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AUTOMATIC REAL TIME IONOGRAM SCALER WITH TRUE HEIGHT ANALYSIS - ARTIST

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Over-the-horizon HF radar detection and sea state monitoring require fairly precise knowledge of the ionospheric reflection point. Automatic scaling of ionograms and calculation of the vertical electron density profile can provide the reflection point characteristics in real time if adequate ionosondes are available at the expected mid-points. The automatic scaling algorithm developed at the University of Lowell extracts the → cont.

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20. ABSTRACT

cont E and F region traces from Digisonde ionograms without any human intervention and automatically produces the corresponding electron density profiles. The algorithm was tested on several thousand Digisonde ionograms covering the four seasons, day, night, quiet and disturbed conditions, as observed at the AFGL Ionospheric Observatory, Goose Bay, Labrador. All important ionospheric parameters are automatically retrieved: foF2, foF1, fminF, MUF(3000), M(3000), range spread, frequency spread, h'F, h'F2, foE, foEs, fminE, h'E, h'Es, and signal amplitude as function of frequency. The electron density profile algorithm uses a polynomial profile-fitting method and is part of the automatic procedure.

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1.0 INTRODUCTION

Renewed interest in HF communication and the use of over-the-horizon radar have created a need for compact and reliable digital ionosondes that automatically scale the ionograms and give the important ionospheric parameters and the vertical electron density profiles to the user in real time. After decades of little progress in the ionosonde field modern digital techniques were finally applied to ionosondes [Bibl and Reinisch, 1978; Grubb, 1979]. To solve the problem of automatic ionogram scaling in a way that is applicable to not only the mid-latitude but also to the high latitude and the equatorial ionosphere requires an ionosonde that provides adequate data even under disturbed ionospheric conditions. Digisonde systems have successfully operated at the polar cap (Thule, Greenland, 76°N), in the auroral region (Goose Bay, Labrador, 54°N, geographic, 65°N geomagnetic) and near the equator (Kwajalein, Marshall Islands and Natal, Brazil). The automatic scaling and true height algorithms discussed in this paper have been tested with Digisonde ionograms from Goose Bay, Labrador which show spread F about 50% of the time. The Air Force Geophysics Laboratory is operating the Goose Bay Ionospheric Observatory since 1972 [Buchau, private communication]. The ionograms from this subauroral station display a large variety of features: quiet and disturbed daytime recordings, spread F during the night, the mid-latitude trough moving over the station, fast variation of the ionospheric parameters and frequent absorption events. Four months of Goose Bay ionograms for the high sunspot year 1980 served as data base for the evaluation of the scaling and true height algorithms. Some 8000 digital ionograms for January, April, July and September 1980 were processed on a CDC 6600 computer. Since manual scaling of the more than 2000 hourly ionograms was available it was possible to evaluate the performance of the autoscaling algorithm. To our knowledge it is for the first time that anybody succeeded to automatically scale a large number of quiet and disturbed ionograms. Since March 1983, the Automatic Real Time Ionogram Scaler with True Height Calculation (A.R.T.I.S.T.) is operating with the Goose Bay Digisonde. The A.R.T.I.S.T. is an 8086 based Digisonde subunit that determines the traces, parameters and profile within one minute per ionogram.

In Section 2 we briefly describe the Digisonde 256 for which the A.R.T.I.S.T. was developed. Section 3 outlines the scaling algorithm and the profile inversion method. Results of the comparison between manual and autoscaling are shown in Section 4.

2.0 DIGISONDE 256

A description of this new digital ionosonde is given in a report by Bibl et al [1981]. In the context of this report it is sufficient to summarize those features that are relevant for the automatic scaling of ionograms. The spaced-receiver drift-Doppler mode of operation will not be described. The system generates for each ionogram scan sixteen independent ionograms identified by different observational parameters from which all relevant information can be drawn. Best automatic scaling results are obtained by monitoring the incidence angle and the polarization of the incident signals together with the Doppler shifts. Either 128 or 256 ranges can be sampled, and range spacings of 2.5, 5.0 or 10 km can be selected. For each pixel, amplitude (logarithmic) and phase (linear) is given with 8 bits resolution. The frequency scan is either logarithmic or linear (Δf from 5 to 200 kHz). When high resolution virtual height measurements are required groups of closely spaced frequencies are transmitted and h' is determined from the phase change with frequency. For a quiet ionosphere the resulting accuracy is a fraction of 1 km. To allow operation in regions with high interference levels the 256 uses phase coherent signal integration over from 5 to 512 pulses at each given sounder frequency. The high frequency pulses have interpulse and intrapulse pseudo-random 180° phase codes that suppress interference as well as high order multiple echoes. For each ionogram frequency the interference level is tested for three neighboring frequencies before transmission; the frequency with the lowest noise level is selected for transmission. The processing gain obtained from this digital technique results in high quality ionograms which can be automtically scaled.

The Digisonde is fully programmable from an on-site terminal as well as remotely via telephone/modem connections.

Data recording on site is on magnetic tape, floppy disk or film and hardcopy printout. The ionograms and/or the scaled data and the electron density profiles can also be printed remotely.

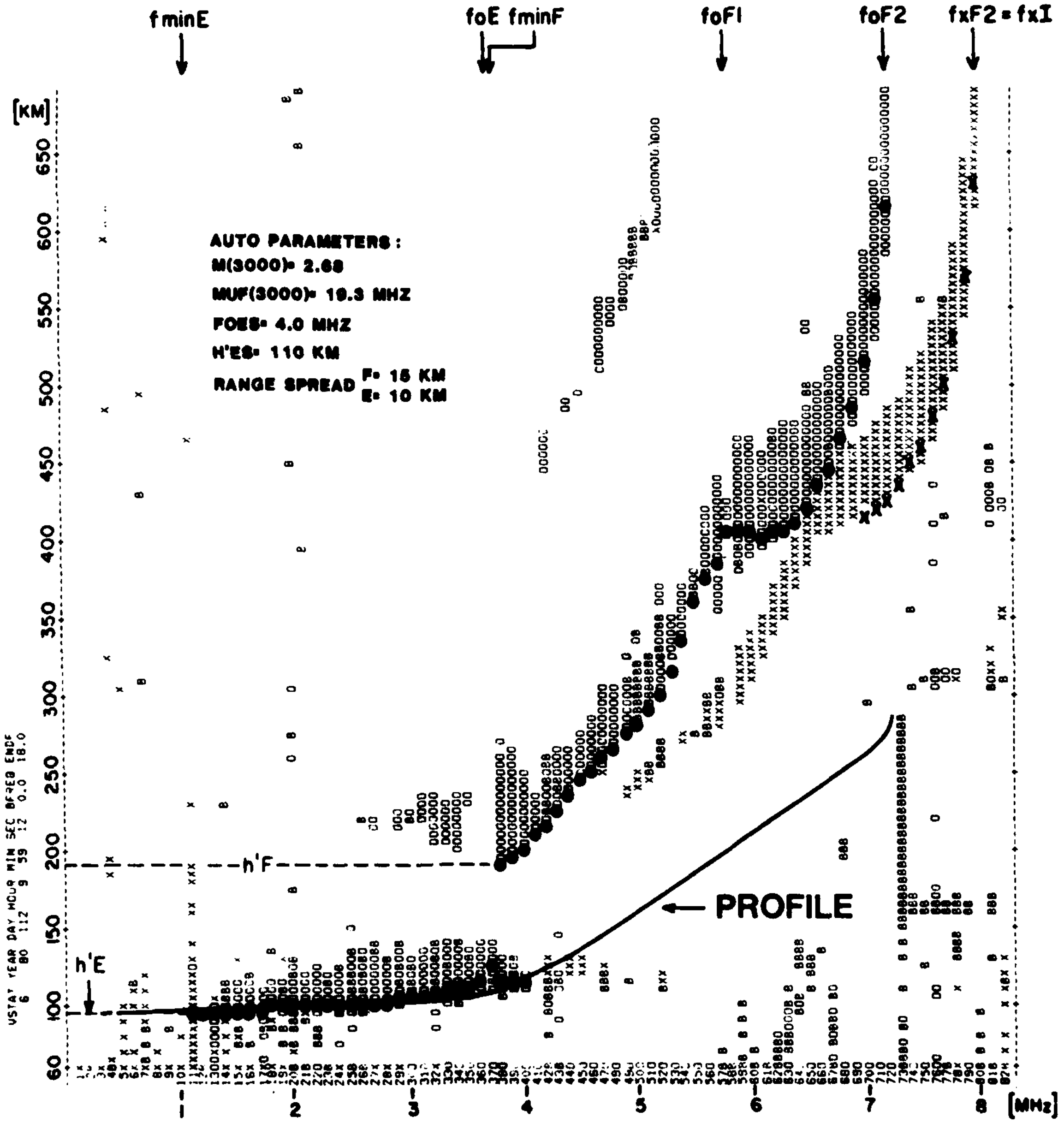
3.0 SCALING ALGORITHM

The ideas and procedures for the automatic scaling of digital ionograms have been published in a series of papers [Reinisch and Huang, 1982; Huang and Reinisch, 1982; Reinisch et al, 1981; Reinisch and Huang, 1983]. It suffices to give a brief summary.

Ideal ionograms (Figure 1), recorded under quiet conditions with a relatively low level of interference, pose no difficulties for automatic scaling, yet they are useful to illustrate some of the scaling procedures. (Manufacturers of ionosondes generally select such quiet ionograms to demonstrate system performance and the capability of automatic scaling. We refer to Figures 3, 4 and 5 for examples of disturbed ionograms which are successfully scaled by the ULCAR algorithm.) The lower part of Figure 2 shows the amplitude ionogram containing all signals. Removal of the non-vertical and X-polarization signals results in the upper ionogram of Figure 2, which is much easier to scale automatically. The X-trace data are not discarded; they are used for the accurate determination of foF2. For bottomside ionograms, the O-trace is generally better presented than the X-trace and our autoscaling effort concentrated therefore on the O-trace. When operating with a Digisonde 256, complete O and X ionograms are available which will improve the determination of the profile between the E and F layer.

It is important to emphasize that even at mid-latitude the percentage of unusual or disturbed ionograms might be as high as 30%. The basic concepts of the scaling procedure must take this into account. In general, the vertical O and X echo traces must be found within spread F signals. Multiples and oblique echoes must be eliminated relying on the amplitude, polarization and incidence angle information contained in the Digisonde ionograms. This is only possible by examining the ionogram in its entirety.

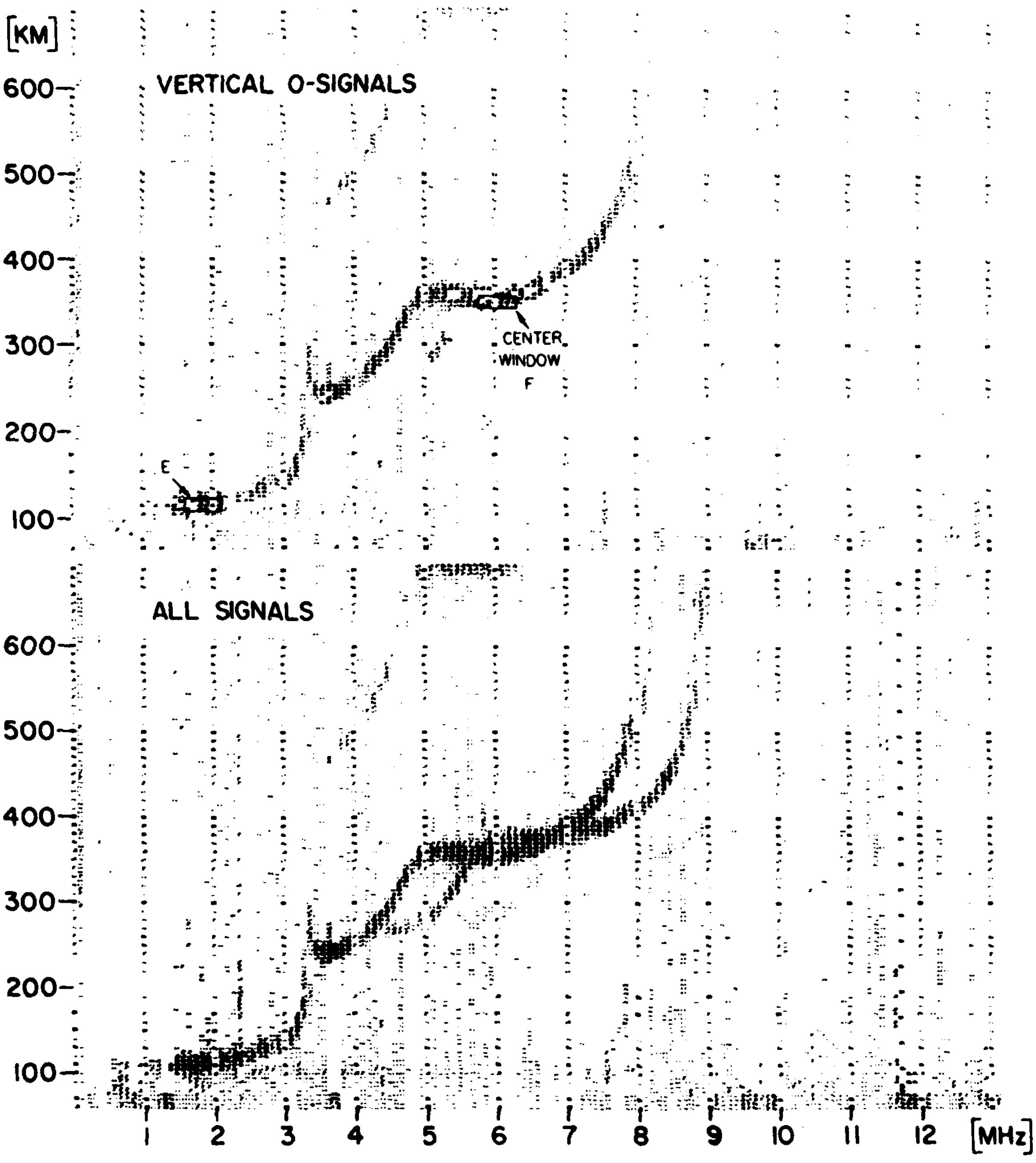
ULCAR JUNE 82



AUTOSCALING FOR RELATIVELY QUIET IONOGRAM

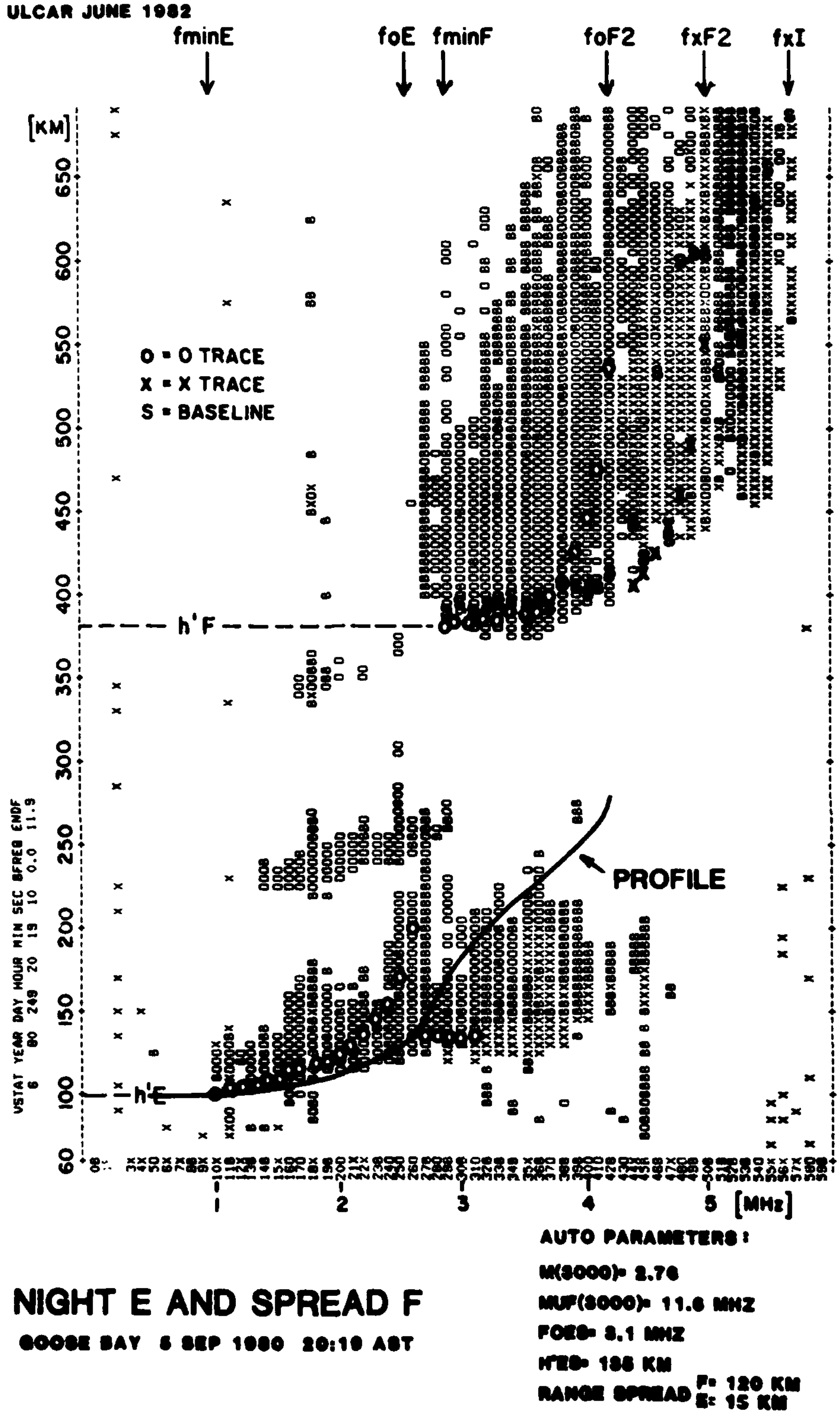
GOOSE BAY 21 APRIL 1980 10:00 AST

Figure 1



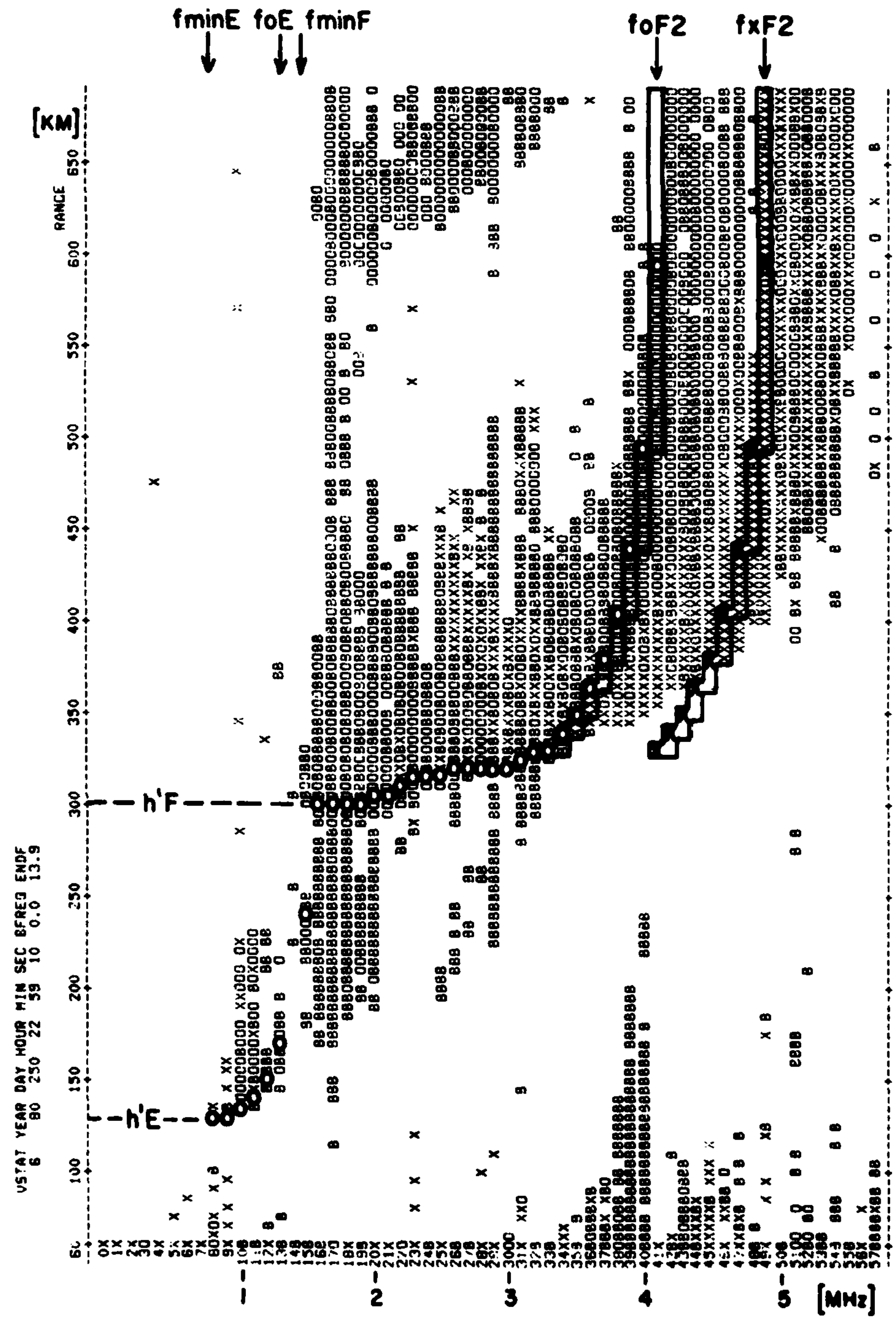
UNDISTURBED DAY IONOGRAM
GOOSE BAY 16 JUN 1980 17:20 AST

Figure 2



ULCAR JUNE 1982
fminE
foE
fminF
foF2
fxF2
fxI
[KM]
O = O TRACE
X = X TRACE
S = BASELINE
h'F
h'E
VSTAT YEAR DAY HOUR MIN SEC BFREQ ENDF
6 80 249 20 19 10 0.0 11.9
PROFILE
[MHz]
AUTO PARAMETERS:
M(3000)= 2.76
MUF(3000)= 11.6 MHZ
FOES= 3.1 MHZ
H'ES= 135 KM
RANGE SPREAD F= 120 KM E: 15 KM
NIGHT E AND SPREAD F
GOOSE BAY 5 SEP 1980 20:19 AST

Figure 3



AMPLITUDE WINDOWS FOR HYPERBOLAS

GOOSE BAY 6 SEP 1980 23:00 AST

Figure 4

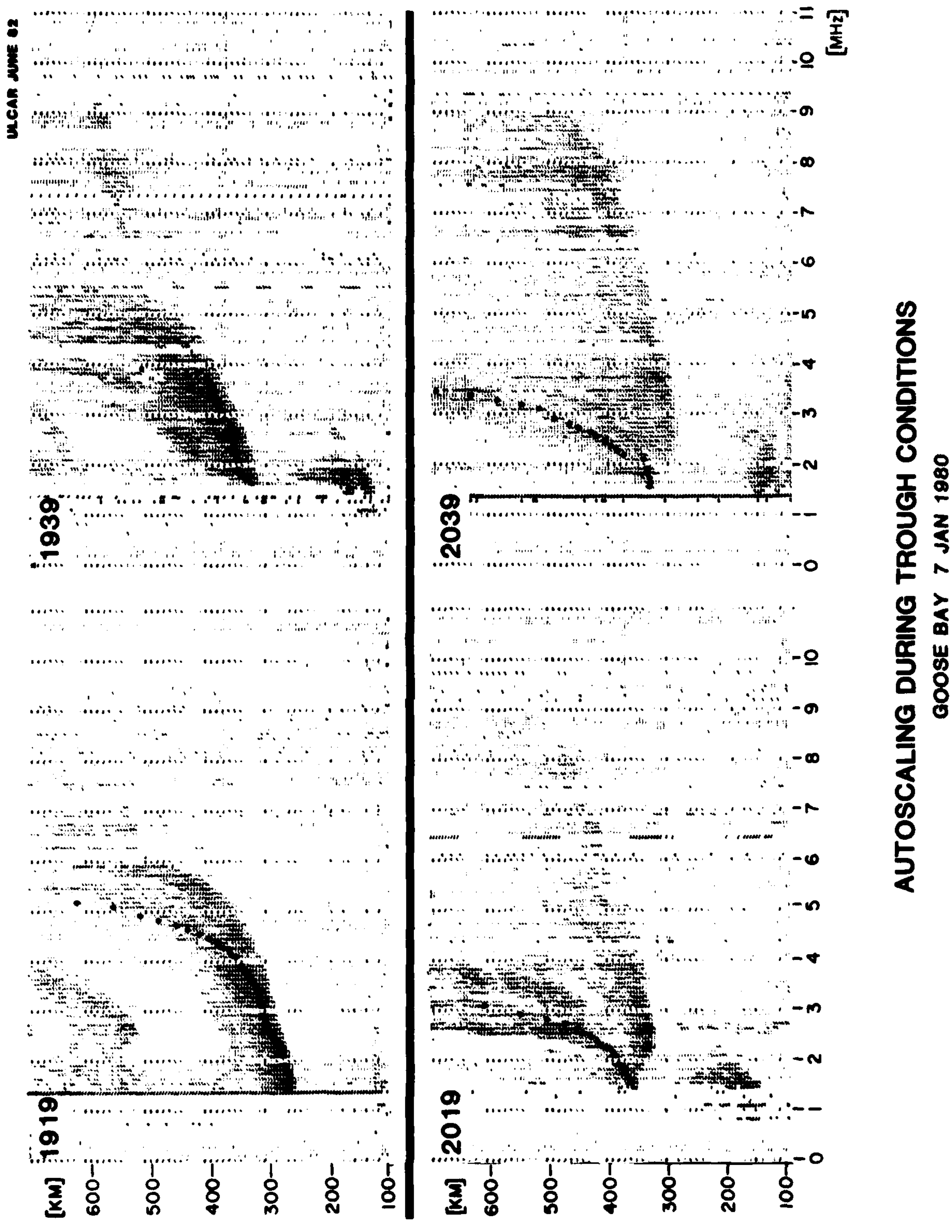

AUTOSCALING DURING TROUGH CONDITIONS
GOOSE BAY 7 JAN 1980
ULCAR JUNE 82
1919
1939
2019
2039
[KM]
[MHz]

Figure 5

To find the F trace the ionogram is surveyed for heights larger than 160 km, and the "center window" (Figure 2) with the maximum signal energy is determined. A first approximate trace, the baseline, is constructed by sliding a searching window toward higher and lower frequencies. Two hyperbolic functions

$$h'_X = r + \frac{1}{a+bf}$$

and

$$h'_O = r + \frac{1}{a+b[f+\frac{1}{2}fH]}$$

are fitted to the O and X amplitude pixels in order to determine foF2, the critical frequency of the F2 layer; f and fH are the sounder and gyrofrequency, respectively.

The main difficulties for the E-region are the identification of E, Es and night E. To find the normal E trace an analytic function is fitted to the amplitude pixels. The function is derived from a parabolic profile and the three parameters of the parabola, height, half width and peak density, are determined such as to maximize the average signal amplitude of the ordinary vertical echoes traced out by the h'(f) function. Continuous O echoes beyond foE are identified as Es trace. To save CPU time, the search for the peak density (or foE) of the parabolic E-layer during daytime is limited to ±0.3 MHz around a predicted median value.

As a special provision for high latitude stations, the program allows the detection of particle ionization in the E region, often called night E [King, 1962]. As soon as the predicted foE values goes below 2.5 MHz, the program tests for critical frequencies of up to 6 MHz. Figure 3 is an example of a night E condition in Goose Bay with foE = 2.6 MHz at 20:19 local time.

Finally the E-region data are investigated for a sporadic E-layer trace. If a continuous echo trace with ordinary vertical echoes can be found for $f > f_E$, its highest frequency is identified as foEs (foEs = 4.0 MHz in Figure 1 and 3.1 MHz in Figure 3). Figures 3 to 5 show scaling examples for quiet and disturbed ionograms.

Having $h'(f_i)$ it is of course possible to calculate the electron density profile [for example, Doupnik and Schmerling, 1965]. Since the autoscaling method produces some occasional wild points which are likely to adversely effect the conventional lamination procedure we developed the profile-fitting technique for the calculation of the F-region profile. The F-profile is represented by a single analytical function consisting of a modified sum of shifted Chebyshev polynomials [Huang and Reinisch, 1982, p. 838, Eq. 6]. The idea of polynomial fitting had been developed earlier by Titheridge [1967]. A parabolic approximation of the E-region profile is automatically obtained in the E layer scaling routine. E and F profiles are joining smoothly allowing for a parabolic valley between the E and F region. Comparisons between manual and autoprofiles are given in Figures 6 and 7. The solid line is the autoprofile. The stars indicate the profile obtained from applying the conventional lamination method to the manually scaled data. An almost identical profile (squares) is obtained when the lamination technique is applied to the autodata.

Examples of automatic profile plots from ARTIST system are shown in Figures 8 and 9 where the transition period for the morning rise on September 15, 1980 (Figure 8) and the evening decline on April 1, 1980 (Figure 9) over Goose Bay, Labrador, are shown.

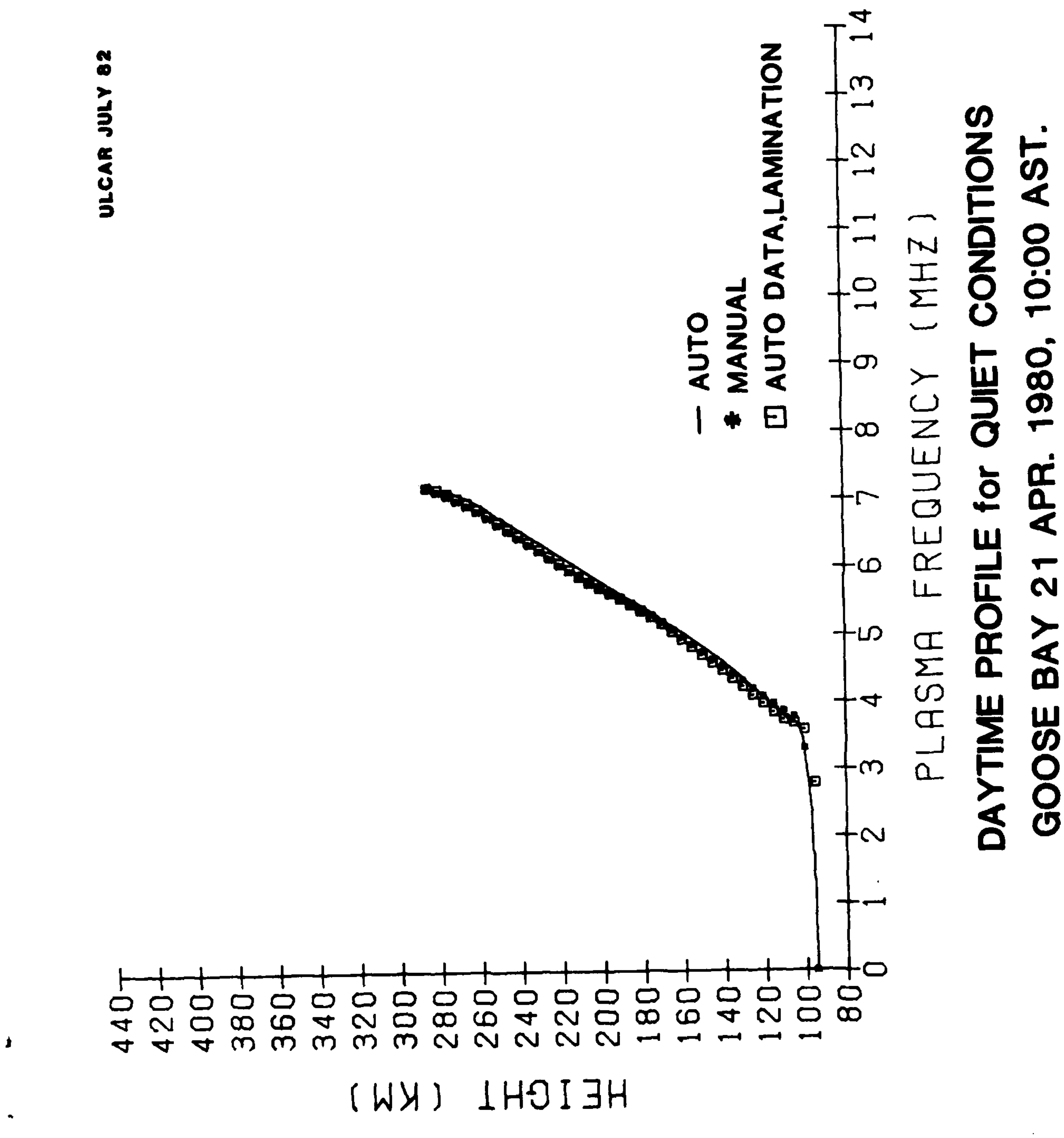

ULCAR JULY 82
AUTO
MANUAL
AUTO DATA,LAMINATION
HEIGHT (KM)
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
PLASMA FREQUENCY (MHZ)
DAYTIME PROFILE for QUIET CONDITIONS
GOOSE BAY 21 APR. 1980, 10:00 AST.

Figure 6

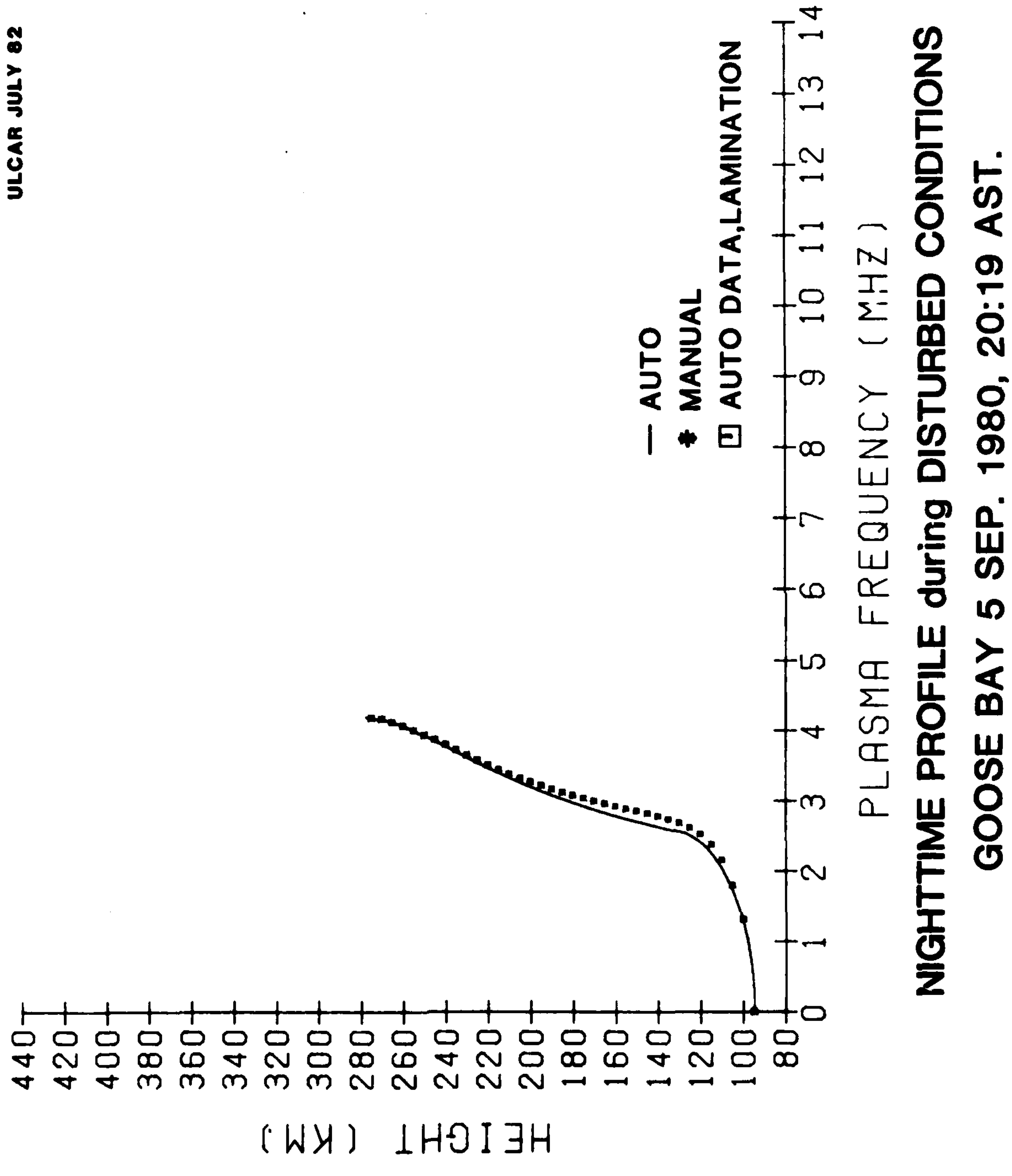

ULCAR JULY 82
— AUTO
* MANUAL
⊡ AUTO DATA,LAMINATION
HEIGHT (KM)
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
PLASMA FREQUENCY (MHZ)
NIGHTTIME PROFILE during DISTURBED CONDITIONS
GOOSE BAY 5 SEP. 1980, 20:19 AST.

Figure 7

/

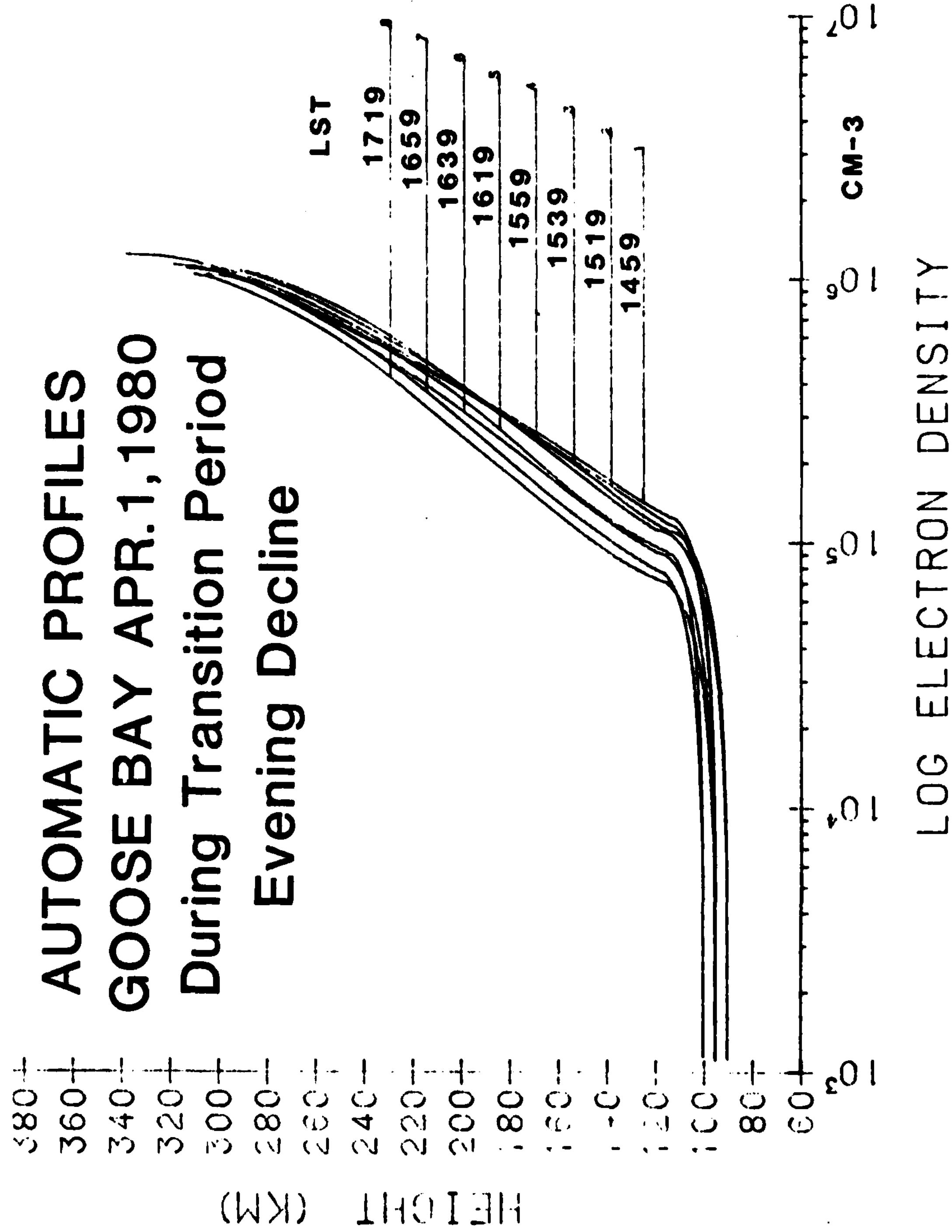

AUTOMATIC PROFILES
GOOSE BAY APR.1,1980
During Transition Period
Evening Decline
LST
1719
1659
1639
1619
1559
1539
1519
1459
CM-3
LOG ELECTRON DENSITY
HEIGHT (KM)

Figure 8

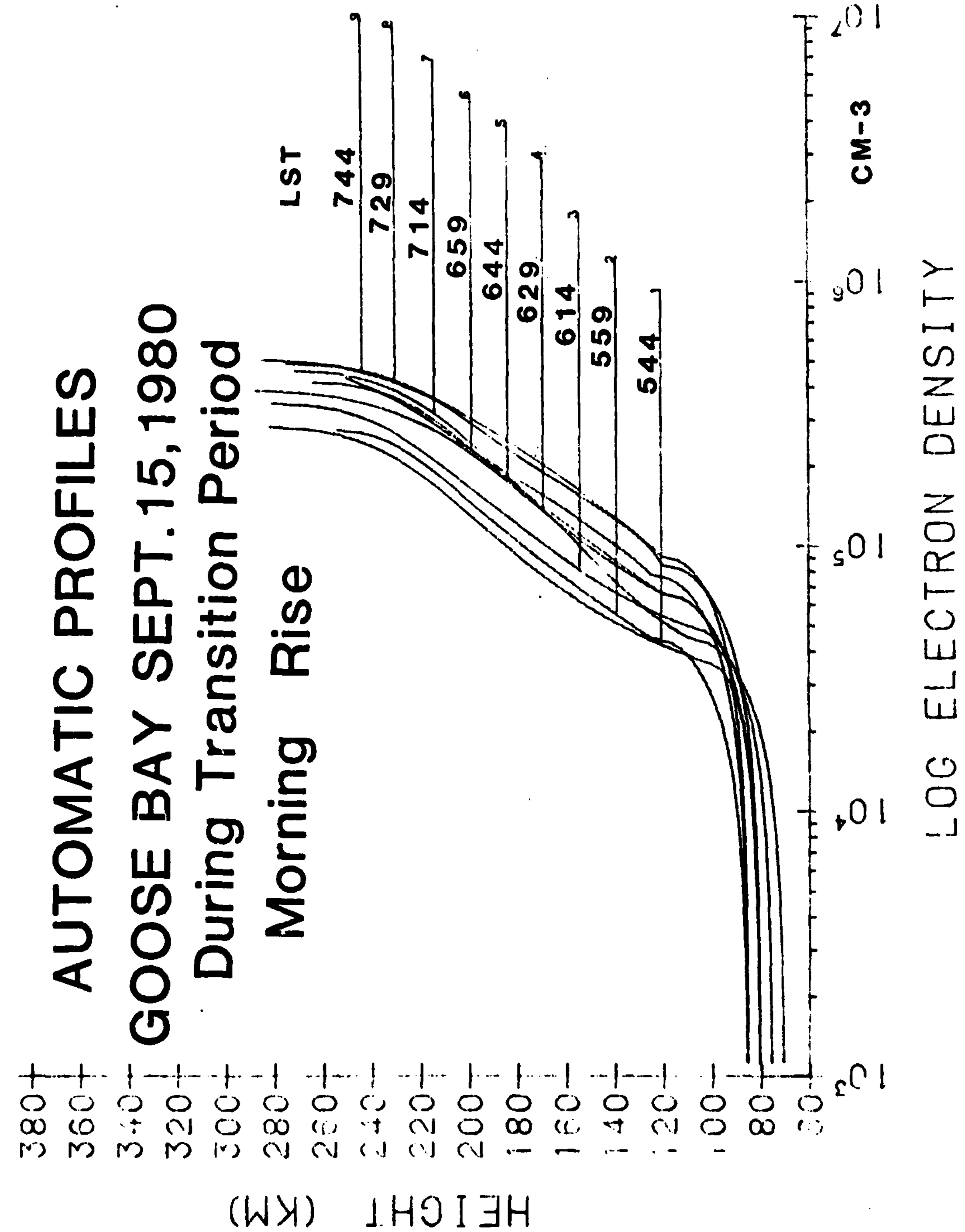

AUTOMATIC PROFILES
GOOSE BAY SEPT.15,1980
During Transition Period
Morning Rise
LST
744
729
714
659
644
629
614
559
544
HEIGHT (KM)
LOG ELECTRON DENSITY
CM-3

Figure 9

/

4.0 COMPARING AUTO- WITH MANUAL SCALING

A complete data base and trace identification are the crucial steps on the way to automatic electron density profiles. To test the performance of the A.R.T.I.S.T. more than 8000 ionograms for January, April, July, and September 1980 from Goose Bay, Labrador, were processed. This data base is representative of one year's data covering all seasons and all types of ionospheric conditions. For the same months - 2200 hourly ionograms were manually scaled. The corresponding autoscaled values were compared with the manual scaled h'F, h'F2, fminF, foE, foEs, h'E and h'Es. The ARTIST program separates the E-region parameters into day and night groups to independently assess the accuracy of night E scaling. Ionograms with technical errors were removed from the data base. A complete description of the comparison can be found in the Test and Evaluation Report by Reinisch et al [1982].

The critical frequency of the F2 layer is perhaps the most important ionospheric parameter. The minimum accuracy requirement for a high latitude station like Goose Bay was set to ±1 MHz for 80% of all ionograms. Figure 10 shows the error distributions for the month of January, Table 1 gives the statistics for all the data. It can be seen that the minimum requirement is by far exceeded. The 1 MHz error limit test is passed by 92% of the ionograms in January, 96% in April, 97% in July and in September. Indeed, 90% of all ionograms satisfy the 0.5 MHz error limit. The curve on the left side of the figure shows the symmetry of the error distribution which is more or less Gaussian in shape, curves for the other three months show similar features. The error statistics for the ionograms without spread F, i.e., daytime ionograms, were established separately. It is satisfying to see that the error curves for all ionograms (dashed curves) are only about 10% lower than those for non-spread ionograms (solid curves).

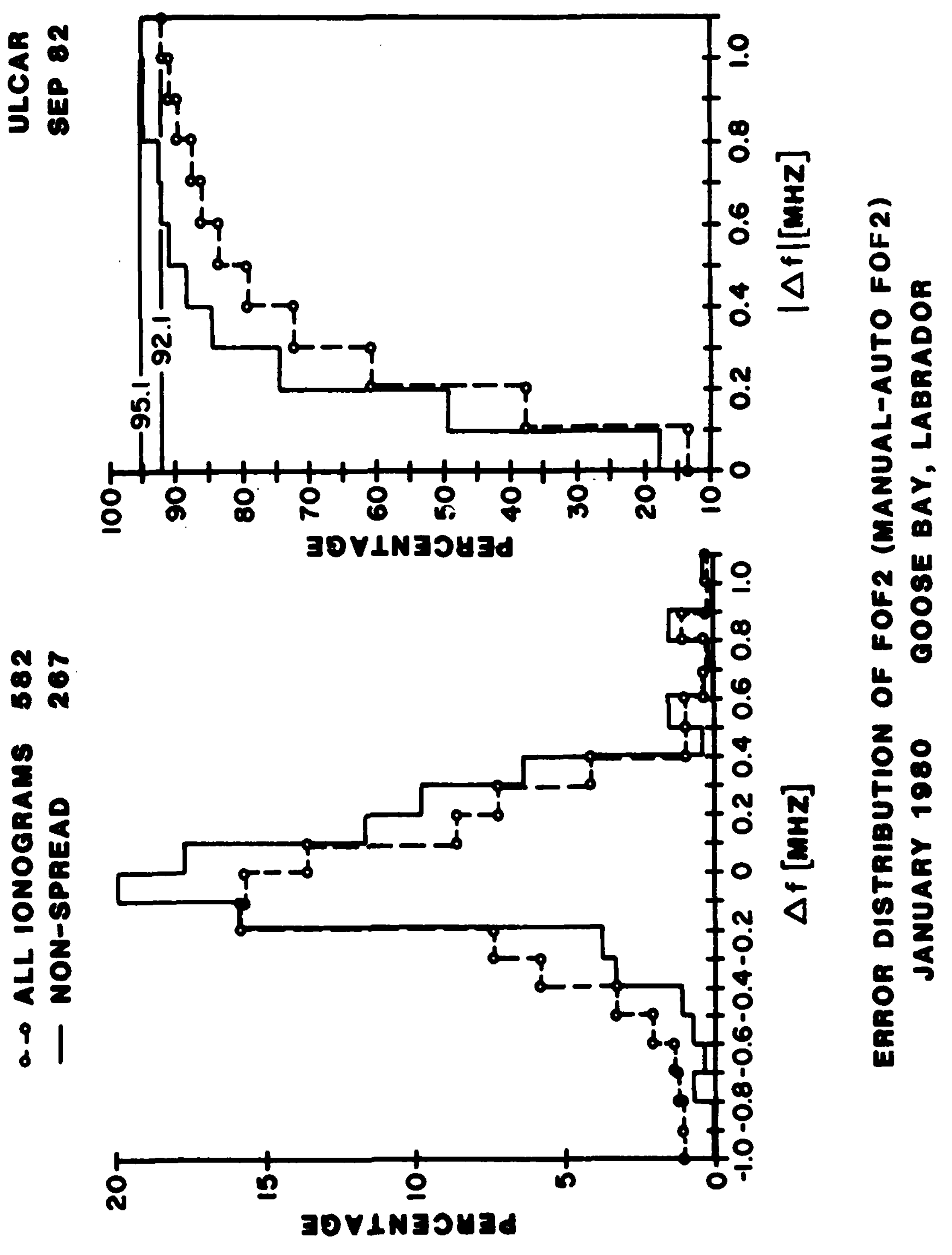

ULCAR
SEP 82
ALL IONOGRAMS 582
NON-SPREAD 267
PERCENTAGE
PERCENTAGE
95.1
92.1
Δf [MHZ]
|Δf| [MHZ]
ERROR DISTRIBUTION OF FOF2 (MANUAL-AUTO FOF2)
JANUARY 1980 GOOSE BAY, LABRADOR

Figure 10

foF2 and MUF Statistics

Table 1

1980	No. of Ionograms	foF2(%) MHz ±0.5	foF2(%) MHz ±1.0	MUF(3000)(%) MHz ±5%	MUF(3000)(%) MHz ±10%	M(3000)(%) MHz ±0.1	M(3000)(%) MHz ±0.2	
January	582	83.5	92.1	69.0	79.7	59.1	77.8	All Ionograms
April	546	90.3	96.2	79.5	87.7	71.6	88.0	
July	528	93.6	97.7	80.2	93.2	65.0	92.6	
September	570	91.6	97.0	80.9	92.0	65.4	81.0	
Four Months	2226	89.6	95.6	77.2	88.0	65.2	82.2	
January	267	91.0	95.1	90.8	96.3	73.8	88.0	Non-Spread
April	288	95.2	98.3	94.4	96.5	82.6	95.1	
July	133	96.2	97.7	82.8	90.3	75.2	85.7	
September	259	93.0	97.0	93.4	97.0	78.8	90.7	
Four Months	947	93.6	96.9	91.1	95.7	78.0	90.6	

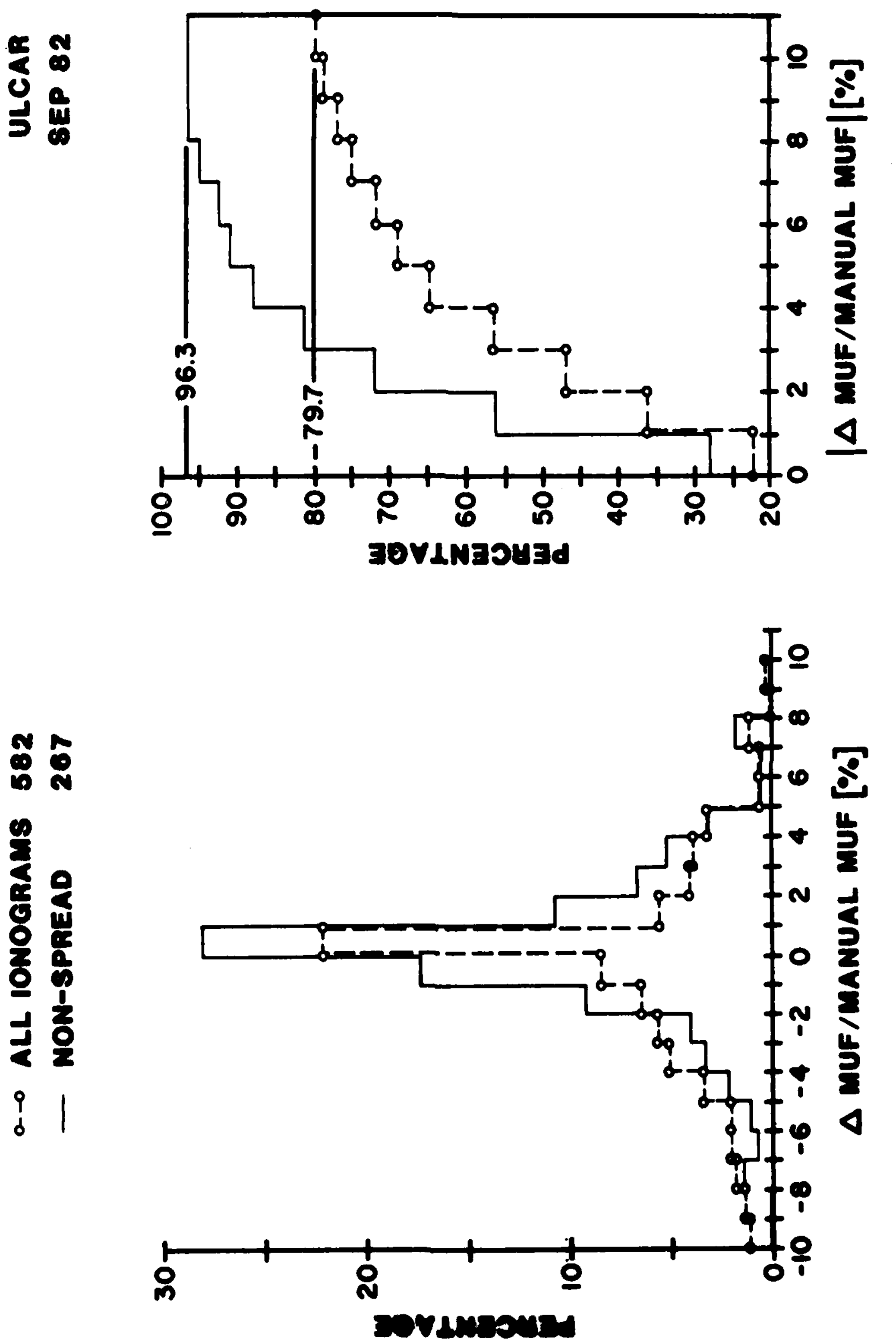
Figure 11 displays the error distribution function of MUF(3000) for January where the error is defined as the percentage difference between the manual and autoscaled value based on the manual reading. In July and September, over 90% of all ionograms have less than 10% errors, in April 88% and in January 80% (see Table 1). Averaged over the four months, 88% of all ionograms are scaled with a MUF(3000) error of less than 10%. If only non-spread ionograms are considered, the statistics of all months improve to 96%. The significantly higher percentage rates for the non-spread ionograms indicates the uncertainty in the MUF definition for spread ionograms. A clarification about our definition of MUF(3000) is in place here. In the ARTIST program the F region h'(f) curve is transformed into an oblique ionogram by multiplying each frequency with the transmission factor M(h')

$$f_{ob} = M(h')f_{vert}.$$

The transmission function M(h') is calculated for a distance of 3000 km by fitting a polynomial to the URSI specified data set [URSI Handbook of Ionogram Interpretation and Deduction, Secton Edition, Nov. 1972, p. 21; World Data Center A Report UAG-23].

The M(3000) propagation factor is derived from the MUF(3000) by dividing it by foF2. The minimum accuracy requirement of $\Delta M = \pm 0.2$ is fulfilled for 82% of all ionograms. In January, which had the highest magnetic activity, only 78% of all ionograms pass the 0.2 error test. For the other three months the percentages are above 81%, see Table 1.

Table 2 summarizes the results for some of the other parameters. The table presents the average values over the four months of data except for the heights h'F, h'F2, and h'E where the data is for the month of April only. This is because the heights have been recalculated by a new procedure that precisely determines the leading edge of the echo trace



ERROR DISTRIBUTION OF MUF(3000) [(MANUAL MUF-AUTO MUF)/MANUAL MUF]
JANUARY 1980 GOOSE BAY, LABRADOR

Figure 11

E and F Region Statistics

Table 2

No. of Ionograms	foF1(%) MHz ±0.2	±0.5	h'F(%)* km ±10	h'F2(%)* km ±10	No. of Ionograms	foE(%) MHz ±0.2	±0.5	h'E(%)* km ±5	±10
2240	80.0	96.4	91.3	96.9	894 (day)	92.9	99.2	90.9	97.0
					1201 (night)	70.9	88.7	80.7	87.7

*Ionograms from April only

in the raw ionograms. The new method has only been applied to the April data. The F region minimum heights are accurate to ±10 km 91% of the time for h'F and 97% of the time for h'F2. The autoscaled results for h'E are accurate to ±5 km for 91% of the day ionograms and for 81% of the night ionograms. foF1 is found to within ±.2 MHz 80% of the time.

For the E region the data are separated into day and night ionograms to better see the effect of the occurrence of night E which is contained in the foE column. Since night E occasionally occurs already in the late afternoon the day/night transition was made when the predicted foE goes below 2.5 MHz. For more than 92% of the day ionograms the foE value is scaled within 0.2 MHz; the corresponding value is 71% for night E. For an error limit of 0.5 MHz, 88% of the night ionograms are successfully scaled. The critical frequency of the sporadic E layer is autoscaled within 0.5 MHz of the manual value for 84% of the day and 69% of the night ionograms.

Automatic evaluation of the electron density profiles depends on the successful scaling of the ionogram traces. Figures 1, 3, 4, and 5 show the A.R.T.I.S.T. can correctly identify the trace under all types of conditions, yielding accurate electron density profiles.

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