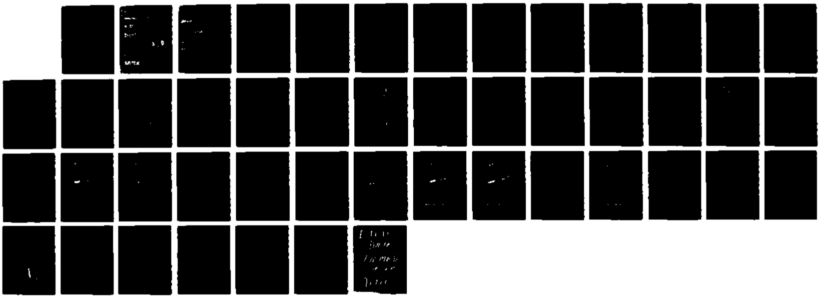
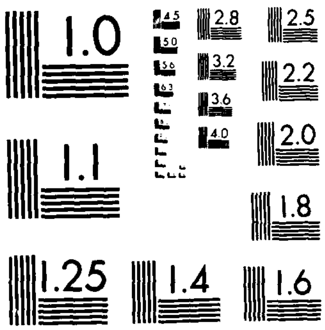
AD-A195 040 IONOSONDE STUDIES OF FIELD-ALIGNED IRREGULARITIES 1/1
DURING HIGH-POWER HF HE..(U) LOWELL UNIV MA CENTER FOR
ATMOSPHERIC RESEARCH L F MCNAMARA ET AL. FEB 88

UNCLASSIFIED ULRF-433/CAR AFGL-TR-88-0168 F/G 4/1 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A195 848

(4)

AFGL-TR-88-0168

DTIC FILE COPY

DIGISONDE STUDIES OF FIELD-ALIGNED IRREGULARITIES DURING HIGH-POWER HF HEATING AT ARECIBO

Leo F. McNamara
Bodo W. Reinisch
Jurgen Buchau

University of Lowell
Center for Atmospheric Research
450 Aiken Street
Lowell, Massachusetts 01854

DTIC
ELECTE
JUN 1 3 1988
S D
H

February 1988

Scientific Report No. 4

Approved for public release; distribution unlimited.

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

88 6 023

"This technical report has been reviewed and is approved for publication."

JACKIE B. WAARAMAA	HERBERT C. CARLSON
Contract Manager	Branch Chief

FOR THE COMMANDER

ROBERT A. SKRIVANEK
Division Director

This document has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify AFGL/DAA, Hanscom AFB, MA 01731. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document requires that it be returned.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-86-0168	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) IONOSONDE STUDIES OF FIELD-ALIGNED IRREGULARITIES DURING HIGH-POWER HF HEATING AT ARECIBO		5. TYPE OF REPORT & PERIOD COVERED Scientific No. 4
		6. PERFORMING ORG. REPORT NUMBER ULRF-433/CAR
7. AUTHOR(s) Leo F. McNamara, Bodo W. Reinisch, Jurgen Buchau *		8. CONTRACT OR GRANT NUMBER(s) F19628-83-C-0092
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of Lowell, Center for Atmospheric Research, 450 Aiken Street, Lowell, Massachusetts 01854		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 464306AJ
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, MA 01731 Contract Monitor: J. B. Waaramaa (LIS)		12. REPORT DATE February 1988
		13. NUMBER OF PAGES 46
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		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

* AFGL/LIS, Hanscom AFB, MA 01731-5000

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

Ionosphere,
~~HF~~ Heating,
Digital Ionosonde, (MJM)
Ray Tracing,

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

Backscatter ionograms recorded by an airborne digital ionosonde during the September 1981 ionospheric HF heating campaign at Arecibo have been simulated using simplified ionospheric models and analytic raytracing techniques. The simulations indicate that irregularities were created at all altitudes from the interaction height (where the plasma frequency was equal to the heater frequency) down to the base of the F layer, but with a preferred

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

cont'd

20. ABSTRACT (Continued)

altitude near the interaction height. There was no evidence for the existence of irregularities at altitudes much above the interaction height. The horizontal east/west extent of the irregularity patch was approximately 100 to 150 km, shifted towards the west with respect to the Arecibo magnetic meridian (asymmetry 25 km to the east/125 km to the west). Transport of irregularities out of the heater beam by thermospheric winds is the likely cause of this asymmetry. The irregularities are only observed, while the aircraft is within an approximately 150 km wide region, bounded to the south by the magnetic latitude through Arecibo. The lack of observation of field-aligned irregularities (F.A.I.s), while to the north of this region, is likely due to the inability of the probing radio waves to achieve perpendicularity in the disturbed region. No reason was found for the general lack of F.A.I. observations while to the south of this region.

TABLE OF CONTENTS

DTIC COPY INSPECTED 6

Accession For
NTIS GRA&I ☑
DTIC TAB ☐
Unannounced ☐
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

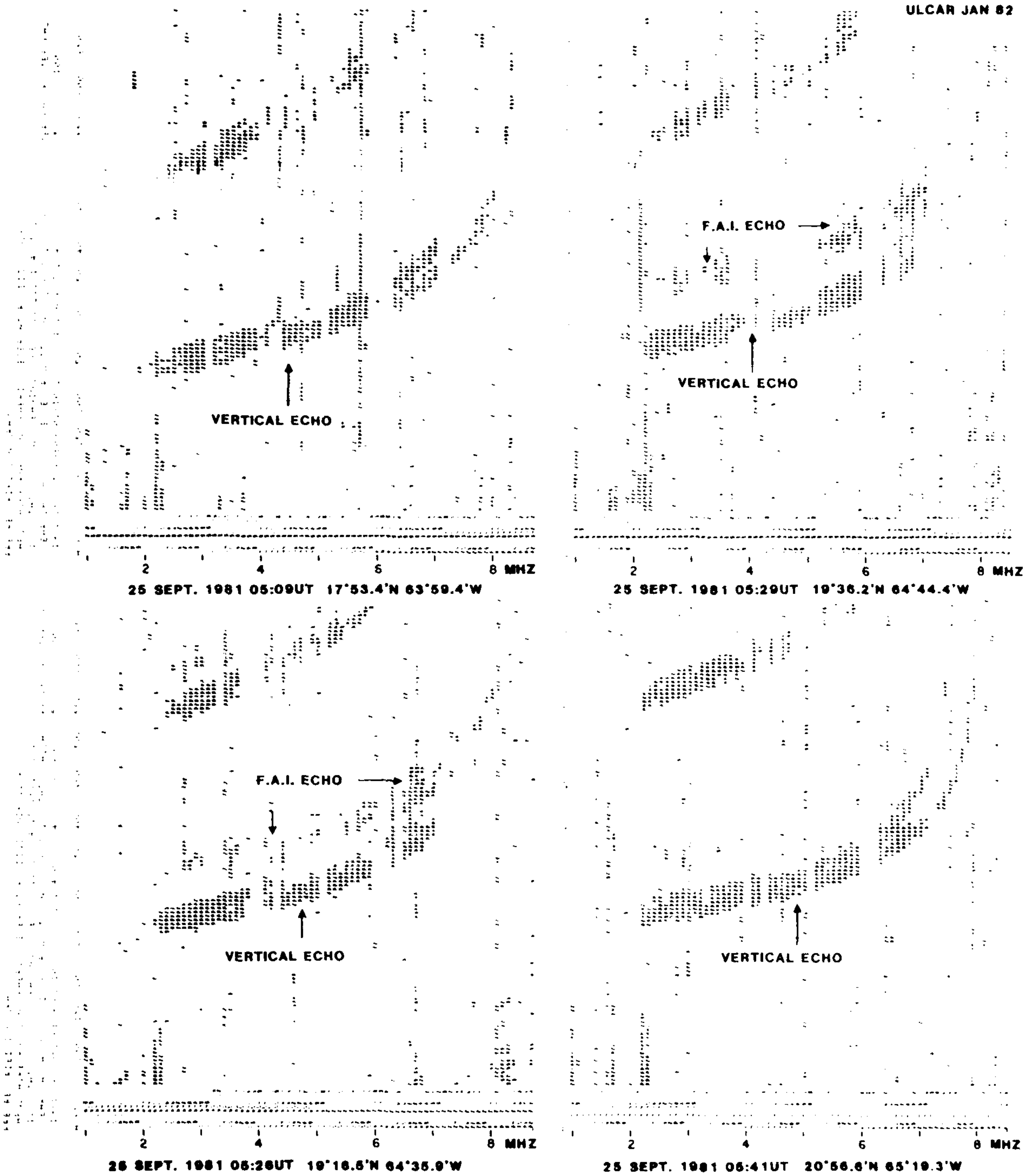
1.0 INTRODUCTION

A variety of experiments were performed during 22-27 September 1981, to probe the ionosphere over Arecibo when it was modified by a 300 kW HF radio transmitter at the Islote heating facility. The monitoring equipment used included an all-sky imaging photometer to determine airglow emissions at 5577 Å and 6300 Å, a zenith spectrometer, a digital ionosonde, and satellite phase and amplitude receivers at 250 MHz, all on board the AFGL Airborne Ionospheric Observatory (Basu et al., 1981; 1982; 1983).

We are concerned here only with the digital ionograms recorded using the digital ionosonde on board the aircraft, a Digisonde 128PS (Bibl and Reinisch, 1978). As illustrated in the status ionograms of Figure 1, some of these ionograms exhibited extra traces which are considered to have arisen by backscattering of the ionosonde transmissions from field-aligned irregularities created by the heater.

The campaign extended over five nights, described as Heater 1, 2, ... 5, or Round Robin (RR) 1, 2, ... 5. These nights were September 22-26, corresponding to UT days of 266 to 270. Oblique scattered traces were observed on all nights, but not at all times, and were usually not well defined because of the high radio noise levels. The most consistent traces were observed during Heater 4 and 5 (UT days 269 and 270), and it is these which will be discussed here.

The times of day considered cover a few hours after midnight. It is interesting to note that the expected "post-midnight collapse" of the ionosphere occurred on only one of the five nights. The heater frequency of 5.1 MHz was below foF2 at all times.



AIRCRAFT DOPPLER IONOGRAMS

ARECIBO HEATING EXPERIMENT (HEATER 3)

Figure 1. Aircraft status ionograms showing the presence of echoes from field-aligned irregularities in two cases (upper right, lower left). The FAI echoes have zero Doppler shift, in agreement with the motion of the aircraft in the magnetic meridian plane and at right angles to the wave propagation vector.

Figure 2 shows the nominal flight pattern, which with some adjustments, based on inflight observations, was flown during heater flights No. 4 and No. 5. The figure also shows the magnetic meridian through the heater facility and the approximate area of the half power beam width of the heater antenna, at an altitude of 300 km, for a heating frequency of 5.1 MHz (the heating frequency used during these experiments).

Figure 3 illustrates the aircraft positions (triangles) at those times when a scattered trace was observed during Heater 5 (UT day 270). The squares are placed due magnetic west from the aircraft position at the respective time at ranges R given by

$$R = \{(h'_{OB})^2 - (h'_{VERT})^2\}^{1/2};$$

h'_{OB} is the radar range of the oblique echoes and h'_{VERT} the virtual height of the overhead ionization measured at the heater frequency. This approximation to determine the location of the field aligned irregularities was used to develop an initial understanding of the general location of the irregularities. The rationale is discussed in Section 2.0. The squares give an estimate of the magnetic N-S extent of the irregularity patch generated by the heater. Note that the aircraft flew well beyond the north-south extent of positions where irregularity backscatter echoes were observed. The squares give also a rough estimate of the most western extent of the irregularities giving rise to the scattered traces.

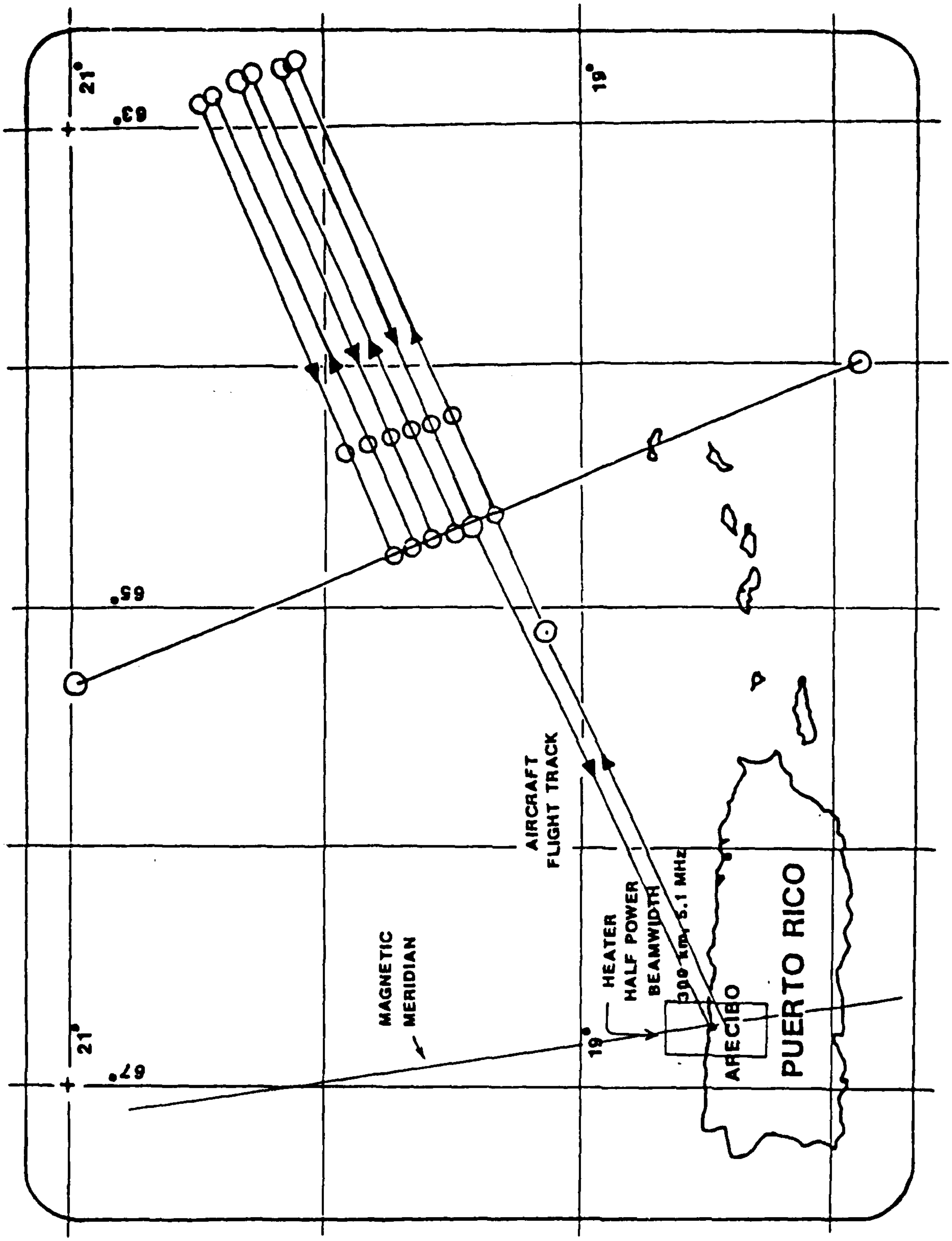


Figure 2. Nominal aircraft flight track for field-aligned irregularities campaign 22-26 September 1981

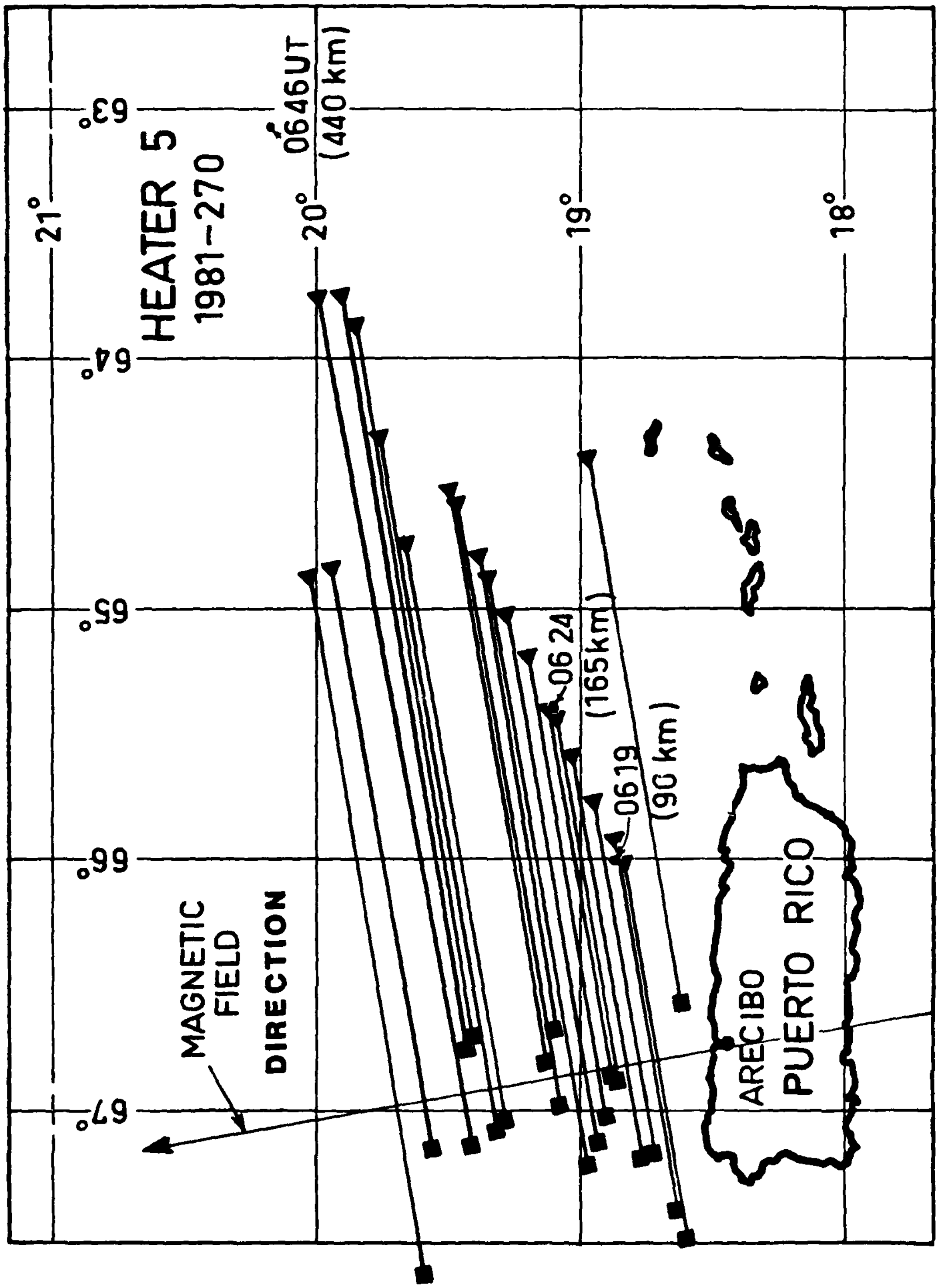


Figure 3. Aircraft locations (triangles) and apparent locations (squares) of irregularities causing backscatter traces on the digital ionograms recorded on UT day 270 of 1981. The ionograms recorded at the three aircraft locations marked are discussed in detail in the text (Heater 5 flight).

2.0 METHOD OF ANALYSIS

In principle, the Arecibo ionograms could be analyzed in the same fashion as the Platteville ionograms (Buchau and McNamara, 1986), using true-height analysis techniques to obtain the vertical electron density profile, N(h), and then tracing rays at various frequencies, elevation angles, azimuths and effective transmitter altitudes (the altitudes of the irregularities). However, the conditions of the Arecibo experiment are such that various simplifications can be made, including the adoption of analytic raytracing procedures.

As the comparison of Figures 2 and 3 shows, most of the backscatter echoes from field aligned irregularities were observed, when the aircraft was in a latitude region which extended from due magnetic east of Arecibo to approximately one degree further north. Similar restrictions of the location of the aircraft during observations of field aligned irregularities were found for flights no. 2 and no. 3 as the summary of the F.A.I. observations (Figure 4) indicates. The exception is flight no. 4 where, of the total of five F.A.I. observations during this night, two fall outside the 1° wide band extending north from the magnetic latitude circle through Arecibo. These two ionograms were taken when the aircraft was at a location which was 1° south of the magnetic latitude circle through Arecibo. No field aligned irregularities were observed during flight no. 1.

The basic assumption that we shall make is that the oblique traces, seen on the ionograms at ranges about 50 km greater than for the overhead trace, arise from the coherent scattering or reflection of radio waves which strike the field-aligned irregularities (generated by the heater)

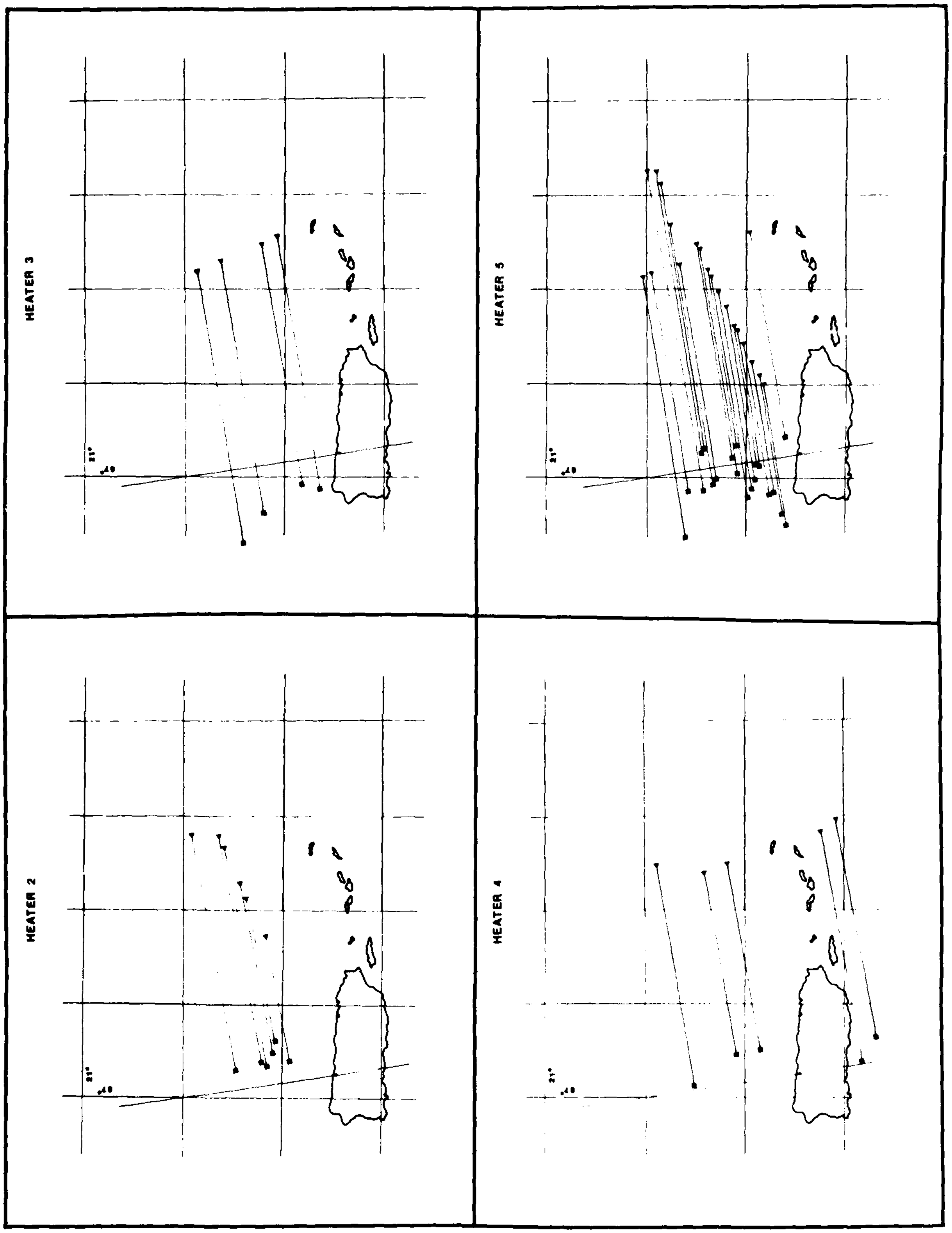


Figure 4. Summary of geographic locations of field-aligned irregularities observed during the campaign of 22-26 September 1981.

horizontally, and at right angles to the direction of the earth's magnetic field. These rays then return along their own path back to the aircraft (see Figure 5).

For a given transmitter location, the locus of reflection points for signals to return to the aircraft is a curved surface. If the transmitted ray is in a plane through the irregularities and at right angles to the magnetic meridian (i.e. magnetic E-W), the ray which returns to the aircraft will be horizontal at the point of reflection. If the plane containing the transmitted ray lies north of magnetic E-W, the rays returning to the aircraft (for the same ionogram and aircraft position) will still be heading upwards to their normal apogee when they get reflected by the irregularities; if the plane lies south of magnetic E-W, the rays will have passed their perigee before they are reflected orthogonally by the irregularities. Since most of the F.A.I. were observed when the aircraft was due magnetic west to approximately 1° north of that magnetic latitude circle, we consider here only the special case of rays travelling in a magnetic E-W plane because of the simplifying approximations which can be made. There will therefore be some ambiguity between range and irregularity altitude, but this does not seem to be an overwhelming problem, consistent interpretation of the observations still being possible.

A further simplification arises from the fact that the propagation of these rays is approximately transverse to the magnetic field, and exactly transverse at the ray apogee. We have therefore used the no-field approximation for the group refractive index of the ordinary ray. The next simplification we have adopted is to replace the actual N(h) profile by a parabolic layer fitted to the peak of the actual profile and passing through a second selected point. This simplification is quite adequate because we are considering

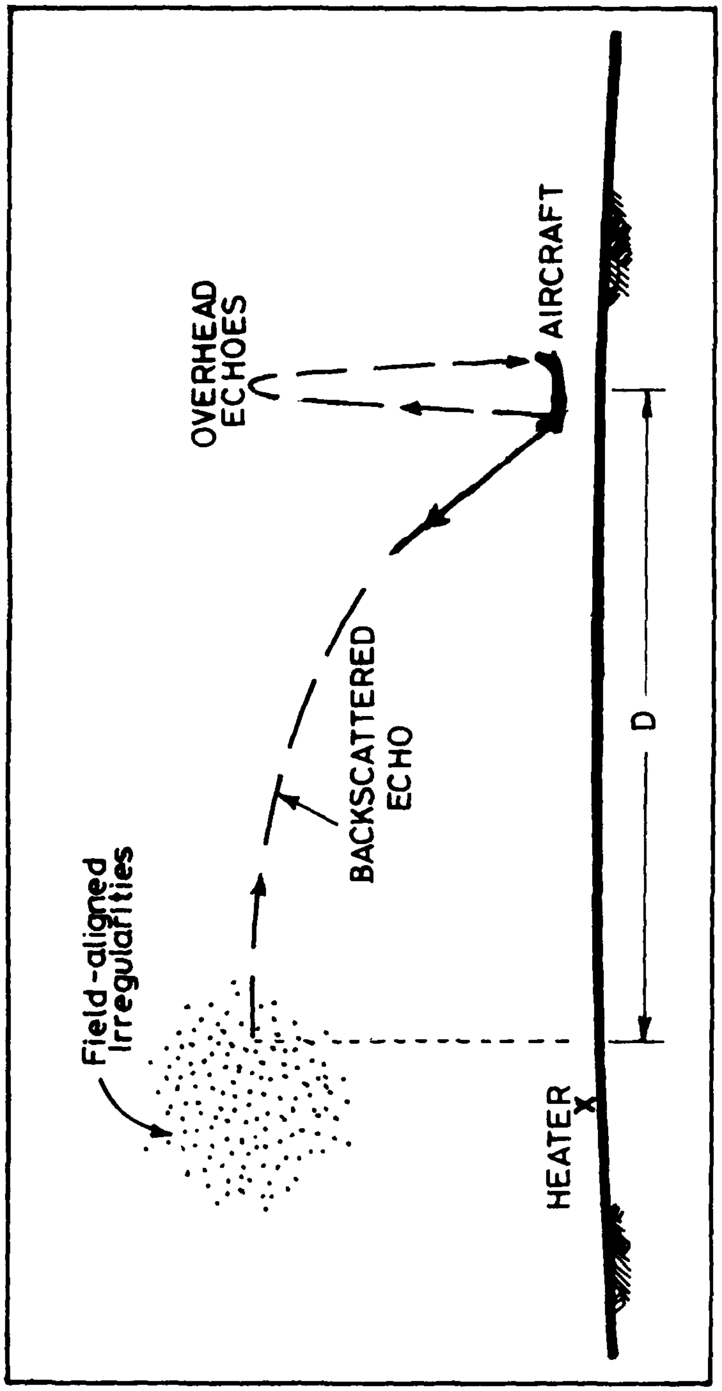


Figure 5. Typical ray paths for echoes from overhead and for signals scattered back to the aircraft from field-aligned irregularities generated by the heater. The backscattered rays strike the irregularities at right angles and are horizontal when they do so.

only nighttime profiles (~0100 LT) which are approximately parabolic. The choice of the second selected point depends on which part of the profile the rays will actually travel through, and is related to the apogees of the rays.

Even when the N(h) profile is a simple parabola, however, analytic solutions do not exist for the parameters we require, such as ray apogee, group path and ground range for a given elevation angle. We have accordingly modified our fitted parabolic profiles into quasi-parabolic profiles and used the results given by Croft and Hoogasian (1968) for raytracing through a quasi-parabolic layer in the absence of a magnetic field.

The quasi-parabolic layer is defined by

$$Ne = N_m \left[1 - \left(\frac{r - r_m}{Y_m} \right)^2 \left(\frac{r_b}{r} \right)^2 \right]$$

where N_m = maximum density of the F2 layer

r_m = Re + hm = radius of F layer maximum

r_b = radius of base height of the layer

Y_m = semithickness.

The factor r_b/r is approximately equal to unity over the altitudes of the layer, so that the layer shape does not differ significantly from that of the simple parabolic layer. However, the solutions for ground range, D, group path, p', phase path, p, and apogee height are now available analytically, and these are given by Croft and Hoogasian (1968). The only difference between the Croft and Hoogasian results and the present ones is that we assume that the rays giving rise to the observed oblique traces are at their apogees when they are reflected from the field-aligned irregularities. Consequently, we have simply divided the Croft and Hoogasian expressions for D and p' by a factor of two.

The N(h) profile which we replace by an appropriate parabolic layer can be obtained by either a true-height analysis of the overhead ionogram or by use of the incoherent scatter radar profiles obtained during the experiment. The latter is preferable, but these profiles were not available for each flight.

For the Heater 4 experiment (local night 25/26 September 1981), we have used the Arecibo incoherent scatter profile, normalized to the maximum value of the electron density of the F2 layer (NMF2) recorded by the ionosonde. In particular, we have used the 05:03:58 UT profile of 26 September, normalized to NMF2 = 1.00×10^{12} el m^{-3}, and replaced by a parabola with NMF2 = 1.00×10^{12} el m^{-3}, HMF2 = 383 km and YM = 112.6 km (see Figure 6). HMF2 is the altitude of the peak of the F2 layer. The parabola matches the normalized observed profile at 275 km. The interaction height corresponding to the heater frequency of 5.1 MHz is 300 km.

For the Heater 5 experiment (local night 26/27 September 1981), no incoherent scatter profile measurement was available. We have therefore used the N(h) profile obtained from the overhead ionogram for 06:24:09 UT using a parabolic lamination technique. The base of this profile is somewhat uncertain because no extraordinary ray data were available at low frequencies for use in the N(h) analysis. The profile was replaced by a parabola with NMF2 = 0.80×10^{12} el m^{-3}, HMF2 = 340 km and YM = 100 km (see Figure 7). The parabola matches the true height profile at 275 km. The interaction height is 266 km.

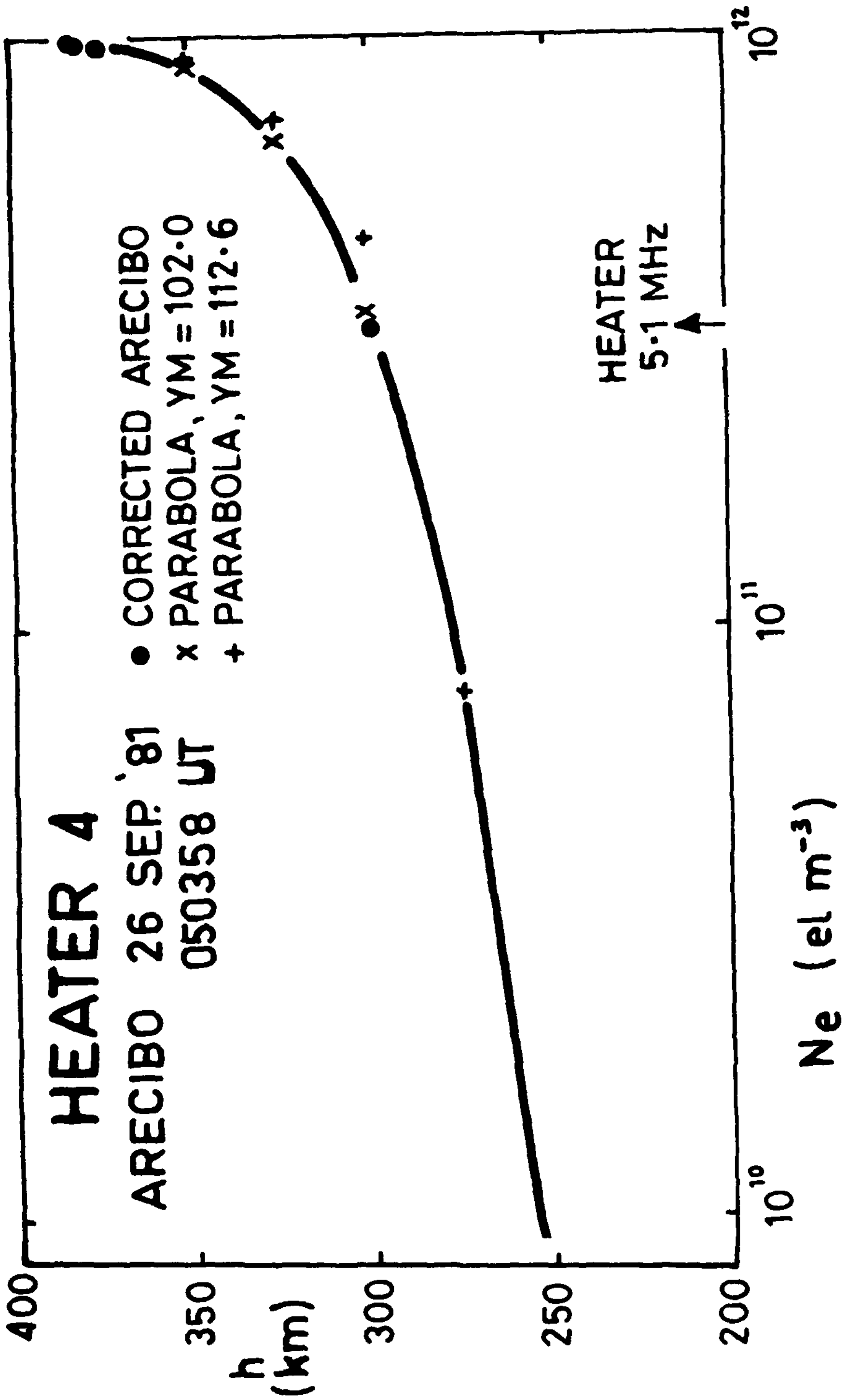


Figure 6. Electron density profile observed at Arecibo, but normalized to the aircraft value of foF2, for 05:03:58 UT on 26 September 1981. For ease of later calculations, the observed profile is replaced by simple parabolic layers with different semi-thicknesses YM.

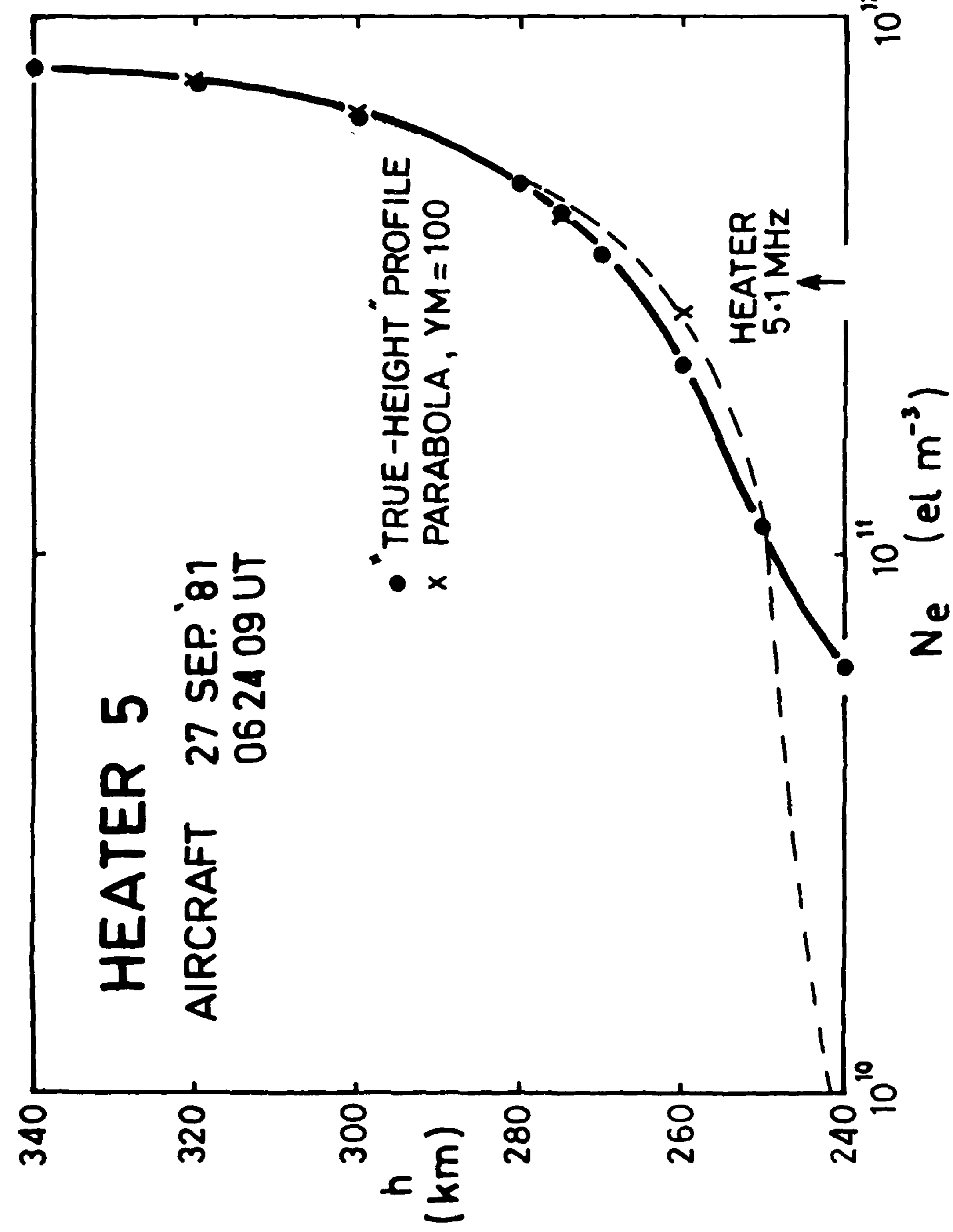


Figure 7. Electron density profile obtained from the aircraft vertical incidence ionogram of 06:24:09 UT, 27 September 1981. This profile is replaced by a parabola with the same hmF2 and a semi-thickness of 100 km.

We considered rays with elevation angles of 1 to 90 degrees, and frequencies up to foF2, obtaining tables which listed corresponding values of frequency, elevation angle, ground range, group path, and height of the ray apogee. We then constructed oblique ionograms for ground ranges between zero (the overhead trace) and 500 km, simply by interpolating in the tables to find the values of group path and apogee corresponding to a particular ground range. These are shown in Figures 8 and 9. In these figures, the small 3-digit numbers are the altitudes of the apogee (H) for the given frequency and ground range (D), which correspond to the altitudes of the irregularities reflecting the signals. The figures are on the same scale as the ionograms, and we interpret the observed oblique traces by overlaying a transparency of either Figure 8 (Heater 4) or Figure 9 (Heater 5) on the observed ionograms. The overlay is slid vertically (and horizontally, if necessary) to align the calculated and observed overhead (vertical incidence) traces.

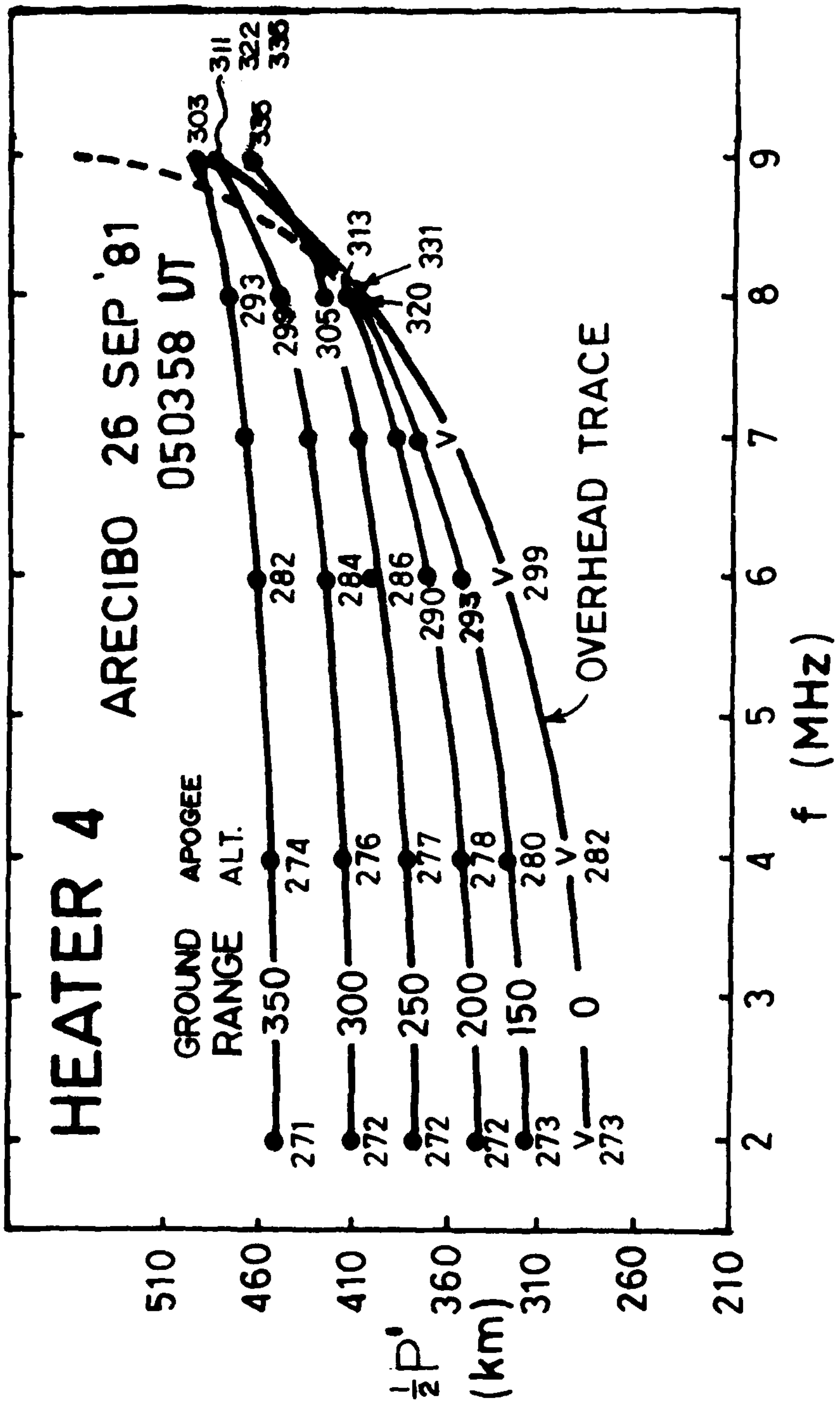


Figure 8. Simulated oblique ionograms for the Heater 4 flights, based on the Arecibo profile of 05:03:58 UT, 26 September 1981. The large numbers show the aircraft range from the backscattering irregularities, while the small numbers show the altitudes of these irregularities.

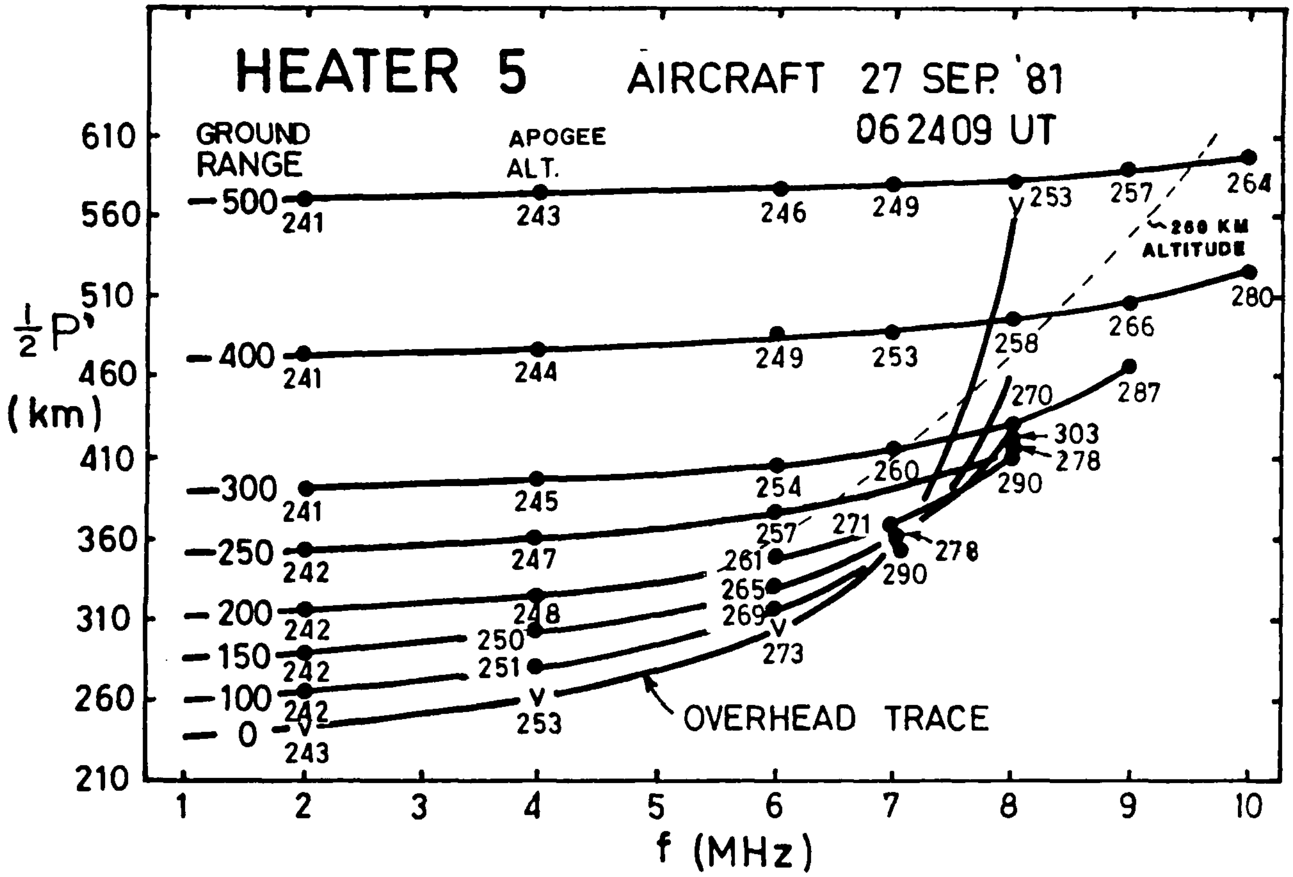


Figure 9. Simulated oblique ionograms for the Heater 5 flight, based on the aircraft overhead ionogram of 06:24:09 UT, 27 September 1981. The large numbers show the aircraft range from the backscattering irregularities, while the small numbers show the altitudes of these irregularities. The dashed line shows the group paths for signals from 6.0 to 9.5 MHz which are scattered from irregularities at an altitude of 260 km.

3.0 INTERPRETATION OF IONOGRAMS

3.1 Heater 4

Oblique echoes were observed only in five ionograms during this flight and we have considered the 04:59:09 UT (Figure 10) and 05:29:09 UT ionograms (Figure 11) which corresponded to ground ranges from the aircraft to the magnetic meridian passing through Arecibo of 240 and 248 km. In the former case, oblique echoes are visible from 5.5 to 8.0 MHz. Overlaying Figure 6 on Figure 8 shows that the irregularities causing the oblique echoes corresponded to D ~ 250-330 km, and altitudes 275-300 km. The irregularities at D ~ 225 km and H ~ 305 km (the higher ones closer to the aircraft) are probed by the 8 MHz signal, while those at D ~ 325 km and H ~ 275 km are probed by the 7 MHz signal. Similarly, overlaying Figure 6 on Figure 9 shows that the irregularities existed at D ~ 225-300 km, and altitudes 274-315 km. The oblique and vertical traces overlap near 8 MHz, and it is not possible to distinguish between them.

Figure 12 shows the ground position of the F.A.I. zone in a geographic presentation, which overlays Figure 2. The heavy bars are the respective F.A.I. ranges, the open circles the respective aircraft locations.

Table 1 summarizes the data relevant to the range and height extent derived from the five ionograms, during which F.A.I. were observed.

Taken together, the five ionograms indicate that the irregularities existed at altitudes from the base of the F layer (~ 274 km) up to about 10 km above the interaction height (at which the plasma frequency is equal to the heater frequency) of 300 km, and that the irregularity patch was about 80 km in magnetic E-W extent, starting ~15 km east and

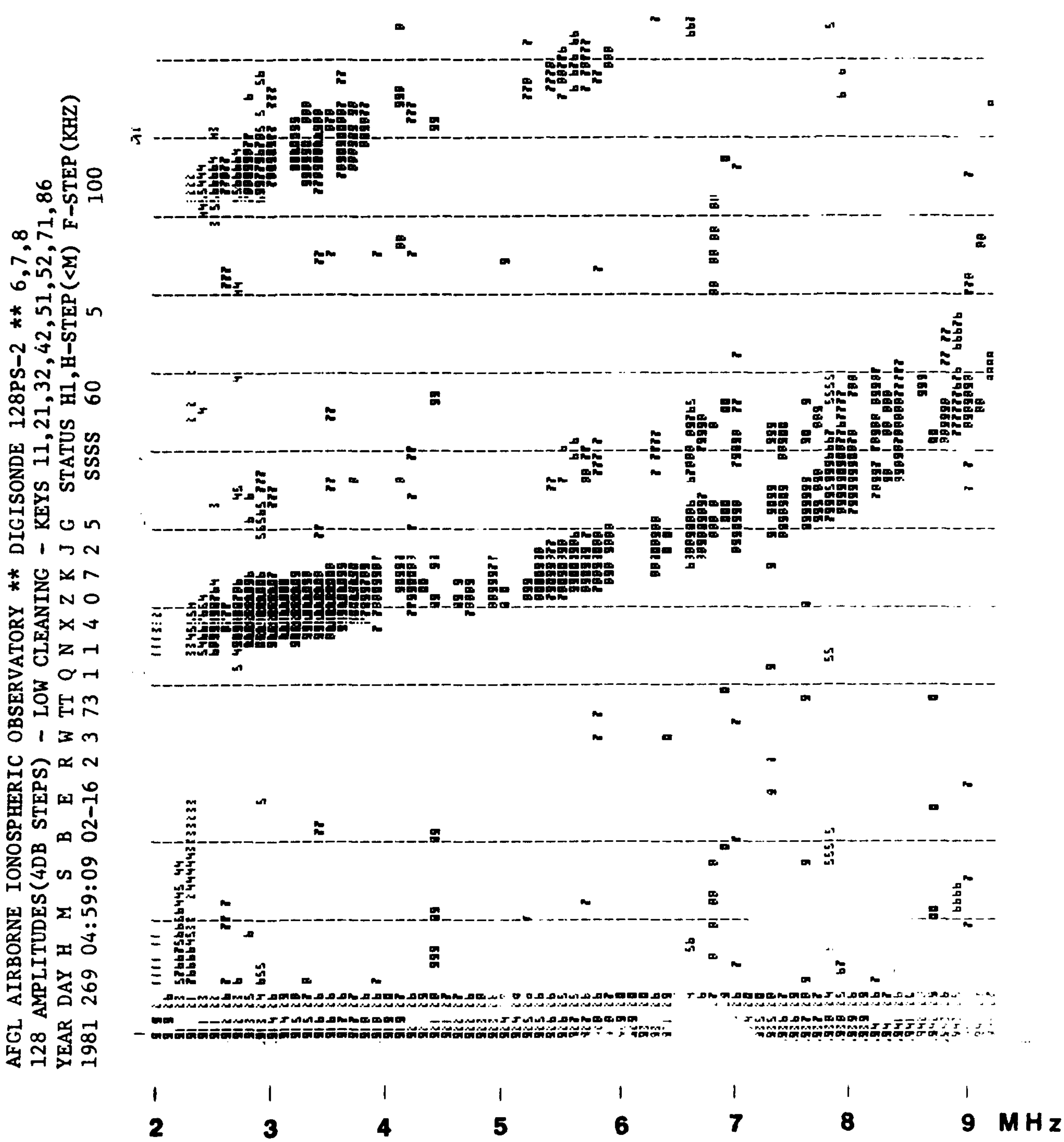


Figure 10. Aircraft amplitude ionogram for 04:59:09 UT on day 269 of 1981 (Heater 4 flight). Backscatter traces can be seen over the frequency range ~5.5 to 8.0 MHz, at a group range of 400 ± 25 km. Aircraft range ~250 km.

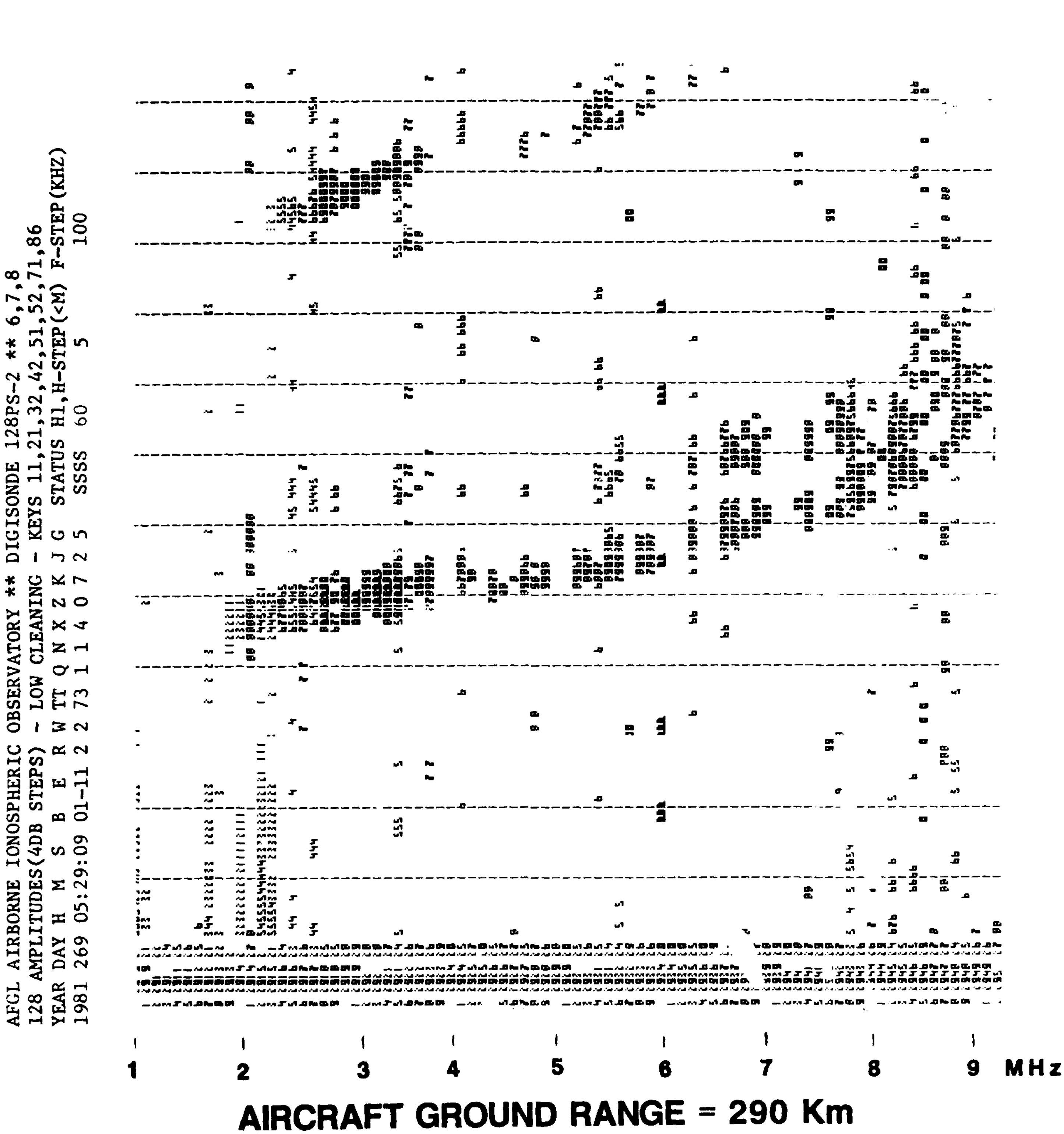


Figure 11. Aircraft amplitude ionogram for 05:29:09 UT on day 269 of 1981 (Heater 4 flight). Patchy backscatter traces can be seen lying about 75 km above the overhead trace. Aircraft range ~290 km.

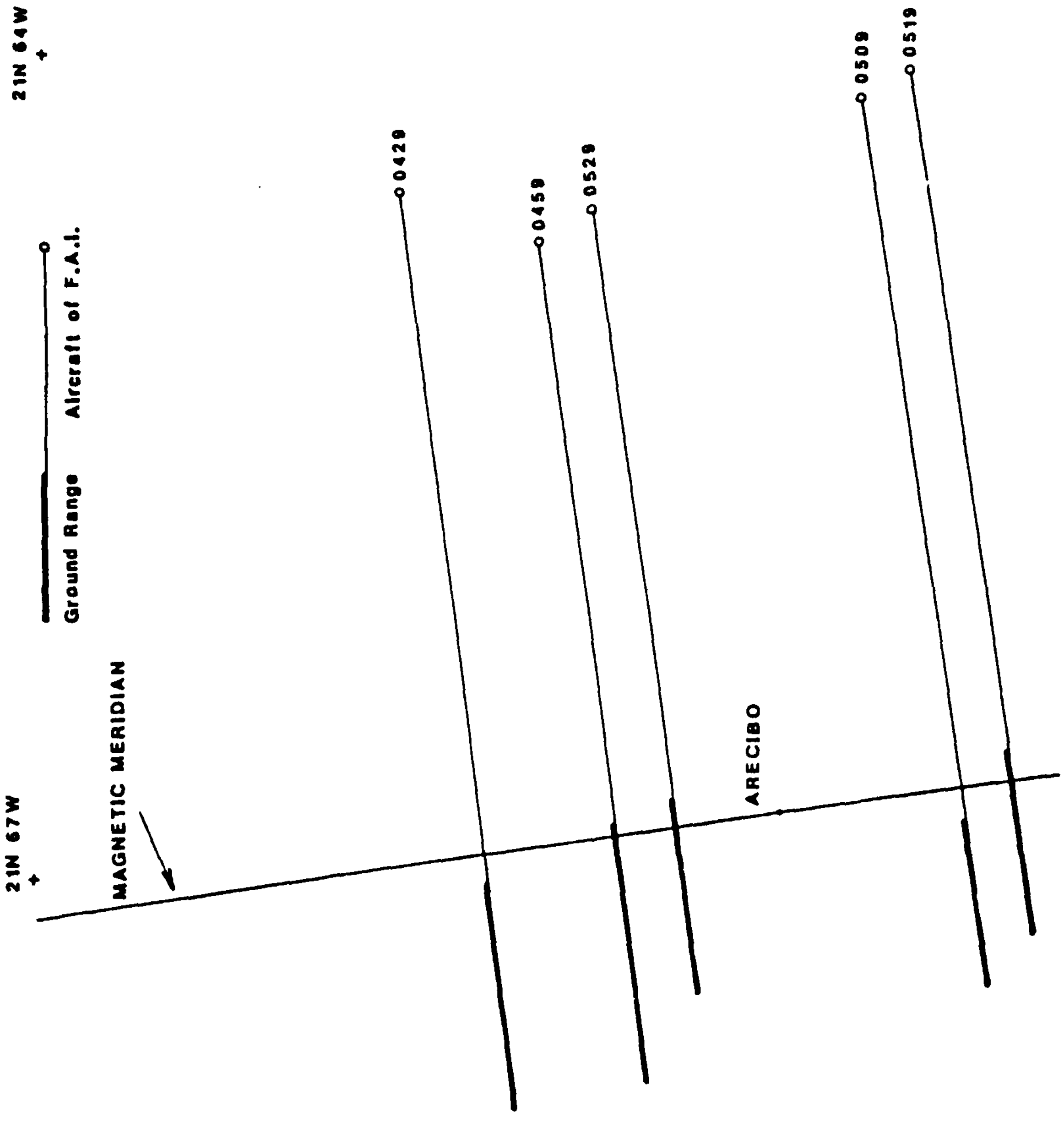


Figure 12. Geographic locations of the field-aligned irregularities observed during Heater Flight No. 4, 26 September 1981. This figure may be overlaid on Figure 2.

Table 1. Summary of F.A.I. Locations Derived for Flight No. 4

UT h:min	Δf MHz	Δh km	D km	Lead. km	Trail. km	H_{min} km	H_{max} km	W km	Δ- km	Δ+ km
04:29	+.1	-15	259	260	350	286	310	90	0	90
04:59	0	0	220	320	239	275	310	100	20	80
05:09	+.4	-10	275	340	272	295	300	70	0	70
05:19	+.3	- 5	278	260	330	286	295	70	20	50
05:29	-.1	0	248	225	300	274	315	75	25	50
Average/Min/Max						Min 274	Max 315	86	13	68

Δf = frequency shift necessary to match overlay ionogram, in MHz.

Δh = height shift necessary to match overlay ionogram, in km.

D = distance from aircraft to Arecibo magnetic meridian.

Lead/Trail = ground distances to leading and trailing edge of F.A.I. signature, determined using overlay ionogram.

H_{min}/H_{max} = minimum and maximum height of F.A.I., determined as above.

W = E/W extent of F.A.I. zone.

Δ-, + = east (-) and west (+) extent of F.A.I. zone with respect to Arecibo magnetic meridian.

extending ~75 km west of the Arecibo magnetic meridian. Irregularities at altitudes substantially above the interaction height would have given rise to scattered echoes at frequencies greater than about 9 MHz, but no such echoes were observed.

3.2 Heater 5

Many more oblique echoes were observed with this flight than for the Heater 4 flight, and we are in this case able to consider the effect of different aircraft ranges to the heated volume. We consider here ionograms corresponding to ranges of ~140 km (06:24:09 UT, Figure 13); ~75 km (06:19:09 UT, Figure 14); and ~400 km (06:46:39 UT, Figure 15). The last two cases correspond to the distances of closest approach and extreme range for Arecibo. The 06:24:09 UT ionogram was the ionogram analyzed to determine the N(h) profile.

One of the difficulties with using a true height analysis of the ionogram is that the base height of the ionosphere so determined will be somewhat uncertain. In this case, the value of fmin was 2 MHz, and this was found to correspond to a true height of 240 km. As the overlay Figure 8 shows, many of the signals which we shall be considering were reflected at apogees just above this base height, so some discrepancies between the predicted and observed oblique traces must be expected simply because we do not know the lower part of the N(h) profile well enough.

Consider first the 06:24:09 UT ionogram (Figure 13). The oblique echoes at ~5.5 MHz indicate that irregularities existed at ranges of 150-300 km, and at altitudes of 254-265 km. The oblique echoes near 6.5 MHz correspond to ranges of 200-300 km, and to altitudes of 260-

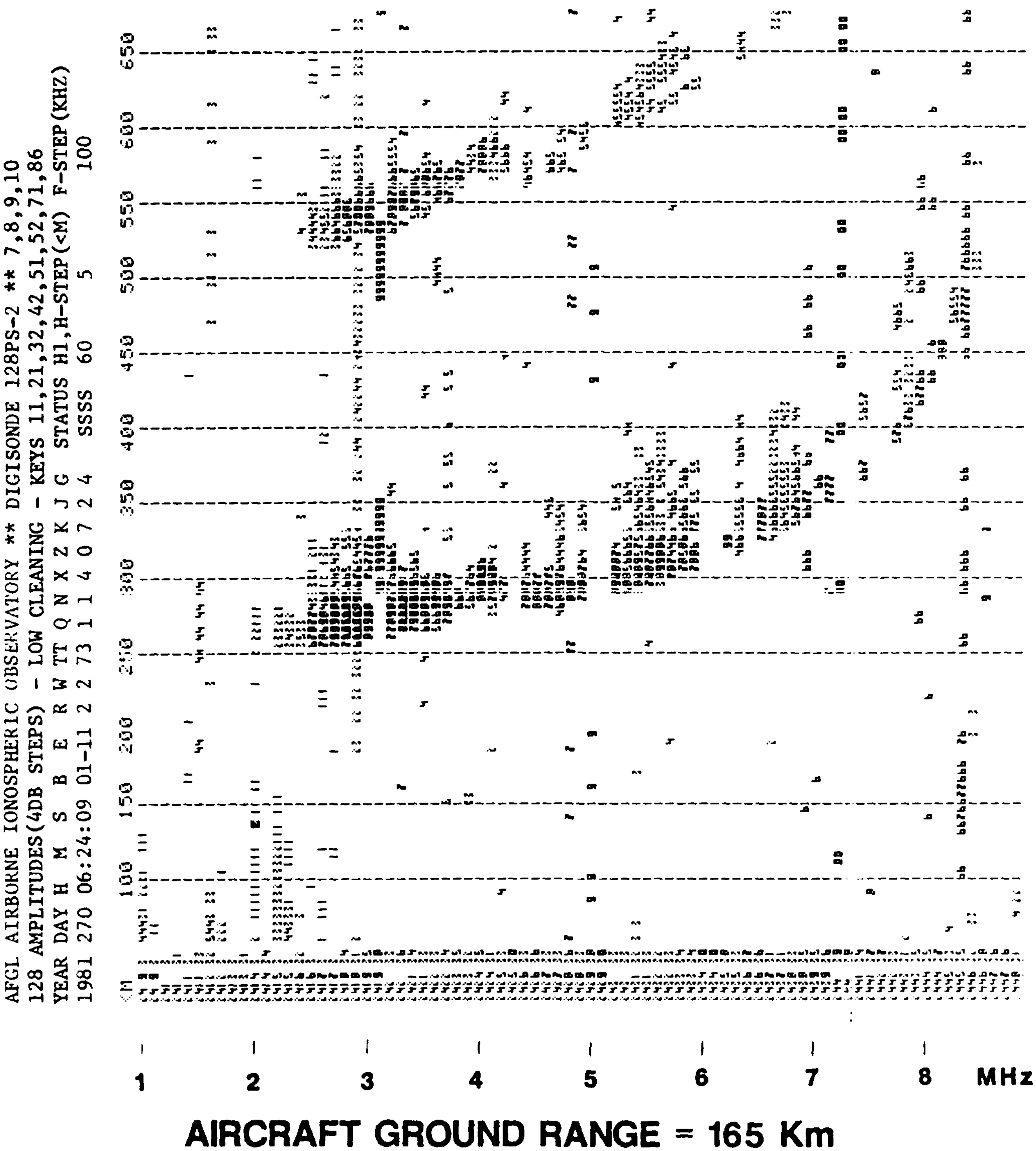
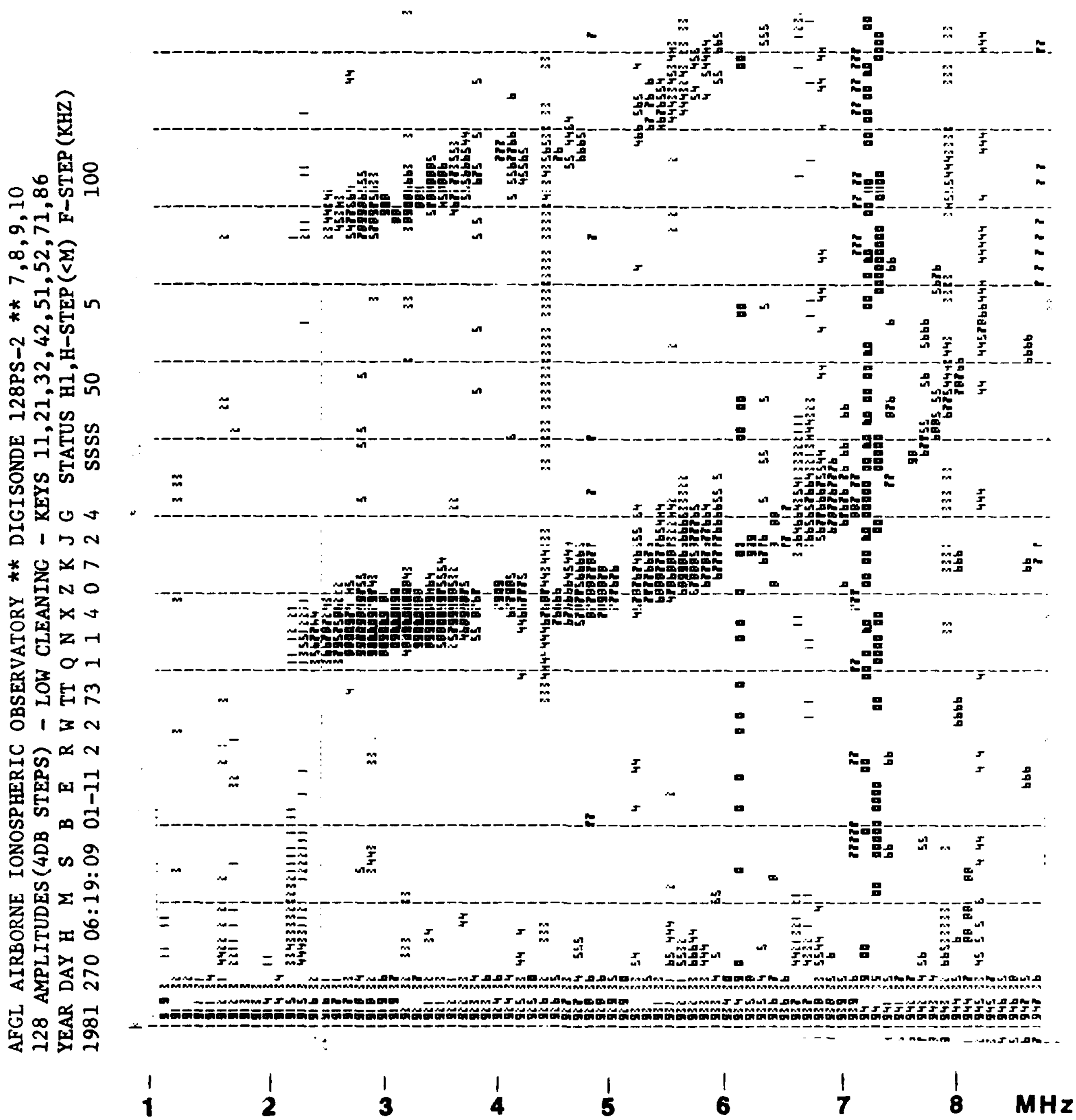
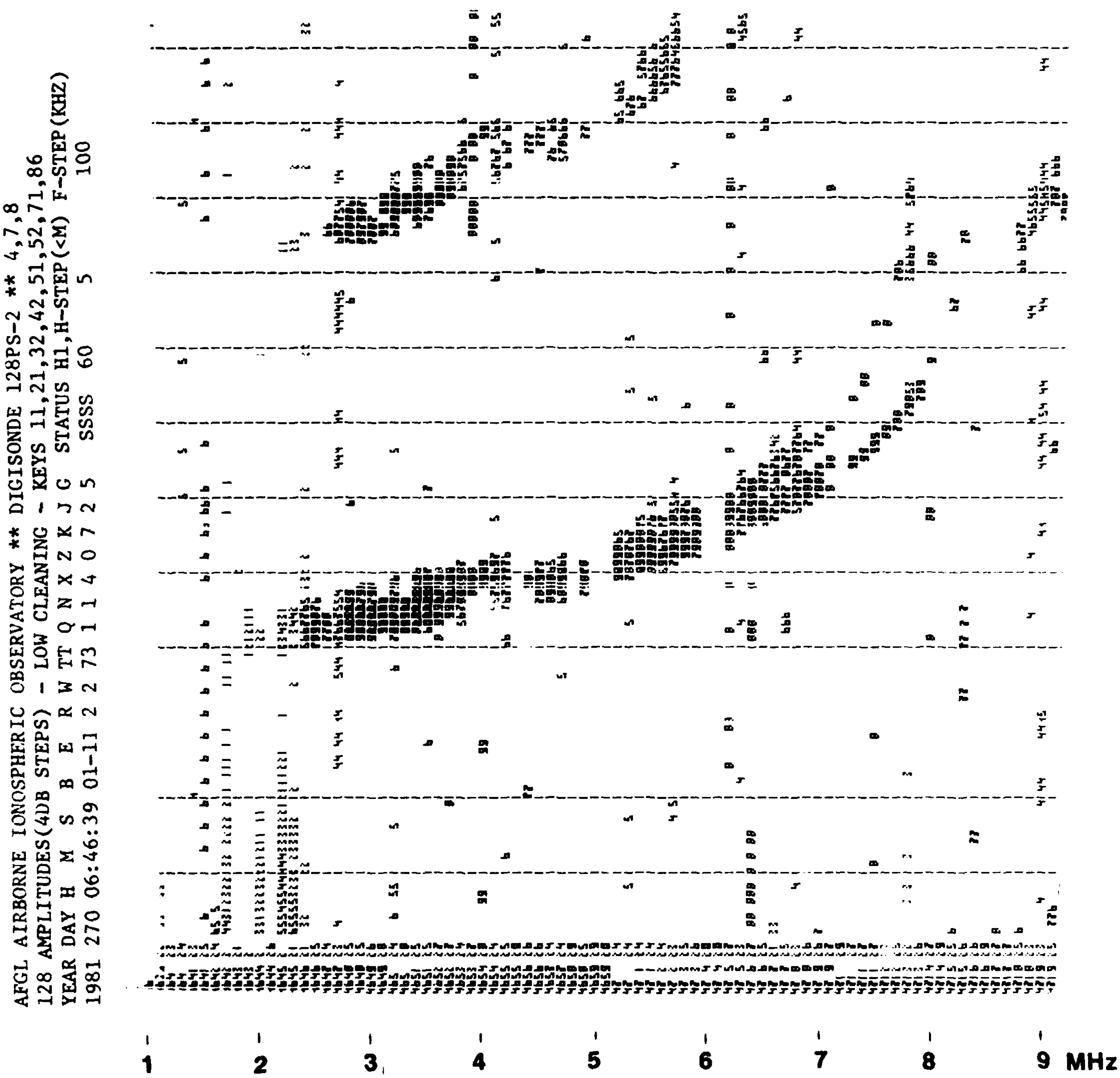


Figure 13. Aircraft amplitude ionogram for 06:24:09 UT on day 270 of 1981 (Heater 5 flight). Backscatter echoes can be seen as broadening of the overhead trace at f ~ 3 MHz, 5.5 - 6.0 MHz, and 6.8 MHz. Aircraft range ~165 km.



AIRCRAFT GROUND RANGE = 090 Km

Figure 14. Aircraft amplitude ionogram for 06:19:09 UT on day 270 of 1981 (Heater 5 flight). The aircraft was only 90 km from the magnetic meridian passing through Arecibo, and there is considerable overlap of the overhead and backscatter traces.



AIRCRAFT GROUND RANGE = 440 Km

Figure 15. Aircraft amplitude ionogram for 06:46:39 UT on day 270 of 1981 (Heater 5 flight). Backscatter echoes can be seen near the frequency of 9 MHz and at group paths of 550 km.

270 km. The echoes near 3 MHz indicate the existence of irregularities near the base of the layer (~240 km) and at ranges from <150 km out to ~250 km. The short-range limit of the oblique echoes was estimated using the difference in Doppler signature between vertical and oblique echoes even though the oblique echoes overlap the overhead echoes (the details of this approach will not be discussed here; for information on the use of Doppler measurements in the interpretation of disturbed ionograms see Buchau et al, 1983).

Considerable overlap of the vertical and oblique traces also occurs for the 06:19:09 UT ionogram (Figure 14). The strong echoes at the lower frequencies indicate the existence of irregularities in the base of the layer. At higher frequencies, the ionosonde samples irregularities higher in the layer. Near 6 MHz, the scattered echoes come from altitudes of 257-265 km and ranges 150-250 km, while near 7 MHz the echoes come from altitutdes of 260-271 km and ranges 200-300 km.

We have included the 06:46:39 UT ionogram here (Figure 15) because of the presence of a discrete echo near 9 MHz and a group range of ~560 km. The overlay (Figure 9) indicates that the echoes correspond to a range of ~430 ±30 km and an irregularity altitude of ~262 ±5 km. This altitude corresponds closely to the interaction height of 267 km given by the true-height analysis, and indicates that the irregularities had a preferred altitude approximately equal to the interaction height.

The 06:51:39 UT ionogram of Figure 16 is a status ionogram in which each pixel shows the Doppler shift rather than the amplitude of the normal display. Filtering the data according to the status allows the elimination of noise and a more reliable trace identification. The overhead trace in

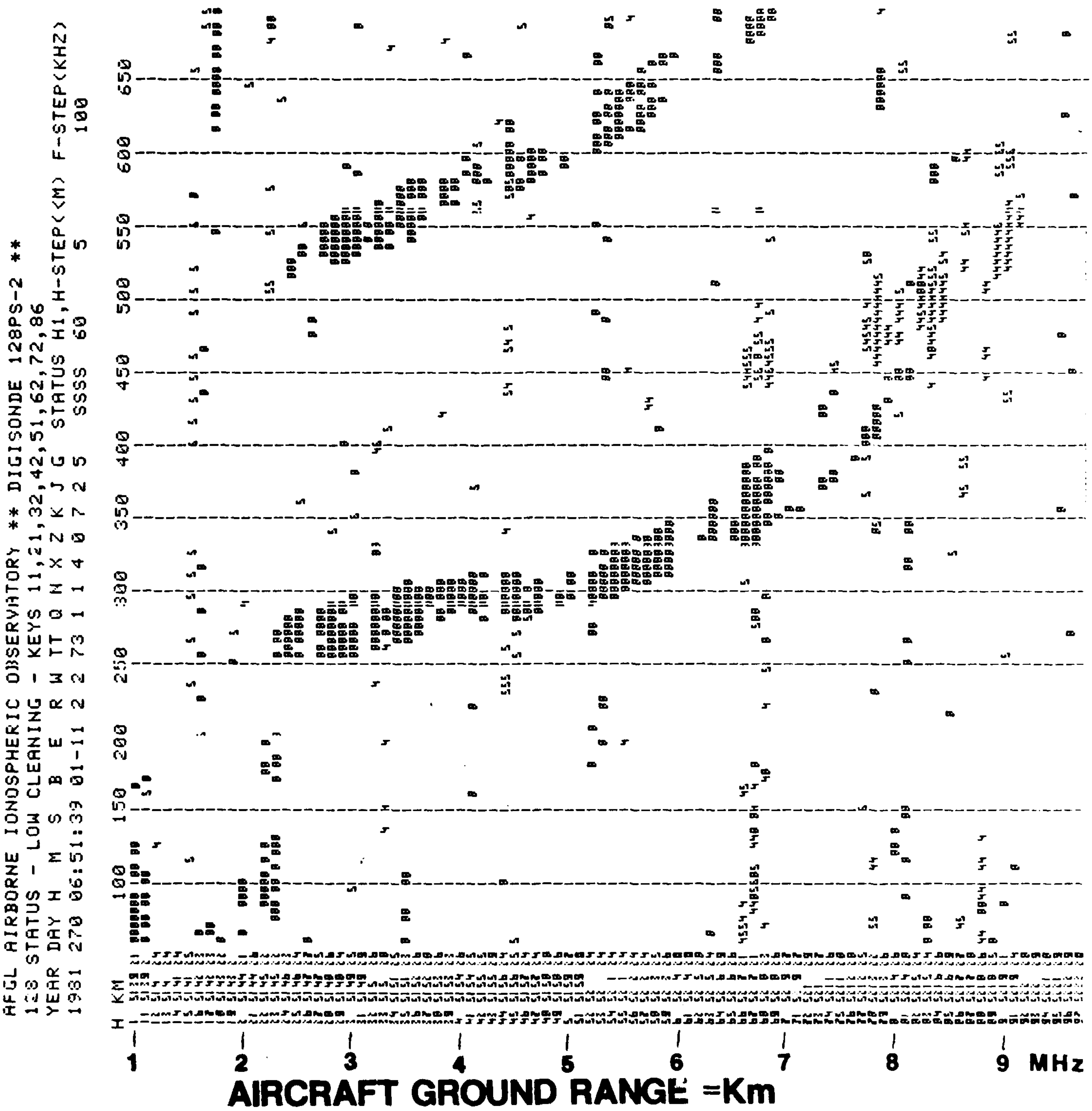


Figure 16. Status ionogram for 06:51:39 UT on day 270 of 1981 (Heater 5 flight). The scattered echoes with group ranges of ~450 to 550 km have positive Doppler shifts, as indicated by the '4' and '5' values for the pixels. The overhead trace ('8') had zero Doppler shift.

Figure 13 is characterized mostly by '8', which corresponds to zero Doppler shift. The scattered traces from 6.6 to 9.1 MHz are characterized by '4' and '5', which correspond to positive Doppler shifts caused by the motion of the aircraft towards the heated volume.

Matching the overlay (Figure 9) to the overhead trace in Figure 16 shows immediately that the scattered echoes are not uniformly distributed over group paths corresponding to ranges of 300 to 500 km. Instead, the echoes tend to cluster around lines of constant irregularity altitude indicating a preference for the altitude range 255 to 265 km. At 9 MHz, there are no scattered echoes below the 266 km point on the 400 km trace, and none above about 258 km (estimate, near the 500 km trace). At 8 MHz, the echoes come from altitudes of about 255 to 265 km. A preference for the same altitude range is also shown by the preceding and following ionograms, confirming that the irregularities had a preferred altitude approximately equal to the interaction height.

The strongly focussed echoes seen on the Platteville Heater ionograms (Buchau and McNamara, 1986) do not appear on any of the Arecibo ionograms, although propagation conditions exist for them to do so. For example, as an inspection of the overlay (Figure 9) for the Heater 5 experiment indicates, 8 MHz signals reflected from irregularities with ground ranges of 155 to 275 km and heights of 275 to 300 km would all yield group paths of 415 ±10 km (see the bundling of the height dots for heights 270 to 300 km at ~415 km). Thus ionograms recorded near 06:30 UT (ground range ~200 km) might be expected to show some evidence of strongly focussed echoes at 8 MHz, but there are in fact no such echoes. This indicates that there were no irregularities at the corresponding altitudes of ~275-300 km, or, in other words, the irregularities did not exist at altitudes much greater than the interaction height (~262-267 km). This conclusion is supported by the lack of scattered echoes on any of the ionograms corresponding to altitudes greater than 270 km, which would have appeared at $f \geq = 10$ MHz.

The detailed analysis of 23 ionograms for flight no. 5, which were analyzed as to the characteristics of F.A.I.'s, is summarized in Table 2. Column designations are explained in connection with Table 1. Twelve additional ionograms show evidence of F.A.I.'s, however, true height analysis and derived ionogram overlays were not available at the time of completion of this report. The ionospheric conditions were not similar enough to those for which the overlay for flight no. 5 (Figure 8) had been developed thus prohibiting extrapolation. However, the shape, behavior and location of observation of these F.A.I. signatures is very similar to those discussed in the report, and their analysis would not have affected the conclusions.

Table 2 shows that the height extent of the F.A.I.'s is confined, as discussed using the ionogram examples, to a narrow height range of from 245 to 270 km, i.e. a region near the heater frequency interaction height.

The ground projection of the F.A.I. zone shown in Figure 17 substantiates findings from flight no. 4, namely the strong shift of the F.A.I. zone towards the west with respect to the Arecibo magnetic meridian. In the average, the F.A.I. zone extends from 25 km to the east to 120 km to the west of the Arecibo magnetic meridian. This is an average width of 145 km in the east/west direction and is in general agreement with the analysis of the sparse data base from flight no. 4.

Table 2. Summary of F.A.I. Locations Derived for Flight No. 5

UT h:min	Δf MHz	Δh km	D km	Lead. km	Trail. km	H_{min} km	H_{max} km	W km	Δ- km	Δ+ km
05:59	+.6	+25	208	225	310	254	261	85	20	65
06:01	+.8	+25	218	225	300	241	258	75	15	60
06:04	+.5	+20	203	200	275 U	242	270	75	20	55
06:06	+.5	+20	181	160	275 U	242	270	115	30	85
06:09	+.4	+25	142	150	300 U	243	270	150	5	145
06:11	+.3	+20	118	150	250 U	243	265	100	+20*	120
06:19	+.1	+15	75	125 U	310 U	247	258	185	+45	230
06:21	+.1	+15	101	130	310 U	245	265	180	+20	200
06:24	0	+10	138	150	300	244	265	150	0	150
06:26	0	+15	162	150 U	310	245 U	270	160	25	135
06:29	+.1	+15	201	210	330	250	260	120	5	115
06:31	+.1	+15	226	250 U	340	245 U	260	90	+10	100
06:34	0	+15	262	290 U	350	258 U	270 U	90	+15	105
06:36	0	+10	288	370	410	258	264	40	+65	105
06:39	0	+10	328	370	420	255	266	50	+25	75
06:41	0	+10	352	400	460	257	267	60	+25	85
06:44	0	+15	388	420	480	257	264	60	+10	70
06:46	0	+15	398	400	480 U	255	266	80	20	60
06:49	0	+15	361	350	450 U	257	267	100	35	65
06:51	-.1	+10	337	320	460 U	253	266	140	35	105
06:52	0	+15	324	300	460 U	252	266	160	40	120
06:53	0	+15	310	300	450 U	256	266	150	25	120
Average						Min 241	Max 270	145	25	120

*A + sign in this column indicates that the F.A.I. zone starts to the west of the Arecibo magnetic meridian.

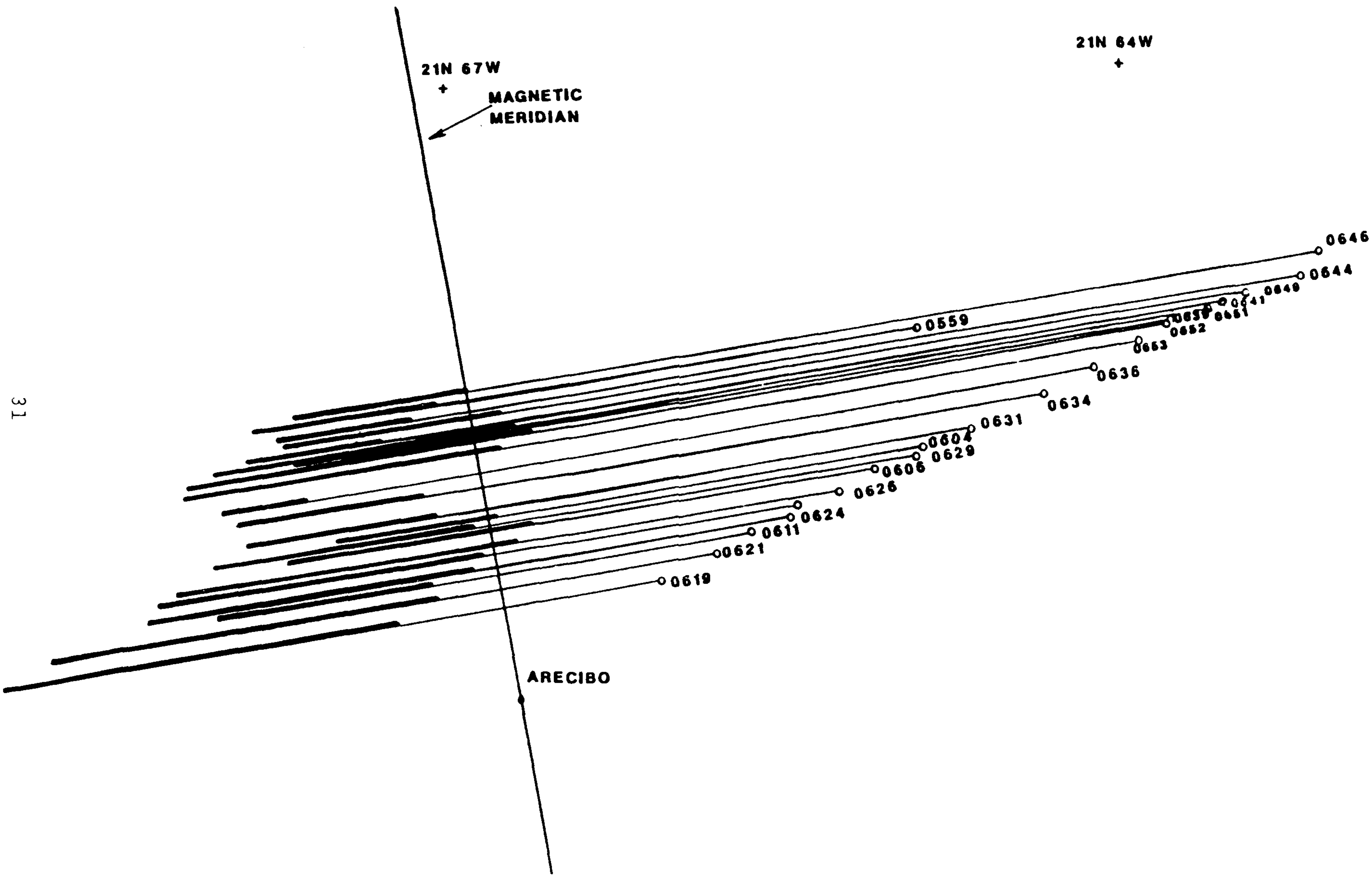


Figure 17. Geographic locations of the field-aligned irregularities observed during Heater Flight No. 5, 27 September 1981. This figure may be overlaid on Figure 2.

4.0 CONCLUSIONS

The ionograms described here indicate that irregularities generated by the Arecibo heater and detected by the ionosonde existed at altitudes between the base of the F layer and about 10 km above the heater transmission interaction height, with a preferred altitude near the interaction height. There was no evidence for the existence of irregularities at greater altitudes, although the peak of the F2 layer was 60-70 km above the interaction heights. Assuming that the backscatter echoes observed at the aircraft came from the magnetic west, the five flights indicated that the patch extended about 150 km north of Arecibo. We observed F.A.I. signatures while the aircraft was to the south of the Arecibo magnetic latitude only in two ionograms. These were obtained during flight no. 4, even though the aircraft flew the long northwest/southeast leg, almost parallel to the Arecibo magnetic meridian, on all five nights. Similarly, once north of the magnetic latitude circle approximately 1.25° north of Arecibo, no F.A.I. evidence was observed. The magnetic E-W extent of the patch can nominally be obtained from the ranges indicated on the overlay ionograms. The aircraft flight path went to a location approximately 2° north of the magnetic latitude of Arecibo on all five flights (during flight no. 5 this northern leg was flown twice) without observing F.A.I.'s at the northern extent of the flight pattern. A ray trace study (Buchau, 1988) suggests that the conditions to achieve perpendicularity in the heated/disturbed zone with ray paths to the south-southwest from the northern extent of the north west/south east flight leg are very marginal. Such conclusions can not be drawn for the northwesterly propagation direction from the southernmost aircraft location. From here F.A.I.'s should be observable at distances out to 375 km, which puts the disturbed region as previously determined well within range. The determination of the east-west extent, while at times hampered by the overlap of F.A.I. and overhead trace, was in general possible due to the clear identification of F.A.I. echoes by their Doppler signatures. These data indicate a width of the F.A.I. zone in the magnetic east/west direction of ~100-145 km. The zone is shifted to the west with respect to the Arecibo magnetic meridian. F.A.I. were observed in the average only 20 km to the east of this reference line. The strong shift of the F.A.I. zone towards the west of the Arecibo magnetic meridian suggests transport of irregularities generated by the heater, out of the heated volume. Burnside et al. (1981) using measurements of Doppler shift of the nighttime $O(^1D)$ 630 nm emission show substantial westward drifts (50-75 m sec^{-1}) of the postmidnight neutral atmosphere (thermosphere) over Arecibo. Similar transport of heater-generated irregularities out of the heater beam had previously been shown by Livingstone (1983) during another airborne heater campaign (Moore, 1983; Buchau and McNamara, 1986).

5.0 ACKNOWLEDGEMENTS

The authors wish to thank Messrs. Jack Waaramaa and Robert Gowell for assistance in operating the Digisonde on board the aircraft. Discussions with Drs. W. Gordon and Santimay Basu were helpful in the interpretation of the oblique scatter observations. We thank Dr. B. S. Dandekar for the ray tracings, which supported the development of Appendix A and the discussion.

6.0 REFERENCES

Basu, S., Su. Basu, S. Ganguly, J. A. Klobuchar and C. M. Rush, "Artificial irregularities generated by ionospheric heating and their effects on transionospheric propagation," Proceedings of Symposium on the Effect of the Ionosphere on Radio Wave Systems, P. 72, Naval Research Laboratory, Alexandria, VA [1981].

Buchau, J., private communication, Air Force Geophysics Laboratory, AFGL/LIS, Hanscom AFB, MA 01731, 1988.

Basu, S., Su. Basu, E. J. Weber, J. G. Moore, J. Buchau, S. Ganguly, W. E. Gordon, M. C. Lee, R. C. Livingstone, B. W. Reinisch and R. A. Behnke, "Multi-technique probing of the artificially modified ionosphere over Arecibo," National Radio Science Meeting, U.S. National Comm. for URSI, Boulder, CO, January 1982.

Basu, S., Su. Basu, S. Ganguly and W. E. Gordon, "Coordinated study of sub-kilometer and 3-m irregularities in the F region generated by high power HF heating at Arecibo," J. Geophys. Res. 88 (A11), 9217-9225 [1983].

Bibl, K. and B. W. Reinisch, "The universal digital ionosonde," Radio Sci., 13(3), 519-530 [1978].

Buchau, J. and L. F. McNamara, "Simulation of ionograms obtained during the October 1979 Platteville heater experiment," Radio Sci., 21(3), 286-296 [1986].

Buchau, J., B. W. Reinisch, E. J. Weber and J. G. Moore, "Structure and dynamics of the winter polar cap F region," Radio Sci., 18(6), 995-1010 [1983].

Burnside, R. G., F. A. Herrero, J. W. Meriwether and J. C. G. Walker, "Optical Observations of Thermospheric Dynamics at Arecibo," J. Geophys. Res., 86, A7, 5532-5540 [1981].

Croft, T. A. and H. Hoogasian, "Exact ray calculations in a quasi-parabolic ionosphere with no magnetic field," Radio Sci., 3(1), 69-74 [1968].

Livingstone, R. C., "Heater-generated intermediate-scale irregularities: Spatial distribution and spectral characteristics," Radio Sci., 18(2), 253-262 [1983].

Moore, J. G., "Airglow Morphology during an Ionospheric Heating Experiment at Platteville, Colorado," AFGL-TR-83-0238 [1983]. ADA137869

Reinisch, B. W., R. W. Gowell, J. G. Moore, J. B. Waaramaa and R. R. Gamache, "Measuring the antenna pattern of the HF heater antenna in Puerto Rico," Scientific Report No. 3, University of Lowell Center for Atmospheric Research, Lowell, MA, and Air Force Geophysics Laboratory Technical Report AFGL-TR-82-0123, Hanscom AFB, MA, ADA119963 [1982].

END
DATE
FILMED
9-88
DTIC