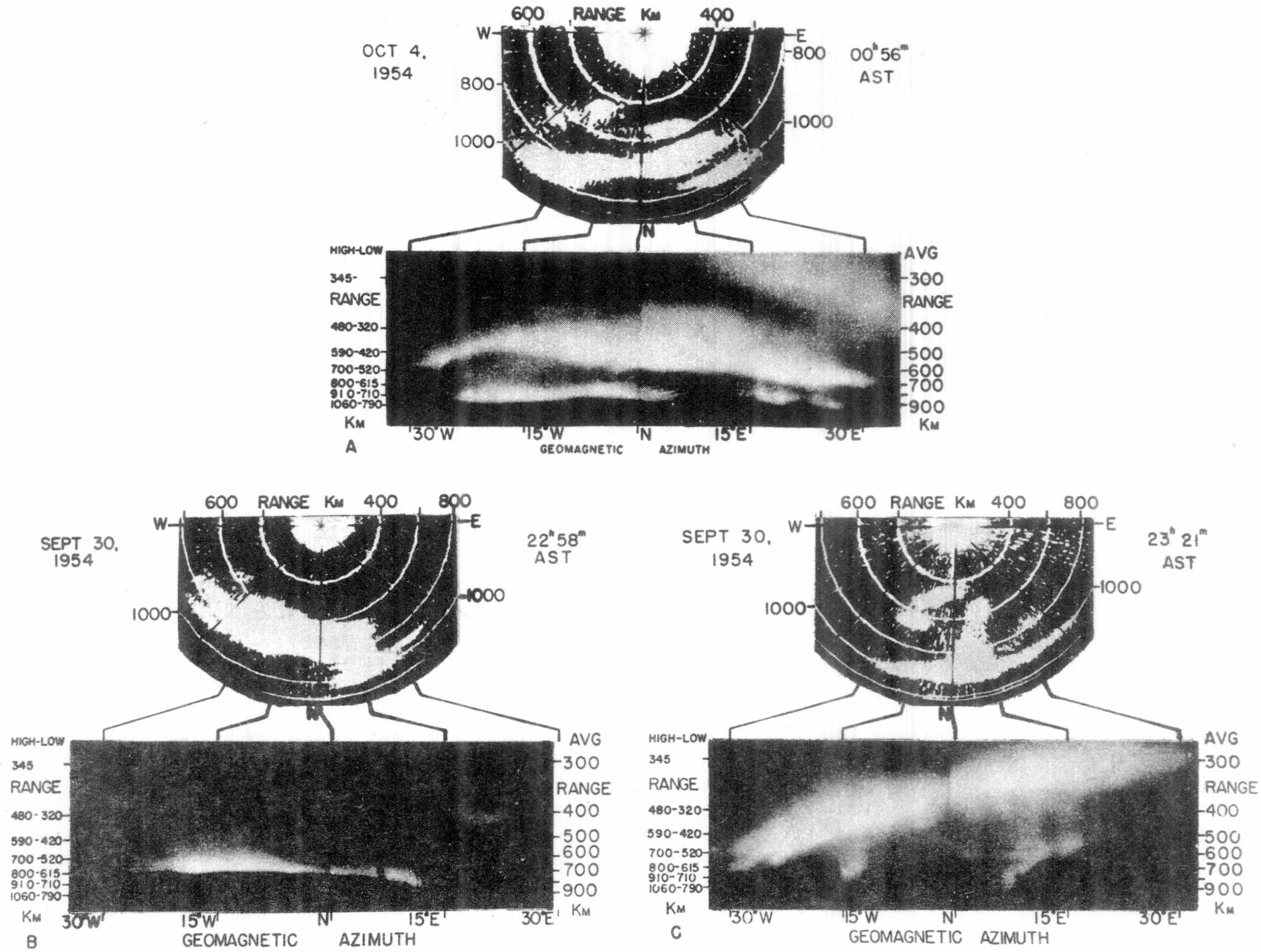


(A) RATIO OF SIMULTANEOUS 51.7 MC/S TO 106 MC/S AURORAL ECHO STRENGTH AS A FUNCTION OF POSITION. DATA FROM JAN 9, 1955



(B) NUMBER OF ECHO EVENTS AS A FUNCTION OF POSITION FOR EACH FREQUENCY SEPARATELY. SAME DATA AS USED IN (A) ABOVE.

Fig. 23



Photographs of Visible Aurora Compared with P.P.I. Presentations of Radar Echoes Taken Simultaneously at College, Alaska — 106 Mc/sec

Fig. 24

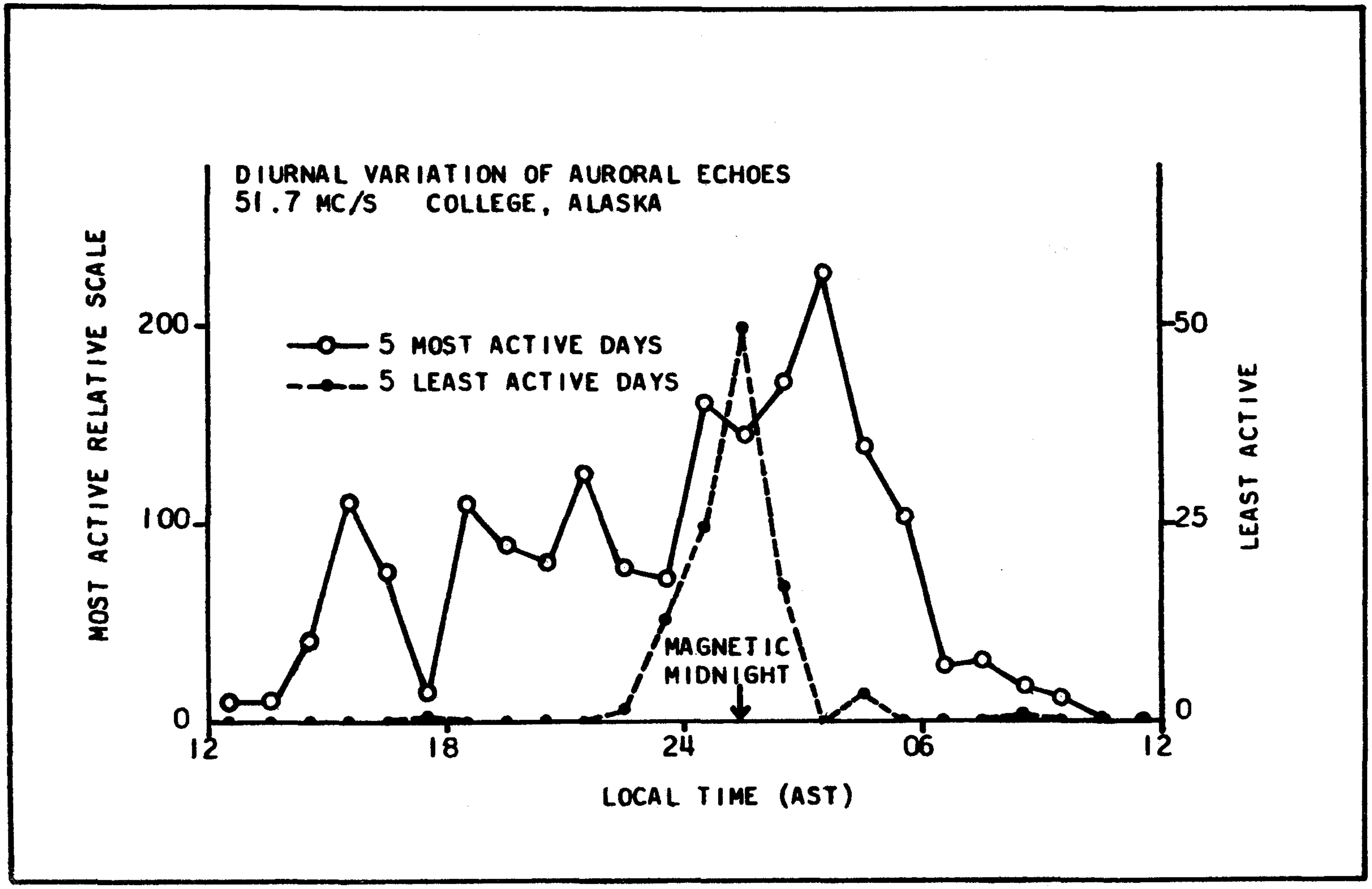
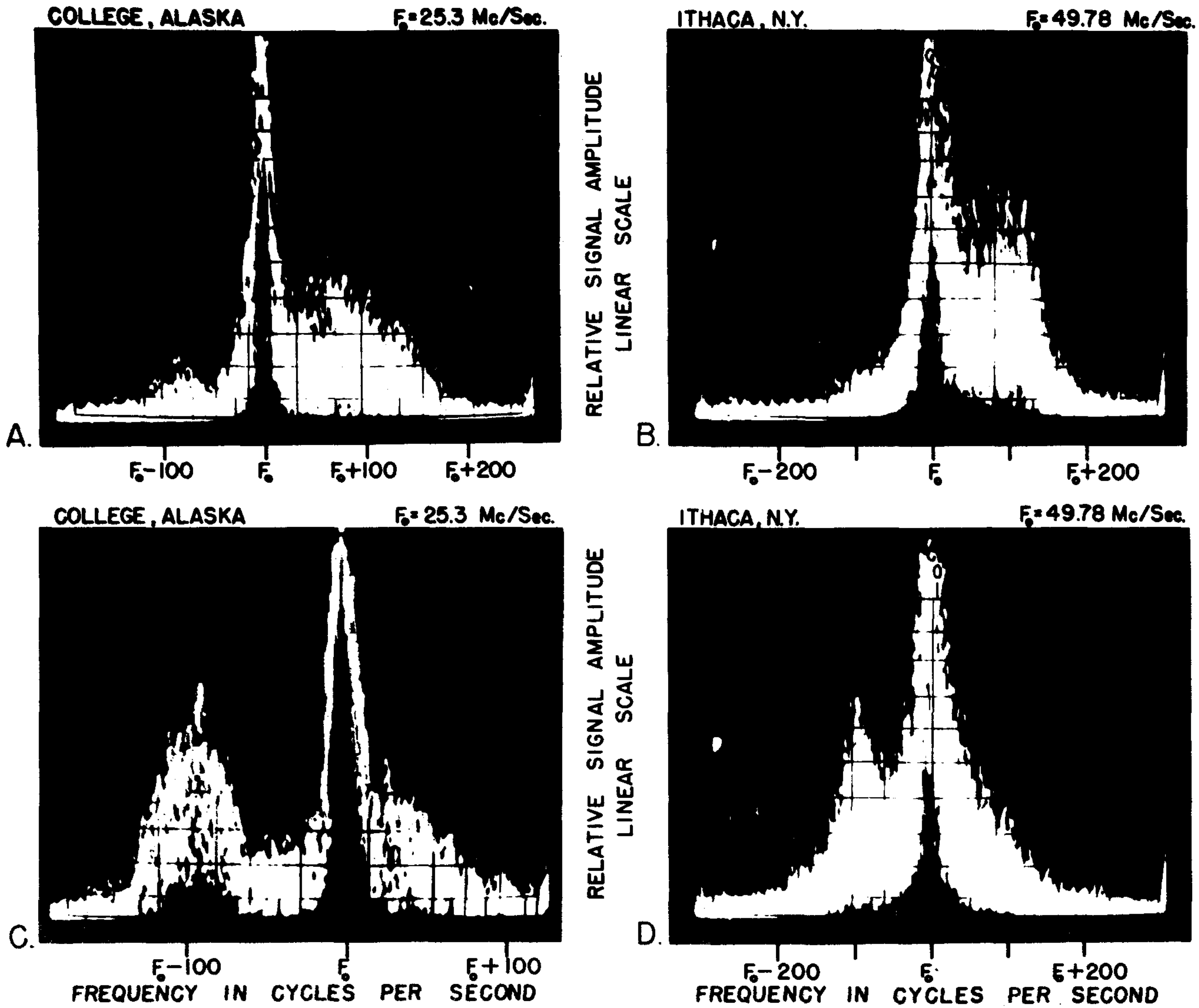

DIURNAL VARIATION OF AURORAL ECHOES
51.7 MC/S COLLEGE, ALASKA
5 MOST ACTIVE DAYS
5 LEAST ACTIVE DAYS
MOST ACTIVE RELATIVE SCALE
LEAST ACTIVE
200
100
0
50
25
0
MAGNETIC
MIDNIGHT
12
18
24
06
12
LOCAL TIME (AST)

Fig. 25

here the distinct preference for midnight on the quiet days, and the way in which the occurrences are spread on the active days. Also note the change of scale between the quiet and disturbed day curves.

Mr. Bowles, in an attempt to discover what was causing the echoes, examined the spectra of the returned echoes and noted a Doppler shift of the returned signal. During the early or homogeneous part of the display, the signal is shifted to higher frequencies, indicating a relative motion toward the observer; in the latter phases after the breakup, the frequency shift is toward the lower frequencies or away from the observer. Fig. 26 shows samples of the spectrograms of the returned signals. There are three types of motion that could cause these shifts: (a) motions along the auroral form, (b) the form moving either toward or away from the observer, or (c) the echoing region moving up or down. Similtaneous observations with a narrow beam antenna disproved (a); observations with pulse equipments disproved (b) - which leaves only the motion up or down within the form. The theory now stands that the discharge which produces the visual aurora and the ionization responsible for auroral echoes is in a downward direction during the first phase and is upward after the breakup.

These results can be extended to auroral reflections occurring between a transmitter and receiver that are not at the same location. By remembering the requirement that the radio ray must strike the aurora at a nearly perpendicular angle, it is easily seen how it would be possible



Radio Frequency Spectra of Auroral Echoes and Transmitted Carrier, F_o

Fig. 26

for the signal to be reflected to a receiver located some distance from the transmitter. However, the diurnal and seasonal variations of auroral activity are so great as to make this type of propagation of no use for communications; but, unfortunately, it is capable of causing interference.

In closing, I want to explain why auroral echoes are seldom, if ever, found on the conventional radar sets in use today. The signal to noise ratio in power is approximately proportional to $G^2 P \lambda^2 \tau^2$. Here G is the gain of the antenna; P is the pulse power; λ is the wavelength; and τ is the pulse length. There are several approximations made to arrive at this expression; however, it gives a relative measure of the sensitivity of the radar to aurora. By substituting the appropriate values for some of the more conventional radar sets as compared to those in use at the Geophysical Institute, it is readily seen why auroral echoes are seldom noticed.

LIST OF FIGURES