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SHORT DURATION SPORADIC E AND DISCRETE AURORAL EVENTS. (U)

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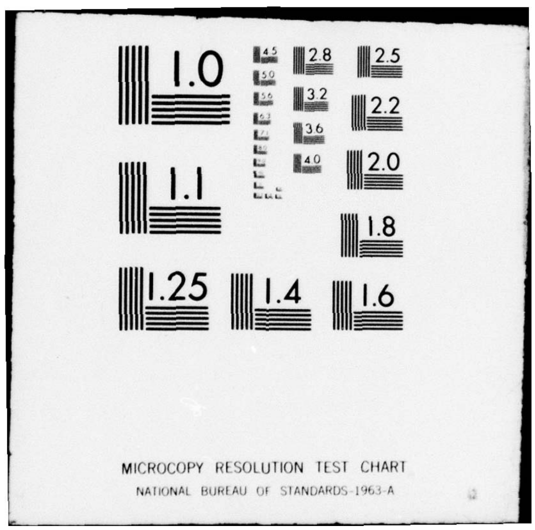
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Short Duration Sporadic E and Discrete Auroral Events

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4 January 1979

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SPACE PHYSICS DIVISION PROJECT 4643
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: AFGL-TR-79-0004 (14)	2. GOVT ACCESSION NO.: AFGL-ERP-649	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): (6) SHORT DURATION SPORADIC E AND DISCRETE AURORAL EVENTS.		5. TYPE OF REPORT & PERIOD COVERED: Scientific. Final.
		6. PERFORMING ORG. REPORT NUMBER: ERP No 649
7. AUTHOR(s): (10) A. Pauline Krukonis, James A. Whalen, Alfred E. Reilly		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Geophysics Laboratory (PHI), Hanscom AFB, Massachusetts 01731		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62101F (16) 46430605 (17) 06
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Geophysics Laboratory (PHI), Hanscom AFB, Massachusetts 01731		12. REPORT DATE: (11) 4 January 1979
		13. NUMBER OF PAGES: 24
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (9) Final rept., (12) 24p.		15. SECURITY CLASS. (of this report): Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Sporadic E
Discrete auroral events

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The relationship that exists between the occurrence of sporadic E and the incidence of visual aurora is utilized as the basis for the determination of the lifetimes of discrete auroral events in the range of (> or =) 15 minutes from measurements of durations of sporadic E ionization. Intercomparisons of optical and ionosonde data from aircraft and ground-based installations are presented.

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Illustrations

Preface

The authors would like to acknowledge Dr. Kund Lassen of the Meteorologisk Institut, Copenhagen, Denmark for arranging the cooperative program with the Greenland stations. We wish to thank Lt Col A. L. Snyder for helpful discussions. Magnetograms used in connection with this paper were obtained from WDC-A for Solar-Terrestrial Physics (Ionosphere).

Short Duration Sporadic E and Discrete Auroral Events

1. BACKGROUND

Our previous studies of the occurrence and duration of discrete auroral events[1] have been based on analyses of auroral photographs, mainly all-sky camera images taken on Arctic flights of the Air Force Geophysics Laboratory (AFGL) Airborne Ionospheric Observatory. These photographs, taken at intervals of one minute during flights in the midnight sector, were arranged in montages (Figure 1) that afforded an effective means of identifying the durations of discrete auroras. From these data, the authors have determined that the fundamental durations of these events fall chiefly in the range of ~15 minutes.

Simultaneous ionosonde and optical measurements made on AFGL flights indicate that the occurrence of sporadic E (Es) has a high degree of correlation with overhead aurora.[2] Similar results have been reported by other investigators' analyses of data from ground-based optical and ionosonde systems: (1) in an early work, Heppner, Byrne and Belon[3] found good correlation between zenithal auroral

(Received for publication 3 January 1979)

1. Krukonis, A.P., and Whalen, J.A. (1978) Occurrence and lifetimes of discrete auroras near midnight (to be submitted to JGR).
2. Wagner, R.A., and Pike, C.P. (1972) A discussion of arctic ionograms, AGARD Conf. Proc. No. 97 on Radar Propagation in the Arctic.
3. Heppner, J.P., Byrne, E.C., and Belon, A.E. (1952) The association of absorption and Es ionization with aurora at high latitudes, J. Geophys. Res. 57:121.

forms; that is, from no aurora to rayed bands, and sporadic E values; (2) Knecht[4] reported that zenithal aurora generally was accompanied by the presence of E_s traces and, further, that auroral brightness could be correlated with the top frequency of Es (ftEs) echoes. Both conclusions find support in the flight results of Wagner and Pike;[2] (3) Hunsucker and Owren[5] showed that ftEs increases with auroral activity. In their survey paper which included aircraft and ground station data, Pittenger and Gassmann[6] demonstrated that, statistically, Es echoes with ftEs≥5 MHz occurred within the auroral oval, the region of the maximum occurrence of visual aurora.

Conversely, neither the flight data nor the literature indicate that overhead aurora is coincident with the occurrence of sporadic E. Buchau, Whalen, and Akasofu[7] and Buchau, Pittenger and Sizoo[8] showed that under quiet magnetic conditions, in the day sector in darkness, Es echoes can occur from areas where the auroras have been present and disappeared or moved. Both Heppner et al[3] and Knecht[4] indicate that ftEs echoes in excess of 5 MHz have been recorded in the absence of overhead aurora and that they may be due to oblique reflections, among other reasons.

Although the close relationship of these phenomena has long been recognized, the durations of discrete auroral events having lifetimes in the range of 15 minutes have not been examined with regard to the durations of sporadic E ionization. In this study, we propose to determine how sporadic E measurements can be used to define the durations of these discrete auroral events.

2. METHOD OF ANALYSIS

Since one of the main objectives of this analysis was to identify periods and durations of sporadic E occurrence and, concurrently, to afford a simple and consistent method of intercomparison of data from the various recording stations, top frequency sporadic E (ftEs) was chosen as the measure for the occurrence of Es.

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4. Knecht, R.W. (1956) Relationships between aurora and sporadic E echoes at Barrow, Alaska, J. Geophys. Res. 61:59.
5. Hunsucker, R.D., and Owren, L. (1962) Auroral sporadic E ionization, J. Res. Nat. Bur. Stand. 66D:581.
6. Pittenger, E.W., and Gassmann, G.J. (1971) High Latitude Sporadic E, AFCRL-71-0082, Environmental Research Paper, No. 347, Bedford, Mass.
7. Buchau, J., Whalen, J.A., and Akasofu, S.-I. (1969) Airborne observation of the midday aurora, Atm. Terr. Phys. 31:1021.
8. Buchau, J., Pittenger, E.W., and Sizoo, A.H. (1970) Arctic Ionosphere and Aurora: Airborne Investigations, AFCRL-70-0280, Environmental Research Paper No. 322, Bedford, Mass.

The use of ftEs, the highest observable Es frequency, resolves the sometimes complex problem of differentiating between the ordinary (foEs) and extraordinary (fxEs) wave reflections which is outside the scope of this analysis, and provides a parameter whose relative numerical value is reproducible by different investigators.

It is recognized that sporadic E ionization may occur in a variety of types as defined by the IGY classification system, depending on the temporal and geographic locations of the recording stations. Identification of Es by type, while scientifically important, is a descriptive procedure, independent of the scaling and, as such, is not critical to this study of Es durations.

Most of the data used in this investigation were recorded in the North auroral zone, mainly along the auroral belt, in winter, and essentially in the midnight sector. In this region, Es occurrence is more prevalent at night, centered between 1800-0200 corrected geomagnetic time (CGT) and about 70° corrected geomagnetic latitude (CGL) and shows little seasonal variation.[6] With increased magnetic activity, there is also a marked trend of increasing incidence of sporadic E with decreasing latitude.

Data from a station located midway between the lower latitudes of the auroral belt and the polar cap were also included in this study. In this region, the spatial characteristics of Es as a function of magnetic activity are quite variable.[9, 10]

In keeping with the recommendation of Smith,[11] limiting top frequencies ≥5 MHz were used to define periods of sporadic E that were to be evaluated against the presence of discrete auroral events. The choice of ≥5 MHz is based on a number of factors, among them: (1) normal E layer echoes (foE) rarely exceed 5 Mhz; thus, any masking by this trace which might affect the identification of Es is reduced; (2) absorption is greatly reduced at this limiting frequency. In the few cases where published data, specifically, blanketing sporadic E (fbEs), the lowest observable Es frequency, are incorporated in the analyses, values of <5 MHz are included for completeness.

The distinction between overhead and oblique sporadic E echoes is frequently difficult to verify. In most instances, the aircraft sounder can distinguish between the two modes. As the aircraft approaches a band of Es, it can follow the apparent downward movement to a minimum height; that is, overhead Es, and then the apparent upward movement as the aircraft moves away. In the case of ground stations, the

9. Davis, T.N. (1963) Negative correlation between polar cap visual aurora and magnetic activity, J. Geophys. Res. 68:4447.

10. Taieb, C.C. (1966) A study of sporadic E at high latitudes, J. Geophys. Res. 71:5757.

11. Smith, E.K. (1957) NBS Circular 582, U.S. Government Printing Office, Washington, D.C.

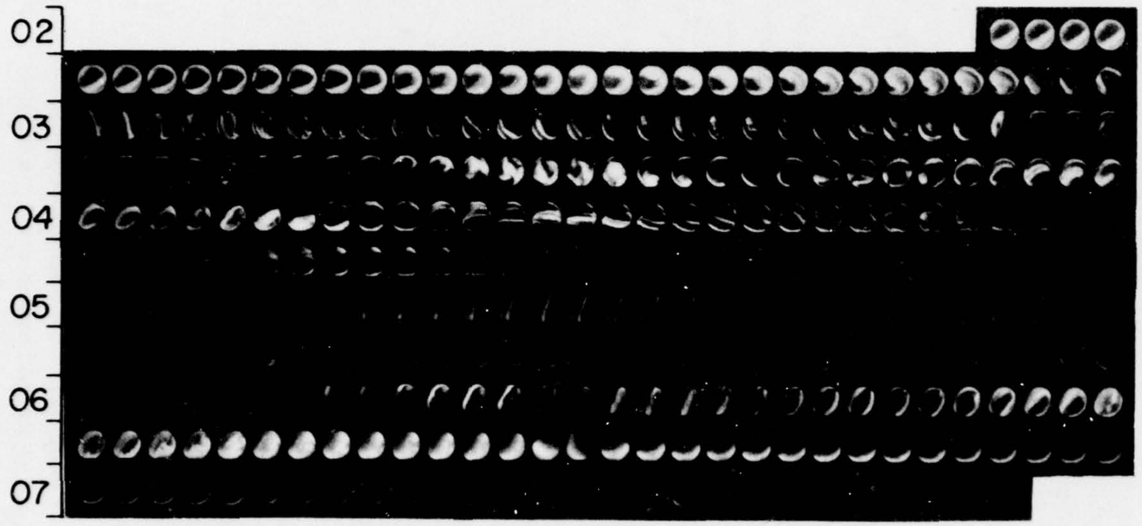

Figure 1. Montage of All-Sky Camera Photographs Taken at One-Minute Intervals on AFGL Flight of 30 January 1973. Time in UT is indicated on the left

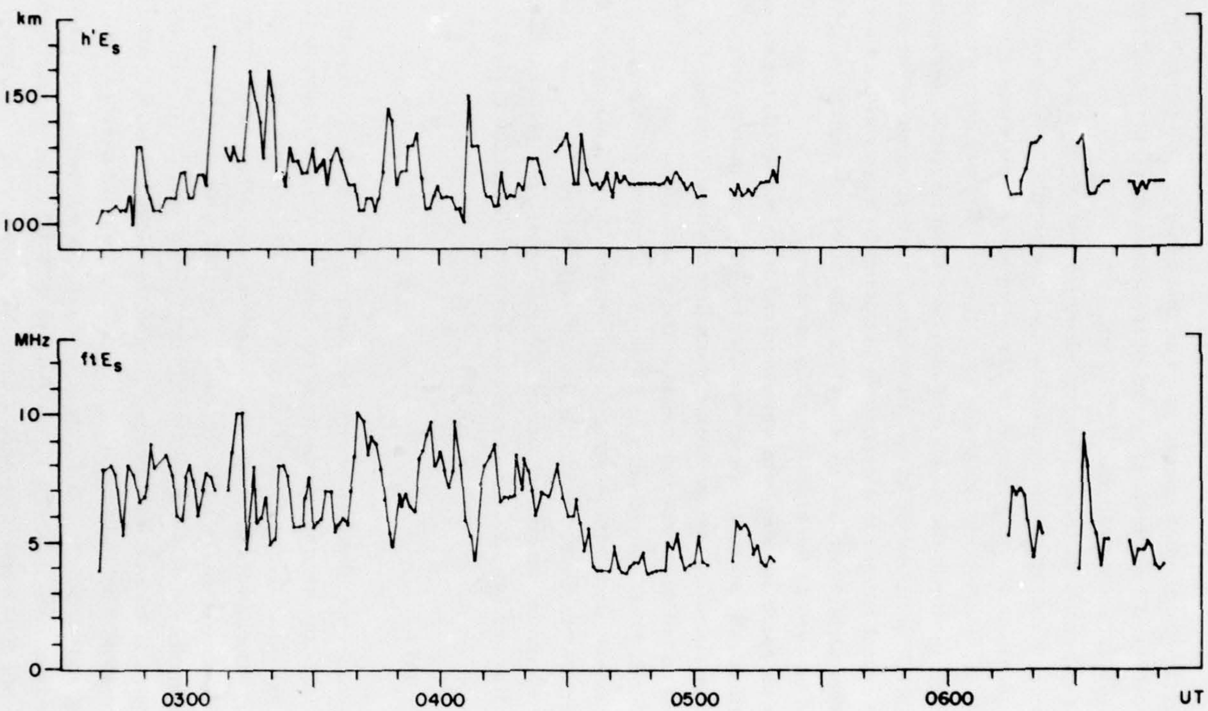

Figure 2. Top Frequency Sporadic E (ftEs) Versus Minimum Virtual Height (h'Es) Recorded on AFGL Flight of 30 January 1973

same differentiation is often uncertain. For this analysis, we interpret sporadic E as being overhead from measurements of the minimum virtual height (h'Es) of the echoes that fall in the range of 90-140 km.

Although Knecht's statistical results[4] indicate that there is a tendency for ftEs≥7 MHz to be recorded when aurora is near the zenith, caution should be exercised in employing a limiting frequency per se to identify overhead Es ionization. As indicated previously, top frequency Es values >6 MHz are not uncommon from oblique echoes and/or in the absence of overhead visual aurora. Irregularities in the ionosphere, stratification of the ionosphere, and brightness of the auroral forms are several factors that contribute to the top frequency of the Es reflection. For consistent identification of overhead Es, the minimum virtual height measurement should be used as the discriminating parameter.

The ionospheric sounder data were obtained from the AFGL flights and from ground stations and, as such, were recorded by different instruments at different locations; consequently, the numbers are not directly comparable. Rather, emphasis is placed on the durations and trends of the phenomena.

In the plotted data, any breaks in a sequence of points are due to any one of a variety of reasons such as instrumental and/or ionospheric data recording problems, calibration periods, or other undefined difficulties.

Where available, other corroborative data, that is, magnetograms, geomagnetic index Kp, and satellite images were incorporated into the analyses.

3. AIRCRAFT DATA

Analogous to the lifetimes of discrete auroras, sporadic E ionization shows great variations in duration, from short periods of several minutes to sustained activity of half an hour or more. This is well illustrated by Figure 2 which displays ionosonde measurements taken at ~1-minute intervals on the AFGL flight of 30 January 1973 (Goose AB to Grand Forks AFB), together with the virtual height ($h'E_s$) of the echoes. These data can be directly correlated with the all-sky camera photographs (Figure 1) taken simultaneously during the flight. Note, in particular, the period from about 0300 to 0400 UT. The appearance of an overhead arc is uniquely reflected by an increase in top frequency sporadic E as seen by the sounder. Within the periods of 0338 to 0349 UT, and 0354 to 0409 UT, that is, during discrete auroral events of ~10 and ~15 minutes duration, respectively, changes in the top frequency of sporadic E echoes follow even subtle variations in "auroral activation." Read together with the $h'E_s$ plot, one can follow the approach of the auroral arcs and identify the periods of overhead positioning together with an estimate of their durations. For most of the period, the two plots mirror each other; that is, increased ftE_s can be identified with decreased minimum virtual height and, in turn, discrete auroral events, as seen on the all-sky camera montage, can be confirmed by these measurements. This is an unusually good example of a one-to-one correlation of overhead aurora and incident sporadic E on a fine-time scale.

4. AIRCRAFT VS. GROUND STATION IONOSONDE DATA

To expand on this association, we undertook to determine how the occurrence and duration of discrete auroral events could be defined via sporadic E measurements from ground-based ionospheric sounders. The aircraft data, optical and ionosonde, represent the ultimate in measurement coordination, both in time and location, for the identification of discrete aurora events. If this good agreement can be realized via ground-based sounders, it would provide a more easily accessible data base than auroral photographs.

In the recent past, most ground stations have reduced their data-taking schedules to half-hour intervals, with only a few selected stations operating on the quarter-hour. It is apparent that, under these circumstances, only judicious spot comparisons can be made with other parameters, and then only on a statistical basis. Events of short duration would most likely be lost or smeared out by the scarcity of measurements.

In the absence of ftE_s records, blanketing sporadic E (fbE_s), usually a short-lived phenomenon, can be used as an indicator of sporadic E. It is generally accepted that fbEs corresponds to the minimum plasma frequency of the Es layer.[12, 13, 14] An increase in the blanketing sporadic E frequency often precedes the onset of magnetospheric substorms. Canadian ground stations record this parameter on a 15-minute basis and publish the numerical values in the form of f-plots. In addition, occurrence of sporadic E is also indicated on a separate E_s block by alphabetic codes consistent with IGY classification types. Numerical results are not plotted.

Some indication of the correlation that may be possible, even with such sparse measurements, is shown in Figure 3. The fbE_s (15-minute) data from Churchill,

12. Besprozvannaya, A.S., and Shchuka, T.I. (1977) Distribution of anomalous ionization in the high-latitude E region according to ground-based sounding, Geomag. and Aeron. (Eng. Trans.), 16 (No. 4):430.

13. Reddy, C.A., and Rao, M. Mukunda (1968) On the physical significance of the E_s parameters fbEs, fE_s, and foEs, J. Geophys. Res. 73:215.

14. Snyder, A.L. (1972) The auroral oval and the high latitude ionosphere, Ph.D. Thesis, University of Alaska.

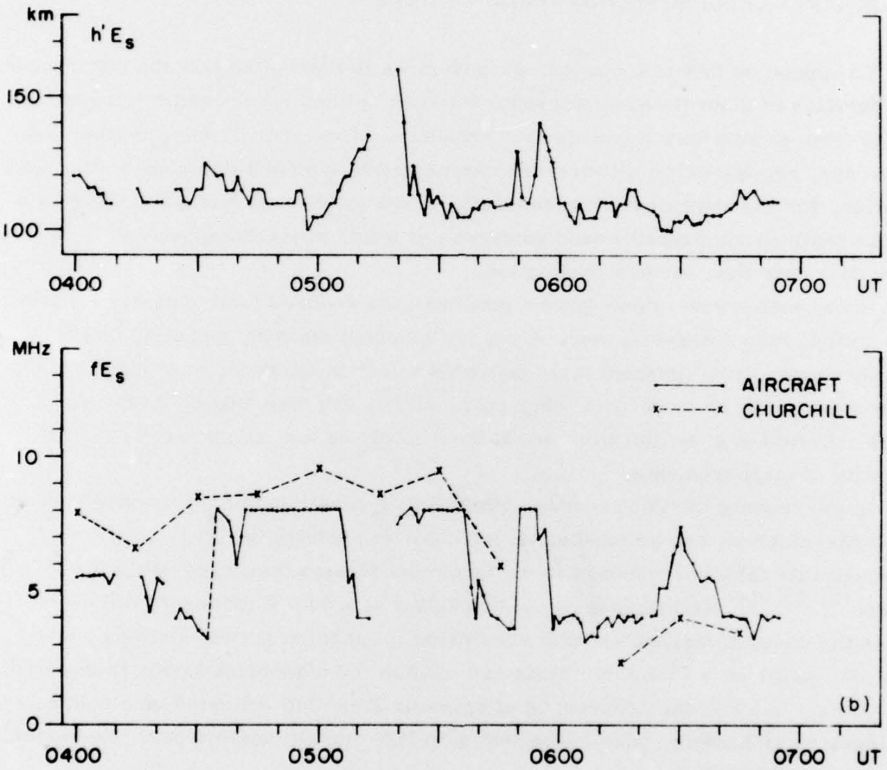

Figure 3. Comparison of Aircraft and Ground Station Ionosonde Data Taken on 19 December 1976. (a) Aircraft Minimum Virtual Height (h'Es) Measurements. (b) Plot of ftEs (1-Minute Data) from Aircraft Versus fbEs (15-Minute Data) Recorded at Churchill.

Manitoba published in Canadian Ionospheric Data[15] is compared with ftE_s (1-minute) data taken on the AFGL flight of 19 December 1976. The period plotted shows the incidence of sporadic E as the aircraft overflew Churchill in a direct line from Pease AFB to Cold Lake, Alberta, Canada. At ~0530 UT, the aircraft was in the immediate vicinity of Churchill. Corrected geomagnetic time for these three hours of the constant midnight flight was 2300±30 minutes. Sustained strong ftE_s echoes in the range of ≥8 MHz (the limit of the frequency band utilized on this flight) occurred at three distinctive periods: ~0441 to ~0506, ~0520 to ~0536, and ~0550 to ~0556 UT; that is, during the events of 25-, 15- and 5-minutes duration. These were followed by a strong echo of ~7 MHz that peaked at ~0630 UT, duration ~20 minutes. In all cases but one, the $h'E_s$ plot identifies the aurora as overhead. Fortuitously, the maximum ftEs for each period occurred on or near the quarter-hour which provided some basis, albeit imperfect, for comparison with ground station ionospheric data. Without reference to actual numbers, the maxima of the Churchill data appear to coincide with the active auroral periods as seen by the aircraft. Magnetograms taken concurrently at College, Alaska[16] show very small but discrete magnetic bays in the H-component that substantially coincide with the periods of increased auroral activity. Similar magnetic signatures were not apparent in the data from Baker Lake and Meanook, two stations far removed from the auroral oval. It is evident that none of the ground-based ionosonde measurements definitively determine the durations of the discrete events, based as they are on intervals that can just as easily obscure the event as record it. Without the availability of the aircraft data in this example, no estimate of duration would be feasible. For the best information, the optimum frequency of usable data-taking should be in the range of at least 5-minute intervals. Admittedly, this schedule might distort events of less than 10 minutes duration, but probably would be of sufficient density to record those in the range of ≥15 minutes.

5. 7, 9, and 13 NOVEMBER 1977

In cooperation with the AFGL flights on the 7th, 9th, and 13th of November 1977, the Greenland stations of Narssarssuaq and Godhavn took sounder measurements on a timetable of approximately 5-minute intervals. Narssarssuaq is an auroral oval station, while Godhavn is located midway between the auroral belt and the polar cap in the transition region,[9, 10] between 75° to 80° north latitude.

15. Canadian Ionospheric Data (1976 and 1977) Dept. Commun., Ottawa, Ontario, Canada.

16. Townshend, John B. (Dec 1976) Preliminary Geomagnetic Data, Open File Report 76-300L, U.S. Dept. Int., Geological Survey.

The flight tracks, with minor variations, were all very similar; that is, east from Goose AB, north to the region of Godhavn, then south to the vicinity of Narssarssuaq, and return west to Goose AB. Geomagnetic conditions, as measured by the Kp index, were quite diverse, varying from a quiet (Q3) day on 9 November to a disturbed (D3) day, 13 November 1977.

Figure 4 compares the incidence and virtual height of sporadic E recorded by the aircraft sounder, versus the same characteristics measured by the two Greenland stations during an auroral event of ~15 minutes duration on 7 November 1977. Kp for this period was 1-, the intermediately active day of the three. At the time of this event, the aircraft was located within <2° of longitude, essentially over Narssarssuaq. In the associated plot, ftE_s maximized at ~0016 UT, at a frequency of ≥10 MHz (the limit of the frequency band in use on the aircraft). By interpolation from the original ionograms, one could estimate that the echoes at the aircraft were probably ≥16 MHz. The ionograms that are displayed to the right of the plots, in each case were recorded at or about 0016 UT.

In comparing the raw and reduced ionogram data, it is evident that the E_s signal was strongest at the aircraft, and decreased markedly with increased latitude at Godhavn. The double peak in ftE_s recorded at Narssarssuaq is also present in the sequence of aircraft ionograms for this period, judging from the two cycles of build-up and decrease of the E_s multiples. From the virtual height plots, one sees that the aurora approached both the aircraft and Narssarssuaq at about the same time, passed overhead, and then retreated. In contrast, although the event at Godhavn is well defined, one cannot say unequivocally that it was overhead.

In this and subsequent plots, there is a slight indication that the minimum virtual heights recorded at Godhavn were systematically higher than those recorded at Narssarssuaq, which is in keeping with the conclusions reported by Gladden.[17] For nighttime, horizontal type E_s (f-type), he found that $h'E_s$ was generally dependent on geographic latitude, with lower heights at lower latitudes.

In any case, the sporadic E measurements clearly define the event at all stations, and the duration can be determined from this parameter.

Similarly, Figure 5 compares ftE_s and $h'E_s$ measurements from the aircraft and ground station sounders for 9 November 1977, a quiet (Q3) day, Kp~0+ during an event that peaked at ~0037 UT. Again, the aircraft was in the immediate vicinity of Narssarssuaq. In direct contrast to the data of 7 November 1977, it is interesting to note that the strongest E_s echoes were recorded at Godhavn, decreasing in relative strength to the aircraft. The ground station $h'E_s$ plots very

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17. Gladden, S.C. (1962) A note on the heights of the different IGY types of Es, Ionospheric Sporadic E, Smith and Maksushita, Ed., 178, Pergammon Press, New York.

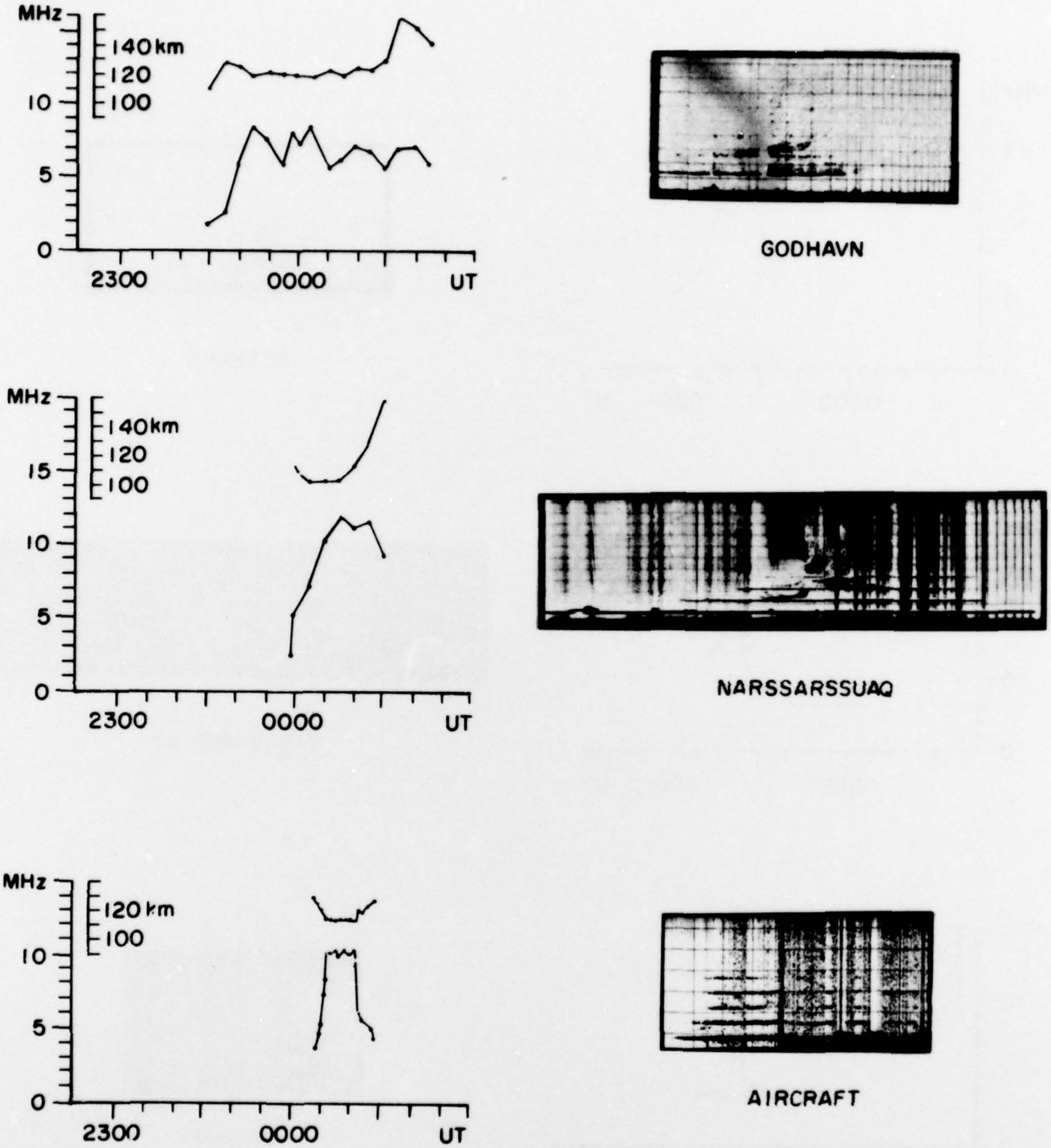

Figure 4. Comparison of ftEs and h'Es Data Measured on 7 November 1977 at the Ionospheric Stations of Narssarssuaq and Godhavn Versus the AFGL Aircraft During a Discrete Auroral Event of ~15 Minutes Duration. The ionograms displayed on the right were recorded at or about 0016 UT

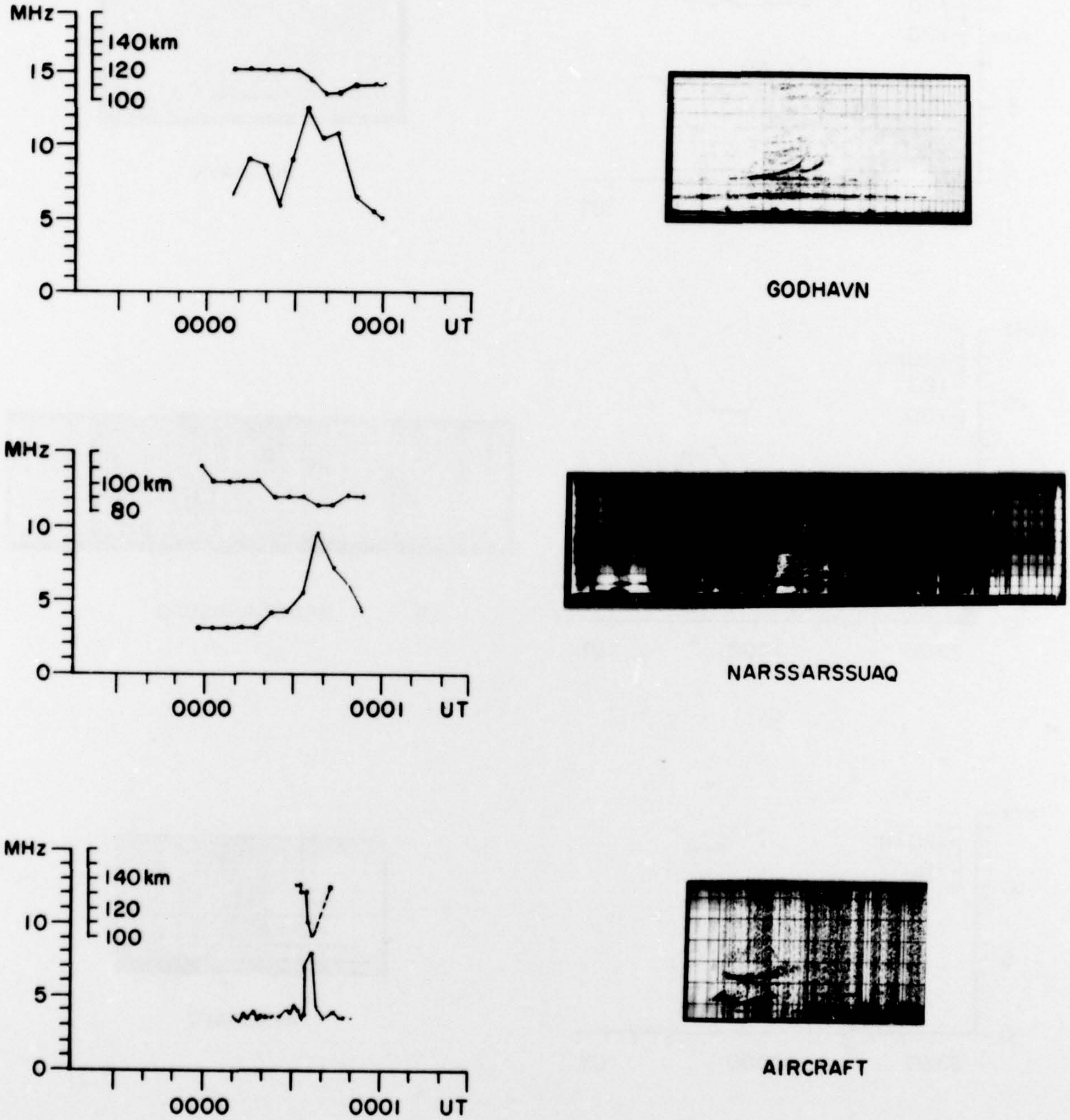

Figure 5. Same as Figure 4. Data from 9 November 1977

explicitly identify the aurora as overhead, as does the aircraft plot. Due to imperfections in the ionogram recordings, the aircraft data can only be used to confirm the occurrence but not the duration of the event; however, from both the Greenland stations, the duration of the event is estimated to be ≤15 minutes, based not only on ftE_s, but more specifically on the $h'E_s$ measurements.

The third data set recorded on 13 November 1977 is shown in Figure 6. This was a disturbed, D3 day with Kp~3+/4 for this event. The aircraft was in the vicinity of Goose Bay. Peak ftEs occurred about 2345-2350 UT. Additional data were available from Goose Bay, taken on a 7.5-minute schedule, and fbEs data at 15-minute intervals were recorded at Churchill. The aircraft data are included for completeness, although data-taking was terminated at the beginning of this event. From Goose Bay and the aircraft, the aurora was seen obliquely with recorded ftEs~4.0 MHz, h'Es ~125 km and ftEs ~5.0 MHz, h'Es ~120 km, respectively. At Narssarssuaq, h'Es measurements indicate that the aurora was overhead, but it is difficult to estimate the duration of any distinct event. On the other hand, the event at Godhavn is well defined, both from evaluation of the ftEs and the minimum virtual height. At Churchill, a pronounced increase in fbEs to 5.7 MHz is likewise recorded at about the same time.

In conjunction with this period, a Defense Meteorological Satellite Program pass (Figure 7), occurred at 2309 UT, just prior to this "event." The locations of the ground stations and the aircraft are indicated on the figure. From the DMSP image, we might infer that the lack of a well-defined event at Narssarssuaq might be the result of a persistent, stationary patch of Es ionization, or that the data-taking schedule was of insufficient frequency to define changes in ftEs. If the DMSP image also reflects the state of the ionosphere at ~2350 UT, then the Godhavn sounder was looking at a different system, polar cap aurora; consequently, the Greenland station measurements cannot be intercompared. Under these conditions, the ionospheric sounder records at Narssarssuaq, and possibly at Churchill, serve only to establish the occurrence of a period of sporadic E activity, but the relative duration cannot be clearly defined.

In these three examples, we have examined the durations of discrete auroral events under a variety of geomagnetically active conditions as measured by Kp, and compared the use of ground station versus aircraft sounder data for the determinations. Although the sample is limited, there is definite evidence that ground-based measurements of ftEs and h'Es can provide a useful yardstick for the estimation of the durations of discrete auroral events.

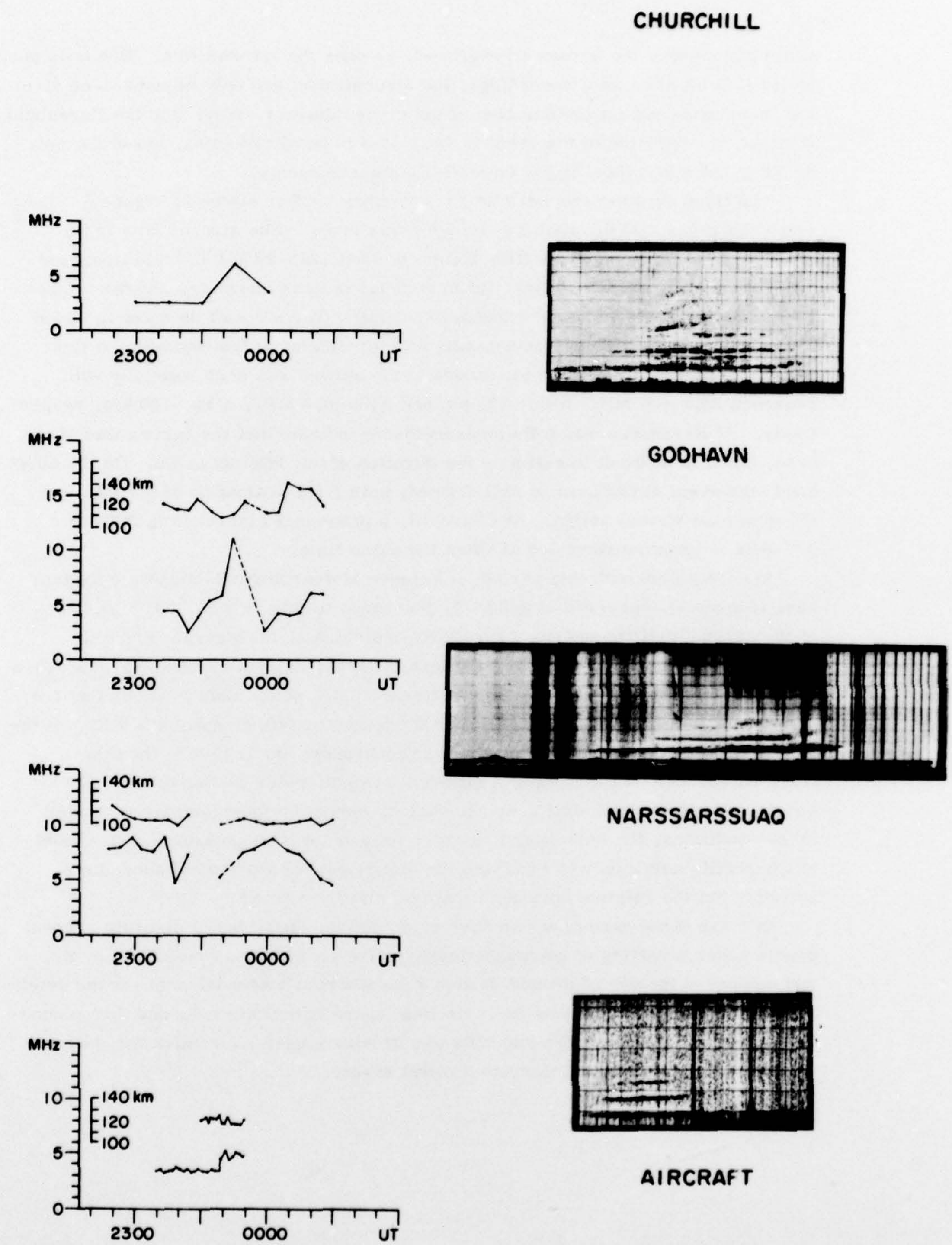

Figure 6. Same as Figure 4 With the Addition of Churchill Data. Measurements recorded on 13 November 1977

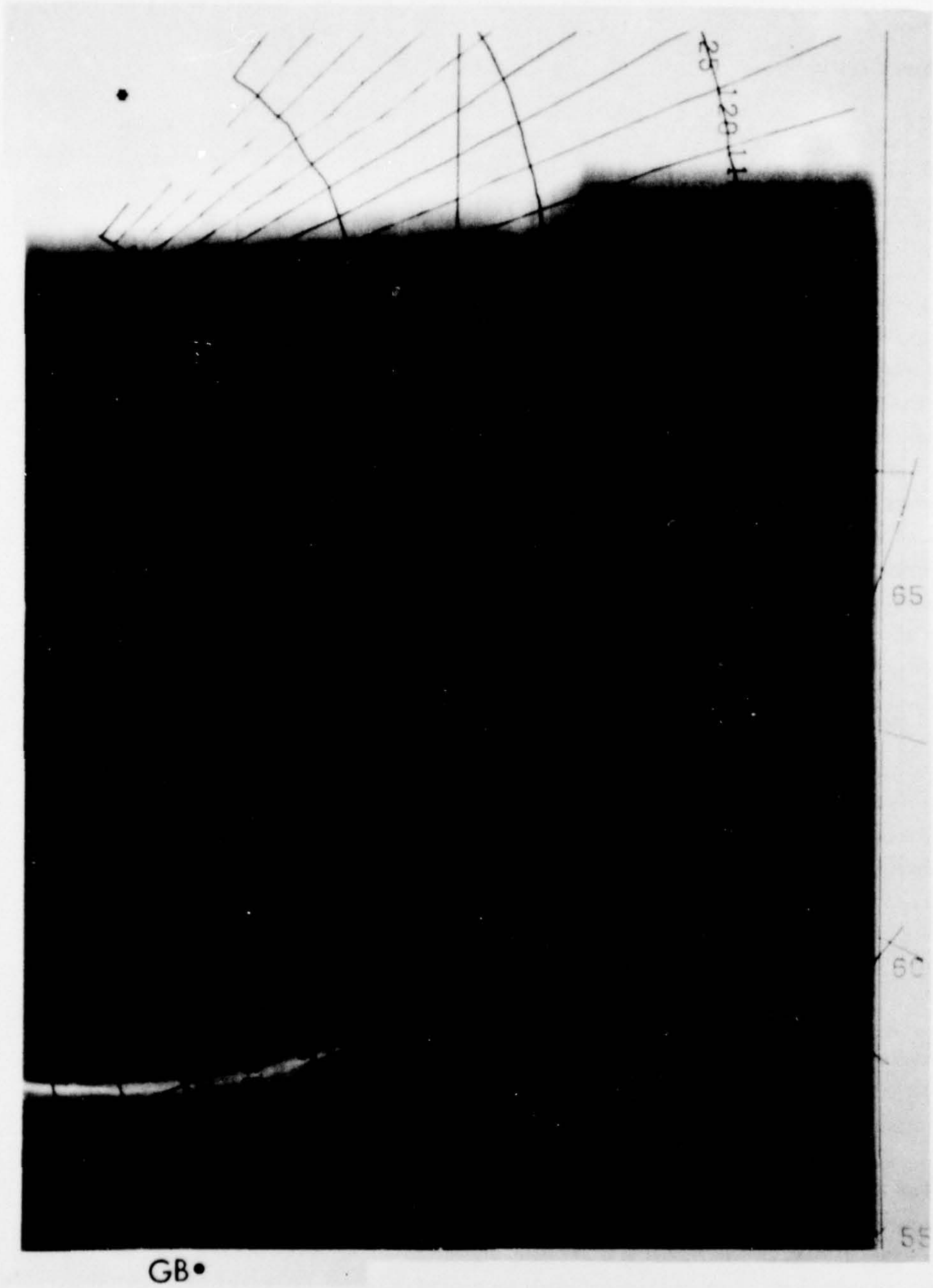

Figure 7. DMSP Image with Geomagnetic Grid Superimposed. North Pole indicated by star, satellite DMSP 13536, orbit 2293, time 2309 UT, date 13 November 1977. Locations of Godhavn (GO), Narssarssuaq (NQ), Goose AB (GB), and the AFGL aircraft are indicated

6. DISCUSSION

The present state of knowledge of the frequency of occurrence of Es ionization and its relation to visual aurora is less well established in the North auroral zone than in the temperate and equatorial zones.[18] Many investigators have made significant contributions to the understanding of its variability: by defining the statistical patterns of occurrence of Es in terms of geographic location, time, and top frequency values;[9] by determining the relationship of the brightness of aurora and/or auroral forms to ftEs;[3, 4] and by demonstrating the inverse correlation between ftEs and virtual height of the reflections.[2] These results are fundamental to the interpretation of this relationship, but they represent the macroview of the phenomena.

In contrast, our recognition of periods of discrete auroral events of short duration, ≥15 minutes, from examination of all-sky camera montages[1], has provided a framework for the study of the coincidence of these ionospheric effects on a microscale. Comparative data from ground-based instruments are also more readily available for short periods from cooperating stations. As demonstrated in the text, we have been able to correlate sounder and optical data from several recording stations and, consequently, the possibility exists for identifying periods of auroral activity via measurements of sporadic E activity. Given a sufficient bank of such data, one could: (1) contribute to the modeling of the temporal and spatial Es characteristics of the E-region; (2) provide a better understanding of the E-region variability; (3) determine if a specific frequency can be correlated with overhead Es ionization; (4) provide more evidence to clarify the relationship between occurrence of aurora and Es ionization.

7. CONCLUSIONS

1. Ground-based ionospheric sounders can provide a valuable method for the determination of the relative duration of discrete auroral events in the range of ≥15 minutes via measurements of the duration of top frequency sporadic E, in conjunction with minimum virtual height data.

2. Our study supports the close association of the occurrence of visual, overhead aurora and incidence of sporadic E, both from ground station and aircraft measurements; however, a one-to-one correlation cannot be confirmed.

3. Clearly, the fine-time scale of the discrete auroral events (≤15 minutes) requires that the data-taking schedules at ground installations be at intervals of ≤5 minutes. Data recorded at intervals >5 minutes tend to smear out and/or obliterate the existence of these events.

18. Whitehead, J.D. (1970) Production and prediction of sporadic E, Rev. Geophys. Space Phys., 8:65.

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3. Heppner, J.P., Byrne, E.C., and Belon, A.E. (1952) The association of absorption and Es ionization with aurora at high latitudes, J. Geophys. Res. 57:121.

4. Knecht, R.W. (1956) Relationships between aurora and sporadic E echoes at Barrow, Alaska, J. Geophys. Res. 61:59.

5. Hunsucker, R.D., and Owren, L. (1962) Auroral sporadic E ionization, J. Res. Nat. Bur. Stand. 66D:581.

6. Pittenger, E.W., and Gassmann, G.J. (1971) High Latitude Sporadic E, AFCRL-71-0082, Environmental Research Paper, No. 347, Bedford, Mass.

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