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The analysis of a three hour flight with 6 latitudinal scans underneath an auroral band shows the close relationship between auroral type sporadic E echoes (E<sub>Sa</sub>) and discrete aurora. The investigation of 49 latitudinal scans through the auroral oval during times of low magnetic activity revealed the existence of a particle produced E layer which is oval aligned, is 20 to 60 wide in corrected geomagnetic latitude and occurs at all corrected geomagnetic times. This layer produces the night E echoes.

A new ionogram analysis procedure, which uses oblique incidence  $\dot{F}$ layer echoes, is demonstrated, and the feasibility of monitoring the latitude of the southern edge of the polar  $\ddot{F}$ -layer irregularity zone by using this new analysis procedure is demonstrated.

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(Paper presented at AGARD Technical Meeting in Lindáu/Harz, Germany in September 1971) A Discussión of Arctic Ionograms

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#### SUMMARY

Examples of arctic ionogram sequences, recorded on the AFCRL Flying Ionospheric Laboratory, are presented. The purpose of this paper is to show that: a) ionogram sequences, recorded on arctic flights, facilitate the interpretation of oblique incidence achoes from E- and F-layer heights, b) parameters of the arctic ionosphere can be mapped by using the "auroral oval" as an ordering system; c) vertical and oblique incidence achoes, appearing on ground station ionograms, can be interpreted in terms of the station's position relative to the auroral oval.

The analysis of a three hour flight with 6 latitudinal scans underneath an auroral band shows the close relationship between auroral type spotadic E echoes (Egg) and discrete auroral band shows the d9 latitudinal scans through the auroral oval during times of low magnetic activity revealed the existence of a particle produced E layer which is oval aligned, is 20 to 6 dide in corrected geomagnetic latitude and docurs at all corrected geomagnetic times. This layer produces the night E echoes.

A new ionògrām analysis procedure, which uses oblique incidence F-layer echoes, is démonstrated, and the feasibility of monitoring the latitude of the southern edge of the polar F-layer irregularity zoné by using this new analysis procedure is demonstrated.

1. INTRODUCTION

Vertical incidence ionograms, racorded in high latitude regions, see often highly complex. Spread echoes and a variaty of oblique echoes, which originate in E- and E-layer heights of the ionosphere, complicate ionograms. In E-layer heights different types of echoes are often simultaneously observed, and their appearance may change rapidly. These complications are the well-known cause of the difficulties which are encountered in scaling and interpreting of arctic ionograms.

It is often difficult to interpret echoes on complex ionograms when only individual sweeps, recorded at long time intervals, are considered. Ionogram shalysis and interpretation can be aided by using ionogram sequences. This technique was used for instance; by Hanson stal(1) to show movements of the night E-layer, and is presently being used in recording vertical incidence swept frequency ionograms on the AFCRL Flying Ionospheric Laboratory. An ionospheric sounder, carried on a high-speed aircraft, is a valuable tool for investigating the arctic ionosphere.

För planning arctic flights the "auroral oval" (Feldstein and Starkov, (2)) has been used as a frame of reference, since it has proved to be an ordering system for many arctic geophysical phenomena. The auroral oval, defined as the region of maximum occurrence of visible aurora at a given instant, is an oval shaped belt surrounding the geomagnetic pole. The öval's position is fixed with respect to the sun and the earth rotates undermeath it. A high-speed aircraft, flying at high latitudes against the earth's rotation, can stay at constant CG local time for many hours while, at the same time, making latitudinal scans. By flying in the direction of the earth's rotation the arcraft's movement relative to the oval can be accelerated, and the entite oval can be investigated into all one 10 hour flight. The corrected geomagnetic (CG) coordinate system (Hultquist, (3), (4), Häkurä, (5)) is used throughout this paper.

Examples are discussed in this paper which demonstrate the usefulness of ionogram sequences, recorded on flights and on the ground, in interpretation of oblique incidence echoes from E- and F-layer heights. Analysis of ionogram sequences, accumulated in cross-section flights through the auroral oval at all CG local times, has permitted the mapping of the occurrence of auroral E and auroral Eg relative to the location of the auroral oval. A special analysis procedure, which uses oblique incidence F-layer echoes for monitoring the latitude of the southern adge of the polar F-layer irregularity zone, is presented.

#### 2. E REGION

Màny statistical investigations and single case studies have been made of the relationship between ionospheric E-region echoes and the visual aurora.

Results, obtained from simultaneous ionogram recordings and observations of aurors, show that good correlation exists between: a) sporadic  $\tilde{E}$  ( $E_S$ ) range and elevation of aurora (Knecht ( $\tilde{6}$ ), Buchau et al. (7), Whalen et al. (8), b) auroral brightness and the top frequency of  $E_S$  echoes (Knecht ( $\tilde{6}$ ), Hunsucker and Owren (9)), c) auroral brightness and the inverse of the virtual height of  $E_S$  echoes for the case of overhead aurora (Harang (10), Knecht ( $\tilde{6}$ )). The results of the work of many researchers are reconsidered in relation to the auroral oval, in a study of the distribution of occurrence of  $\tilde{E}_S$  in high latitudes, by Pittengar and Gassmann (11).  $E_S$  echoes with top frequencies >5 MHz were found to occur in an oval pattern and to have a pronounced maximum in the oval's night sector, indicating a close relationship to the location of maximum occurrence of visual aurora.

Simultaneous occurrence at a station of night E (or "auroral E", a term proposed by Penndorf (12) for this particle produced layer) and aurora has been reported by King (13) and Bullen (14). On the other hand Hanson et al. (1) found no hour-to-hour correlation of night E with aurora. Night E has also been observed equatorward of visual aurora (King (15)). With increasing magnetic activity auroral E (night E) is observed at lower latitudes than in quiet conditions, which augusts a relationship between auroral E and the auroral oval. Whalen et al. (8) found close relation between non-discrete, continuous aurora and aurora E (night E) on cross-section flights through the moon sector of the auroral oval.

Óbseirvátions of the relationship betwéen E<sub>sa</sub> schoes and aurora and between night E and the locatien of the auroral oval, réported here, were made during cross-section flights through the auroral oval.

2.1. RELATIONSHIP BETWEEN AURORAL E. AND VISUAL AURORA

A section of a flight is discussed where the aircraft crossed several times underneath a stable auroral band. Vertical incidence ionograms and all-sky photographs used for this analysis were simultaneously recorded at one minute intervals on 14 December 1968 during a flight from Labrador to Alaska. The flight track was planned so that the midnight sector of the auroral oval could be monitored for more than 9 hours while 18 latitudinal cross-sections, extending over 3° to 3-1/2° CG latitude, were made within the auroral belt. Recording of ionograms and all-sky photographs started on scan 4 and continued through the end of the flight. The flight track is shown in Figure 1 in geographic coordinates on the left side and in CG latitude and CG local time on the right side.

Quiet magnétic conditions prevailed during the flight,  $K_p = 0_+$ , 1, 1. In the first part of the flight no discrete aurora was observed, and only occasional brightening of the sky and very faint unstructured forms in the north ware observed. No E<sub>g</sub> was recorded during this time; however; s band of auroral E was observed which will be discussed later. At 6 UT (at the start of latitudinal scan 7) an oval-aligned arc déveloped which extended from the west to the east horizon. During the following 6 hours this aurora was seen constantly while the aircraft moved to the west; crossing underneath the aurora from south to south 12 times. In the last three hours of the flight (9 to 12 UT) the aurora was at times very active often filling the entire field of view of the all-sky camera (1000 km diameter); quiet conditions returned in between; During the 6 hours when discrete aurora was observed auroral E<sub>g</sub> was reconditions returned in between; stilling the flight. When the all-sky camera (1000 km diameter); quiet conditions returned in between; stilling the flight. When the strict was observed aurora from south parsed underneath it, and then moved away from it; the vitual height of the Egg echo regularily decreased from high ranges, levelled off at a minimum value and increased again. When overfiead aurora was observed over the entire width of the latitudinal scans, the time history of any of the individual bends or other forms could not be followed, the h'Egg stayed at minimum values, no oblique traces were seen. As soon as a band or arc could again be defined and it's zenith angle determined, the time variation of h'Egg and of the slant ranges to the surora seen.

In the upper part of Figure 3; the virtual height of E<sub>sa</sub> (open circles) and the slant ranges to the visible surform (full circles connected by dotted line) are plotted versus UT. They were recorded during the 3 hours when a stable auroral arc or band was crossed 6 times. Encircles numbers indicate the scan number in the sequence of latitudinal crossings. The slant ranges to the aurora were determined from the all-sky photographs assuming that the lower edge of the aurora was determined from the all-sky photographs assuming that the lower edge of the aurora was grown the faurora can be followed in passes 9 through. . since the location of the bands (extending east-west) was in the center latitude of the scans. In scan 7 the sircraft turned before reaching the norther adge of the aurora, and on the return scan the southern edge had moved to the north. The fact that the virtual height of the Egg and the slant range to the aurora change simultaneously during the 6 crossings underneath the aurora band indicates that the region of inization, causing the Egg achoos, must be limited in latitudinal extent to the vicinity of the discrete aurora. The suroral brightness increased during the period investigated. During passes 7 and 8 the aurora was very faint, h'Ega was 130-135 km when the aurora was overhead. Increased aurora brightness was observed in passes 9 and 10, the recorded minimum virtual height of Esa was 120 km when the aurora was overhead. Finally, (passes 11 and 12) h'Egg had decreased to 105 km, and the brightness of the overhead aurora had again increased. From 0610 to 0730 UT (i.e. pass 7 through most of pass 9) simultaneous photometer measurements of the 55778 emission were made (Whalen, private communication). When visible aurora was overhead during this time, the correlation between the spectral line intensity and the inverse virtual height of Ega

Assuming that the height above ground of the lower edge of the auroral form, is identical with the virtual height of the Ess when the aurors is in the aircraft zenith, the slant ranges were replotted for passes 7, 8, 11 and 12; The improved fit of the resulting slant ranges to the aurors and h'Ess curves is shown in the lower part of Figure 3. (Arrows below the time scale in pass 12 indicate the times for which ionograms and all-sky photographs are shown later; in Figure 5).

The correlation between auroral brightness and top frequency  $(f\bar{E}_{SA})$  of the  $\bar{E}_{SA}$  echoes, found by other investigators, is confirmed by the measurements of this flight; faint aurora from (6-7 UT) is accompanied by fEss only occasionally over 4 MHz; increased auroral brightness (from 7-8 UT) by fEssars 5 MHz; rather bright aurors (from 8-9 UT), by fEss between 8 and 9 MHz. Therefore, it follows that the h'Essa is inversely related to fEss. In Figure 4 the virtual height of Ess, recorded in passes 7 through 12 when aurors was observed in the zenith, are plotted versus the top frequency of the Ess echo.

Figure 5 gives examples of ionograms and all-sky photographs recorded on pass 12. Simultaneously recorded ionograms and all-sky frames are label'ed a, through d, and show that the range of the  $E_{ga}$  echo decreases when the auroral band is approached. Arrows below the time scale (pass 12) of Figure 3, lower part, indicate the times when the frames were recorded.

2.2 OCCURRENCE OF AURORAL E (NIGHT E) IN RELATION TO THE AURORAL OVAL

The close association between  $E_{SA}$  echoes and discrete aurora has been demonstrated. A few examples follow of the occurrence of auroral E (night E) echoes in relation to the auroral oval. The auroral E (night E) echoes were identified according to the description on page 106 of the IGY Manual (16). This definition, originally given by Hanson et al. (1), was found to be clear and comprehensive. Figure 2, upper part, shows two examples of auroral E (night E) echoes, recorded during arctic flights. A band of auroral E (night E) was regularly found in the three flights of December 1968 with a total of 16 cross-sections of the auroral oval at CG noon in darkness, reported by Whalen et al. (8). Characteristics of this particle

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produced continuous B layer that are of interest here, are as follows; In the noon sector it extends about 5° southward from the instantaneous location of the discrete auroral at the northern edge, at the location of overhead aurora; the typical z-achoes transform to Esa at the same virtual height; from north to south the critical frequency of the auroral z layer increases, while the virtual height decreases.

Subsequent investigations of ionogram sequences from cross-section flights through other sectors of the auroral oval confirmed the existence of an oval aligned E- layer of particle origin.

AURORAL E OBSERVED IN THE NIGHT SECTOR OF THE AURORAL OVAL

In Figure 6 the tracks of cross-section flights through the night sector of the auroral oval are shown. The flights were made during the time from February 1968 through February 1971, and they were selected for this survey because of quiet magnetic conditions during the flights. Kp indices were 0 to 2 during most of the time; exceptions are Kp = 3 for part of flights d and a, and Kp = 4- at the start of flight b. A total of 33 latitudinal scans through, or within the night sector of the oval were made along the flight tracks; flights d, e, and f are "oval stationary" flights with several scans in the same CG time sector; 2 flights were made along flight route c. The heavy dotted lines indicate the flight tracks where auroral E (night E) with critical frequencies >2 MHz was observed; 2 MHz being the low frequency limit of the sitborne sounder. Auroral E occurs in a continuous band that extends over several degrees of latitudes A black bar across the flight track indicates the location of the maximum critical frequency limit of that scans. In the owal stationary flight f. The for maximum critical frequency is of 4 scans for flight e; and in 5 out of 15 scans for flight f. The for maximum was found at identical latitudes in every scan of a particular oval stationary flight. This is true also for the second maximum at 69° CG latitude in flight a. Th the last of the 4 scans of flight a nondeviative absorption had increased, auroral wird scans in the for the second maximum at 69° CG

Flight f is the flight of 14 December 1968 where, as mentioned before, no auroral bands or arcs were observed in the first part of the flight, only some barely visible forms and areas of brightness were noticed. Auroral E was observed continuously until E<sub>38</sub> appeared simultaneously with the auroral arc that had formed. (Occasionally oblique E echoes could be seen in the presence of E<sub>38</sub>). This observation confirms the relation of auroral E and a non-discrete form of aurora, found in the non sector of the auroral oval (Wanken et al. (8). For all other flights the location of the band of night E relative to the position of discrete aurora is not investigated here.

In the latitudinal distribution of for a second maximum, as seen in flight a, is sometimes observed during more disturbed conditions. Concluding from the results of Whalen at al. (8), electron precipitation with a spectrum, hardening equatorward, is likely responsible for the auroral E-layer. Froton precipitation was found to be the cause for a second maximum in the morth, recorded in a previous flight and not included here. Conditions in flight a are still under investigation. No second maximum of for was observed in the other flights shown in Figure 6. In flights b and d, and perhaps in some scans of f, the auroral E (night E) region may have extended farther to the north of the flight tracks, and a second maximum may, therefore, have excaped observation. However, no increase in the E critical fraquency was indicated near the norther the source is submarized the observations of cross-section flights through the night sector of the auroral oval in quiet magnetic conditions; a) during all corease with decreasing latitude that was established for the normal extends for the pattern of for in the night sector also.

#### ENHANCED for IN THE DAY SECTOR OF THE AURORAL OVAL, IN SUNLIGHT

Particle produced ionization in E-layer häight häs also been observed in the sector 08 through 21 CG time for times of low magnetic activity under sunlit conditions. In daylight the normal E-layer is produced by photoionization; where particle precipitation causes additional ionization, an enhanced critical frequency of the E layer is measured, with an for that is higher than that corresponding to the zenith angle of the sun at that given time and location. Figure 7 shows (plotted in CG latitude and CG time) the routes of 9 flights performed in the summer of 1970 and 1971 which yielded a total of 16 cross-sections through the auroral oval. All flights were made in daylight and during magnetic conditions characterized by Kp 0 to 3- (except for one crossing with Kp 4-). Heavy black lines along the flight tracks indicate the latitudes where enhanced for crossing with Kp 4-). Heavy black lines along the flight tracks indicate the latitudes where enhanced for crossing with Kp 4-). Heavy black lines areas where the enhancement was very little. In every crossing of the oval a single belt of enhanced  $f_0E$  was observed, the latitudinal extent of which varied from 2° to 6°. Considerable variation in the location of the enhanced for region is located between 67° and 73° CG latitude compared with 71° and 78° for 16 crossings through the accord at latitude of the region of enhanced E ionization is found at 70° to 71° CG latitude in 5 out of 8 cases. This coincides with the results from cross-section flights during the same time interval, presented in Figure 6.

#### SPREAD E

Characteristic of the suroral E (night E) echo trace observed during dark hours is the spread near the critical frequency. Spread near the critical frequency of the E layer is also observed in ionograms recorded in the region of for enhancement, in daylight. The spread E is observed so regularly with enhanced for that Bullen (14) uses occurrence of spread E in daytime ionograms as one criterion to determine from ionograms the existence of particle produced ionization. In Figure 8 an example is gi.en to illustrate the change in appearance of the E echo traces from normal to spread and back to normal. The ionograms were recorded during a flight in daylight across the oval belt. Within the latitude band where for was enhanced, spread E was observed continuously. However, on the return (N to S) when the aircraft crossed the region of enhanced E again, the spread near the critical frequency of E was rather weak and not seen in every ionogram (one ionogram per minute being recorded). いたいようたいないないないないないないとう

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#### AURORAL E OBSERVED CONTINUOUSLY AROUND THE AURORAL OVAL

The cross-section flights through the suroral oval belt at mearly all times accumulated statistical avidence for the validity of the E layer pattern which was first astablished for the noon sattor in darkness. The question arises whether this pattern is slop valid as an instantaneous picture around the auroral oval.

In the 10 hour circumoval flight of 5 Jañuary 1970 nearly the entire oval belt was investigated. In Figure 9 the thin continuous line is the flight track plotted in CG latitude and CG local time. The decrease of  $f_{OE}$  with increasing CG latitude was found in all sections of the flight where the flight track deviated from its primarily eastward course and circularly evident from 7 to 9 CG local time, 14 to 16 CG local time, and at the end of the flight near midnight. Using the  $f_{OE}$  values from analysis of the innograms recorded during the flight, contour lines of  $f_{OE}$  were drawn, shown as heavy lines in Figure 9; the dotted lines connect extrapolated values. At 02 and 04 CG local time ( in Figure 9) E choes were seen obliquely; they originated from a layer 5 of the flight track, as could be determined by photometric measurements. The figure presents a quasi-instantaneous picture of the occurrence of auroral E (night E) as derived from data taken on this flight. The 5th of January 1970 was a day of low megnetic activity.

#### GROUND STATION DATA REVIEWED IN RELATION TO OVAL-ALIGNED E LAYER PATTERN

The È layer pattern for quiet days, dérived from the sircreft data; can be tested by ground station data. As an example in Figure 10; in the center; a graph is shown from Hanson; et al. (1) of the time variation of the critical frequency of a night E echo observed during a 5 hour period at Port Chimo on 26 January 1952; a magnatically quiet day. The ioningrams, from Which the critical frequencies are derived, are reproduced in their paper and show typical examples of night E (auroral E) echoes. The hour by hour positions of the station relative to the Qui auroral oval are marked by triangles, the first corresponding to 16 LT (docal time at Fort Chimo). If on this day an approximately oval-aligned E region was present as indicated, the station would move under the 3.0 MHZ for the 3.0 Ki for the station for a term auroral oval it would move under the 3.0 MHZ for contour at 18 LT. Due to the steep gradient versus latitude in for a the station would be for the E region, the instrow band of maximum for is overhead before 19 LT. From 19 to 20 LT the station works through the northern part of the sight E region.

#### 2.3. SUPPLARY AND RESULTS

1) Analýsis of ionogram saquances and simultaneous all-sky photographs from a flight making six latitudinal scans in the midnight sector of the autoral oval under quiet magnetic conditions shows that: a) The racorded auroral type Estato (Esa) is returned from a spatially limited area conditions shows that: a) The racorded auroral type Estato (Esa) is returned from a spatially limited area conditions shows that: a) the racorded auroral type Estato (Esa) is returned from a spatially limited area conditions shows that: a) the racorded auroral type Estato (Esa) is returned from a spatially limited area confined to the latitudinal extent of the visible aurora, b) Good correlation exists between the brightness of aurora in the zenith, the inverse of the Virtual height of the Esa; and the top frequency of the Esa. Consequently, in case of overhead aurora, the top frequency increases with decreasing virtual height of the Esa. The results of the analysis also appears to support the assumption that the Esa echoes originate from a height identical with that of the lower edge of the aurora.

2) Ionogram sequences from cróss-section flights through the öval belt during times of low megnetic activity show the existence of an oval-aligned region of auroral could belt during times of low megnetic activity show the existence of an oval-aligned region of auroral could belt. By which has a width of  $2^{\circ}-6^{\circ}$  latitude. It extends equatorward from the location of the auroral oval if the day sector of the suroral oval and is located within the oval belt in the night sector. Of a total of 49 latitudinal scans through the oval belt, at times from 07 through noon to 04 Corrected Geomagnetic Time, 38 show the presence of auroral E, 16 of the 22 scans through the auroral oval's night sector exhibit the same latitudinal pattern found (by Whalen et al. (8)) in the non sector in derkness; namely, decrease of virtual height of the E layer from north to south corrects of the E layer from north to south corrects of the E layer critical frequency from north to south. The analysis of day flights through the suroral oval resulted in the mapping of the regions where enhanced for was recorded, i.e. where for was higher than to be expected from photofonization. Although the latitudinal distribution of the measurements in darkness, as are the results of a 10 hour circumoval flight in which auroral E (night E) was cordinated of the man ensurements in darkness.

#### 3. POLAR F-LAYER

The high-latitude F layer has been investigated by many workers, and several basic features are now known. Muldrew (18), using Alouette topside ionograms, first showed the existence of the main F-layer trough. Petrie (19) established that the occurrence of spread F on Alouette ionograms maximized in an oval-shaped region which encircled the geomagnetic pole. Akasofu (20) later identified Petrie's spread-F region as being coincident with the quiet time auroral oval, hence a "spread-F oval". Thomas and Andrews (21) showed that the distribution of topside F-layer electron density enhancements, scaled from Alouette ionograms, maximized in an elongated ring, the "plasma ring", which, similar to the spread-F oval, encircled the geomagnetic pole. Ionograms recorded on the Flying Ionospheric Laboratory during cross-section flights through the day sector of the auroral oval were compared with Alouette electron density and showed that the topside polar F-layer plasma ring existed in the bottomside as an F-layer irregularity zone (22). On these flights the latitudinal extent of the F-layer irregularity zone was determined from ionogram movies recorded on the aircraft sounder. An example which illustrates how the aircraft's motion is used to interpret Flayer features on ionograms is shown in this next section.

#### 3.1. AIRBORNE F-LAYER MEASUREMENTS

In the top half of Figure 11 the aircraft's flight route on August 22, 1970 is indicated by the dashed line drawn on a CG latitude and CG local time grid. The night sector of the auroral oval for Q=2 magnetic conditions is indicated by heavy solid lines. A sequence of aircraft ionograms is shown in the bottom-half of Figure 11. The latters next to the ionograms refer to the aircraft's positions, marked by the same

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letters on the flight route map, when the tonograms were recorded. In ionogram A there is a varitical incidence P-layer scho at 200 km, the first and second P-layer multiple schoes, and an extra scho at about 425 km. In ionogram B the extra scho is at a range of about 490 km, while in ionogram C, recorded just before the sircraft turned; the extra scho is at a range of about 530 km. The change in range of the extra scho corresponds to about the distance that the arreat fails way from the southern edge of the extra scho corresponds to about the distance that the arreat scho is then an oblique incidence scho which; most likely, is produced by a reflecting surface located north of the aircraft mear the over towards the over in the oblique incidence echo is now closer in slant range than the vertical incidence F-layer echo. Thus, the original oblique incidence echo is moving down in range as the dircraft the in conograms D and E show the oblique incidence echo is now closer in slant range than the vertical incidence F-layer echo. Thus, the original oblique incidence echo, is moving down in range and will become a vertical incidence F-layer echo. The slant range to the extra echo is plotted versus universal time in Figure 12. The letters on the abecies refer to the aircraft's positions which are noted in Figure 11 by corresponding letters. All of the ionogram, recorded at the rate of one per minute, contain a strong oblique incidence echo, therefore, the slant range to the same as for any could be plotted with an accuracy of 410 km. One sees a uniform increase to the time during which the aircraft turned, and the everts is slant range is due to the slant range to the time during which the aircraft turned, and the decrease in slant range is due to the size affect of the time during which the aircraft turned, and the decrease is slant range is due to the aircraft flying north, towards the oval. This example demonstrates how F-layer echose, which occur in a sequence of ionograms, can be uniquely identified and followed

#### 3.2. F-LAYER MEASUREMENT AT GOOSE BAY

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From Öctober 27-29; 1970 the Flying Ionöspheric Laboratory vas located on the ground at Goose Bay, Labrador: Goose Bay is located at geographic Goordinates 54°M, 60°W or at CG Goordinates 65.5°M; 22°W. The location of Goose Bay; indicated by triangles, and the Q=3 suroral oval have been plotted in Figure 13 on a CC latitude and time grid; From Figure 13 one can see that Goose Bay moves towards the oval during the afternoon and evening, that Goose Bay is underneath the oval near midnight, and that Goose Bay moves away from the oval in the morning; During this three day period at Goose Bay the after operated continuously; the photometer and auroral all-sky camere were used at night for discussed here; schematic drawings, showing the mein F-layer trough and the F-layer irregularity zone, are presented.

A sequênce ôf Goose Bay ionogrêms, recorded on October 27, 1970, is shown in Figure 14. These ionograms were recorded during the late afternoon and evening from 1720 to 2110 local time; and F-layer súnset occurred at about 1830 local time. Analysis of these ionograms, recorded on 35 mm film, was facilitated by Viewing a 16 mm movie of the ionograms a number of times and by following P-layer features frame by frame in the movie. Later, these features were identified and numbered on these single 35 mm frames. Ionogram A shows Well defined ordinary and extraordinary wave components of an echo, labelled I, from an F layer produced by the sun and an extra echo; labelled III, at 725  $\pm$  20 km between the first and second solar F-layer multiple echo. Jonogram B shows that echo III has moved down in range to 625  $\pm$  20 km and has become better defined than before. The movie presentation of the ionograms; recorded between these two selected frames, shows echo III before. The movie presentation of the ionograms, recorded between these two selected items, shows ether moving down in range. Tonogram C shows the solar F-layer echo, echo i, the first solar F-layer multiple echo, labelled I', echo III, and a new extra echo, labelled II, at 475 10 km; Echoes, similar to those labelled II and III, have been identified by Stanley (23) and Bowman (24) as echoes which are produced by oblique incidence reflections from the poleward wall of the main F-layer trough. Echoes II and III are also similar to the oblique incidence echo that was reflected from the region of the oval in the airborne ionogram sequence in Figure 11. Thus, echoes II and III are probably oblique incidence echoes which are produced by reflecting surfaces located north of Goose Bay in the vicinity of the main F-laver trough and the F-layer irregularity zone. Ionogram D shows the solar F-layer echo, echo I, with no multiple echoes and the oblique incidence echo, echo II. The absence of a solar F-layer multiple echo would suggest that at this time a curvature in the structure of the plasma frequency contours is passing over Goose Bay and is causing ionospharic defocussing. Further suggestion for the presence of a curvature is the 30 km increase in virtual height of the solar F-layer acho which occurs between ionograms B and D. In ionogram E one sees cho I from the solar F layer, oblique incidence echo II, and what may be the reappearance of oblique incidence echo III. Bates (25) has pointed out that since aspect sensitivity of the reflecting surface is a problem encountered in the analysis of oblique incidence achoes, the appearance and disappearance of oblique incidence echoes can often be impossible to follow. Ionogram F contains a complex overlapping of echoes I, II, and III between 275 and 400 km which cannot be interpreted with certainty. However, a multiple reflection of echo II may now be seen; thus, echo II must be nearly overhead at this time.

A sequence of schematic drawings of F-layer structure, which could produce echoes I, II, and III, can provide some understanding of the ray path geometry involved in producing these echoes. The schematics, seen in Figure 15, we're drawn by assuming that during the late afternoon and evening the main F-layer trough and the F-layer irregularity zone would move from the north towards Goose Bay. The schematics are composed of constant plasma frequency contours which extend north and south from Goose Bay. One schematic cross-section has been drawn for each ionogram in Figure 14. Virtual heights and plasma frequencies, taken from ionograms A through F, were used as the quantitative basis for the respective schematics. The earth's curvature was taken into account when the grid for the achematics was drawn. The ionosonde in the aircraft has a frequency threshold of 2 MHz. The trough, which has an 50F2 equal to or less than 2 MHz (18) (23), was not seen directly on the ionograms, and its presence has been inferred by ionogram A. The solar F-layer echo, acho 1 in ionogram A, can be produced by ray path 1 in schematic A. Echo III can be produced by ray path III which has been constructed by assuming that a reflecting surface is located north of Goose may at about the 250 km level. Accordingly, the 725 km slamt range to echo III in ionogram A corresponds to a northward horizontal distance of about 650 km as is shown in schematic A. The reflecting surface has been assumed to be the F-layer irregularity zone and has been represented in the schematics by a kink in the plasma frequency contours. In schematic B the irregularity zone is closer to Goose Bay than in schematic A, while in schematic C the distance between Goose Bay and the irregularity zone has not changed. These distances are consistent with the slant ranges to echo III which are seen in ionograms B and C. The appearance of echo II in ionogram C is interpreted as indicative of the onset of the trough.

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at this time because solar production; which fills in and smooths over the trough during daytime (25), has almost cased by now; The shepe of the trough, has been drawn by using Borman's (24) trough contours as a model with the exceptions that the troughs, which he saw during the 10%; were wider by a factor of 4 or 5 and deeper than the trough shown here. In innogram D'the absence of multiple echoes suggests that the trough is passing mear Goose Bay at this time and is causing defocussing. For this reason, the trough is shown nearly overhead of Goose Bay in schematic D. Reho III is missing in ionogram D. One reason for this may be aspect sensitivity of the realistic D. Reho III is missing in ionogram D. One reason for this may be aspect sensitivity of the realistic D. Reho III is missing in ionogram D. One reason for this may be aspect sensitivity of the realistic D. Reho III is missing in ionogram D. One reason for this may be aspect sensitivity of the realistic p. Scho III is missing in ionogram D. One reason because ionogram E may contain eaching the irregularity some. In schematic E ray path III is drawn because ionogram E may contain echo III. The trough has been drawn with about the same shape in schematic D. Because ionogram P contains a very complex overlapping of echoes, the interpretation given to these echoes in schematic F should be treated with caution. The appearance of a multiple acho of echo II, which up to now had been oblique and did not display a multiple echo, suggests that the trough has passed over Goose Bay and that Goose Bay is now located on the poleward side of the trough. Rehoes 1 ml III are barely discernable in ionogram F but, after examining other ionograms which were recorded at about the same time as this ionogram F but, after examining other ionograms which interpreted as seen in schematic F. That is, it appears the echo I has moved out in range since the time that ionogram I was recorded; while echo III appears to have moved down in range since then:

#### 3.3 MONITORING THE F-LAYER TRREGULARITY ZONE

In this section a new ionogram analysis procedure is presented, and crawild: and the head of the southern and the southern an

The slant range plotter för October 28, 1970 is seen in Figure 17. The letter b indicates the presence of overhead blanketing Ess which did not permit the detection of oblique incidence F-layer schoes. The presence of survers in the zenith, noted by the arrow at 2000 LT, was again determined from the intensity of the 55778 spectral line and it occurred about 1 3/4 hours earlier than on the previous night. The daily sum of the geomagnetic activity indicated by squares, was detected earlier than on the previous night. The daily sum of the geomagnetic activity indicated by squares, was detected earlier than on the previous night. The daily sum of the geomagnetic activity indices, Kp, on Oct. 27 was Exp=9 and on Oct. 28 we Exp=22. The difference in onset times of the irregularity zone on these two days can readily be explained by the difference in magnetic activity on the two days. If one puts the slant range date for these days onto auroral ovels of different Q value, then the reason for the difference in the onset times between the two days can be seen clearly. A Q=1 and a Q=3 oval were selected for the date of October 27 and 28 respectively, and they are seen in Figures 18 and 19. The date points are plotted on a CG local time and CG latitude grid. In general the date points fit the two different ovals quite well but, in Figure 19, there is a sudden departure of the date points from the southern edge of the oval at about 17 to 18 CG time. This appears to be a real effect because it was possible to follow an echo, similar to echo III in Figure 14, on each ionogram recorded during this period. If the reflecting surface underwent an latitudinal oscillation at this time, it could produce this effect. It appears then that the latitude of the southern edge of the F-layer irregularity zone can be monitored by plotting the slant ranges to certain oblique incidence echoes onto the slant range plotter.

#### 3.4 CONCLUSIONS

A special analysis of vertical and oblique incidence F-layer echoes, seen on vertical incidence ionograms, was presented. Results from the analysis suggest that the latitude of the southern edge of the polar F-layer irregularity some can be monitored, therefore, on the spot analysis of ground station ionograms from Goose Bay, Labrador; can probably lead to a real-time or near real-time monitoring of the polar F-layer irregularity zone for 6 to 8 hours of each day. Furthermore, the time when the main F-layer trough passes over Goose Bay can be specified on each day. The close coincidence which was shown to exist between the location of aurora and the F-layer irregularity zone suggests that the CG latitude of the southern edge of the auroral ovel, in the afternoon and evening sectors, can similarly be monitored.

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6. Flight tracks of flights through the night sector of the auroral oval; thick dotted lines mark the latitudes where night E (auroral E) was observed; black bars indicate the location of maximum for for each latitudinal scan; a) 10/11 October 1969, b) 21 April 1969, c) 12 and 4 mec 1969, d) 24 November 1970, e) 1/2 February 1971, f) 14 December 1968, and g) 5/6 February 1968.





Figure 8. Ionograms recorded on a flight traversing a region where enhanced for was observed on 9 June 1971. On the flight track, plotted in CG coordinates, heavy lines indicate the latitudes of enhanced for. The arrows mark the locations where ionograms a, through g, were recorded.

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Figure 10. Time variation of foE as experienced by a ground station moving, relative to the oval, through a belt of E ionization.

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Figure 12. The slant range to the extra echo seen in the airborne ionogram sequence is plotted versus universal time. The letters refer to the aircraft's position.



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Figure 13. The Q=3 suroral oval is plotted on a grid of CG latitude and CG local time, and the location of Goose Bay is indicated by triangles.



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Figure 14. Goose Bay ionograms recorded on October 27, 1970.

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Figure 16. The slant range to the southern edge of the suroral oval from Goöse Bay is plotted as a heavy solid line versus 60°W local time. The slant range to the F-layer irregularity zone from Goöse Bay on Occober 27, 1970 is indicated by squares. An arrow indicates the onset of aurora in the senith at Goose Bay.



Figure 17. The slant range to the southern edge of the auroral oval from Goose Bay is plotted as a heavy solid line versus 60°W local time. The slant range to the P-layer irregularity zone from Goose Bay on October 28, 1970 is indicated by squares. An arrow indicates the onset of aurora in the zenith at Goose Bay.



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Figure 18. The latitude of the southern edge of the F-layer irregularity zone on October 27, 1970, indicated by squares, is plotted on a CG latitude and CG local time grid. The Q=1 oval is indicated by heavy solid lines.



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Figure 19. The latitude of the southern edge of the F-layer irregularity zone on October 28, 1970, indicated by squares, is plotted on a CG latitude and CG local time grid. The Q=3 oval is indicated by heavy solid lines. The letter b indicates the presence of blanketing Egg.