GCA TECHNICAL REPORT NO. 65-22-N

N66-11748

(ACCESSION NUMBER)

(THRU)

31

(PAGES)

1

(CODE)

CR 68050

(NASA CR OR TMX OR AD NUMBER)

13

(CATEGORY)

FACILITY FORM 602

ROCKET OBSERVATIONS OF SPORADIC E AND RELATED FEATURES OF THE E REGION

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GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 2.00

Microfiche (MF) .50

ff 653 July 65

GCA CORPORATION

Bedford, Massachusetts

CONTRACT NO. NASw 1083

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

HEADQUARTERS

WASHINGTON 25, D. C.

AUGUST 1965

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ABSTRACT

Observations of structural features of the electron density profile of the E region are presented. These were obtained using a rocket-borne probe having a resolution of about 10 m in height and about 1 percent in electron density. Daytime profiles show thin-layer Es having sharply-defined upper and lower boundaries and thickness of a few km. At night, the profiles at mid-latitudes are characterized by the generally-irregular nature below 120 km. The marked tendency to horizontal stratification is noted.

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ROCKET OBSERVATIONS OF SPORADIC E AND RELATED FEATURES OF THE E REGION†

L. G. Smith

EXPERIMENTAL TECHNIQUE

The electron density profiles given in this paper have been obtained with a direct-measurement technique derived from the Langmuir probe. A payload used in these measurements is shown in Figure 1. The nose tip of the rocket is insulated from the payload and the current to it measured as the potential is programmed in the following way. At intervals of 2 seconds, a ramp is applied which sweeps the potential from -2.7 to +2.7 volts. The duration of the ramp is 0.5 seconds. This is the normal Langmuir probe mode where probe current is analysed as a function of voltage to give electron temperature and electron density. In the remaining 1.5 seconds of the cycle, the potential is held constant at +2.7 volts. The current is proportional to electron density and rapid changes can be observed. The height resolution is limited only by the rocket velocity and the frequency response of the electrometer and telemetry system. The resolution obtained is about 10 m in height and about 1% in electron density. In addition a dynamic range of about five orders of magnitude in electron density is obtained with a non-linear electrometer. Further details of the instrumentation are given by Smith [1]*.

The payload shown in the figure also carried a circular disc electrode on the cylindrical section of the housing. This electrode was found to be less satisfactory than the nose tip electrode and was not used on subsequent flights.

The constant of proportionality between probe current and electron density for those cases where it could be determined is given in Table 1. Here sensitivity is the current in microamperes equivalent to an electron density of 1×10^5 cm^{-3}. Except where noted the determination was made on the basis of the maximum electron density in the E layer derived from the ionosonde observation of f_oE. These values have been used to estimate the sensitivity appropriate to the nighttime flights for which no direct determination of this factor could be made.

† Paper presented at the Sporadic E Seminar, Estes Park, Colorado, June 1965. To be published in J. Res. NBS, Section D (Radio Science).

* Numbers in [ ] throughout the text represent reference numbers.

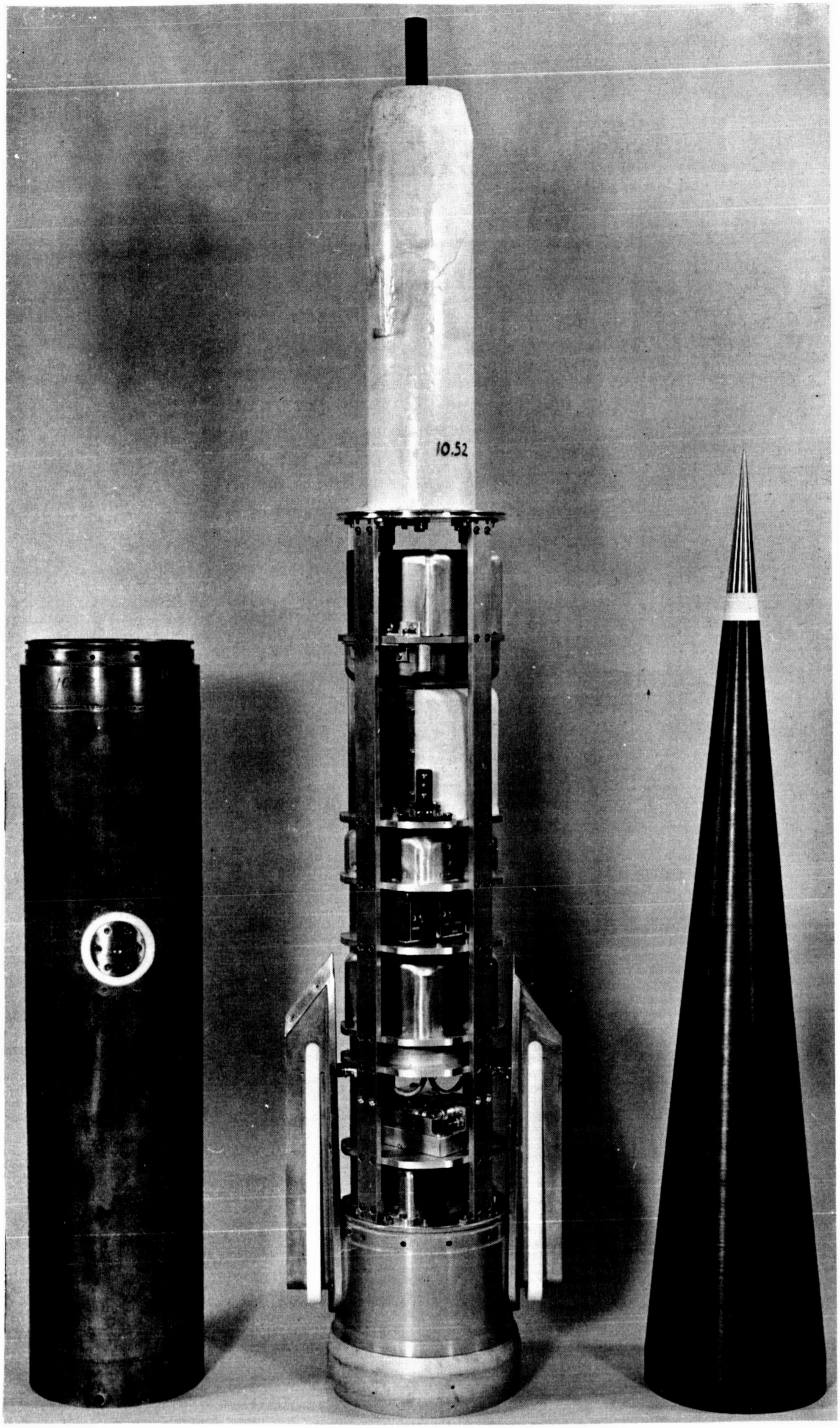

Figure 1. Payload of Nike Cajun 10.52.

Table 1: Nose Tip Probe Sensitivity

Rocket Number	Electrode	Sensitivity	Remarks
4.48	20° cone	11.1	
14.31	20° cone	11.2	
14.86	11° cone	7.7	
14.87	11° cone	12.7	Flat-Spin
14.88	11° cone	16.8	Flat-Spin
14.91	11° cone	6.7	
14.92	11° cone	5.9	
14.93	11° cone	6.9	
14.94	11° cone	6.5	
14.143	11° cone	15.5	
14.144	11° cone	8.6	Comparison with CW propagation
14.145	11° cone	3.9	experiment.
14.146	11° cone	5.8	
14.149	ogive	4.5	

Note: Sensitivity is expressed as current (microamps) equivalent to an electron density of 1×10^{5} cm^{-3}.

Three different electrode shapes have been used up to the present time, as indicated in Table 1. The sensitivity of the conical electrode with an included angle of 11^{o} has been found to show a dependence on the magnetic aspect angle (i.e., the angle between the longitudinal axis of the rocket and the magnetic field). This accounts for the high sensitivity of the two rockets (14.87 and 14.88) which precessed into a flat spin (the rocket axis nearly horizontal). Two of the nighttime rockets (10.51 and 10.99) with this type of electrode also executed this motion so that the appropriate sensitivity of the probe in these two flights is estimated to be about 15 microamp (for 10^5 cm^{-3}). The other nighttime flights (10.52, 10.108 and 10.109) having this type of electrode remained in the normal upright attitude and the sensitivity of the probe for these flights is estimated to be 6.5 microamp. This is a mean value of sensitivity for flights using the same electrode type, excluding the two which precessed into flat-spins and also excluding 14.143 which gave an unusually high sensitivity value. Starting with the flights of October 1964, the shape of the electrode was changed to that of an ogive so that the aspect dependence of probe current would be reduced. A provisional sensitivity value of 4.5 microamp has been obtained from 14.149. This value is appropriate to the probes on the twilight flights 14.194 and 14.195.

DAYTIME OBSERVATIONS

Aerobee 4.48 was launched from Wallops Island at 0743 EST on 25 May 1962. The probe in this flight was one of several secondary experiments; the primary mission was to flight test a payload recovery system. This vehicle passed through a Sporadic-E layer and gave the electron density profile shown in Figure 2.

The feature of particular interest in this profile is the very sharply defined upper and lower boundaries of the layer. The electron density at the lower side increases from 8.8×10^4 cm^{-3} to 2.5×10^5 cm^{-3}, a factor of 2.8, in 900 m. The layer thickness is 3.0 km. The gaps in the profile, indicated by the dashed line, represent periods when the electron temperature was being measured by sweeping the probe voltage. A problem with the commutation of the telemetry signal allowed only a few sweeps to give electron temperature data. A value of $300 \pm 100^{\circ}$K was obtained from the sweep at 104 km, in the layer.

The ionosonde at Wallops Island had shown the presence of Es on each observation taken at 5-minute intervals from 0600 to 0845 EST. During the rocket flight, the value of fEs was relatively steady at 5.2 mc/s and the virtual height varied between 105 and 110 km.

A second example of an Es layer having sharply defined boundaries was observed in a recent rocket flight in the South Pacific. Nike Apache 14.232, launched at 1214 LST (75°W) at 48°S magnetic latitude, on ascent showed a layer 2.4 km thick centered at 99.8 km. On descent the layer was observed to be centered at the same height, but with lower peak electron density and a thickness of 1.5 km.

On the same expedition another rocket (14.230) showed an Es layer having a thickness of 1.9 km and centered at 115 km. This rocket was launched at 0846 LST on 5 April 1965 at about 16°S magnetic. Two other rockets in this series launched on 20 March and 9 April at the magnetic equator and about 32°S magnetic respectively did not show any features that can be identified as Es layers.

An interesting case of a small layer whose peak electron density was less than that of the E layer was found on the flight of Nike Apache 14.143. The profile from the ascent of the rocket is shown in Figure 3. This is the actual telemetry record. The dashed line has been added to emphasize the structual features; it has no theoretical significance. The dots have also been added to the original; these are periods when the probe voltage is being swept.

The record shows a characteristically smooth profile from the first detectable signal at 49 km up to 84 km. From 84 to 92 km the profile shows a "granular" structure in which fine variations are visible down to a vertical

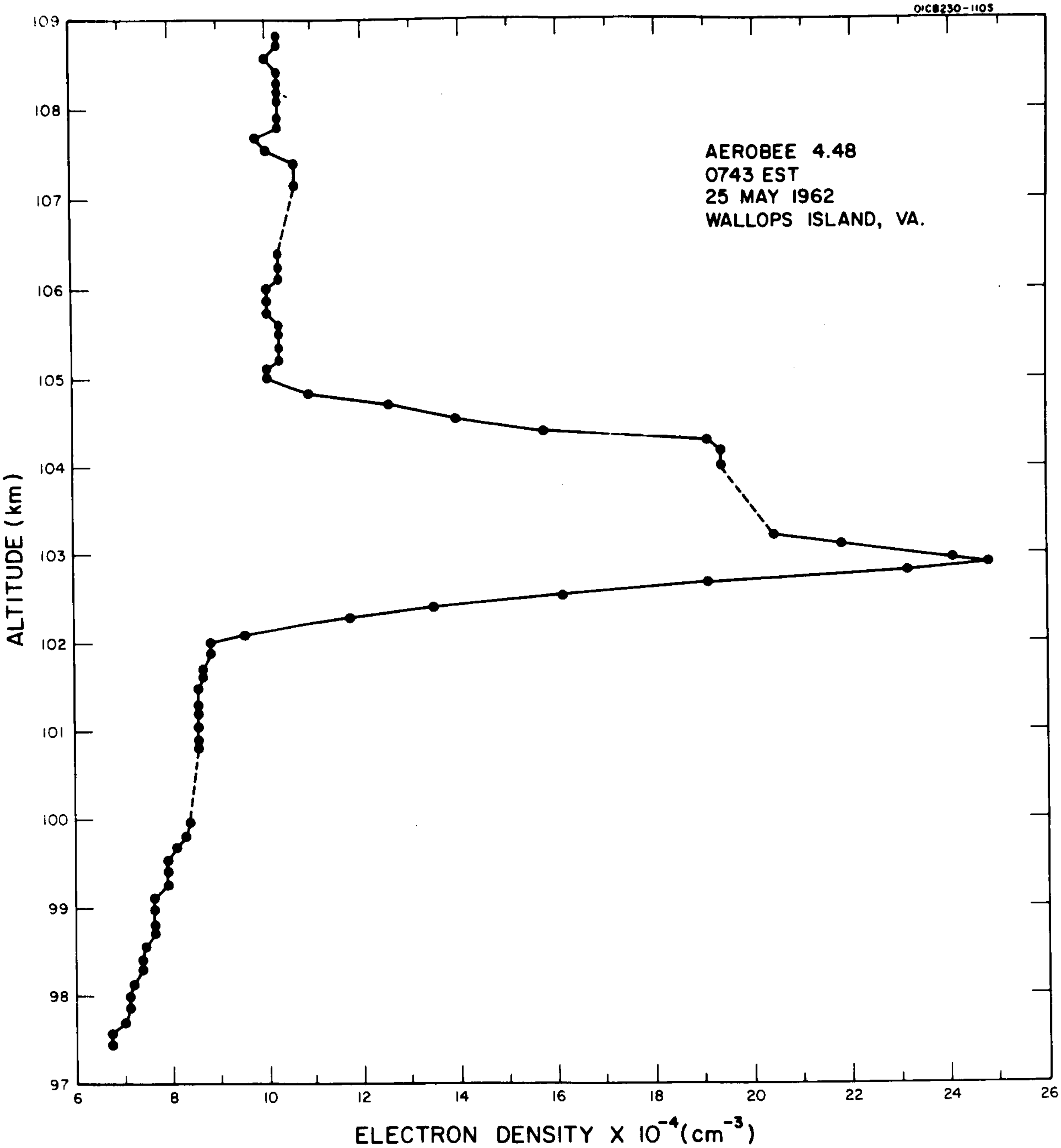

Figure 2. Sporadic-E layer, 25 May 1962.

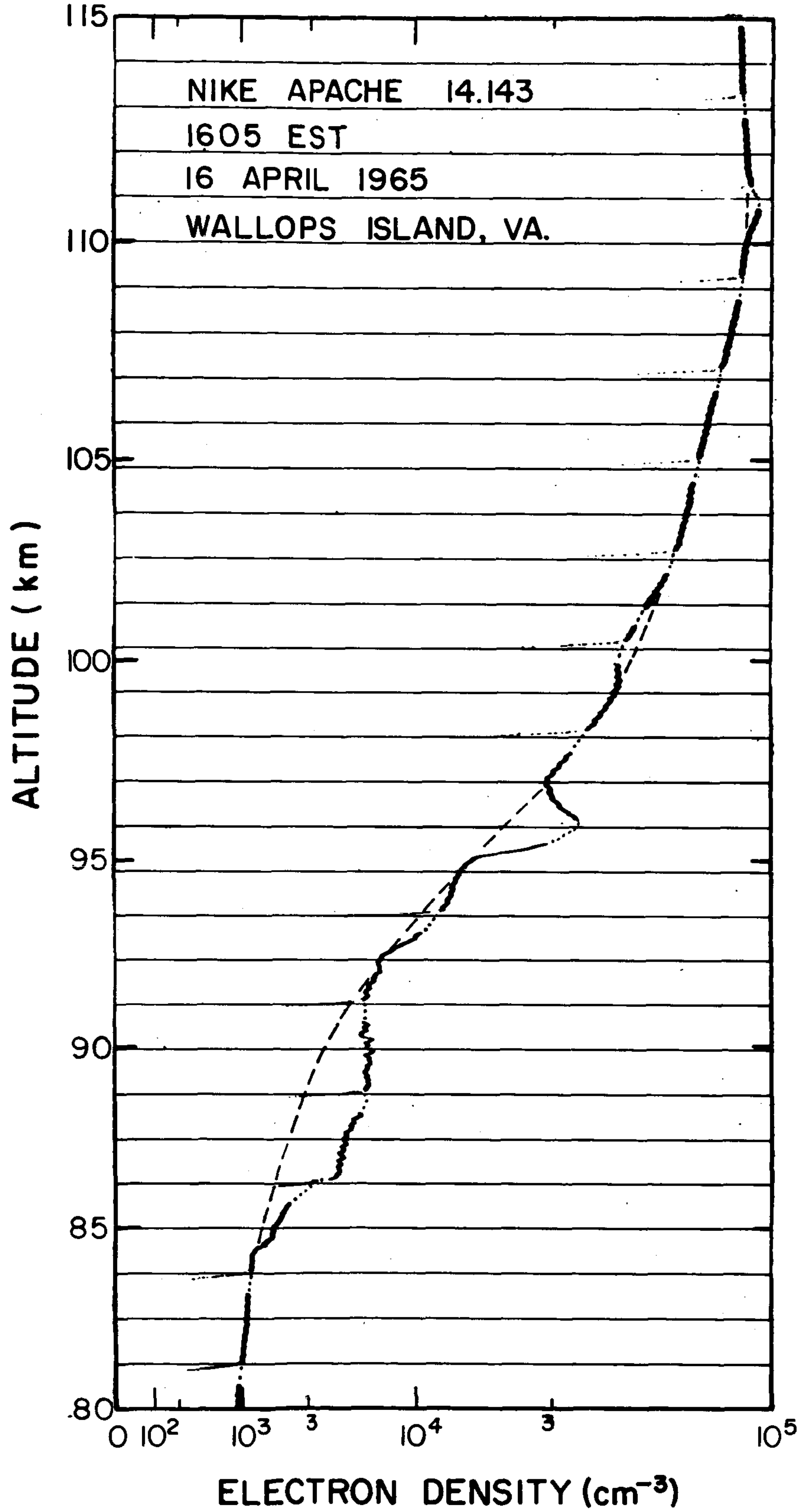

Figure 3. Daytime electron density profile including a small layer at 96 km, 16 April 1965.

resolution of 100 m. Above 92 km these granulations are not present (the ripple on the trace is caused by the spin of the rocket), but other structual features having vertical dimensions of the order of 1 km are seen. The interesting feature of this record is the peak at 96 km which is also present on the descent profile and is identified as a small layer. The maximum electron density (3.4×10^4 cm^{-3}) in this layer is less than the maximum electron density of the E layer (8.4×10^4 cm^{-3}). The layer can be seen in the ionosonde record. The total thickness of the layer is 1.8 km and the electron density at the peak exceeds the interpolated value (the dashed line) at that altitude by a factor of 1.7. A smaller feature is also seen at 111 km. The maximum electron density is 6 percent above that of the adjacent region. It has a total vertical extent of 1.5 km and is not present on the descent profile.

These daytime observations of Sporadic E in mid-latitudes show that the total thickness of the layer ranges from about 1.5 km for a weak layer to 3.0 km for an intense layer. It also appears that the intense layers tend to be rectangular in their profile whereas the smaller layers are more rounded.

The intense daytime layers show a preference for altitudes within a few km of 100 km. This suggests that there is some property of the atmosphere peculiar to this height having the nature of an instability which, when suitably triggered, results in an avalance-type of electron production. Some evidence for this can be seen in profiles taken at Fort Churchill during the solar eclipse of 20 July 1963. Enlarged sections of the actual telemetry records of four rockets are shown in Figure 4. As before the profile is interrupted for a sweep at two-second intervals. The regular small ripple is an effect of rocket spin. The maximum phase of the eclipse occurred at 100 km at 1506 CST.

The profile from Nike Apache 14.92 shows very clearly a region or irregularities between 101.0 and 103.9 km. The amplitude in electron density is $\pm$ 18 percent and the amplitude in height is about 0.4 km. The sharpness of the boundaries of the region, the altitude of the center (102.5 km), and the thickness (2.9 km) strongly suggest an association with Sporadic E although none was recorded by the Churchill ionosonde. This region of irregularities is also present on the descent profile at a horizontal distance of 63 km from those on the ascent profile. The other three profiles show less clear evidence of the irregularities; the amplitude for these is about $\pm$ 10 percent and there is some indication of a decrease in altitude during the sequence.

This phenomenon was also observed on the only other daytime flight using the DC probe at Fort Churchill. It occurs in the height interval from 102.6 to 106.7 km in the data from Nike Apache 14.88, launched at 1503 CST on 14 July 1963. It has not been seen in the data obtained from launchings at Wallops Island.

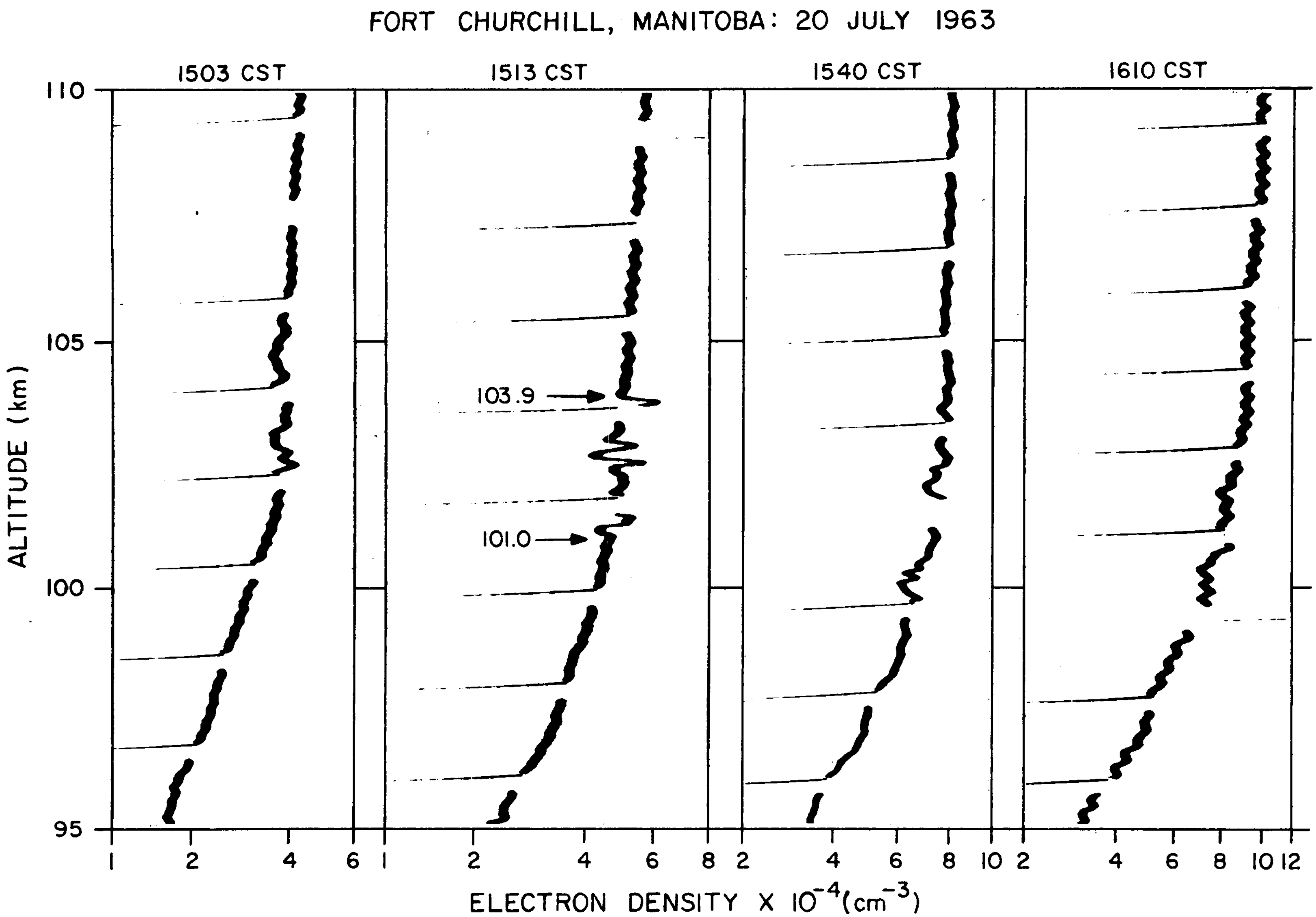

Figure 4. Irregularities in the electron density profiles, 20 July 1963.

NIGHTTIME OBSERVATIONS

The first flight using the DC probe technique gave the profiles shown in Figure 5. This vehicle was launched about 3 hours after ground sunset ($\chi = 90^{\circ}$) and is notable for the layer about 1 km thick centered at 102.5 km. The peak electron density is 3×10^4 cm^{-3}. An Es echo was recorded by the ionosonde at a virtual height of 110 km. The discrepancy in height seems to be characteristic of nighttime observations whereas in daytime generally good agreement has been found. Above 120 km, the low value of electron density of the order of a few hundred per cm^{-3} may also be noted. If this results from recombination along, a coefficient of about 3×10^{-7} cm^3 sec^{-1} is deduced.

The existence of a nighttime E layer between about 90 and 120 km can be interpreted in two ways. First, there is a source of ionization limited to altitudes below 120 km: meteorites have been suggested and corpuscular radiation provides another possibility. Alternatively the recombination rate, although initially high ($\geq 1 \times 10^{-7}$ cm^3 sec^{-1} as shown by eclipse observations), is greatly reduced when the rapidly recombining ion species have disappeared and only those with smaller recombination coefficients remain.

Whatever the explanation of this E layer at night, it is a persistent feature although the structure varies greatly on the different occasions for which observations are available. This is illustrated by the profiles from Nike Apache 10.52 shown in Figure 6. This flight was made shortly before sunrise with the whole trajectory still in darkness. An upper layer at 112.7 km is clearly seen. The peak electron density is 1.8×10^5 cm^{-3}. In the altitude range from 101 to 107 km, the profiles show significant differences. The principal peak is observed at 106 km on the ascent profile but at 102 km on the descent profile. The ionosonde indicated the presence of Es although the virtual height appears to be 135 km.

The wind-shear theory of the formation of Sporadic E has provided the incentive for a series of rocket flights in which nearly simultaneous observations of the electron density profile and the wind profile have been obtained. Initially, separate rockets were used for the two measurements but lately a combined payload has been developed and the electron density profile is obtained on the ascending portion of the trajectory and the wind profile from vapor released on the descending portion. The electron density profiles for seven flights from Wallops Island, Virginia are given in the present paper; the wind observations are presented by Bedinger and Knaflich [2].

The first flight, Nike Cajun 10.99, was held on the launch pad for occurrence of Es as indicated by the ionosonde. The profiles obtained on ascent and descent are shown in Figure 7. A strong layer is observed on the descent profile between 98 and 102 km. The peak electron density went off scale at 2×10^4 cm^{-3}. The ascent profile shows a bifurcation of the layer.

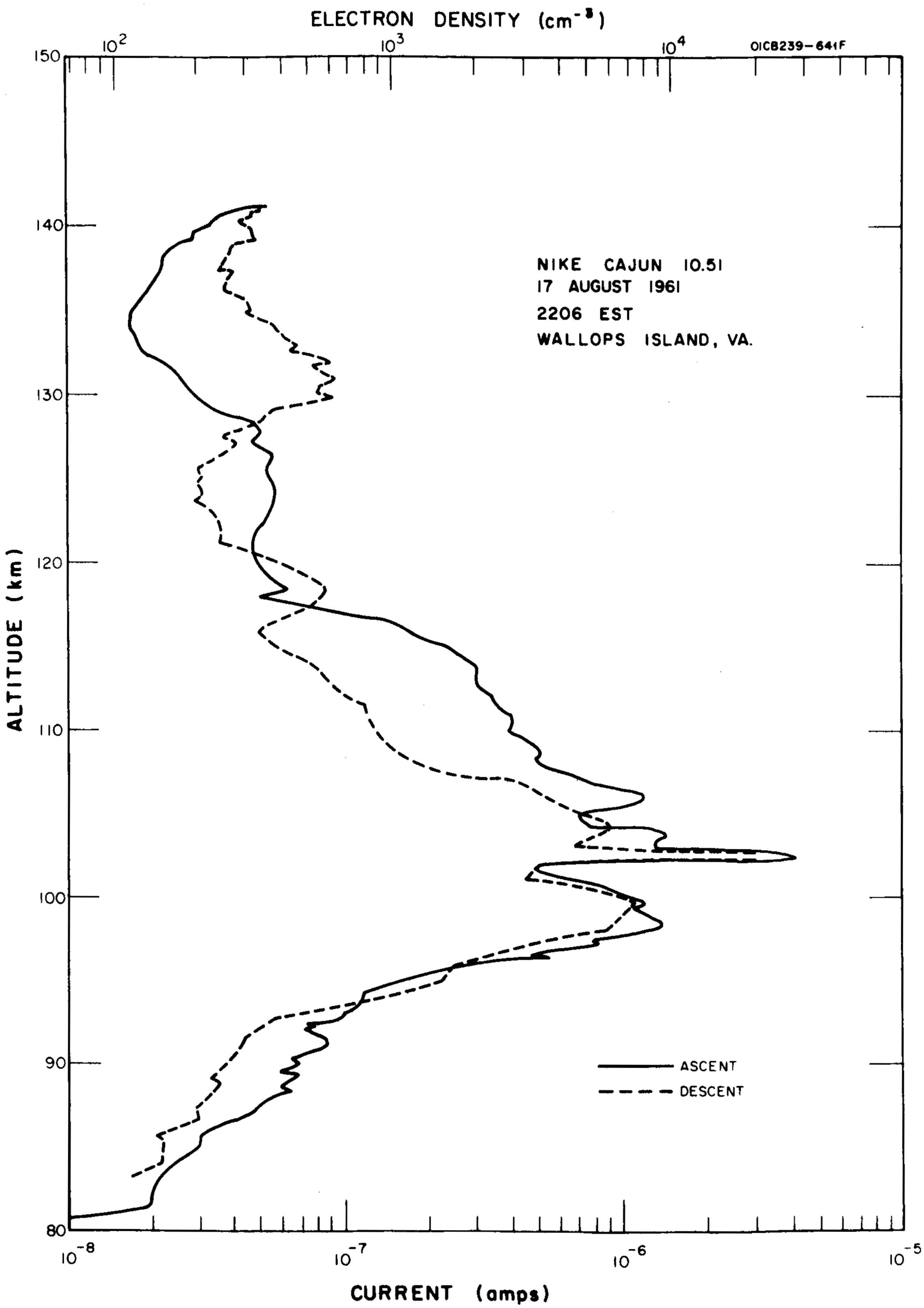

Figure 5. Electron density profiles 3 hours after ground sunset, 17 August 1961.

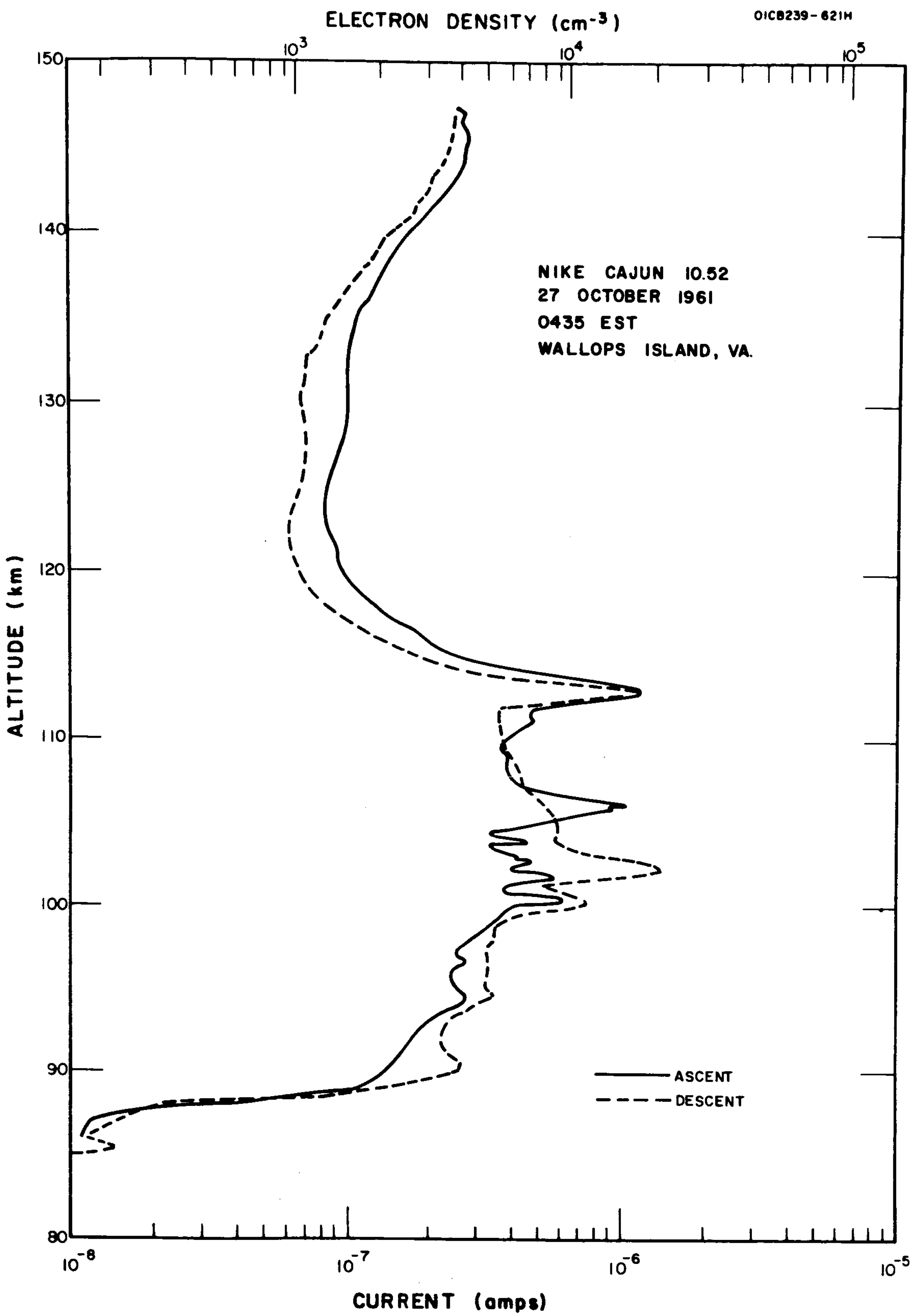

Figure 6. Sunrise electron density profiles, 27 October, 1961.

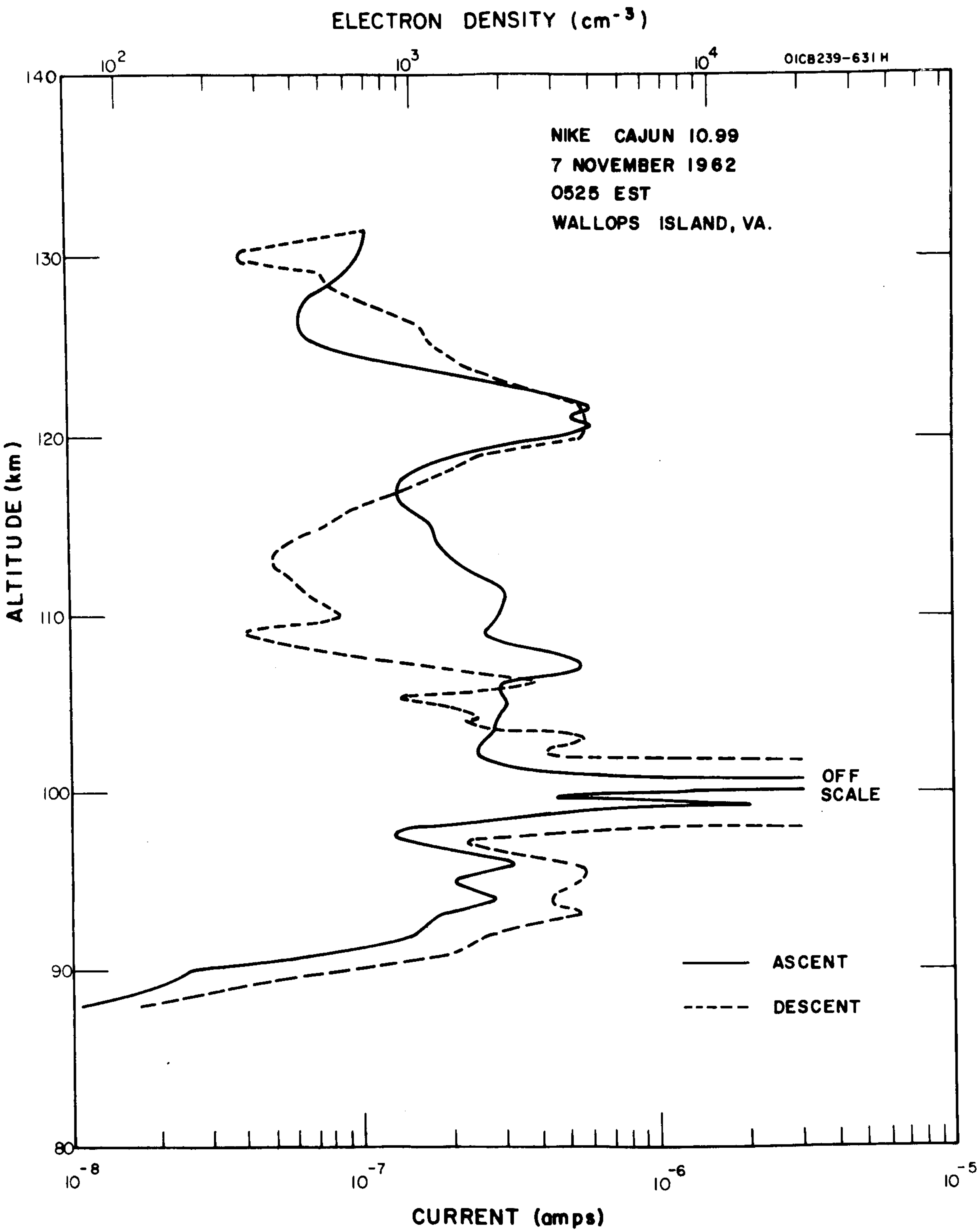

Figure 7. Sunrise electron density profiles, 7 November 1962.

An upper layer centered at 121 km should also be noted. The peak electron density in this layer is 4×10^3 cm^{-3}.

The next flight was made in a disturbed ionosphere at sunrise. The ionosonde record was completely blank during the flight of Nike Cajun 10.108 launched at 0557 EST. The F2 critical frequency had dropped below 1.9 mc/s and from 0459 to 0605 EST no echo was seen. The electron density profiles are shown in Figure 8. The maximum electron density in this profile is 1.4×10^4 cm^{-3} at 111 km. The nighttime E layer is again present, but, compared with earlier and subsequent nighttime profiles, it is lacking in major structural features. Small layers may be identified at 100 km and 111 km.

The electron density profiles from Nike Cajun 10.109 are shown in Figure 9. This flight was at sunset. The lack of correspondence between the profiles in the height range 108 to 118 km may be noted. The maximum values of electron density on ascent and descent are about equal (1.5×10^5 cm^{-3}), but the altitudes are 111 and 116 km respectively. The ionosonde recorded fEs ranging from 7.7 to 9.6 mc/s during the flights with a virtual height of 110 km.

Three rocket flights on the morning of 15 July 1964 provide an interesting sequence showing the change in shape and altitude of two sporadic E layers during sunrise. The launch times of the three rockets were selected to show the development of the D region at sunrise. This aspect of the data has been discussed by Bowhill and Smith [3].

The first rocket (14.144) was launched at 0300 EST with the trajectory in darkness. The electron density profiles (ascent and descent), Figure 10, show two prominent layers. The upper layer at 119 km has a peak electron density of 2×10^4 cm^{-3} and the lower layer at 95 km has a peak electron density of 3×10^4 cm^{-3}. The electron density falls off rapidly above the upper layer to a minimum value of 200 cm^{-3} at 148 km. Between the two layers the electron density reaches a minimum value of 1×10^3 cm^{-3}.

The next flight (14.145) was made 80 minutes later with the earth shadow at a height of 35 km (at launch). The upper layer now has a maximum electron density of 5×10^4 cm^{-3} at 114 km and the lower layer a maximum electron density of 7×10^4 cm^{-3} at 93 km. These values are approximately double those of the preceding profile. The electron density between the layers and above the upper layer has increased as a result of ionizing radiation striking the region.

The third flight (14.146) followed after after a further interval of 65 minutes. The two layers can still be identified in spite of a considerable increase in electron density throughout the region. The upper layer has a maximum electron density of 8×10^4 cm^{-3}, roughly a 50 percent increase over the preceding observation, while the maximum electron density of the lower layer has decreased considerably to a value of 2×10^4 cm^{-3}.

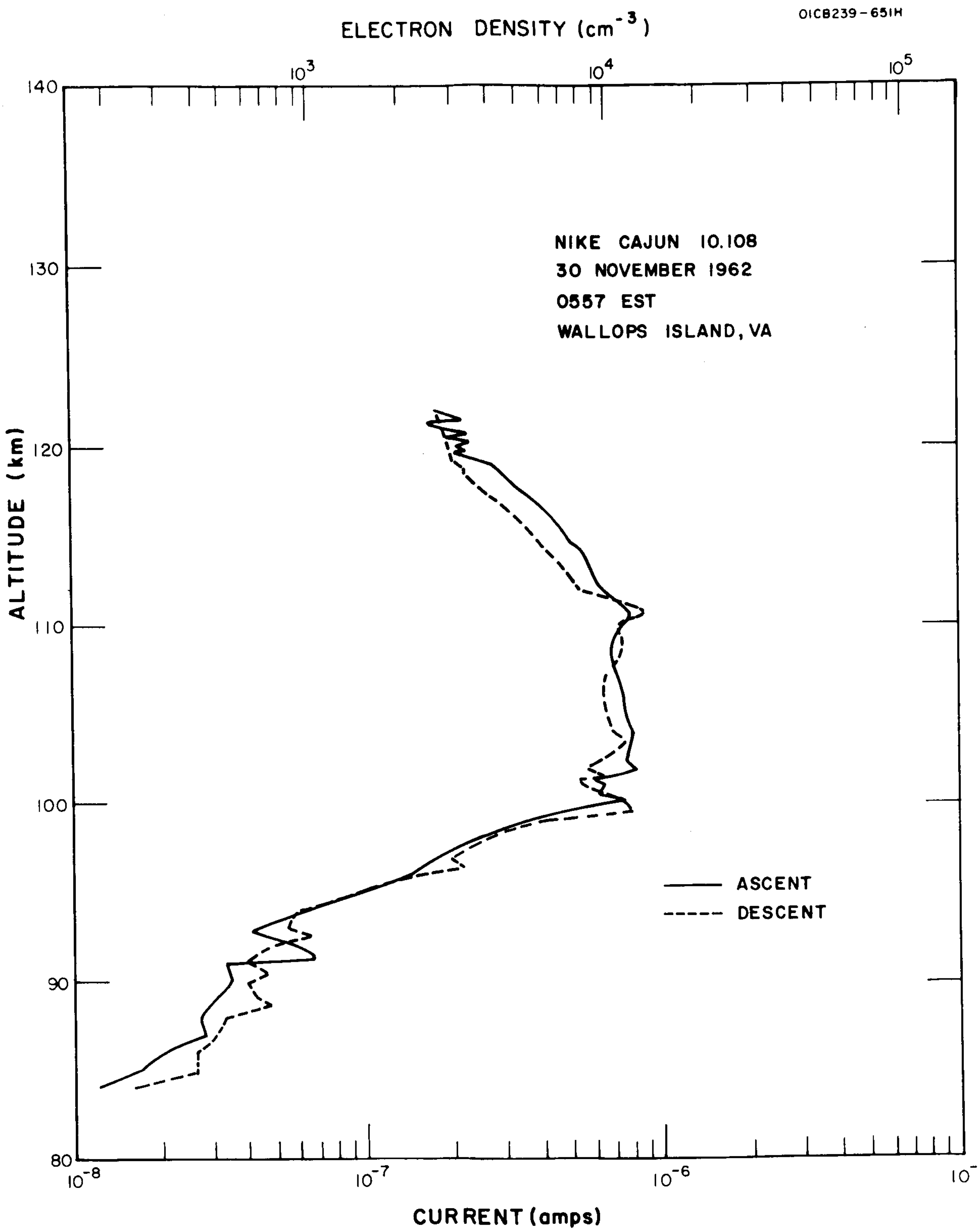

Figure 8. Sunrise electron density profiles, 30 November 1962.

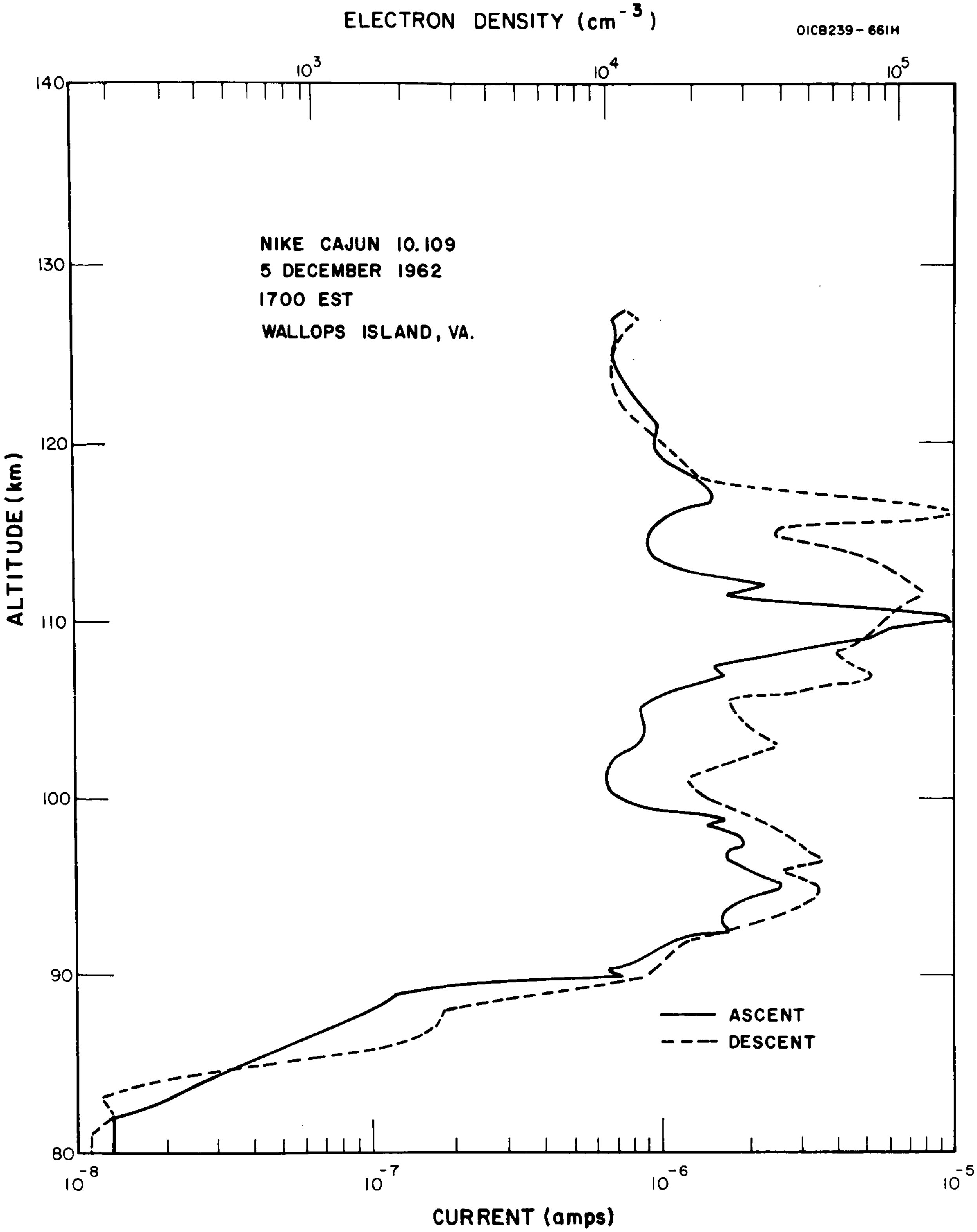

Figure 9. Sunset electron density profiles, 5 December 1962.

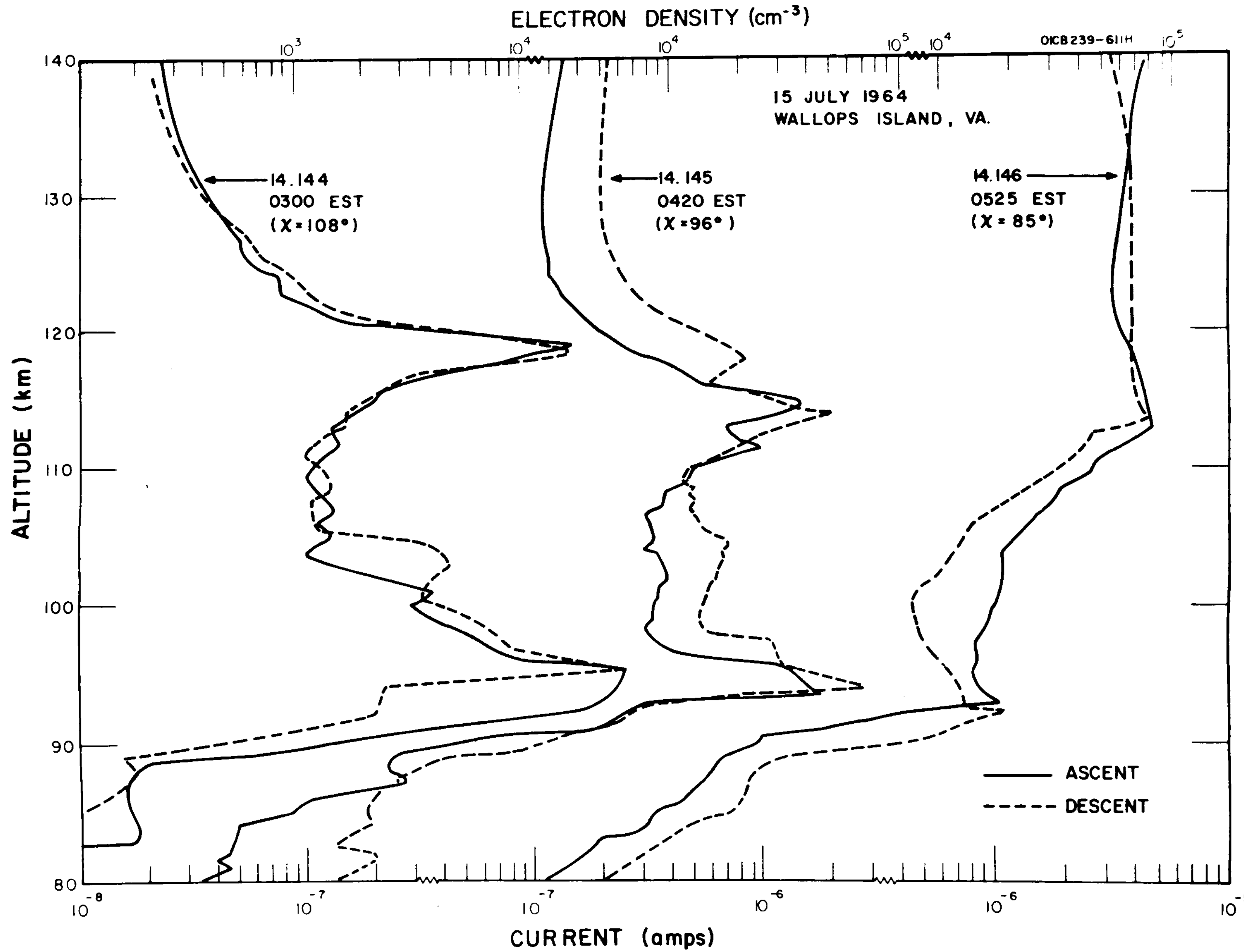

Figure 10. Sequence of electron density profiles on the morning of 15 July 1964.

The most interesting aspect of this series of observations is the persistence of the two principal layers. The total duration of the observations was 150 minutes (from the ascent profile of 14.144 to the descent profile of 14.146). The altitudes of the layers remained constant within 4.5 km for the upper layer and 2 km for the lower layer and the maximum electron density in both layers was from 2×10^4 cm^{-3} to 8×10^4 cm^{-3}.

The final two profiles presented here were made using payloads which combine the probe instrumentation with the vapor canister used for the wind determination. The electron density profile for these flights is obtained only on the ascending portion of the trajectory. When sodium vapor is released, as on Nike Apache 14.194, the electron density probe is immediately contaminated and no further useful data is obtained. When trimethylaluminum (TMA) is released, as on Nike Apache 14.195, the probe is affected but the main features of the electron density profile can still be recognized. Thus the strong sporadic E layer seen at 113 km and the lesser layer at 94 km, Figure 11, can be clearly seen on the telemetry record during rocket descent and their altitudes determined. This flight was made during evening twilight on 7 October 1964. The electron density profile obtained from the flight of Nike Apache 14.149, nearly 12 hours later, is shown in Figure 12. The peak at 96 km may be noted.

The lower side of the nighttime E layer occasionally shows a pronounced ledge having electron density gradients comparable with the lower boundary of a strong sporadic E layer. Four of the profiles given here contain such ledges; one of them shows two distinct ledges. The altitudes are given in Table 2.

Table 2: Altitudes of Ledges

Rocket Number	Date	Altitude
10.52	27 Oct. 1961	88 km
10.109	5 Dec. 1962	89.5 km
14.145	15 July 1964	91 km 93 km
14.194	8 Oct. 1964	95 km

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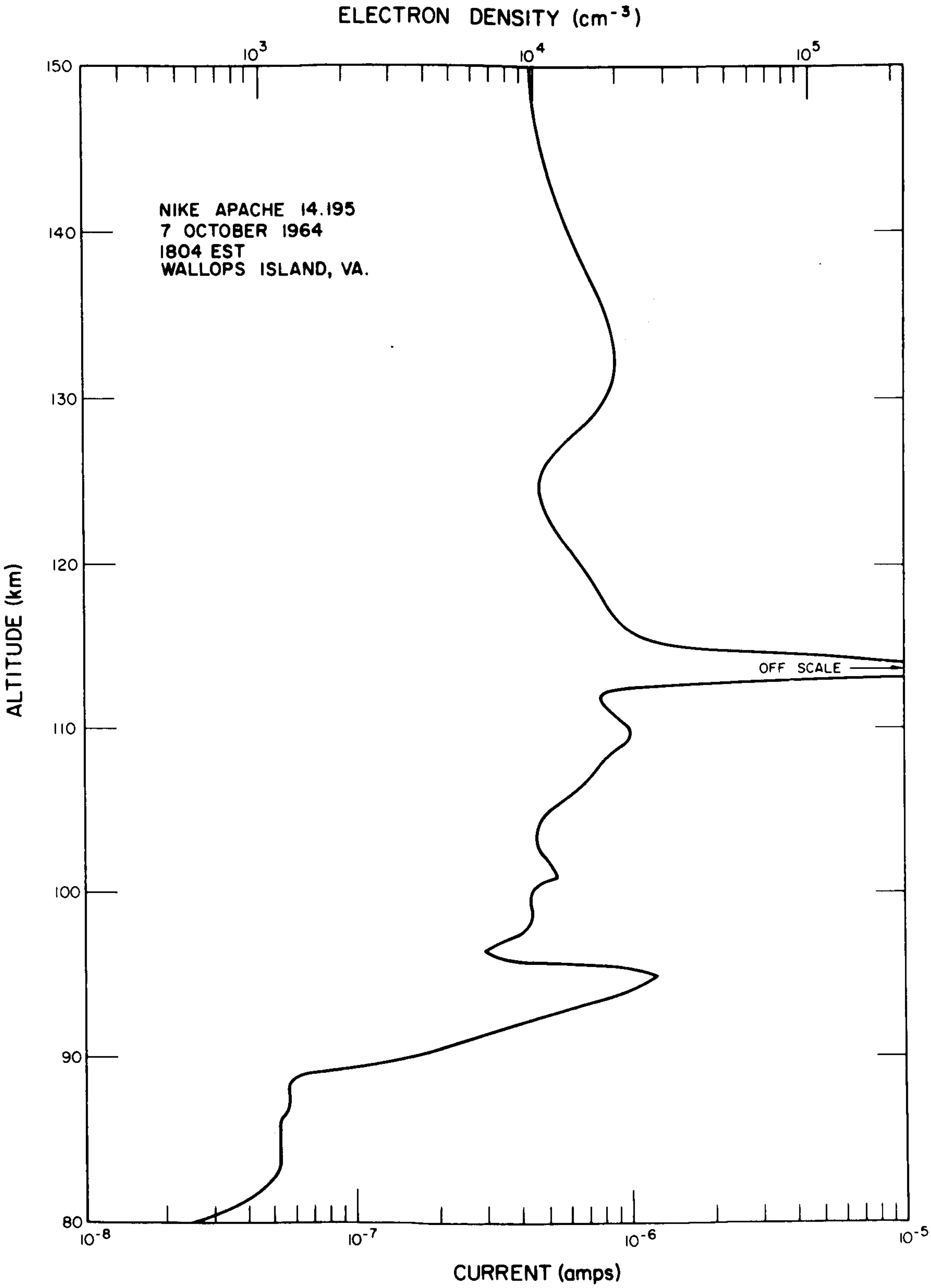

Figure 11. Sunset electron density profile, 7 October 1964.

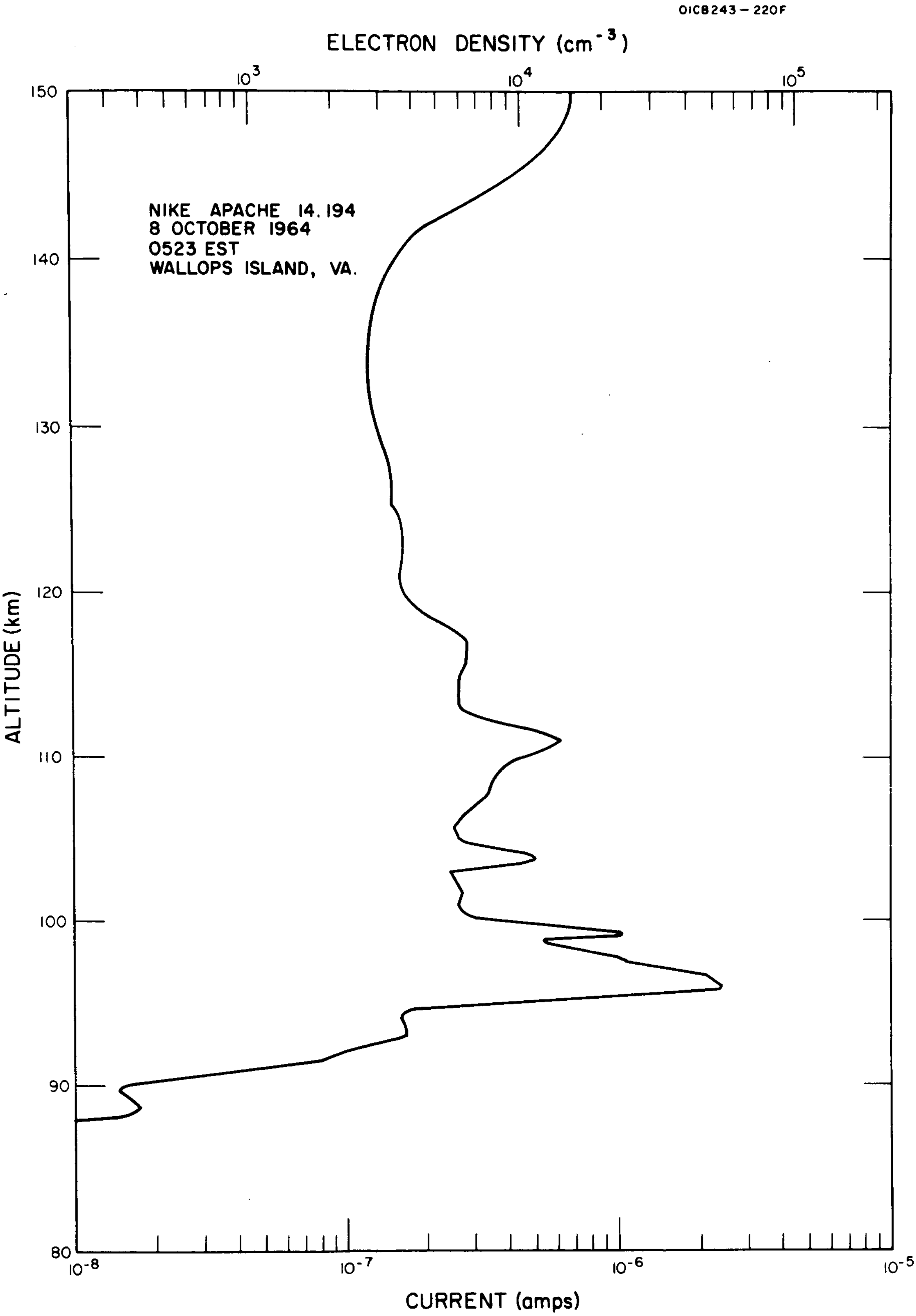

Figure 12. Sunrise electron density profile, 8 October 1964.

CONCLUSIONS

Features on the electron density profile having a vertical extent of no more than a few kilometers are seen on some of the daytime and most of the nighttime profiles. The features are generally seen on profiles from both ascent and descent of the rocket. The existence of high accuracy trajectory data for rocket launches at Wallops Island allows a determination of the tilt of the layers. Table 3 has been prepared using the data from the flights described earlier in this paper and one subsequent flight (Nike Apache 14.147). The altitude given in the table is that of the maximum electron density in the layer. In a few cases the point of maximum electron density was off-scale or occurred during a voltage sweep; for these the center of the layer was used. The altitudes include a correction for earth curvature and represent heights above a reference spheroid. The altitudes are considered to be accurate to within 50 m.

The altitude difference is taken to be positive when the layer is higher on the descent profile. The horizontal separation of the two points at which the rocket passed through each layer is also given. The angle of tilt is calculated from the altitude difference and the horizontal separation. Since the layers are following the curvature of the earth, this tilt represents an average deviation from the local horizontal.

The total of 18 layers given are based on data from 11 rocket flights. Three of the layers are indicated as minor features and probably should not be identified as sporadic E layers. With two exceptions, the tilt lies between +37' and -45'. The mean value is -7' which is not significantly different from zero. It is likely that the two largest values of tilt result from the passage of the rocket through two distinct layers separated both horizontally and vertically.

The values given for horizontal separation, range from 33 to 123 km, indicating that the layers have considerable horizontal dimensions.

The altitude at which sporadic E layers are observed range from 93 to 121 km. The most intense layers, particularly those in daytime, show a preference for altitudes near 100 km.

There is some evidence that the irregularities which characterize the nighttime structure below 120 km are suppressed at times of geomagnetic activity.

The investigation thus far has been principally concerned with mid-latitude phenomena. It is planned to make further flights with the combined payload at Fort Churchill, though the occurrence of auroral disturbances complicates the interpretation of the data. It is also considered important to investigate equatorial Es. In spite of the relatively high incidence of Es at the magnetic equator, it appears that no in-situ observations have yet shown any feature of the electron density profile which can be associated with Es.

Table 3: Tilts of Thin Layers in the E Region

Rocket and Date	Altitude km Ascent	Altitude km Descent	Altitude Difference km	Horizontal Separation km	Tilt
Nike Cajun 10.51 17 August 1961	102.52	102.64	+0.12	73.3	$+0^\circ$ 05'
Nike Cajun 10.52 27 October	112.92 106.34	112.50 101.83	-0.42 -4.51	45.1 50.6	-0° 32' -5° 06'
Nike Cajun 10.99 7 November 1962	120.51 100.05	120.93 100.00	+0.42 -0.05	38.9 66.8	$+0^\circ$ 37' -0° 03'
Nike Cajun 10.108 30 November 1962	110.81 99.96	110.72 99.62	-0.09* -0.34*	33.3 46.8	-0° 09' -0° 25'
Nike Cajun 10.109 5 December 1962	110.64	116.11	+5.47	51.7	$+6^\circ$ 02'
Nike Apache 14.143 16 April 1964	95.98	96.26	+0.28*	119.3	$+0^\circ$ 08'
Nike Apache 14.144 15 July 1964	119.07 95.26	118.14 95.28	-0.93 +0.02	82.5 106.5	-0° 39' $+0^\circ$ 01'
Nike Apache 14.145 15 July 1964	114.60 93.12	113.25 93.11	-1.35 -0.01	102.1 123.1	-0° 45' -0° 00'
Nike Apache 14.146 15 July 1964	112.41 93.07	113.13 92.36	+0.72 -0.71	95.0 110.4	$+0^\circ$ 26' -0° 22'
Nike Apache 14.195 7 October 1964	113.04 93.99	112.78 94.02	-0.26 +0.03	97.4 112.1	-0° 07' $+0^\circ$ 01'
Nike Apache 14.147 10 November 1964	101.46	101.11	-0.35	107.5	-0° 11'

*Minor layer

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3. Bowhill, S. A. and Smith, L. G., "Rocket Observations of the Lowest Ionosphere," to be published in Space Research 6, 1965.

ROCKET MEASUREMENTS OF SPORADIC E†

L. G. Smith

CONCLUDING REMARKS

A considerable amount of data on the electron density profile of Es layers has been accumulated starting with Seddon's [1] experiments using his CW propagation technique. More recent data has been presented at this conference. The motivation for recent observations has resulted from the wind shear theory. It should be pointed out that the determination of winds by the vapor trail technique is at present limited to night and twilight observations. Now Es in mid-latitudes, where most of these observations are being taken, is primarily a daytime phenomenon and the basic statistical information on Es has been derived from ground-based radio techniques. Thus the rocket data is unfortunately biased by the nighttime observations.

It is not sufficient for theories to explain only nighttime Es; the more intense daytime cases must also be explained. An adequate theory must be able to explain, for example, a layer observed by Seddon at White Sands, New Mexico, at midday on 29 June 1956. He found a peak electron density of 4.5×10^5 cm^{-3} at an altitude of 100.8 km with a total layer thickness of about 2 km. The blanketing frequency of this layer would be about 6 mc/s. The electron density of the region adjacent to the layer was 1.5×10^5 cm^{-3}. A few examples of similarly intense daytime layers have since been observed on other rocket flights by other investigators using different measuring techniques. The existence of layers of this magnitude can no longer be in doubt.

It is now well established from rocket observations that the blanketing frequency corresponds to the maximum plasma frequency in the layer. It is not yet clear whether the echoes at higher frequencies for which the layer is transparent result from small-scale irregularities in the electron density profile (preferred by Bowhill) or from steep gradients or ledges (suggested by Seddon). Both types of features can be seen in the profiles obtained on rocket flights.

The radar back-scatter technique indicates roughly circular clouds of about 200 km in diameter. Data from ionosondes (Whitehead) points to a lenticular shape of the order of 10 km by 100 km. The rocket observations indicate horizontal dimensions of at least 50 km and therefore tend to support the back-scatter observations.

†Presented at the Sporadic-E Seminar, Estes Park, Colorado, June 1965. To be published in J. Res. NBS, Section D (Radio Science).

The total thickness of daytime layers increase from 1.5 km for the smaller layers to 4 km for the most intense layers. The thicker layers tend to be more rectangular in profile than the smaller layers.

The question of the tilt of layers is not yet resolved. Radio observations indicate tilts of a few degrees, whereas, except in rare instances the rocket data shows the layers to be constant in height (above mean sea level) to within 1 km over horizontal distances of about 100 km.

On the question of horizontal motion of Es clouds, it was stated that 90% of the clouds seen by the radar back-scatter technique had no motion. The remaining 10% had an average velocity of 50 m/sec. The rocket observations indicate that the wind velocity at the altitude of Es layers has a value of about 50 m/sec in the majority of cases. This apparent discrepancy requires further investigation.

Several measurements of electron temperature in Es layers have been made using rockets instrumented with Langmuir probes (or variations thereof). No clear relation between electron temperature in the layer and in the adjacent region is found. For example, Giraud quotes the results of three different flights: in one the layer was cooler than the adjacent region; in a second case both layer and adjacent region were relatively cool; and in a third case the layer was warmer than the adjacent region.

It must be recognized that the measurement of electron temperature is a difficult experiment. The large dynamic range of current needed for a reliable determination makes measurements impossible for electron densities less than about 10^4 cm^{-3}. Thus it is suitable for measurements in the daytime E region where the electron density is of the order of 10^5 cm^{-3} but at night, in the same region, the electron density rarely exceeds 10^4 cm^{-3} except in the Es layers themselves.

A further difficulty results from the low electron temperatures in the lower E region. The neutral gas temperature at 100 km is probably about $200^\circ K$ (as in the U.S. Standard Atmosphere, 1962). It is expected that the electron temperature at this altitude would have the same value, which corresponds to a mean electron energy of about 2×10^{-2} volt.

Under ideal conditions this would be difficult but not impossible to measure but as Leavens indicated earlier in discussion of rocket observations significant errors can be introduced by contamination of the surface of the probe. The only conclusion that can safely be drawn from the available data is that the electron temperature in an Es layer does not exceed $750^\circ K$; it is probably much less than this value. The question on the temperature differential between the layer and the adjacent region requires further investigation.

This symposium has drawn attention to the importance of investigating other fundamental properties of Es layers. Probably the most significant at the present time is the positive ion composition. The greatest practical difficulty here is the rapid scan rate required by the mass spectrometers currently used in rocket investigations. The total time the rocket spends in the Es layer is only one or two seconds while the scan time of a rocket mass spectrometer is generally about two seconds. Giraud reports that his co-workers are planning an experiment in which this difficulty will be circumvented by using a continuous system in which only certain pre-selected positive ion species are recorded, thus giving virtually unlimited height resolution. This experiment should help resolve the question of whether the positive composition in the layer differs from that in the adjacent region; it was pointed out by Axford and Cunnold and by Whitehead that the wind-shear theory would result in a relatively greater concentration of the slowly recombining species (such as the matellic ions) in the layer.

The question of the presence of negative ions in Es layers was also raised at this conference. It would seem to be a no more difficult problem to use an ion mass spectrometer for negative ions than for positive ions and hence to establish the presence, if any, of negative ions both in the layer and the adjacent region.

One other measurement which seems to be feasible with existing (or slightly modified) rocket instrumentation is the investigation of magnetic field discontinuities at the upper and lower boundaries of the Es layer. It was pointed out by Axford that this experiment would require a sensitivity of the order of one gamma (1×10^{-5} gauss). The relative thinness of Es layers (less than 4 km) makes the detection of a change of this magnitude just about possible.

Finally, the proposed experiments of the Rocky Mountain Science Council point out the advantages of combining related instrumentation on one or more rockets. In addition to winds, electron density, and electron temperature it is planned to include instrumentation for neutral atmospheric density and airglow.

It is now clear that it is much easier to penetrate the Es layer with a rocket than had been thought in the earlier days. When an ionosonde at the launch site (or within, say, 10 km of it) indicates the presence of blanketing sporadic E it is certain that the rocket will find a layer whose peak electron density is close to that given by a plasma frequency equal to that of the blanketing frequency. It is therefore now feasible to plan much more sophisticated experiments and more systematic experimenta investigating the detailed structure and properties of Es layers than have yet been attempted.

REFERENCE

1. Seddon, J. C., "Sporadic E as Observed with Rockets," NASA Technical Note D-1043, July 1961.